Reducing Ultra-Clean Transportation Fuel Costs with HyMelt® Hydrogen

Final Report

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Work Performed Under Cooperative Agreement No. DE-FC26-02NT41102

By

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DISCLAIMER

ABSTRACT

The agreement for work performed for this project was originally executed on September 19, 2002 and was modified on July 16, 2007 with Amendment No. M010. This document is the final report.

EnviRes acquired, processed and shipped approximately 20 tons of Illinois #6 coal, 10 tons of high sulfur petroleum coke and 50 drums of high sulfur aromatic extract to MEFOS. MEFOS performed extensive thermochemical modeling of the gasification section of the process. EnviRes participated with MEFOS in design modifications to existing equipment and MEFOS implemented and commissioned these changes. The initial test campaign in June 2003 demonstrated significant challenges to lance injection of carbonaceous feed to a lesser extent challenges to oxygen injection with lances. A second test campaign in September 2003 using a submerged tuyere in the side of the gasification vessel for feed injection demonstrated much improved performance, but the tuyere configuration was not suitable for scale up. A third test campaign in December 2003 demonstrated a commercially viable tuyere configuration that met or exceeded the performance of the second campaign. The extra test campaigns necessitated de-scoping some of the other tasks to stay within budget.

Kvaerner performed a detailed process simulation of the entire process. Kvaerner worked with Dow Chemical to develop a process design and cost estimate for the acid gas removal system. Kvaerner worked with UOP to develop a process design and cost estimate for hydrogen purification. Kvaerner integrated these designs and cost estimates to allow cost a comparison of water gas shift vs. using CO as fuel.

Siemens Westinghouse Power Corporation performed CFD modeling coupled with reaction modeling of a W501D5A gas turbine burning the CO rich gas produced by the HyMelt® process using catalytic combustion. The major focus was on anticipated emissions of CO and NOx over a range of operating conditions. Through agreement with DOE, work on this task was not completed.

Instead of doing HyMelt above-atmospheric pressure testing in a molten iron bath, technical information and intellectual property related to the Pressurized Coal Iron Gasification (P-CIG) process was purchased. The P-CIG process had previously demonstrated coal gasification at a rate of 0.5 ton of coal per hour per ton of molten iron with continuous coal and oxygen feeds in a 3.5 foot ID reactor at 3 bara pressure. Based on an analysis of all the HyMelt and P-CIG data, it was concluded that there were five critical technical challenges that needed to be addressed in a commercial design:

1. Operation at 35 bar
2. Continuous slag tapping at elevated pressures
3. Achieving adequate tuyere and refractory life between repairs/replacements
4. Predicting and handling dust emissions at 35 bar
5. Achieving an acceptable coal feed particle size

It is believed that each of these challenged can be properly addressed in a commercial design.

A conceptual design of a commercial-scale HyMelt gasification plant was prepared based on 1000 stpd of an 80/20 blend of coal and biomass as the feedstock. The projected economics of producing all high-purity hydrogen with a HyMelt gasification facility was found to be significantly better than either conventional gasifier facilities or steam methane reforming. EnviRes worked with Aker Solutions to prepare a Design Basis Memorandum for a first-of-a-kind (FOK) HyMelt plant.

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I. Report

A. Introduction

This is the final report to the U.S. Department of Energy's National Energy Technology Laboratory on the work performed on "Reducing Ultra-Clean Transportation Fuel Costs with HyMelt® Hydrogen" under Cooperative Agreement No. DE-FC26-02NT41102. Exhibit 1 provides the Statement of Project Objectives extracted from the contract.

The preferred method of operating the HyMelt system is to continuously feed coal/biomass, oxygen and steam (for temperature control) into the gasifier at the same time. The HyMelt gasifier is able to achieve superior performance because the gasification reactions occur in the liquid phase of a molten iron bath. Incoming coal and biomass rapidly decompose and the carbon dissolves in the molten iron bath. By maintaining about 2 weight percent carbon in the molten iron bath at all times, the incoming oxygen reacts very rapidly with the pre-dissolved carbon to produce carbon monoxide with a minimal formation of byproduct carbon dioxide. By delinking the decomposition reaction (coal/biomass to carbon) from the oxygen reaction (carbon to carbon monoxide), the HyMelt process is able to minimize carbon dioxide make during CO formation. This translates into a significantly lower oxygen consumption, higher syngas product yield and lower coal/biomass consumption. It should also be noted that these fast liquid-phase reaction kinetics can result in smaller reactor volumes and higher carbon utilization than conventional gasifiers.

Due to the high solubility of carbon in molten iron, the HyMelt process can also be operated in a "swing mode", where the coal/biomass and oxygen feeds are alternated and the dissolved carbon level is allowed to vary from, say, 1 to 4 weight percent. Using multiple reactors, this approach permits the production of separate hydrogen and carbon monoxide-rich product streams. Studies indicate, however, that there are relatively few opportunities in the marketplace for such a capability.

EnviRes firmly believes that the USA needs to reduce its dependence on foreign oil and chemicals and believes the use of efficient gasification of coal and biomass can make a big difference. EnviRes plans to complete the development and commercialization of the HyMelt system and build dozens of gasifiers throughout the USA to produce Fischer-Tropsch liquids, chemicals, etc.

HyMelt, like most coal gasification systems, offers major environmental advantages over coal-burning power plants. The carbon dioxide is readily captured in the acid gas removal system and can be compressed for reuse in a variety of ways. Gaseous sulfur is also recovered in the acid gas removal system and can be readily converted into elemental sulfur, sulfuric acid or other beneficial sulfur-based compounds. Mercury is removed with activated carbon which can be regenerated by heating, if appropriate. Inorganics in the coal are recovered in a glassified, non-leachable slag that can be beneficially reused in a variety of applications. Because HyMelt produces less byproduct carbon dioxide than conventional gasifiers inside the reactor, it has a smaller carbon footprint for a given quantity of syngas produced.

In addition to developing options for carbon dioxide utilization, EnviRes plans to co-feed biomass with coal to minimize the carbon footprint. Many different biomass types need to be considered, such as miscanthus, switch grass, sawdust, waste wood, algae, biosolids, animal manure and animal carcasses. By increasing the feed biomass content and product CO2 utilization, HyMelt gasification plants can achieve a negative carbon footprint, thereby improving the earth's atmosphere.

B. Experimental

All the experimental methods used for this program are described in the attached Exhibits.

C. Results and Discussion

Task 1

On Task 1, we were supposed to do project management and planning, preparation and shipment of feedstock materials, predictive modeling of the HyMelt process, combustion analysis/modeling and design and fabrication of pilot plant-specific molten iron bath apparatus. All results and discussion of these activities are provided in Exhibit 26.

Task 2.1

On Task 2.1, we were supposed to do carbon monoxide-rich fuel gas combustion testing. Siemens Westinghouse Power Corporation performed CFD modeling coupled with reaction modeling of a W501D5A gas turbine burning the CO rich gas produced by the HyMelt process using catalytic combustion. However, EnviRes and DOE decided to discontinue this effort in order to have more funds available for other activities in this program. The results and discussion of the work completed on this activity are provided in Exhibit 26.

Task 2.2

On Task 2.2, we were supposed to do HyMelt atmospheric testing in a molten iron bath. EnviRes acquired, processed and shipped approximately 20 tons of Illinois #6 coal, 10 tons of high sulfur petroleum coke and 50 drums of high sulfur aromatic extract to MEFOS. MEFOS performed extensive thermochemical modeling of the gasification section of the process. EnviRes participated with MEFOS in design modifications to existing equipment and MEFOS implemented and commissioned these changes. The initial test campaign in June 2003 demonstrated significant challenges to lance injection of carbonaceous feed to a lesser extent challenges to oxygen injection with lances. A second test campaign in September 2003 using a submerged tuyere in the side of the gasification vessel for feed injection demonstrated much improved performance, but the tuyere configuration was not suitable for scale up. A third test campaign in December 2003 demonstrated a commercially viable tuyere configuration that met or exceeded the performance of the second campaign. All of the results and discussion of this activity are provided in Exhibit 26.

Task 2.3

On Task 2.3, we were supposed to do HyMelt above-atmospheric pressure testing in a molten iron bath. However, as a result of increasing costs and delays, EnviRes and DOE decided instead to have EnviRes purchase all the technical information and intellectual property related to the Pressurized Coal Iron Gasification (P-CIG) process from Interproject Service AB ("IPS"), a Swedish company, in 2007. During testing in the 1980s at MEFOS, the P-CIG process was successfully demonstrated with continuous coal and oxygen feeds in a 3.5 foot ID reactor at 3 bara pressure during many days of operation. Non-confidential excerpts from a comprehensive report on the P-CIG tests are provided in Exhibit 2. Exhibit 3 shows a critical bench-scale study on fume formation performed by IPS. (Note: Pages labeled 259 and 261 are missing and cannot be found.) U.S. patents obtained by IPS are given in Exhibits 24 and 25.

The P-CIG data demonstrated that coal could be processed at a rate of 0.5 ton of coal per hour per ton of molten iron. The P-CIG data were also very helpful in identifying critical issues that must be addressed in a commercial operation, as explained below:

<u>35 bara operating pressure</u>. Gasifier capacity and economic feasibility are enhanced by operating at significantly elevated pressures. The first commercial HyMelt gasifier and associated equipment are being designed to operate at 35 bara. Systems will be designed to continuously monitor gasifier skin temperatures and to cause a rapid, controlled drop to in gasifier pressure to atmospheric if a potential refractory breach is detected. FactSage, an advanced thermodynamic modeling program, was used to estimate the effect of high pressures on thermodynamic equilibria in the HyMelt gasifier. FactSage results are reported in Exhibit 11.

<u>Continuous slag tapping at elevated pressures</u>. P-CIG efforts to continuously tap slag at 3 bara were not successful, mainly due to freezing of the slag prior to recovery. EnviRes is designing a novel slag tapping/quenching system. A physical water model and advanced computational fluid dynamics (CFD) modeling will be used to test and optimize the design. To be successful, the slag must flow freely out of the reactor without interruption and must contain less than 5 percent iron carryover. The quench vessel must be designed to prevent an uncontrolled steam explosion in case a process upset sends large quantities of molten slag and iron into the vessel. Two different design options for removing the slag are being considered.

<u>Tuyere and refractory repair frequency</u>. It is uncertain how long a HyMelt reactor can operate before it becomes necessary to repair the tuyeres and refractory. Refractory wear tends to highest around the tuyere area, where a hot spot is created by highly exothermic oxygen reactions as it enters the reactor. Data on refractory wear was measured at MEFOS during HyMelt testing and by during P-CIG testing. By developing advanced refractory materials and designing a deep refractory working thickness, EnviRes hopes to achieve between 6-12 months of operation between tuyere and refractory replacements. If appropriate, EnviRes will incorporate a full HyMelt reactor spare. The HyMelt reactor(s) will have a spare bottom that can be repaired and pre-dried off line. Based on similar experiences replacing bottom heads in steel plants, Aker Solutions estimates that a HyMelt reactor can be "turned around" in about 3 days. Once HyMelt is fully operational, EnviRes anticipates an on-stream availability of 90-95%. Using

fundamental models, Impact Technology Consultants™ developed design recommendations for the HyMelt reactor tuyeres, as shown in Exhibit 12.

Gasifier dust emissions at 35 bara. P-CIG data showed that the raw gas leaving the reactor contained 18-23 gm/Nm^3 when operating at about 3 bara and that the dust contained about 30% carbon. A fundamental question that has not been addressed is what will happen to the dust concentration and composition as the reactor pressure is raised to 35 bara. On the page labeled 265 of Exhibit 3, Dr. Axelsson shows a graph (Fig. 7) of dust ("fume") creation during bench-scale laboratory tests at different pressures. At low sulfur contents, the fume concentration in the gas was shown to drop from about 9 to 4 g/Nm^3 as the pressure was increased from 2 to 4 bara. This implies that the fume formation is approximately inversely proportional to pressure, which is consistent with fume formation theories postulating that dust is formed by vaporization of iron in hot spots and by bursting bubbles. In the first commercial project, definitive data on dust formation will be obtained when operating at a pressure of 35 bara. The first commercial design will assume a total dust concentration of 60 gm per actual cubic meter of untreated syngas. The quenching system and downstream equipment will be designed to handle up to 5 times this level.

Impact of coal particle size. P-CIG data were also used to evaluate the impact of coal particle size on gasifier performance. The first page of Exhibit 17 shows Table A:A1 from a P-CIG report. The percentage of the particles that would pass through 200 mesh (i.e. smaller than 0.074 mm) is hand-written on the right hand side of the page. Table A:A1 also shows the coal compositions, which were fairly similar (8-15% ash, 0.3-1.2% S). The remaining pages of the attachment show results from the P-CIG campaigns, sorted in order of decreasing particle size. The graph plots the percent carbon conversion in the P-CIG gasifier versus feed rate (ton/hr of feed per ton of metal). Different colors represent different amount passing through 200 mesh. The purple line is the same as the green line except that the carbon conversions were estimated based on carbon in the ash rather than oxygen consumed. There is a lot of scatter in the data, so it's hard to draw firm conclusions, but we noted the following: (a) The "best operations" (high conversions at high feed rates) were mainly purple and green points, corresponding to >90% passing through 200 mesh, with only one red point (14-28% passing) occurring at feed rates above 0.35 t/hr-t and (b) the largest particle feeds (1% passing – blue points) were among the lowest conversions measured, although only two tests were conducted. As expected, these results suggest that larger particle feeds result in poorer carbon conversions (presumably as a result to slower dissolution rates), but more data are needed to fully understand the impact of particle size on HyMelt performance/capacity.

Task 3.1

On Task 3.1, we were supposed to analyze gas turbine performance and costs. Some of this analysis is provided in Exhibit 26, but as mentioned earlier, all the work on this task was not completed.

Task 3.2

On Task 3.2, we were supposed to prepare a HyMelt plant Design Basis Memorandum (DBM). A conceptual design of a commercial-scale HyMelt gasification plant was prepared. Overall project economics were calculated using 1000 stpd of an 80/20 blend (based on dry weight) of coal and biomass as the feedstock. Exhibit 19 shows the estimated composition of the coal, biomass and blended feedstock. Preliminary material and energy balances for the HyMelt gasifier in this case are shown in Exhibit 20.

The commercial project economics for this case are shown in Exhibit 21. These results assumed that a Siemens-type gasifier plus a HyMelt gasifier are installed and that the HyMelt gasifier is used as the main workhorse (i.e. the Siemens-type gasifier is used as a hot spare). The results show an economically viable project with an IRR of 36% on an all-equity basis.

There are a few critical reasons for the strong economic performance of this project: (a) the values of urea and ammonium nitrate in the Midwest were very high at the time of this analysis, (b) a used ammonia plant and a used nitric acid plant were incorporated into the project to minimize investment costs and construction time, (c) an accelerated project schedule of 2 years after project financing was assumed, and (d) the cost of coal with 2-3% sulfur delivered was assumed to be $60 per short ton.

Exhibit 22 shows a comparison of a HyMelt gasification facility (1 gasifier plus 1 full spare) with conventional gasifier facilities and with steam methane reforming (SMR). This comparison was made when 1000 tpd of 80/20 coal/biomass are converted completely to high-purity hydrogen and sold for $22.4/million btu. (SMR's hydrogen rate was set equal to HyMelt's.) This comparison shows that if HyMelt performs as expected, HyMelt economics are superior to conventional processes. On an all-equity basis, HyMelt's IRR was 43%, versus 36%, 23% and 31% for Siemens-type gasifiers, GE gasifiers and steam methane reforming, respectively. One major reason for this superior performance relative to conventional gasifiers is that HyMelt's lower CO2 make during CO formation (described earlier) results in significantly lower oxygen consumption and higher hydrogen yields. A lower capital cost also helps, which is results from HyMelt's faster kinetics and smaller reactors.

EnviRes worked with Aker Solutions (formerly Aker Kvaerner) to prepare a Design Basis Memorandum for a first-of-a-kind (FOK) HyMelt plant. In December 2007, Aker completed a Front End Loading 2 (FEL2) study that contained process flow diagrams, a material and energy balance, utility requirements and capital cost estimates. The costs had an accuracy of about +-25%. Aker then investigated ways to reduce the capital costs and, in February 2008, issued revised capital cost estimates that lowered the gasifier island costs by about 20%. After February 2008, the scope of the project was modified as follows:

- Instead of assuming 2 HyMelt reactors, the project assumed one Siemens-type gasifier and one HyMelt reactor.
- Coke oven gas was deleted as a hydrogen source.
- Additional facilities were added downstream to convert ammonia into urea and ammonium nitrate.
- CO2 compression and storage were deleted from the costs.

Mercury was removed from the syngas with an activated carbon system. Capital costs for carbon dioxide compression/storage were included in the original scope. The design of the reactor effluent system was modified to remove dust as well as water-soluble impurities in a venturi-scrubber. The pressure/temperature of the venturi scrubber was optimized to provide a steam/dry gas molar ratio of about 1/1 prior to entering the water-gas shift section. An improved high-pressure pneumatic conveying system similar to the Wilsonville design was included. A Selexol/PSA H2 system was used for syngas cleanup.

Details of the Design Basis Memorandum are contained in the following exhibits:

- Exhibit 4 contains flow diagrams and mass balances for the entire commercial plant.
- Exhibit 5 contains a preliminary plant layout (assuming a clear and level site).
- Exhibit 6 contains a diaram of a HyMelt reactor/slag removal/quenching ("RSQ") system being developed.
- Exhibit 7 contains design basis specifications for the commercial plant.
- Exhibit 8 contains quality assurance and control procedures used by Aker Solutions.
- Exhibit 9 proposes a monitoring and sampling plan for the HyMelt system.
- Exhibit 10 contains commercial and technical risk identified by Aker Solutions.
- Exhibits 13a-b contain Gantt charts for a typical commercial project.
- Exhibit 14 provides a major equipment list for the plant after the scope changes listed above.
- Exhibit 15 contains utility estimates for the plant after the scope changes.
- Exhibit 16 shows the FEL 2 capital cost estimates issued in February 2007 (prior to the scope changes).
- Exhibit 18 discusses environmental, health and safety aspects of the design.

Exhibit 23 contains a report on the coke oven gas design.

Task 4

On Task 4, we were supposed to prepare a HyMelt project data package and project final report. This report, in its entirety, represents these deliverables.

D. Conclusion

All HyMelt testing in MEFOS using top entry lances for feedstock injection gave unacceptable carbon dissolution rates. At low feed rates both petroleum coke and coal resulted in approximately 70% of theoretical. At higher feed rates the rate of carbon dissolution dropped rapidly to near 20% of theoretical. Carbon dissolution rates for oil were even worse. Carbon dissolution rates could be improved with better injection lance design, but we felt that the probability of obtaining 98% of theoretical is unlikely with top entry lances.

Preliminary results based on visual observation and preliminary operating data indicate that submerged injection of coal and petroleum coke results in a much better carbon dissolution rate. The carbon dissolution rate also appears to be less dependent on coal or coke feed rate. Subsequent data reported by MEFOS from the September 2003 testing campaign agreed with initial observations. Testing in December 2003 used a more commercial compatible tuyere design. The composition of major gas streams appears to closely approach that predicted by thermodynamic equilibrium.

We significantly improved carbon dissolution rates by injecting feed with a submerged tuyere rather than a top entry lance. It appears that the 5% to 8% dust loss is the only carbon that is not otherwise reacted as thermodynamically predicted or fails to dissolve in the metal. We believe that much less dust loss will occur in pressurized operation. We would capture and recycle most of this material in commercial operation. We attained a maximum feed rate of 10 kg/min for coal and 18 kg/min using petroleum coke with a single tuyere in September testing. In December testing we attained a maximum feed rate of 27 kg/min for coal and 27 kg/min for coke using two submerged injection tuyeres. This leads us to believe that higher carbon dissolution rates could be attained with an additional tuyere or tuyeres.

We were able to measure and quantify trace constituents. We observed gas yields for major and trace constituents to be near thermodynamic equilibrium. Other than increased CO in the product hydrogen stream when coal is fed resulting from oxygen contained in the coal, there is little difference in the product stream compositions for coal compared to that for coke.

We were able to demonstrate a commercially viable tuyere configuration in December testing.

Hydrogen purging to remove sulfur does not appear to be attractive, however, during the testing much more sulfur disappeared than could be accounted for by H_2S appearing in the product gas. Further investigation of this phenomenon appears warranted.

Based on the economic analysis by Kvaerner, we believe that shifting carbon monoxide to hydrogen may not be economically attractive at an incremental cost of $2.86/kSCF above fuel value. Use of water gas shift to produce hydrogen imposes an added cost to gasification processes.

Based on an analysis of all the HyMelt and P-CIG data, it was concluded that there were 5 critical technical challenges to a successful commercial plant:

1. Operation at 35 bar
2. Continuous slag tapping at elevated pressures
3. Achieving 6-12 months between tuyere and refractory repairs
4. Predicting and handling dust emissions at 35 bar
5. Achieving an acceptable coal particle size

It is believed that each of these challenged can be properly addressed in a commercial design.

The projected economics of producing all high-purity hydrogen with a HyMelt gasification facility is significantly better than either conventional gasifier facilities or steam methane reforming.

E. References

All references are provided in the attached exhibits.

II. Exhibits

Exhibit 1	Statement of Project Objectives (11 pages)
Exhibit 2	Excerpts from P-CIG Final Report (4 pages)
Exhibit 3	P-CIG Fume Formation Study (10 pages)
Exhibit 4	Flow Diagrams and Material Balances (31 pages)
Exhibit 5	Preliminary Plant Layout (1 page)
Exhibit 6	HyMelt RSQ System (1 page)
Exhibit 7	Design Basis Specifications (18 pages)
Exhibit 8	QA-QC Description (24 pages)
Exhibit 9	HyMelt Sampling & Monitoring (5 pages)
Exhibit 10	Commercial and Technical Risk Analysis by Aker (8 pages)
Exhibit 11	FactSage Simulation Results (1 page)
Exhibit 12	HyMelt Tuyere and Reactor Design Calculations (3 pages)
Exhibit 13a	Gantt Chart Summary (1 page)
Exhibit 13b	Gantt Chart Details (6 pages)
Exhibit 14	Major Equipment List including Urea and Conventional Gasifier (9 pages)
Exhibit 15	Utility Estimates including Urea and Conventional Gasifier (3 pages)
Exhibit 16	FEL 2 Capital Cost Estimate through NH3 (1 page)
Exhibit 17	Impact of Coal Particle Size (6 pages)
Exhibit 18	Environmental, Health and Safety Aspects (11 pages)
Exhibit 19	Coal and Biomass Blend Calculations (1 page)
Exhibit 20	HyMelt M&E Balance – Preliminary by EnviRes (2 pages)
Exhibit 21	Project Commercial Economics – by EnviRes (2 pages)
Exhibit 22	Gasifier Economic Comparisons – by EnviRes (1 page)
Exhibit 23	Coke Oven Gas Design (39 pages)
Exhibit 24	U.S. Patent 4,496,369 (4 pages)
Exhibit 25	U.S. Patent 4,511,372 (6 pages)
Exhibit 26	Details of Tasks 1, 2.1 and 2.2 (338 pages)

Exhibit 1 Statement of Project Objectives (11 pages)

STATEMENT OF PROJECT OBJECTIVES

REDUCING ULTRA-CLEAN TRANSPORTATION FUEL COST WITH HYMELT® HYDROGEN

A. Project Objectives

The overall objective of this agreement is to conduct experimental research and process evaluations to assist in the development of a design basis memorandum, and performance and cost assessment for the integration of the HyMelt® technology in a typical refinery application. The HyMelt® technology which combines the elements of hydrocarbon gasification with steelmaking technology offers the capability to produce separate streams of high-pressure, high-purity hydrogen and carbon monoxide-rich fuel gas from fossil fuels such as coal, petroleum coke, and pitch at a higher efficiency, but at a cost much lower than conventional production methods. The high-pressure, high-purity hydrogen is required by the commercially-available hydrotreating processes used by the oil refining industry to produce the ultra-clean transportation fuels that meet the strict specifications of today's marketplace. The carbon monoxide-rich fuel gas that is produced separately by the HyMelt® technology may be used for the generation of electric power and/or steam.

B. Project Scope

The Recipient shall conduct experimental research and process evaluations to assist in the development of a design basis memorandum, and performance and cost assessment for the integration of the HyMelt® technology in a typical refinery application. The work conducted under this Cooperative Agreement will meet the following goals of the Ultra-Clean Transportation Fuels Initiative:

- Produce ultra-clean fuels from one or more hydrocarbon feedstocks that will result in a cleaner environment, a stable fuel supply at reasonable prices, more jobs, and continued prominence of the United States in global energy production.

- Establish the data base needed to design, construct, and operate innovative, pre-commercial scale, clean fuel production facilities that are intended to be either stand-alone or integrated with an existing refinery.

The HyMelt® technology combines the elements of fossil fuel gasification with steelmaking technology to convert these hydrocarbons to separate hydrogen and carbon monoxide-rich product gas streams using a molten iron bath. A systematic approach for the development of the HyMelt® technology involving experimental testing and mathematical modeling efforts will address the following technical objectives:

- Develop the appropriate HyMelt® injection technology (lances and/or tuyeres) for the hydrocarbon feed that maximizes melt stirring, produces optimum carbon dissolution, and to minimizes solid accretion during the hydrogen production step and for the oxygen and steam feeds that restore molten iron bath to its original temperature and carbon composition while minimizing the formation of carbon dioxide.

- Understand HyMelt® reactor chemistry as a function of pertinent independently controllable process parameters, via modeling and experimental operations using commercially available modeling software and pilot plant operations with standard analytical techniques.

- Prepare a HyMelt® Design Basis Memorandum that incorporates all data collected during the experimental testing into a form usable for the preparation of a full commercial plant design.

- Evaluate the use of the carbon monoxide-rich fuel gas for the production of electricity by conducting sub-scale validation combustion tests and gas turbine combustor modeling studies..

The work to be performed during this effort is divided into two budget periods. Budget Period 1 includes project initiation and HyMelt® testing at atmospheric pressure. Budget Period 2 includes HyMelt® testing at elevated pressure and evaluating commercial-scale HyMelt® process conceptual designs. A decision point at the conclusion of Budget Period 1 will determine whether to (1) initiate HyMelt® testing at elevated pressure, (2) continue with HyMelt® testing at atmospheric pressure, or (3) abandon the project. Details of the scope of work are provided in the following tasks.

C. Tasks to be Performed

<u>BUDGET PERIOD 1</u> (TASKS TO DECISION POINT)

Task 1 - Project Definition and Initiation

This task addresses the detailed organization and management of the project required to achieve its technical objectives. This task will be performed under the direction and coordination of the Recipient's technical personnel making use of management consultants, and technical subcontractors. The work to be performed under this task is divided into the following activities:

Task 1.1	Project Management and Planning
Task 1.2	Preparation and Shipment of Feedstock Materials
Task 1.3	Predictive Modeling of the HyMelt® Process
Task 1.4	Combustion Analysis/Modeling
Task 1.5	Design and Fabrication of Pilot Plant-Specific Molten Iron Bath Apparatus

Task 1.1 - Project Management and Planning

The Recipient shall prepare a Project Management Plan designed to achieve the project objectives covering the entire project period. This report will include a detailed reporting on the key activities or tasks to be performed, program manager, and key personnel as identified in the Cooperative Agreement. The Project Management Plan shall include a work breakdown structure and supporting narrative that concisely addresses the overall project as set forth in the agreement. In addition, the Project Management Plan shall provide a concise summary of the technical objectives and technical approach for each Task and, where appropriate, for each subtask. The Project Management Plan shall provide detailed schedules and planned expenditures for each Task including charts, contingency analysis, and all major milestones and decision points, including the development of the criteria upon which all GO/NO GO decisions are based. The Project Management Plan shall be submitted to the DOE Contracting Officer's Representative (COR) for approval within 60 days of execution of the Cooperative Agreement. The Project Management Plan shall be revised as recommended by the DOE COR or whenever project requirements are changed by Cooperative Agreement amendment. The Recipient shall submit recommended revisions to the Project Management Plan if such revisions are deemed desirable for optimum achievement of program objectives. Incorporation of recommended Project Management Plan changes must be approved by the DOE COR before implementation. The plan shall be submitted once after award of each Phase of the Cooperative Agreement and after any financial assistance change. DOE will review the report and advise the Recipient on the acceptability of the Project Management Plan or the need for additional information within 30 days after submittal to the DOE. The final Project Management Plan will then be submitted within 30 days of notice of acceptability of the draft Project Management Plan. The Recipient will also prepare a project technical plan that will include a detailed test plan for experimental testing conducted in the molten iron bath and a project risk analysis.

Task 1.2 - Preparation and Shipment of Feedstock Materials

The following feedstocks will be investigated during the course of the project:

Feedstocks	**Liquid**	**Delayed Coke**	**Coal**
Description	Marathon Ashland Petroleum LLC aromatic extract	Derived from Venezuelan or Mayan crude	Illinois # 6
Form	Liquid	Dried & Ground to < 1mm	Dried & Ground to < 1mm
Sulfur, Weight Percent	5	5	5%

Sufficient quantities of each material will be procured, prepared in accordance with the material specification, and delivered for use in the low pressure, molten iron bath testing.

Task 1.3 - Predictive Modeling of the HyMelt® Process

Detailed mass and energy balances, tailored to the operating conditions of the molten iron bath environment, will be prepared for each of the three feedstocks. In association with these system balances, thermodynamic simulations of the HyMelt® two-step operation using the FACT computer modeling package will be conducted. An interim report describing the range of anticipated operating conditions and citing model predictions for gas and melt compositions as a function of the operating parameters.

Task 1.4 - Combustion Analysis/Modeling

Evaluation of the HyMelt® carbon monoxide-rich fuel gas properties will be performed along with a literature search on similar fuels. Kinetics/computational fluid dynamics modeling of a Siemens Westinghouse diffusion flame synthesis gas combustor will be conducted. The modeling will be conducted using natural gas, refinery synthesis gas, and the HyMelt® carbon monoxide-rich fuel gas. The results will be compared for combustor mechanical configuration and functional compatibility.

Task 1.5 - Design and Fabrication of Pilot Plant-Specific Molten Iron Bath Apparatus

Each piece of apparatus required for the atmospheric pressure molten iron bath testing will be developed separately, and will consist of the performance of design analyses, preparation of engineering drawings, and fabrication.

Task 1.5.1 - Lances for Solid Feed and Oxygen Blowing

Top-feeding lances will be designed to feed powdered solid at a rate commensurate with the capabilities of surrounding molten iron bath pilot-plant equipment. Lances will be fabricated capable of feeding both of the solid feedstocks and also for use in oxygen blowing.

Task 1.5.2 - Liquid Feed System

An appropriate liquid pumping and injection system will be designed to be integrated with surrounding molten iron bath pilot-plant equipment. A system capable of feeding the aromatic extract will be fabricated.

Task 1.5.3 - Design and Fabrication of a Reactor Shell for High-Pressure Molten Iron Bath Operation

This will be performed in two separate budget periods. In Budget Period 1, a molten iron bath reactor capable of continuous operation up to five atmospheres will be designed. The start of Budget Period 2 will follow the decision point to proceed to high pressure testing. If a decision is made to conduct high pressure testing, engineering drawings and fabrication of the reactor will be completed during Budget Period 2.

Task 2 - Project Testing

This task addresses the experimental testing conducted in a molten iron bath to produce high-purity hydrogen and carbon monoxide-rich fuel gas from hydrocarbon feedstocks. Experimental combustion testing of the carbon-monoxide-rich fuel gas will also be conducted. This task will be performed under the direction and coordination of the Recipient's technical personnel making use technical subcontractors. The work to be performed is divided into the following three activities:

Task 2.1	Carbon Monoxide-Rich Fuel Gas Combustion Testing
Task 2.2	HyMelt® Atmospheric Pressure Testing in a Molten Iron Bath
Task 2.3	HyMelt® Above-Atmospheric Pressure Testing in a Molten Iron Bath

Task 2.1 - Carbon Monoxide-Rich Fuel Gas Combustion Testing

Sub-scale combustion testing of the carbon monoxide-rich fuel gas will be conducted at full pressure and gas turbine temperature to characterize the following: fuel injector parameters and characteristics; ignition characteristics; general combustion characteristics; and kinetics. The experimental testing will support diffusion flame combustion of the carbon monoxide-rich fuel gas and compare it with natural gas. A one-burner approach will be selected for conceptual design studies and major design and operating features will be tested and evaluated at sub-scale. Tests will be conducted under subcontract using existing combustion test facilities. Tube trailers of premixed gas will be utilized to simulate the actual HyMelt® carbon monoxide-rich fuel gas.

Task 2.2 - HyMelt® Atmospheric Pressure Testing in a Molten Iron Bath Unit

Specific work to be performed under this task includes commissioning of the molten iron bath unit through operation and evaluation of results.

Task 2.2.1 - Preparations for Atmospheric Pressure Operation of the Molten Iron Bath Unit

The existing molten iron bath unit and equipment will be prepared for HyMelt® testing at atmospheric pressure. Project-specific apparatus will be integrated with exiting equipment.

Task 2.2.2 - Cold Tests for Atmospheric Pressure Operation of the Molten Iron Bath Unit

Before the start-up of operation at elevated temperature, all units and equipment will be tested separately, and where possible, as part of the integrated system.

Task 2.2.3 - Hot Commissioning for Atmospheric Pressure Operation of the Molten Iron Bath Unit

Hot tests of the complete system will be performed to evaluate the functionality of various subsystems: (1) liquid feed, (2) solid feed, (3) oxygen blowing, (4) gas analysis, (5) dust sampling, and (6) process control.

Task 2.2.4 - Process Performance Tests for Atmospheric Pressure Operation of the Molten Iron Unit

Hydrocarbon feedstock injection tests and oxygen blowing tests will be conducted at atmospheric pressure in the molten iron unit as a function of material feed rates, lance height, and bottom stirring intensity. During the tests, measurements and sampling will made for the evaluation of melt composition, gas composition, and thermal balance.

Task 2.2.5 Evaluation of Results from Atmospheric Pressure Operation of the Molten Iron Bath Unit

Experimental results will be evaluated in terms of heat and mass balances and will be compared with the results of predictive modeling. Using the experimental data, predictions will be made for the behavior of elevated pressure operation.

Decision Point **- Based on the criteria developed under Task 1.1 - Project Management and Planning, a decision will be made whether to (1) initiate**

fabrication of the elevated pressure molten iron bath unit and conduct elevated pressure testing under Task 2.3, (2) continue with atmospheric testing in the existing molten iron bath unit, or (3) abandon the project.

BUDGET PERIOD 2 (TASKS AFTER DECISION POINT)

Task 2.3 – HyMelt® Elevated Pressure Testing in a Molten Iron Bath Unit

Specific work to be performed under this task is the purchase of pilot-scale data and evaluation of results from the injection of coal into a molten iron reactor operating at a pressure of 3 bar.

Task 2.3.1 - Contract to Purchase Data

Execute contract to purchase all available data from InterProject Service AB (IPS) on pilot plant testing of the Coal Iron Gasification (CIG) Process and the Pressurized Coal Iron Gasification (P-CIG) Process.

Task 2.3.2. – Technology Transfer

Hold meeting with representatives of IPS and complete technology transfer.

Task 2.3.3 - Evaluation of Results from Elevated Pressure Operation of the Molten Iron Bath Unit

Experimental results from elevated-pressure operation will be evaluated in terms of heat and mass balances and will be compared with the results of predictive modeling of elevated-pressure operation based on atmospheric-pressure data. Using the elevated-pressure experimental data, predictions will be refined to develop scale-up rules.

Task 3 - Project Analysis

This task analyzes and uses the experimental data produced under this effort to conduct performance evaluations, cost evaluations, and conceptual design studies for the HyMelt® in various commercial embodiments. This task will be performed under the direction and coordination of the Recipient's technical personnel making use technical subcontractors. The work to be performed is divided into the following two activities:

Task 3.1 - Integrated Gasification Combined Cycle (IGCC) Performance and Cost Assessment

Task 3.2 - HyMelt® Plant Design Basis Memorandum

Task 3.1 - IGCC Performance and Cost Assessment

An estimate of the IGCC plant performance and costs for a gas turbine operating on the HyMelt® carbon monoxide-rich fuel gas will be performed. Activities will include updated gas turbine performance estimates, definition of required turbine modifications, estimated combined cycle performance, and budgetary estimates of capital, operating, and maintenance costs.

Task 3.2 - HyMelt® Plant Design Basis Memorandum (DBM)

The DBM is defined as a document consisting of a conceptual engineering design for the use of the HyMelt® technology in a commercial-scale first-of-a-kind gasification plant and an appropriation-quality capital cost estimate for such a plant in comparison to competitive gasification plants. The DBM will be prepared by an engineering procurement and contractor (EPC) and will incorporate the results of all prior testing and studies, i.e., all of the engineering information necessary to design a commercial-scale demonstration HyMelt® plant.

Task 3.2.1 - EPC Introduction to HyMelt®

The Recipient will conduct a briefing with the EPC to review the complete project plan and the EPC's role in the project. The test plan and all data collected from the molten iron bath testing will be evaluated by the EPC to assure that the pilot-plant testing performed answers key questions and provides suitable information for the DBM.

Task 3.2.2 - Conceptual Design Iteration and Cost Estimate

Based on design concepts provided by the Recipient together with the available experimental data, the EPC will prepare an independent conceptual design and capital cost estimate of a commercial-scale HyMelt® gasification plant. This activity will include description of all plant subsystems and development of flow sheets including but not limited to (1) feedstock receiving, storage and handling, (2) reactor feeding and injection systems, (3) reactors and reactor appurtenances, (4) gas cooling, (5) off-gas solids removal, (6) gas recycle systems, (7) solids recycle systems, (8) high pressure valving and pressure regulation, (9) product gas handling, and (10) process specifications for budgetary estimates of air, acid gas scrubbing, sulfur and pressure swing adsorber plants.

Task 3.2.3 - First Integration of Pilot-Plant Data

Following the completion of testing in the molten iron bath unit at atmospheric pressure, the results will be reviewed and evaluated. Appropriate data will be incorporated into the DBM.

Task 3.2.4 - Comparison of Process Economics for Competitive Processes

Estimates for comparably-sized commercial-scale plants will be developed for HyMelt®, steam methane reforming, and partial oxidation processes.

Task 3.2.5 - Define First-of-a-Kind (FOK) Commercial-Scale HyMelt® Project

A FOK commercial-scale project will be selected from several candidates identified by the Recipient.

Task 3.2.6 - Prepare FOK Design and Cost Estimate for Commercial-Scale HyMelt® Project

An independent conceptual design and capital cost estimate of the FOK commercial-scale HyMelt® project for the selected application will be prepared. This activity will include description of all plant subsystems and development of flow sheets including but not limited to (1) feedstock receiving, storage and handling, (2) reactor feeding and injection systems, (3) reactors and reactor appurtenances, (4) gas cooling, (5) off-gas solids removal, (6) gas recycle systems, (7) solids recycle systems, (8) High pressure valving and pressure regulation, (9) product gas handling, and (10) process specifications for budgetary estimates of air, acid gas scrubbing, sulfur and pressure swing adsorber plants.

Task 3.2.7 - Second Integration of Pilot-Plant Data

Following the completion of testing in the molten iron bath unit at elevated pressure, the results will be reviewed and evaluated. Appropriate data will be incorporated into the DBM.

Task 3.2.8 - Completion of DBM and Cost Estimate for FOK Commercial-Scale Project

Following receipt of the final test data from the molten iron bath unit, the DBM and appropriation quality cost estimate for the FOK commercial-scale project will be completed.

Task 4 - Project Conclusion

This task finalizes all work completed in the effort to fulfill the stated technical objectives of the project. This task will be performed under the direction and coordination of the Recipient's technical personnel. The work to be performed is divided into the following two activities:

Task 4.1 - Preparation of the HyMelt® Project Data Package
Task 4.2 - Preparation of the Project Final Report.

Task 4.1 - Preparation of HyMelt® Project Data Package

All data including all of the individual deliverables will be assembled into a form readily used by the developers of the FOK commercial-scale plant.

Task 4.2 - Project Final Report

The final report which reviews the proceedings of the project and summarizes its findings and conclusions will be prepared.

D. Deliverables

The Recipient shall provide reports in accordance with the attached reporting requirements checklist and the instructions accompanying the checklist. In addition to the reports listed in the "Reporting Requirements Checklist," the participant shall provide the following reports:

Budget Period 1
Project Management Plan

Topical Report - HyMelt® Testing at Atmospheric Pressure
Detailed description of the HyMelt® atmospheric pressure test program including the apparatus design, test plan, discussion of results, conclusions, and recommendations for future work. Appendices will contain all of the data collected.

Topical Report - Carbon Monoxide-Rich Fuel Gas Combustion Testing
Detailed description of the carbon monoxide-rich fuel gas combustion test program including carbon monoxide-rich fuel gas combustion evaluation, analysis, and modeling, combustor design, test plan, discussion of results, conclusions, and recommendations for future work. Appendices will contain all of the data collected.

Budget Period 2

Updated Project Management Plan

Topical Report - HyMelt® Testing at Elevated Pressure
Detailed description of the HyMelt® elevated pressure test program including the apparatus design, test plan, discussion of results, conclusions, and recommendations for future work. Appendices will contain all of the data collected.

Topical Report - IGCC Plant Performance and Costs
Preliminary estimate of the performance and costs for a gas turbine operating on the HyMelt® carbon monoxide-rich fuel gas in an IGCC plant including updated gas turbine performance estimates, definition of required turbine modifications, estimated combined cycle performance, and budgetary estimates of capital, operating, and maintenance costs.

Topical Report - Conceptual Design of a Commercial-Scale HyMelt® Gasification Plant
Conceptual design and cost estimate for a commercial-scale HyMelt® Gasification Plant including a comparison with similarly sized steam methane reforming (SMR) and partial oxidation processes (POX) plants.

Topical Report - Design Basis Memorandum for a FOK HyMelt® Plant
Conceptual design, cost estimate of appropriation quality, and risk analysis for a FOK commercial-scale HyMelt® plant.

Topical Report - HyMelt® Technology Full Project Data Package
Assembles all experimental data, modeling results, conceptual design evaluations into a form that can be readily used by the developers of the FOK commercial-scale HyMelt® Plant.

Exhibit 2 Excerpts from P-CIG Final Report (4 pages)

INTERPROJECT PROCESSTEKNIK AB

INTERPROJECT SERVICE AB – NIPPON STEEL CORPORATION
JOINT DEVELOPMENT PROJECT P-CIG

P – C I G

The pressurized coal iron gasification process

I Report of pilot plant experiments

MEFOS 1985 - 86

INTERPROJECT SERVICE AB
MARS 1987

CONTENTS

SUMMARY

4.6 Wear of lining and tuyeres

4.7 Material balances

5. DISCUSSION

REFERENCES

APPENDIX

1. List of symbols
2. Calculation methods
3. Table A:A1 Composition of raw materials
   - A:B1-B5 Slag composition
   - A:C1-C2 Metal composition
   - A:D1-D3 Dust/gas sampling results
   - A:E1 Analysis of sludge water
   - A:F1-F3 Results from test PC33-42

SUMMARY

The pressurized P-CIG process is an improvement of the basic molten bath gasification process. It can be optimized for continuous production of a pure coal gas. The pressurization of the process has a number of positive effects:

- *the reactor and off-gas system can be made more compact for a given gasification capacity*
- *sculling problems at the gas outlet can be decreased*
- *the gasification capacity can be increased*
- *the dust formation can be decreased*
- *the pressurized gas can be utilized directly for certain purposes, where pressure is necessary*

The planned pilot plant test program has been successfully concluded. The design of the pressurized reactor including auxiliary equipment, sampling equipment etc and the general function of the complete system have been to full satisfaction after some initial problems have been overcome and certain modifications have bee made. The test campaigns have resulted in deeper understanding and increased know-how about reactions and phenomena involved in the process.

The process productivity has been increased successively during the test campaigns. For shorter periods peak quantities of up to 100 m^3 *n gas/*m^2 *min (reactor cross sectional area) were reached. An average value of 60-70* m^3 *n gas/*m^2 *is established. The corresponding injection rate will be approximately 500 kg coal/ton Fe, h. Further increase of this value should be possible.*

A carbon conversion efficiency (carbon yield) over 95 % has been established with peak values close to 100 %. The "cold gas efficiency" of this process is higher when compared with other gasification processes.

The process control system including the pressurized sublance has functioned satsifactorily. Further development of the computer model is foreseen.

The generated gas mixture has proven very stable. The average component characteristics for one coal type have been:

63-65	% CO	
30-32	% H_2	
0.2-1.0	% CO_2	
3-4	% N_2	*(from coal and transport gas)*

The sulphur content has been very low. Measured before the scrubber the lowest noted value is 3 ppm, with average values around 55-60 ppm. The sulphur content measured after the wet scrubber was in the very low field 0.2-2.1 ppm. All heavy metals components in the gas were caught near to 100 % in the dust filter (except Hg).

Different kinds of coal has been processed with good results. For the pilot plant, however, coal with high carbon content was preferred due to the heat balance of this small reactor. Problems of this kind are not expected in a commercial size reactor.

The following items still remain to be studied and developed:

- *slag discharging methods and separation of slag and metal*
- *continuous operation of the entire system for longer periods of time*
- *refractory wear under various operational conditions*

Exhibit 3 P-CIG Fume Formation Study (10 pages)

15

FUME FORMATION DURING INJECTION OF OXIDIZING GASES IN IRON

by

Carl-Lennart Axelsson*)

SYNOPSIS

For the study of fume formation from an iron bath during injection of coal and oxygen, experiments were carried out in laboratory scale. The fume formation rate was measured both at atmospheric pressure and at pressure above atmospheric.

The results have demonstrated that such parameters as carbon and sulphur content of melt and total pressure has a great influence on the rate of fuming. The sulphur content in the melt decreased the rate of fuming strongly at low carbon contents in melt. No such influence of sulphur was seen in experiments with a high carbon content in melt.

I INTRODUCTION

Fume from oxygen steelmaking processes is more an environmental problem than a metallic yield problem. But, if the aim of the process is to produce an energy rich gas and great amounts of gas are generated the fume problem will change its character and the yield of metal and recovery of physical heat would be of great importance. Still, it could be of interest for the steelmakers to improve the knowledge about the mechanism of fume formation.

At the Division of Ferrous Metallurgy, experiments have been carried out since 1975, in which coal, lime, oxygen and iron ore concentrate have been injected into a carbon containing iron bath for production of hot metal and gas.

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*) Department of Ferrous Metallurgy, Royal Institute of Technology, S-100 44 Stockholm, Sweden

A subject, which recently has met an increasing interest is coal gasification by injection of coal, oxygen and slag formers into a hot metal bath. The gasification will be maintained by a simultaneous carburization and decarburization at a constant carbon content (∿ 2 %). The aim with the present work was to get information of possibilities to affect the fume formation during simultaneous injection of an oxidizing gas and coal into a metal bath.

A gasification process could be very similar to an oxygen steelmaking process. One example is the OBM (Q-BOP) process where oxygen is blown into the melt through multiple tuyeres from the bottom of the vessel. In this case, the tuyeres and the refractory near to the tuyeres is protected from the oxidizing heat by cracking of an simultaneous injected hydrocarbon gas. The OBM process could be modified to an gasification process by additional tuyeres for coal feeding.

In this new process, problems will occur in the same way as in the related steelmaking process. One of the problems would be fume formation. Fume rate in the OBM process is 2 to 4 kg Fe/min, m^2 [1]. If this is divided through the specific decarburization rate (eg. 40 kg C/min, m^2) [1,2], the amount of fume per kg carbon would be 50 to 100 g. Hence, if 2 Nm^3 gas are made per kg of coal, the fume formed may be in the order of 25 to 50 g Fe/Nm^3 gas. In a gasifier with 150 ton iron and gasifying 150 ton coal/hour, 180 to 360 ton iron would be transferred to fume per day.

II MECHANISMS OF FUME FORMATION

Two main theories tries to explain the mechanism of fume formation in oxygen steelmaking.

One of them is the "bubble bursting mechanism" whereby iron is transported into the gas phase.

III EXPERIMENTAL

Experiments were made in two different types of laboratory equipment: an injection furnace with atmospheric pressure and a furnace that could be operated at pressure above atmospheric.

The principle of the furnace for atmospheric pressure, in which most of the experiment were carried out is shown in Fig. 2.

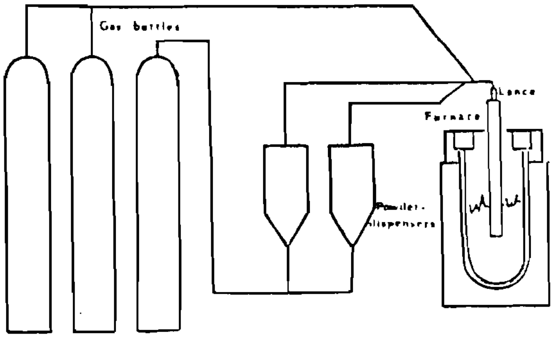


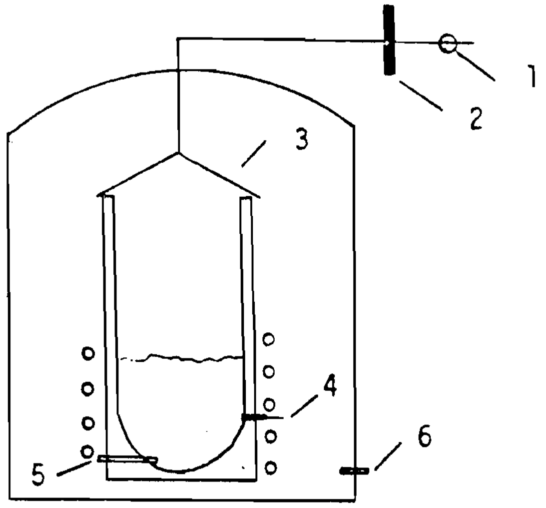
Fig. 2. Schematic arrangement of laboratory equipment

The induction furnace has a sintered alumina crucible and a melt capacity of 20 kg. The diameter of the crucible is 18 cm and the bath dept is about 15 cm.

Powderous material is injected into the melt through a lance made of sintered alumina and with a inside diameter of 6 mm. The lance is submerged in the melt to a level of 10 cm below the bath surface.

The powder feeding is achieved by a powder dispenser of fluidizing type with argon as carrier gas.

The emitted fume was sampled with a filter equipment showed in Fig. 3. One part of the generated fume was sampled with a probe, placed 5 cm below the upper part of the curcible. The ratio between the probe area and the effective crucible area was 0.1.



1. Pressure regulator
2. Filter
3. Hood
4. Thermocouple
5. Injection tube
6. Gas for pressure

Fig. 4. Schematic arrangement of laboratory equipment for pressure above atmospheric

and sulphur composition of bath. The rate of injected oxygen was 30 Nl/min. The total argon flow rate was 20 Nl/min which together with the oxygen gave a gas velocity of about 30 m/s in the upper part of the lance.

TABLE I

Material	% C_{tot}	% V.M$^{x)}$	% moist.	% ash	% S	% Fe_3O_4	% Fe_2O_3
Coal	71,7	8,7	2,6	21,6	2,0	-	-
Iron ore	-	-	-	-	0,04	82,9	2,7

x) d.a.f.

IV RESULTS

The initial experiments were made in order to get information of the fume level in this type of gasification experiments but also to test the experimental apparatus. The result is shown in Table II.

TABLE II

Experiment	O_2 Nl/min	Ar Nl/min	C-bath %	S-bath %	Fume g/Nm^3
1	30	20	0,67	0,44	30,8
2	30	20	0,53	0,48	29,6

Both experiments gave a fume rate of about 30 g/Nm^3.
Two series of experiments were then made with a carbon content in bath ranging from 0.11 % to 0.80 % and 2.94 % to 4.76 % respectively. The experiments were made with different sulphur content in the bath and the result is shown in Fig.5.

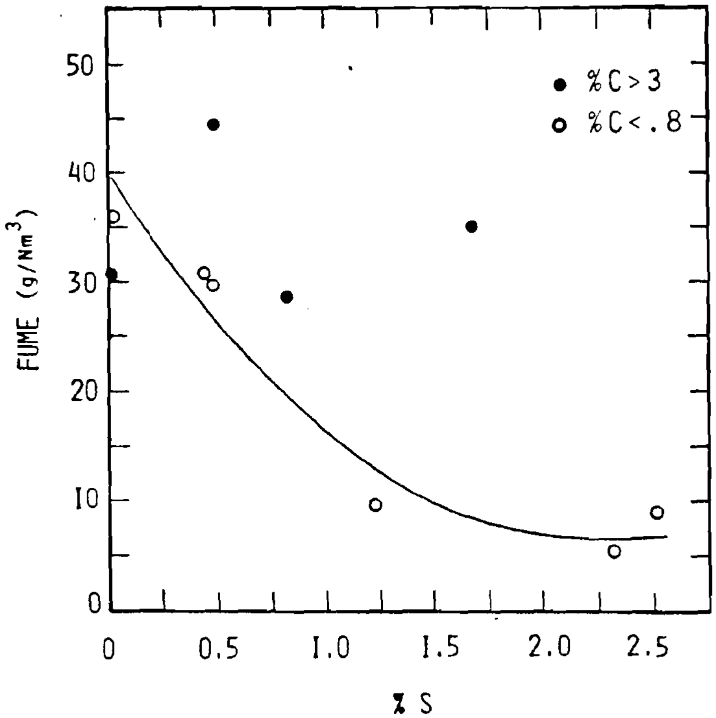


Fig. 5. Fume related to the mean sulphur content of melt

A comparison shows a strong influence of sulphur on fuming at low carbon content. The same tendency could not be seen in the experiments with high carbon content.

The fume rate was also studied during injection of iron ore powder. Four experiments were made with an average carbon content in the bath of 0.98 % and a sulphur content of 0.41 %. The result (Fig. 6) shows a slightly decreasing fume rate with increasing feeding rate of iron ore. The opposite tendency was shown with increasing oxygen flow rate.

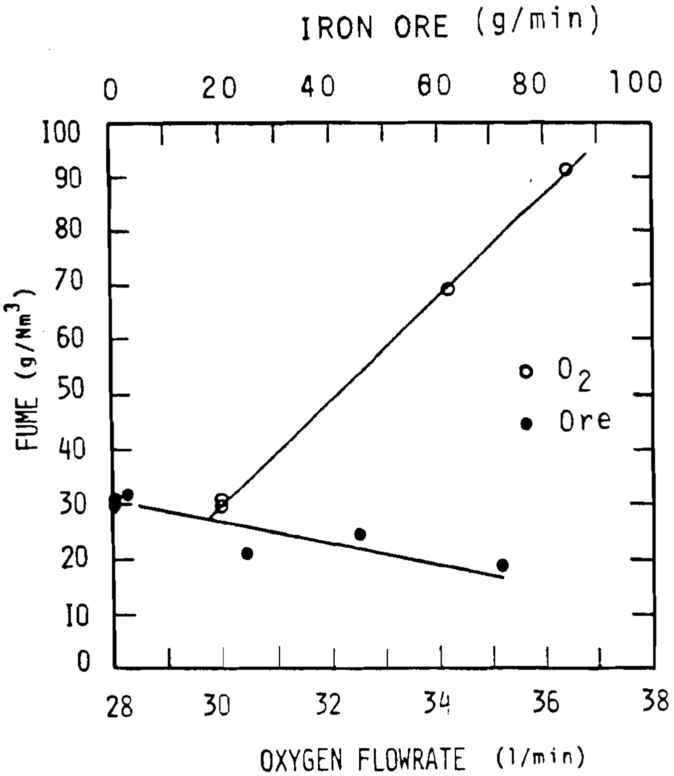


Fig. 6. Fume related to the oxygen flow rate and the injected iron ore.

As was mentioned earlier a few experiments has also been made in a pressurized induction furnace with a possible meniscal pressure of 4 bar. Results from eight experiments at different pressure and with an average carbon content in the bath of 0.61 % ± 0.05 %

and a sulphur content of 0.92 % ± 0.05 % are summarized in Fig. 7. The P_{O_2}/P_{Ar} ratio was 0.5.

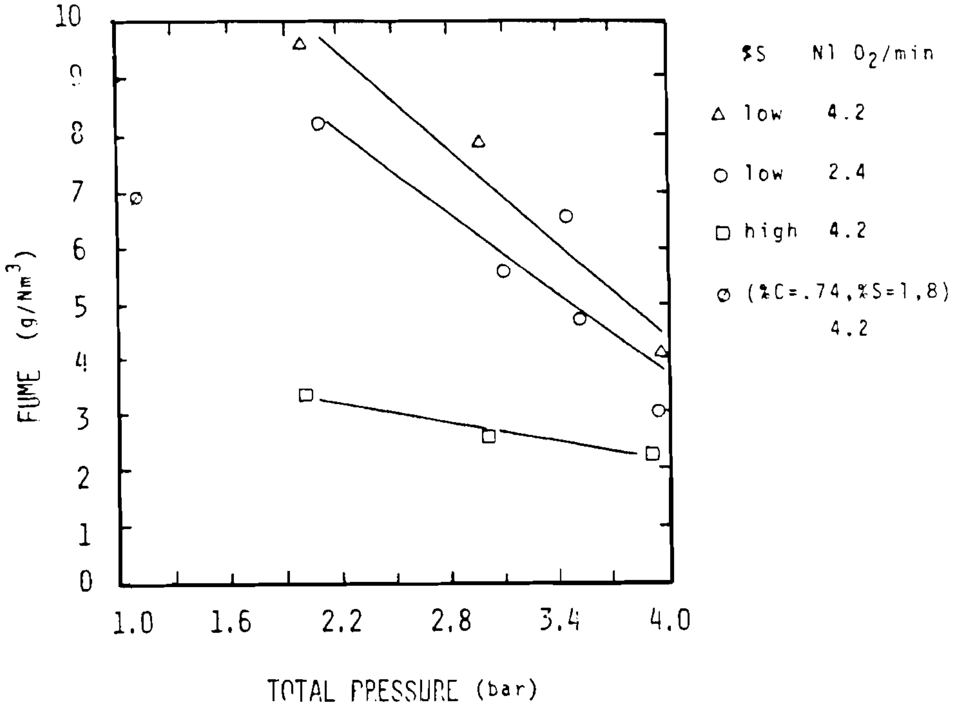


Fig. 7. Fume related to total pressure

Fig. 7 also gives the fuming at various pressure at high sulphur content in the bath. In this case carbon content was 0.11 % ± 0.07 and the sulphur content was 1.75 % ± 0.19.

As seen from Fig. 7 the fuming rate decreases with increasing pressure in the first mentioned experiments. At high sulphur content in the bath, the average fume rate is lower and seems not to be strongly influenced by the pressure.

However, the results from the pressurized experiments follows the same tendency as was presented in Fig. 5. At low carbon content in the bath, fuming will be greatly influenced of the sulphur content in the bath.

V DISCUSSION

A few interesting aspects of the experimental results will be discussed in the following.

One result from the experiments is that carbon and sulphur content in the bath influence the rate of fuming greatly. Also the total pressure of the system will influence the fume rate.

In this investigation the fume rate was found to be very dependent of the sulphur content in the bath at low carbon content in the bath. An increase in the sulphur content decreases the rate of fuming greatly both at 1 bar and at higher pressure. (Fig. 4,6).

A drastical decrease in the fume rate have been reported from experiments with low carbon content in the bath[7]. The authors explain the phenomena with the slow rate of diffusion of carbon on the metal side concerning the reaction

$$CO_2(g)+\underline{C} = 2\ CO\ (g)$$

at the gas metal interface. Hence, at low carbon content, a thin layer of oxide will be formed on the metal surface due to the reaction

$$CO_2(g)+Fe = FeO + CO(g)$$

That oxide layer will protect the metal surface and vaporization of iron will be very small. A critical value for a steelmaking process was mentioned to be round 0.3 % carbon in the melt.

The overall reaction of gasification in molten iron is very sensible to changes in bath carbon and sulphur content. Due to the mutual positive interaction between carbon and sulphur, the dissolution rate of carbon will decrease with increasing carbon activity in the melt.

The yield of injected coal will decrease with increasing carbon activity and the bath will be decarburized.

This phenomena was happening in the experiments with high carbon and sulphur content in the melt. It was occuring in both the normal pressure and the over pressure experiments. One possibility is that the slow dissolution rate of carbon also influence the rate of fuming.

Another interesting result from the atmospheric pressure experiments is the high sulphur content in the fume.

Results from ten experiments were coal and oxygen were injected in melts with carbon content ranging from 0.43 % to 4.76 % and sulphur content from 0.4 % to 1.64 % is summarized in Fig. 8.

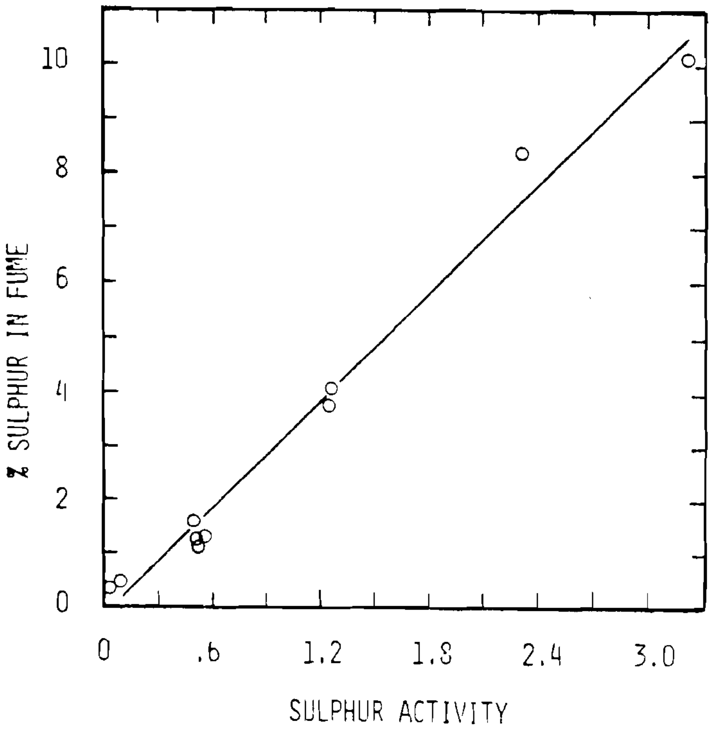


Fig. 8. The mean sulphur content in fume related to the sulphur activity in the melt

Sulphur activity is calculated using first order interaction coefficients ($e_S^S = -0.028$, $e_S^C = 0.113$) [9].

VI CONCLUSION

containing iron melts show that

- increasing sulphur content in a low carbon melt strongly decreases the amount of emitted fume
- increasing oxygen flow rate increases the fume rate very much
- injection of additional iron ore powder slowly decreases the rate of fuming
- an increased total pressure in the system decreases the fuming rate at low carbon content in the bath.

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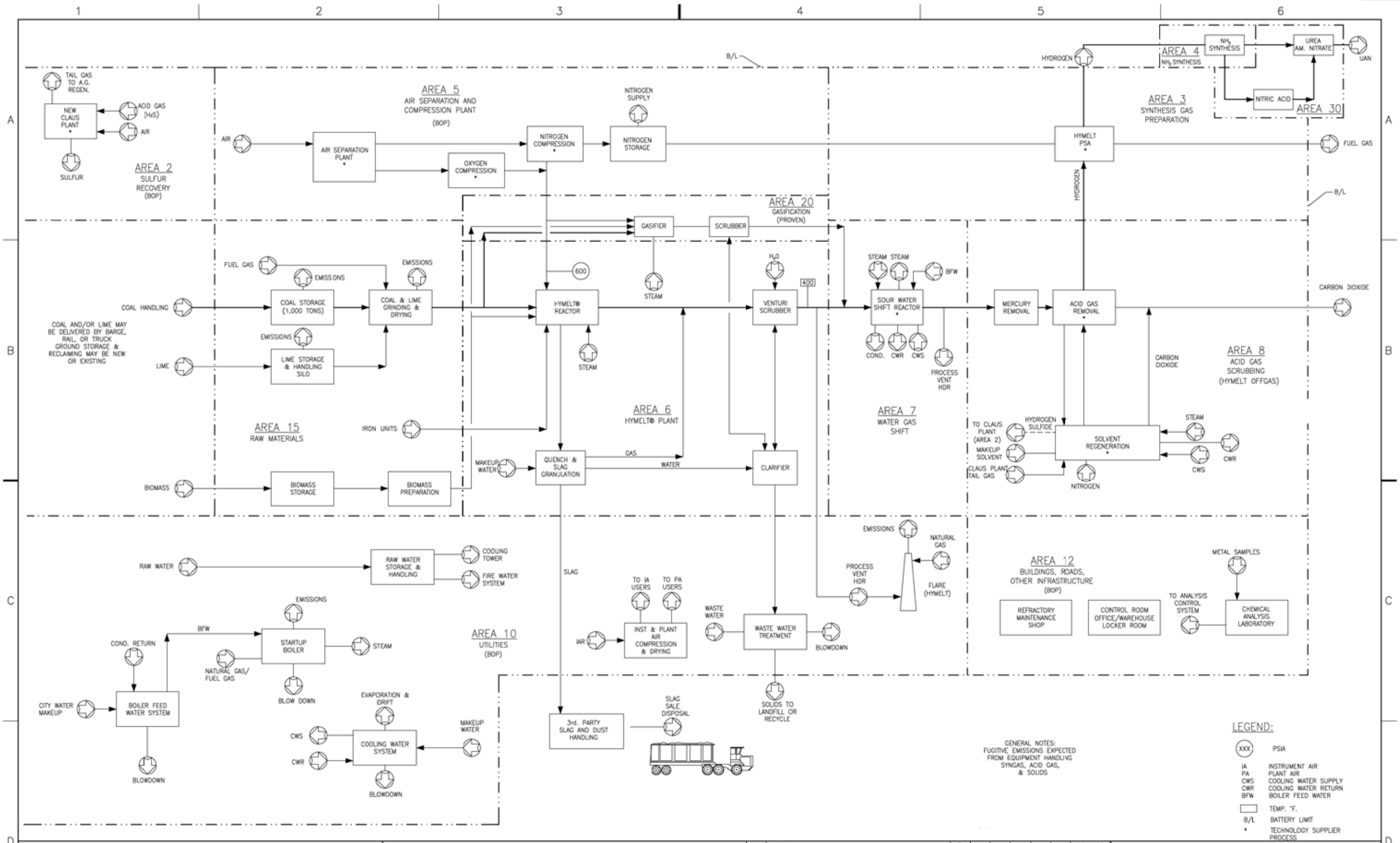
Exhibit 4 Flow Diagrams and Material Balances (31 pages)

Description	**Type**	**Number**	**Rev.**
Coal to Nitrogen Products	BFD	R-00-0001	C
Process Drawing List	BFD	R-00-0002	A
Stream Description	PFD	R-00-0003	C
Stream Description	PFD	R-00-0004	C
Stream Description	PFD	R-00-0005	C
Claus Sulfur Recovery	PFD	R-02-0002	C
Pressure Swing Adsorption	PFD	R-03-0004	E
Ammonia Plt Synthesis Section	PFD	R-04-0001	B
Ammonia Plt Refrigeration	PFD	R-04-0002	B
Ammonia Plt Steam Balance	PFD	R-04-0003	B
Ammonia Storage and Flare	PFD	R-04-0004	B
Air Separation Plant	PFD	R-05-0001	B
HyMelt® Reactor	PFD	R-06-0001	F
Exhaust Gas Cleaning	PFD	R-06-0002	F
Gas Quench/Slag Granulation	PFD	R-06-0003	E
Fume and Dust Collection	PFD	R-06-0004	E
Water Gas Shift	PFD	R-07-0001	I
Mercury Removal	PFD	R-08-0001	F
Selexol®Acid Gas Removal	PFD	R-08-0002	G
Selexol®Acid Gas Removal	PFD	R-08-0003	D
Cooling Tower	PFD	R-10-0001	B
Demin. Water, Start-up Boiler, Fire Protection	PFD	R-10-0002	B
Wastewater Treatment	PFD	R-10-0003	B
Boiler Chem.Treat. Emergency N2,Air Supply	PFD	R-10-0004	B
Flare and Sanitary System	PFD	R-10-0005	B
Emergency Power	PFD	R-10-0006	B
Coal Grind/Dry & Lime Receiving	PFD	R-15-0001	G
Coal/Lime Injection	PFD	R-15-0002	G
531 STPD UREA Plant	PFD	PFS-01	
525 STPD Nitric Acid Plant	PFD	PFS-02	
665 STPD Ammonium Nitrate Plant	PFD	PFS-03	
NH3 Synthesis –Mat'l Balance	PFD	65386-FD-001	K
NH3 Refrigeration- Mat'l Balance	PFD	65386-FD-002	K
NH3 Steam Balance	PFD	65386-FD-003	K



GENERAL NOTES:
FUGITIVE EMISSIONS EXPECTED FROM EQUIPMENT HANDLING SYNGAS, ACID GAS, & SOLIDS

LEGEND:

(XXX)	PSIA
IA	INSTRUMENT AIR
PA	PLANT AIR
CWS	COOLING WATER SUPPLY
CWR	COOLING WATER RETURN
BFW	BOILER FEED WATER
▭	TEMP. °F.
B/L	BATTERY LIMIT
*	TECHNOLOGY SUPPLIER PROCESS

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
C	OCOD SUBMITTAL	TI			MJF	PFA		02JUN08
B	COST REDUCTION	TI			MJF			12FEB08
A	PRELIMINARY	KK	WRR		MJF	TM		10JAN08

AkerSolutions™

PRELIMINARY
NOT APPROVED FOR CONSTRUCTION
TYPE OF ISSUE
24x36

AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANT

AREA DESIGNATIONS
PROCESS BLOCK FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHARGE CODE	SCALE	DRAWING NO.	REV.
A0757603		NONE	R-00-0001	C

1/10 1/8-1/4 3/16-3/8-3/4 1/2- 1

Stream	34-1 H2 , HyMelt PSA Out	34-2 Tailgas, HyMelt PSA	61-1 Coal Feed	61-2 Coal to Grinding	61-3 Ground Coal to Baghse	61-4 Ground Coal to Bin	61-5 Dried Coal	61-6 Nitrogen Transport	61-7 Combustion Air to Dryer
Temperature ° F	100.0	100.0	60.0	60.0	150.0			100.0	60.0
Pressure psia	401.4	24.7	14.7	14.7	14.7			165.0	14.7
Velocity, fps	60.0	70.0						70.0	
Line Size, inches	12.0	18.0			48.0			3.0	
Hydrogen, lbs/hr	13,457.3	1,835.1							
Carbon Monoxide	0.2	9.4							
Carbon Dioxide	0.2	8,313.1							
Oxygen	0.0	0.0							3,007.6
Nitrogen	1.9	4,822.1			277,653.8			8,333.3	9,959.9
Methane	0.0	75.4							
Ethane	0.0	0.0							
Ethylene	0.0	0.0							
Propane	0.0	0.0							
Propylene	0.0	0.0							
Benzene	0.0	0.0							
Toluene	0.0	0.0							
Xylene	0.0	0.0							
Hydrogen Sulfide	0.2	1.1							
Carbonyl Sulfide	0.0	1.0							
Hydrogen Cyanide	0.0	0.2							
Ammonia	0.0	0.1							
Sulfur Dioxide	0.0	0.0							
Sulfur	0.0	0.0							
Water	0.1	25.2	7,101.4	7,101.4	7,101.4	1,666.7	1,666.7		
Hydrogen Chloride	0.0	0.3							
Mercury			0.0	0.0	0.0	0.0	0.0		
Coal, ash free, moisture free			74,480.0	74,480.0	74,480.0	74,480.0	74,480.0		
Ash			7,186.7	7,186.7	7,186.7	7,186.7	7,186.7		
Lime									
Slag									
Iron									
Total, lbs per hour	13,459.9	15,082.9	88,768.1	88,768.1	366,421.9	83,333.4	83,333.4	8,333.3	12,967.4
Design Flow , lbs/hr			266,304.4	130,434.8	120,000.0	120,000.0			
Molecular wt									
Hours/ day operation			8.0	24.0					
Total, tons per hour			44.4	44.4					
Normal Flow, gpm									
Design Flow , gpm									
Volume Flow, scfm	42,165.7	8,071.3			62,637.4			1,880.0	2,840.6
Volume Flow cuft/min	1,660.0	5,174.3			73,358.0			180.0	
Hydrogen, lb mol/hr	6,675.2	910.3							
Carbon Monoxide	0.0	0.3							
Carbon Dioxide	0.0	188.9							
Oxygen		0.0							94.0
Nitrogen	0.1	172.1						297.6	355.7
Methane		4.7							
Hydrogen Sulfide	0.0	0.0							
Carbonyl Sulfide		0.0							
Hydrogen Cyanide		0.0							
Ammonia		0.0							
Sulfur Dioxide		0.0							
Sulfur		0.0							
Water	0.0	1.4							
Hydrogen Chloride		0.0							
Mercury		0.0							
Coal (ash & water free)		0.0							
Ash		0.0							
Lime		0.0							
Slag		0.0							
Iron									
Total, lbmol/hr	6,675.3	1,277.8						297.6	449.7

Stream	61-8 Natural Gas	61-9 Coal to Feed Hopper	61-10 Rcycle Gas-Grinding Mill	62-1 Lime	62-2 Injection Gas to Reactor	62-3 Lime to Reactor	62-4 Exhaust N2- Coal	62-5 Coal to Reactor	62-6 Exhaust Air- Dust	62-7 Exhaust Air- Lime
Temperature ° F	60.0	100.0	180.0	60.0	100.0			100.0	500.0	100.0
Pressure psia	45.0	115.0	15.0		615.0			615.0	14.7	14.7
Velocity, fps	70.0									
Line Size, inches	2.0		48.0							
Hydrogen, lbs/hr										
Carbon Monoxide										
Carbon Dioxide					28,223.6					
Oxygen				169.6					19.5	169.6
Nitrogen		8,333.3		558.2			8,333.3		64.3	558.2
Methane	599.6									
Ethane										
Ethylene										
Propane										
Propylene										
Benzene										
Toluene										
Xylene										
Hydrogen Sulfide										
Carbonyl Sulfide										
Hydrogen Cyanide										
Ammonia										
Sulfur Dioxide										
Sulfur										
Water		1,666.7						1,666.7		
Hydrogen Chloride										
Mercury		0.0						0.0		
Coal, ash free, moisture free		74,480.0						74,480.0		
Ash		7,186.7						7,186.7		
Lime				7,318.3		7,318.3				
Slag										
Iron										
Total, lbs per hour	599.6	91,666.7		8,046.1	28,223.6	7,318.3	8,333.3	83,333.4	83.8	727.8
Design Flow , lbs/hr				32,184.4						
Molecular wt										
Hours/ day operation										
Total, tons per hour				4.0						
Normal Flow, gpm										
Design Flow , gpm										
Volume Flow, scfm	236.7		25,000.0							
Volume Flow cuft/min										
Hydrogen, lb mol/hr										
Carbon Monoxide										
Carbon Dioxide										
Oxygen										
Nitrogen										
Methane										
Hydrogen Sulfide										
Carbonyl Sulfide										
Hydrogen Cyanide										
Ammonia										
Sulfur Dioxide										
Sulfur										
Water										
Hydrogen Chloride										
Mercury										
Coal (ash & water free)										
Ash										
Lime										
Slag										
Iron										
Total, lbmol/hr	37.5	0.0		0.0	0.0	0.0	0.0	0.0	0.0	0.0

Stream	62-8 Cyclone Dust	62-9 Cyclone Dust to Reactor	63-1 Solids injection	63-2 Oxygen Injection	63-3 Steam Injection	63-4 Slag	63-5 Scrap iron	63-6 Reactor Offgas	64-1 Quench Exhaust
Temperature ° F	500.0	100.0	100.0	100.0	500.0	2,700.0	100.0	2,700.0	902.0
Pressure psia	14.7	600.0	615.0	615.0	615.0	515.0	14.7	515.0	514.0
Velocity, fps				60.0	60.0			60.0	60.0
Line Size, inches				6.0	3.0			24.0	24.0
Hydrogen, lbs/hr			0.0					4,983.0	4,983.0
Carbon Monoxide			0.0					148,720.3	148,720.3
Carbon Dioxide			28,223.6					11,683.6	11,683.6
Oxygen	19.5		0.0	59,800.0					0.0
Nitrogen	64.3		0.0					1,347.5	5,305.0
Methane			0.0					85.2	85.2
Ethane			0.0					0.0	
Ethylene			0.0					0.0	
Propane			0.0					0.0	
Propylene			0.0					0.0	
Benzene			0.0					0.0	
Toluene			0.0					0.0	
Xylene			0.0					0.0	
Hydrogen Sulfide			0.0					981.3	981.3
Carbonyl Sulfide								1,728.7	1,728.7
Hydrogen Cyanide			0.0					15.5	15.5
Ammonia			0.0					2.0	2.0
Sulfur Dioxide			0.0					0.0	
Sulfur						677.9			
Water			1,666.7		5,395.6			0.0	86,003.5
Hydrogen Chloride			0.0					90.0	90.0
Mercury			0.0					0.0	0.0
Coal, ash free, moisture free			74,480.0					0.0	
Ash	0.0	0.0	7,186.7			7,186.7			0.0
Lime	0.0	0.0	7,318.3			7,318.3			0.0
Slag			0.0					0.0	0.0
Iron	842.6	842.6	842.6			1,687.0	1,734.6	890.3	890.3
Total, lbs per hour	926.4	842.6	119,717.9	59,800.0	5,395.6	16,869.9	1,734.6	170,527.4	260,488.4
Design Flow , lbs/hr									
Molecular wt									
Hours/ day operation									
Total, tons per hour							0.9		
Normal Flow, gpm									
Design Flow , gpm									
Volume Flow, scfm								51,769.8	82,901.1
Volume Flow cuft/min								8,977.0	6,205.4
Hydrogen, lb mol/hr								2,472.0	2,486.0
Carbon Monoxide								5,309.5	5,340.0
Carbon Dioxide								265.5	267.0
Oxygen				1,868.8					
Nitrogen								66.8	175.2
Methane								5.3	5.3
Hydrogen Sulfide								28.8	29.0
Carbonyl Sulfide								28.8	28.9
Hydrogen Cyanide								0.6	0.6
Ammonia								0.1	0.1
Sulfur Dioxide									0.0
Sulfur									
Water					299.8				4,773.7
Hydrogen Chloride								2.5	2.5
Mercury									
Coal (ash & water free)									
Ash									
Lime									
Slag									
Iron								15.9	15.9
Total, lbmol/hr	0.0	0.0	0.0	1,868.8	299.8	0.0	0.0	8,195.8	13,124.2

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
C	OCOD SUBMITTAL	TI			MJF	PFA		04JUN08
B		CMO	MJF		MJF	MJF		07DEC07
A		CMO	MJF		MJF	MJF		10OCT07

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TYPE OF ISSUE

24x36

B MJF 12DEC07 A MJF 10OCT07

AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANT

STREAM DESCRIPTION
PROCESS FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHARGE CODE	SCALE	DRAWING NO.	REV.
A0757603		NONE	R—00—0003	C

1/10 1/8–1/4 3/16–3/8–3/4 1/2– 1

Stream	64-2	64-3	64-5	64-4	64-11	64-12	64-13	64-15	64-16	64-17	64-18	64-19	65-1	65-2	65-3	65-4	65-5	65-6	65-7	65-8	65-9	65-10	71-1	71-2	71-3	71-4	71-5	71-6	71-7
	BFW to Quench	N2- Atomiz.	Exhaust Gas to Venturi	Dust - Hot Gas Filter	Exhaust Gas-Venturi	Venturi Blow-down	Venturi Makeup	Filtrate	Strainer Blow-down	Venturi Recirc. Liquor	Emergency Quench Relief	Steam to Circ. Heater	Slag Gran. Spray Water	Slag Gran. Water Disch.	Gran.Slag to Lockhop.	Makeup Water	Gran. Slag to Dumpster	Classifier O'flow	Strainer Blow-down	Slag Pile Runoff	Slag to Process.	Cooling Water Return	Syngas to 1st Stage WGS	Steam to WGS	Syngas WGS 1st Quench In	Syngas WGS 2nd Rx In	Syngas WGS 2nd Rx Out	Syngas WGS 2nd Quench Out	Syngas 1st Rx Out
Temperature ° F	120.0	100.0	902.0	902.0	400.9	402.8	360.0	402.8	402.8	389.0	300.0	395.0	120.0	215.0	215.0	100.0	190.0	190.0	215.0	160.0	160.0	115.0	669.2	600.0	706.1	342.6	597.0	403.6	940.0
Pressure psia	629.0	629.0	504.0	504.0	496.0	486.0	516.0	25.0	14.7	516.0	30.0	115.0	565.0	515.0	14.7	515.0	14.7	14.7	515.0	14.7	14.7	50.0	486.0	546.0	470.1	469.1	463.3	458.3	476.0
Velocity, fps	8.0	60.0	60.0	1.0	60.0	5.0	5.0	5.0	3.0	8.0	200.0	100.0	8.0	3.0		8.0		3.0	5.0	5.0		5.0	60.0	60.0	60.0	60.0	60.0	60.0	60.0
Line Size, inches	6.0	2.0	24.0	3.0	20.0	4.0	6.0	3.0	2.0	8.0	36.0	16.0	6.0	6.0	12.0	2.0		4.0	2.0	2.0		12.0	24.0	6.0	24.0	24.0	24.0	24.0	24.0
Hydrogen, lbs/hr			5,011.8		5,012.0	1.8	0.0		0.1	8.6													5,010.2		15,323.2	15,323.2	15,734.9	15,734.9	15,323.2
Carbon Monoxide			149,573.4		149,573.4	319.3	0.0		12.8	1,509.7													149,256.9		5,970.3	5,970.3	238.9	238.9	5,970.3
Carbon Dioxide			11,750.7		11,750.7	70.4	0.0		2.8	338.9													11,680.3		236,813.4	236,813.4	245,818.7	245,818.7	236,813.4
Oxygen			0.0		0.0	0.0	0.0		0.0	0.0													0.0		0.0	0.0	0.0	0.0	0.0
Nitrogen		3,957.5	4,908.1		4,919.3	10.4	0.0		0.4	47.6													4,908.1		4,908.1	4,908.1	4,908.1	4,908.1	4,908.1
Methane			85.2		85.2	0.3	0.0		0.0	1.4													85.0		85.2	85.2	85.2	85.2	85.2
Ethane			0.0		0.0	0.0	0.0		0.0	0.0													0.0		0.0	0.0	0.0	0.0	0.0
Ethylene			0.0		0.0	0.0	0.0		0.0	0.0													0.0		0.0	0.0	0.0	0.0	0.0
Propane			0.0		0.0	0.0	0.0		0.0	0.0													0.0		0.0	0.0	0.0	0.0	0.0
Propylene			0.0		0.0	0.0	0.0		0.0	0.0													0.0		0.0	0.0	0.0	0.0	0.0
Benzene			0.0		0.0	0.0	0.0		0.0	0.0													0.0		0.0	0.0	0.0	0.0	0.0
Toluene			0.0		0.0	0.0	0.0		0.0	0.0													0.0		0.0	0.0	0.0	0.0	0.0
Xylene			0.0		0.0	0.0	0.0		0.0	0.0													0.0		0.0	0.0	0.0	0.0	0.0
Hydrogen Sulfide			987.2		987.2	15.3	0.0		0.6	71.6													971.9		1,936.9	1,936.9	1,936.9	1,936.9	1,936.9
Carbonyl Sulfide			1,736.0		1,736.0	40.2	0.0		1.6	189.8													1,700.0		1.0	1.0	1.0	1.0	1.0
Hydrogen Cyanide			15.5		15.4	1.1	0.0		0.0	5.3													15.4		15.4	15.4	15.4	15.4	15.4
Ammonia			2.0		1.8	0.2	0.0		0.0	1.1													1.8		1.8	1.8	1.8	1.8	1.8
Sulfur Dioxide			0.0		0.0	0.0	0.0		0.0	0.0													0.0		0.0	0.0	0.0	0.0	
Sulfur			0.0		0.0	0.0	0.0		0.0	0.0					677.9		677.9				677.9		0.0		0.0	0.0	0.0	0.0	
Water	86,000.0		86,003.5		141,500.0	44,506.7	100,003.2	44,437.7	1,780.3	309,819.4		65,833.2	168,699.1	118,089.4	50,609.7	23,617.9	16,869.9	33,739.8	6,748.0	7,230.0	9,639.9	534,213.8	141,500.5	0.0	49,338.6	211,484.4	207,796.5	247,788.7	49,338.6
Hydrogen Chloride			90.0		4.5	85.5	0.0	85.5	0.0	596.2					0.0		0.0						6.9		4.5	4.5	4.5	4.5	4.5
Mercury			0.0		0.0										0.0		0.0						0.0		0.0	0.0	0.0	0.0	0.0
Coal, ash free, moisture free			0.0												0.0		0.0												
Ash			0.0												7,186.7		7,186.7				7,186.7								
Lime			0.0												7,318.3		7,318.3				7,318.3								
Slag			0.0												0.0		0.0				0.0								
Iron			0.1	890.2	1.5	-1.4									1,687.0		1,687.0				1,687.0								1.5
Total, lbs per hour	86,000.0	3,957.5	260,163.5	890.2	316,563.8	45,050.0	100,003.2	44,523.2	1,798.6	312,588.7	0.0	65,833.2	168,699.1	118,089.4	67,479.6	23,617.9	33,739.8	33,739.8	6,748.0	7,230.0	26,509.9	534,213.8	315,136.8	64,118.6	314,398.3	476,544.1	476,541.8	516,534.0	314,399.8
Design Flow , lbs/hr																													
Molecular wt																													
Hours/ day operation																													
Total, tons per hour															33.7		16.9				13.3								
Normal Flow, gpm	172.0					90.1	200.0	89.0	3.6	1,500.0			337.4	236.2		47.2		67.5	13.5	14.5		1,068.4							
Design Flow , gpm																													
Volume Flow, scfm			82,800.4		82,788.7						82,800.4														102,150.4	159,001.1	158,997.9	173,019.7	102,150.4
Volume Flow cuft/min			6,320.8		4,057.2						59,219.8														7,156.2	7,680.0	10,245.6	9,206.6	8,496.7
Hydrogen, lb mol/hr			2,486.0		2,486.1	0.9			0.0	4.3	2,486.0												2,485.2		7,600.8	7,600.8	7,805.0	7,805.0	7,600.8
Carbon Monoxide			5,340.0		5,340.0	11.4			0.5	53.9	5,340.0												5,328.7		213.2	213.2	8.5	8.5	213.2
Carbon Dioxide			267.0		267.0	1.6			0.1	7.7	267.0												265.4		5,380.9	5,380.9	5,585.5	5,585.5	5,380.9
Oxygen			0.0		0.0				0.0	0.0	0.0												0.0		0.0	0.0	0.0	0.0	0.0
Nitrogen		141.3	175.2		175.6	0.4			0.0	1.7	175.2												175.2		175.2	175.2	175.2	175.2	175.2
Methane			5.3		5.3	0.0			0.0	0.1	5.3												5.3		5.3	5.3	5.3	5.3	5.3
Hydrogen Sulfide			29.0		29.0	0.5			0.0	2.1	29.0												28.5		56.8	56.8	56.8	56.8	56.8
Carbonyl Sulfide			28.9		28.9	0.7			0.0	3.2	28.9												28.3		0.0	0.0	0.0	0.0	0.0
Hydrogen Cyanide			0.6		0.6	0.0			0.0	0.2	0.6												0.6		0.6	0.6	0.6	0.6	0.6
Ammonia			0.1		0.1	0.0			0.0	0.1	0.1												0.1		0.1	0.1	0.1	0.1	0.1
Sulfur Dioxide			0.0		0.0				0.0		0.0												0.0		0.0	0.0	0.0	0.0	0.0
Sulfur			0.0		0.0				0.0		0.0												0.0		0.0	0.0	0.0	0.0	0.0
Water	4,777.8		4,773.7		7,854.0	2,470.4	5,550.8		98.8	17,196.9	4,773.7	3,657.4											7,854.2	3,559.0	2,738.6	11,738.7	11,534.0	13,753.8	2,738.6
Hydrogen Chloride			2.5		0.1						2.5												0.1		0.1	0.1	0.1	0.1	0.1
Mercury																													
Coal (ash & water free)					0.0																								0.0
Ash					0.0																								0.0
Lime					0.0																								0.0
Slag					0.0																								0.0
Iron					0.0																								
Total, lbmol/hr	4,777.8	141.3	13,108.2	0.0	16,186.7	2,485.9	5,550.8	0.0			13,108.2	3,657.4		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		16,171.6	3,559.0	16,171.6	25,171.7	25,171.2	27,391.0	16,171.6

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
C	OCCD SUBMITTAL	TI			MJF	PFA		04JUN08
B		CMO	MJF		MJF	MJF		07DEC07
A		CMO	MJF		MJF	MJF		10OCT07

Aker Solutions

PRELIMINARY
NOT APPROVED FOR CONSTRUCTION

24x36
TYPE OF ISSUE

△ MJF 12DEC07 △ MJF 10OCT07

AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANT

STREAM DESCRIPTION
PROCESS FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHANGE CODE	SCALE	DRAWING NO.	REV.
A0757603		NONE	R–00–0004	C

1/10 1/8–1/4 3/16–3/8–3/4 1/2– 1

Stream	71-8	71-9	71-10	71-11	71-12	71-13	71-14	71-15	71-16	71-17	71-18	81-1	82-1	82-2	82-3	82-4	82-5	82-6	82-7	82-8	82-9	83-1
	Syngas WGS Cooler outlet	CWR from WGS Cooler	BFW to 1st WGS Quench	BFW to 2nd WGS Quench	Syngas 3rd Rx Out	Steam to Stripper	BFW Total to WGS	Process Condensate - Syngas	BFW to 3rd Stage WHB	LP Steam from WHB	Process Cond - Stripper Bottoms	Syngas Mercury Removal Inlet	Syngas Mercury Removal Outlet	Syngas, AGR Outlet	Acid Gas to Sulfur Recovery	Med Press. CO2 Flash	Low Press. CO2 Flash	Makeup Water	Steam to Reboiler	CWR from Reflux Cond.	CWR - Recycle Gas Cooler	CWR from Refrig. Unit
Temperature ° F	100.0	112.1	230.0	230.0	448.0	280.0	230.0	100.0	230.0	389.0	163.0	100.0	100.0	78.0	110.0	48.0	44.0	205.0	348.0	115.0	115.0	115.0
Pressure psia	445.4	50.0	520.1	513.3	452.4	115.0	530.1	444.4	200.0	115.0	20.0	444.4	439.4	411.4	26.7	44.7	17.7	114.7	134.7	65.0	65.0	65.0
Velocity, fps	60.0	8.0	5.0	5.0	60.0	100.0	8.0	3.0	8.0	100.0	3.0	60.0	60.0	60.0	60.0	60.0	60.0	3.0	60.0	3.0	3.0	3.0
Line Size, inches	18.0	24.0	6.0	3.0		8.0	6.0	8.0	6.0	24.0	10.0	16.0	16.0	12.0	6.0	24.0	24.0	1.0	16.0	16.0	10.0	24.0
Hydrogen, lbs/hr	15,752.2				15,752.2		0.0	44.8				15,707.5	15,707.5	15,292.3	22.8	385.7	4.1					
Carbon Monoxide	9.6				9.5		0.0	0.3				9.6	9.6	9.6	2.8	66.4	1.4					
Carbon Dioxide	246,178.7				246,178.7		0.0	79,913.4				166,265.4	166,265.4	8,313.3	3,103.1	164,507.6	69,043.8					
Oxygen	0.0				0.0		0.0	0.0				0.0	0.0	0.0	0.0	0.0	0.0					
Nitrogen	4,908.1				4,908.1		0.0	177.9				4,908.1	4,908.1	4,824.0	3.9	79.8	0.6					
Methane	85.2				85.0		0.0	7.5				85.2	85.2	75.4	0.5	8.3	0.3					
Ethane	0.0				0.0		0.0	0.0				0.0	0.0	0.0	0.0	0.0	0.0					
Ethylene	0.0				0.0		0.0	0.0				0.0	0.0	0.0	0.0	0.0	0.0					
Propane	0.0				0.0		0.0	0.0				0.0	0.0	0.0	0.0	0.0	0.0					
Propylene	0.0				0.0		0.0	0.0				0.0	0.0	0.0	0.0	0.0	0.0					
Benzene	0.0				0.0		0.0	0.0				0.0	0.0	0.0	0.0	0.0	0.0					
Toluene	0.0				0.0		0.0	0.0				0.0	0.0	0.0	0.0	0.0	0.0					
Xylene	0.0				0.0		0.0	0.0				0.0	0.0	0.0	0.0	0.0	0.0					
Hydrogen Sulfide	1,936.9				1,936.9		0.0	1,261.7				1,936.9	1,936.9	1.4	1,960.8	0.7	0.7					
Carbonyl Sulfide	1.0				1.0		0.0	0.0				1.0	1.0	1.0	0.6	0.0	0.0					
Hydrogen Cyanide	15.4				15.4		0.0	14.0				15.4	15.4	0.2	1.5	0.0	0.0					
Ammonia	1.8				1.8		0.0	1.7				1.8	1.8	0.1	1.2	0.0	0.0					
Sulfur Dioxide	0.0				0.0		0.0	0.0				0.0	0.0	0.0	0.0	0.0	0.0					
Sulfur	0.0				0.0		0.0	0.0				0.0	0.0	0.0	0.0	249.9	203.8					
Water	247,651.5	4,995,756.0	162,000.0	39,960.0	247,651.5	37,088.5	201,960.0	247,257.0	204,008.4	200,008.2	280,636.7	394.6	394.6	25.2	127.9	0.0	0.0	1,079.2	60,920.0	770,500.0	190,000.0	1,422,500.0
Hydrogen Chloride	4.5				4.5		0.0	0.0				4.5	4.5	0.3	0.0	0.0	0.0					
Mercury	0.0						0.0					0.0	0.0	0.0								
Coal, ash free, moisture free	0.0						0.0					0.0	0.0	0.0								
Ash	0.0						0.0					0.0	0.0	0.0								
Lime	0.0						0.0					0.0	0.0	0.0								
Slag	0.0						0.0					0.0	0.0	0.0								
Iron	1.5						0.0					1.5	1.5	1.5								
Total, lbs per hour	516,546.3	4,995,756.0	162,000.0	39,960.0	516,544.6	37,088.5	201,960.0	328,678.3	204,008.4	200,008.2	280,636.7	189,331.2	189,331.2	28,544.2	5,225.2	165,298.4	69,254.7	1,079.2	60,920.0	770,500.0	190,000.0	1,422,500.0
Design Flow , lbs/hr																						
Molecular wt																						
Hours/ day operation																						
Total, tons per hour																						
Normal Flow, gpm								494.5	408.0		561.3							2.2		1,541.0	380.0	2,845.0
Design Flow , gpm		9,991.5	324.0	79.9			403.9															
Volume Flow, scfm	173,025.9											74,724.0	74,724.0	50,237.1	927.5	24,905.5	9,963.5					
Volume Flow cuft/min	6,139.0											2,657.2	2,687.4	1,853.8	558.8	7,985.7	8,004.2					
Hydrogen, lb mol/hr	7,813.6				7,813.6			22.2				7,791.4	7,791.4	7,585.5	11.3	191.3	2.0					
Carbon Monoxide	0.3				0.3			0.0				0.3	0.3	0.3	0.1	2.4	0.1					
Carbon Dioxide	5,593.7				5,593.7			1,815.8				3,777.9	3,777.9	188.9	70.5	3,738.0	1,568.8					
Oxygen	0.0											0.0	0.0	0.0								
Nitrogen	175.2				175.2			6.4				175.2	175.2	172.2	0.1	2.9	0.0					
Methane	5.3				5.3			0.5				5.3	5.3	4.7	0.0	0.5	0.0					
Hydrogen Sulfide	56.8				56.8			37.0				56.8	56.8	0.0	57.5	0.0	0.0					
Carbonyl Sulfide	0.0				0.0							0.0	0.0	0.0	0.0	0.0	0.0					
Hydrogen Cyanide	0.6				0.6			0.5				0.6	0.6	0.0	0.1							
Ammonia	0.1				0.1			0.1				0.1	0.1	0.0	0.1							
Sulfur Dioxide	0.0				0.0							0.0	0.0									
Sulfur	0.0				0.0							0.0	0.0			7.8	6.4					
Water	13,746.2	277,542.0	9,000.0	2,220.0	13,746.2	2,058.6	11,220.0	13,724.3	11,323.7	11,101.7	15,590.9	21.9	21.9	1.4	7.1			59.9	3,384.4			
Hydrogen Chloride	0.1				0.1							0.1	0.1	0.0								
Mercury	0.0																					
Coal (ash & water free)	0.0												0.0									
Ash	0.0												0.0									
Lime	0.0												0.0									
Slag	0.0												0.0									
Iron																						
Total, lbmol/hr	27,392.0	277,542.0	9,000.0	2,220.0	27,392.0	2,058.6	11,220.0	15,606.8	11,323.7	11,101.7	15,590.9	11,829.7	11,829.7	7,953.1	146.8	3,942.8	1,577.3	59.9	3,384.4	0.0		

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
C	OCOD SUBMITTAL	TI			MJF	PFA		04JUN08
B		CMO	MJF		MJF	MJF		07DEC07
A		CMO	MJF		MJF	MJF		10OCT07

AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANT

AkerSolutions

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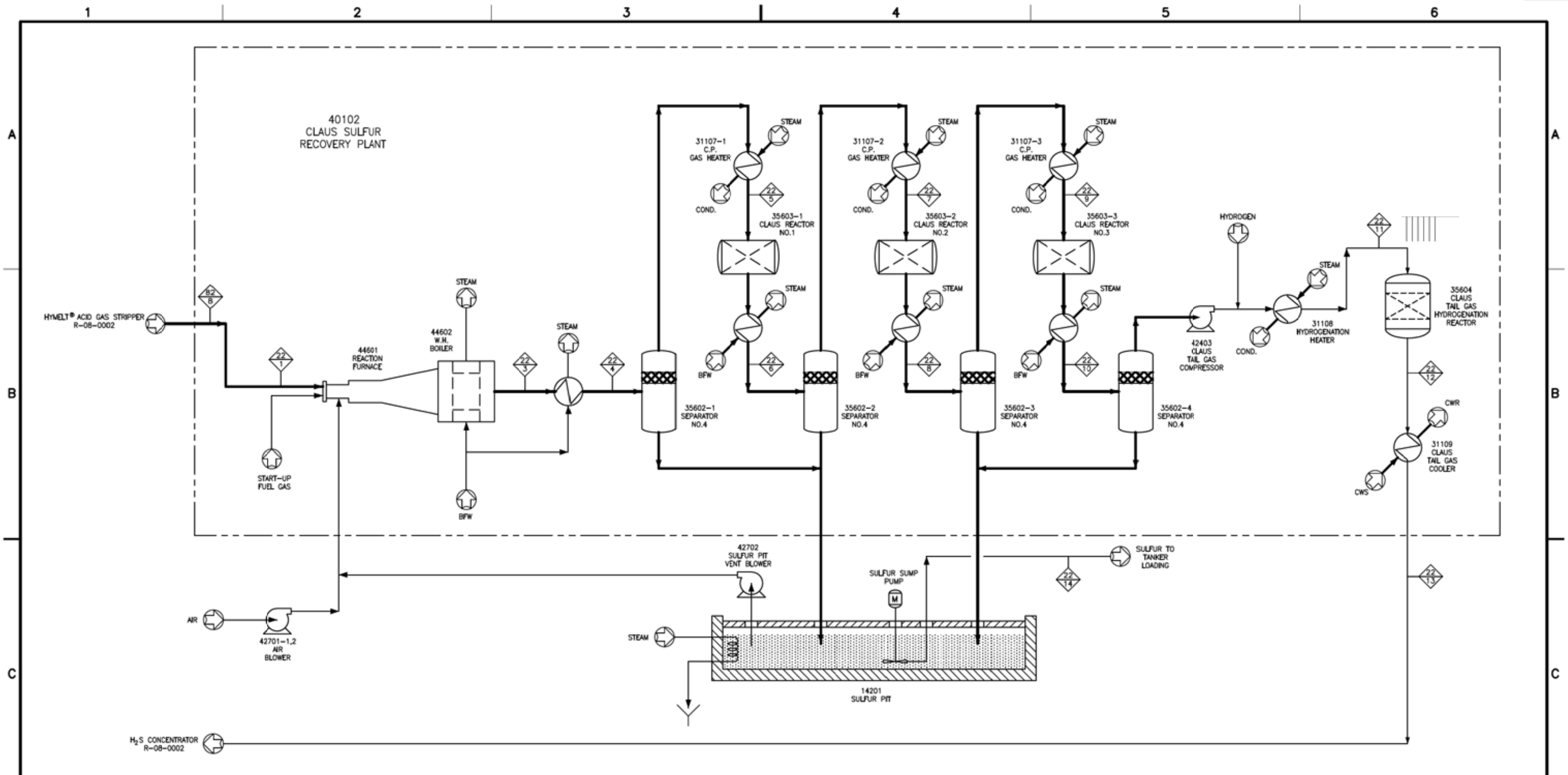
NOT APPROVED FOR CONSTRUCTION
TYPE OF ISSUE

24x36

STREAM DESCRIPTION
PROCESS FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHARGE CODE	SCALE	DRAWING NO.	REV.
A0757603		NONE	R–00–0005	C

B MJF 12DEC07 A MJF 10OCT07



LEGEND

UTILITY DESIGNATION

N2 – NITROGEN

MAIN PROCESS LINE

AUXILIARY LINE

STREAM NO.

PRESSURE PSIG

PRESSURE MM HG, ABS

GALLONS PER MINUTE

STD FT^3/MIN
(60°F & 14.7 PSIA)

LBS./HR.

TEMPERATURE °F

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
C	OCOD SUBMITTAL	TI			MJF	PFA		02JUN08
B		MLS						
A	PRELIMINARY	LMc	MJF		MJF	MJF		20AUG07

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE

AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANT

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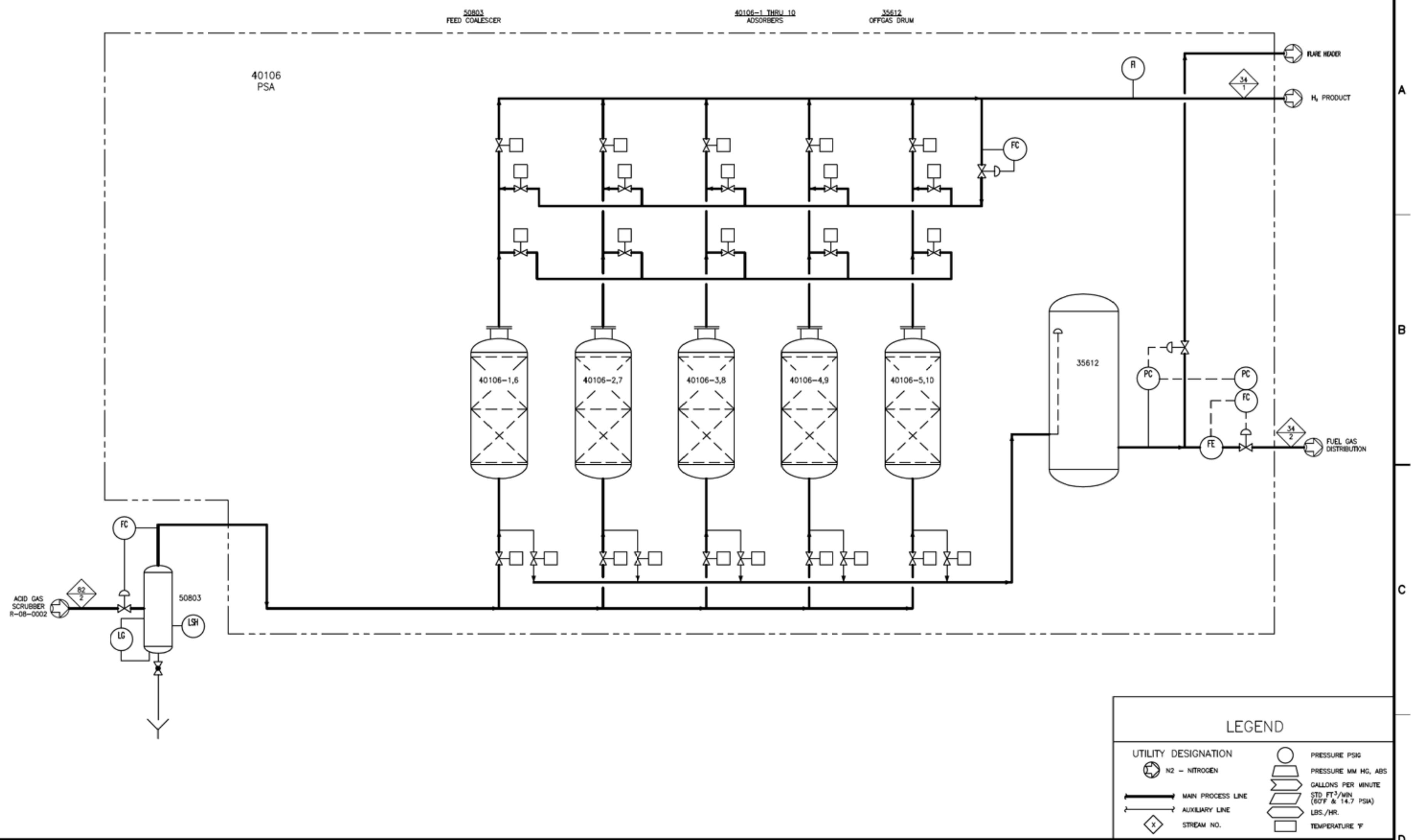
TYPE OF ISSUE

CLAUS SULFUR RECOVERY
PROCESS FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHANGE CODE	SCALE	DRAWING NO.	REV.
A0757603			R–02–0002	C

NONE

1/10 1/8–1/4 3/16–3/8–3/4 1/2– 1



REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
E	OCOD SUBMITTAL	TI			MJF	PFA		02JUN08
D	REVISED AS SHOWN	TI			MJF			12FEB08

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
C	CHANGED ITEM NUMBER	RB	MJF		MJF	TM		30OCT07
B	FEL 2 SCOPE, STREAM NO.	CMO			MJF			08OCT07
A	PRELIMINARY	LMc	MJF		MJF	MJF		20AUG07

1/10 1/8-1/4 3/16-3/8-3/4 1/2- 1

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TYPE OF ISSUE

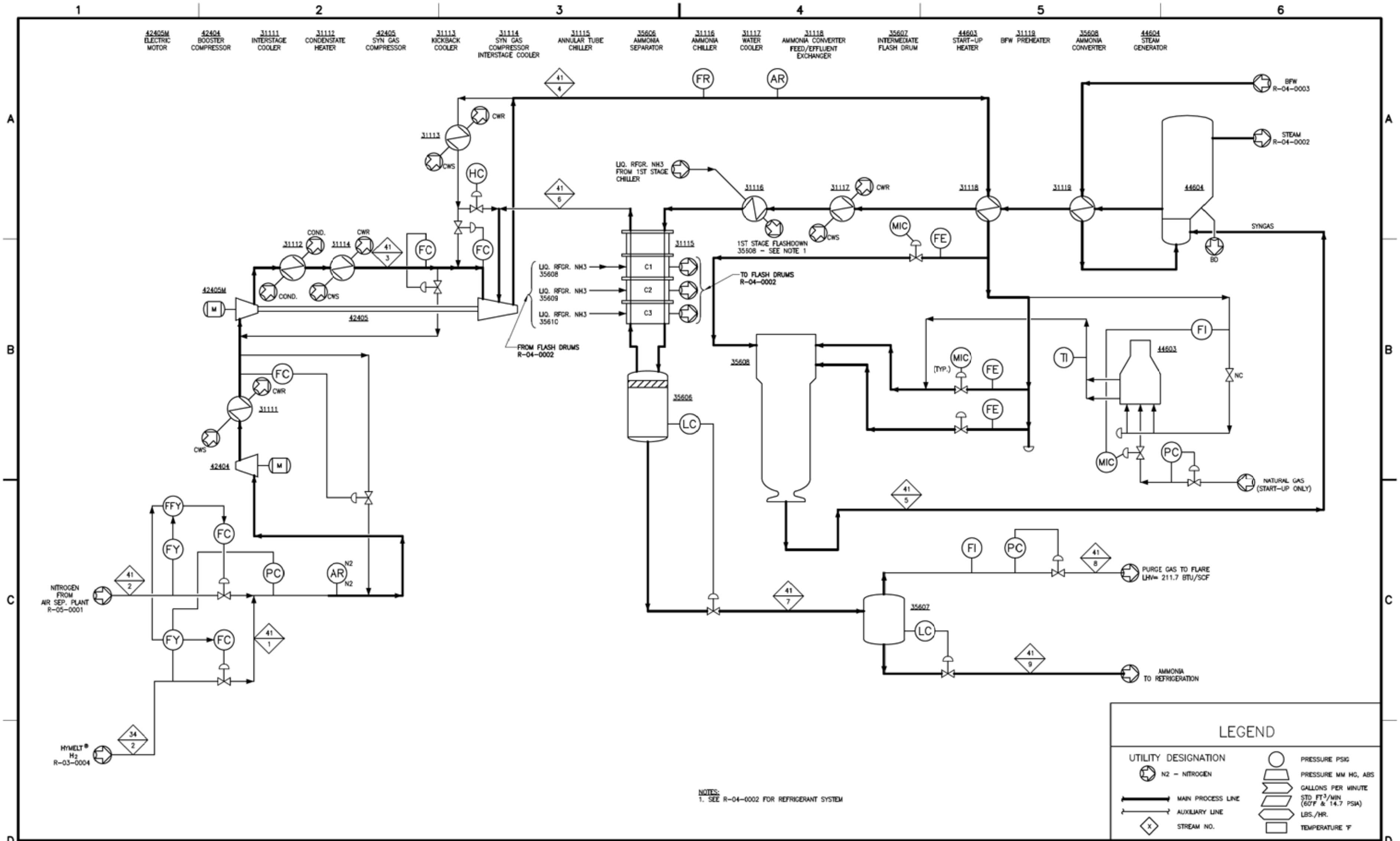
△ MJF 30OCT07
TM 30OCT07

△ MJF 08OCT07

AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANT

HYMELT® COAL GASIFICATION
PRESSURE SWING ADSORPTION
PROCESS FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHARGE CODE	SCALE	DRAWING NO.	REV.
A0757603		NONE	R-03-0004	E



NOTES:
1. SEE R-04-0002 FOR REFRIGERANT SYSTEM

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
B	OCOD SUBMITTAL	TI			MJF	PFA		02JUN08
A	PRELIMINARY	LMc	MJF		MJF	MJF		20AUG07

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AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANT

AMMONIA PLANT, SYNTHESIS SECTION
PROCESS FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHARGE CODE	SCALE	DRAWING NO.	REV.
A0757603			R-04-0001	B

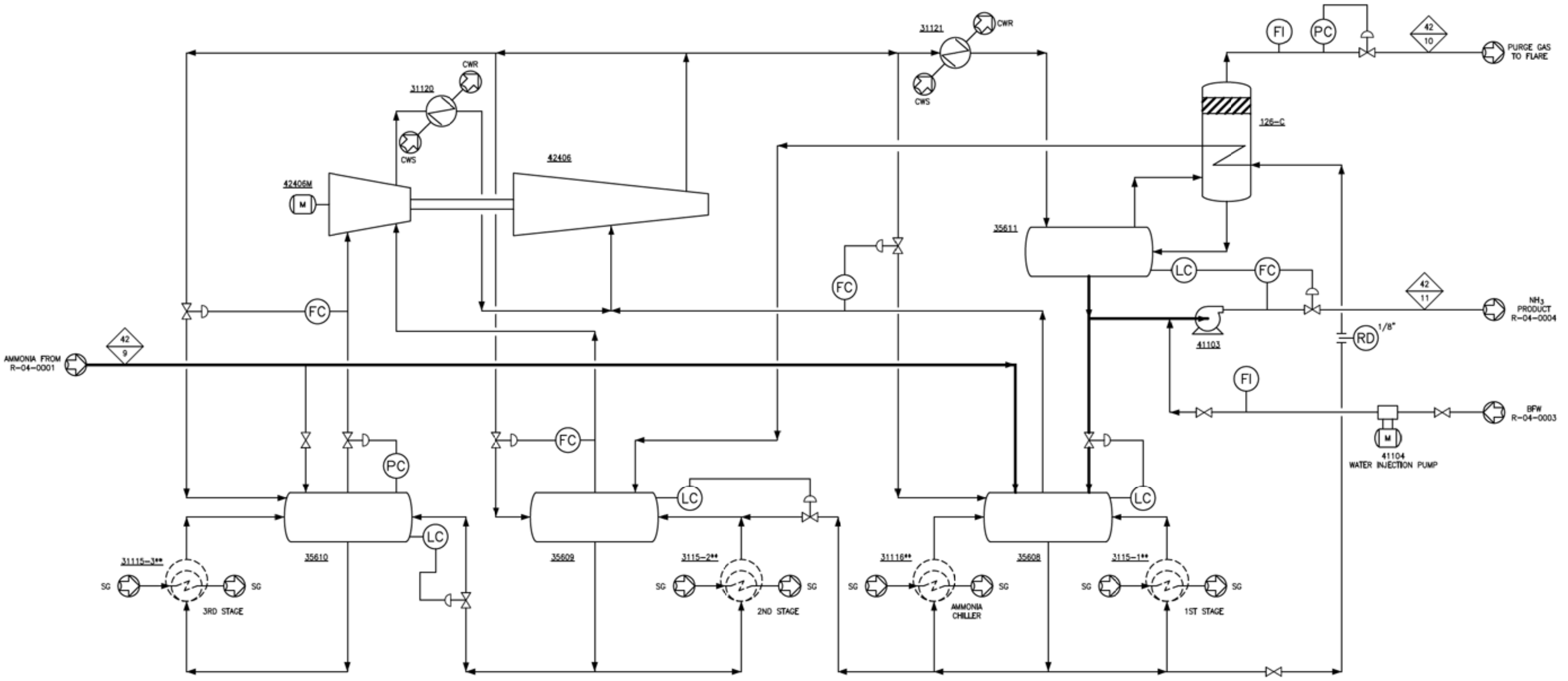
NONE

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE

1/10 1/8-1/4 3/16-3/8-3/4 1/2- 1

31115	35610	42406M	42406	35609	31120	31121	35608	35611	31122	41103	41104
ANNULAR TUBE CHILLER	THIRD STAGE REFRIGERANT FLASH DRUM	ELECTRIC MOTOR	AMMONIA REFRIGERANT COMPRESSOR	SECOND STAGE REFRIGERANT FLASH DRUM	REFRIGERANT COMPRESSOR INTERSTAGE COOLER	REFRIGERANT CONDENSER	FIRST STAGE REFRIGERANT FLASH DRUM	REFRIGERANT RECEIVER	FLASH GAS CHILLER	WARM AMMONIA PRODUCT PUMP	WATER INJECTION PUMP



GENERAL NOTES:
1. ** ALSO SHOWN ON DRAWING R-04-0001
2. SG=SYNGAS

LEGEND

UTILITY DESIGNATION
N2 – NITROGEN
MAIN PROCESS LINE
AUXILIARY LINE
◇ STREAM NO.

○ PRESSURE PSIG
PRESSURE MM HG, ABS
GALLONS PER MINUTE
STD FT^3/MIN (60'F & 14.7 PSIA)
LBS./HR.
☐ TEMPERATURE °F

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
B	OCOD SUBMITTAL	TI			MJF	PFA		02JUN08
A	PRELIMINARY	LMc	MJF		MJF	MJF		20AUG07

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE

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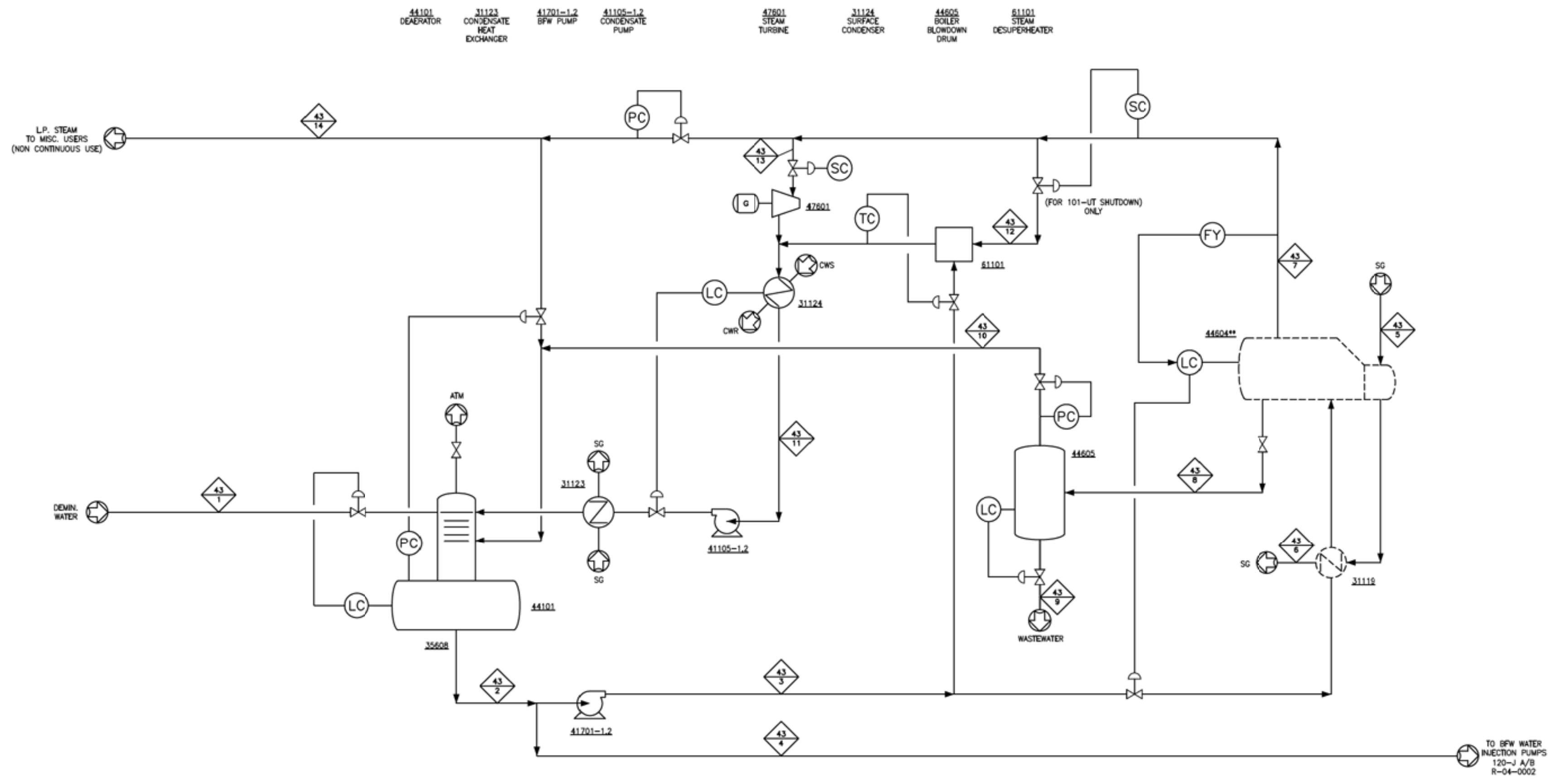
AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANT

AMMONIA PLANT, REFRIGERATION SECTION
PROCESS FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHARGE CODE	SCALE	DRAWING NO.	REV.
A0757603		NONE	R-04-0002	B

1/10 1/8-1/4 3/16-3/8-3/4 1/2- 1



LEGEND

UTILITY DESIGNATION

N2 – NITROGEN

MAIN PROCESS LINE

AUXILIARY LINE

STREAM NO.

PRESSURE PSIG

PRESSURE MM HG, ABS

GALLONS PER MINUTE

STD FT³/MIN (60°F & 14.7 PSIA)

LBS./HR.

TEMPERATURE °F

GENERAL NOTES:
1. SEE DRAWING R–04–0001 FOR SG ROUTING
2. SG=SYNGAS

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
B	OCOD SUBMITTAL	TI			MJF	PFA		02JUN08
A	PRELIMINARY	LMc	MJF		MJF	MJF		20AUG07

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE

1/10 1/8–1/4 3/16–3/8–3/4 1/2– 1

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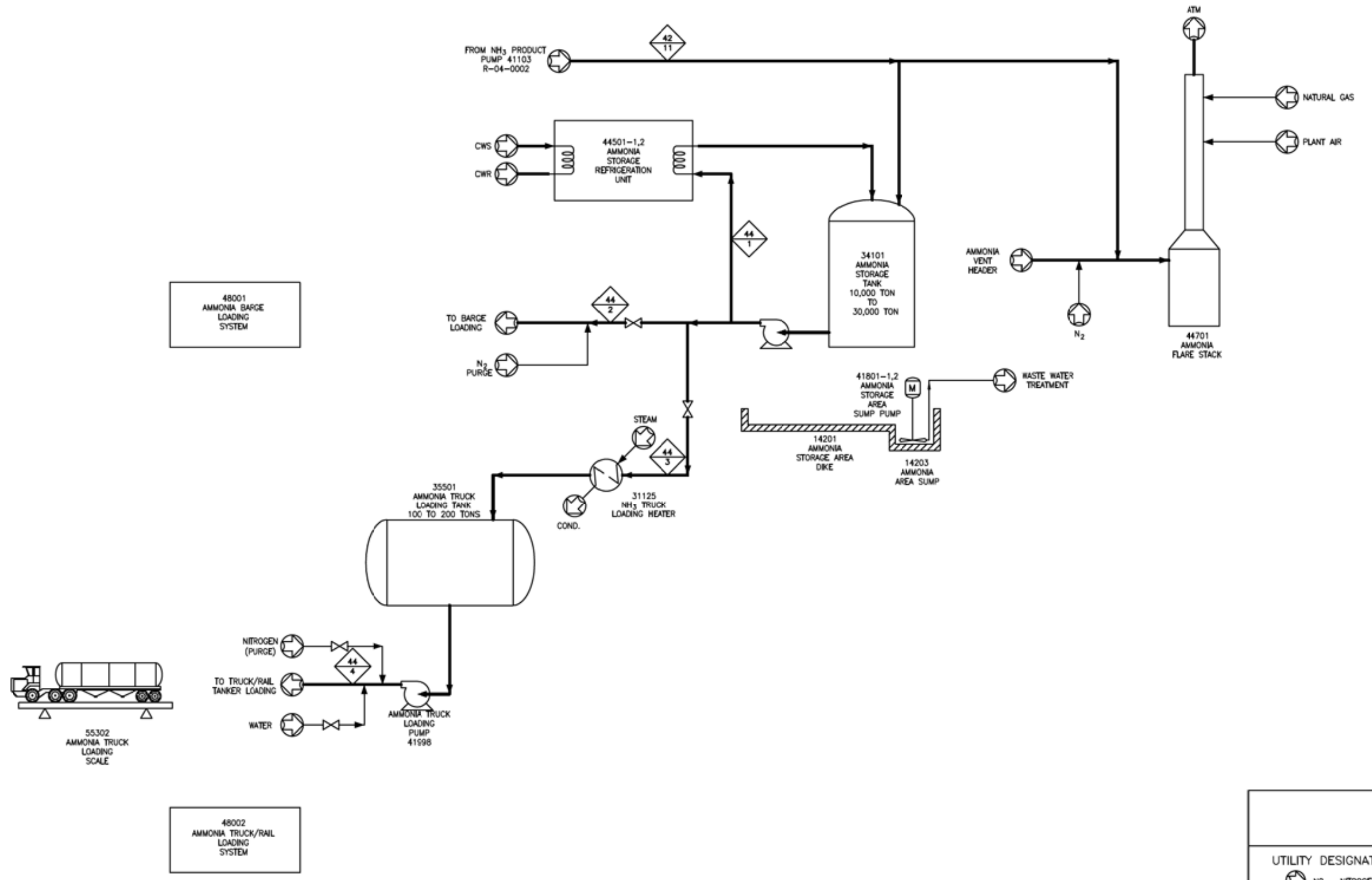
24x36 TYPE OF ISSUE

AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANT

AMMONIA PLANT, STEAM BALANCE
PROCESS FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHARGE CODE	SCALE	DRAWING NO.	REV.
A0757603			R–04–0003	B

NONE



LEGEND

UTILITY DESIGNATION

⇨	N2 – NITROGEN
━	MAIN PROCESS LINE
─	AUXILIARY LINE
◇ X	STREAM NO.
○	PRESSURE PSIG
⏢	PRESSURE MM HG, ABS
⟩	GALLONS PER MINUTE
▱	STD FT^3/MIN (60°F & 14.7 PSIA)
⬡	LBS./HR.
☐	TEMPERATURE °F

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
B	OCOD SUBMITTAL	TI			MJF	PFA		02JUN08
A	PRELIMINARY	LMc	MJF		MJF	MJF		20AUG07

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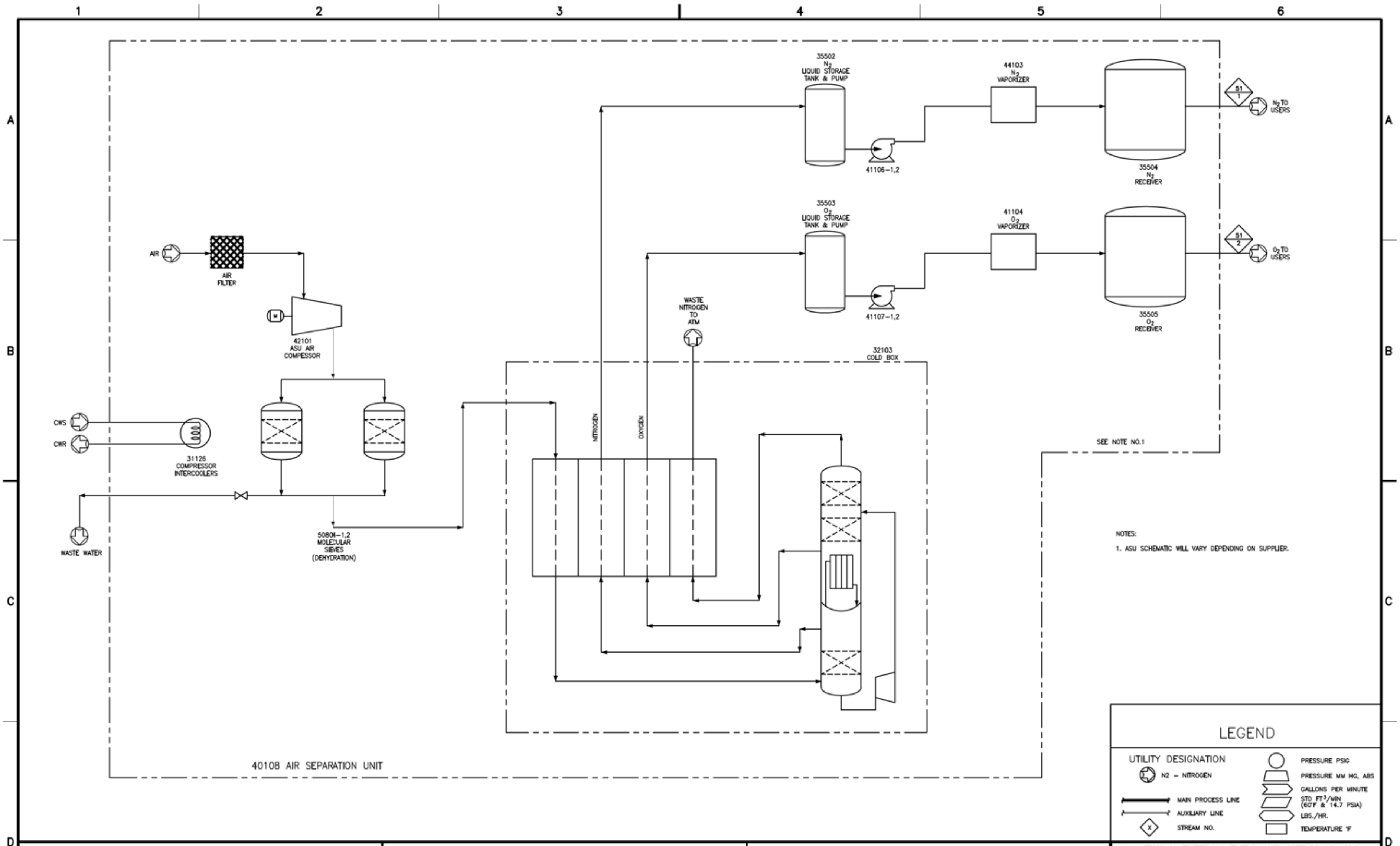
24x36 TYPE OF ISSUE

AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANT

AMMONIA STORAGE + FLARE
PROCESS FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHANGE CODE	SCALE	DRAWING NO.	REV.
A0757603		NONE	R-04-0004	B

1/10 1/8-1/4 3/16-3/8-3/4 1/2- 1



NOTES:

1. ASU SCHEMATIC WILL VARY DEPENDING ON SUPPLIER.

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
B	OCOD SUBMITTAL	TI			MJF	PFA		02JUN08
A	PRELIMINARY	LMc	MJF		MJF	MJF		20AUG07

Aker Solutions

PRELIMINARY

NOT APPROVED FOR CONSTRUCTION

24x36

TYPE OF ISSUE

AMERICAN FREEDOM FUELS AND CHEMICALS, LLC

COAL TO NITROGEN PRODUCTS PLANT

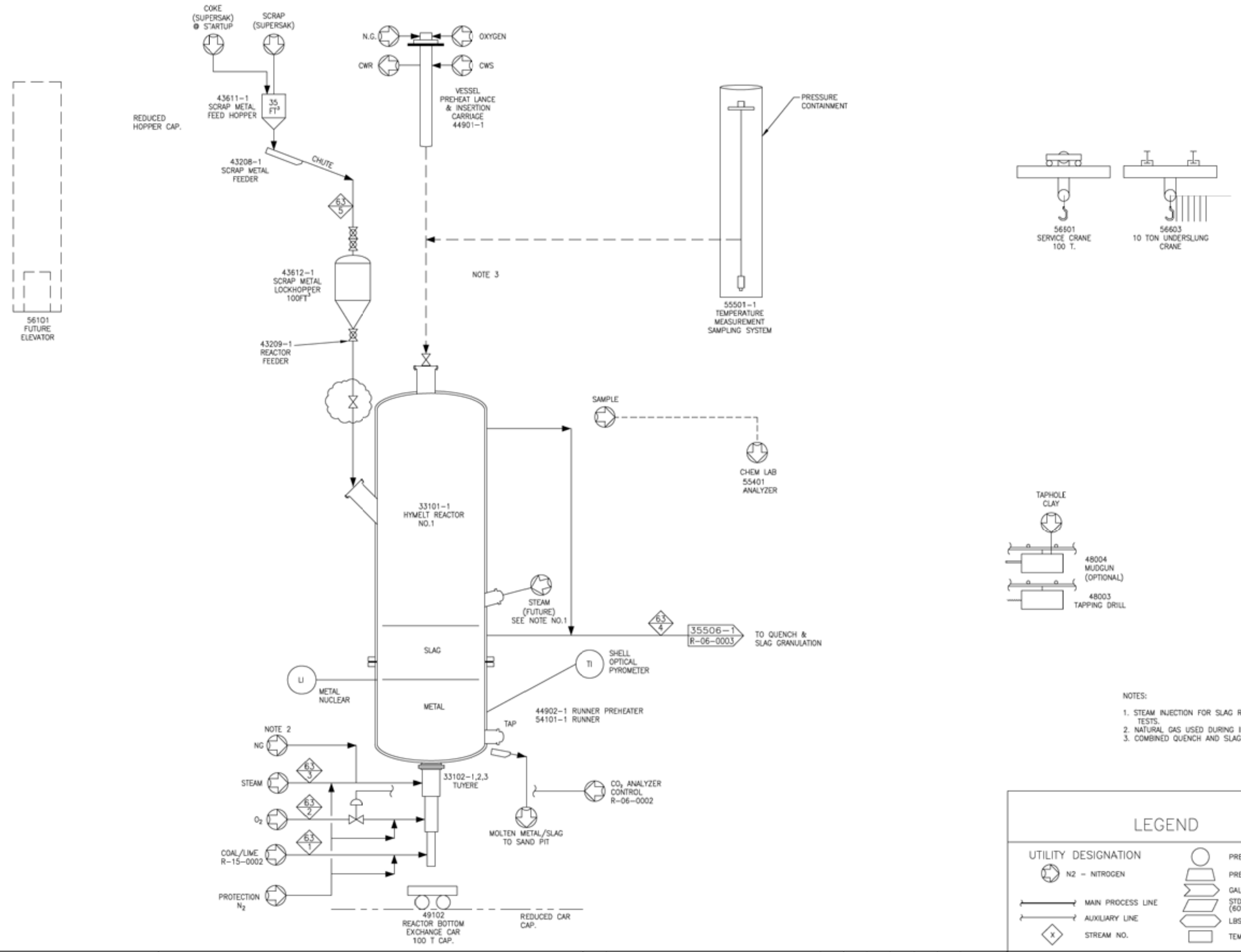
AIR SEPARATION PLANT
PROCESS FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHARGE CODE	SCALE	DRAWING NO.	REV.
A0757603		NONE	R–05–0001	B

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE

1/10 1/8–1/4 3/16–3/8–3/4 1/2– 1



NOTES:

1. STEAM INJECTION FOR SLAG REGENERATION TESTS.
2. NATURAL GAS USED DURING IDLING OF BATH.
3. COMBINED QUENCH AND SLAG GRANULATION.

LEGEND

UTILITY DESIGNATION

○	N2 – NITROGEN
⟼	MAIN PROCESS LINE
⟼	AUXILIARY LINE
◇ X	STREAM NO.
○	PRESSURE PSIG
⏢	PRESSURE MM HG, ABS
⟩	GALLONS PER MINUTE
▱	STD FT³/MIN (60°F & 14.7 PSIA)
⬡	LBS./HR.
▭	TEMPERATURE °F

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
F	OCOD SUBMITTAL	TI			MJF	PFA		02JUN08
E	COST REDUCTION PRESENTATION	TI			MJF			12FEB08
D	REDUCED 43611 SCRAP METAL BIN TO 35 FT MOVE SCRAP ADD.	CMO			MJF	PFA		19DEC07

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
C	ADD 44903, ELEVATOR, 56603, REVIEW MTG. 18DEC07	CMO			MJF	PFA		19DEC07
B	REVISED PER A0757500	CMO			MJF			07DEC07
A	PROTOTYPE CONCEPT	CMO			MJF			08OCT07

AkerSolutions™

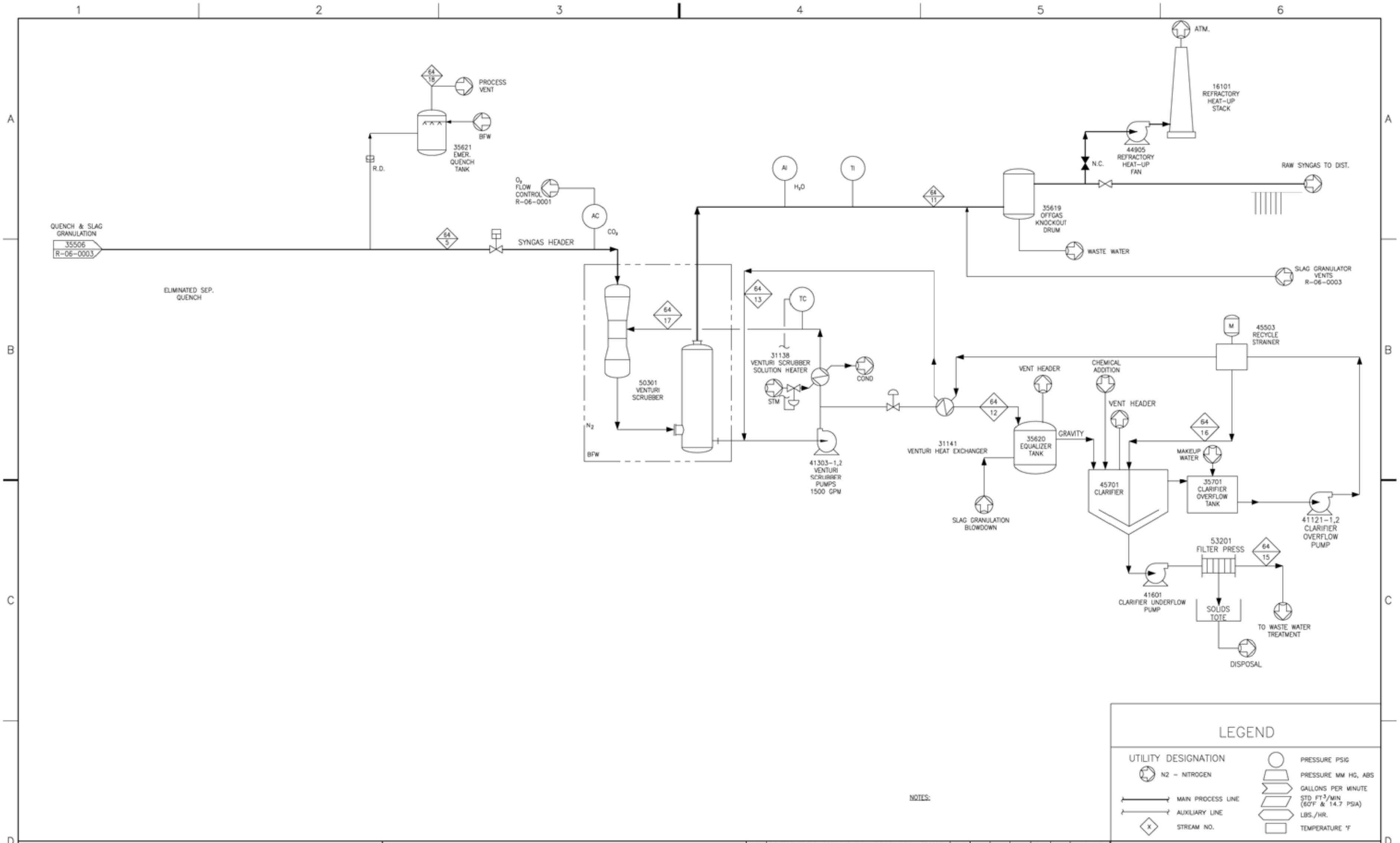
PRELIMINARY
NOT APPROVED FOR CONSTRUCTION
TYPE OF ISSUE
24x36

AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANT

HYMELT® MODULE
HYMELT® REACTORS
PROCESS FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHARGE CODE	SCALE	DRAWING NO.	REV.
A0757603		NONE	R-06-0001	F

1/10 1/8-1/4 3/16-3/8-3/4 1/2- 1



REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
C	DELETED FILTER, 50805, & AUX., REVIEW MTG. 18DEC07	CMO			MJF	PFA		19DEC07
B	REVISED PER A0757500	CMO			MJF			07DEC07
A	PROTOTYPE SCOPE	CMO			MJF			08OCT07

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
F	OCOD SUBMITTAL	TI			MJF	PFA		02JUN08
E	REVISED AS SHOWN	TI			MJF			12FEB08
D	ADDED HEAT FAN/STACK 44905/16101	KK			MJF			08JAN08

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE

AkerSolutions™

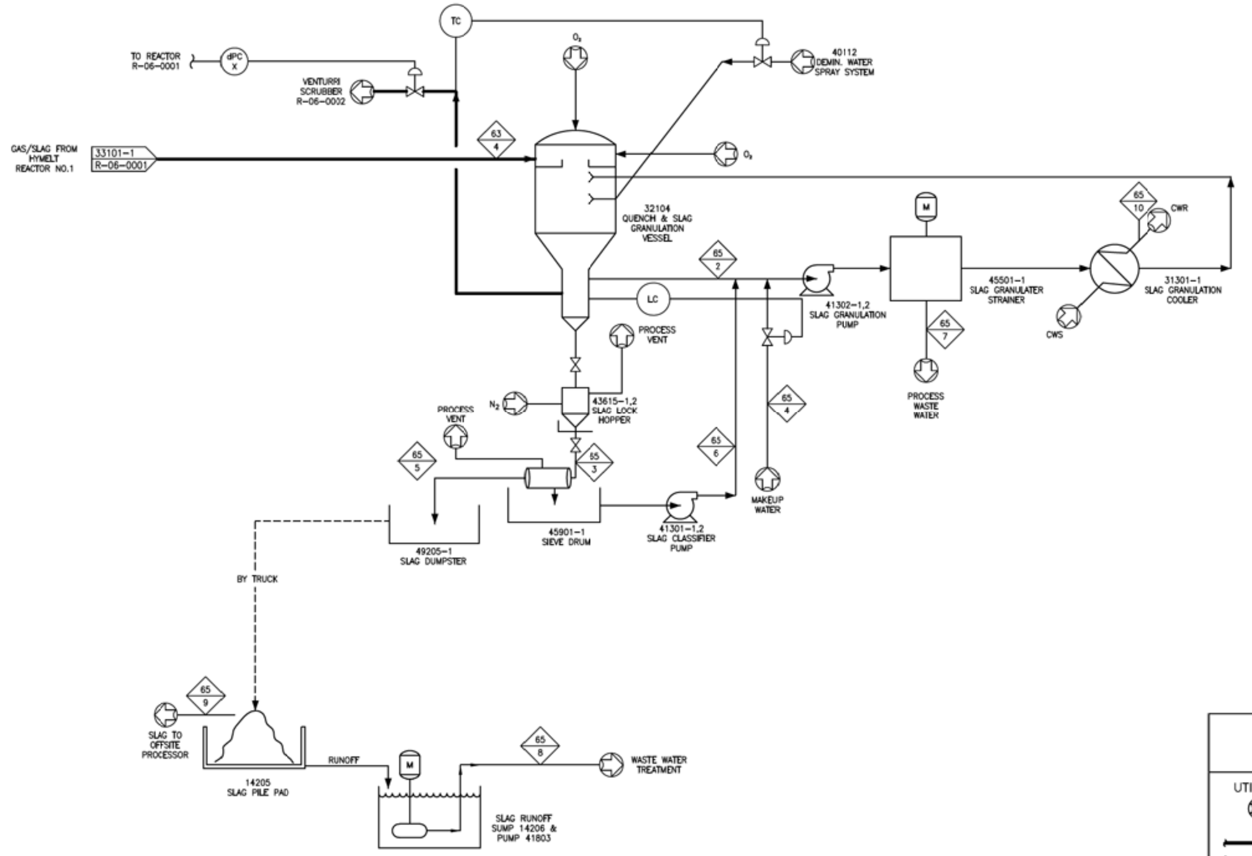
PRELIMINARY
NOT APPROVED FOR CONSTRUCTION
24x36
TYPE OF ISSUE

AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANT

HYMELT® MODULE
EXHAUST GAS CLEANING
PROCESS FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHARGE CODE	SCALE	DRAWING NO.	REV.
A0757603		NONE	R-06-0002	F

1/10 1/8-1/4 3/16-3/8-3/4 1/2- 1



LEGEND

UTILITY DESIGNATION

⇨	N2 – NITROGEN
⟶	MAIN PROCESS LINE
⟶	AUXILIARY LINE
◇ X	STREAM NO.
○	PRESSURE PSIG
⏢	PRESSURE MM HG, ABS
〉	GALLONS PER MINUTE
▱	STD FT^3/MIN (60°F & 14.7 PSIA)
⬡	LBS./HR.
▭	TEMPERATURE °F

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
E	OCOD SUBMITTAL	TI			MJF	PFA		02JUN08
D	REVISED AS SHOWN	TI			MJF			12FEB08

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
C	REVIEW MTG. 18DEC07	CMO			MJF	PFA		19DEC07
B	REVISED PER A0757500	CMO			MJF			07DEC07
A	PREOTOTYPE SCOPE	CMO			MJF			08OCT07

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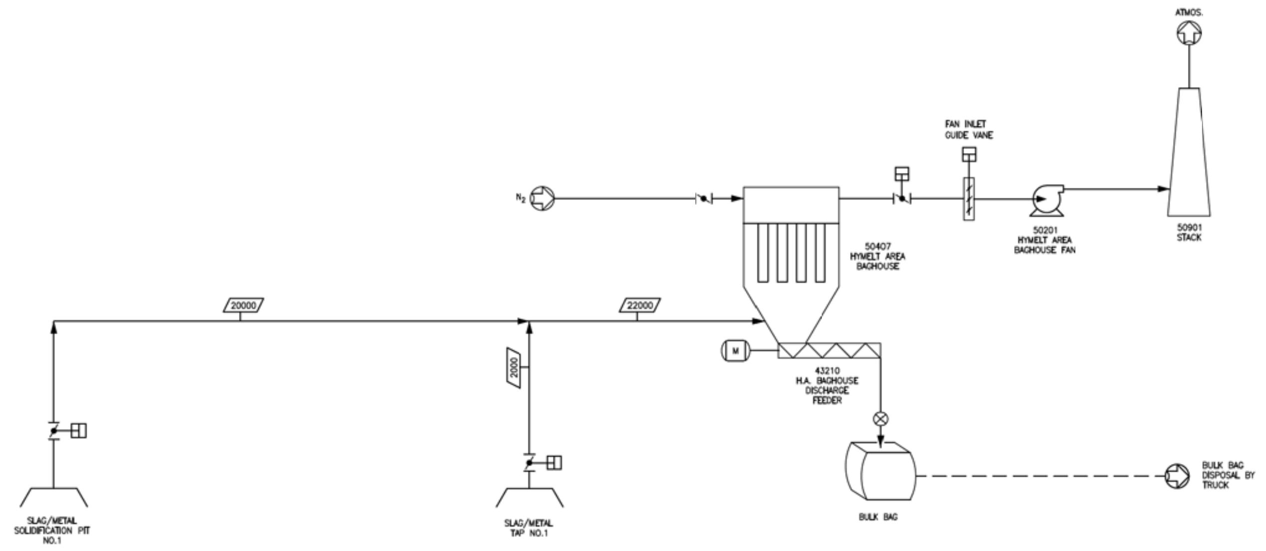
TYPE OF ISSUE

AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANT

HYMELT® MODULE
GAS QUENCH/SLAG GRANULATION
PROCESS FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHARGE CODE	SCALE	DRAWING NO.	REV.
A0757603		NONE	R-06-0003	E

1/10 1/8-1/4 3/16-3/8-3/4 1/2- 1



LEGEND

UTILITY DESIGNATION

N2 – NITROGEN

MAIN PROCESS LINE

AUXILIARY LINE

◇ STREAM NO.

○ PRESSURE PSIG

PRESSURE MM HG, ABS

GALLONS PER MINUTE

STD FT³/MIN (60°F & 14.7 PSIA)

LBS./HR.

☐ TEMPERATURE °F

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
C	DELETED FINES DUST COLLECTION, REVIEW MTG. 18DEC07	CMO			MJF	PFA		19DEC07
B	REVISED PER A0757500	CMO			MJF			07DEC07
A	PROTOTYPE SCOPE	CMO			MJF			08OCT07

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
E	OCOD SUBMITTAL	TI			MJF	PFA		02JUN08
D	REVISED AS SHOWN	TI			MJF			12FEB08

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE

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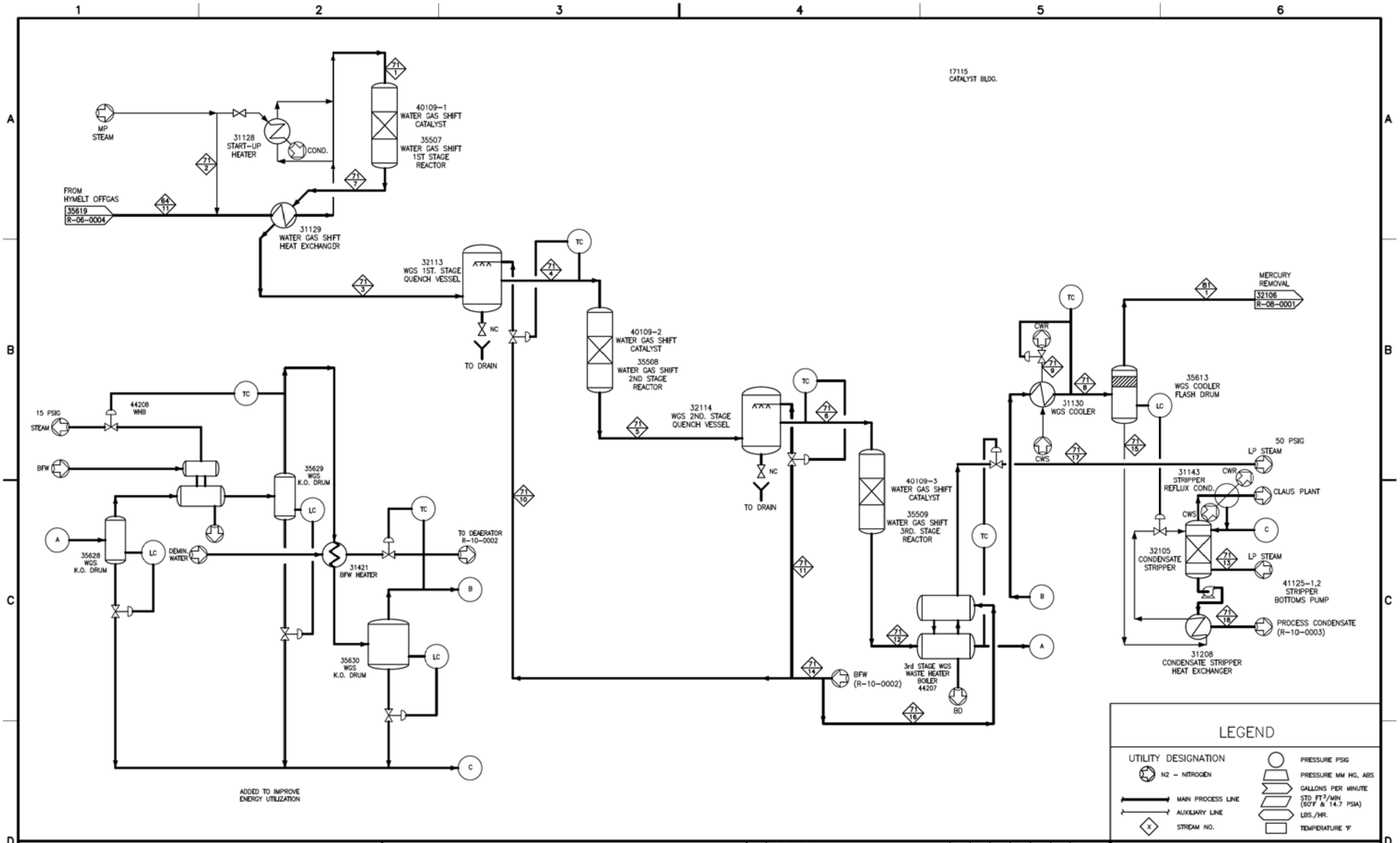
AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANT

HYMELT® PROTOTYPE PLANT
FUME AND DUST COLLECTION
PROCESS FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHARGE CODE	SCALE	DRAWING NO.	REV.
A0757603		NONE	R–06–0004	E

1/10 1/8–1/4 3/16–3/8–3/4 1/2– 1



REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
I	OCOD SUBMITTAL	TI			MJF	PFA		02JUN08
H	REVISED AS SHOWN	TI			MJF			12FEB08
G	CHANGED STREAM NO. TAG	CMO	MJF					05DEC07
F	CHANGED STREAM NO. TAG	CMO	MJF		MJF	TM		28NOV07
E	REROUTED LINE "12"	CMO						14NOV07
D	ADDED 44207 & 31208	CMO	MJF		MJF	TM		07NOV07

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
C	GENERAL REVISION	RB	MJF		MJF	TM		29OCT07
B	ADDED STREAM NO.; COS HYDROLYSIS	CMO			MJF			08OCT07
A	PRELIMINARY	LMc	MJF		MJF	MJF		21AUG07

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TYPE OF ISSUE

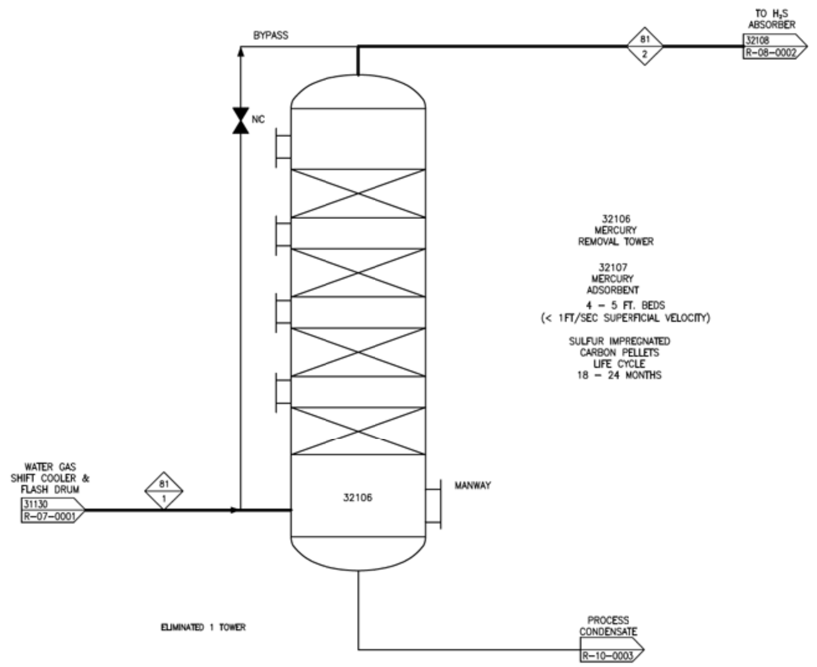
AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANT

WATER GAS SHIFT
PROCESS FLOW DIAGRAM

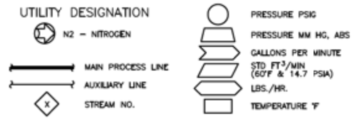
CONTRACT NO.	ENGINEERING CHANGE CODE	SCALE	DRAWING NO.	REV.
A0757603		NONE	R-07-0001	I

1/10 1/8-1/4 3/16-3/8-3/4 1/2- 1

MJF 12DEC07
MJF 28NOV07 TM 28NOV07
MJF 29OCT07
MJF 29OCT07 TM 29OCT07
MJF 08OCT07



LEGEND



REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
F	OCOD SUBMITTAL	TI			MJF	PFA		12FEB08
E	REVISED AS SHOWN	TI			MJF			12FEB08
D	REVISED 81/2 STREAM	CMO	MJF		MJF	TM		29NOV07

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
C	REMOVED 47602 REFERENCE	RB	MJF		MJF	TM		29OCT07
B	FEL 2 SCOPE	CMO			MJF			08OCT07
A	PRELIMINARY	LMc	MJF		MJF	MJF		21AUG07

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TYPE OF ISSUE

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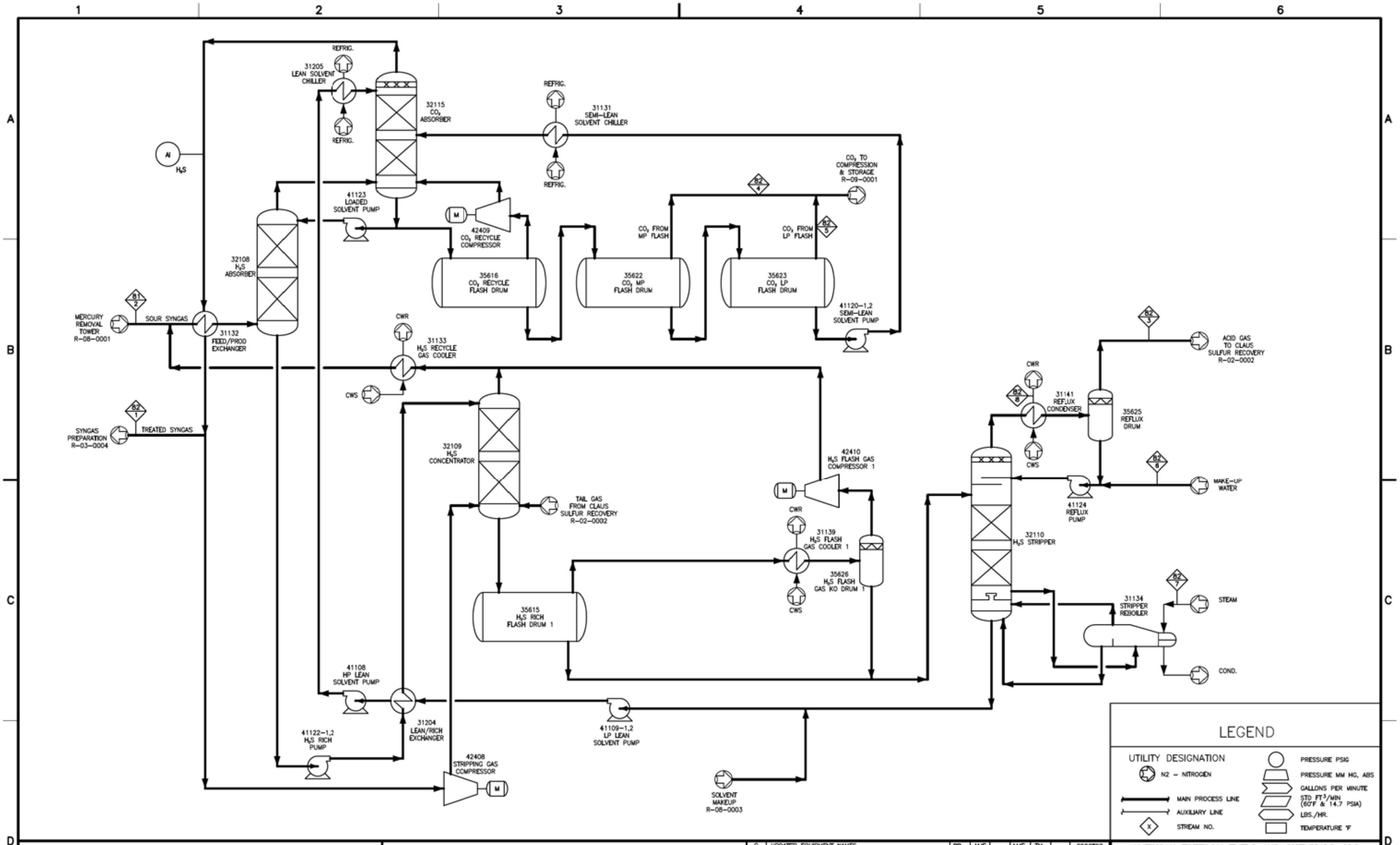
AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANT

ACID
MERCURY REMOVAL
PROCESS FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHARGE CODE	SCALE	DRAWING NO.	REV.
A0757603		NONE	R-08-0001	F

⚠ MJF 29NOV07 TM 29NOV07
⚠ MJF 29OCT07 TM 29OCT07
⚠ MJF 08OCT07

1/10 1/8–1/4 3/16–3/8–3/4 1/2– 1



REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
G	OCOD SUBMITTAL	TI			MJF	PFA		02JUN08
F	DELETED PER VOP	TI			MJF			12FEB08
E	REVISED PER STREAM NO'S & NUMBER OF EQUIPMENT	CMO	MJF		MJF			07DEC07
D	REVISED PER VOP PFD	CMO	MJF		MJF	TM		29NOV07

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
C	UPDATED EQUIPMENT NAMES	RB	MJF		MJF	TM		29OCT07
B	FEL 2 SCOPE	CMO			MJF			08OCT07
A	PRELIMINARY	LMc	MJF		MJF	MJF		21AUG07

AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANTS

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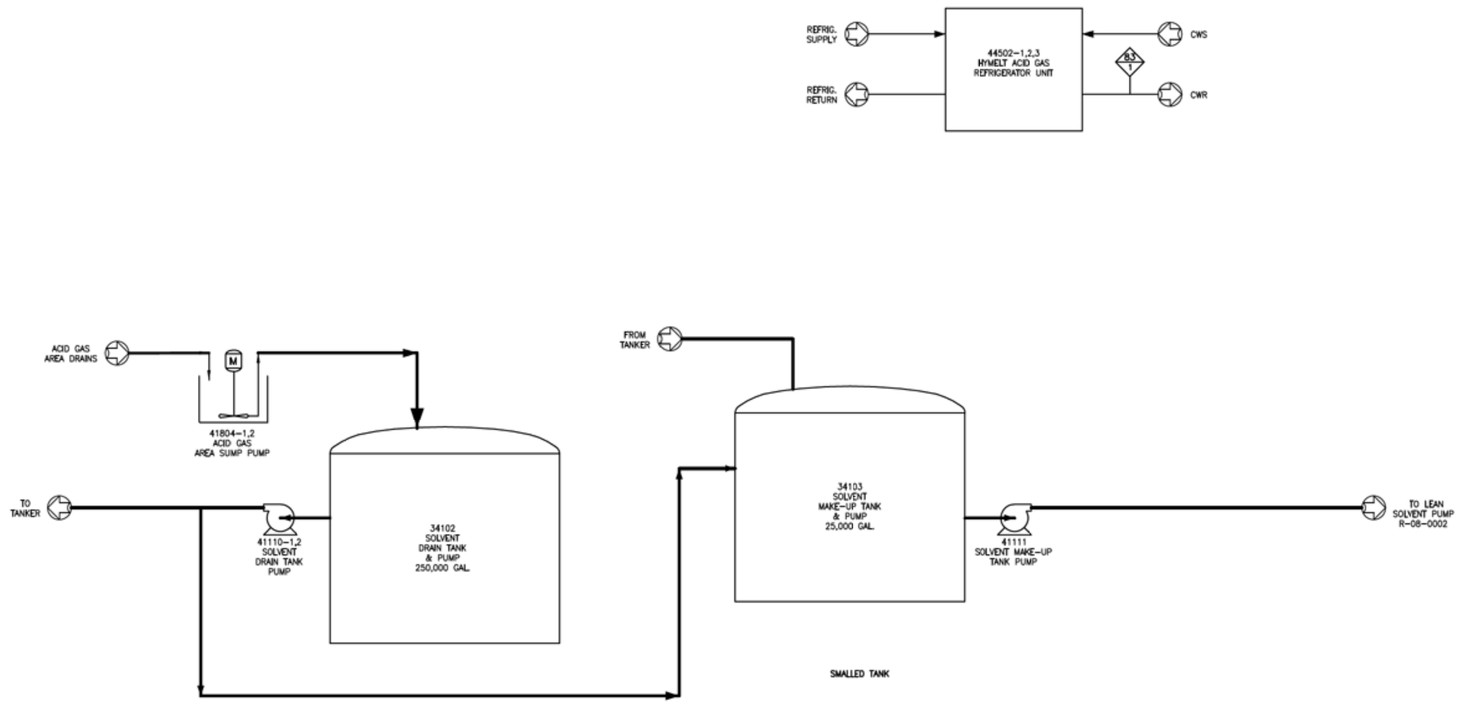
TYPE OF ISSUE

SELEXOL® ACID GAS REMOVAL
PROCESS FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHARGE CODE	SCALE	DRAWING NO.	REV.
A0757603		NONE	R-08-0002	G

1/10 1/8-1/4 3/16-3/8-3/4 1/2- 1

△ MJF 12DEC07 TM 12DEC07 △ MJF 29NOV07 TM 29NOV07 △ MJF 29OCT07 TM 29OCT07



LEGEND

UTILITY DESIGNATION

N2 – NITROGEN

MAIN PROCESS LINE

AUXILIARY LINE

STREAM NO.

PRESSURE PSIG

PRESSURE MM HG, ABS

GALLONS PER MINUTE

STD FT^3/MIN (60°F & 14.7 PSIA)

LBS./HR.

TEMPERATURE °F

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
C	REVISED AS SHOWN	TI			MJF			12FEB08
B	REVISED STREAM NO'S & NUMBER OF EQUIPMENT	CMO			MJF			07DEC07
A	MOVED FROM DWG. R–08–0002	CMO			MJF			28NOV07
D	OCOD SUBMITTAL	TI			MJF	PFA		02JUN08

AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANT

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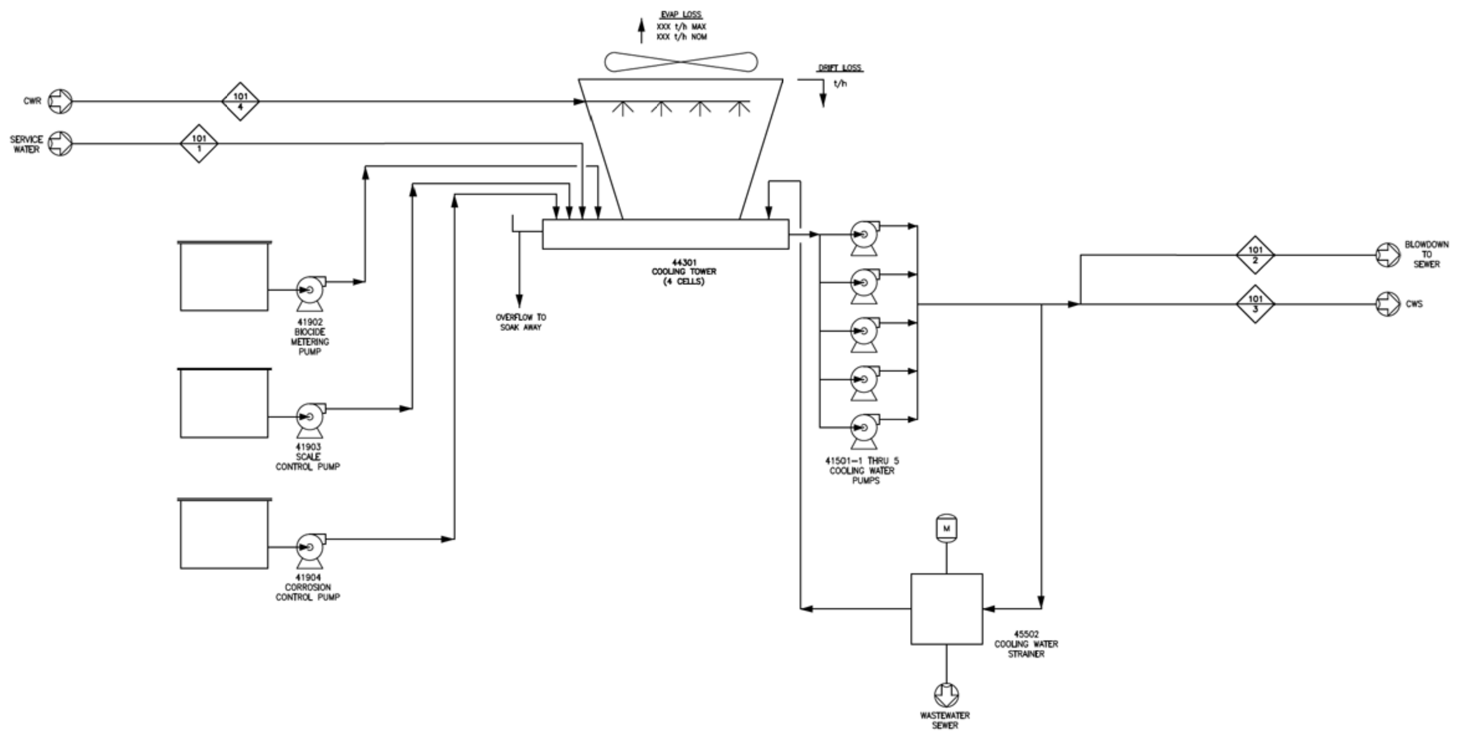
24x36 TYPE OF ISSUE

SELEXOL® ACID GAS REMOVAL
PROCESS FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHANGE CODE	SCALE	DRAWING NO.	REV.
A0757603		NONE	R–08–0003	D

B MJF 12DEC07

1/10 1/8–1/4 3/16–3/8–3/4 1/2– 1



LEGEND

UTILITY DESIGNATION

N2 – NITROGEN

MAIN PROCESS LINE

AUXILIARY LINE

◇ STREAM NO.

○ PRESSURE PSIG

PRESSURE MM HG, ABS

GALLONS PER MINUTE

STD FT^3/MIN (60°F & 14.7 PSIA)

LBS./HR.

□ TEMPERATURE °F

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
B	OCOD SUBMITTAL	TI			MJF	PFA		02JUN08
A	PRELIMINARY	LMc	MJF		MJF	MJF		21AUG07

AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANT

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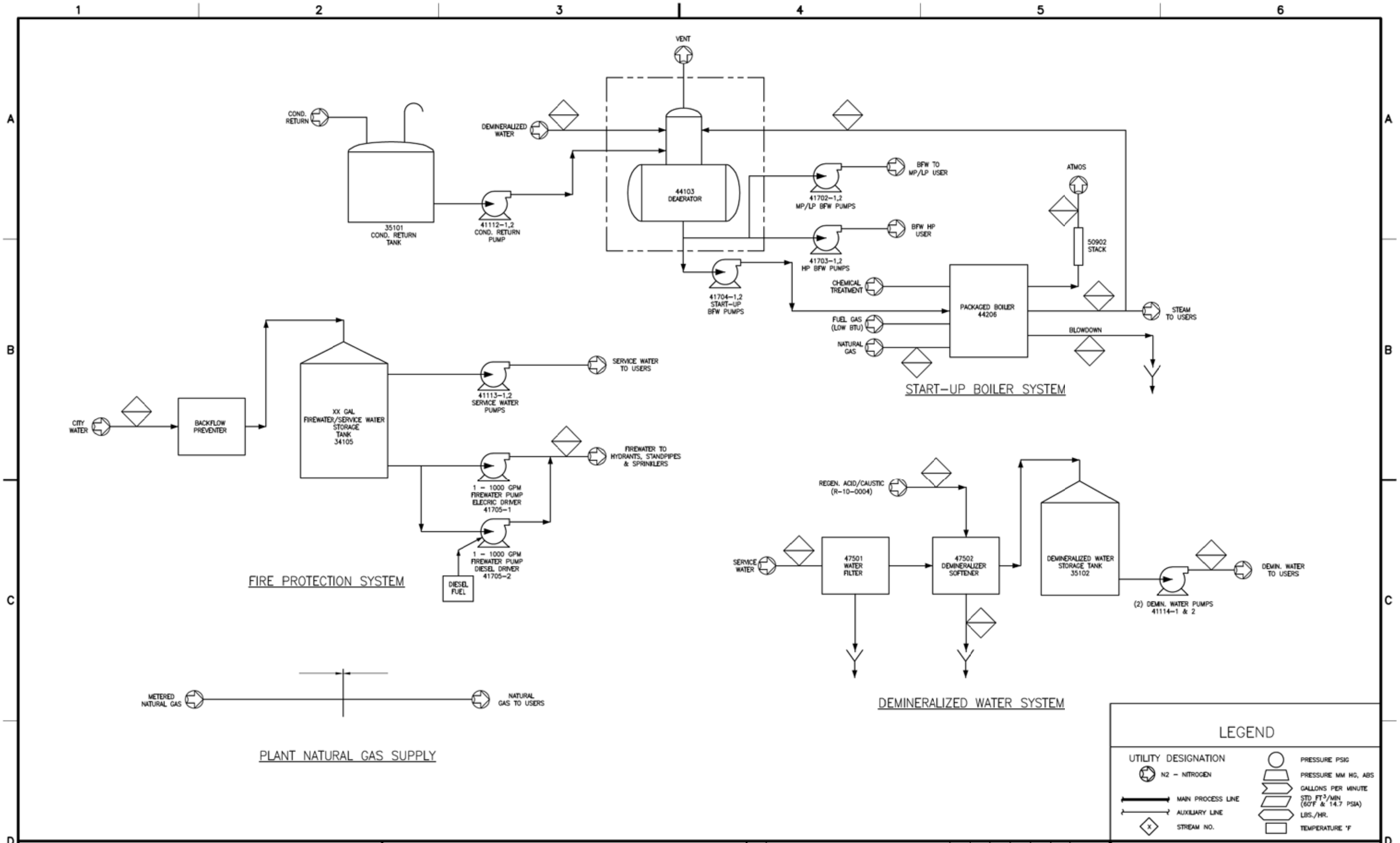
COOLING TOWERS
PROCESS FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHANGE CODE	SCALE	DRAWING NO.	REV.
A0757603		NONE	R-10-0001	B

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE	REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE

1/10 1/8–1/4 3/16–3/8–3/4 1/2– 1



REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
B	OCOD SUBMITTAL	TI			MJF	PFA		02JUN08
A	PRELIMINARY	LMc	MJF		MJF	MJF		21AUG07

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TYPE OF ISSUE

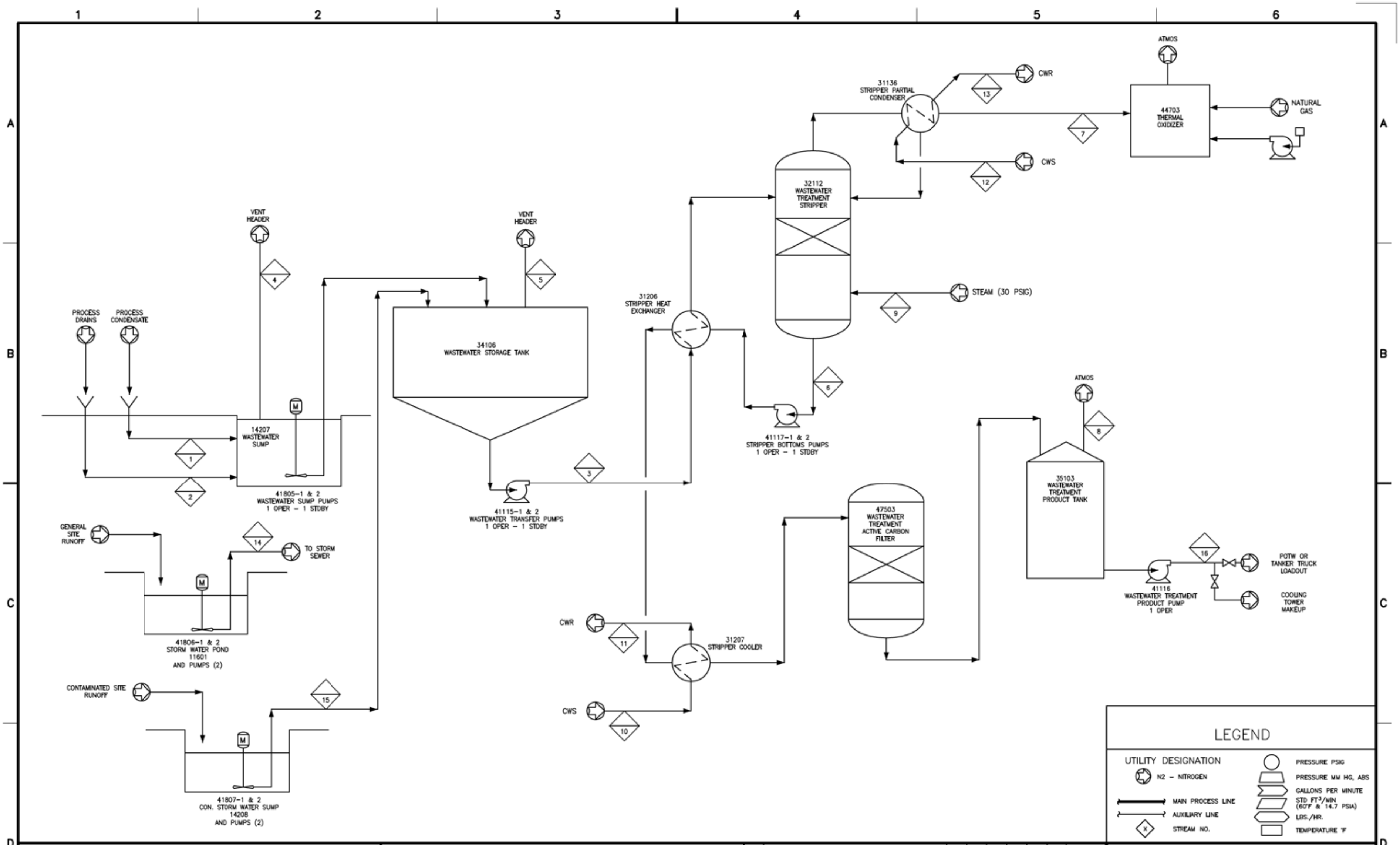
AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANT

DEMIN. WATER, START–UP BOILER, N. GAS SYSTEMS
& FIRE PROTECTION PROCESS FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHARGE CODE	SCALE	DRAWING NO.	REV.
A0757603		NONE	R–10–0002	B

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE	REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE

1/10 1/8–1/4 3/16–3/8–3/4 1/2– 1



REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
B	OCOD SUBMITTAL	TI			MJF	PFA		2JUN08
A	PRELIMINARY	LMc	MJF		MJF	MJF		21AUG07

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE

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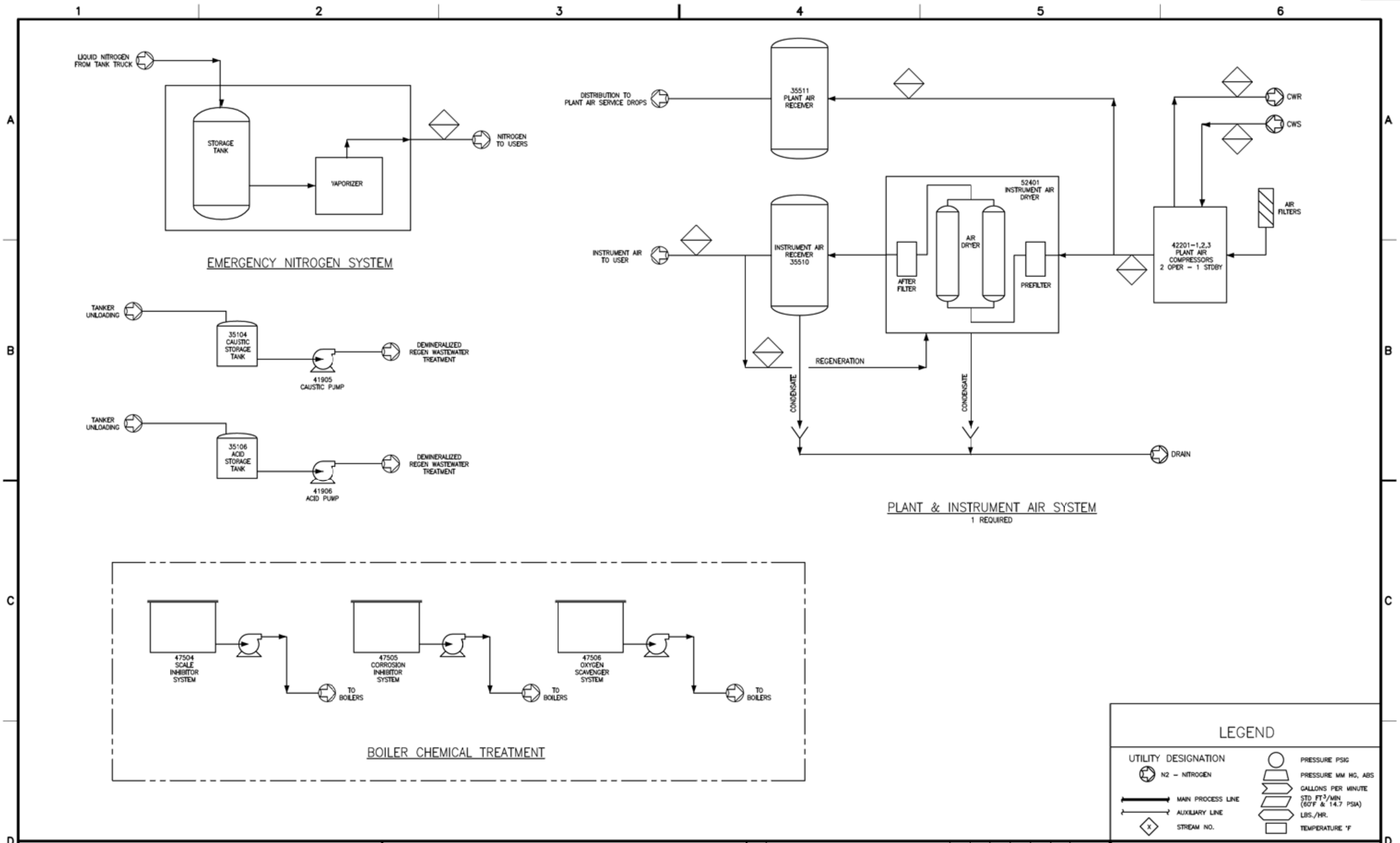
AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANT

WASTEWATER TREATMENT
PROCESS FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHARGE CODE	SCALE	DRAWING NO.	REV.
A0757603			R–10–0003	B

NONE

1/10 1/8–1/4 3/16–3/8–3/4 1/2– 1



REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
B	OCOD SUBMITTAL	TI			MJF	PFA		2JUN08
A	PRELIMINARY	LMc	MJF		MJF	MJF		21AUG07

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE

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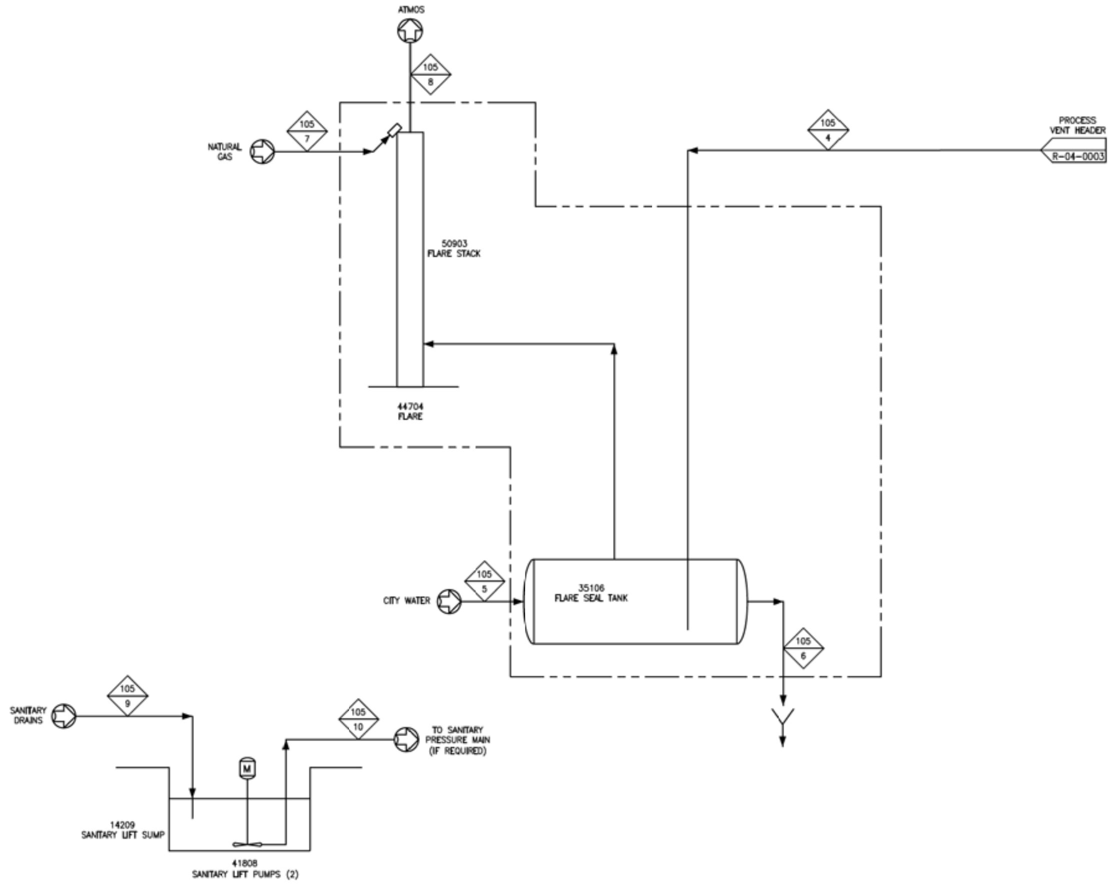
AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANT

BOILER CHEM. TREAT., EMERGENCY N_2
& AIR SUPPLY SYSTEMS
PROCESS FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHARGE CODE	SCALE	DRAWING NO.	REV.
A0757603			R-10-0004	B

NONE

1/10 1/8-1/4 3/16-3/8-3/4 1/2- 1



LEGEND

UTILITY DESIGNATION

N2 – NITROGEN

MAIN PROCESS LINE

AUXILIARY LINE

◇ STREAM NO.

○ PRESSURE PSIG

PRESSURE MM HG, ABS

GALLONS PER MINUTE

STD FT³/MIN (60°F & 14.7 PSIA)

LBS./HR.

▭ TEMPERATURE °F

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
B	OCOD SUBMITTAL	TI			MJF	PFA		2JUN08
A	PRELIMINARY	LMc	MJF		MJF	MJF		21AUG07

AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANT

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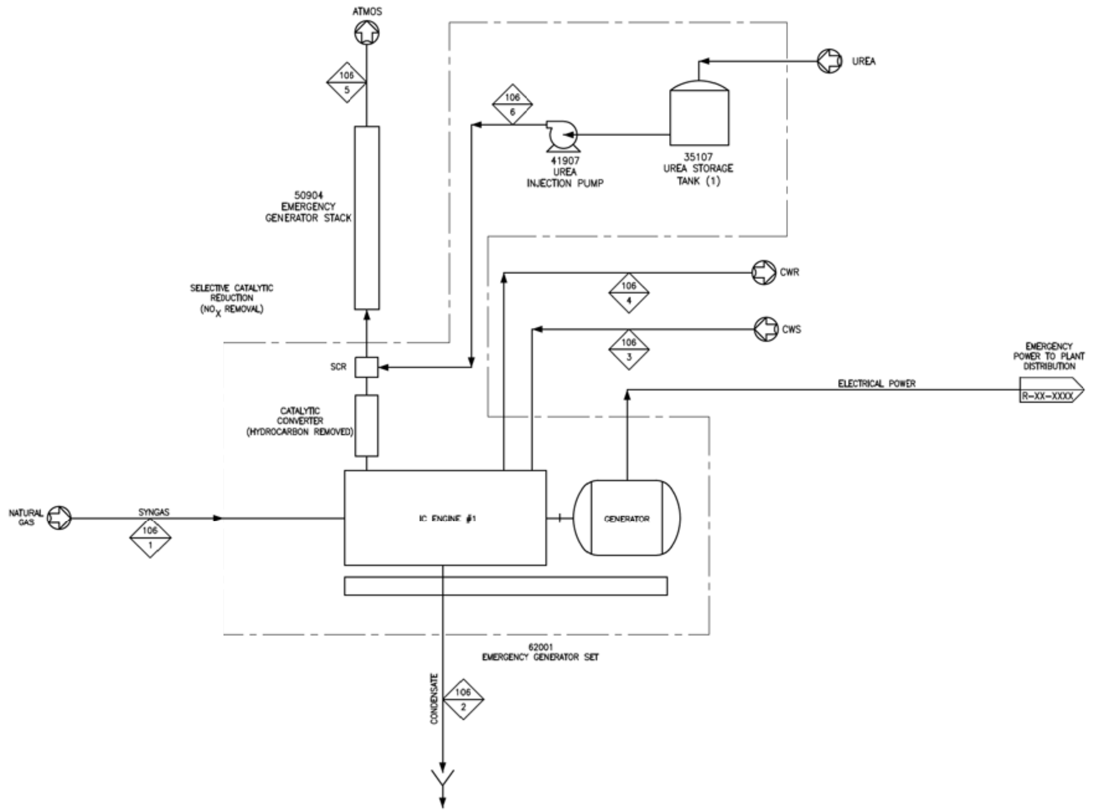
TYPE OF ISSUE

FLARE GAS & SANITARY SYSTEMS
PROCESS FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHANGE CODE	SCALE	DRAWING NO.	REV.
A0757603			R–10–0005	B

NONE



EMERGENCY POWER PRODUCTION

LEGEND

UTILITY DESIGNATION

N2 – NITROGEN

MAIN PROCESS LINE

AUXILIARY LINE

◇ STREAM NO.

○ PRESSURE PSIG

PRESSURE MM HG, ABS

GALLONS PER MINUTE

STD FT^3/MIN (60°F & 14.7 PSIA)

LBS./HR.

☐ TEMPERATURE °F

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
B	OCOD SUBMITTAL	TI			MJF	PFA		2JUN08
A	PRELIMINARY	LMc	MJF		MJF	MJF		21AUG07

AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANT

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TYPE OF ISSUE

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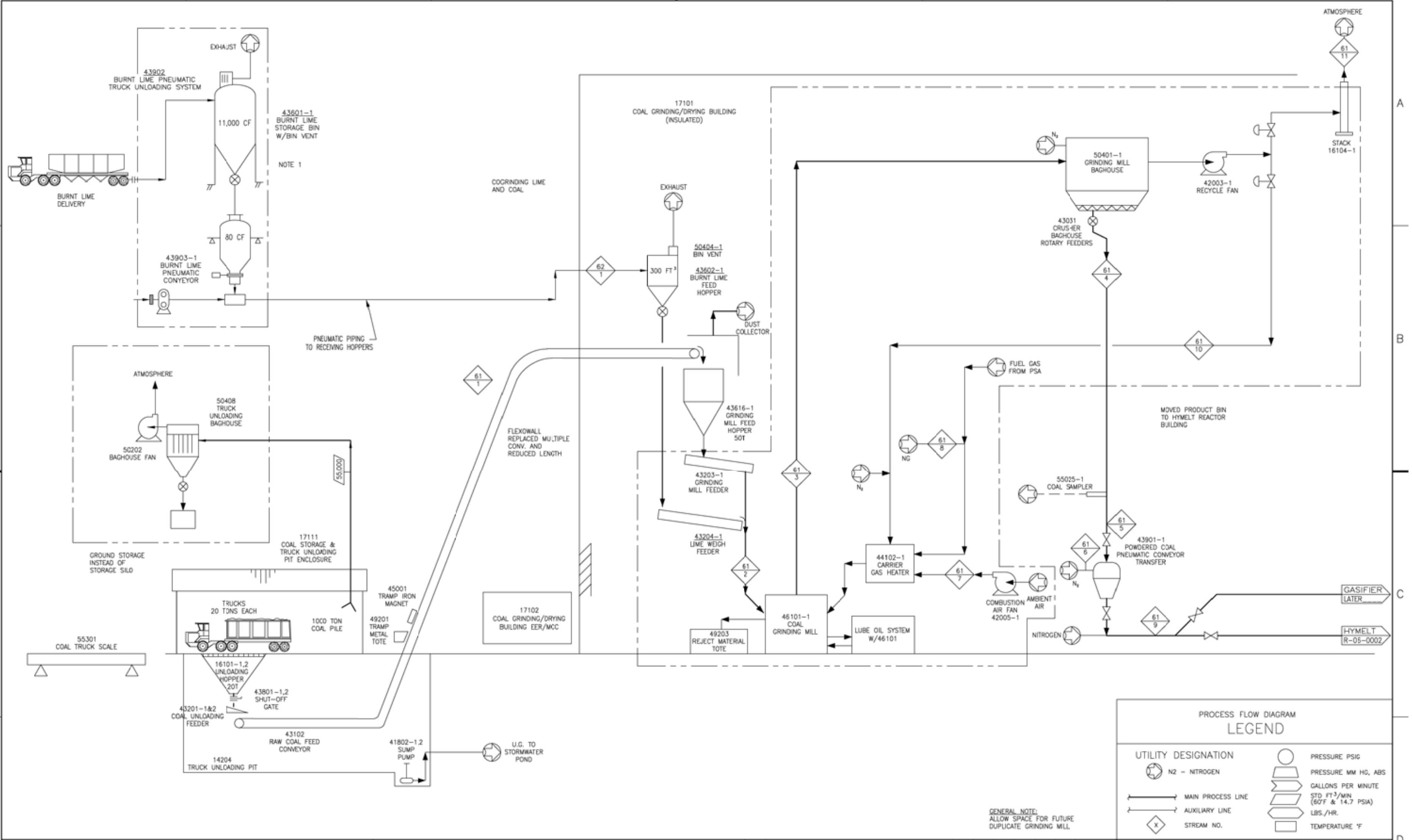
EMERGENCY POWER PRODUCTION
PROCESS FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHARGE CODE	SCALE	DRAWING NO.	REV.
A0757603		NONE	R-10-0006	B

1/10 1/8-1/4 3/16-3/8-3/4 1/2- 1



GENERAL NOTE:
ALLOW SPACE FOR FUTURE
DUPLICATE GRINDING MILL

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
G	OCOD SUBMITTAL	TI			MJF	PFA		02JUN08
F	REVISED AS SHOWN	TI			MJF			12FEB08
E	ADDED COGRINDING	KK			MJF			10JAN08
D	DEL 16102 COAL BIN, MOVE 16103 PRODUCT BIN	KK			MJF			08JAN08

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
C	PER AUG. 6 2007 REVIEW MEETING	MLS	MJF		MJF	MJF		20AUG07
B	BOTTOM TUYERE CONCEPT	LMc	MJF	JPC	MJF	RMG		24JULY07
A	TOP LANCE CONCEPT	CMO	WRR		MJF			18APR07

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TYPE OF ISSUE

E MJF 30OCT07
TM 30OCT07

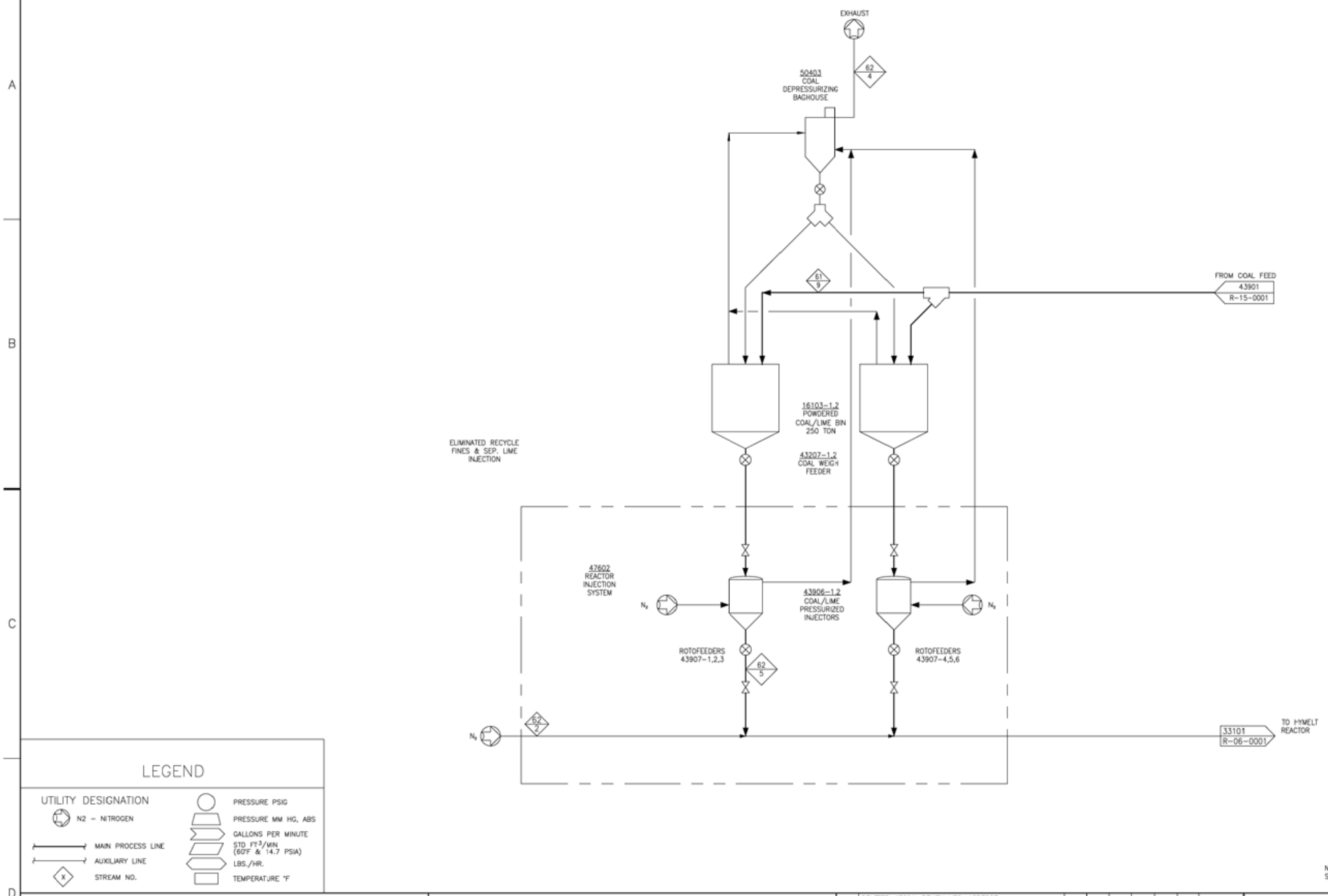
D MJF 08OCT07

AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANT

RAW MATERIALS AREA
COAL GRIND/DRY AND LIME RECEIVING
PROCESS FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHANGE CODE	SCALE	DRAWING NO.	REV.
A0757603		NONE	R-15-0001	G

1/10 1/8-1/4 3/16-3/8-3/4 1/2- 1



NOTE 1: ALLOW SPACE FOR
SECOND LIME STORAGE BIN

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
G	OCOD SUBMITTAL	TI			MJF	PFA		02JUN08
F	REVISED AS SHOWN	TI			MJF			12FEB08
E	DELETE BURNT LIME INJECTORS	KK			MJF	MJF		10JAN08
D	REPLACE 43608 FEED HOPPER W/16103 PWRD COAL BIN	KK			MJF	MJF		08JAN08

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE
C	DELETED 43601, REVIEW MTG. 18DEC07	CMO			MJF	MJF		19DEC07
B	REVISED PER A0757500	CMO			MJF			07DEC07
A	PROTOTYPE SCOPE	CMO			MJF			18APR07

REV.	DESCRIPTION	DRAWN	CHKD	DL	DM	PM/EM	CL	DATE

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AMERICAN FREEDOM FUELS AND CHEMICALS, LLC
COAL TO NITROGEN PRODUCTS PLANT

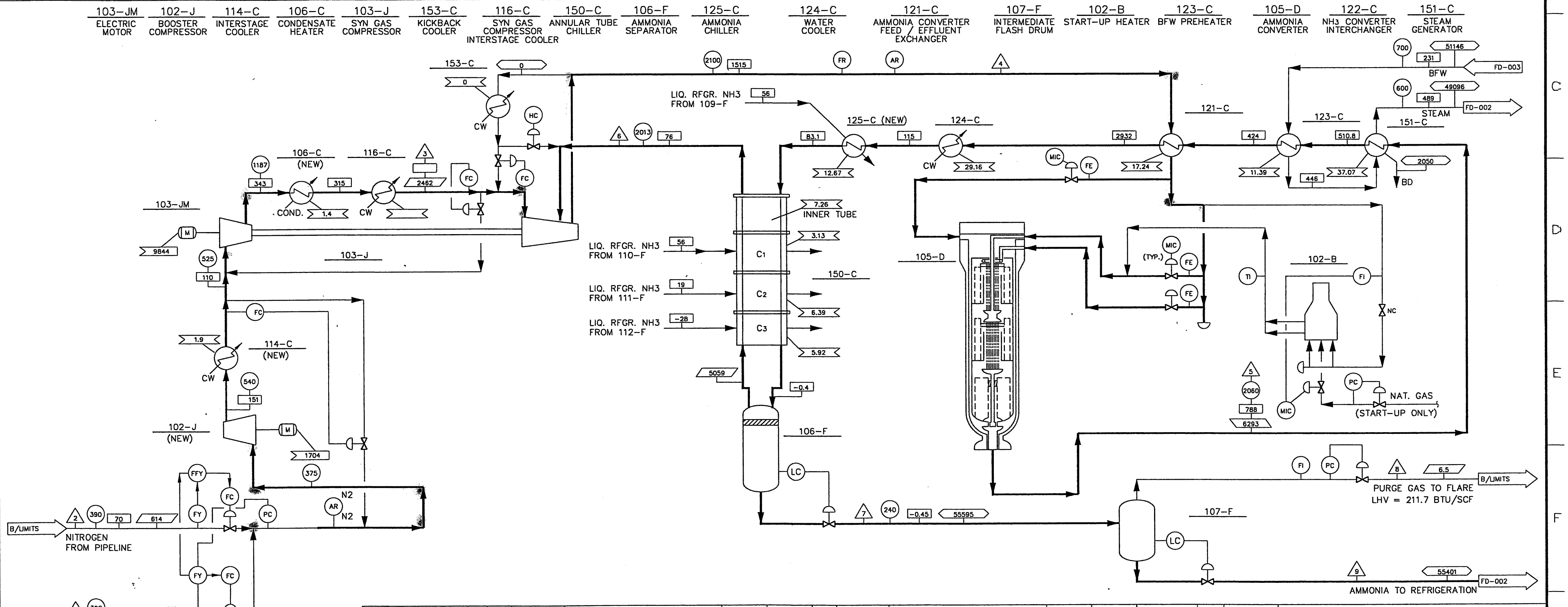
RAW MATERIALS AREA
COAL/LIME INJECTION
PROCESS FLOW DIAGRAM

CONTRACT NO.	ENGINEERING CHARGE CODE	SCALE	DRAWING NO.	REV.
A0757603		NONE	R-15-0002	G

1/10 1/8-1/4 3/16-3/8-3/4 1/2- 1

STREAM NO.		1		2		3		4		5	
DESCRIPTION		HYDROGEN FROM PIPELINE		NITROGEN FROM PIPELINE		MAKE-UP GAS		NH3 CONVERTER INLET		NH3 CONVERTER OUTLET	
COMPONENT	MOL WT	LB MOL/HR	MOL %	LB MOL/HR	MOL %	LB MOL/HR	MOL %	LB MOL/HR	MOL %	LB MOL/HR	MOL %
HYDROGEN H_2	2.02	4864.93	99.9			4864.93	74.982	14602.44	73.678	9748.52	58.785
NITROGEN N_2	28.01	4.87	0.1	1618.2	99.99	1623.07	25.016	4867.48	24.559	3249.51	19.595
AMMONIA NH_3	17.03							312.88	1.579	3548.83	21.4
ARGON Ar	39.95			0.16	0.01	0.16	0.02	36.47	0.184	36.47	0.22
TOTAL (DRY)		4869.8	100.00	1618.36	100.00	6488.16	100.00	19819.27	100.00	16583.33	100.00
WATER LB. MOL./HR.											
TOTAL LB MOL/HR (WET)											
TOTAL LBS./ HR.											
AVG. MOL. WT.											

STREAM NO.	6		7		8		9													
DESCRIPTION	RECYCLE GAS		HIGH PRESSURE SEPARATOR OUTLET		FLASH GAS TO FUEL		NH3 TO LOW PRESSURE SEPARATOR													
COMPONENT	LB MOL/HR	MOL %	LB MOL/HR	MOL %	LB MOL/HR	MOL %	LB MOL/HR	MOL %	LB MOL/HR	MOL %	LB MOL/HR	MOL %	LB MOL/HR	MOL %	LB MOL/HR	MOL %	LB MOL/HR	MOL %	LB MOL/HR	MOL %
HYDROGEN H_2	9737.5	73.043	11.02	0.338	10.03	58.815	0.98	0.0304												
NITROGEN N_2	3244.41	24.337	5.09	0.157	4.64	27.225	0.63	0.0195												
AMMONIA NH_3	312.88	2.347	3235.96	99.501	2.26	13.262	3230.5	99.949												
ARGON Ar	36.34	0.273	0.13	0.004	0.12	0.694	0.04	0.0011												
TOTAL (DRY)	13331.13	100.00	3252.2	100.00	17.05	100.00	3232.15	100.00		100.00		100.00		100.00		100.00		100.00		100.00
WATER LB. MOL./HR.																				
TOTAL LB MOL/HR (WET)																				
TOTAL LBS./ HR.																				
AVG. MOL. WT.																				



CALC. # 174608

LEGEND
- △ STREAM NUMBER
- ○ PRESSURE, PSIG
- ▭ TEMPERATURE, °F
- ⋈ DUTY, MM BTU/HR.
- ⬭ FLOW, LB./HR.
- ▱ FLOW, MSCFH (60°F)
- ▷ POWER, HP

REV	DATE	DESCRIPTION	DRAWN	CHECKED	REV	DATE	DESCRIPTION	DRAWN	CHECKED
K	02/20/02	"AS BUILT" (NO CHANGES) FIELD VERIFIED-M.WALKER & E.JOHNSON	RC	OA	E	9/30/96	COASTAL UPDATE	MA	MRG
J	05/15/97	CASALE UPDATE	wps		D	9/19/96	UPDATE PER 9/18 MTG.	CRS	
H	12/10/96	GENERAL COASTAL UPDATE	MA	MRG	C	9/16/96	FINAL REPORT ISSUE	CRS	
G	11/18/96	GENERAL COASTAL UPDATE	MA	RVC	B	9/5/96	MAJOR CONTROLS ADDED	CRS	
F	11/7/96	COASTAL UPDATE	MA	PMG	A	8/26/96	ISSUE FOR CLIENT COMMENTS	JFC	

DRAWN BY	JFC	5/14/96
CHECKED		
PROCESS APPROVED		
PROCESS MGR APPROVED		
PROJ MGR APPROVED		
CLIENT APPROVED		

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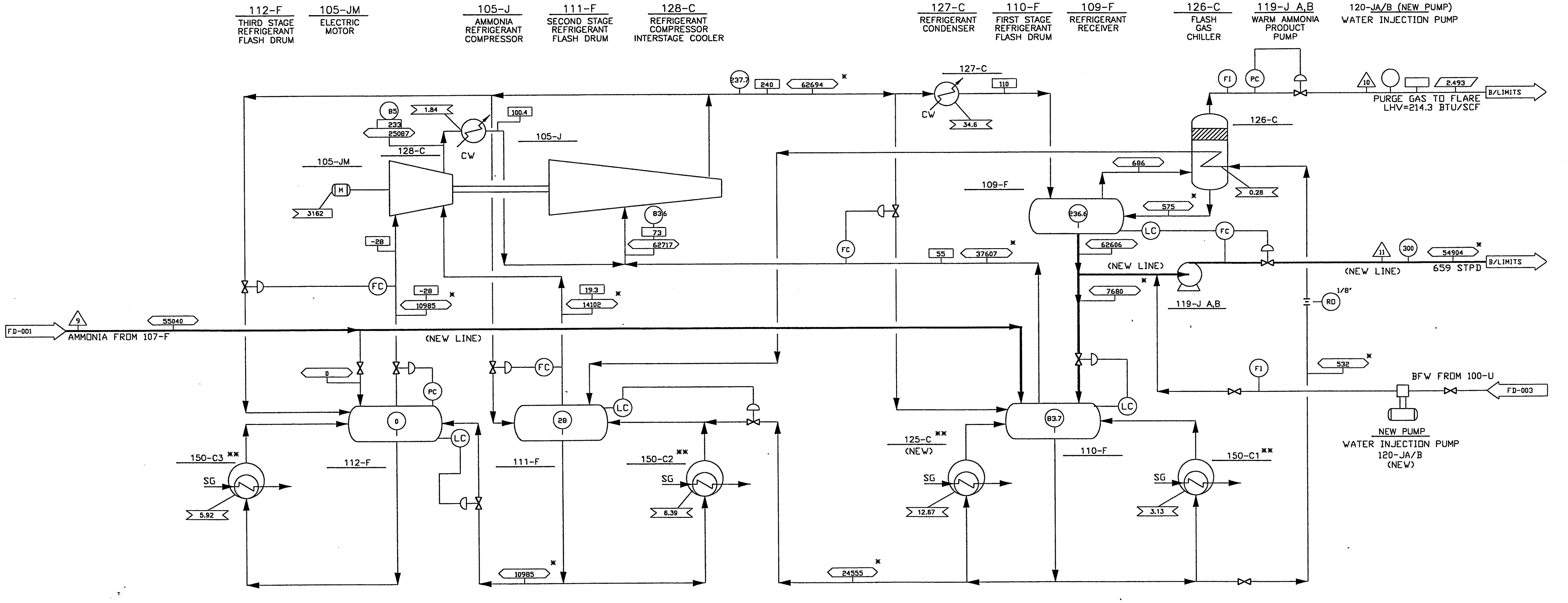
COASTAL OYSTER CREEK CHEMICALS, INC.
OYSTER CREEK, TEXAS
AMMONIA PLANT RELOCATION
SYNTHESIS SECTION
BASE CASE: 660 STPD AMMONIA

PROCESS FLOW DIAGRAM

SCALE	DRAWING NUMBER	REV.
NONE	65386-FD-001	K

STREAM NO.			9		10		11																									
DESCRIPTION			NH3 TO LOW PRESSURE SEPARATOR		REFRIGERANT OFF GAS		HOT AMMONIA PRODUCT																									
COMPONENT		MOL WT	LB MOL/HR	MOL %	LB MOL/HR	MOL %	LB MOL/HR	MOL %	LB MOL/HR	MOL %	LB MOL/HR	MOL %	LB MOL/HR	MOL %	LB MOL/HR	MOL %	LB MOL/HR	MOL %	LB MOL/HR	MOL %	LB MOL/HR	MOL %	LB MOL/HR	MOL %	LB MOL/HR	MOL %	LB MOL/HR	MOL %	LB MOL/HR	MOL %	LB MOL/HR	MOL %
HYDROGEN	H_2	2.02	0.98	0.0304	0.34	5.21	0.64	0.02																								
NITROGEN	N_2	28.01	0.63	0.0195	0.28	4.19	0.35	0.011																								
AMMONIA	NH_3	17.03	3230.5	99.949	5.94	90.39	3224.56	99.968																								
ARGON	Ar	39.95	0.04	0.0011	0.01	0.21	0.03	0.001																								
TOTAL (DRY)		▨	3232.15	100.00	6.57	100.00	3225.59	100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00		100.00
WATER LB. MOL./HR.		▨		▨		▨		▨		▨		▨		▨		▨		▨		▨		▨		▨		▨		▨		▨		▨
TOTAL LB MOL/HR (WET)		▨		▨		▨		▨		▨		▨		▨		▨		▨		▨		▨		▨		▨		▨		▨		▨
TOTAL LBS./ HR.		▨	▨		▨		▨		▨		▨		▨		▨		▨		▨		▨		▨		▨		▨		▨		▨	
AVG. MOL. WT.		▨	▨		▨		▨		▨		▨		▨		▨		▨		▨		▨		▨		▨		▨		▨		▨	



** ALSO SHOWN ON DRAWING 65386-FD-001

* FLOW AS NH3 ONLY

CALC. # 174624

LEGEND	
△	STREAM NUMBER
○	PRESSURE, PSIG
▭	TEMPERATURE, °F
⋈	DUTY, MM BTU/HR.
⬭	FLOW, LB./HR.
▱	FLOW, MSCFH (60°F)
▭	POWER, HP

REV	DATE	DESCRIPTION	DRAWN	CHECKED	REV	DATE	DESCRIPTION	DRAWN	CHECKED
K	02/20/02	"AS BUILT" (NO CHANGES) FIELD VERIFIED–M.WALKER & E.JOHNSON	RC	OA	E	9/26/96	COASTAL UPDATE	JWL	RVC
J	5/15/97	CASALE UPDATE	PG	RVC	D	9/19/96	UPDATE PER 9/18 MTG.	CRS	
H	12/10/96	GENERAL COASTAL UPDATE	MA	RVC	C	9/16/96	FINAL REPORT ISSUE	CRS	
G	11/18/96	GENERAL COASTAL UPDATE	MA	RVC	B	9/5/96	MAJOR CONTROLS ADDED	CRS	
F	11/7/96	COASTAL UPDATE	MA	PMG	A	8/26/96	ISSUE FOR CLIENT COMMENTS	JFC	

DRAWN BY	JFC	5/14/96
CHECKED		
PROCESS APPROVED		
PROCESS MGR APPROVED		
PROJ MGR APPROVED		
CLIENT APPROVED		

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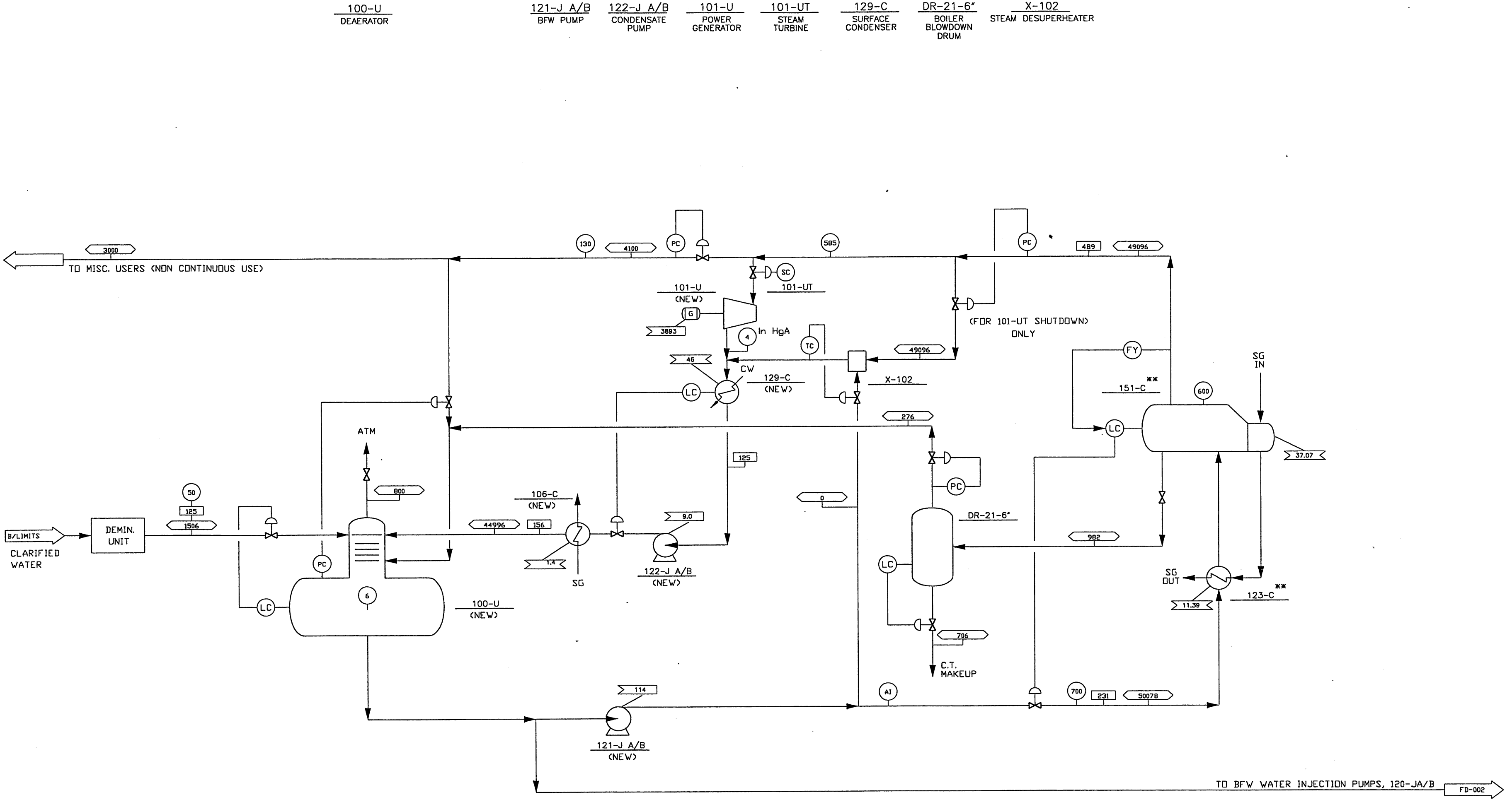
OYSTER CREEK, TEXAS
AMMONIA PLANT RELOCATION
REFRIGERATION SECTION
BASE CASE: 660 STPD AMMONIA

PROCESS FLOW DIAGRAM

SCALE	DRAWING NUMBER	REV.
NONE	65386-FD-002	K



** SEE 65386-FD-001

CALC. # 174402

LEGEND	
△	STREAM NUMBER
○	PRESSURE, PSIG
▭	TEMPERATURE, °F
⋊	DUTY, MM BTU/HR.
⬭	FLOW, LB./HR.
▱	FLOW, MSCFH (60°F)
⋊	POWER, HP

REV	DATE	DESCRIPTION	DRAWN	CHECKED	REV	DATE	DESCRIPTION	DRAWN	CHECKED
K	02/20/02	"AS BUILT" (NO CHANGES) FIELD VERIFIED–M.WALKER & E.JOHNSON	RC	OA	E	9/30/96	COASTAL UPDATE	MA	MRG
J	5/16/97	CASALE UPDATE	JWL	RVC	D	9/19/96	UPDATE PER 9/18 MTG.	CRS	
H	12/10/96	GENERAL COASTAL UPDATE	MA	MRG	C	9/16/96	FINAL REPORT ISSUE	CRS	
G	11/18/96	GENERAL COASTAL UPDATE	MA	MRG	B	9/5/96	MAJOR CONTROLS ADDED	CRS	
F	11/7/96	COASTAL UPDATE	MA	PMG	A	8/26/96	ISSUE FOR CLIENT COMMENTS	JFC	

DRAWN BY	JFC	7/16/96
CHECKED		
PROCESS APPROVED		
PROCESS MGR APPROVED		
PROJ MGR APPROVED		
CLIENT APPROVED		

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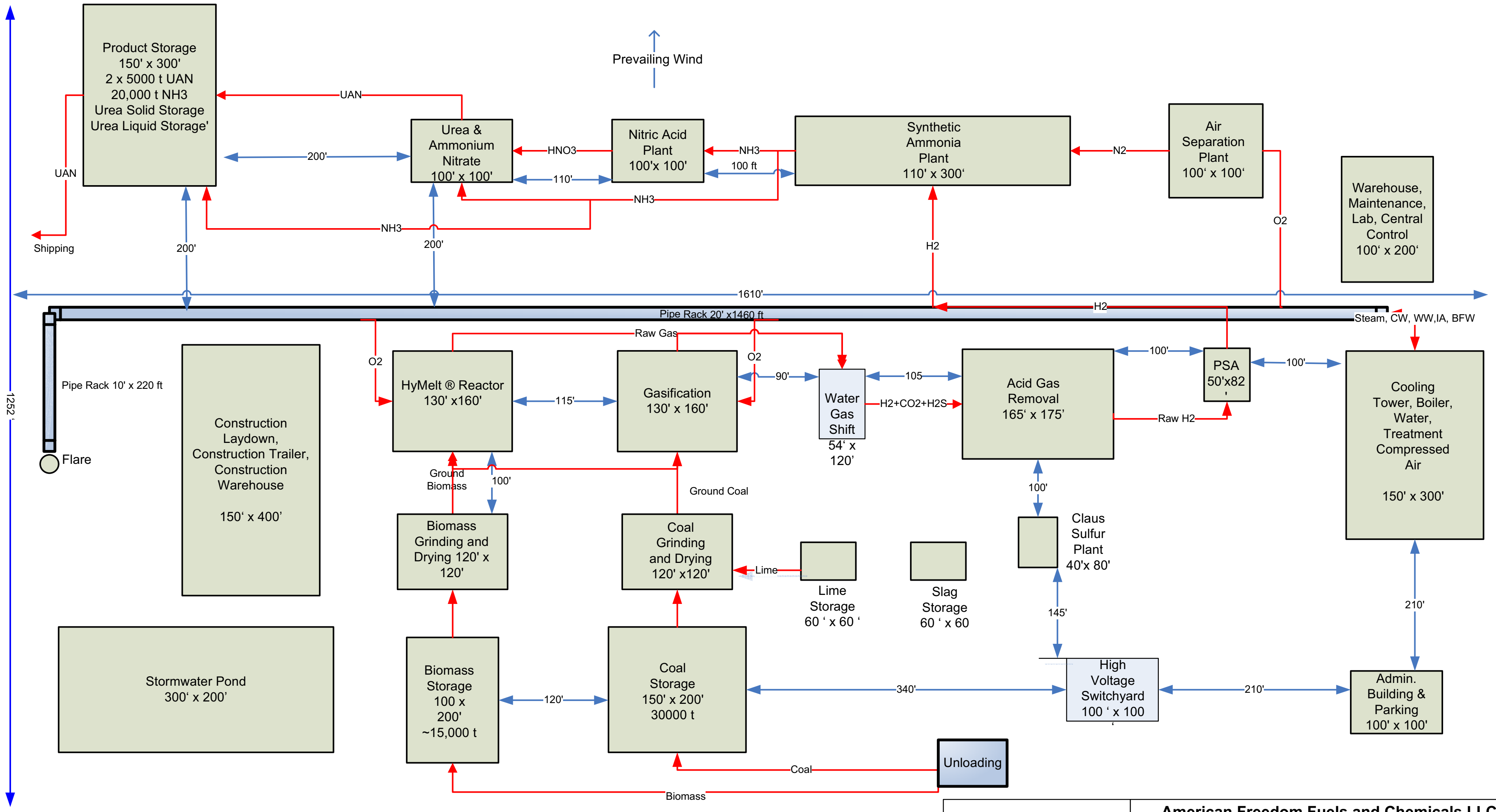
COASTAL OYSTER CREEK CHEMICALS, INC.
OYSTER CREEK, TEXAS
AMMONIA PLANT RELOCATION
BASE CASE : 660 STPD AMMONIA
STEAM BALANCE

PROCESS FLOW DIAGRAM

SCALE	DRAWING NUMBER	REV.
NONE	65386-FD-003	K

Exhibit 5 Preliminary Plant Layout (1 page)



Note: Total Area ~ 45 acres

D	OCDO Submittal	3JUN08	MJF
REV.	DESCRIPTION	DATE	BY

Preliminary

AkerSolutions

A0757603

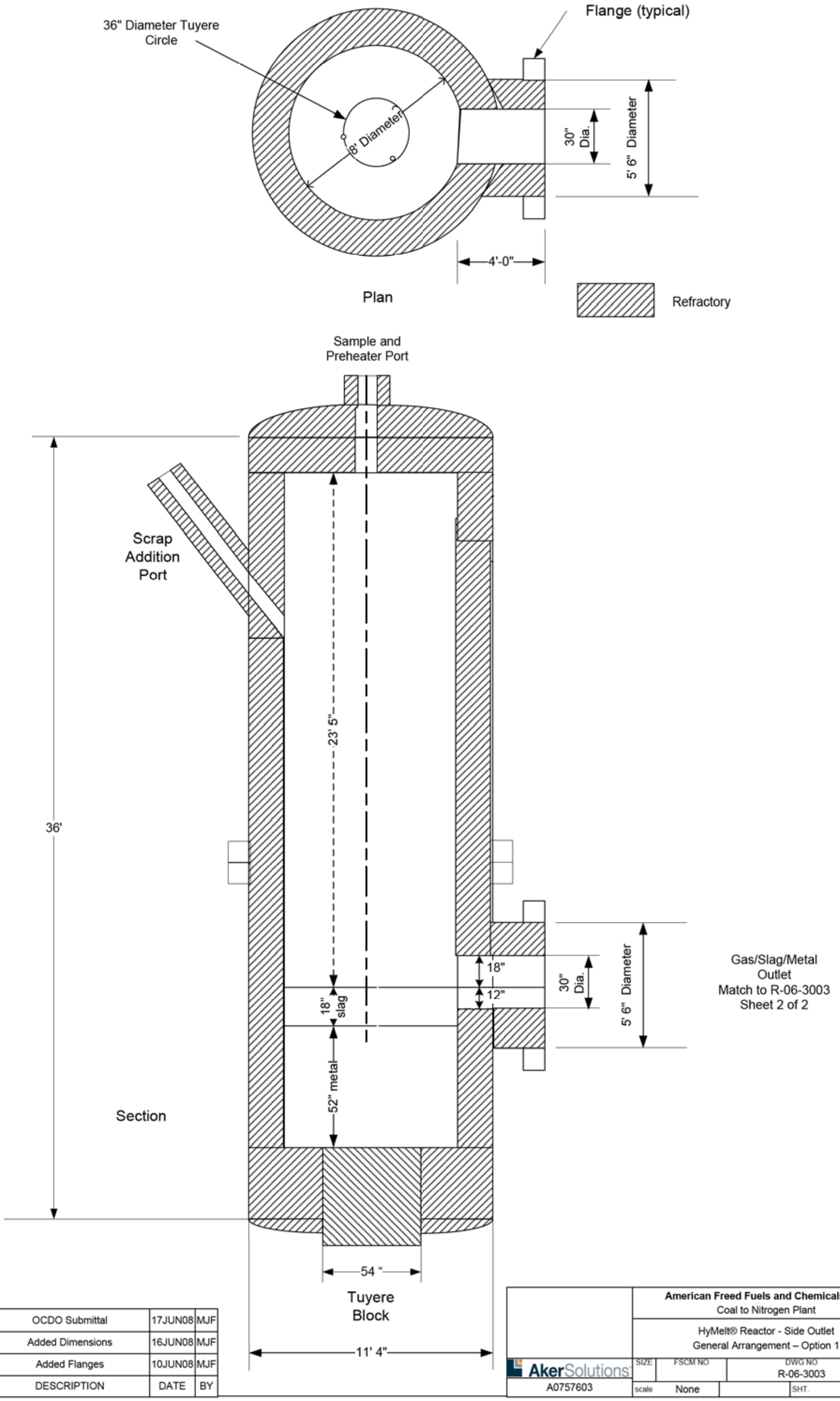
American Freedom Fuels and Chemicals LLC

Coal to Nitrogen Products Plant

Conceptual Plot Plan

SIZE	FSCM NO	DWG NO	REV
		R-00-9001	D
SCALE None		SHEET 1 OF 1	

Exhibit 6 HyMelt RSQ System (1 page)



D	OCDO Submittal	17JUN08	MJF
C	Added Dimensions	16JUN08	MJF
B	Added Flanges	10JUN08	MJF
REV.	DESCRIPTION	DATE	BY

American Freed Fuels and Chemicals LLC
Coal to Nitrogen Plant

HyMelt® Reactor - Side Outlet
General Arrangement – Option 1

SIZE	FSCM NO	DWG NO	REV
		R-06-3003	D

A0757603

scale None SHT. 1 OF 2

Exhibit 7 Design Basis Specifications (18 pages)

Aker Solutions

DESIGN BASIS

A0757603	B10	1 of 18
Contract No.	Design Basis No.	Page

SUBJECT: PROCESS DESIGN BASIS
COAL TO NITROGEN PRODUCTS PLANT

CLIENT: American Freedom Fuels and Chemicals LLC

FACILITY: Coal to Nitrogen Products Plant

LOCATION:

DISCIPLINE: Process ORIGINATOR: Michael Friedrich

REVISION	A	B	C	D				
DATE OF ISSUE dd MMM yy	15 May 07	30 JUL 07	12 DEC 07	06 JUN 08				
TYPE OF ISSUE	R = Review	A = Approval	D = Design	C = Construction	V = Void			
	R	R	R	R				
APPROVALS								
Discipline Leader		MJF	MJF	MJF				
Discipline Manager	MJF	MJF	MJF	MJF				
QC Engineer								
Project / Engineering Manager		MJF	TSM	TSM				
Client (If Required)								
Other								

REFERENCES:

TABLE OF CONTENTS

1.0 Introduction

1.1 American Freedom Fuels and Chemicals LLC plans to construct facility that will gasify coal and biomass to produce raw gas consisting of mostly carbon monoxide and hydrogen. The carbon monoxide will be converted to hydrogen by means of water gas shift process. The hydrogen and pure nitrogen will be combined to produce ammonia. The ammonia will be combined with carbon monoxide to form urea. Nitric acid will be produced by oxidizing nitrogen. Ammonium nitrate will be manufactured by absorbing the unreacted ammonia from the Urea plant with nitric acid solution.

1.2 The scope of the process design basis will be to identify the critical process design parameters for each system or area of the facility.

2.0 Raw Material Preparation

2.1 Coal will be delivered to the plant by truck or rail. Approximately 30,000 tons of coal will be stored on site. The feed to the plant will be about 1000 tpd with 100% coal. The coal will be delivered to a coal day bin that will feed an air swept roller mill. The roller mill will grind and dry the coal to approximately 200 mesh and 1% moisture. Lime will also be added to the coal feed as required to meet the specification for molten slag properties.

2.2 A portion of the feed to the plant will be biomass such as switchgrass, miscanthus or black locust. The biomass may vary between 0 and 50% of the feed to the gasification area. The biomass will be prepared by a combination size crushing, grinding, screening and drying. The storage capacity will be about 15000 tons.

2.3 Bulk Lime will be received dried and ground. The lime will be transported in pneumatic tank truck and conveyed to a storage bin.

2.4 Scrap metal punchings will be received in bulk bags delivered to the feed bin as needed using a hoist.

2.5 Storage requirements

Description	Units	Value	Comment
Coal Bulk Density	Lbs/ft3	50	
Coal Day Bin	Tons	1000	
Lime or Flux Storage Time	Days	4	
Iron or scrap metal storage time	Days	1	
Coal Pile Storage	Days	30	
Biomass Pile Storage	Days	30	

2.6 Petroleum coke storage will be a future consideration. Pet Coke will be an alternate feed material.

2.7 Coal Properties – typical properties

Description	Units	Value	Comment
Carbon	Wt%	72.64	Dry basis
Hydrogen	Wt%	5.38	
Nitrogen	Wt%	1.65	
Oxygen	Wt%	9.57	
Inorganic (ash)	Wt%	8.8	
Sulfur	Wt%	1.96	
Volatile Matter	Wt%	35 to 37	
Ash Composition			
• SiO2	Wt%	55.0	
• Al2O3	Wt%	30.0	
• Ti	Wt%	1.5	
• CaO	Wt%	2.0 to 4.5	
• K2O	Wt%	2.0	
• MgO	Wt%	1	
• Na2O	Wt%	0.5 to 1.0	
• Fe	Wt%	5.5 t0 6.0	
• P2O5	Wt%	0.28	
• SO3	Wt%	2.95	
• Undetermined	Wt%	0.34	
Minor Elements			
• Mercury	ppm	0.11 average	.057 to 0.178
• Copper	Wt%	< 0.1	
• Chromium	Wt%	< 0.1	
• Nickel	Wt%	< 0.1	
• Manganese	Wt%	< 0.1	
Free Moisture	Wt%	6	
Particle size		later	

3.0 Gasification

3.1 A commercially proven gasifier will convert coal and biomass to carbon dioxide and hydrogen. Pure oxygen will be fed to partially oxidize the feedstock and steam will be added to moderate the temperature and provide some additional hydrogen. The slag or ash will be removed from the gasifier and temporarily stored onsite. A third party will process the slag or ash so that it can be recycled or sent to a landfill.

3.2 The gas leaving the gasifier will be quenched to about 400° F. The intent is to evaporate water into gas to prepare for the downstream water gas shift reaction. A ratio of 1 mole of water vapor to 1 mole of raw gas is recommended for an efficient reaction.

3.3 Particulate will be removed in a high pressure drop venturi scrubber with variable throat. The venturi scrubber will be designed to remove particulate down to about 5 mg/NM^3. A portion of the scrubbing loop will be pumped to a clarifier to remove solids. The water will be conditioned to neutralize acids that are absorbed from the raw gas.

4.0 HyMelt® Plant

Pulverized Coal, lime, steam and oxygen will be injected into the HyMelt® Reactor. The reactor will be a fixed, vertical, refractory lined vessel filled partially with molten iron. The carbon in the coal will dissolve into the iron. Oxygen will react with the iron to form carbon monoxide. The hydrogen in the coal will be liberated as the carbon-hydrogen bonds are broken. Ash components will report to a slag phase. Lime or other flux agents will be added to control the amount of sulfur dissolved in the metal. The fluxes will also maintain fluidity in the slag phase and maintain prevent excessive refractory deterioration.

4.0.1 Slag will normally be granulated under pressure and removed as solid from through a lock hopper.

4.0.2 The molten slag and metal may also be tapped from the reactor for maintenance or shutdown situations. The reactor will operate at 500 psig. Prior to tapping, the reactor will be depressurized. A tap hole will be drilled below the slag level and the molten slag will be directed through a refractory lined launder to a sand pit. Similarly, molten metal may be tapped through a lower tap hole and solidified in the sand pit.

4.1.1 HyMelt® Reactor Design Criteria

Description	**Units**	**Value**	**Comment**
Coal Feed Rate	Tpd	1000	Appalachian Coal
Reactor Parameter			
• Orientation		Vertical	
• Tippable		No	Fixed vessel. Vessel will not be rotated.
• Internal Diameter	Feet	8 ft. diameter	Internal reaction space
• Maximum operating Pressure	Psig	500	
• Minimum operating pressure	Psig	100	
• Freeboard	n		
• Molten iron inventory	Ton/hr Carbon per ton iron	0.5	
Feed Sulfur partition			

Description	**Units**	**Value**	**Comment**
• Reporting to gas as Hydrogen Sulfide	%	25	To be determined
• Reporting to slag as Calcium Sulfide	%	75	To be determined
Average carbon in iron	%	2	

Description	**Units**	**Value**	**Comment**
Slag Characteristic			
• Liquid at operating temp.			Assumed freeze point is 2600 F
• Basicity		1.0	Or minimum required to prevent sulfur accumulation in the metal and maintain fluidity
Dust Content	gm/m^3	60	Max conc = 300 gm/m3
Number of Feed Inlets			
• No. of tuyeres		3	Per Impact Report FEB08
• Maximum ID transport line	Inches	6	
• Steam nozzles in slag @ Lance		1	To be used to spring sulfur from slag as H_2S-experimental, position to be determined.

4.1.2 FACTSAGE Results

The following tables are the results of material balance calculation around the reactor using equilibrium thermodynamic application software " FACTSAGE". The run is dated 28DEP07 and was done at 30 atmos. The information may be used as a basis for creating a detailed heat and material balance.

Gas Phase

	Vol%	%/%CO	ppmv	ppbv
CO	67.44			
H2	30.02			
N2	0.81			
H2O	0.76	0.0113		
CO2	0.47	0.0069		
H2S	0.39		3,878	

Gas Phase				
	Vol%	%/%CO	ppmv	ppbv
COS	0.30	0.0045	3,037	
CH4	0.06	0.0008	571	
HCN	0.01	0.0001	70	
K	0.00		46	
HS	0.00		44	
H	0.00		28	
NH3	0.00		14	
KOH	0.00		8	
Na	0.00		8	
KCN	0.00		5	
CS2	0.00		5	5,010
H2CO	0.00		4	4,400
S2	0.00		4	3,800
C2H2	0.00		3	3,390
CS	0.00		2	2,040
CH3	0.00		1	1,330
C2H4	0.00		1	779
NaCN	0.00		1	740
H2S2	0.00		1	585
Fe	0.00		1	527
KH	0.00		0	443
HCO	0.00		0	353
NaOH	0.00		0	343
S	0.00		0	212
HNCO	0.00		0	192
NaH	0.00		0	148
CH2CO	0.00		0	104
OH	0.00		0	45
Fe(OH)2	0.00		0	40
SO	0.00		0	38
FeS	0.00		0	29
SiO	0.00		0	21

Gas Phase				
	Vol%	%/%CO	ppmv	ppbv
SiS	0.00		0	16
Mg	0.00		-	-
Total	100.27			

Metal Phase			
	Wt%	ppmw	ppbw
Fe	90.030		
S	7.496		
C	2.136		
O	0.313	3,130	
N	0.012	116	
H	0.005	45	
Si	0.000	3	
CaO	0.000	0	175
AlO	0.000	0	93
Al	0.000	0	80
MgO	0.000	0	28
Total	99.991		

Major Slag Phase				
	Major Phase Wt%	Minor Phase Wt%	Combined Wt%	Combined ppmw
CaO	42.28	-	41.98	
SiO2	28.93	-	28.72	
Al2O3	16.00	-	15.89	
CaS	9.36	-	9.29	
FeO	0.80	-	0.79	
K2O	0.78	-	0.77	
MgO	0.68	-	0.68	
Na2O	0.56	-	0.55	

Major Slag Phase				
	Major Phase Wt%	Minor Phase Wt%	Combined Wt%	ppmw
Ti	-	66.46	0.48	
FeS	0.17	-	0.17	
MgS	0.16	-	0.16	
K2S	0.16	-	0.16	
Na2S	0.12	-	0.12	1,201
S	-	16.68	0.12	1,194
N	-	13.58	0.10	972
C	-	3.27	0.02	234
Fe2O3	0.00	-	0.00	8
	100.00	99.99	100.00	
Grams	16,499	119	16,618	

Coal Feed to HyMelt	
Elements (dry)	
Carbon	72.64%
Hydrogen	5.38%
Nitrogen	1.65%
Chlorine	0.00%
Sulfur	1.96%
Oxygen	9.57%
Ash	8.80%
	100.00%
Ash Analysis	
SiO_2	54.00%
Al_2O_3	30.00%
TiO_2	1.50%
CaO	2.00%

Coal Feed to HyMelt	
Elements (dry)	
K_2O	2.00%
MgO	1.00%
Na_2O	1.25%
Fe_2O_3	7.85%
P_2O_5	0.00%
SO_3	0.00%
Cu, Cr, Ni, Mg	0.40%
Total	100.00%

4.2 Reactor Refractory System

An uncoooled brick type system will line the inside of the refractory system. An insulating layer will be installed between the outside vessel shell and the working lining. Similar systems are in service on Basic Oxygen Furnaces used for pneumatic steelmaking.

Description	Units	Value	Comment
Refractory System		Magnesium and carbon based brick working lining.	Ambient air cooling. Water cooled nozzles where required for pressure vessel design.
Outside Vessel Design Temperature	° F	400 to 500	
Refractory Life Cycle	months	12	Minimum
Breakout protection			Temperature monitoring of shell
Molten Iron temperature	° F	2400 t0 3000	Maximum

4.2.1 Refractory Maintenance facilities will be assumed to be supplied by an outside service company.

4.3 Startup and Charging

4.3.1 The HyMelt® reactor refractory will be preheated with gas fired burner inserted into the base of reactor. Exhaust gases will be directed through the refractory lined ductwork and exit through a temporary vent.

4.3.2 The reactor will be charged with coke and solid scrap steel or iron. The coke will be ignited with gas burners. The burning coke will melt the initial steel or iron. Combustion gases will be withdrawn through the system and exhausted to atmosphere after particulate removal.

4.4 Feed System

4.4.1 Coal and lime will be pneumatically conveyed into the HyMelt® Reactor through a bottom tuyere.

4.4.2 Steam and oxygen will also be injected into the bottom tuyere into concentric tubes.

4.4.3 Feed injection parameters

Pneumatic conveying	Unit	Value	Comment
• Transport gas type		Nitrogen or Carbon dioxide	
• Design transport gas flowrate			Per pneumatic conveying supplier
• Particle size distribution	mesh	70% passing 200	12SEP07 EnviRes to AKTS e-mail
• Maximum Moisture	Wt%	1 to 2	12SEP07 EnviRes to AKTS e-mail
Design steam rate	Lbs/hr	See mass balance	EnviRes calculation
Design oxygen flow rate	Lbs/hr	See mass balance	EnviRes calculation

4.4.4 Iron Makeup

Iron will be lost from the bath from dust and slag carryover. The bath will be restored by charging scrap metal punchings by gravity into the molten iron bath. The scrap metal will be stored in a bin and fed periodically into the HyMelt® vessel through a lock hopper and feeder arrangement.

4.5 Raw Gas and Slag Handling

4.5.1 Molten slag will overflow from the reactor into a slag/metal separator. Raw gas will exit the top of the reactor and will be fed into the slag/metal separator to keep the slag molten. Metal will settle by gravity in the separator and flow back into the reactor. The slag will overflow 12” high dam and enter the combination gas quencher and slag granulator. Water will be sprayed into the gas quench and granulation chamber to cool the gas to 400°F and solidify the slag. Water will be distributed through weirs at the top of the spray chamber to wet the walls. The solidified slag will fall by gravity to the bottom of a cone bottom tank. The cooled gas will be directed through a side nozzle to the venturi scrubber, The unevaporated water will be sent through a strainer and heat exchangers to the clarifier. The slag will be withdrawn through a lock hopper and fed to a dewatering classifier or drum. The dewatered slag will be conveyed to a slag pile and trucked offsite for processing. The decanted water will be returned to the granulation system.

4.5.2 Metal and slag must be drained from the reactor to inspect and maintain the refractory working lining. The HyMelt® vessel will be depressurized, purged and isolated from the gas train. A tap hole filled with clay and sealed with a quick release pressure cover will be opened. The tap hole will be located just above the floor of the reactor. A Blast furnace type drill will be used to remove the clay plug and allow the molten metal and slag to flow through a runner into a sand pit. After cooling and freezing, the metal and slag will be dug up with a front end loader and shipped to a slag processor for reclamation and disposal.

4.5.3 An alternate method may be used to drain the reactor for maintenance. The metal will run to a refractory lined ladle. The ladle will be carried to a pit and dumped. The metal will freeze and will be dug out for reclamation and disposal.

4.5.4 Emissions hoods will direct fume during tapping to a housekeeping baghouse.

4.6 Raw Gas Processing

4.6.1 The exhaust gas from the HyMelt® Reactor will be quenched with atomized spray water to about 400ºF. The gas will then pass through a venturi scrubber to remove water soluble contaminants such as hydrogen chloride and remove particulate. The venturi scrubber will operate at about 400° F and will saturate the gas with water vapor in preparation for the downstream water gas shift reaction.

5.0 AIR SEPARATION AND COMPRESSION PLANT

5.1 An air separation plant will produce oxygen and nitrogen. The nitrogen will be compressed to about 400 psig and sent to the ammonia plant. The oxygen and nitrogen will be compressed to about 700 psig and sent to the HyMelt® reactor.

5.2 Nitrogen may also be utilized as the transport gas for feeding solids into the HyMelt® reactor.

5.3 Nitrogen will be used as an inert gas for various purge streams throughout the plant.

5.4 Oxygen and nitrogen specifications

Description	**Units**	**Value**
Product Nitrogen purity for Synthetic ammonia	Vol. % Nitrogen	99.99

Description	Units	Value
Product Oxygen purity for HyMelt® process	Vol. % Oxygen	99.00
Purge nitrogen purity	Vol. % Oxygen	99.00
Product Nitrogen pressure	Psig	700
Product Oxygen pressure	Psig	700

6.0 WATER GAS SHIFT

6.1 Carbon monoxide in the Syngas will be reacted with water vapor over a catalyst to produce hydrogen. The gas will be heated indirectly to about 600°F. Three stages of reaction will be used to maximize the conversion of carbon monoxide to hydrogen. Organic carbon will be converted to hydrogen sulfide in the reactors.

6.2 The temperature between stages will be adjusted by quenching the reactor outlet with water. No steam will be added to the gas. The ratio of water vapor to dry gas will be approximately 1 to 1.

6.3 Steam at 600 psig will be used to preheat the raw gas at startup. Once the reaction is established heat will be exchanged in a between the gas exiting the first reactor and the incoming feed.

6.4 Waste heat from the 3rd reactor will be converted low pressure steam in two waste heat boilers. The first unit will produce 50 psig steam and the second unit will produce 15 psig.

6.5 Exhaust from the second waste heat boiler will be used to preheat boiler feedwater.

6.6 Water that condensed during heat recovery will be removed in vapor/liquid separators. The water will be sent to a countercurrent steam stripper to remove acid gases. The condensate will be sent to the process condensate recovery system.

6.7 The gas for the BFW Heater will be cooled to about 100 °F and sent to acid gas removal system.

7.0 ACID GAS SCRUBBING (HYMELT® SYNGAS)

C 7.1 An acid gas scrubbing system using UOP Selexol technology will be designed and installed to remove inorganic sulfur from the gas. The rich scrubbing solutions will be regenerated and the acid gas will be sent to a Claus Sulfur recovery plant. The tail gas from the Claus plant will be treated and recycled back into the H2S Concentrator.

7.2 The carbon dioxide will also be removed in a second Selexol absorber. The rich scrubbing liquor will also be regenerated in a series of flash drums. Some of the carbon dioxide from the flash drums will be used by the UAN plant to produce urea. The balance of the carbon dioxide will be vented.

7.3 A mercury adsorber will be placed in front of the H2S Absorber. Activated carbon beds impregnated with sulfur will remove mercury from the raw gas. Periodically, the carbon loaded with mercury and other trace compounds will changed.

8.0 SYNTHESIS GAS PREPARATION

8.1 Hydrogen Separation

8.1.1 Oxygen and sulfur must be removed to low levels prior to ammonia synthesis. Hydrogen will also be recovered in either a pressure swing adsorption. The rejected gas from the hydrogen separation will be used as a low heating value fuel gas. The fuel gas will be combusted to produce steam for the plant.

9.0 SYNTHETIC AMMONIA PLANT

9.1 The Syngas will be mixed with nitrogen in 3 to 1 ratio and compressed to 600 psig. The gas will be reacted in a catalytic loop to produce ammonia. The anhydrous ammonia product will be the primary feedstock for producing urea and ammonium nitrate.

9.2 The ammonia plant will be a refurbished facility capable of producing 700 tpd of anhydrous ammonia. The plant was originally designed by M.W. Kellogg.

9.3 Approximately 20,000 tons of storage will be installed as a buffer and also to ship ammonia product by truck or rail. A new flare will also be installed to combustion ammonia that must be vented due to pressure relief or other emergency.

10.0 Urea and Ammonium Nitrate Plant (UAN)

10.1 The UAN solution pant will be capable of producing 1500 STPD UAN solution.

10.2 The UAN plant will consist of the following units:

10.2.1 A Urea plant producing 535 STD of urea solution (75 to 83% by wt. The urea plant will react anhydrous ammonia and carbon dioxide to form ammonium carbamate at 4000 psig. The ammonium carbamate will be dehydrated to urea.

10.2.2 Nitric acid plant producing 525 STPD of nitric acid at 57 wt% (minimum). The nitric acid is produced by reacting air with ammonia over a catalyst to form nitrogen trioxide. The nitrogen trioxide is absorbed in water to form nitric acid. The feedstock for the nitric acid plant is the unreacted ammonia and carbon dioxide that are vented from the urea plant. The gases are vented from the high pressure separator in the Urea plant.

10.2.3 An ammonium nitrate plant that will produce 665 STPD of 75 to 83 wt% ammonium nitrate solution. The vent from the urea plant's low pressure separator will be contacted with nitric acid solution in a countercurrent absorber to produce ammonium nitrate. The ammonium nitrate solution is mixed with urea to produce a standard product grade UAN solution.

10.3 The gas outlet from the ammonium nitrate scrubber will be treated in a vent scrubber to remove traces of ammonia.

10.4 The UAN solution will be stored in two storage tanks that will hold 5000 tons each. The UAN solution will be loaded into tankers for transport by rail or road.

11.0 UTILITIES

11.1 Electric power will be assumed to be available at the battery limits at 69,000 volts.

11.2 City Water will be assumed to be available at the battery limit. The pressure will be assumed to be 30 psig. City water will be the source of all makeup water for boilers, cooling towers, as well as potable use.

11.3 Firewater system will be installed inside the plant boundary to protect buildings and equipment

11.4 Natural gas will be assumed to be available at the plant boundary. The pressure will be assumed to be 30 psig

11.5 Process wastewater will be pretreated and discharged a local POTW (Publicly Owned Treatment Works).

11.6 Sanitary drains will be discharge through the sewer system directly to the POTW.

11.7 Stormwater will be inventoried at new pond onsite as required by state regulations. The water will be discharged to surface streams if it is not contaminated.

11.8 A recirculated cooling tower system will be installed.

11.9 A boiler will be required that will be fired with natural gas and low heating value PSA tail gas. The boiler will supply steam to be used for heating and gasification.

11.0 SITE CONDITIONS AND PREPARATION

11.1 The current site will be located at *later.* The site grade will be raised to *late*r feet elevation and the top of the finished slab will be *later* feet elevation.

11.2 The soil is mainly *later.* The initial study will assume a bearing design load of *Later* lbs/ft2. Bedrock will be assumed to be between *later* ft below grade.

11.3 Fencing and green space border – later

11.4 Seismic conditions – Reference Civil Design Basis B40

11.5 Wind load conditions – Reference Civil Design Basis B40

11.6 Ambient Temperatures

11.6.1 Winter Design 0°F

11.6.2 Summer Design 100 °F

11.6.3 Summer Wet Bulb 78 °F

12.0 BUILDINGS, ROADS AND OTHER INFRASTRUCTURE

12.1 The facility will include control room, office, warehouse and employee locker room.

12.2 Maintenance facilities will be supplied through outside service companies

12.3 Truck access will be through *later*. The facility *will/will not* have rail access.

13.0 ENVIRONMENTAL

13.1 The plant will be designed to be a minor air emission source. Primary pollutants will be below 100 tpy (CO, NOx, SOX, VOC's, and PM10). Hazardous pollutants must be below 10 tpy each or 25 tpy total.

13.2 Effluent requirements – later

13.3 Solid Waste later

13.4 Process Hazards

Molten iron
Molten slag
Syngas (hydrogen)
Hydrogen sulfide gas
Carbon monoxide gas
Compressed gases - oxygen, nitrogen
Coal dust
Natural gas

14.0 UNITS OF MEASUREMENT

14.1 English and Metric units of measurement will be used on engineering documents.

14.2 Typical Units

Description	US Units	US Abbreviation	Metric Units	Metric Abb.
Solids flow	tons per hour	tph	Tonnes per hour	te/h
Liquid Flow	Gallons per minute	gpm	Cubic meters per hour	m^3/h
Gas Flow	Standard cubic feet per minute	scfm	Normal cubic meters per hour	Nm^3/h
Mass Flow	Pounds per hour	Lbs/hr	Kilograms per hour	Kg/h
Temperature	Degrees Fahrenheit	F	Degrees Centigrade	C
Pressure	Pounds per square inch gage	Psig	Atmospheres , gage	barg
Pressure	Inches water column	“ w.c.	Millimeters water column	Mm w.c.
Vacuum absolute	Inches mercury	“ Hg	Millimeters mercury	Mm Hg or torr
Density	Pounds per cubic foot	Lbs/ft^3	Kilograms per cubic meter	Kg/m^3

14.3 Standard Conditions

14.3.1 US Standard Conditions: 14.69 psia and 60ºF.

14.3.2 Metric Normal Conditions: 1 bar gage and 0ºC.

15.0 DESIGN FACTORS

15.1 The general philosophy for determining design capacities for process equipment will be to add 10% to the operating flowrate. Specific design factors for classes of equipment and line sizing will be developed later.

15.2 Rotating equipment such as pumps and blowers up to 200 hp will have installed standby units. Large motor driven compressor will not have installed standby units. Long delivery spare parts such as rotors will be procured for compressors without installed spares.

15.3	Plant Availability Design	95%
	Plant Availability expected	90% maximum

Exhibit 8 QA-QC Description (24 pages)

QA/QC DESCRIPTION

THE FOLLOWING DOCUMENT DESCRIBES THE GENERAL PROCEDURES THAT WILL BE UTILIZED BY AKER SOLUTIONS TO EXECUTE THE COAL TO NITROGEN PRODUCTS PROJECT. THE PROCEDURES WERE DEVELOPED AND WILL BE ENFORCED TO ASSURE A THE HIGHEST LEVEL OF QUALITY THROUGHOUT THE ENGINEERING, PROCUREMENT AND CONSTRUCTION PROCESS.

ENGINEERING

Aker Solutions utilizes an engineering discipline-oriented organization, which is based on assigned job engineers who have the specific engineering responsibilities for the project. These job engineers oversee the efforts of engineers, designers and drafters in conjunction with the engineering managers of each discipline. The personnel assigned to a project utilize an in-house library of standards and procedures, purchased and in-house engineering programs and CAD systems.

PROCESS TECHNOLOGY

Aker Solutions' Process Technology Group consists of engineers with significant experience and expertise in the industries and technologies served by Aker Solutions. In particular these engineers have hands-on experience in basic design, research, engineering and operation in the areas of minerals processing, chemicals, polymers, metals, petroleum, energy and environmental.

During the early phase of project development, Process Technology will define the initial scope of a project, the optimum process route and the principal equipment. Process Technology also provides the process design, process and plant descriptions, design basis, initial process flow diagrams, equipment requirements and initial equipment list. They are also involved in guiding plant layout and calculating operating conditions.

The Group will often lead or assist in various value improving practices such as process simplification, waste minimization, and energy optimization.

As a project proceeds the group will provide ongoing technical guidance, supplying input and answering a wide variety of questions from other members of the project team. The Process Technology engineer is the connection between the Aker Solutions detail engineers and the Client's engineers and/or operators and any licensors.

Process Technology oversees a project from a technical perspective to ensure that the Client performance requirements are met in a timely manner, consistent with the project budget.

For every project involving process responsibility that Aker Solutions undertakes, a process job engineer is assigned to manage the total process design effort. Other process engineers are assigned, as needed, to efficiently meet the needs of the project. Each project is assigned a Process Technology Manager who is responsible to periodically review the technical correctness of the design and to ensure the work is performed in accordance with Client technical objectives.

The duties of the process engineer are much the same for all projects whether for an engineering, procurement and construction job or feasibility study. The primary difference is the degree of detail required and extent to which other disciplines are involved. For all projects, the services of engineers in other disciplines are available.

A process engineer's primary function is to work with the Client to establish the basic design concepts for each project. This effort is documented by preparation of the following:

- Process flow diagrams with plant material balances
- Engineering flow diagrams depicting equipment, piping and instrumentation
- Process Specifications defining sizes, capacities, operating conditions and design requirements for all vessels and mechanical equipment to be supplied
- Process Descriptions to explain the required functioning of various processing systems
- Process Safety Reviews

These documents provide the basis for other engineering sections to prepare the design drawings, specifications and requisitions needed to define a complete project.

The process engineer works on a day-to-day basis with other engineering disciplines involved in such areas as plant layout, instrument and electrical system design, safety hazard evaluation and the design of vessels and mechanical equipment.

The Group makes use of computer-aided methods for designing plant systems. The Aker Solutions computer library contains proprietary programs developed both in-house and by outside sources. Through our telecommunications terminals, Aker Solutions is able to utilize a broad range of process-oriented software packages and customized programming, using the facilities of computer service centers.

Process engineering software includes programs for use in the following general categories:

- Computation of material and energy balances.
- Calculation of physical properties of materials and vapor-liquid equilibrium.
- Analysis of fluid flow systems.
- Heat Transfer

- Equipment Sizing
- Simulation Modeling
- Process Hazard Analysis

CIVIL ENGINEERING (SITE, CONCRETE, STRUCTURAL STEEL, ARCHITECTURAL)

The work of Aker Solutions' Civil Engineering Department encompasses the design engineering of site work, concrete structures, steel structures and industrial architectural building. The types of documents prepared by this department may include specifications, calculations, construction drawings and requisitions.

As process and general arrangements of a project are being developed, geotechnical data is obtained to make necessary decisions for deep or shallow foundations. Climatic conditions and seismic implications are investigated as well as a review of Client standards and all country and local code requirements.

When general arrangements near completion and equipment is defined, sitework and building design will commence. Sitework may include; site preparation, cuts and fill, storm water collection and removal, retention basins, plant roads, parking areas, trackwork, sewage systems and finish grading. Building and equipment foundations and structures including retaining walls, explosion walls, silos, stacks, bins, hoppers, conveyor galleries, frames, crane runways and all structural elements are analyzed and designed to meet all the necessary requirements and standards and effects of vibration, impact and deflection criteria. This work is done with both manual calculations and the use of state-of-the-art software.

Design drawings of office buildings, locker rooms, laboratories, control rooms, restrooms, equipment rooms and some process buildings are prepared by our architects. Our architectural group also investigates the requirements for various systems such as roofing, siding, painting, insulation and sound transmission and attenuation. Studies of personnel traffic flow, means of egress, safety and handicap requirements are included as well as preparation of documents for building permitting when required.

MECHANICAL ENGINEERING

Facility Planning

The Facilities Planning Group is responsible for coordinating all the physical dimensions of the property (plot plans), the process building layout and the equipment arrangement inside the building. The arrangements are developed with consideration given to safety, material flow, construction and maintenance access.

Engineering and Equipment

The Engineering and Equipment Group is responsible for the design, selection and procurement of the process and plant equipment items. Working closely with the process engineer, who determines initial sizing parameters, the engineer will consider the capability of the equipment in the required application, specify the necessary parameters and features and then prepare the requisition for inquiry. After a review of the quotations, a recommendation is presented and the requisition for purchase is issued. As a final step, the vendor drawings are reviewed along with the installation and operation manuals for conformance with the specified requirements. This group also prepares any required equipment lists, spare parts lists, lubrication lists and participates in start-up activities as required.

Vessels

The Vessels Group maintains the responsibility for the complete ASME code design of tanks, columns, high pressure and high temperature containers and reactors. The Vessels Group engineers are also responsible for the preparation of drawings showing overall dimensions, nozzle orientation and fabrication requirements and participate in quality assurance inspection trips to the fabricators' shops. The Vessels Group also has the additional responsibility of selecting heat exchangers and vessel agitators based on the process engineer’s requirements.

Bulk Materials Handling

The Bulk Materials Handling Group is responsible for the design of bulk material handling systems. Based on the nominal process flow-rates, this group designs the system and calculates component sizes required for the desired system performance, (i.e., conveyor's width, speed, horsepower and braking requirements). The Bulk Materials Handling Group also sizes, selects and procures the components needed to meet these design parameters.

Environmental Control

The Environmental Control Group maintains knowledge of process fume collection systems, housekeeping dust collection systems, heating, ventilating and air conditioning (HVAC) systems and noise abatement designs. Using federal and state environmental protection requirements, the facility is designed with the appropriate collection equipment (baghouses, electrostatic precipitators, SCR or SNCR systems or scrubbers) specified and installed to meet these codes. The Environmental Control Group also provides assistance to the Client in obtaining necessary environmental permits for the facility.

In the area of HVAC, the group maintains familiarity with state and local building and energy codes and designs offices, control rooms and employee facilities within applicable guidelines. Assistance is provided to the Client in obtaining the required building permits. Utilizing the group's extensive experience and expertise, ventilation systems are designed to provide a comfortable work environment at a reasonable cost.

Noise in the workplace is a concern for the workers. The need to provide equipment sound attenuation, enclosed quiet rooms or ear protection is determined by the Environmental Control Group. The development of noise maps, based on existing and similar facilities, is the first step in a noise abatement program. A review of the equipment being purchased as well as its relative location to each other and to worker location assignments is made and a preliminary noise map is developed to anticipate areas where special abatement designs must be taken into consideration. During operation a noise survey is made and compared with the design for any final adjustments.

Combustion, Furnaces, Refractory and Ductwork

The design or procurement of process furnaces along with the necessary combustion systems, refractories and large ductwork systems is the responsibility of this group. These engineers have extensive familiarity with high temperature applications such as boiler plant, cokemaking facilities, zinc and aluminum smelting and processing, and all aspects of the primary side of steelmaking, electric furnace shops, ladle metallurgy and caster facilities.

The design of large diameter, thin walled; long span ductwork has been developed and applied successfully by this group's engineers. This ductwork is usually lined and must be able to carry internal dust loads as well as the normal wind, earthquake and snow loads.

PIPING ENGINEERING

The Piping Engineering Department provides experience to a plant design. Detail piping orthographic drawings are developed from general arrangement drawings. Other documents generated during the project include piping related specifications, material requisitions and sub-contract requisitions. Piping isometric drawings, three dimensional drawings, and fabrication details can also be provided, when required.

Piping design and specifications are developed in accordance with the latest versions of ASME, ANSI, ASTM, DIN and NFPA Codes and Standards. Piping flexibility analysis is performed using CAESAR II Stress Analysis software. In-house developed software is utilized in wall thickness calculations, hydraulic calculations and support design.

ELECTRICAL ENGINEERING

Aker Solutions offers our Clients a total design concept in electrical engineering. The Electrical Department has the experience to engineer and design electrical power systems from the public utility supply point to the local control and instrument device level.

Our Electrical Department has the expertise to engineer and design transmission towers, high voltage switchyards, medium and low voltage substations and motor control distribution centers. Capability also exists to work with specific apparatus controllers for AC, DC and variable frequency drives, rectification equipment, uninterruptible power supplies, AC and DC arc furnace control and power systems.

Computer programs are utilized to perform load studies, short circuit studies, flicker analysis and relay coordination analysis. These analyses are performed in order to assure that bus ampacities, transformer sizes and circuit breaker current ratings are properly selected to achieve a safe and efficient installation. Depending on the complexity of the system, additional studies for power factor correction, flicker control, static var compensation, harmonic disturbance and ground mat design, if applicable, will be performed. Proper coordination and design is essential in preventing facility shutdowns due to minor electrical faults.

Designing a high voltage switchyard is a complex and demanding process. Aker Solutions' electrical engineers take into account the electrical, physical and economic aspects as well as the Client's specific requirements. Areas that our electrical engineers consider during the electrical design phase are the public utility parameters, equipment ratings, voltage levels, switching arrangements, protection schemes, surge protection, system monitoring and ground currents. The physical design portion of high voltage switchyards considers the selection of air or gas insulated equipment, space availability, structural configuration, equipment arrangements, transmission line and ground grid design. Aker Solutions' experienced electrical engineers consider all of the above when performing a complete electrical analysis and design.

Consideration is given to the proper separation of loads when designing the medium and low voltage substations. The number of feeders must be consistent with the load location and system availability. Equipment selection, protective schemes and general design are based on safety and economic factors as well as specific Client requirements.

Our electrical engineers base the selection of motor control systems on the analysis of the driven equipment. This analysis determines such factors as speed, torque, brake horsepower, variable loads and physical shock to the equipment. Integrated motor control systems are provided for continuous processing lines to assure proper operation. Non-process systems such as fire protection, lighting and communications are developed in accordance with applicable codes, standards and Client requirements.

The complete electrical design is documented with reports and drawings. Plan drawings of the power, lighting, grounding, control and instrumentation as well as single lines and control diagrams are developed in such a manner as to simplify construction and to provide a clear aid for maintenance and troubleshooting. A complete electrical design is essential in helping to guard against injuries to personnel, equipment damage and costly down time.

INSTRUMENTATION AND PROCESS CONTROL

When designing process plants, the Instrument and Control Systems (I&C) engineers are an integral part of the basic engineering effort. During the initial engineering phase, I&C engineers work closely with the process engineers to ensure that a controllable process is developed.

Field measurement and control devices are carefully specified to assure functionality and reliability. Where purchased equipment or subsystems are involved, I&C engineers work closely with the vendors to assure that the field devices furnished with equipment packages meet the plant standards and that equipment vendor furnished control system components are fully integrated with the overall plant control system.

Aker Solutions has extensive experience designing central control systems using both conventional controls and integrated systems employing PLCs, Distributed Control Systems and computers. For a project involving expansion of existing facilities, the I&C engineers work closely with the Client to either integrate the new control system components with an existing system, or to design a new system to match the standards of control functionality and equipment selection. Central systems are designed not only to insure proper process control, but also to facilitate the plant operation and produce the information needed to manage the entire facility.

Where higher levels of control are involved, such as Level 2 process control, I&C engineers work closely with the systems integrator. This close working relationship ensures that the proper data and commands are exchanged between the control levels and that the total plant control and management system works smoothly.

Integrated systems are fully staged and tested prior to delivery, using field response modeling when appropriate. If higher level control is involved, it is fully integrated into the testing. This effort saves time at start-up by providing an opportunity for debugging the system, and for operator training without having to wait for completion of field installation and commissioning.

The I&C engineers work closely with the construction forces to supervise installation, ring-out, calibration and commissioning of the field equipment and to assist the process and Client engineers with start-up.

Level 2 process control engineers work with Client personnel and process experts to specify the exact calculations for a given production system. The calculations are then integrated into the system's software, operator displays and operating parameters accordingly. Complex models may be employed to simulate the process before control actions are determined. The software is designed so that calculations and models can be altered without shutting down the system.

An effective control system must support the work of the plant operators. Aker Solutions develops systems that complement manual operations and provide the correct information to the operating personnel at the correct time. Reports, video displays and control panels are engineered for ease of use. Control system reports and displays are designed to be modified as the operation changes. Level 2 engineers work closely with I&C engineers to make sure that real-world data is properly communicated to the computer and that the computer's commands and directions are properly sent to and correctly used by, the Level 1 control system. Special care is taken to assure that the total plant functions properly in the real-world, real-time environment of actual process operations.

COMPUTERIZED DESIGN AND DRAFTING

Aker Solutions maintains in-house Computer Aided Engineering (CAE) Systems, including 2 and 3 dimensional application software that permits design/drafting to be performed in an economical and efficient manner. AutoCAD and PDMS software are available to provide design/drafting services for our Clients.

The terminals are distributed through the Engineering Departments and are used to execute design and drawings as follows:

Discipline	**Type of Drawing**
Facilities Planning	Layout and General Arrangement Drawings
Process Technology	Block Flow Diagrams, Process Flow Diagrams, Piping/Instrumentation Diagrams, and Utility Balances
Instrumentation & Control Systems	Logic Diagrams, P&IDs, Loop Diagrams, Ladder Logics, Control Room Arrangements, Installation Details, Block Diagrams, Panel Arrangements and Cabinet Wiring Diagrams
Electrical	Single Lines, Elementary Diagrams, Conduit/Cable Schedules, Equipment Lists, Lighting Diagrams, Grounding and Standards, Physicals, Conduit Routing, Tray Routing
Piping	Utility Flow Diagrams, Standards, Schematics, Aboveground and Underground Systems, Orthographics, Plans and Sections, Bill Of Materials
Civil/Architectural	Concrete Foundations, Structural Drawings, Piling Plans, Soils Boring Locations, Architectural, Drawings, Schedules and Standards
Mechanical	Vessel and Tank Drawings, Conveyor Drawings and Standards, HVAC Drawings and Standards, Refractory Drawings, Details and Standards and HVAC and Dust/Fume Collection System Flow Diagrams and Balances

The capabilities of Aker Solutions engineers are augmented by the availability and usage of a complement of technical computer systems. Process simulations, structural and mechanical designs, piping stress analysis and a myriad of other computations are performed by engineering personnel.Through our telecommunications terminals, Aker Solutions engineers and designers are able to access a broad range of software packages and customized programming and use the facilities of many computer service bureaus.

The combined availability of these resources and access to proprietary and third party programs constitute a major resource for use in the execution of projects.

PROJECT MANAGEMENT AND TURNKEY CAPABILITIES

PROJECT, CONSTRUCTION AND COMMISSIONING MANAGEMENT

In today's competitive environment it is imperative that large capital projects are brought into full-scale production by the fastest, most economical method, such that return on invested capital starts at the earliest time. Our Clients need to bring their facilities on-line quickly, producing a quality product, using new or current technology, meeting the production needs on or before schedule, at or under the budgeted cost. The differences today are locations can be anywhere in the world, product qualities have improved, technologies are changing rapidly, production requirements are higher, schedules are shorter and budgets are decreasing.

All of these factors demand an emphasis on meeting the objectives in a rapidly changing environment due, in part, to the abundance of information and its accessibility through the “information age.”

Project, construction and commissioning management at Aker Solutions is a profession, not a part-time assignment. It is the “binding agent” or catalyst that ensures that the team is focused on project objectives. Technology, schedule and cost risks are managed. With ever-changing factors influencing the execution of projects, teams need to have and be proficient in the use of the best project management systems available. This requires a commitment of resources, people and capital and continuing training and development. It encourages our management personnel to be a “hands-on” team member and contributor, not a reporter. This better enables our managers to provide leadership and direction with an understanding of the impacts on the total project or program.

Through our own Intranet, with tools such as a personnel resource database, we are able to address project needs expediently. Aker Solutions shares people between our various offices worldwide to best suit many project needs. Our purchasing personnel are linked to many other offices worldwide to ensure that the material and equipment delivery needs of projects are met. Aker Solutions is connected to jobsites via the Internet and can transmit digital camera photographs to our engineering personnel. Videoconference facilities are available in our offices.

Aker Solutions managers come from a variety of companies including operating, equipment suppliers, engineering and construction. This is by design not by accident. This variety provides a "cross-pollination" of experience, knowledge and skills; and provides constructability insight, operability logic and know-how during the basic design phases that is second nature.

The final product of the operating facility is the objective of the Aker Solutions team. To meet the challenge of effective project management in attaining this goal, a Project Manager is typically assigned as the Proposal Manager. This ensures that proper project execution strategy is formulated in the earliest phase, in as much detail as possible. Then, if awarded the contract, the Proposal Manager transitions into the role of Project Manager. This encourages early “buy-in” of the team.

For cost effective and timely completion of a project a sound commissioning plan must be established. This effort begins in the engineering phase with the proper planning of engineering packages that supports the orderly and phased turnover of completely tested and operating systems; a turnover that meets with the training and operating needs of the Client.

With these types of qualifications focus on our Clients' objectives is easy. Engineering, procurement, construction and commissioning activities become interwoven in time and attitude into the total project philosophy consistent with our Clients' needs.

PROJECT MANAGEMENT

Project Management at Aker Solutions is a program that provides our Clients with experienced people, proven management systems and professional support capabilities. This program moves engineering and construction projects from planning to full operation through an interrelated series of well-coordinated and economically executed activities. Aker Solutions brings each project a full range of resources in the areas of management, engineering, procurement, construction, commissioning, plant operation and maintenance and coordinates the availability of these services with those of subcontractors to produce an operating facility meeting Client approval.

Aker Solutions resources are extremely flexible and adapt easily to varying situations. Rather than attempting to force projects into rigid organizational channels, we form a project team to function as a specialized module within the framework of the Client's requirements and organization.

The essence of project management is planning and control on a scale which encompasses the total project. The project management team forms the hub of all activities and schedules, directs, monitors and coordinates the flow of information among all participants to maintain unified and effective project execution. This team is also chartered to report on the physical progress of the project, maintain project on schedule and costs within budget and initiate prompt remedial action where and when circumstances warrant.

Aker Solutions utilizes an integrated set of comprehensive systems that comprise the Project Management Systems. These systems assist the project managers in the effective management of projects, particularly complex ones, by providing the information needed to assess the current status of any aspect of the project. The Aker Solutions Systems support the objective of project management -- a successful project completed on time and within budget. To achieve this, three systems address the project requirements from the points of view of cost management, time management and production management.

In all cases, Aker Solutions assigns a Project Manager as the focal point for liaison with the Client during all phases of the project. This will assure that the Client will not need to seek out different managers or groups to resolve problems or to discuss objectives. Moreover, this arrangement assures that all information will be channeled to the proper area of responsibility.

The Project Manager is responsible for the day-to-day management and administration of the project. He guides and leads the members of the task force, constantly monitors costs and maintains scheduled progress by directing and coordinating the activities and efforts of all project participants. Assignment of all personnel to the project team is subject to Project Manager approval. It is the responsibility of the Project Manager to keep Client and Aker Solutions management apprised of project developments at all times on both a formal and informal basis. He has access to the full resources of Aker Solutions for personnel, assistance, consultation and problem solving.

PROJECT MANAGEMENT SYSTEMS

Two things are necessary for the management of projects: skilled managers and systems to help them manage effectively. People manage projects; systems enhance their efforts by providing the tools to formulate cost, time and production plans. Making these plans visible enables Project Management to measure and control performance.

Aker Solutions experience in utilizing project management systems is extensive. The systems have been developed and enhanced over a period of more than 30 years. With the exception of Primavera scheduling software, all of our systems were developed in the Aker Solutions Engineering and Construction group. They consist of optimized and specialized information organization and reporting modules. Depending on the size and complexity of a project, the use of the systems may range from minimal use on small projects to the application of the total systems on major projects.

The same systems are used on all projects, whether cost plus or fixed price. Their use is highly integrated into day-to-day operations, not only within the controls group, but in all line groups: engineering disciplines, procurement and construction.

Aker Solutions Project Management Systems consist of state-of-the-art computer hardware and software and, more important, the techniques for using these tools effectively to manage today's engineering, procurement and construction projects competitively within schedule and budget. At Aker Solutions, systems are an integral part of all phases of project management.

Effective project control starts with the subdivision of the work into manageable pieces with clear assignment of responsibility. To do this, two formal work breakdown structures are used, the Project Structure and the Standard Structures. They are arranged hierarchically where each element may be divided into a number of lower level details, similar to an organization chart.

The Project Structure defines plant areas, project phases and similar project-specific features. The Standard Structure is a framework for costs and classifies project costs into standard categories to facilitate control and also reflect the line organization responsible for controlling these costs.

The work breakdown structures enable the three systems to associate each element of the work with: the cost for performing the work, the time it is scheduled to be performed and the set of production items which is to be produced; engineering documents, purchased components and on-site fabrication and installation of construction items. The final level of detail is the operations necessary to produce each work item.

The structure also permits reports to be focused on the need of each user without unnecessary detail, a consistent theme throughout Aker Solutions Project Management Systems.

Cost Management

At Aker Solutions, the Project Management Team controls projects. Specifically, management and control of project costs are the responsibility of the Project Team under the close direction of a Project Manager. The team, composed of Engineering, Procurement, Construction and the Project Manager assisted by the Planning Engineer and the Cost Engineer, monitor, control and forecast final cost during the life of the project. The Team's mission, as related to cost control, is to forecast in an accurate and timely fasion, any deviations from the plan. This allows alternative courses of action to be developed so that corrective action is taken. It is recognized that the Project Team has the responsibility to ensure successful implementation of the project execution plan. This is accomplished by a cooperative team effort by each participating unit's management and departments.

Project planning is an integral part of any cost system. Planning data, trends and exceptions are reviewed for favorable and unfavorable variances in the cost forecasting process. Working closely with Engineering, Purchasing, Construction and Cost Engineering, the Project Planner is responsible for preparing and reporting against the Project Strategic Plan. In addition, the Planner is responsible to see that the individual Engineering, Procurement, Equipment Delivery and Construction schedules meet the Strategic Plan objectives.

Forecasting of Engineering, Purchasing and Construction support hours is the responsibility of the appropriate Project Engineering, Procurement, Construction and Administration Managers, with review and concurrence of the Project Manager.

Levels of approval, both for total dollar value of an authorization to purchase or approve variances from the budget, have been established for all equipment, bulk materials and subcontracts. Requirements for more meaningful comparisons to the budget on the Quotation Analyses have been established and priced negative lists and minimum cost allowances for each subcontract are required. In addition to the cost evaluation, bulk quantities of material and scope of work is evaluated for its impact on the project.

For monitoring the progress of craft labor (Direct Hire and Subcontractor), a productivity monitoring system is used by Construction. It is the responsibility of the Estimating Department to provide the estimated quantities and units for this system via in-house estimate development or through organization of quantity data received from subcontractors for use at the construction site. Engineering is responsible to forecast the quantities based on their design to completion. Construction is responsible for field auditing and updating the estimated quantities and units during the progress of the project. The Cost

Engineer is responsible for reviewing, at the construction site, these monitoring systems on a monthly basis.

Construction indirects will be forecasted by the Cost Engineer with the assistance of Construction using Manpower Schedules, Rental Equipment Reports and other control documents prepared at the construction site, as well as the latest Construction Schedule.

Restrictions are in place to permit early recognition of quantity underruns and favorable labor trends. Recognition of unfavorable items is taken at the time a final cost to completion is determined. Additional guidelines have been established to ensure consistency in handling escalation, contingency, reserves and allowances, department responsibility, flow of information and recognition of profit or loss.

Procedures for the handling of project changes and project fieldwork modifications are implemented to resolve issues with the Client and recover costs prior to the work being performed. Cost of vendor or subcontractor corrective work is recorded and the charges rebilled and recovered on a current basis.

Formal Project Cost Review sessions are held on a regular basis. Cost reports are normally issued monthly.

Time Management

The key element of the Time Management System is the Critical Path Network Processor. The subsystem assists in the development of an integrated formal plan, a road map for the execution of the project.

The Project Planning Team is led by the Project Planner acting on behalf of the Project Manager and includes the project's Engineering, Procurement and Construction managers. The plan this team produces meets essential project targets and makes effective use of resources.

Most important, because the managers responsible for the work actually develop the plan, the plan is feasible and has their commitment. The Project Planner's role is to represent the Project Manager in the interest of the project as a whole and to act as planning expert, assuring a smooth interface between the team members and the computer tools.

Emphasis is placed on an in-depth review of the critical path network each reporting period. This ensures proactive measures are implemented addressing the most critical activities.

Production Management

The Production Management System is a set of proprietary programs that helps line managers control day-to-day production operations. The key subsystem is the Production Status Subsystem, a unique system that tracks the status of discrete production products: engineering documents, material items and on-site fabrication and erection of construction items. A major function of this subsystem is the objective calculation of performance based on standard operations performed in the production of these items.

The field portion of this system is supported by a network of microcomputers that provide field personnel with a flexible, low cost, personal tool to control their work. This approach to supporting the information needs of the field overcomes the problems traditionally associated with the handling of many small work items. These facilities also communicate summaries of cost and progress to the higher-level systems based in the home office.

The Production Management System is closely coupled with the Cost and Time Management Systems, forming an integrated set of systems that provide managers with consistent data at several levels of detail.

PROCUREMENT SERVICES

The Procurement Department at Aker Solutions is a line organization consisting of purchasing, expediting and traffic personnel under the direction of the purchasing manager. Bolstered by top management support, the department is responsible for the procurement activities on all Aker Solutions projects. This responsibility starts with pre-qualification and continues through the estimating, execution and start-up phases of a project. Such involvement ensures continuity and sufficient time for careful planning of procurement activities. The result is a procurement team, led by a Project Procurement Manager that is intimately familiar with and can be more responsive to the needs of the project. This directly affects Aker Solutions' ability to complete a project on time and within budget.

Our procurement personnel are accustomed to working on projects on which all departments represented on the task force are considered to be of equal importance. A key member of the task force, the Project Procurement Manager (1) organizes and directs all project procurement activities; (2) analyzes special project requirements and develops plans and procedures to ensure compliance; (3) establishes procedures to coordinate procurement activities with those of others on the project team; and (4) has reporting and control responsibilities.

Aker Solutions' Procurement Department has many years of experience in "project buying," and we feel that such an approach has produced benefits for Aker Solutions, which flow automatically to meet Client requirements. First, personnel assigned to a project typically develop a personal interest in the project that tends to produce better overall performance. Our people also become familiar with the project's needs, which promotes efficiency. A single point of contact in purchasing - the Project Procurement Manager - ensures a faster response to questions. Finally, such an organization produces continuity that generates a more uniform approach to procurement activities.

Aker Solutions believes that our approach to project execution enhances the ability of the project team to exert and maintain control, the main ingredient of a successful job.

Aker Solutions has established a Global Procurement Group to utilize international market intelligence to obtain the most competitive pricing on a worldwide basis for the equipment and materials supplied by Aker Solutions.

Globalization and integration of Aker Solutions' systems and strategies are used to bring cost savings to our clients while managing the ever-increasing pace of technological and market change.

CONSTRUCTION MANAGEMENT

Aker Solutions offers an entire range of construction management services for projects including personnel and systems for site development, process facilities, infrastructures and construction facilities.

As part of its construction management program, Aker Solutions provides Clients with capable and experienced managers who have a thorough knowledge of the management systems and procedures to successfully accomplish the following functions:

- Constructability reviews.
- Provide input for the project plan.
- Prepare subcontract bid packages, assist in the prequalification of subcontractors, receive and evaluate quotations, recommend contract awards and control contract documents.
- Develop, coordinate and review schedules for all subcontractors.
- Plan and direct the construction activities.
- Perform resource leveling to improve efficiency and minimize cost.
- Monitor construction progress and assume adherence to requirements for quality construction.
- Provide logistical support and control.
- Establish and maintain a communications network.
- Institute and enforce safety programs.
- Furnish inventory control for equipment and materials.
- Provide interface between construction and the other major project phases of engineering, procurement and commissioning.

Through its many years of providing construction management services to the power generation, chemicals, minerals, metals, steel, coal and many other industries, Aker Solutions has a long list of satisfied Clients.

CONSTRUCTION APPROACH

Although construction is traditionally and naturally considered a field-related activity, Aker Solutions construction personnel begin work as soon as a contract is awarded. The Construction Manager assists the Planning and Scheduling Group in planning the construction activities for the initial schedule and works with the Engineering Group to assure that the plant is constructible and provides needed information during the preparation of the budget estimate to insure the accuracy of the cost data. Once the project begins, the Construction Manager assigns appropriate personnel to the project so that they can become familiar with the scope of work as soon as possible. This practice ensures that the field staff is fully prepared when it moves onto the site.

Once mobilization is underway and construction activities shift entirely to the field, basic construction plans are firmed-up and construction begins.

An onsite staff of superintendents, field engineers, controls engineers and others, plan, control and direct all site activities, as well as relay information back to the home office.

As installation progresses, the field engineering team assembles statistics on the quantities actually installed. The actual quantities installed are measured by a first-hand count of weight/area/cubage/unit/etc. and compared to the scheduled quantities. Any discrepancies observed require action by either altering workforce assignments or adjusting the schedule.

Weekly meetings help point out problem areas early enough for the supervisors to act effectively. The process of measuring, monitoring, and comparing continues through construction and pre-operational testing phases. The site staff receives preparatory information such as design engineering drawings when released for approval, copies of specifications, copies of purchase orders, equipment lists, motor lists, material summaries, monthly progress reports, shipping documents and others. With this information the staff monitors home office progress and advises the Project Manager of variances between the actual and the estimated quantities involved.

The Project Manager in turn judges the affect these variances have on the construction schedule. Field monitoring continues as equipment/material is delivered to ensure that the correct quantities arrive when due, that they are suitable for installation, that they are properly stored and that they are correctly inventoried.

As installation progresses, observations are made, as previously mentioned, to gather data on quantities installed and the progress made. Progress and cost are continually compared against schedule and budget and this vigilance carries the project through to a successful conclusion and a quality operating plant.

COMMISSIONING SERVICES

As part of its Construction Management Services, Aker Solutions can also provide total Commissioning Services that can help to eliminate malfunctions and lost time when a plant goes into operation. In today's economic climate, plant owners and operators cannot afford to lose time and money to bring a plant on stream. A properly commissioned plant immediately begins turning out the product in the expected quantity and quality.

Aker Solutions offers four (4) service programs, Quality Assurance, Pre-operational Testing, Operations Assistance and Maintenance Assistance, to make the transition from construction to production fast, smooth and profitable.

Quality Assurance

Through the Quality Assurance program, Aker Solutions provides impartial third-party observation of equipment manufacture and installation. This program helps to assure the proper quality of equipment and workmanship in the finished project.

Pre-operational Testing

The pre-operational testing program provides precise inspection and testing documentation. All equipment is checked for proper operating specifications and subjected to dry run testing to ensure that all equipment is operational and ready for start-up.

Operations Assistance

Upon completion of the construction phase, Aker Solutions can perform the commissioning of the new project. In the operations assistance program, Aker Solutions supplies a team of technical personnel to augment the Client's supervisory forces during this critical period. The engineers and technicians who comprise this team are experienced in the mechanics of the plant operation. This invaluable assistance complements the operations training program by providing engineers and technicians who work in cooperation with the owner's plant supervisors and reinforce the training effort by providing additional hands-on operational assistance and training during the commissioning period.

The team can help to interpret data and, based upon this data, assist the owner's operators in fine-tuning the plant process. The team's expertise can assist in making the correct decisions, thus ensuring optimum operating performance and bolstering personnel confidence.

The Aker Solutions team can assist in operations around the clock, seven days a week and, upon agreement, can perform these services for as long as required.

Maintenance Assistance

Maintenance Assistance is a complementary program to the maintenance-training program that is conducted during plant construction. This assistance can be provided during the plant start-up period. Aker Solutions can make available personnel experienced in the Client's equipment maintenance, the same people, in most cases, which have been involved in pre-operational testing and maintenance planning for the plant equipment. The maintenance assistance team works with the Client's maintenance supervisors during the critical start-up period. Pumps, motors, fans, turbines and compressors - and all other critical equipment - may be irreparably damaged or may cause the loss of a process due to an improper maintenance procedure or failure to isolate a faulty component. The Aker Solutions team assists the Client's maintenance supervisors and gives an extra degree of expertise that is critical during start-up.

As with the operations assistance program, Aker Solutions, upon agreement, can make the maintenance assistance team available to the Client for as long a period as desired.

HEALTH, SAFETY & ENVIRONMENT MINDSET

Health, Safety and Environment (HSE) is a core value in Aker Solutions. This means that we take a personal responsibility for HSE because we care about people, the environment and our company. Aker Solutions has established within our HSE policy that accidents are unacceptable. It is our policy to provide safe places of employment and to establish sound operating practices which results in safe working conditions and efficiency of operations.

Other elements of HSE include a common HSE operating system and standards, mandatory HSE training, shifting the focus for measurements and incentives from lagging to leading indicators, and improving the mechanisms for best practice sharing and learning across the company. Aker Solutions' HSE policy is integrated throughout all stages of a project, all levels of the organization and all engineering disciplines.

As an organization, it is vital for Aker Solutions to work systematically to ensure continual improvement in our HSE culture and performance. Aker Solutions conducts operations through efficient use of materials and energy, with minimum waste and damage to the environment. We design products and services to have no undue environmental impact, to be safe and to be efficient in consuming energy and natural resources.

Aker Solutions also recognizes that accident prevention is an operating responsibility and has adopted the philosophy that safe operations demand the same direction and control as is given other methods of successful management. Line management is held directly responsible for providing leadership and continuing efforts toward accident prevention. A proactive rather than reactive management approach, regular visits and meetings portrays that HSE excellence is the only acceptable outcome.

Safety Program

Aker Solutions assures safe operations on our projects by administration of a safety program that is committed to at the highest levels of management. Because each project has unique hazards that must be dealt with, a viable safety program must be tailored and coordinated to the specific requirements of each project. Aker Solutions' "core" program, however, always includes the following minimal requirements:

- Employee safety indoctrination
- Immediate accident investigation
- Daily jobsite inspections
- Monthly comprehensive jobsite inspections
- Weekly craft safety meetings
- Weekly staff safety meetings
- Management-labor safety committee
- Monthly safety committee inspections
- Monthly safety committee meetings
- All supervisory personnel and key craftsmen receive formal first-aid training

All of the above requirements must be documented to facilitate periodic audits by an Aker Solutions Safety Manager.

Perhaps the most important aspect of a safety program on a given project is coordinating Aker Solutions' "core" program with the Client's existing plant program.

Coordination in the following areas is critical and is discussed before work begins:

- Lockout programs
- General safety rules
- Plant emergency and warning signals
- Fire protection and fire brigade procedures
- Personal protective equipment requirements
- Known noise exposure areas
- Hot work procedures
- Hazardous chemical data
- Confined space entry
- Other areas, as appropriate

If subcontractors are required for a project, Aker Solutions will always pre-qualify subcontractors, even those we have regularly collaborated with on projects. Only subcontractors who are capable of working to the high safety standards that Aker Solutions and the Client require are employed on site. We require subcontractors to give health and safety the highest priority. Subcontractors must be responsive to the pro-active efforts Aker Solutions makes to control and coordinate their activities in the interest of high levels of safety performance on the site.

All of the above areas are essential to protecting Client/Aker Solutions personnel and are a part of the specific site program. These areas have all contributed to Aker Solutions' excellent safety program. Aker Solutions safety procedures have historically produced site safety programs with results better than the national averages in the industry.

QUALITY ASSURANCE

Aker Solutions operates under a three tier Quality Management System.

Tier 1 – Business Manual

- Defines the policy adopted by the company and the basic quality program.

Tier 2 – General Procedures Manual

- Defines general method of operation interfacing all division disciplines and delegates responsibility for addressing the requirements of the Quality Policy Manual.

Tier 3 – Engineering and Construction Division Work Instruction Manual

- Provides detailed work instructions to be followed by company personnel in day-to-day activities.
- Provides information to be used on projects such as engineering specifications, standards, quality plans, etc.

Aker Solutions provides Clients with a single point of contact within our organization for all project needs. This single line management interface, typically between the Client's Project Manager and the Aker Solutions Project Manager, will allow for maximum efficiency in the overall management and communication of the project team. With the exception of interface required during project review meetings, typically all interaction between the two companies will be very streamlined through project management, with some necessary exceptions. Our project execution organization is also structured such that the management of the Client and Aker Solutions have the opportunity to interface on critical project/business concerns that cannot effectively be addressed on the project management level.

Client projects are sometimes staffed and resourced from our pool of talented, qualified team members. This sharing of resources is our normal mode of operation and has proven to be successful in terms of overall execution quality and reduced cost. As larger projects progress toward the detailed design stage, Aker Solutions has the ability to leverage our low cost engineering center in India to deliver a highly beneficial cost advantage to our clients. This method of workshare is not new to our team members and is routinely utilized. Essentially it allows for around-the-clock productivity at a lower cost.

Front End Engineering

The first phase of the Coal to Nitrogen Project will include sufficient engineering to develop a definitive capital cost estimate. The engineering effort is often refered to as Front End Loading or Front End Engineering. The approach minimizes cost overuns and schedule delays during the project execution phase. The cost overuns and delays are typically due to poor definition of the scope of work and performance objectives.

Organization

Aker Solutions assembles a team for each project. For a front end engineering effort, an engineering manager would be named who has primary responsibilities for interfacing with the client and assuring that satisfactory project documents are delivered on time and at or below budget.

Engineers from process technology, mechanical, civil, instrumentation, electrical, and estimating disciplines would be assigned. As documents and drawings are developed, they would be reviewed and checked internally by discipline department heads. The documents are sent out for client review. The client's comments are returned to the discipline engineer and revisions are made. Periodic meetings are scheduled as required to help meet the project objectives for quality, schedule, and budget. The final documents are issued for design in a front end engineering package.

1.0 Kickoff

A kickoff meeting is scheduled with the client to review project scope/objectives and plan the project. Some detailed information may be exchanged and plans are made to gather additional information at the plant site if necessary.

2.0 Project Scope and Design Basis

The Engineering Manager will develop a project procedure document that outline the organization chart and protocols for making contacts between companies. The scope of the project will also be documented. The various disciplines will be requested to develop a list of their tasks and documents and assign manhours and expected completion dates.

The Process Engineer will develop a process design basis that will outline the process deliverables, functional requirements for each system or operation in the process, process and engineering data, and health, safety and environmental requirements.

Once the project procedure and process design basis are issued, the individual disciplines will issue their respective design bases that describe what documents they will develop, specific project requirements, and a listing of codes or standards to be followed.

3.0 Process Flow Diagram/Heat and Material Balance/Equipment List

The process flow diagrams(PFD) will be drafted and issued for review. Following approval, the heat and material balance will be performed and the results incorporated on a chart on the PFD's. An equipment list is started as the PFD's are developed. The list is updated and issued periodically as information is developed.

4.0 Plant General Arrangements

The Mechanical department will begin a plot plan and selected elevations to describe the overall facility space and building requirements. This work begins as soon as an the PFD's and equipment list are released. The general arrangements are also updated as new information or requirements are identified from the process engineer, client or vendors.

5.0 Process Work

Once the process design basis, plant general arrangements, PFD's and equipment list have been approved by the client, work can begin on the piping and instrumentation diagrams (P&ID's) and the process datasheets. The process engineer will initiate the P&ID's and process datasheets and then send them to piping, instruments, and the mechanical group for their comments. An internal meeting is typically held to coordinate all comments on complex systems. Revisions are made and these documents are issued for approval. A meeting may be scheduled with the client at this time to review the P&ID's and datasheets.

The process engineer will develop utility balance diagrams or tables that show each user and its flow, pressure and temperature requirements.

An initial process safety review meeting may be called at this time to identify specific process hazards and to give guidance to downstream design and procurement activities.

A description may also be initiated at this time to provide guidance to the instrumentation and control design effort.

6.0 Mechanical Equipment and Vessels

Requisitions will be developed for mechanical equipment and vessels to solicit quotations for major items. The requisitions may include the process datasheets, mechanical specifications or vessel drawings as required. The requisitions will be sent to qualified suppliers to request bids.

The quotations will be reviewed and bid tabulation made to compare the technical and commercial details. The recommendation of the mechanical engineer will be approved by the project manager and the designated technical manager.

7.0 Instrument Index, datasheets, control system configuration

An instrument index can be developed after the P&ID's are issued. The instrument engineer will then begin developing datasheet for field instruments. Preliminary sizing of control and relief valves is part of this effort.

A configuration diagram will be developed to present an overview of the control system.

A functional specification may also be developed to describe the control system requirements.

8.0 Piping

The issue of the P&ID's allows the piping group to initiate a piping specification that describes the type of piping, fittings and valves to be used for each service. A line index is also prepared. Piping will also develop routing diagrams for utility systems like cooling water, steam, and instrument air based on the general arrangements and the utility balance information. Piping will initially size the utility header lines. The process engineer will check the line sizing effort.

9.0 Electrical

A motor list will be developed when the equipment list is issued. The equipment list typically shows the connected horsepower. A single line diagram showing the distribution of power to the various substations and users will be developed. The motor list will be updated to include major electrical equipment.

10.0 Civil

The civil engineer will review the general arrangements and project data to determine building, site preparation and foundation requirements. Requirements will be incorporated into a specification format and added to the scope of work.

11.0 Estimating

The estimating group will the develop the plant cost and determine a strategy for pricing. Equipment pricing may be solicited from vendors or taken from in-house pricing. Bulk quantities will be estimated from takeoffs. Additional sizing and sketches will be developed as required to support the takeoff effort. Subcontract pricing for various disciplines will be obtained if required by the level of estimating accuracy.

After estimating the engineering and craft labor requirements and receiving delivery time for major equipment, a construction schedule will be developed and revised as needed to meet the project objectives.

A total cost and schedule will be issue after an internal management risk review.

If the total cost and schedule does meet the project objectives, a value management team may be assigned to review the design documents and cost estimate. The recommendations of the value management team are reviewed by the client's management. Those recommendations that are accepted are incorporated into the front end design and cost estimate.

12.0 Final Report

A final report will be assembled and delivered to the client once all the tasks have been completed and the client has approved the individual documents.

Exhibit 9 HyMelt Sampling & Monitoring (5 pages)

Aker Solutions

SPECIFICATION

A0757603 Contract No.

R002S Specification No.

1 of 5 Page

SUBJECT: HyMelt® Module Sampling and Monitoring

CLIENT: American Freedom Fuels and Chemicals LLC

FACILITY: Coal to Nitrogen Products

LOCATION: Later

DISCIPLINE: Process Technology

ORIGINATOR: M.J.Friedrich

REVISION	A							
DATE OF ISSUE dd MMM yy	18 JUN 08							
TYPE OF ISSUE	R = Review	A = Approval		D = Design		C = Construction		V = Void
	R							
APPROVALS:								
Discipline Leader								
Discipline Manager	MJF							
QC Engineer								
Project / Engineering Manager	PFA							
Client (If Required)								
Other								

<u>REFERENCES</u>:

1.0 Coal, lime, steam and oxygen will be fed to the HyMelt® Module to produce a raw gas that will be processed to produce a pure hydrogen stream. The operating objectives will be to produce the gas efficiently and reliably. The gas will be cooled to 400° F and the particulate loading will be reduced to 5 mg/Nm^3. A number of process variables will be monitored and adjusted during operations. Certain process media will be sampled and analyzed periodically.

2.0 Monitored Process Variables – HyMelt® Module

Equipment or System	**Monitored Variable**	**Frequency**	**Typical**	**Comment**
Coal/Lime Injection	N2 Pressure	Hourly	700 psig	
	N2 Flow	Hourly		
	Coal/Lime Mass Flow	Hourly		
	Injector Pressure	Hourly	700 psig	
ReactorTuyere	O2 Mass Flow	Hourly		
	O2 Pressure	Hourly	700 psig	
	Steam Mass Flow	Hourly		
	Steam Pressure	Hourly	700 psig	
Reactor	Metal Level	Shift	52”	External Probe
	Reactor Pressure	Hourly	500 psig	
	Metal Temperature	Shift	2750° F	External Probe
	Reactor Shell Temperature	Hourly	400 ° F	Pyrometer
Scrap Addition	Scrap Addition Weight	Hourly		
	Lockhopper Pressure	Hourly	0 to 500 psig	Depends on cycle
Slag Separator	Gas Temperature	Hourly	2650 ° F	
Slag Granulator/Gas Quench	Gas Outlet Temperature	Hourly	400° F	
	Water Wall Flowrate	Hourly		
	Spray water flowrate	Hourly		
	Spray water temperature	Hourly	275 to 350 F	

Equipment or System	Monitored Variable	Frequency	Typical	Comment
	Water Level	Hourly		
	Nitrogen Flowrate	Hourly		
	Blowdown Flowrate	Hourly		
	Internal Gas Openings	Daily		Visual through site port. Checking for slag buildup.
Oxyfuel Burner @ Slag Separator	Fuel Gas Flow	Hourly		
	Oxygen Flow	Hourly		
	Control temperature	Hourly	3000° F	
Slag LockHopper	Level	Hourly		
	Pressure	Hourly		
Venturi Scrubber	Water Level	Hourly		
	Gas Pressure Drop	Hourly	65 inches WC	Objective is 5 mg/Nm3 particulate
	Blowdown Flowrate	Hourly		
	Gas Outlet Hydrogen, Carbon Monoxide and Carbon Dioxide Concentration	Hourly	2% CO2	
	Gas Mass Flowrate	Hourly		
	Gas Outlet Temperature	Hourly	400 F	
	Water concentration in the gas	Hourly	50% by volume	Water Gas Shift requires 1 to 1 molar ratio, Dry Gas to Water
	Gas Outlet Pressure	Hourly	482 psig	
Emergency Quench	Water Level	Hourly		
	Gas Temperature	Hourly	Below 600 F	

2.1 Instrumentation to monitor the variables will be specified during the Front End Engineering phase. Instrumentation will include thermocouples, pressure transmitters, flowmeters and analyzers. The control system, as well as the strategy for controlling the process, setting alarms and storing and reducing data will be identified.

3.0 Process Media Sample and Analyses

Equipment or System	Media Sample	Frequency	Analysis	Comment
Coal/Lime Injection	Coal/Lime	Shift	Particle size	80% less than 200 mesh
			Moisture	1 to2 %
Scrap Lock Hopper	Scrap Steel	At Receipt	Particle size	2 "x ¼"
			Moisture	1 to 2%
			Element Analysis	
Reactor	Oxygen	Weekly	Oxygen concentration	
	Molten Metal	Shift	Carbon	
			Sulfur	
		Daily	Compound Analysis	
	Slag	Daily	Compound Analysis	Determine Basicity, Sulfur & Iron content. Al2O3, SiO2, CaO
Slag Granulator/Gas Quencher	Circulating Water	Shift	pH	6 to 9
			TSS	
		Daily	TDS	
			Chlorides	
			Sulfides	
			Total Organics	
			Hardness	
			Ammonia	
Slag Granulator	Slag	Daily	Compound Analysis	Determine Basicity, Sulfur & Iron content. Al2O3, SiO2, CaO
Venturi Scrubber	Circulation Water	Shift	pH	6 to 9 desired
			TSS	
		Daily	TDS	
			Chlorides	
			Sulfides	
			Total Organics	
			Hardness	
			Ammonia	

Equipment or System	Media Sample	Frequency	Analysis	Comment
	Gas Outlet	Dailey	Solids content	
Clarifier	Filter Cake	Daily	Solids composition	Compounds and elemental
			Moisture	
		Weekly	Particle size distribution	

3.1 The Coal to Nitrogen Products Plant will have a laboratory to analyze the metal and slag. Typically, carbon and sulfur in iron can be determined quickly using an infrared spectrographic analyzer. Slag compounds can be identified using X-ray diffraction.

3.2 The laboratory will also analyze water chemistry using commercially available machines for characteristics such as pH, conductivity, and organics. Other analyses will be run using wet chemistry methods to determine TSS, TDS, hardness, etc. The laboratory equipment will be identified during Phase 1.

4.0 Operating Manual

4.1 A general operating manual will be developed that will guide the operator with regards to monitoring and sampling. The plant manager will need to develop practices that specify the division of work among the supervision, operating, maintenance and laboratory personnel.

Exhibit 10 Commercial and Technical Risk Analysis by Aker (8 pages)

American Freedom Fuels and Chemicals LLC
Coal to Nitrogen Products Plant
Commercial Risk Assessment

Item No.	Description	Issue/Comment	Potential Consequence	Recommendation
1.0	General	Definitive capital cost higher than expected	Project delay Return on investment reduced	FEL 3 Value Engineering
1.1	Labor	Resources not available	Project delay Additional costs	Analyze labor market, constructability study, FEL 3
1.2	Taxes, insurance and other fees	Uncertain	Additional costs	Estimated, FEL 3
1.3	Freight	Uncertain	Additional costs	Estimated, FEL 3
1.4	Subcontract Claims	Uncertain	Additional costs	Contingency
1.5	Licensing Fees	Uncertain	Additional costs	Estimated, FEL 3
1.6	Escalation on materials	Inflation uncertain	Additional costs	Estimated,
2.0	PSA	PSA long delivery , limited suppliers	Schedule delay, higher costs	Detail schedule analysis. Purchase early
3.0	HyMelt® Reactor	Long startup, unexpected process failures, shorter life cycle	Plant not able to achieve production goals. Cash flow reduced.	Proven gasifier installed in parallel. Prepare HyMelt startup plan that includes development testing. Integrate with HyMelt module design and any analysis. Allow adequate funding for a possible testing while conventional unit is operating.
4.0	Ammonia Plant	Overall system performance guarantee may not be available. Used equipment	Schedule delays due to unknowns in equipment condition. Plant must be disassembled, refurbished, shipped and rebuilt	Detail schedule analysis. Purchase early
5.0	Air Separation	Long delivery	Schedule delays	Start negotiations with ASU

Item No.	Description	Issue/Comment	Potential Consequence	Recommendation
	Plant			supplier early
5.1	Oxygen Compression	Compressor – long delivery item, limited supplier	Schedule delay, higher costs	Purchase early.
5.2	Nitrogen Compression	Compressor – long delivery item, limited supplier	Schedule delay, higher costs	Purchase early.
6.0	HyMelt Plant	Long Equipment design and delivery	Schedule delay	Detail schedule analysis. Purchase early
7.0	Acid Gas Removal – Selexol	UOP resources limited. Design delay Heat exchangers are long delivery	Schedule delay	Detail schedule analysis. Purchase early
8.0	Wastewater Treatment	Environmental requirements and permitting unknown	Schedule delay	Start design and permitting application ASAP.
8.1	Flare	Environmental requirements and permitting unknown	Environmental requirements and permitting unknown	Start design and permitting application ASAP.
8.2	Stormwater Pond	Environmental requirements and permitting unknown	Environmental requirements and permitting unknown	Start design and permitting application ASAP.
8.3	Emergency Power	Generators can be long delivery	Schedule delay	Finalize Design, FEL 3
9.0	Site preparation	Site specifics unknown	Schedule delay	Prioritize gathering site info.
9.1	Infrastructure	Infrastructure specifics unknown	Schedule delay	Prioritize gathering infrastructure info.

American Freedom Fuels and Chemicals LLC
Coal to Nitrogen Products Plant
Technical Risk Assessment

Item	Description	Issue/Comment	Potential Consequence	Recommendation
1.0	Raw Material Preparation			
1.1	Material Receiving & Storage	Truck traffic May be restricted due to local regulations or weather. Fugitive particulate	Loss of HyMelt gas production	1 day storage bin included in design. Facility designed for daylight receipt of coal. Dust collection included.
1.2	Coal Grinding & Drying	Reliability, combustible dust results in fire. Uncertainty in particle size requirement for tuyere.	Loss HyMelt gas production, loss of equipment. Additional screening equipment may be required.	Plant will be designed to use inert gas environment. Equipment is highly reliable. Prevent. maintenance and spare parts recommended. Recommendation from Impact Technology on particle size.
1.3	Biomass Preparation	Not defined, limited commercial experience with high pressure pneumatic injection	Plugging of lines, equipment failure.	Identify commercial gasifier technology supplier with biomass experience and know-how. Test biomass preparation equipment before committing to purchase. Development plan required to use biomass for HyMelt.
2.0	Gasification Plant	Not defined	On-line time is less than expected.	Identify commercial gasifier technology supplier with high reliability experience.
3.0	HyMelt Plant			
3.1	Reactor Injection System	Single supplier for high pressure injection. Not demonstrated commercially at the required pressure. Recycle Fines may be difficult to handle.	Failure results in loss of production or operation at lower pressure and lower throughput. Fines may not be recycled. Additional	Clyde Material Handling expects to have commercial application at high pressure installed soon. Clyde plans to mix fines with lime before injection.

Item	Description	Issue/Comment	Potential Consequence	Recommendation
			makeup steel costs.	
3.2	HyMelt Reactor	Failure of refractory lining or shell. Fire	Loss of HyMelt gas production. Equipment loss and/or personnel injury.	Working with experienced refractory supplier for iron & steel. Shell will be designed and tested to ASME code. Temperature will be monitored on shell for hot spots and give early warning of breakout. Brick lined protection wall included.
3.3	Tuyere	Tuyere plugs Life of tuyere requires periodic tapping of bath and removal of bottom.	Loss of HyMelt gas production. Reduces availability. Molten slag or iron creates fume, heat.	Backup gas designed to keep tuyere open. Impact technology to recommend design based on experience and analysis. First plant will have proven gasifier technology. Second plant will have standby HyMelt reactor. System designed to collect fume and protect structure personnel and equipment.
3.4	Slag Removal and Granulation	Slag granulation is first of kind application due to high pressure. Slag may freeze. Sudden surge in slag or metal may cause explosion when it contacts water. Slag and metal may not separate adequately.	Loss of equipment, personnel injury, Loss of HyMelt gas production. Carryover of metal requires more makeup Slag freezes in transfer line and plugs.	Test the design of the slag system using analytical tools such as CFD or other calculations. Process safety review. EnviRes has commissioned University to predict slag properties. A slag/metal separation trough will be specified before granulation. Slag and gas will flow through same line to keep slag molten.
3.5	Particulate Removal	Particle size and loading uncertain. Venturi may not perform as well.	Excessive particulate from reactor could overload Venturi	Variable pressure drop venturi scrubber can be specified to adjust performance.

Item	Description	Issue/Comment	Potential Consequence	Recommendation
			system and have a negative economic impact. Excessive carryover from Venturi scrubber would shorten life cycle of water gas shift catalyst.	
3.6	HCl Removal /Venturi Scrubber	Inadequate removal of HCL. Amount of HCL in the gas is not known for certain.	Corrosion of downstream equipment. Reduced life for water gas shift catalyst. Excessive Blowdown for venture circuit	Caustic soda should be added to venturi scrubbing circuit to keep pH neutral. Simulated coal gasification tests recommended to determine offgas contaminants.
4.0	Air Separation Plant	Reliability	Loss of production	Plant size is within range of most ASU plants.
4.1	Oxygen Compression	Failure of high pressure pumps or compressors	Loss of HyMelt gas production	Redundancy or availability should be specified for the ASU supplier
4.2	Nitrogen Compression	Failure of high pressure pumps or compressors	Loss of ammonia production.	Redundancy or availability should be specified for the ASU supplier
5.0	Water Gas Shift	Startup heater may need to heat gas to a higher temperature.	Reaction does not achieve conversion rate.	Startup heater may be natural gas fired instead of steam. Catalyst vendor will review.
5.1	Reactors	Carbon monoxide conversion is too low.	Reduces ammonia production.	Three-stage system included to maximize conversion. Catalyst vendor needs to review final design.
5.2	Interstage Quench	Water droplets from quench may spall catalyst.	Catalyst life reduced/more maint.	Plan to utilizeTurbosonics for quench system design.

Item	Description	Issue/Comment	Potential Consequence	Recommendation
5.3	Condensate Treatment	Stripper process design uncertain.	Stripper underdesigned, water quality not met.	Process design to be reviewed by experts.
6.0	Acid Gas Removal & Sulfur Recovery			
6.1	Mercury Removal	Mercury content in raw gas is uncertain	Mercury not removed. Environmental regulations not met.	Activated carbon column specified. Unit will be overdesigned.
6.2	Acid Gas Removal – Selexol	Materials of construction uncertain. Contaminants in product gas	Corrosion potential Potential fouling of PSA	UOP requested to provide recommendation. UOP Selexol process specified. It has strong record in similar applications.
6.3	Claus Sulfur Recovery	Tail gas from Claus Plant can cause environmental problem. Fugitive vents contain H2S.	Environmental authority may fine or require shutdown.	Supply system that will condition tail gas so that it can be recycled into the process. A fugitive vent collection system for the pit will be installed.
7.0	PSA			
7.1	PSA	Offgas may foul adsorbent.	Loss of feedstock to ammonia plant	Design and operate upstream units to meet PSA spec.
8.0	Ammonia Plant	Used equipment failure	Loss of production	Used equipment will be inspected

Item	Description	Issue/Comment	Potential Consequence	Recommendation
				and refurbished as required
8.1	Ammonia Storage and Flare	Potential release	Requires evacuation of area	Flare system included to destroy ammonia fumes. Process safety reviews included.
9.0	UAN Plant	Proven Technology		Require performance warranty from technology supplier
10.0	Utilities			
10.1	Cooling Tower	Capacity may be over or underdesigned	Underdesign leads to lower performance and less production or quality	Final process design required before cooling tower capacity can be finalized.
10.2	Steam System	Capacity may be over or underdesigned	Underdesign leads to lower performance and less production or quality	Final process design required before steam system capacity can be finalized.
10.3	Wastewater Treatment	Final discharge requirements are not known. Raw wastewater flow and composition are uncertain	Authorities will issue fines or reduce operating throughput. May add capital or operating cost.	Finalize overall material balance and effluent permit application. Current design assumes discharge to POTW with some pretreatment included. Monitoring of initial wastewater composition recommended.
10.4	Firewater/Service Water	Firewater/service water requirements uncertain	Additional capital costs	Final design will include review of regulations and consultation with expert.
10.5	Instrument & Plant Air	IA & PA requirements uncertain	Additional capital costs	Final design will include listing all users and estimating requirements
10.5	Flare	Flare size and header size uncertain	Additional capital costs	Final design will include listing all sources and estimating requirements.
10.6	Stormwater Pond	Drainage and pond size uncertain	Additional capital costs	Final design will include stormwater drainage analysis and

Item	**Description**	**Issue/Comment**	**Potential Consequence**	**Recommendation**
				pond sizing
10.7	Emergency Power	Emergency Power requirements uncertain	Additional capital costs	Final design will include listing all users and estimating requirements.
11.0	Site preparation	Site preparation requirements uncertain	Additional capital costs	Included fill to bring area above flood plain, relocated railroad. Final design will include site survey and investigation.
12.0	Infrastructure	Sizing of and number of buildings and roads uncertain. High voltage requirements uncertain.	Additional capital costs	Final design will include review of building and road requirements.

Exhibit 11 FactSage Simulation Results (1 page)

FactSage Results on HyMelt at 30 Ata with Al2O3 9-28-07

Gas Phase				
	Vol%	%/%CO	ppmv	ppbv
CO	67.44			
H2	30.02			
N2	0.81			
H2O	0.76	0.0113		
CO2	0.47	0.0069		
H2S	0.39		3,878	
COS	0.30	0.0045	3,037	
CH4	0.06	0.0008	571	
HCN	0.01	0.0001	70	
K	0.00		46	
HS	0.00		44	
H	0.00		28	
NH3	0.00		14	
KOH	0.00		8	
Na	0.00		8	
KCN	0.00		5	
CS2	0.00		5	5,010
H2CO	0.00		4	4,400
S2	0.00		4	3,800
C2H2	0.00		3	3,390
CS	0.00		2	2,040
CH3	0.00		1	1,330
C2H4	0.00		1	779
NaCN	0.00		1	740
H2S2	0.00		1	585
Fe	0.00		1	527
KH	0.00		0	443
HCO	0.00		0	353
NaOH	0.00		0	343
S	0.00		0	212
HNCO	0.00		0	192
NaH	0.00		0	148
CH2CO	0.00		0	104
OH	0.00		0	45
Fe(OH)2	0.00		0	40
SO	0.00		0	38
FeS	0.00		0	29
SiO	0.00		0	21
SiS	0.00		0	16
Mg	0.00		-	-
Total	100.27			

liters 1078.10

Grams of H2S= 190.3790
Grams of COS= 149.0926
Grams of S= 258.6963

Metal Phase			
	Wt%	ppmw	ppbw
Fe	90.030		
S	7.496		
C	2.136		
O	0.313	3,130	
N	0.012	116	
H	0.005	45	
Si	0.000	3	
CaO	0.000	0	175
AlO	0.000	0	93
Al	0.000	0	80
MgO	0.000	0	28
Total	99.991		

Major Slag Phase				
	Major Phase	Minor Phase	Combined	
	Wt%	Wt%	Wt%	ppmw
CaO	42.28	-	41.98	
SiO2	28.93	-	28.72	
Al2O3	16.00	-	15.89	
CaS	9.36	-	9.29	
FeO	0.80	-	0.79	
K2O	0.78	-	0.77	
MgO	0.68	-	0.68	
Na2O	0.56	-	0.55	
Ti	-	66.46	0.48	
FeS	0.17	-	0.17	
MgS	0.16	-	0.16	
K2S	0.16	-	0.16	
Na2S	0.12	-	0.12	1,201
S	-	16.68	0.12	1,194
N	-	13.58	0.10	972
C	-	3.27	0.02	234
Fe2O3	0.00	-	0.00	8
	100.00	99.99	100.00	
Grams	16,499	119	16,618	

Grams of S= 726.45

Coal Feed to HyMelt	
Elements (dry)	
Carbon	72.64%
Hydrogen	5.38%
Nitrogen	1.65%
Chlorine	0.00%
Sulfur	1.96%
Oxygen	9.57%
Ash	8.80%
	100.00%
Ash Analysis	
SiO_2	54.00%
Al_2O_3	30.00%
TiO_2	1.50%
CaO	2.00%
K_2O	2.00%
MgO	1.00%
Na_2O	1.25%
Fe_2O_3	7.85%
P_2O_5	0.00%
SO_3	0.00%
Cu, Cr, Ni, Mg	0.40%
Total	100.00%

Exhibit 12 HyMelt Tuyere and Reactor Design Calculations (3 pages)

In general, the single-tuyere design developed by Impact is very similar to the baseline Aker Kvaerner design, with the exception of the shell diameter, which is larger for the Impact design as a result of Impact's assumption of 24 inches of refractory instead of 18 inches used in the Aker Kvaerner design.

Figure 1 provides cross-sections of estimated plumes and reactor inside surfaces at the nominal metal bath height for single- and three-tuyere reactors. In the case of the three-tuyere reactor, the plumes are spaced so that they impact neither each other nor the reactor wall, as mentioned previously.

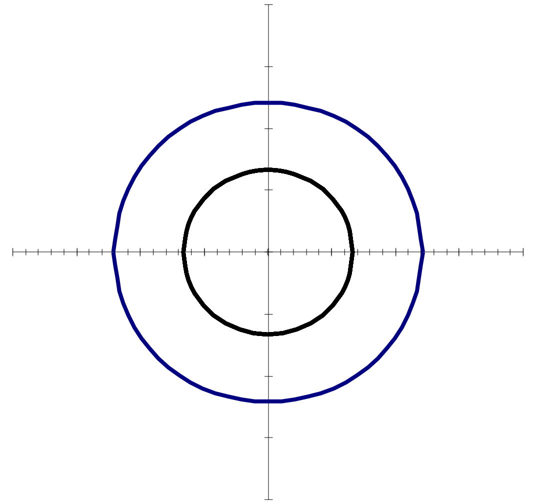
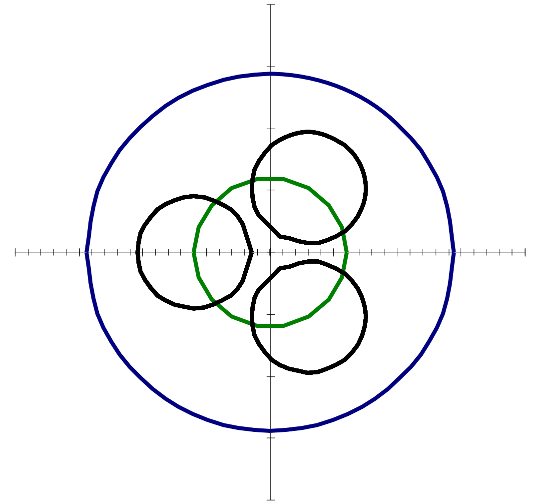
Cross-Section of Single-Tuyere Plume and Reactor	Cross-Section of Three-Tuyere Plume and Reactor
	

Figure 1 Estimated cross section of plume(s) and reactor inside diameter at the nominal metal bath surface. Legend: blue curve represents internal reactor surface, black curves represent plume boundaries, and green curve represents tuyere-center circle.

Estimated Optimum Number of Tuyeres

The Impact reactor design model includes a cost estimation routine. This routine is useful for optimizing the number of tuyeres. Figure 2 contains a plot of relative capital cost versus number of tuyeres. The relative capital cost includes terms for the shell, supports, refractory, tuyeres, and basic instrumentation.

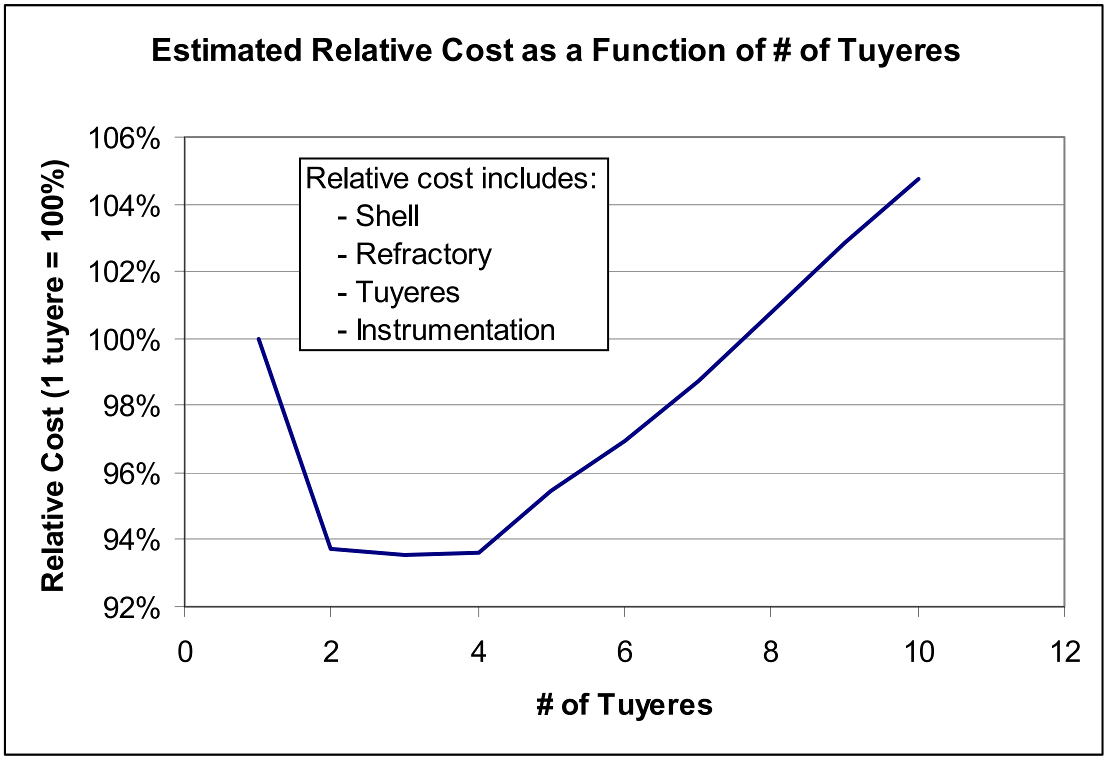


Figure 2 Estimated relative capital cost of reactor as a function of number of tuyeres.

The minimum predicted capital cost occurs when 4 tuyeres are used, although there is little cost difference from two to four tuyeres. From the standpoint of minimizing transverse sloshing waves in the reactor, three tuyeres is preferable to two tuyeres, so three or four tuyeres is recommended.

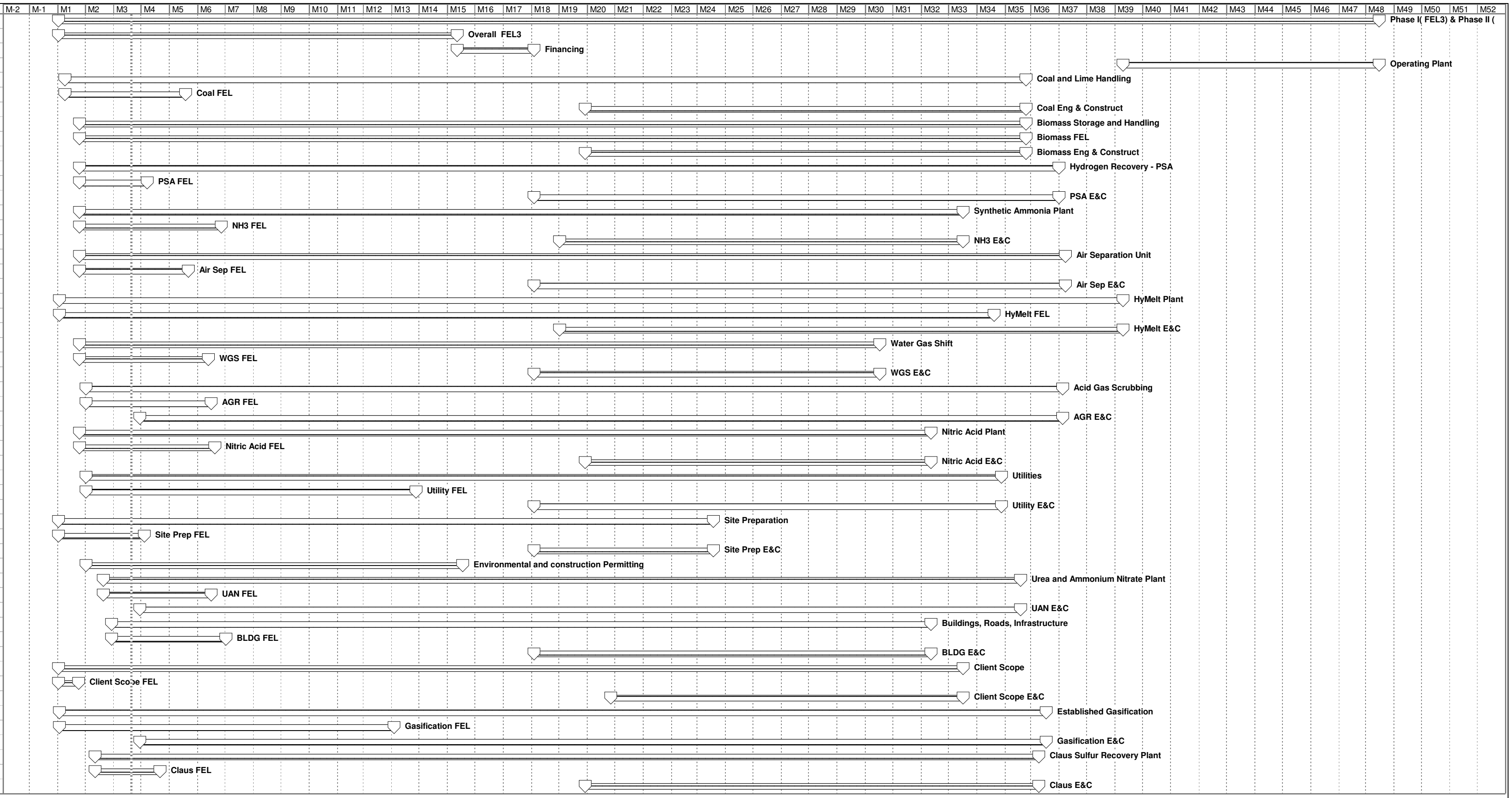
Discussion

The preliminary results above have been developed based on a design methodology that has been validated for tuyere operation at relatively small scale (up to ½ inch center pipe O.D.) and at reactor operating pressure up to about 125 psig. While the basic science behind this approach is expected to extend to higher pressures and larger scales, independent validation is recommended prior to finalizing the tuyere design. Furthermore, the use of at least three tuyeres is recommended for three primary reasons:

1. Reactor operation can be continued if one tuyere becomes plugged by either bath metal or feed solids.
2. Smaller tuyeres have less likelihood of suffering containment loss in the event of a loss of flows.
3. Use of three tuyeres is predicted to result in nearly the lowest reactor capital cost.

Exhibit 13a Gantt Chart Summary (1 page)

ID	Task Name
1	Phase I(FEL3) & Phase II (EPC)
2	Overall FEL3
24	Financing
27	Operating Plant
35	Coal and Lime Handling
36	Coal FEL
51	Coal Eng & Construct
56	Biomass Storage and Handling
57	Biomass FEL
75	Biomass Eng & Construct
80	Hydrogen Recovery - PSA
81	PSA FEL
97	PSA E&C
102	Synthetic Ammonia Plant
103	NH3 FEL
121	NH3 E&C
126	Air Separation Unit
127	Air Sep FEL
144	Air Sep E&C
149	HyMelt Plant
150	HyMelt FEL
176	HyMelt E&C
184	Water Gas Shift
185	WGS FEL
199	WGS E&C
204	Acid Gas Scrubbing
205	AGR FEL
223	AGR E&C
229	Nitric Acid Plant
230	Nitric Acid FEL
246	Nitric Acid E&C
251	Utilities
252	Utility FEL
268	Utility E&C
273	Site Preparation
274	Site Prep FEL
286	Site Prep E&C
290	Environmental and construction Permitting
303	Urea and Ammonium Nitrate Plant
304	UAN FEL
321	UAN E&C
327	Buildings, Roads, Infrastructure
328	BLDG FEL
339	BLDG E&C
344	Client Scope
345	Client Scope FEL
350	Client Scope E&C
355	Established Gasification
356	Gasification FEL
369	Gasification E&C
375	Claus Sulfur Recovery Plant
376	Claus FEL
384	Claus E&C



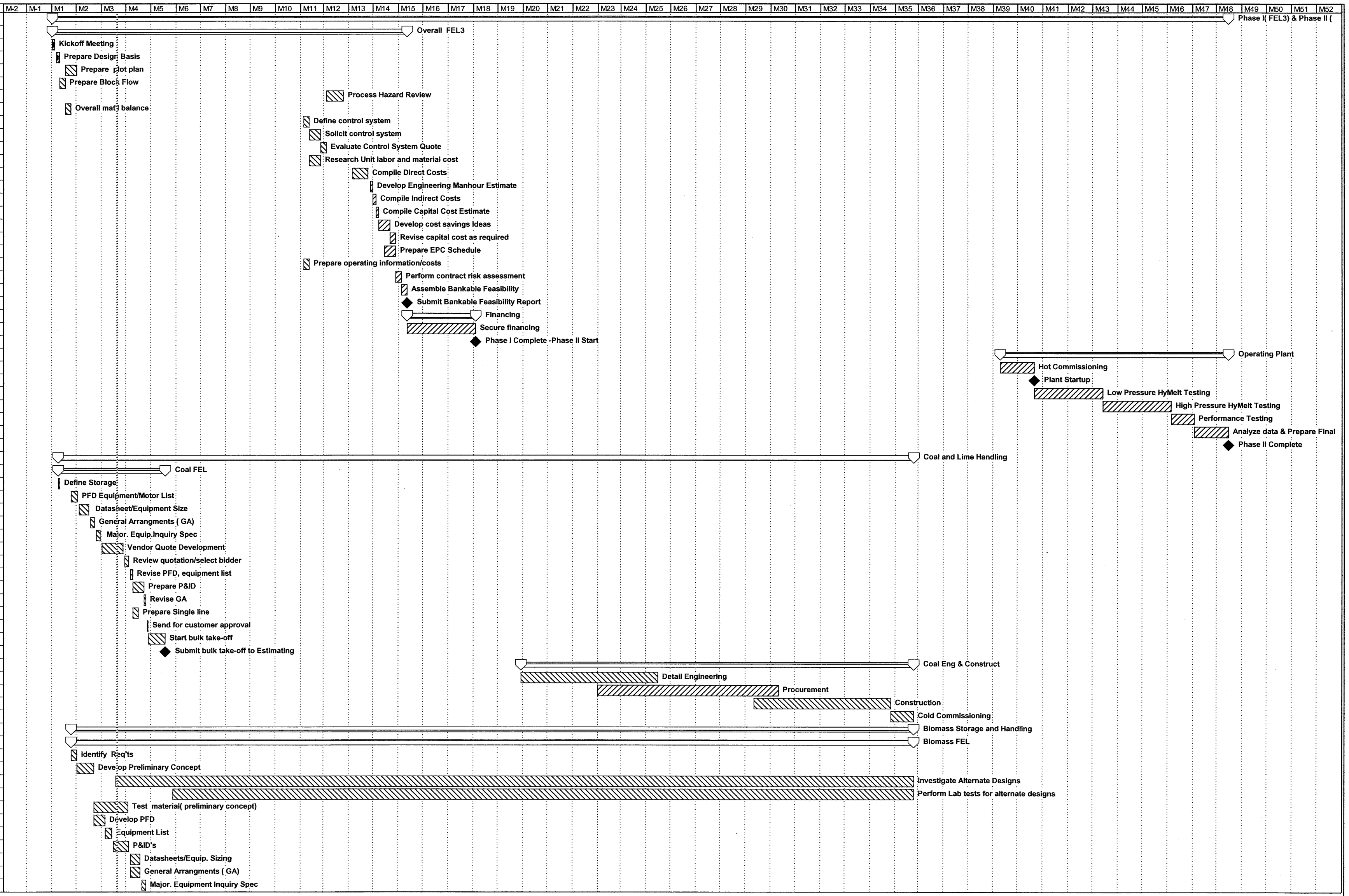
Project: **American Freedom Fuels and Coal to Nitrogen Product Plant**
Date: Fri 6/20/08

Task	▨	Critical Task	▨	Milestone	◆	Rolled Up Task	▨	Rolled Up Milestone	◇	Split		Project Summary		Deadline	⇩
Task Progress	▬	Critical Task Progress	▬	Summary		Rolled Up Critical Task	▨	Rolled Up Progress	▬	External Tasks		Group By Summary			

AKER SOLUTIONS

Exhibit 13b Gantt Chart Details (6 pages)

ID	Task Name
1	**Phase I(FEL3) & Phase II (EPC)**
2	**Overall FEL3**
3	Kickoff Meeting
4	Prepare Design Basis
5	Prepare plot plan
6	Prepare Block Flow
7	Process Hazard Review
8	Overall mat'l balance
9	Define control system
10	Solicit control system
11	Evaluate Control System Quote
12	Research Unit labor and material cost
13	Compile Direct Costs
14	Develop Engineering Manhour Estimate
15	Compile Indirect Costs
16	Compile Capital Cost Estimate
17	Develop cost savings Ideas
18	Revise capital cost as required
19	Prepare EPC Schedule
20	Prepare operating information/costs
21	Perform contract risk assessment
22	Assemble Bankable Feasibility
23	Submit Bankable Feasibility Report
24	**Financing**
25	Secure financing
26	**Phase I Complete -Phase II Start**
27	**Operating Plant**
28	Hot Commissioning
29	Plant Startup
30	Low Pressure HyMelt Testing
31	High Pressure HyMelt Testing
32	Performance Testing
33	Analyze data & Prepare Final Report
34	Phase II Complete
35	**Coal and Lime Handling**
36	**Coal FEL**
37	Define Storage
38	PFD Equipment/Motor List
39	Datasheet/Equipment Size
40	General Arrangments (GA)
41	Major. Equip.Inquiry Spec
42	Vendor Quote Development
43	Review quotation/select bidder
44	Revise PFD, equipment list
45	Prepare P&ID
46	Revise GA
47	Prepare Single line
48	Send for customer approval
49	Start bulk take-off
50	Submit bulk take-off to Estimating
51	**Coal Eng & Construct**
52	Detail Engineering
53	Procurement
54	Construction
55	Cold Commissioning
56	**Biomass Storage and Handling**
57	**Biomass FEL**
58	Identify Req'ts
59	Develop Preliminary Concept
60	Investigate Alternate Designs
61	Perform Lab tests for alternate designs
62	Test material(preliminary concept)
63	Develop PFD
64	Equipment List
65	P&ID's
66	Datasheets/Equip. Sizing
67	General Arrangments (GA)
68	Major. Equipment Inquiry Spec

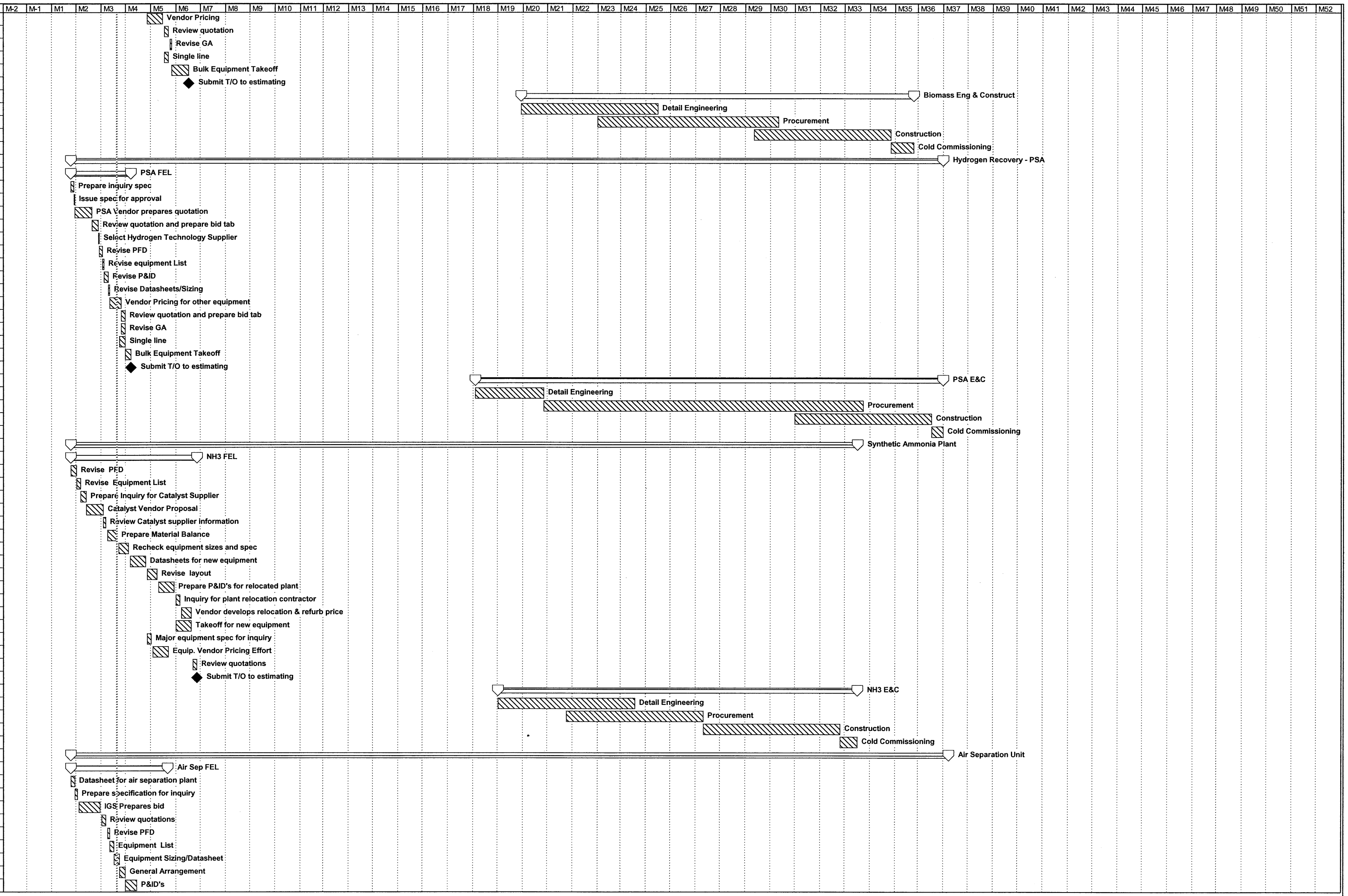


Project:**American Freedom Fuels and Coal to Nitrogen Product Plant**
Date: Fri 6/20/08

Task	▨	Critical Task	▨	Milestone	◆	Rolled Up Task	▨	Rolled Up Milestone	◇	Split	┆	Project Summary	▬	Deadline	⇩
Task Progress	▬	Critical Task Progress	▬	Summary	▭	Rolled Up Critical Task	▨	Rolled Up Progress	▬	External Tasks	▬	Group By Summary	▬		

AKER SOLUTIONS

ID	Task Name
69	Vendor Pricing
70	Review quotation
71	Revise GA
72	Single line
73	Bulk Equipment Takeoff
74	Submit T/O to estimating
75	**Biomass Eng & Construct**
76	Detail Engineering
77	Procurement
78	Construction
79	Cold Commissioning
80	**Hydrogen Recovery - PSA**
81	**PSA FEL**
82	Prepare inquiry spec
83	Issue spec for approval
84	PSA Vendor prepares quotation
85	Review quotation and prepare bid tab
86	Select Hydrogen Technology Supplier
87	Revise PFD
88	Revise equipment List
89	Revise P&ID
90	Revise Datasheets/Sizing
91	Vendor Pricing for other equipment
92	Review quotation and prepare bid tab
93	Revise GA
94	Single line
95	Bulk Equipment Takeoff
96	Submit T/O to estimating
97	**PSA E&C**
98	Detail Engineering
99	Procurement
100	Construction
101	Cold Commissioning
102	**Synthetic Ammonia Plant**
103	**NH3 FEL**
104	Revise PFD
105	Revise Equipment List
106	Prepare Inquiry for Catalyst Supplier
107	Catalyst Vendor Proposal
108	Review Catalyst supplier information
109	Prepare Material Balance
110	Recheck equipment sizes and spec
111	Datasheets for new equipment
112	Revise layout
113	Prepare P&ID's for relocated plant
114	Inquiry for plant relocation contractor
115	Vendor develops relocation & refurb price
116	Takeoff for new equipment
117	Major equipment spec for inquiry
118	Equip. Vendor Pricing Effort
119	Review quotations
120	Submit T/O to estimating
121	**NH3 E&C**
122	Detail Engineering
123	Procurement
124	Construction
125	Cold Commissioning
126	**Air Separation Unit**
127	**Air Sep FEL**
128	Datasheet for air separation plant
129	Prepare specification for inquiry
130	IGS Prepares bid
131	Review quotations
132	Revise PFD
133	Equipment List
134	Equipment Sizing/Datasheet
135	General Arrangement
136	P&ID's

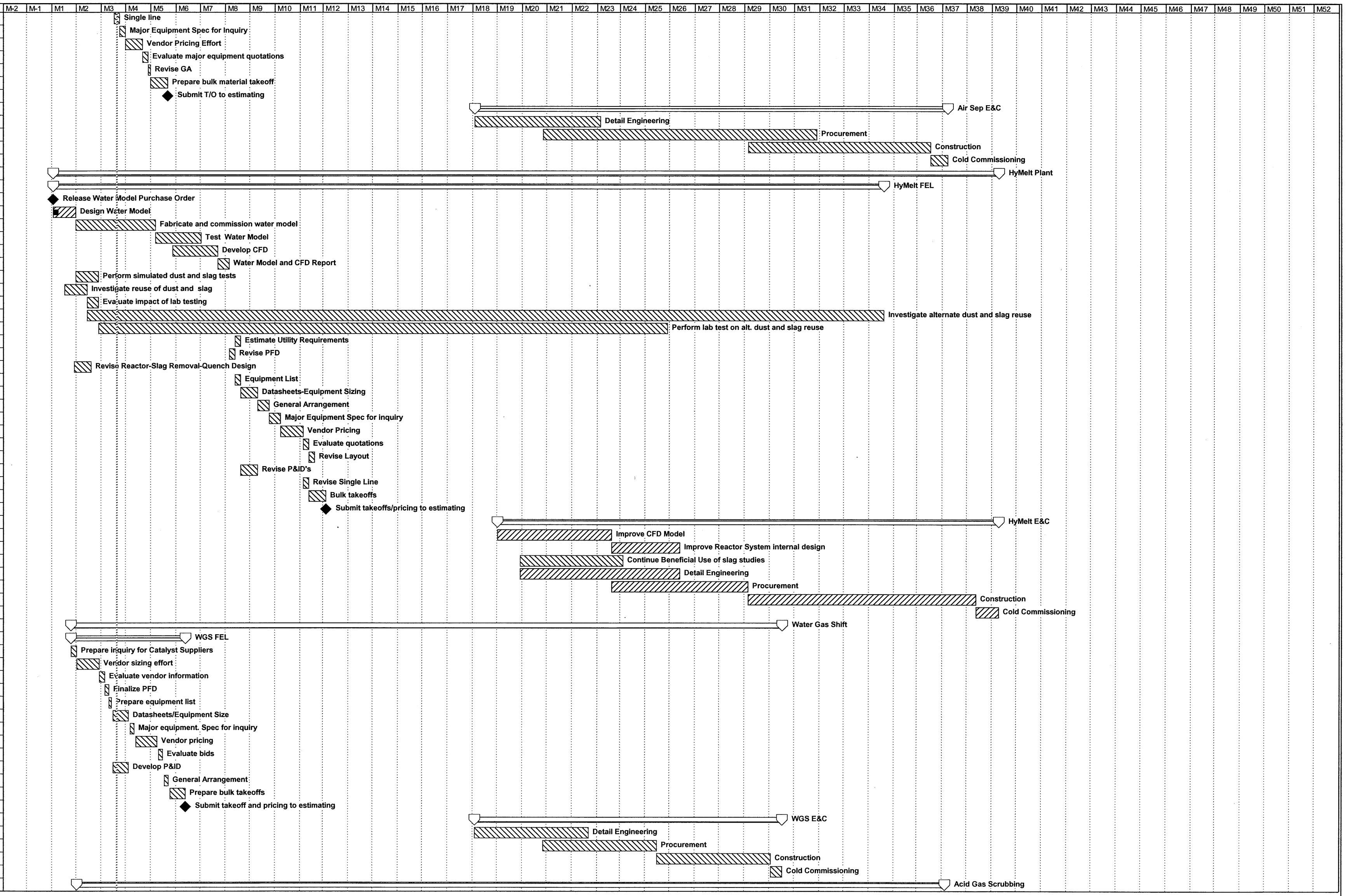


Project:American Freedom Fuels and Coal to Nitrogen Product Plant
Date: Fri 6/20/08

Task	▨	Critical Task	▨	Milestone	◆	Rolled Up Task	▨	Rolled Up Milestone	◇	Split	┆	Project Summary	▬	Deadline	⇩
Task Progress	▬	Critical Task Progress	▬	Summary	▭	Rolled Up Critical Task	▨	Rolled Up Progress	▬	External Tasks	▬	Group By Summary	▬		

AKER SOLUTIONS

ID	Task Name
137	Single line
138	Major Equipment Spec for Inquiry
139	Vendor Pricing Effort
140	Evaluate major equipment quotations
141	Revise GA
142	Prepare bulk material takeoff
143	Submit T/O to estimating
144	**Air Sep E&C**
145	Detail Engineering
146	Procurement
147	Construction
148	Cold Commissioning
149	**HyMelt Plant**
150	**HyMelt FEL**
151	Release Water Model Purchase Order
152	Design Water Model
153	Fabricate and commission water model
154	Test Water Model
155	Develop CFD
156	Water Model and CFD Report
157	Perform simulated dust and slag tests
158	Investigate reuse of dust and slag
159	Evaluate impact of lab testing
160	Investigate alternate dust and slag reuse
161	Perform lab test on alt. dust and slag reuse
162	Estimate Utility Requirements
163	Revise PFD
164	Revise Reactor-Slag Removal-Quench Design
165	Equipment List
166	Datasheets-Equipment Sizing
167	General Arrangement
168	Major Equipment Spec for inquiry
169	Vendor Pricing
170	Evaluate quotations
171	Revise Layout
172	Revise P&ID's
173	Revise Single Line
174	Bulk takeoffs
175	Submit takeoffs/pricing to estimating
176	**HyMelt E&C**
177	Improve CFD Model
178	Improve Reactor System internal design
179	Continue Beneficial Use of slag studies
180	Detail Engineering
181	Procurement
182	Construction
183	Cold Commissioning
184	**Water Gas Shift**
185	**WGS FEL**
186	Prepare inquiry for Catalyst Suppliers
187	Vendor sizing effort
188	Evaluate vendor information
189	Finalize PFD
190	Prepare equipment list
191	Datasheets/Equipment Size
192	Major equipment. Spec for inquiry
193	Vendor pricing
194	Evaluate bids
195	Develop P&ID
196	General Arrangement
197	Prepare bulk takeoffs
198	Submit takeoff and pricing to estimating
199	**WGS E&C**
200	Detail Engineering
201	Procurement
202	Construction
203	Cold Commissioning
204	**Acid Gas Scrubbing**

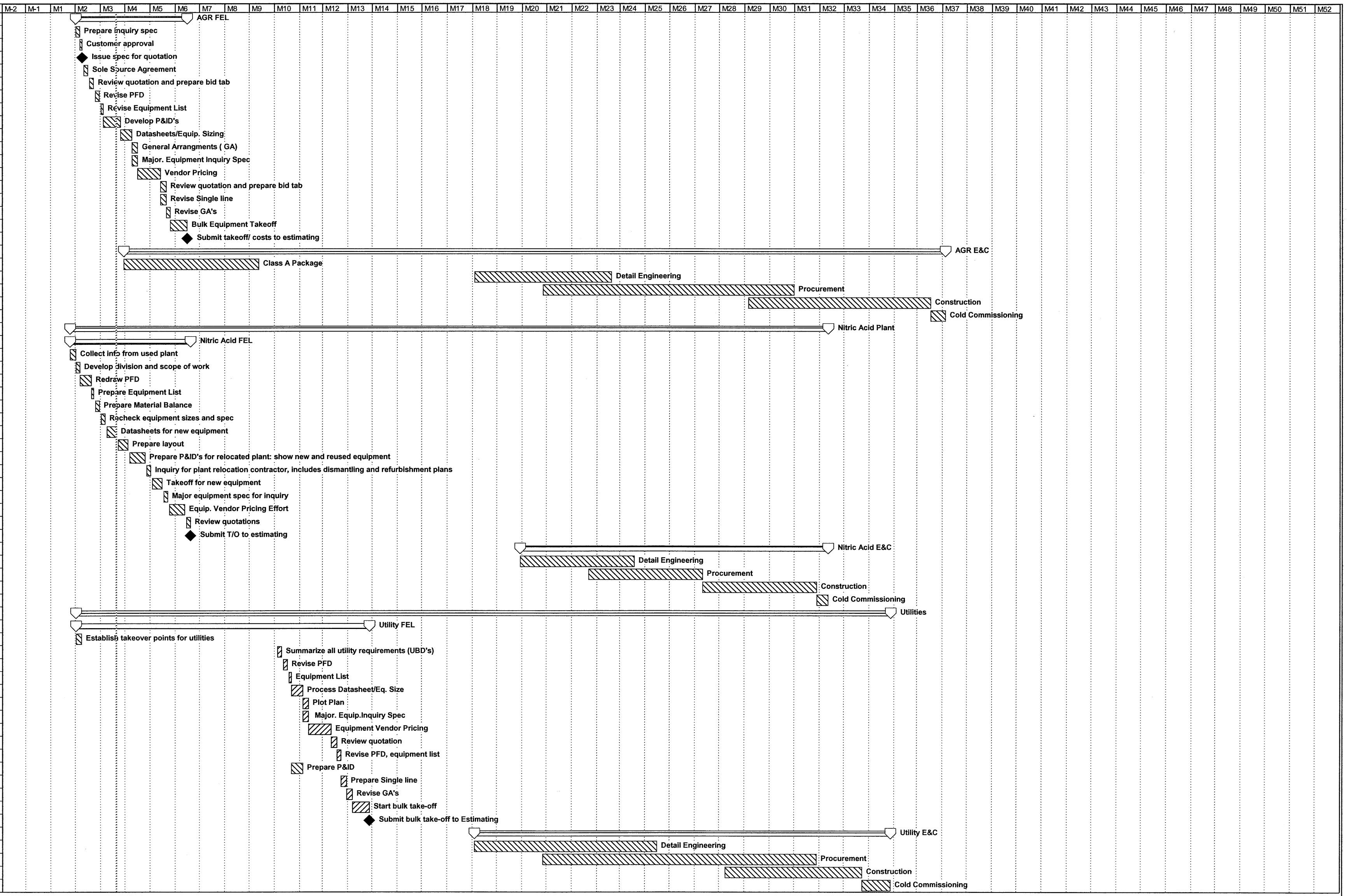


Project:American Freedom Fuels and Coal to Nitrogen Product Plant
Date: Fri 6/20/08

Task	▨	Critical Task	▨	Milestone	◆	Rolled Up Task	▨	Rolled Up Milestone	◇	Split	┆	Project Summary	▬	Deadline	⇩
Task Progress	▬	Critical Task Progress	▬	Summary	▭	Rolled Up Critical Task	▨	Rolled Up Progress	▬	External Tasks	▬	Group By Summary	▬		

AKER SOLUTIONS

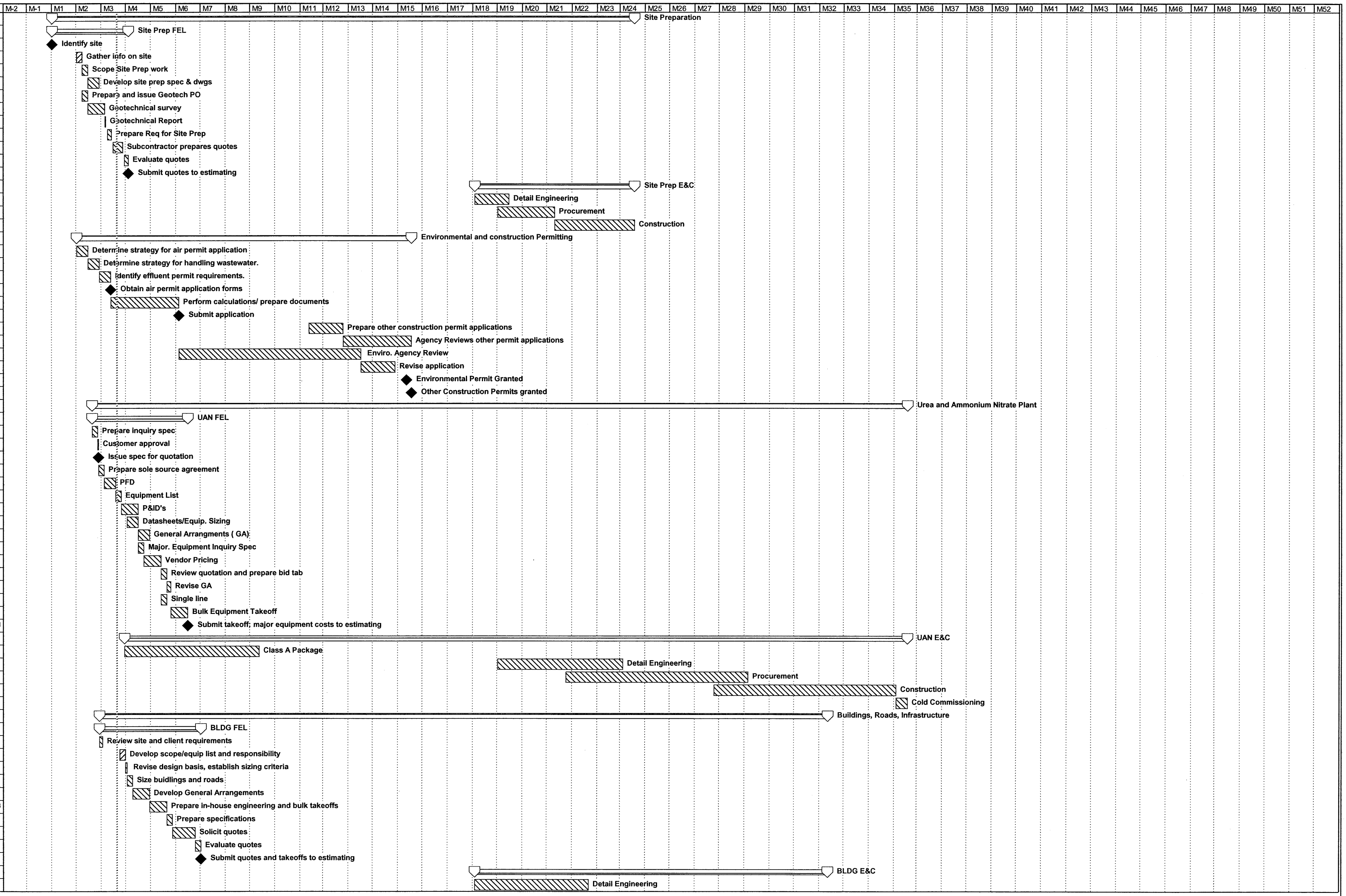
ID	Task Name
205	AGR FEL
206	Prepare inquiry spec
207	Customer approval
208	Issue spec for quotation
209	Sole Source Agreement
210	Review quotation and prepare bid tab
211	Revise PFD
212	Revise Equipment List
213	Develop P&ID's
214	Datasheets/Equip. Sizing
215	General Arrangments (GA)
216	Major. Equipment Inquiry Spec
217	Vendor Pricing
218	Review quotation and prepare bid tab
219	Revise Single line
220	Revise GA's
221	Bulk Equipment Takeoff
222	Submit takeoff/ costs to estimating
223	AGR E&C
224	Class A Package
225	Detail Engineering
226	Procurement
227	Construction
228	Cold Commissioning
229	Nitric Acid Plant
230	Nitric Acid FEL
231	Collect info from used plant
232	Develop division and scope of work
233	Redraw PFD
234	Prepare Equipment List
235	Prepare Material Balance
236	Recheck equipment sizes and spec
237	Datasheets for new equipment
238	Prepare layout
239	Prepare P&ID's for relocated plant: show new a
240	Inquiry for plant relocation contractor, includes (
241	Takeoff for new equipment
242	Major equipment spec for inquiry
243	Equip. Vendor Pricing Effort
244	Review quotations
245	Submit T/O to estimating
246	Nitric Acid E&C
247	Detail Engineering
248	Procurement
249	Construction
250	Cold Commissioning
251	Utilities
252	Utility FEL
253	Establish takeover points for utilities
254	Summarize all utility requirements (UBD's)
255	Revise PFD
256	Equipment List
257	Process Datasheet/Eq. Size
258	Plot Plan
259	Major. Equip.Inquiry Spec
260	Equipment Vendor Pricing
261	Review quotation
262	Revise PFD, equipment list
263	Prepare P&ID
264	Prepare Single line
265	Revise GA's
266	Start bulk take-off
267	Submit bulk take-off to Estimating
268	Utility E&C
269	Detail Engineering
270	Procurement
271	Construction
272	Cold Commissioning



Project:American Freedom Fuels and Coal to Nitrogen Product Plant Date: Fri 6/20/08	Task	▨	Critical Task	▨	Milestone	◆	Rolled Up Task	▨	Rolled Up Milestone	◇	Split	┆……┆	Project Summary	▬	Deadline	⇩
	Task Progress	▬	Critical Task Progress	▬	Summary	▭	Rolled Up Critical Task	▨	Rolled Up Progress	▬	External Tasks	▬	Group By Summary	▬		

AKER SOLUTIONS

ID	Task Name
273	**Site Preparation**
274	**Site Prep FEL**
275	Identify site
276	Gather info on site
277	Scope Site Prep work
278	Develop site prep spec & dwgs
279	Prepare and issue Geotech PO
280	Geotechnical survey
281	Geotechnical Report
282	Prepare Req for Site Prep
283	Subcontractor prepares quotes
284	Evaluate quotes
285	Submit quotes to estimating
286	**Site Prep E&C**
287	Detail Engineering
288	Procurement
289	Construction
290	**Environmental and construction Permitting**
291	Determine strategy for air permit application
292	Determine strategy for handling wastewater.
293	Identify effluent permit requirements.
294	Obtain air permit application forms
295	Perform calculations/ prepare documents
296	Submit application
297	Prepare other construction permit applications
298	Agency Reviews other permit applications
299	Enviro. Agency Review
300	Revise application
301	Environmental Permit Granted
302	Other Construction Permits granted
303	**Urea and Ammonium Nitrate Plant**
304	**UAN FEL**
305	Prepare inquiry spec
306	Customer approval
307	Issue spec for quotation
308	Prepare sole source agreement
309	PFD
310	Equipment List
311	P&ID's
312	Datasheets/Equip. Sizing
313	General Arrangments (GA)
314	Major. Equipment Inquiry Spec
315	Vendor Pricing
316	Review quotation and prepare bid tab
317	Revise GA
318	Single line
319	Bulk Equipment Takeoff
320	Submit takeoff; major equipment costs to estim
321	**UAN E&C**
322	Class A Package
323	Detail Engineering
324	Procurement
325	Construction
326	Cold Commissioning
327	**Buildings, Roads, Infrastructure**
328	**BLDG FEL**
329	Review site and client requirements
330	Develop scope/equip list and responsibility
331	Revise design basis, establish sizing criteria
332	Size buidlings and roads
333	Develop General Arrangements
334	Prepare in-house engineering and bulk takeoffs
335	Prepare specifications
336	Solicit quotes
337	Evaluate quotes
338	Submit quotes and takeoffs to estimating
339	**BLDG E&C**
340	Detail Engineering

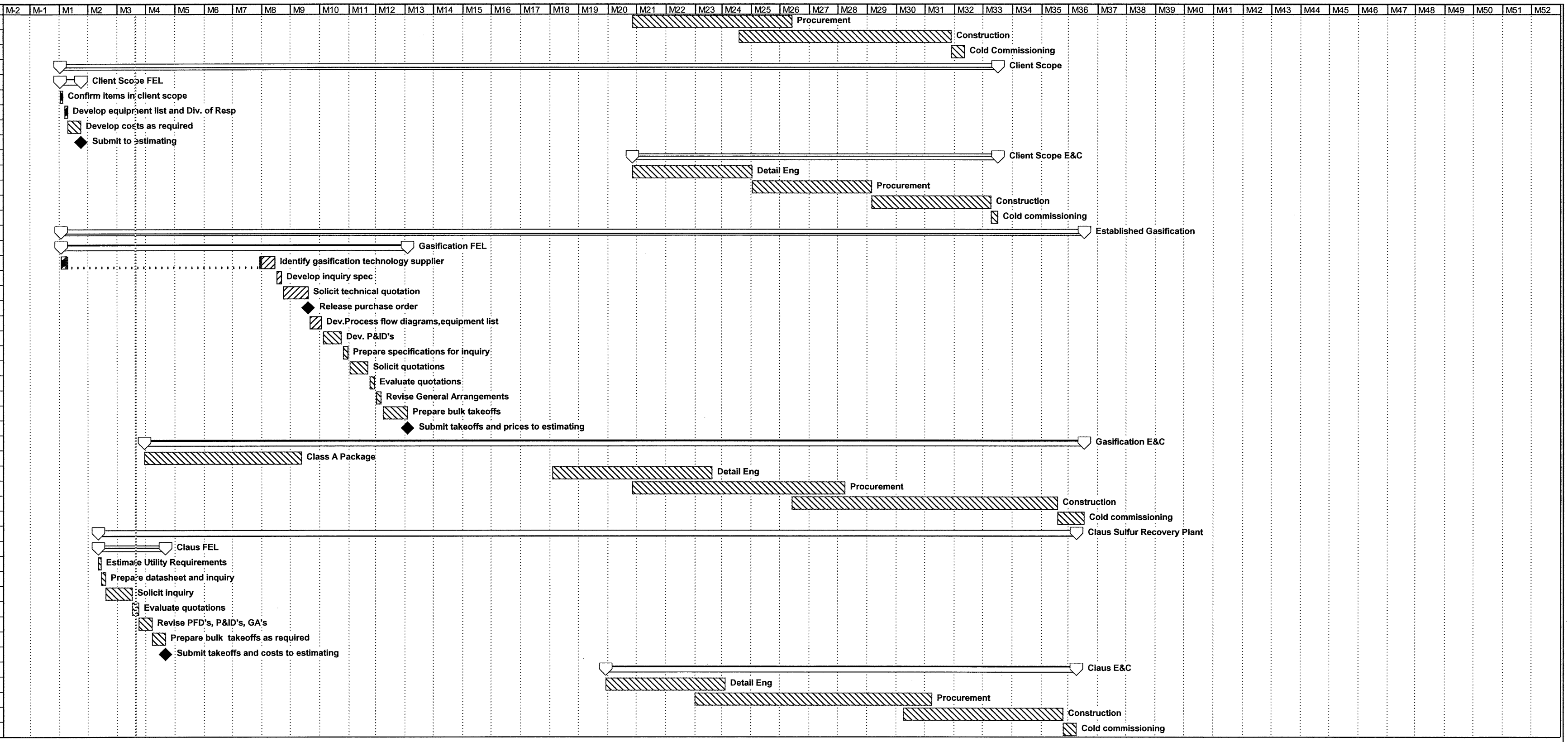


Project:American Freedom Fuels and Coal to Nitrogen Product Plant
Date: Fri 6/20/08

Task	▧	Critical Task	▨	Milestone	◆	Rolled Up Task	▧	Rolled Up Milestone	◇	Split	┃………┃	Project Summary	▬	Deadline	⇩
Task Progress	▬	Critical Task Progress	▬	Summary	▭	Rolled Up Critical Task	▨	Rolled Up Progress	▬	External Tasks	▒	Group By Summary	▬		

AKER SOLUTIONS

ID	Task Name
341	Procurement
342	Construction
343	Cold Commissioning
344	**Client Scope**
345	**Client Scope FEL**
346	Confirm items in client scope
347	Develop equipment list and Div. of Resp
348	Develop costs as required
349	Submit to estimating
350	**Client Scope E&C**
351	Detail Eng
352	Procurement
353	Construction
354	Cold commissioning
355	**Established Gasification**
356	**Gasification FEL**
357	Identify gasification technology supplier
358	Develop inquiry spec
359	Solicit technical quotation
360	Release purchase order
361	Dev.Process flow diagrams,equipment list
362	Dev. P&ID's
363	Prepare specifications for inquiry
364	Solicit quotations
365	Evaluate quotations
366	Revise General Arrangements
367	Prepare bulk takeoffs
368	Submit takeoffs and prices to estimating
369	**Gasification E&C**
370	Class A Package
371	Detail Eng
372	Procurement
373	Construction
374	Cold commissioning
375	**Claus Sulfur Recovery Plant**
376	**Claus FEL**
377	Estimate Utility Requirements
378	Prepare datasheet and inquiry
379	Solicit inquiry
380	Evaluate quotations
381	Revise PFD's, P&ID's, GA's
382	Prepare bulk takeoffs as required
383	Submit takeoffs and costs to estimating
384	**Claus E&C**
385	Detail Eng
386	Procurement
387	Construction
388	Cold commissioning



Project:American Freedom Fuels and Coal to Nitrogen Product Plant
Date: Fri 6/20/08

Task	▨	Critical Task	▨	Milestone	◆	Rolled Up Task	▨	Rolled Up Milestone	◇	Split	┃……┃	Project Summary	▬	Deadline ⇩
Task Progress	▬	Critical Task Progress	▬	Summary	▭	Rolled Up Critical Task	▨	Rolled Up Progress	▬	External Tasks	▒	Group By Summary	▬	

AKER SOLUTIONS

Exhibit 14 Major Equipment List including Urea and Conventional Gasifier (9 pages)

AKER SOLUTIONS
ITEM LIST

Contract :	**A0757603**	**DATE:**	**June 20, 2008**
Client:	**American Freedom Fuel and Chemicals, LLC**	**REVISION:**	**A**
Facility:	**Coal to Nitrogen Products Plant**	**Preliminary Issue**	
Location:	**USA**	**I**	

Rev.	**Area**			**Description**	**Technology**
	0			General	N/A
	2			Sulfur Recovery	Claus
	3			Synthesis Gas Preparation	PSA
	4			Ammonia Synthesis	MW Kellogg
	5			Air Separation and Compression Plant	N/A
	6			HyMelt® Plant	HyMelt®
	7			Water Gas Shift	
	8			Acid Gas Scrubbing	Selexol™
	10			Utilities	N/A
	11			Site Preparation	N/A
	12			Buildings, Roads, and Other Infrastructure	N/A
	15			Raw Materials (Coal, Lime, Biomass)	N/A
	20			Gasification	Later
	30			Nitrogen Products (Urea)	UAN-32
	31			Nitrogen Products(Nitric Acid)	UAN-32
	32			Nitrogen Products (Ammonium Nitrate)	UAN-32

AKER SOLUTIONS **Preliminary**
ITEM LIST
CONTRACT : **A0757603** **REVISION: A**
CLIENT: **American Freedom Fuel and Chemicals, LLC** **DATE: 20 JUN08**
FACILITY: **Coal to Nitrogen Products Plant**
LOCATION: **USA**

Rev	Date Added or Deleted	Area	Equipment Number	Drawing Number	Total	Oper.	Stand-by	Title
		02	14201	R-02-0002	1	1		Sulfur Pit
		02	31101	R-02-0002	1	1		Sulfur Condenser No. 1
		02	31102	R-02-0002	1	1		Sulfur Condenser No. 2
		02	31103	R-02-0002	1	1		Sulfur Condenser No. 3
		02	31104	R-02-0002	1	1		Sulfur Condenser No. 4
		02	31107	R-02-0002	3	3		Claus Plant Gas Heater
		02	31108	R-02-0002	1	1		Hydrogenation Heater
		02	31109	R-02-0002	1	1		Claus Tail Gas Cooler
		02	35602	R-02-0002	4	4		Claus Plant Separators
		02	35603	R-02-0002	3	3		Claus Reactors
		02	35604	R-02-0002	1	1		Tail Gas Hydrogenation Reactor
		02	40102	R-02-0002	1	1		Claus Sulfur Recovery Plant
		02	40103	R-02-0002	1	1		Claus Plant Reactor Catalyst
		02	40104	R-02-0002	1	1		Claus Plant Hydrogenation Catalyst
		02	41901	R-02-0002	1	1		Sulfur Sump Pump
		02	42403	R-02-0002	1	1		Claus Tail Gas Compressor
		02	42701	R-02-0002	2	1	1	Claus Plant Air Blower
		02	42702	R-02-0002	1	1		Sulfur Pit Vent Blower
		02	44601	R-02-0002	1	1		Claus Plant Reaction Furnace
		02	44602	R-02-0002	1	1		Claus Plant Waste Heat Boiler
		03	35612	R-03-0004	1	1		PSA Offgas Drum
		03	40106	R-03-0004	1	1		Pressure Swing Adsorber System
		03	40107	R-03-0004	5	5		Pressure Swing Adsorber
		03	50803	R-03-0004	1	1		PSA Feed Coalescer
		04	14201	R-04-0004	1	1		Ammonia Storage Area Dike
		04	14203	R-04-0004	1	1		Ammonia Area Sump
		04	31111	R-04-0001	1	1		Interstage Cooler
		04	31112	R-04-0001	1	1		Condensate Heater
		04	31113	R-04-0001	1	1		Kickback Cooler
		04	31114	R-04-0001	1	1		Syngas Compressor Interstage Cooler
		04	31115	R-04-0001	1	1		Annular Tube Chiller
		04	31116	R-04-0001	1	1		Ammonia Chiller
		04	31117	R-04-0001	1	1		Water Cooler
		04	31118	R-04-0001	1	1		Ammonia Converter Feed/Effluent Exchanger
		04	31119	R-04-0001	1	1		BFW Preheater
		04	31120	R-04-0002	1	1		Refrigerant Compressor Interstage Cooler
		04	31121	R-04-0002	1	1		Refrigerant Condenser
		04	31122	R-04-0002	1	1		Flash Gas Chiller
		04	31123	R-04-0003	1	1		Condensate Heat Exchanger
		04	31124	R-04-0003	1	1		Surface Condenser
		04	31125	R-04-0004	1	1		Ammonia Truck Loading Heater
		04	34101	R-04-0004	1	1		Ammonia Storage Tank
		04	35501	R-04-0004	1	1		Ammonia Truck Loading Tank
		04	35606	R-04-0001	1	1		Ammonia Separator
		04	35607	R-04-0001	1	1		Intermediate Flash Drum

AKER SOLUTIONS **Preliminary**
ITEM LIST
CONTRACT : **A0757603** **REVISION: A**
CLIENT: **American Freedom Fuel and Chemicals, LLC** **DATE: 20 JUN08**
FACILITY: **Coal to Nitrogen Products Plant**
LOCATION: **USA**

Rev	Date Added or Deleted	Area	Equipment Number	Drawing Number	Total	Oper.	Stand-by	Title
		04	35608	R-04-0002	1	1		First Stage Refrigerant Flash Drum
		04	35609	R-04-0002	1	1		Second Stage Refrigerant Flash Drum
		04	35610	R-04-0002	1	1		Third Stage Refrigerant Flash Drum
		04	35611	R-04-0002	1	1		Refrigerant Receiver
		04	41103	R-04-0002	2	1	1	Warm Ammonia Product Pump
		04	41104	R-04-0002	2	1	1	Water Injection Pump
		04	41105	R-04-0002	2	1	1	Ammonia Plt Condensate Pump
		04	41701	R-04-0003	2	1	1	Ammonia Plt BFW Pump
		04	41801	R-04-0004	2	1	1	Ammonia Storage Area Sump Pump
		04	41998	R-04-0004	2	1	1	Ammonia Truck Loading Pump
		04	41999	R-04-0004	2	1	1	Ammonia Transfer/Loading Pump
		04	42404	R-04-0001	1	1		Booster Compressor
		04	42405	R-04-0001	1	1		Syngas Compressor
		04	42406	R-04-0002	1	1		Ammonia Refrigerant Compressor
		04	44101	R-04-0003	1	1		Ammonia Plt Deaerator
		04	44501	R-04-0004	2	1	1	Ammonia Storage Refrigeration Unit
		04	44603	R-04-0001	1	1		Start-up Heater
		04	44604	R-04-0001	1	1		Steam Generator
		04	44605	R-04-0003	1	1		Boiler Blowdown Drum
		04	44701	R-04-0004	1	1		Ammonia Flare Stack
		04	47601	R-04-0003	1	1		Steam Turbine Generator
		04	48001	R-04-0004	1	1		Ammonia Barge Loading System
		04	48002	R-04-0004	1	1		Ammonia Truck/Rail Loading System
		04	55302	R-04-0004	1	1		Ammonia Truck Loading Scale
		04	61101	R-04-0003	1	1		Steam Desuperheater
		05	31126	R-05-0001	1	1		ASU Compressor Intercooler
		05	32103	R-05-0001	1	1		ASU Cold Box
		05	35502	R-05-0001	1	1		Liquid Nitrogen Tank
		05	35503	R-05-0001	1	1		Liquid Oxygen Tank
		05	35504	R-05-0001	1	1		Nitrogen Receiver
		05	35505	R-05-0001	1	1		Oxygen Receiver
		05	40108	R-05-0001	1	1		Air Separation Plant
		05	41106	R-05-0001	2	1	1	Liquid Nitrogen Pump
		05	41107	R-05-0001	2	1	1	Liquid Oxygen Pump
		05	42101	R-05-0001	1	1		ASU Air Compressor
		05	44103	R-05-0001	1	1		Nitrogen Vaporizer
		05	44104	R-05-0001	1	1		Oxygen Vaporizer
		05	50804	R-05-0001	2	1	1	ASU Molecular Sieve
		06	16101	R-06-0002	1	1		Refractory Heat-up Stack
		06	14205	R-06-0003	1	1		Slag Pile Pad
		06	14206	R-06-0003	1	1		Slag Runoff Sump
		06	31138	R-06-0002	1	1		Venturi Scrubber Solution Heater
		06	31141	R-06-0002	1	1		Venturi Heat Exchanger
		06	31301	R-06-0003	1	1		Slag Granulation Cooler
		06	32104	R-06-0003	1	1		Quench & Slag Granulation Vessel

AKER SOLUTIONS **Preliminary**
ITEM LIST
CONTRACT : **A0757603** **REVISION: A**
CLIENT: **American Freedom Fuel and Chemicals, LLC** **DATE: 20 JUN08**
FACILITY: **Coal to Nitrogen Products Plant**
LOCATION: **USA**

Rev	Date Added or Deleted	Area	Equipment Number	Drawing Number	Total	Oper.	Stand-by	Title
		06	33101	R-06-0001	1	1		HyMelt® Reactor
		06	33102	R-06-0001	3	3		Tuyere
		06	35619	R-06-0002	1	1		Offgas Knockout Drum
		06	35620	R-06-0002	1			Equalizer Tank
		06	35621	R-06-0002	1	1		Emergency Quench Tank
		06	35701	R-06-0002	1	1		Clarifier Overflow Tank
		06	41121	R-06-0002	2	1	1	Clarifier Overflow Pump
		06	41301	R-06-0003	2	1	1	Slag Classifier Pump
		06	41302	R-06-0003	2	1	1	Slag Granulation Pump
		06	41303	R-06-0002	2	1	1	Venturi Scrubber Pump
		06	41601	R-06-0002	1	1		Clarifier Underflow Pump
		06	41803	R-06-0003	2	1	1	Slag Runoff Sump Pump
		06	43208	R-06-0001	1	1		Scrap Metal Feeder
		06	43209	R-06-0001	1	1		Reactor Feeder
		06	43210	R-06-0004	1	1		HyMelt Area Baghouse Discharge Feeder
		06	43611	R-06-0001	1	1		Scrap Metal Feed Hopper
		06	43612	R-06-0001	1	1		Scrap Metal Lockhopper
		06	43615	R-06-0003	1	1		Slag Lock Hopper
		06	44901	R-06-0001	1	1		Vessel Preheat Lance
		06	44902	R-06-0001	1	1		Runner Preheater
		06	44905	R-06-0002	1	1		Refractory Heat-up Fan
		06	45501	R-06-0003	1	1		Slag Granulator Strainer
		06	45503	R-06-0003				Recycle Strainer
		06	45701	R-06-0002	1	1		Clarifier
		06	45901	R-06-0003	1	1		Sieve Drum
		06	48003	R-06-0001	1	1		Tapping Drill
		06	48004	R-06-0001	1	1		Mudgun
		06	49102	R-06-0001	1	1		Reactor Bottom Exchange Car
		06	49205	R-06-0003	1	1		Slag Dumpster
		06	50201	R-06-0004	1	1		HyMelt® Area Baghouse Fan
		06	50301	R-06-0002	1	1		Venturi Scrubber
		06	50407	R-06-0004	1	1		HyMelt® Area Baghouse
		06	50901	R-06-0004	1	1		HyMelt® Area Baghouse Stack
		06	53201	R-06-0002	1	1		Filter Press
		06	54101	R-06-0001	1	1		Runner
		06	55501	R-06-0001	1	1		Temperature Measurement & Sampling Device
		06	56101	R-06-0001	1	1		Freight Elevator (future)
		06	56601	R-06-0001	1	1		100 Ton Service Crane
		06	56603	R-06-0001	1	1		10 Ton Underslung Crane
		06	67101	R-06-0001	1	1		HyMelt Vessel Refractory
		07	17115	R-07-0001	1	1		Catalyst Building
		07	31128	R-07-0001	1	1		Water Gas Shift Startup Heater
		07	31129	R-07-0001	1	1		Water Gas Shift Heat Exchanger
		07	31130	R-07-0001	1	1		Water Gas Shift Cooler
		07	31143	R-07-0001	1	1		Stripper Reflux Condenser
		07	31208	R-07-0001	1	1		Condensate Stripper Heat Exchanger

AKER SOLUTIONS **Preliminary**
ITEM LIST
CONTRACT : **A0757603** **REVISION: A**
CLIENT: **American Freedom Fuel and Chemicals, LLC** **DATE: 20 JUN08**
FACILITY: **Coal to Nitrogen Products Plant**
LOCATION: **USA**

Rev	Date Added or Deleted	Area	Equipment Number	Drawing Number	Total	Oper.	Stand-by	Title
		07	31421	R-07-0001	1	1		Boiler Feed Water Heater
		07	32105	R-07-0001	1	1		Condensate Stripper
		07	32113	R-07-0001	1	1		Water Gas Shift 1st Stage Quench Vessel
		07	32114	R-07-0001	1	1		Water Gas Shift 2nd Stage Quench Vessel
		07	35507	R-07-0001	1	1		Water Gas Shift Reactor-1st stage
		07	35508	R-07-0001	1	1		Water Gas Shift Reactor-2nd stage
		07	35509	R-07-0001	1	1		Water Gas Shift 3rd Stage Reactor
		07	35613	R-07-0001	1	1		WGS Cooler Flash Drum
		07	35628	R-07-0001	1	1		WGS K.O. Drum
		07	35629	R-07-0001	1	1		WGS K.O. Drum
		07	35630	R-07-0001	1	1		WGS K.O. Drum
		07	40109	R-07-0001	3	3		WGS Catalyst-1st, 2nd, 3rd Stg Reactors
		07	44207	R-07-0001	1	1		Water Gas Shift Waste Heat Boiler-3rd Stg
		07	44208	R-07-0001	1	1		Low Pressure Waste Heat Boiler
		08	31131	R-08-0002	1	1		Semi-Lean Solvent Chiller
		08	31132	R-08-0002	1	1		Feed/Product Exchanger
		08	31133	R-08-0002	1	1		H2S Recycle Gas Cooler
		08	31134	R-08-0002	1	1		Stripper Reboiler
		08	31139	R-08-0002	1	1		H2S Flash Gas Cooler
		08	31141	R-08-0002	1	1		Reflux Condenser
		08	31204	R-08-0002	1	1		Lean/Rich Exchanger
		08	31205	R-08-0002	1	1		Lean Solvent Chiller
		08	32106	R-08-0001	1	1		Mercury Removal Tower
		08	32107	R-08-0001	1	1		Mercury Adsorbent
		08	32108	R-08-0002	1	1		H2S Absorber
		08	32109	R-08-0002	1	1		H2S Concentrator
		08	32110	R-08-0002	1	1		H2S Stripper
		08	32115	R-08-0002	1	1		CO2 Absorber
		08	34102	R-08-0002	1	1		Solvent Drain Tank
		08	34103	R-08-0002	1	1		Solvent Make-up Tank
		08	35615	R-08-0002	1	1		H2S Rich Flash Drum
		08	35616	R-08-0002	1	1		CO2 Recycle Flash Drum
		08	35622	R-08-0002	1	1		CO2 MP Flash Drum
		08	35623	R-08-0002	1	1		CO2 LP Flash Drum
		08	35625	R-08-0002	1	1		Reflux Drum
		08	35626	R-08-0002	1	1		H2S Flash Gas KO Drum
		08	40111	R-08-0002	1	1		Acid Gas Removal Technology
		08	41108	R-08-0002	2	1	1	HP Lean Solvent Pump
		08	41109	R-08-0002	2	1	1	LP Lean Solvent Pump
		08	41110	R-08-0003	2	1	1	Solvent Drain Tank Pump
		08	41111	R-08-0003	1	1		Solvent Make-up Tank Pump
		08	41120	R-08-0002	2	1	1	Semi-Lean Solvent Pump
		08	41122	R-08-0002	2	1	1	H2S Rich Pump
		08	41123	R-08-0002	2	1	1	Loaded Solvent Pump
		08	41124	R-08-0002	2	1	1	Reflux Pump
		08	41804	R-08-0003	2	1	1	Acid Gas Area Sump Pump

AKER SOLUTIONS **Preliminary**
ITEM LIST
CONTRACT : **A0757603** **REVISION: A**
CLIENT: **American Freedom Fuel and Chemicals, LLC** **DATE: 20 JUN08**
FACILITY: **Coal to Nitrogen Products Plant**
LOCATION: **USA**

Rev	Date Added or Deleted	Area	Equipment Number	Drawing Number	Total	Oper.	Stand-by	Title
		08	42408	R-08-0002	1	1		Stripping Gas Compressor
		08	42409	R-08-0002	1	1		CO2 Recycle Compressor
		08	42410	R-08-0002	1	1		H2S Flash Gas Compressor
		08	44502	R-08-0003	3	1	1	HyMelt® Acid Gas Refrigeration Unit
		10	11601	R-10-0003	1	1		Storm Water Pond
		10	14207	R-10-0003	1	1		Wastewater Sump
		10	14208	R-10-1003	1	1		Contaminated Stormwater Sump
		10	14209	R-10-1005	1	1		Sanitary Lift Sump
		10	31206	R-10-1003	1	1		Stripper Heat Exchanger
		10	31207	R-10-1003	1	1		Stripper Cooler
		10	31136	R-10-1003	1	1		Stripper Partial Condenser
		10	32112	R-10-1003	1	1		Wastewater Treatment Stripper
		10	34105	R-10-0004	1	1		Fire and Service Water Storage Tank
		10	34106	R-10-0003	1	1		Wastewater Storage Tank
		10	35101	R-10-0002	1	1		Condensate Return Tank
		10	35102	R-10-0003	1	1		Demineralized Water Storage Tank
		10	35103	R-10-0003	1	1		Wastewater Treatment Effluent Tank
		10	35104	R-10-0004	1	1		Caustic Storage Tank
		10	35105	R-10-0004	1	1		Acid Storage Tank
		10	35106	R-10-0005	1	1		Flare Seal Tank
		10	35107	R-10-0006	1	1		Urea Storage Tank
		10	35510	R-10-0004	1	1		Plant Air Receiver
		10	35511	R-10-0004	1	1		Instrument Air Receiver
		10	41112	R-10-0002	2	1	1	Condensate Return Pump
		10	41113	R-10-0002	2	1	1	Service Water Pump
		10	41114	R-10-0002	2	1	1	Demineralized Water Pump
		10	41115	R-10-0003	2	1	1	Wastewater Transfer Pump
		10	41116	R-10-0003	1	1		Wastewater Treatment Effluent Pump
		10	41117	R-10-0003	2	1	1	Stripper Bottoms Pump
		10	41501	R-10-0001	5	4	1	Cooling Water Pump
		10	41702	R-10-0002	2	1	1	MP/LP BFW Pump
		10	41703	R-10-0002	2	1	1	HP BFW Pump
		10	41704	R-10-0002	2	1	1	Start-up BFW Pump
		10	41705	R-10-0002	2	1	1	Firewater Pump
		10	41805	R-10-0003	2	1	1	Wastewater Sump Pump
		10	41806	R-10-0003	2	1	1	Storm Water Sump Pump
		10	41807	R-10-0003	2	1	1	Contaminated Storm Water Sump Pump
		10	41808	R-10-0005	2	1	1	Sanitary Lift Pump
		10	41902	R-10-0001	1	1		Biocide Metering Pump
		10	41903	R-10-0001	1	1		Scale Inhibitor Metering Pump
		10	41904	R-10-0001	1	1		Corrosion Inhibitor Metering Pump
		10	41905	R-10-0004	1	1		Caustic Metering Pump
		10	41906	R-10-0004	1	1		Acid Metering Pump
		10	41907	R-10-0006	1	1		Urea Injection Pump
		10	42201	R-10-0004	3	2	1	Plant Air Compressor
		10	44103	R-10-0002	1	1		Deaerator

AKER SOLUTIONS **Preliminary**
ITEM LIST
CONTRACT : **A0757603** **REVISION: A**
CLIENT: **American Freedom Fuel and Chemicals, LLC** **DATE: 20 JUN08**
FACILITY: **Coal to Nitrogen Products Plant**
LOCATION: **USA**

Rev	Date Added or Deleted	Area	Equipment Number	Drawing Number	Total	Oper.	Stand-by	Title
		10	44207	R-10-0002	1	1		Package Boiler
		10	44301	R-10-0001	1	1		Cooling Tower
		10	44703	R-10-0003	1	1		Thermal Oxidizer
		10	45502	R-10-0001	1	1		Cooling Water Strainer
		10	47301	R-10-0004	1	1		Liquid Nitrogen Storage System
		10	47501	R-10-0002	1	1		Water Filter
		10	47502	R-10-0002	1	1		Demineralizer
		10	47503	R-10-0003	1	1		WWT Activated Carbon Filter
		10	47504	R-10-0004	1	1		BFW Scale Inhibitor System
		10	47505	R-10-0004	1	1		BFW Corrosion Inhibitor System
		10	47506	R-10-0004	1	1		BFW Oxygen Scavenger System
		10	50902	R-10-0002	1	1		Boiler Stack
		10	50903	R-10-0005	1	1		Flare Stack
		10	50904	R-10-0006	1	1		Emergency Generator Stack
		10	52401	R-10-0004	1	1		Instrument Air Dryer
		10	62001	R-10-0006	1	1		Emergency Generator
		12	17105	N/A	1	1		Office Building w/ Locker Room
		12	17106	N/A	1	1		Chemical Analysis Room
		12	17107	N/A	3	3		Electrical Equipment Rooms
		12	17108	N/A	1	1		HyMelt Reactor Building
		12	51103	N/A	1	1		Maintenance/Warehouse HVAC
		12	51105	N/A	1	1		Office Building w/ Locker Room HVAC
		12	51106	N/A	1	1		Chemical Analysis Room HVAC
		12	51107	N/A	4	4		Electrical Equipment Rooms HVAC
		12	56601	N/A	1	1		HyMelt Building Service Crane
		12	60180	N/A	1	1		Restrooms and showers
		12	61501	N/A	1	1		Control System
		12	62002	N/A	1	1		High Voltage Substation
		12	66101	N/A	1	1		Fireproofing
		12	66102	N/A	1	1		Fire Monitoring System
		12	66103	N/A	1	1		Fire protection Equipment
		12	56000	N/A	10		10	Maintenance Hoists (exact quantity later)
		15	16101	R-15-0001	2	2		Unloading Hopper
		15	16103	R-15-0001	2	2		Powdered Coal/Lime Bin
		15	16104	R-15-0001	1	1		Stack
		15	17101	R-15-0001	1	1		Coal Grinding Building
		15	17102	R-15-0001	1	1		Coal Grinding EER/MCC Building
		15	17104	R-15-0001	1	1		Coal Grinding Control Room
		15	17111	R-15-0001	1	1		Truck Unloading Pit Enclosure
		15	41802	R-15-0001	2	1	1	Sump Pump
		15	42003	R-15-0001	1	1		Recycle Fan
		15	42005	R-15-0001	1	1		Combustion Air Fan
		15	43031	R-15-0001	1	1		Crusher Baghouse Rotary Feeder
		15	43102	R-15-0001	1	1		Raw Coal Feed Conveyor
		15	43201	R-15-0001	2	2		Coal Unloading Feeder
		15	43203	R-15-0001	1	1		Grinding Mill Feeder
		15	43204	R-15-0001	1	1		Lime Weigh Feeder

AKER SOLUTIONS **Preliminary**
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FACILITY: **Coal to Nitrogen Products Plant**
LOCATION: **USA**

Rev	Date Added or Deleted	Area	Equipment Number	Drawing Number	Total	Oper.	Stand-by	Title
		15	43207	R-15-0001	1	1		Coal Weigh Feeder
		15	43601	R-15-0001	1	1		Burnt Lime Storage Bin
		15	43602	R-15-0001	1	1		Burnt Lime Feed Hopper
		15	43616	R-15-0001	1	1		Grinding Mill Feed Hopper
		15	43801	R-15-0001	2	2		Shut-off Gate
		15	43901	R-15-0001	1	1		Powdered Coal Pneumatic Conveyor
		15	43902	R-15-0001	1	1		Burnt Lime Pneumatic Truck Unloading System
		15	43903	R-15-0001	1	1		Burnt Lime Pneumatic Conveyor
		15	43906	R-15-0001	2	2		Coal/Lime Pressurized Injectors
		15	43907	R-15-0001	6	6		Rotary Feeders
		15	44102	R-15-0001	1	1		Carrier Gas Heater
		15	45001	R-15-0001	1	1		Tramp Iron Magnet
		15	46101	R-15-0001	1	1		Coal Grinding Mill
		15	47602	R-15-0001	1	1		Reactor Injection System
		15	49201	R-15-0001	1	1		Tramp Metal tote
		15	49203	R-15-0001	1	1		Reject Material Tote
		15	50202	R-15-0001	1	1		Baghouse Fan
		15	50401	R-15-0001	1	1		Grinding Mill Baghouse
		15	50403	R-15-0001	1	1		Coal Depressurizing Baghouse
		15	50404	R-15-0001	1	1		Bin Vent
		15	50408	R-15-0001	1	1		Truck Unloading Baghouse
		15	51101	R-15-0001	1	1		Coal Grinding Building HVAC
		15	51102	R-15-0001	1	1		Coal Grinding EER/MCC Building HVAC
		15	51104	R-15-0001	1	1		Coal Grinding Control Room HVAC
		15	55025	R-15-0001	1	1		Coal Sampler
		15	55301	R-15-0001	1	1		Coal Truck Scale
		15	Later	Later	1	1		Biomass Receiving and Handling Items-later
		20	Later	Later	1	1		Gasification Module Items - Later
		30	B3002	PFS 01	1	1		Carbon Dioxide Compressor
		30	C3602	PFS 01	1	1		Ammonia Scrubber
		30	E3202	PFS 01	1	1		Ammonia Heater
		30	E3401	PFS 01	1	1		Primary Reactor
		30	E3601	PFS 01	1	1		Ammonia Flasher
		30	E3603	PFS 01	1	1		Ammonia Condenser
		30	E3801	PFS 01	1	1		L.P. Decomposer
		30	E3811	PFS 01	1	1		No. 1 Decomposer
		30	F3608	PFS 01	1	1		Liquid Ammonia Filter
		30	M3203	PFS 01	1	1		Mixing Tee
		30	P3201	PFS 01	2	1	1	Ammonia Feed Pumps
		30	P3605	PFS 01	2	1	1	Ammonia Recycle Pumps
		30	P3816	PFS 01	2	1	1	Scrubber Water Pumps
		30	R3404	PFS 01	1	1		Secondary Reactor
		30	S3802	PFS 01	1	1		LP Off-Gas Separator
		30	S3812	PFS 01	1	1		No.1 Decomposer Separator
		30	V3604	PFS 01	1	1		Ammonia Surge Tank
		30	V3814	PFS 01	1	1		No.2 Decomposer
		31	B1004	PFS02	1	1		Air Compressor Set

AKER SOLUTIONS **Preliminary**

ITEM LIST

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CLIENT: **American Freedom Fuel and Chemicals, LLC** **DATE: 20 JUN08**

FACILITY: **Coal to Nitrogen Products Plant**

LOCATION: **USA**

Rev	Date Added or Deleted	Area	Equipment Number	Drawing Number	Total	Oper.	Stand-by	Title
		31	B1812	PFS02	1	1		Abator Air Mix Blower
		31	C1606	PFS02	1	1		Absorber
		31	E1009	PFS02	1	1		Surface Condenser
		31	E1203	PFS02	1	1		Off-Gas Superheater
		31	E1403	PFS02	1	1		Expander Gas Heater
		31	E1404	PFS02	1	1		Waste Heat Boiler
		31	E1408	PFS02	1	1		Steam Superheater
		31	E1410	PFS02	1	1		Tail Gas Heater/Platinum Filter Shell
		31	E1412	PFS02	1	1		Steam Tail Gas Preheater
		31	E1413	PFS02	1	1		Air/Tail Gas Interchanger
		31	E1601	PFS02	1	1		Air Heater
		31	E1602	PFS02	1	1		Cooler Condenser
		31	E1616	PFS02	1	1		Bleach Air Cooler
		31	E1803	PFS02	1	1		Economizer
		31	F1001	PFS02	1	1		Inlet Air Filter
		31	F1204	PFS02	1	1		Off-Gas Filter
		31	F1411	PFS02	1	1		Platinum Filter Element
		31	F1604	PFS02	1	1		Discharge Air Filter
		31	F1811	PFS02	1	1		Abator Air Mix Filter
		31	H1801	PFS02	1	1		Exhaust Stack
		31	M1410	PFS02	1	1		Off-Gas/Air Mixer
		31	M1805	PFS02	1	1		Ammonia/Tail Gas Mixer
		31	M1806	PFS02	1	1		Off-Gas/Air Premixer
		31	P1010	PFS02	2	1	1	Condensate Pumps
		31	R1402	PFS02	1	1		Converter
		31	R1804	PFS02	1	1		NOx Abator
		31	S1405	PFS02	1	1		Steam Drum
		32	C5401	PFS03	1	1		Vent Scrubber
		32	E5005	PFS03	1	1		Circulated AN Cooler
		32	E5203	PFS03	1	1		Solution Cooler
		32	E5404	PFS03	1	1		Circulated Condensate Cooler
		32	P5002	PFS03	2	1	1	Nitric Acid Feed Pumps
		32	P5004	PFS03	2	1	1	AN Scrubber Pumps
		32	P5202	PFS03	2	1	1	UAN-32 Product Pump
		32	P5403	PFS03	2	1	1	Process Condensate Pumps
		32	P5405	PFS03	2	1	1	Absorber Feedwater Pumps
		32	R5003	PFS03	1	1		Neutralizer /Scrubber
		32	T5001	PFS03	1	1		Nitric Acid Surge Tank
		32	T5201	PFS03	1	1		Solution Mix Tank
		32	T5402	PFS03	1	1		Process Condensate Tank

Exhibit 15 Utility Estimates including Urea and Conventional Gasifier (3 pages)

Rev	Area	Coal to UAN	Hi. Press. Steam	Med. Press. Steam	Low Press. Steam	Lower Press. Steam	Cooling Water	Hi Press N2	Low Press N2	O2	Nat. Gas	PSA Tail Gas	BFW	BFW	Makeup water	Recycled Water**	Wastewater	Compres. Air	Carbon Dioxide	Power Avg. Demand
		Pressure, psig	**700**	**120**	**65**	**15**	**100**	**700**	**125**	**700**	**30**	**15**	**700**	**250**	**50.0**	**0.0**	**0.0**	**125**	**5**	
Rev	**Area**		**lbs//hr**	**lbs//hr**	**lbs//hr**	**lbs/hr**	**gpm**	**lbs//hr**	**lbs//hr**	**lbs//hr**	**MM BTU/h**	**MM BTU/h**	**gpm**	**gpm**	**gpm**	**gpm**	**gpm**	**scfm**	**lbs/hr**	**kw hr/hr**
F	**1**	**Urea- Ammonium Nitrate**	**37,627**		**28,571**		**17,363**						**134**		**50**	**-133**		**50**	**45,946**	**5,090**
	2	Claus Plant									5									
	2	WHB 44602	-4,079										8			0				
	2	Sulfur Condensers			-2,594									5		0				
	2	CP Heaters 31107			538															
	2	Hydrogenation Heater, 31108	600																	
	2	CP Gas Cooler					100													
	2	Sulfur Pit			1,000															
F	**2**	**Claus Plant Subtotal**	**-3,479**	**0**	**-1,056**	**0**	**100**	**0**	**0**	**0**	**5**		**8**	**5**	**0**	**0**	**0**	**200**	**0**	**145**
F	3	Deleted							0									0		
F	3	Deleted					0													
F	3	Delelted					0		0											
	3	HyMelt PSA							45			-114						30		
	3	**PSA Subtotal**	**0**	**0**	**0**	**0**	**0**	**0**	**45**	**0**	**0**	**-114**	**0**	**0**	**0**	**0**	**0**	**30**	**0**	**365**
	4	N2 Feed						48,000												
	4	Ammonia Plant Heat exchangers																		
	4	Steam Generator(151c), 44604	-45,000	-4,100									100				2			
	4	114-c					152													
	4	106 c					112													
	4	116 c					80													
	4	153 c					80													
	4	124 c					2,333													
	4	128 c					147													
	4	127 c					2,768													
	4	Steam Turbine, 101-ut	45,000																	
	4	Misc, users		4,100																
	4	129 c					3,680													
	4	Ammonia Storage Refrig. 44501					336													
	4	NH3 Truck Loading Heater,31125			6,000				443											
	4	Ammonia Flare, 44701									5									
	4	**NH3 Subtotal**	**0**	**0**	**6,000**	**0**	**9,688**	**48,000**	**443**	**0**	**5**		**100**	**0**	**0**	**0**	**2**	**300**	**0**	**10,747**
	5	Compressor Intercoolers, ASU, 31126					400													
	5	ASU Evaporator,			10,000															
	5	**ASU Subtotal**	**0**	**0**	**10,000**	**0**	**400**	**0**	**0**	**0**	**0**		**0**	**0**	**0**	**0**	**0**	**200**	**0**	**0**
	6	HyMelt Reactor	5,400				500			59,800										
	6	HyMelt Reactor Nozzles																		
C	6																			

A0757500
MJF

		Coal to UAN	Hi. Press. Steam	Med. Press. Steam	Low Press. Steam	Lower Press. Steam	Cooling Water	Hi Press N2	Low Press N2	O2	Nat. Gas	PSA Tail Gas	BFW	BFW	Makeup water	Recycled Water**	Wastewater	Compres. Air	Carbon Dioxide	Power Avg. Demand
		Pressure, psig	**700**	**120**	**65**	**15**	**100**	**700**	**125**	**700**	**30**	**15**	**700**	**250**	**50.0**	**0.0**	**0.0**	**125**	**5**	
Rev	**Area**		**lbs//hr**	**lbs//hr**	**lbs//hr**	**lbs/hr**	**gpm**	**lbs//hr**	**lbs//hr**	**lbs//hr**	**MM BTU/h**	**MM BTU/h**	**gpm**	**gpm**	**gpm**	**gpm**	**gpm**	**scfm**	**lbs/hr**	**kw hr/hr**
F	**1**	**Urea- Ammonium Nitrate**	**37,627**		**28,571**		**17,363**						**134**		**50**	**-133**		**50**	**45,946**	**5,090**
	6	Venturi Scrubber Heater, 31138	1,000																	
	6	Slag Granulation Cooler, 31301					1,068													
	6	Reactor Quench, 32104						1,773							172					
	6	Venturi Makeup,50301													111					
	6	Slag Granulation Makeup, 35506													19					
	6	Slag Pit Pump 41803															14			
	6	Powdered Coal Pneu.Conv. 43901							1,119									79		
	6	Burnt Lime Pneu.Conv, 43903																28		
F	6	Deleted																		
	6	Reactor Injection System, 47602						25,266												
	6	Vessel Preheat Lance, 44901									3									
	6	HyMelt Area Baghouse, 50407							222											
	6	Coal Grinding Mill, 46101							454		1	16								
	6	Scrap Metal Lock Hopper, 43612						62												
	6	Process Vent Header							443											
	6	Slag Metal Runner									1									
	6	**HyMelt®Subtotal**	**6,400**	**0**	**0**	**0**	**1,568**	**27,101**	**2,238**	**59,800**	**4**	**16**	**0**	**0**	**302**	**0**	**14**	**107**	**0**	**1,698**
C	7	WGS Cooler 31130					3,000													
C	7	Waste Heat Boiler, 44207			-50,000									102			2			
C	7	Waste Heat Boiler, 44208				-85,000								173						
C	7	WGS Quench, 32113													65					
C	7	WGS Quench, 32114													32					
C	7	Condensate Stripper, 32105				19,600										-235				
C	**7**	**WGS Subtotal**	**0**	**0**	**-50,000**	**-65,400**	**3,000**	**0**	**0**	**0**	**0**		**0**	**275**	**97**	**-235**	**2**	**0**	**0**	**0**
F	8	H2S Recycle Gas cooler 31133 7 H2S Compress Intercooler					368													
F	8	Reflux Condenser, 31141					1,200													
F	8	Stripper Reboiler, 31134		55,172																
F	8	H2S Flash Cooler, 31139 & Lean Solvent Cooler					93													
F	8	HyMelt AG Refrig. Unit					2,498													
	8	Selexol Makeup, 41124													3		2			

		Coal to UAN	Hi. Press. Steam	Med. Press. Steam	Low Press. Steam	Lower Press. Steam	Cooling Water	Hi Press N2	Low Press N2	O2	Nat. Gas	PSA Tail Gas	BFW	BFW	Makeup water	Recycled Water**	Wastewater	Compres. Air	Carbon Dioxide	Power Avg. Demand
		Pressure, psig	700	120	65	15	100	700	125	700	30	15	700	250	50.0	0.0	0.0	125	5	
Rev	Area		lbs//hr	lbs//hr	lbs//hr	lbs/hr	gpm	lbs//hr	lbs//hr	lbs//hr	MM BTU/h	MM BTU/h	gpm	gpm	gpm	gpm	gpm	scfm	lbs/hr	kw hr/hr
F	1	**Urea- Ammonium Nitrate**	37,627		28,571		17,363						134		50	-133		50	45,946	5,090
	8	Compressor Seals						454	454											
F	8	**HyMelt® AGR Subtotal**	0	55,172	0	0	4,159	454	454	0	0	0	0	0	3	0	2	300	-225,264	4,437
F	9	Deleted CO2 Compression																		
F	9	Deleted CO2 Compression																		
F	9	Deleted CO2 Compression																		
F	9	Deleted CO2 Compression																		
F	9	**CO2 Subtotal**	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0
F	10	Cooling Tower,													1,087	364	363			
E	10	Deaerator/Demineralizer				7,134									396					
F	10	Main Plant Boiler	-40,548	-55,172	0						15	98	81			4				
	10	Flare Stack, 50903							443				5							
F	10	**Utilities Subtotal**	-40,548	-55,172	0	7,134	0	0	443	0	15	98	86	0	1,483	368	363	500	0	3,652
F	12	**Infrastructure Subtotal**													3					406
F		**Grand Total**	0	0	-6,485	-58,266	36,278	75,555	3,624	59,800	29	0	329	281	1,939	0	383	1,687	-179,318	26,540
								tpd	tpd	tpd									tpd	
								907	43	718									2152	Excess CO2 vented

		Nitrogen Requirement, lbmol/h	1710	47880	lb/h
		NH3 produced, lbs/h	58140		
		Ammonia tpd	698		

	Note	Revision history
	**	Recycled water used for cooling tower makeup

Exhibit 16 FEL 2 Capital Cost Estimate through NH3 (1 page)

AKER KVÆRNER	AREA 1 COG CONDITIONING	AREA 2 ACID GAS SCRUBBING	AREA 3A COG SYNGAS PREP	AREA 3B HYMELT SYNGAS	AREA 4 SYNTHETHIC AMMONIA PLANT	AREA 6A HYMELT 1 RXR	AREA 7 WATER GAS SHIFT	AREA 8 ACID GAS SCRUBBING	AREA 9 CO2 COMPRESS & STORAGE	AREA 10 UTILITIES	AREA 11 SITE PREP	AREA 12A MISC INFRASTRUCT.	AREA 12B MISC INFRASTRUCT.	TOTALS ALL AREAS (Coal/COG to NH3)	TOTALS Areas 3B,6,7,8,12A (Coal to H2)
EQUIPMENT	7,885,291	12,287,968	4,259,713	5,489,013	33,308,547	31,933,695	4,937,518	20,733,692	13,639,214	11,784,923		1,527,351	6,673,054	154,459,978	64,621,269
PIPING	1,226,175	1,271,959	207,942	196,559		3,148,558	1,177,581	2,253,888	2,666,721	3,540,955		396,132		16,086,470	7,172,719
CIVIL	196,317	235,666	29,030	157,328		3,026,419	236,274	637,423	498,218	1,351,719	6,889,504	971,399	3,429,557	17,658,853	5,028,843
STEEL	173,415	135,196	34,394			9,400,918			523,686	312,446		2,422,987		13,003,042	11,823,905
INSTRUMENTS	567,046	365,792	196,702	184,093		4,545,748	930,047	1,258,376	2,409,591	1,842,791				12,300,186	6,918,264
ELECTRICAL	19,079	17,124	7,064	78,870		5,969,686	691,439	2,764,062	39,278	717,752		110,911		10,415,263	9,614,966
INSULATION	428,970	366,358	58,010	38,153		236,527	199,978	396,300	1,490,477	478,109				3,692,883	870,959
PAINT	96,649	106,481	19,291	15,524		1,872,915	64,930	130,203	129,991	354,271				2,790,255	2,083,572
Total Direct Field Costs	10,592,942	14,786,544	4,812,144	6,159,541	33,308,547	60,134,465	8,237,767	28,173,944	21,397,178	20,382,965	6,889,504	5,428,780	10,102,610	230,406,930	108,134,496
CONSUMABLES	86,108	88,458	24,928	23,077		768,793	90,449	213,585	229,697	275,129	279,774	57,526	163,313	2,300,836	1,153,430
VENDOR REPRESENTATIVES	45,789	66,561	21,983	28,875		236,606	33,651	123,071	87,844	78,987	11,133	22,350	36,904	793,756	444,553
EQUIPMENT RENTAL	131,000	147,600	50,600	37,100		981,500	105,300	352,100	325,000	407,800	396,347	156,400	231,360	3,322,107	1,632,400
OFFICE FIELD STAFF	71,756	73,715	20,773	19,231		640,661	75,374	177,988	191,414	229,274	233,145	47,938	136,094	1,917,364	961,191
CONTRACT FEE	215,269	221,144	62,320	57,692		1,921,983	226,123	533,963	574,242	687,823	699,435	143,814	408,282	5,752,091	2,883,574
TEMP CONST FACILITIES	43,054	44,229	12,464	11,538		384,397	45,225	106,793	114,848	137,565	139,887	28,763	81,656	1,150,418	576,715
Indirect Field Costs	592,976	641,707	193,069	177,513	0	4,933,940	576,122	1,507,499	1,523,046	1,816,579	1,759,721	456,790	1,057,609	15,236,571	7,651,863
Total Field Costs	11,185,918	15,428,251	5,005,213	6,337,053	33,308,547	65,068,405	8,813,889	29,681,443	22,920,224	22,199,544	8,649,225	5,885,570	11,160,220	245,643,501	115,786,360
FREIGHT	457,891	665,612	219,834	288,746		2,366,062	336,514	1,230,710	878,445	789,874	111,330	223,501	369,036	7,937,556	4,445,533
ESCALATION	317,788	443,596	144,364	184,786		1,804,034	247,133	845,218	641,915	611,489	206,685	162,863	303,078	5,912,952	3,244,035
DETAIL ENGINEERING	635,576	887,193	288,729	369,572		7,817,480	823,777	1,690,437	1,283,831	1,222,978	413,370	434,302	808,209	16,675,454	11,135,569
PROJ. MGT / PROC. / H.O. SUPPORT	529,647	739,327	240,607	307,977		3,006,723	411,888	1,408,697	1,069,859	1,019,148	344,475	271,439	505,131	9,854,919	5,406,725
CONSTRUCTION MGT.	635,576	887,193	288,729	369,572	1,998,513	3,608,068	494,266	1,690,437	1,283,831	1,222,978	413,370	325,727	606,157	13,824,416	6,488,070
START-UP & COMMISSIONING	317,788	443,596	144,364	123,191	999,256	2,405,379	164,755	563,479	427,944	407,659	0	108,576	202,052	6,308,040	3,365,379
CONTINGENCY	1,408,019	1,949,477	633,184	798,090	5,082,884	12,050,661	1,355,067	4,453,250	3,420,726	3,846,314	1,824,922	1,334,156	2,511,699	40,668,448	19,991,224
Total Non-Field Costs	4,302,286	6,015,994	1,959,811	2,441,935	8,080,653	33,058,408	3,833,400	11,882,228	9,006,550	9,120,440	3,314,153	2,860,564	5,305,362	101,180,000	54,080,000
Total Installed Cost 18DEC07	15,490,000	21,440,000	6,970,000	8,780,000	41,390,000	98,130,000	12,650,000	41,560,000	31,930,000	31,320,000	11,960,000	8,750,000	16,470,000	346,830,000	169,860,000
Cost Reductions	0	0	0	0	0	-$35,533,755	-1,346,045	-10,648				-818,172		-37,710,000	-37,710,000
Rev. Total Installed Cost 19FEB08	15,490,000	21,440,000	6,970,000	8,780,000	41,390,000	62,600,000	11,300,000	41,550,000	31,930,000	31,320,000	11,960,000	7,930,000	16,470,000	309,120,000	132,150,000

Exhibit 17 Impact of Coal Particle Size (6 pages)

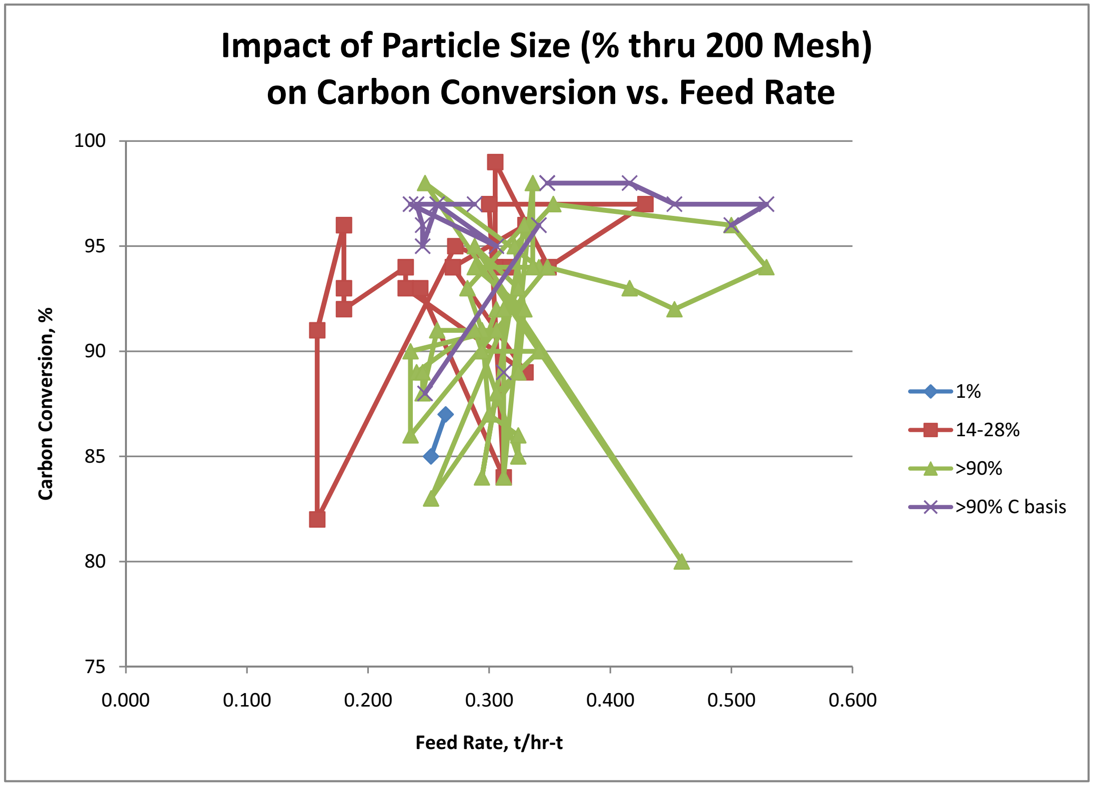
Exhibit 3b

Table A:A1 Composition of raw mate .ls

	Proximate analysis (dry)							Ultimate analysis (incl moist)								Trace (incl moist) (µg/g)						
	PC	Moist	VM	Ash	Cfix	HHV	LHV	C	H	N	O	S	S	S	S	Cl	Zn	Cu	Pb	Hg	As	Cd
		(%)	(%)	(%)	(%)	(kJ/kg)		(%)	(%)	(%)	(%)	(%)	(FeS)	(SO_4)	(org)							
A1	1-5	2.2	35.2	15.0	49.7	28.4	27.4	66.9	4.7	2.1	11.1	0.45	0.09	0.020	0.34	<0.01	51.0	39.0	19.0	0.12	6.0	-
A2	6-18:1	2.7	34.7	14.0	51.3	29.0	27.9	67.2	4.9	2.3	11.7	0.33	-	-	-	·	·	·	·	·	·	·
B	18:2-28	0.5	22.5	9.4	68.0	32.4	31.5	79.5	4.2	1.2	5.4	0.33	0.05	0.005	0.28	<0.01	8.5	10.0	5.7	0.05	0.7	0.11
C	29	2.0	31.9	15.4	52.7	28.5	27.6	67.8	4.3	1.4	10.2	1.18	-	-	-	-	-	-	-	-	-	-
D1	30	2.3	33.7	9.4	57.0	30.3	29.3	72.7	4.7	1.7	11.2	0.61	0.027	0.110	0.42	0.02	-	-	-	-	-	-
D2	31+41-42	2.5	32.5	13.2	54.3	28.8	27.9	68.4	4.4	1.6	11.6	1.10	0.067	0.330	0.68	0.02	-	-	-	-	-	-
E	32-41	0.9	32.8	8.5	58.8	32.3	31.3	77.1	4.7	1.7	7.2	0.84	-	-	-	0.03	-	-	-	-	-	-
Lime																-	180	36	-	0.13	-	1.00

	Ash (%)								Particle size (mm)						% thru 200 mesh (.074 mm)
	Fe_3O_4	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	S	CO_2	>0.5	0.25	0.125	0.063	>0.063		
A1	-	52.2	19.3	5.4	9.50	4.0	-	-	6.3	27.0	38.7	28.0	0.0	KOZNEZT, U.S.S.R.	28
A2	-	54.9	20.2	6.6	5.20	3.1	-	-	27.7	31.9	26.2	10.1	4.0	KOZNEZT, U.S.S.R.	14
B	-	53.2	26.8	5.6	4.70	1.3	-	-	0.6	0.4	3.9	37.7	57.5	SVEAKUL, NORWAY	95
C	-	52.0	23.7	8.5	4.04	1.8	-	-	0.2	0.8	4.2	43.6	51.3	SCOTLAND	95
D1	-	59.2	21.6	7.0	2.80	1.3	-	-	86.7	9.9	2.1	0.9	0.2	KOZNEZT, U.S.S.R.	1
D2	-	51.7	18.8	13.2	4.40	2.2	-	-	8.4	30.4	47.5	12.2	1.5	KOZNEZT, U.S.S.R.	14
E	-	44.5	21.3	11.5	6.00	2.3	-	-	0.0	0.6	7.0	61.2	31.2	{LONGYER BYEN, NORWAY BLACK WATER, AUSTRALIA	92
Lime	-	2.5	1.0	-	93.50	1.3	0.02	0.3							
Dolo-lime	-	0.2	0.1	0.4	59.50	40.5	0.01	0.2							
Iron ore	3.0	2.0	0.5	91.3	0.10	0.3									
Refr. DS0017 (wall)		0.1	0.1	0.2	0.70	99.0									
BK0012 (bott)		0.6	0.4	0.5	1.00	97.0									

	30a	30b	7	9a	9b	10a	10b	11	12a	12b	12b	13	14	15a	15b	16a	16b	16c
Time, min	137	137	125	60	60	60	60	80	47	47	47	160	80	120	120	73	73	73
Coal type/size	D1	D1	A2	A2	A2	A2	A2	A2	A2	A2	A2	A2	A2	A2	A2	A2	A2	A2
Pressure, barg	2.0	1.5	1.0	1.0	1.5	0.2	1.0	0.0	0.5	1.0	0.0	0.5	2.0	1.0	1.0	1.5	1.6	1.0
Feed rate, t/hr-t	0.264	0.252	0.330	0.270	0.330	0.231	0.231	0.180	0.180	0.180	0.180	0.158	0.158	0.272	0.316	0.305	0.305	0.349
Conversion																		
Voi/Voc	87	85	96	94	89	93	94	92	93	93	96	91	82	95	94	94	99	94
Dust basis																		
Coal % thru 200 mesh	1	1	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14	14



17	18a	31	6	32a	32b	32c	33a	33b	33c	34	35a	35b	35a	36b	37a	37b	38
190	125	185	40	100	100	100	147	147	147	160	240	240	260	260	160	160	90
A2	A2	D2	A1	E	E	E	E	E	E	E	E	E	E	E	E	E	E
1.0	2.0	1.6	0.9	1.1	2.0	1.5	2.0	2.0	2.0	2.0	1.6	2.0	2.0	2.0	2.0	1.6	1.0
0.429	0.300	0.312	0.243	0.341	0.247	0.459	0.288	0.324	0.252	0.324	0.329	0.306	0.294	0.341	0.306	0.294	0.329
97	97	84	93	94	98	80	95	93	83	89	92	92	90	90	88	84	96
	95			96	88												
14	14	14	28	92	92	92	92	92	92	92	92	92	92	92	92	92	92

39a	39b	40a	40b	41	18b	19a	19b	20	21a
300	300	240	240	300	125	85	85	130	230
E	E	E	E	E/C2	B	B	B	B	B
2.0	2.0	2.0	2.0	2.0	1.0	1.0	0.5	2.0	1.7
0.282	0.294	0.300	0.324	0.324	0.288	0.240	0.245	0.245	0.257
93	91	87	86	85	91	89	89	88	91
					97	97	96	95	97
92	92	92	92	94	95	95	95	95	95

21b	22	23	24a	24b	25a	25b	26a	26b	27a	27b	27c	28a	28b	28c	29
230		210	95	95	80	85	100	100	143	143	143	140	140	140	275
B	B	B	B	B	B	B	B	B	B	B	B	B	B	B	C
1.7	1.5	0.5	0.6	1.0	2.0	2.0	2.0	2.5	2.0	2.0	2.0	2.0	2.0	2.0	2.0
0.306	0.235	0.235	0.348	0.348	0.416	0.453	0.529	0.500	0.353	0.321	0.329	0.288	0.336	0.336	0.312
91	90	86	94	94	93	92	94	96	97	95	92	94	94	98	84
95	97		98	98	98	97	97	96							89
95	95	95	95	95	95	95	95	95	95	95	95	95	95	95	95

42

60
C2
1.0
0.312

92

95

Exhibit 18 Environmental, Health and Safety Aspects (11 pages)

Aker Solutions

SPECIFICATION

A0757603	R003S	1 of 11
Contract No.	Specification No.	Page

SUBJECT: Environmental, Health and Safety Aspects

CLIENT: American Freedom Fuels and Chemicals LLC

FACILITY: Coal to Nitrogen Products

LOCATION: Later

DISCIPLINE: Process Technology ORIGINATOR: M.J.Friedrich

REVISION	A						
DATE OF ISSUE dd MMM yy	23 JUN 08						
TYPE OF ISSUE	R = Review	A = Approval		D = Design	C = Construction		V = Void
	R						
APPROVALS:							
Discipline Leader							
Discipline Manager	MJF						
QC Engineer							
Project / Engineering Manager	PFA						
Client (If Required)							
Other							

REFERENCES:

Table of Contents

1.0 Introduction

1.1 The following is a description of the Environmental, Health and Safety aspects of the proposed Coal to Nitrogen Products plant. The plant will convert coal and biomass to a raw gas containing carbon monoxide and hydrogen and other contaminants. The particulate will be removed in the first stage and then most of the carbon monoxide will be reacted with water vapor to form hydrogen. The hydrogen sulfide will be removed and recovered as liquid sulfur. The hydrogen will be purified and used as a feedstock with nitrogen to manufacture anhydrous ammonia. The ammonia will feed plant to produce urea. Unreacted ammonia will be fed to a nitric acid plant. The nitric acid will be combined with additional unreacted ammonia to produce ammonium nitrate. Urea, ammonium nitrate and urea/ammonium nitrate solution are the primary products.

1.2 The plant will have a number of process hazards that has the potential to affect the health and safety of the workers and community as well as environment of the surrounding area. The plant will be designed and operated to eliminate these hazards from causing harm to people or damage to the environment. A process hazard review process will be implemented during the design process and continued during operations to identify the various process hazards. The review committee will recommend actions to the project manager and plant manager when potential serious process hazard risks are identified.

2.0 Hazardous Process Materials

2.1 The following table lists the major process materials that will be found in the plant. Potential hazards and the safeguards that will be included in the design are listed for each material.

Area	Material	Potential Hazard	Safeguard
Raw Materials	Coal	Fire	• Fire hydrants and hose reels throughout the plant. • Sprinkler systems, • Fire Detection in bins, • Inert gas purge in grinding mill and storage bins.
	Coal	Particulate – air borne	• Conveyor transfer and bin vents points will have dust collection system to a fabric filter. • Outdoor transfer or storage piles will use mist dust suppression.
	Coal	Contaminated ground water	• Stormwater from coal storage will be collected, monitored and treated if necessary.
	Lime	Particulate –air borne	• All lime handling will be contained using pneumatic conveyors. • Bin exhausts will have fabric filters.
	Biomass	Fire	Same as coal safeguards
		Particulate – air	Same as coal Safeguards

Area	Material	Potential Hazard	Safeguard
		borne	
HyMelt® Plant	Molten Metal and slag	Fire	• Molten metal will be contained in refractory lined system. • Outside shell of reactor will be monitored for temperature to determine if there is wear or a fault in the refractory system. • Special sand pit will be used to dump molten metal and slag
	Molten Metal and slag	Fume	Fume from molten metal and slag will be collected and sent to a housekeeping bagfilter system when the reactor is dumped for maintenance.
	Molten Metal and slag	Explosion when contacted with water	• Sand pit will be kept dry for maintenance • Slag will be granulated continuously using relatively high flow of water to avoid rapid reaction. • Granulation pressure vessel will have rupture discs to protect against over pressure. Exhaust gas will be sent to an emergency quench vessel and then to a flare.
	Slag	Contaminated Wastewater	Stormwater from slag storage will be collected, monitored and treated if necessary.
	Scrap Metal	Contaminated with hazardous materials	Scrap metal will be monitored at receipt. Only clean scrap will be accepted.
	Oxygen	Fire	• Fire hydrants, hose reels, sprinklers • Fire detection and alarms • Fire breaks in steel piping • Nickel containing trim in control valves • Automatic shutoff
	Nitrogen	Low oxygen due to displacement	• Detectors and alarms in confined spaces
	Steam	Burns	• All steam piping and related equipment will be insulated for personnel protection
	Steam	Explosion due to overpressure	• Design will follow ASME Boiler code for pressure vessels. • All pressure vessels will have relief

Area	Material	Potential Hazard	Safeguard
			valves that discharge to safe locations.
	Raw Syngas	Fire	• Fire hydrants, hose reels, sprinklers • Fire detection and alarms • Automated shutdown • Raw Syngas is normally contained in pressure piping and vessels. •
	Raw Syngas	Particulate – plugging equipment, pollution	• Venturi scrubber will remove particulate
	Raw Syngas	Carbon Monoxide poisoning	• Stationary and personal carbon monoxide monitors and alarms. • All buildings and rooms to be well ventilated. • All process waters will be degassed before entering drain systems.
	Raw Syngas	Sulfur- pollution	• Water Gas shift will convert organic sulfur to inorganic sulfur • Acid Gas Removal System (Selexol) will remove Hydrogen Sulfide to 1 PPM • Sulfur will be recovered as liquid sulfur for sale
	Raw Syngas	Mercury- - pollution	• Activated Carbon bed will collect mercury • Saturated carbon bed will be taken offsite for recycle or safe disposal.
	Process contact water	Suspended solids - pollution	• Clarifier and filters will collect and concentrate solids as a cake • Cake will be either sent to a recycler or sent to secure landfill.
	Process Contact water blowdown	Pollution, acidic or basic, high COD, heavy metals	• Process contact water will be treated to meet pretreatment requirements for discharge to POTW or surface stream.
Water Gas Shift	Hydrogen	Fire	• See Raw Syngas
	Carbon dioxide	Low oxygen due to displacement	See Nitrogen
	Catalyst	Particulate, airborne	• Workers will wear dust respirators when charging and dumping reactors

Area	**Material**	**Potential Hazard**	**Safeguard**
	Spent Catalyst	Solid waste pollution	• Catalyst will be sent to recycler or sent to secure landfill.
	Sour Water	Pollution, acidic, volatile organics	• Sour water condensate will be steam stripped and recycled back into the process or treated before discharge. The offgases will be sent to the Claus plant to recover the sulfur dispose of the organic compounds.
Acid Gas Removal	Selexol Solvent	Ground Pollution	• Area will be curbed and all spills will be collected and either recycled or treated or sent offsite for disposal. • A drain tank will collect the solvent during maintenance. The solvent will be pumped back into the system after maint.
	Carbon Dioxide Vent	Global Warming	• A portion of the carbon dioxide will e used as feedstock to produce urea.
Cooling Tower	Mist and particulate	Air borne pollution	• Cooling tower will have mist eliminators to minimize droplet carryover. • Suspended solid loading will be minimized by controlling Blowdown. • Sidestream strainer will help minimize TSS.
Boiler	Fluegas	Nitrous Oxides-Pollution	• Boiler will use low or ultra low NOx burners to meet NOx emission standards
	Fluegas	Sulfur Dioxide-pollution	• Fuel gas will be low in sulfur
	Flue gas	Carbon Monoxide - pollution	• High efficiency burner will be specified
	Blowdown	Effluent –pollution	• Blowdown will be collected and treated to meet discharge requirements
	Boiler treatment chemicals	Toxic, ground pollution	• Contained in diked areas • Separated to prevent rapid reactions • Fire protection included.
Demineralizer	Blowdown	Effluent – pollutions	See Boiler Blowdown
	Acid/Caustic	Chemical burns/ pollutions/reactions	• Water treatment chemicals will be stored in diked areas. Spills will be contained • Caustic and acid tanks will be separated to prevent rapid reactions

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Area	Material	Potential Hazard	Safeguard
Wastewater	Contaminated water	Surface water Pollution	• Water will be treated to meet discharge requirements • Steam stripper and activated carbon beds will be used as a minimum to remove organic and dissolved gases.
	Stripper offgas	Air pollution	• Organics will be destroyed in a thermal oxidizer
Flare	Flammable Gases	Fire, excess heat can harm workers and equipment	• Flare will be designed to be high enough or separated from normal operating areas to minimize health risk. • Flare will have automated burner safety management system to prevent explosions. • Flare will have inert gas purge to prevent explosive mixtures • Water seal will prevent flashbacks.
Emergency Power	Flue Gas	Air pollutions	• NOx, CO, particulate control will be included with the emergency power package
Synthetic Ammonia	Ammonia	Toxic	• Ammonia will be sent to a flare if there is an accidental discharge
UAN32	Nitric Acid	Corrosive	• Nitric acid processing will be contained in diked areas
UAN 32	Urea	Pollution	• Urea processing will be contained in diked areas

3.0 Compatibility with Environmental Laws including the Clean Air Act

3.1 The Coal to Nitrogen Products plant will be designed to meet all environmental laws for air emissions, effluent, solid waste, noise and noxious odors.

3.2 Total annual air emissions of each major contaminant will be controlled to less than 100 tons so that the facility will be considered a minor source. Hazardous air pollutants will meet the minor source category threshold of 25 tpy or less. The largest sources of air emissions will be the boiler, emissions from material handling, and the carbon dioxide vented from the acid gas removal system.

3.3 The design will meet the ambient air quality standards for all pollutants through a combination of using best available control technology and through stacks designed to disperse the pollutants to the required levels

3.4 Dispersion studies will also be utilizes to determine if the plant has any impact on visibility or acid deposition in protected wilderness areas. The results of such studies will guide the specification of pollution control technologies and the height of the stacks required.

3.5 Wastewater will be treated to meet either pretreatment standard for the local publicly owned treatment works (POTW) or for discharge to a nearby surface stream. The anticipated treatment would include removal of suspended solids, oil and grease, ammonia, and total organics.

3.6 Solid waste may include the filter cake from the dust collected by the venturi scrubber and the suspended solids from slag granulation. Studies are scheduled to determine if this material has any recoverable value for agricultural, building materials or iron value. If no uses can found and the cost to recycle the material is prohibitive, the material will be tested and sent to the appropriate landfill.

3.7 Another solid waste will be the slag that will be continuously granulated. The same types of studies are scheduled for the slag as the dust.

3.8 Iron from the reactor will be dumped approx. every three months prior to maintenance on the bottom tuyeres and the reactor refractory. The metal will be sent to a recycler to recover the iron units.

3.9 Waste refractory will either be sent to a secure landfill. Recycling will be explored once the plant is operating.

4.0 Process Products

4.1 The following table lists the intermediate and final products from the Coal to nitrogen product plant, their environmental classification and methods proposed for disposition.

Product	Environmental Classification	Method of Disposition	Comment
Hydrogen	Highly Flammable, Severe explosion hazard, products of combustion are not hazardous. Acute systemic hazard for inhalation is low.	Feedstock for the synthetic ammonia plant	Intermediate
Fuel Gas from PSA	Same as hydrogen for flammability and explosion. Carbon monoxide in the gas raises the acute systemic to a high rating.	Fuel for the steam boiler	Intermediate
Carbon Dioxide	Inert material, Acute systemic for inhalation is slight but can be an asphixiant in high concentrations. Global warming gas.	Part is feedstock for the Urea plant and the balance is vented.	Intermediate and final for vent.
Ammonia (anhydrous)	High for Acute local irritant, ingestion and inhalation. Moderate	Feedstock for the urea plant. May be	Intermediate for urea and

	fire hazard when exposed to flame. Moderate explosion hazard. Toxic fumes(NOx) emitted when burned	sold as anhydrous product also	final for ammonia sales
Nitric Acid (aqueous)	Highly corrosive material. High for Acute local irritant, ingestion, inhalation. Also high for acute systemic inhalation. Moderate for chronic local irritant. Fire hazard is moderate since it is a powerful oxidizing agent Explosion hazard slight when contacted with reducing agents Emits toxic NOx fumes when heated. Will react with water or steam and produce heat and toxic fumes.	Feedstock for the ammonium nitrate plant	Intermediate
UAN, Urea& Ammonium Nitrate Solutions	Low irritant, not flammable as aqueous solution. Toxic gases will be emitted if solution is heated to decomposition (237F) Solution may become explosive if combined with a hazardous substance or dried to a low percentage of water. Spills need to be cleaned without flushing. Contaminated soil can be spread like fertilizer.	Product to be shipped by tanker over the road, rail or barge	Final product
Slag	May emit hydrogen sulfide, may leach heavy metals. Testing required. Not flammable.	Feedstock for recycling operation or may be landfilled	
Clarifier Filter Cake (Dust)	May emit hydrogen sulfide, may leach heavy metals. Testing required. May be flammable when dried.	Feedstock for recycling operation or may be landfilled	

5.0 Emission Control Technology Comparison

5.1 Coal Gasification compared to Coal Combustion

5.1.1 The following table compares the technologies utilized to remove various pollutants from coal gasification processes and coal combustion processes.

Pollutant	Coal Gasification	Coal Combustion	Comment
Particulate	Utilizes high pressure drop venturi scrubber to remove micron size	Bagfilter utilized to meet PM10 and 2.5	Venturi selected to humidify air for water gas shift. Venturi will also

	particles. Typically 5 mg/NM3 expected.		absorb hydrochloric acid. Bagfilter is able to remove smaller particles.
Organic sulfur	Water gas shift process converts to inorganic H2S. 1 PPM level expected.	Converted to sulfur dioxide in combustion process	Organic sulfur conversion must be addressed in coal gasification prior to sulfur removal.
Inorganic sulfur	Selexol process washes H2S out of gas to ppm levels. Sulfur is recovered as salable product using Claus Plant	Lime slurry based scrubber washes SO2 from flue gas. Sulfur may be recovered as calcium sulfate that can be used to produce gypsum.	Coal gasification can achieve lower sulfur levels in gas. Byproduct sulfur has wider range of uses than gypsum and may be more valuable.
Nitrous Oxides	Nitrous oxides are not produced during gasification process. NOx can be controlled in ultra low NOx burners for combustion of Syngas. Nitrogen bearing compounds are removed from the gas such as ammonia.	Coal combustion produces more NOx than either liquid or gas fuels. Selective catalytic combustion is typically specified to meet environmental requirements.	Coal gasification results in lower NOx. NOx removal is not required in the base production of Syngas.
Carbon monoxide	Carbon monoxide is produced in the gasification process. The carbon monoxide will be present in a fuel gas. Efficiency conversion to CO2 can be accomplished in gas combustion by controlling the temperature and oxygen level.	Coal combustion results in some carbon monoxide. Post combustion oxidation may be required for some locales.	Gasification may result in a less expensive carbon monoxide abatement system.
Mercury	Activated carbon beds will be remove mercury to low levels (ppm)	Activated carbon is typically injected into the flue gas to capture mercury. Up to 90 % removal can be achieved.	Lower levels of mercury can be removed from coal gas. Removal of Hg may be more economical with gasification.
Dioxin	Typically not formed in reducing environment.	May be formed depending on coal and flue gas temperature profile	Coal Combustion may require special controls for dioxins
Carbon Dioxide	Carbon Dioxide removed by the Selexol process.	Carbon dioxide is not typically removed from the	Carbon dioxide removal from combustion process

	The carbon dioxide vent is nearly 100% pure which allows it be recovered for other uses or sequestered	coal combustion process. Scrubbers would need to be installed.	would be more expensive than gasification.

5.2 Wastewater treatment

5.2.1 The process wastewater will contain organics and nitrogen bearing compounds such as ammonia. Typically, steam stripping will remove the bulk of volatile organics and free ammonia. Activated carbon may be used to lower organics and heavy metals to lower levels. The exact treatment system specified will depend on the effluent discharge requirements. Chemical or biological oxidation of the contaminants may be required. Treatability work to determine the optimum program cannot be accomplished prior to the plant startup. A flexible treatment program will be installed that may include offsite treatment until the plant operation becomes established.

5.3 Fugitive Emissions

5.3.1 Material handling will create fugitive emissions during transfers and from wind. The plant will utilize dust collection systems at stationary point sources. Portable sources will require dust suppression using water fog nozzles. Particulate from storage piles will be minimized by covering the piles or using sodium silicate sprays to form a surface that minimizes dust formation.

5.3.2 Seals for rotating equipment and for valves and flanged piping that handles fluids with volatile organics will be monitored to minimize fugitive emissions. Seals will be tightened or repaired as required. Compressors will utilize seals externally purged with inert gas. Pumps may be used mechanical seals.

Exhibit 19 Coal and Biomass Blend Calculations (1 page)

Coal and Biomass Blend Calculations

Blend % -->	80%	20%	100%
Composition, wt%	Coal	Biomass	Blend
C	72.64	48.50	67.81
H	5.38	6.30	5.56
O	9.57	43.37	16.33
N	1.65	0.30	1.38
S	1.96	0.10	1.59
Cl	-	0.13	0.03
Inorg	8.80	1.30	7.30
Total	100.00	100.00	100.00
HHV, btu/lb	12,500	7,224	11,445
Moisture, as rec'd, wt%	8.0	14.2	9.24

Exhibit 20 HyMelt M&E Balance – Preliminary by EnviRes (2 pages)

ON-STREAM MATERIAL BALANCE

Case: Coal/Biomass to N Products Project
Date: 6/20/2008

Flows in lb/hr	HHV btu/lb	Reactor Raw Syngas	Quench Water	Quenched Syngas	Dewatered Slag	Venturi Dried Dust	Unshifted Syngas	Unshifted AGR Prod	Syngas to WGS	Prod from WGS	Shifted Gas AGR Prod	Extracted CO2
H2	61,100	4,897	0	5,693	0	0	336	336	5,357	11,958	11,958	0
CO	4,347	110,623	0	99,560	0	0	5,874	5,874	93,686	1,967	1,967	0
CO2	0	10,429	0	27,810	0	0	1,641	131	26,169	146,441	11,715	136,235
H2S	7,100	638	0	638	0	0	38	0	601	601	0	0
Slag/dust	0	10,929	0	0	9,004	1,926	0	0	0	0	0	0
H20	0	4,269	126,405	123,559	0	0	7,290	26	116,269	628	443	0
N2	0	16,391	0	16,391	0	0	967	967	15,424	15,424	15,424	0
CH4	23,879	443	0	443	0	0	26	0	417	417	417	0
NH3	9,668	0	0	0	0	0	0	0	0	0	0	0
Total		158,620	126,405	274,096	9,004	1,926	16,172	7,334	257,924	177,437	41,925	136,235
State		Vapor	Liquid	Vapor	Solid	Solid	Vapor	Vapor	Vapor	Vapor	Vapor	Vapor
Temp, F		2,700	100	782	120	120	400	120	400	120	120	120
Press, psig		500	500	490	0	0	490	480	490	470	460	8
Density, lb/ft3		0.305	62.400	0.678			0.980	1.330	0.980	1.315	0.441	0.152
Avg. MW		20.7	18.0	18.9			18.9	17.7	18.9	17.8	6.1	44.0
Ht cap, btu/mol-F		9.12	8.42	8.46			8.09	7.00	8.09	8.93	7.14	12.96
Vol flow, acfm		8,672		6,733			275	92	4,388	2,249	1,584	14,927
HHV, mil btu/hr		795						46			749	
HHV, BTU/lb		5,013									17,869	
Flows in lb-mol/hr	MW											
H2	2.0	2,429	0	2,824			167	167	2,658	5,932	5,932	0
CO	28.0	3,949	0	3,554			210	210	3,345	70	70	0
CO2	44.0	237	0	632			37	3	595	3,327	266	3,096
H2S	34.1	19	0	19			1	0	18	18	0	0
Slag/dust	56.1	195	0	0			0	0	0	0	0	0
H20	18.0	237	7,017	6,859			405	1	6,454	35	25	0
N2	28.0	585	0	585			35	35	551	551	551	0
CH4	16.0	28	0	28			2	0	26	26	26	0
NH3	17.0	0	0	0			0	0	0	0	0	0
Total		7,679	7,017	14,501			856	415	13,645	9,959	6,870	3,096

	Syngas Products from PSA		Syngas with		Clean Unshft	H2 from	Added	Feed to	NH3	Pure H2	F-T
Flows in lb/hr	H2	Fuel Gas	H2/CO ratio	Pure H2	Syngas	COG	N2	NH3	Product	Product	Tail Gas
H2	10,404	1,555	0	10,404	336	0	0	10,404	0	0	0
CO	0	1,967	0	0	5,874	0	0	0	0	0	0
CO2	0	11,715	0	0	131	0	0	0	0	0	0
H2S	0	0	0	0	0	0	0	0	0	0	0
Slag/dust	0	0	0	0	0	0	0	0	0	0	0
H20	0	443	0	0	26	0	0	0	0	0	0
N2	11,568	3,856	0	11,568	967	0	36,629	48,197	0	0	0
CH4	0	417	0	0	0	0	0	0	0	0	0
NH3	0	0	0	0	0	0	0	0	58,308	0	0
Total	21,972	19,953	0	21,972	7,334	0	36,629	58,601	58,308	0	0
State	Vapor	Vapor	Vapor	Vapor	Vapor	Vapor	Vapor	Vapor	Liquid	Vapor	Vapor
Temp, F	120	120	120	120	120	120	120	120	120	120	120
Press, psig	450	5	450	450	480	450	450	450	0	0	0
Density, lb/ft3	0.279	0.046	#DIV/0!	0.279	1.330	#DIV/0!	1.982	0.603		#DIV/0!	#DIV/0!
Avg. MW	3.9	15.4	#DIV/0!	3.9	17.7	#DIV/0!	28.0	8.5		#DIV/0!	#DIV/0!
Ht cap, BTU/mol-F	6.89	8.22	#DIV/0!	6.89	7.00	#DIV/0!	6.84	6.88		#DIV/0!	#DIV/0!
Vol flow, acfm	1,313	7,200	0	1,313	92	0	308	1,621		0	0
HHV, mil btu/hr	636	114	0	636	46	0				0	0
HHV, BTU/lb		5,688	#DIV/0!	28,931	6,280	#DIV/0!				#DIV/0!	#DIV/0!
Flows in lb-mol/hr											
H2	5,161	771	0	5,161	167	0	0	5,161	0	0	0
CO	0	70	0	0	210	0	0	0	0	0	0
CO2	0	266	0	0	3	0	0	0	0	0	0
H2S	0	0	0	0	0	0	0	0	0	0	0
Slag/dust	0	0	0	0	0	0	0	0	0	0	0
H20	0	25	0	0	1	0	0	0	0	0	0
N2	413	138	0	413	35	0	1,307	1,720	0	0	0
CH4	0	26	0	0	0	0	0	0	0	0	0
NH3	0	0	0	0	0	0	0	0	2,081	0	0
Total	5,574	1,296	0	5,574	415	0	1,307	6,881	2,081	0	0

REACTOR MATERIAL AND ENERGY BALANCE

	Flow		Ht of Formation		Cp=a+bT+cT^2+d/T^2 (cal/gmol-K)				Cp x Del T (cal/gmol)			Q (BTU/hr)	
	(lb/hr)	lbmol/hr	MW	cal/gmol	a	b	c	d	T2 (K)	T1 (K)	Q	from CpxT	from ht forma
Reactor In													
CxHx - water-free	55,497						See input page		298	377		-2,618,890	-30,982,353
Org N, as N2 (g)	1,044	37	28	0	6.5	0.001			298	377	-543	-36,428	incl above
Org O, as O2 (g)	12,351	386	32	0	8.27	0.000258	0	-187,700	298	377	-528	-366,582	incl above
Org S, as rhomb S	1,201	37	32	0	3.63	0.0064			298	377	-460	-31,022	incl above
Inorganics, as Si	5,541	197	28	0	5.74	0.000617		-101,000	298	377	-399	-141,769	incl above
H2O (g) in C feed	2,339	130	18	-68,317	8.22	0.00015	0.00000134		298	377	-669	-156,446	15,967,238
Makeup iron	366	7	56	0	4.13	0.00638			298	322	-146	-1,720	0
Solids, as CaO	3,748	67	56	0	11				298	322	-263	-31,614	0
N2 (g)	15,347	548	28	0	6.5	0.0010			298	311	-87	-85,732	0
CH4 (g) addition	0	0	16	-17,889	5.34	0.0115			298	311	-113	0	0
O2 (g) (fr O bal)	51,767	1,618	32	0	8.27	0.000258	0	-187,700	298	311	-81	-235,163	0
H2O (g) from ht bal	9,420	523	18	-57,798	8.22	0.00015	0.00000134		298	527	-1,950	-1,835,154	54,400,382
CO2 (g) addition	0	0	44	-94,052	10.34	0.00274		-195,500	298	311	-116	0	0
Total in	158,621												
Reactor Out													
H2	4,897	2,429	2	0	6.62	0.00081			1,755	298	10,859	47,483,389	0
H2O	4,269	237	18	-57,798	8.22	0.00015	0.00000134		1,755	298	15,297	6,524,872	24,652,887
CH4	443	28	16	-17,889	5.34	0.0115			1,755	298	24,986	1,243,343	-890,201
C dust	674	56	12	0	2.673	0.002617		-116,900	1,755	298	6,823	689,207	0
Fe dust	1,252	22	56	3,560	4.13	0.00638			1,755	298	15,563	627,823	143,615
Slag, as CaO	9,004	161	56	0	11				1,755	298	16,029	4,632,416	0
H2S	638	19	34	-4,815	7.2	0.0036			1,755	298	15,878	535,271	-162,325
N2	16,391	585	28	0	6.5	0.001			1,755	298	10,968	11,550,462	0
CO2	10,429	237	44	-94,052	10.34	0.00274		-195,500	1,755	298	17,516	7,471,390	-40,116,498
CO (from C bal)	110,623	3,949	28	-26,416	6.6	0.0012			1,755	298	11,413	81,133,180	-187,789,276
Total	158,620								Subtotal			156,350,833	-164,776,530
									Environmental loss				2,637,600
--									Incremental heat loss (gain)				5,762,149
Elemental analysis of C feedstock									Net heat input req'd				-25,948
C	51,288	4,270	12										
H, as H2	4,208	2,088	2										

Note: Ht of formation of liquid Fe set equal to ht of fusion

Reactor Mat Bal Check (lb/hr)		IN	OUT
	C	51,288	51,288
	H	5,524	5,524
	N	16,391	16,391
	O	74,562	74,562
	S+solids	10,856	10,856

Exhibit 21 Project Commercial Economics – by EnviRes (2 pages)

PROJECT ECONOMICS

Case Coal/Biomass to N Products Project
Date prepared 6/20/2008
Time to startup after finance 2 years
Time of loan payback 10 years
Interest rate on debt 8.5 %/year
Assumed debt portion 0 % of total capital
On-stream factor 95 %

			Totals	2 Gasifiers	Unshifted AGR	WGS	Shifted Gas AGR	Syngas PSA H2	Extra CO2 Compress	Used NH3 Plant	Liquor From Urea-Only Plant	(Used HNO3) UAN Plant	Urea Granules from UAN Plant	Cogen Plant w/ Offsites	Fischer-Tropsch Plant	- Methanol Plant	Extras
Design on-stream capacity				1,000	31	3,458	3,341	7,123	0	731	0	731	499	0	0	0	
Operating on-stream capacity				1,000	31	3,458	3,341	7,123	0	731	0	731	499	0	0	0	
Units				tpd C feed as rec'd	mol/hr CO2	mol/hr CO	mol/hr CO2	mol/hr feed	tpd	tpd NH3	tpd urea	tpd NH3 feed	tpd urea	mil btu/hr fd	bpd liquids	tpd	
Estimated Capital Costs			$	$	$	$	$	$	$	$	$	$	$	$	$	$	$
BL installed equipment	2008	base year	336,061,996	141,062,228	857,903	11,329,669	22,315,400	8,754,797	0	39,079,161	0	82,819,899	29,842,940	0	0	0	0
Off-sites	25	% of BL	84,015,499														
Startup and commissioning	3	% of BL	10,081,860														
Upfront royalty/fees			16,927,467	16,927,467													
Legal fees			0														
Bank advisory fee	2	% of total debt	0														
Approx. int prior to loan payback	14.9	% debt/year	0														
Debt service reserve	6	months debt serv	0														
Maintenance reserve	50	% of matl & suppl	0														
Approx. SG&A prior to start up	0.50	x annual SG&A	3,540,627														
Working capital	2	months O&M	13,905,123														
Total capital cost			464,532,573														
Operating and Maintenance Costs	Unit Values		$/year	$/year		$/year	$/year	$/year	$/year	$/year	$/year	$/year	$/year	$/year	$/year	$/year	$/year
H2	3.43	$/kscf	0														
C feedstock	59.8	$/ton as rec'd	20,720,526	20,720,526													
Oxygen	45.0	$/ton	9,064,839	9,064,839													
Nitrogen	25.0	$/ton	6,976,292	2,862,790	694		74,001			4,038,808							
Power	5.5	cents/kwh	10,636,192	777,192					0	6,550,791	0	3,274,439	33,770		0	0	0
Cooling water	6.0	cents/k gal	1,074,546	46,976	1,078		114,988				0	854,804	56,700		0	0	
Boiler feed water	1.40	$/k gal	517,603	120,236		208,589				73,028		115,749					
HP steam (600+ psig)	10.72	$/k lb	(1,275,437)	840,524							0	(2,115,961)			0	0	
MP & LP steam	10.61	$/k lb	4,569,054		40,410	(8,170,693)	4,311,011				0	6,196,753	2,191,572			0	
Makeup iron	350	$/ton	314,966	314,966													
CaO	70	$/ton	1,091,753	1,091,753													
Catalysts and other			1,314,239							104,468	0	983,116	226,655		0		
H2S disposal cost	0	$/ton	0		0		0										
Slag disposal cost	0	$/ton	0	0													
Direct operating labor, man-yrs	75	k $/man-yr	3,000,000	975,000	included	included	included	included	included	900,000	0	1,125,000	included	included	0	0	included
Maintenance labor @	0.7	%/yr on-site inv	2,352,434	<--													
Control lab labor @	5	% of oper labor	150,000	<--													
Maintenance materials @	1.5	%/yr on-site inv	5,040,930	<--													
Operating supplies @	20	% of oper labor	600,000	<--													
Plant overhead @	60	% of oper labor	1,800,000	<--													
Taxes and insurance @	2.0	%/yr fixed inv	8,401,550	<--													
Running royalty @	0	% of revenues	0	<--													
SG&A @	2.5	% of sales	7,081,254	<--													
Total O&M cost			83,430,739														
Approx. Debt Service			0														
Total Costs			83,430,739														
Revenues																	
NH3	750.0	$/ton	0							0							
Urea	655.8	$/ton urea	161,954,924								0	161,954,924					
NH4NO3	422.4	$/ton AN	108,909,645									108,909,645					
F-T diesel fuel	169.0	$/bbl	0												0		
F-T naphtha	114.4	$/bbl	0												0		
F-T wax	195.0	$/bbl	0												0		
Methanol	478	$/ton	0													0	
H2	22.4	$/mbtu	0					0									
Fuel gas	9.60	$/mbtu	12,385,600	(332,347)				12,717,947							0	0	
Power	5.5	cents/kwh	0											0			
CO2	10	$/ton	0						0		0	(2,516,353)					
Total revenues			283,250,169														
Free cash flow			199,819,430														
EBITA, $/year			199,819,430														
Approx. equity, $			464,532,573														
First year return on equity, %			43.0%														
Avg IRR to owners (excl. inflation), %			36.4%														

OPERATING REQUIREMENTS AND SOURCES OF REVENUES

Case Coal/Biomass to N Products Project
Date prepared 6/20/2008

Operating requirements	Totals	Gasifiers	Unshifted AGR	WGS	Shifted Gas AGR	Syngas PSA H2	Extra CO2 Compress	Used NH3 Plant	Liquor From Urea-Only Plant	(Used HNO3) UAN Plant	Urea Granules from UAN Plant	Cogen Plant w/ Offsites	Fischer-Tropsch Plant	- Methanol Plant	- - Extras
H2, scfm	0														
C feedstock, tpsd	1,000	1,000													
Oxygen supply, lb/hr	48,412	48,412													
Nitrogen supply, scfm	15,121	6,205	2		160			8,754							
Power, KW	31,579	1,698	77		8,263		0	14,312	0	7,154	74		0	0	0
Cooling water, gpm	38,273	1,568	36	2,406	3,838				0	28,532	1,893		0	0	
Boiler feed water, gpm	740	172		298				104		166					
HP steam, lbs/hr	(14,294)	9,420							0	(23,714)			0	0	
MP & LP steam, lbs/hr	51,762		458	(92,565)	48,839				0	70,202	24,828			0	
Makeup iron, t/yr	900	900													
CaO, t/d	45	45													
Catalysts and other, $/year	1,314,239							104,468	0	983,116	226,655		0		
H2S sent to disposal, lb/hr	638		38		601										
Slag produced, lb/hr	8,999	8,999													
Direct operating labor, # of operators	40	13	included	included	included	included	included	12	0	15	included	included	0	0	included
Sources of revenues															
NH3, tpd	0							0							
Urea (70% liquor), tpd as urea	712								0	712					
Ammonium nitrate (83% solution), tpd as AN	744									744					
F-T diesel fuel, bpsd	0												0		
F-T naphtha, bpsd	0												0		
F-T wax, bpsd	0												0		
Methanol, tpsd	0													0	
H2, mil btu/hr	0					0									
Fuel gas, mil btu/hr	155	(4)				159							0	0	
Power, MW	0											0			
Net Compressed CO2 product, tpd	0	0					0		0	(726)					

Cash Flows for Simplified Internal Rate of Return Calcs		Startup time=
Year	Description	2
1	Equity	(232,266,286)
2	"	(232,266,286)
3	Free cash flow (before inflation)	199,819,430
4	"	199,819,430
5	"	199,819,430
6	"	199,819,430
7	"	199,819,430
8	"	199,819,430
9	"	199,819,430
10	"	199,819,430
11	"	199,819,430
12	"	199,819,430
13	"	199,819,430
14	"	199,819,430
15	"	199,819,430
16	"	199,819,430
17	"	199,819,430
18	"	199,819,430
19	"	199,819,430
20	"	199,819,430
21	"	199,819,430
22	"	199,819,430

Exhibit 22 Gasifier Economic Comparisons – by EnviRes (1 page)

COMPETITIVE PROJECT ECONOMICS - H2 FROM C FEEDSTOCK

			HyMelt Gasifiers	Siemens-type Gasifier	GE Gasifier	SMR
Date prepared	6/20/2008					
On-stream factor			95%	95%	90%	95%
C feedrate, short tons per stream day (sd)			1000	1000	1000	NA
Hydrogen product rate, million scf per sd			53.4	53.5	43.8	53.4
Time to startup after finance	2	years				
Time of loan payback	10	years				
Interest rate on debt	8.5	%/year				
Assumed debt portion	0	% of total capital				
Estimated Capital Costs			$	$	$	$
BL installed equipment	2008	base year	141,004,740	162,155,451	211,843,063	115,171,013
Off-sites	25	% of BL	35,251,185	40,538,863	52,960,766	28,792,753
Startup and commissioning	3	% of BL	4,230,142	4,864,664	6,355,292	3,455,130
Upfront royalty/fees			0	0	0	0
Legal fees			0	0	0	0
Bank advisory fee	2	% of total debt	0	0	0	0
Approx. int prior to loan payback	14.9	% debt/year	0	0	0	0
Debt service reserve	6	months debt serv	0	0	0	0
Maintenance reserve	50	% of matl & suppl	0	0	0	0
Approx. SG&A prior to start up	0.5	x annual SG&A	1,803,698	1,803,698	1,803,698	1,803,698
Working capital	2	months O&M	7,302,503	7,640,930	6,532,648	1,381,654
Total capital cost			189,592,268	217,003,604	279,495,466	150,604,249
Operating and Maintenance Costs	Unit Values		$/year	$/year	$/year	$/year
H2	3.43	$/kscf	0	0	0	0
C feedstock	59.756	$/ton as rec'd	20,720,526	20,720,526	20,720,526	0
Oxygen	45	$/ton	8,731,821	11,252,867	11,453,693	0
Nitrogen	25	$/ton	2,941,835	2,796,778	0	0
Power	5.5	cents/kwh	777,192	736,287	990,565	906,462
Cooling water	6.0	cents/k gal	169,803	176,057	94,554	25,967
Boiler feed water	1.40	$/k gal	345,270	345,670	3,593,514	1,955,426
HP steam (600+ psig)	10.72	$/k lb	927,967	820,099	(11,592,000)	(16,950,481)
MP & LP steam	10.61	$/k lb	(4,209,971)	(4,146,637)	(1,432,736)	11,528,367
Makeup iron	350	$/ton	280,455	0	0	0
CaO	70	$/ton	1,091,753	1,202,033	0	0
Catalysts and other			0	0	0	0
H2S disposal cost	0	$/ton	0	0	0	0
Slag disposal cost	0	$/ton	0	0	0	0
Direct operating labor, man-yrs	75	k $/man-yr	975,000	975,000	975,000	975,000
Maintenance labor @	0.7	%/yr on-site inv	987,033	1,135,088	1,482,901	806,197
Control lab labor @	5	% of oper labor	48,750	48,750	48,750	48,750
Maintenance materials @	1.5	%/yr on-site inv	2,115,071	2,432,332	3,177,646	1,727,565
Operating supplies @	20	% of oper labor	195,000	195,000	195,000	195,000
Plant overhead @	60	% of oper labor	585,000	585,000	585,000	585,000
Taxes and insurance @	2.0	%/yr fixed inv	3,525,118	4,053,886	5,296,077	2,879,275
Running royalty @	0	% of revenues	0	0	0	0
SG&A @	2.5	% of sales	3,607,396	3,607,396	3,607,396	3,607,396
Total O&M cost			43,815,018	45,845,577	39,195,887	8,289,925
Approx. Debt Service			0	0	0	0
Total Costs			43,815,018	45,845,577	39,195,887	8,289,925
Revenues						
NH3	750	$/ton	0	0	0	0
Urea	655.85	$/ton urea	0	0	0	0
NH4NO3	422.39	$/ton AN	0	0	0	0
F-T diesel fuel	169	$/bbl	0	0	0	0
F-T naphtha	114.4	$/bbl	0	0	0	0
F-T wax	195	$/bbl	0	0	0	0
Methanol	478.18	$/ton	0	0	0	0
H2	22.4	$/mbtu	135,102,787	128,276,259	110,769,100	135,102,787
Fuel gas	9.6	$/mbtu	9,193,052	9,899,425	355,060	(73,038,644)
Power	5.5	cents/kwh	0	0	0	0
CO2	10	$/ton	0	0	0	0
Total revenues			144,295,839	138,175,684	111,124,160	62,064,143
Free cash flow			100,480,821	92,330,107	71,928,274	53,774,218
EBITA, $/year			100,480,821	92,330,107	71,928,274	53,774,218
Approx. equity, $			189,592,268	217,003,604	279,495,466	150,604,249
First year return on equity, %			53.0%	42.5%	25.7%	35.7%
Avg IRR to owners (excl. inflation), %			43.5%	36.0%	22.7%	30.8%

Exhibit 23 Coke Oven Gas Design (39 pages)

NATCO	Project:	Synthetic Ammonia from Coke Oven Gas and Coal Project
Client: AKER KVAERNER FOR ENVIRES	Equipment:	Pressure Swing Adsorption Unit
Client Ref: -	Natco Ref:	J10556

TECHNICAL STUDY DOCUMENT
PRESSURE SWING ADSORPTION UNIT PSA

CUSTOMER: AKER KVAERNER FOR ENVIRES

PROJECT: SYNTHETIC AMMONIA FROM COKE OVEN GAS AND COAL PRESSURE SWING ADSORPTION UNIT.

PROJECT No.: J10556

PROCESS ENGINEER: MR C. GODWIN

SALES MANAGER: MR C. ROPER

ISSUING OFFICE: NATCO UK LIMITED

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APPENDICIES

APPENDIX A - Oil Screw Compressor
APPENDIX B - Storage Tank calculation
APPENDIX C - Preliminary Material Balance and Process flow Diagram
APPENDIX D - Piping and Instrumentation Diagrams (P&ID's)
APPENDIX E - Specifications Datasheets
APPENDIX F - Preliminary Plot Plan

1.0 SUMMARY

The following study was commissioned by EnviRes/CTL Ashland and Aker Kvaerner Technical Services (Purchase order No. A0755501-R001-0001).This study has been carried out on the proposal to recover Hydrogen from a Coke Oven Gas (COG) stream using Pressure Swing Adsorption (PSA) technology.

The scope of the study is detailed in section 5.0 of this report.

2.0 INTRODUCTION

Natco UK Limited have been commissioned by EnviRes/CTL Ashland and Aker Kvaerner Technical services to carry out a feasibility and verification study on the recovery of Hydrogen from Coke Oven Gas (COG) at an existing AK STEEL process plant in Ashland Kentucky. The COG Conditioning and PSA plant are part of a wider process design being undertaken by Aker Kvaerner, in order to produce synthesised Ammonia from Coke Oven Gas (COG).

The study has been commissioned to assess the options for the PSA purification unit prior to further upstream processing for Ammonia synthesis and refining. The study has reviewed the compression of COG, Pre-purification, PSA purification, Hydrogen pre-treatment, and has reported on its findings.

The submission of Heat and Material balances, Process Flow Diagrams (PFD's), Process Instrument Diagrams (P&ID's), Plot Plan and preliminary Datasheets for vessels and rotating machines were agreed with EnviRes/CTL Ashland as the deliverables for this study.

Included with this design study is the budgetary cost for plant engineering, design and equipment supply for Pre-purification/COG conditioning, PSA Plant, and Hydrogen Pre-treatment.

Indicative prices for the COG compressor have also been identified.

3.0 COKE OVEN GAS EXPERIENCE

For many years, Natco (as Howmar) licensed its PSA technology to a medium sized domestic Japanese engineering contractor, Cosmo Engineering Corporation (CEC).

They had a particular interest and specialty in supplying hydrogen generating plants to the local market, mainly based upon the steam reforming of methanol under license from Mitsubishi Gas Chemical for the crude hydrogen production (or front end) section.

Pressure swing adsorption was used to purify the hydrogen from the crude hydrogen and Natco technology was used exclusively for this purpose.

However, CEC also supplied ‘stand alone’ PSA’s also using Natco technology and one such application was for the purification of coke oven gas for Nippon Sanso (translates as Japanese Oxygen) who are a domestic industrial gas supplier.

The plant was installed at a steel works, Kokan Centre, in the district of Hiroshima, Japan.

It had a product capacity of 1,000 Nm3/hr of pure hydrogen and operated at a pressure of 9 Bar(a).

The flowscheme was configured as follows

- The coke oven gas was compressed to operating pressure in a two stage oil injected screw compressor
- Two sacrificial activated carbon beds, one on line and one standby, principally to remove naphthalene with each sized for 6 months operation.
- PSA to purify the hydrogen
- De-oxo unit to remove oxygen from the product

The plant was successfully commissioned and performance tested on 28th - 29th December 1985, and the following performance was achieved.

J1303 PSA for Nippon Sanso/Kokan Sanso centre operation data.

1. Feedstock

	Design	Actual
H_2	53.45	54.5
N_2	3.76	2.80
CH_4	28.51	29.30
O_2	0.3	0.21
CmHn	5.4	3.74
CO_2	2.19	2.49
CO	6.29	6.96
Water	Sat	Sat
Total	100 vol %	100 vol %
Temperature	40°C	46.2°C

Pressure (Inlet) (Outlet)	 9.4 kg/cm^2(g) -	 9.0 kg/cm^2(g) 8.9 kg/cm^2(g)
Feed Gas Flow Rate	2,711 Nm^3/hr	2,702 Nm^3/hr

Note: The flow rate, instruments values have been corrected for temperature and pressure.

2. Product Hydrogen

	Design	Actual
Flow rate	1,000 Nm^3/h	1,032 Nm^3/h
Hydrogen recovery	69%	70%
'RUN' cycle time	4min	5 min and 15 sec to 5 min and 40 sec
Repress Gas flow	1,175 Nm^3/hr	810 Nm^3/hr
Impurity in the Product Hydrogen (Guarantee)		
	Design	Actual
CH_4	<1.0 ppmV	No Peak
CO_2	<1.0 ppmV	No Peak
CO	<1.0ppmV	No Peak
O_2	<500 ppmV	3.4 ppmV
N_2+Ar	<9.0 ppmV Expected	6.6 ppmV
NH_3	-	0.0
Purity of Hydrogen product		
	Design	Actual
Vol %	99.95	99.999

Note that we are uncertain of the current situation with the plant but CEC have advised us that they believe it to be shut down.

4.0 DESIGN BASIS

The Study is to examine the PSA technical feasibility and capacity using the following feed stock as defined by Aker Kvaerner Design Basis B-10 Rev A dated 15/04/07, amended by AK e-mail dated 25/09/2007 with attached Excel file 'COG Feed Analysis' and acknowledge/clarified by Natco UK Limited dated 26/09/07.

4.1 Feedstock

Description	Units	Design	Comment
Hydrogen	Volume %, dry	56.31	
Carbon Monoxide	Volume %, dry	5.06	
Carbon Dioxide	Volume %, dry	1.26	Some removal expected with desulfurization process
Oxygen	Volume %,dry	0.78	Max. excursion observed- Dan Howell 14SEP07
Nitrogen	Volume %,dry	6.81	
Methane	Volume %,dry	23.34	
Ethane	Volume %,dry	0.39	
Ethylene	Volume %,dry	1.85	
Propane	Volume %,dry	0.1	
Propylene	Volume %,dry	0.29	
Benzene	Volume %,dry	0.35	Coke plant light oil removal could be improved.
Toluene	Volume %,dry	0.16	
Xylene	Volume %,dry	0.00	
Hydrogen Sulfide	ppm, dry basis	5	New acid gas system will be specified to meet this level to avoid problems in the PSA
Hydrogen Cyanide	ppm, dry	5	New acid gas system will be specified to meet this level to avoid problems in the PSA
Ammonia	Volume %,dry	0.04	50% removal experienced in existing COG Desulfurization- Dan Howell 14SEP07
Sulfur Dioxide	Volume %,dry	0.004	Acid gas removal systems are not designed to remove SO2. Only partial removal expected.
Organic Sulfur COS,CS2	Volume %,dry	0.01	Only partial removal of organic sulfur expected in Acid Gas removal. Wilson and Wells, pg 268 estimates 20 to 30 grains/100 ft3 in raw gas and 50% removal in Light Oil Scrubbers
Water vapor content of COG	Volume	3.21	Saturated at 35 C. Variation depends on total pressure at B/L.
Naphthalene content of COG	Volume %,dry	0.01	Based on inspection of data. 70% removal of Naphthalene in Light Oil Scrubbers and saturation at 35 C. 14SEP07
Particulate content of COG	mg/Nm3,dry	5	Typical particulate loading for gas cleaning systems
HCl	Volume %	0.0001	Assumed. Coke plant has ammonia water scrubbers
NOx	Volume %	0.0001	Assumed based on ' Coal, Coke and Coal Chemicals',
Temperature of COG at Light Oil Scrubber	Degrees C	35	
COG production	Million scfd	38	Based on variation of approx. +- 20% as seen in data from AK Steel Coke Plant (Nov.2006) analyzed by Dan Howell.
Pressure of Coke Oven Gas at inlet to PSA	Psig	400	

4.2 Product

PSA Outlet (H_2 Product);

Flow (100% Hydrogen)	mmscfd	17	
Pressure	psi(g)	375	
Temperature	°F	95 - 100	Approx
Hydrogen Purity			
Hydrogen	Vol %	99.9	Min (water saturated)
Design Turndown	%	30	

4.3 Offgas

Offgas Temperature	95 – 100 °F
Offgas Pressure (minimum)	10 psi(g) (Notes 1&2)

Notes:

1. Minimum pressure measured downstream of PSA offgas FCV.
2. In order that hydrogen recovery performance is achieved, it is important that this pressure is not exceeded.

4.3.1 Battery Limit Conditions of Feed, Product and Relief Header

Stream	**Operating Conditions**		**Design Conditions**	
	Temp (°F)	Pressure psi(g)	Temp (°F)	Pressure (psi(g)
Feed Gas to PSA	95-100	406	150	510
Product Hydrogen	95-100	375	150	460
Offgas exit PSA	100	10 (Notes 1&2)	150	70
Flare header at PSV outlet	Ambient	TBA	TBA	TBA

4.3.2 Nitrogen

Pressure		
Operating	Norm	100 psi(g) 600 psi(g)
Temperature		
Operating	Norm.	77-81 °F
Quality		
Content		99.5 mol% with max 20ppmv O_2

4.3.3 Instrument Air

Pressure		
Operating	Min. Normal Design	60 psi (g) 80 psi (g) 100 psi (g)
Design for actuators		100 psi (g)
Temperature		
Norm		Ambient
Design		150 °F
Quality		Dry, Oil Free and clean
Dew Point		-20.0 °C

4.3.4 Cooling water

Supply pressure	60 psi (g)
Supply Temperature	85^{0}F
Return temperature	110^{0}F
Return Pressure	40 psi (g)

4.3.5 Power

Power	LV	120
	MV	460
	HV	4000

4.4 Utility consumption

Oil Filled Gas Screw Compressor requirements;

First Stage	kW	5000
Second stage	kW	6000
Cooling water (Heat exchanger)	lb/hr	153,572
Cooling water compressor	lb/hr	544,301
Instrument Air	ft^3	1800
Nitrogen (Purge)	ft^3	290,000

4.5 Study Assumptions

Ambient conditions

Barometric Pressure	14.7 psia
Ambient temperature	24 to 100 °F

4.6 Exceptions

- The study except where specifically stated otherwise is restricted to a process design review only;
- Detailed instrument design and engineering;
- Detailed pipe design.
- All and any costs quoted are of 'indicative' accuracy only.

5.0 SCOPE OF STUDY

The scope of the study is limited to the following, which is detailed below;

- The study covers the pre- and post- purification of the COG in the PSA unit and advises on the most suitable equipment;
- Information on PSA technology, detailing the required equipment and operating conditions in order to maximise hydrogen production reliability and purity.
- Provide preliminary basic design information for ancillary equipment such as COG compressor and storage tank.

6.0 PROCESS DESCRIPTION

The following process descriptions should be read in conjunction with Process Flow Diagrams (PFD's) J10556 – 1002/1003 and Process and Instrument Diagrams (P&ID's) J10556 – 1010/1011/1012/1013/1014. The process description is intended to give a detailed narrative of the system but also serves as a justification for the equipment selected thereby highlighting some of the difficulties in processing coke oven gas for hydrogen purification.

Coke oven gas is delivered to the PSA Unit at approximately 429psig and 100^{0}F. At this stage the COG contains hydrocarbons liquids and sulphur compounds that would be poisons to the adsorbents in the PSA Unit and must therefore be removed / reduced in the pre-purification and conditioning.

Under flow control, at approximately 38mmscfd the COG is routed to the Feed Coalescer V-212. The purpose of this equipment is to prevent liquid carry over of hydrocarbons to the upstream units, the coalescer is under level control and all liquids flow to drain.

The liquid free gas then passes out of the Feed Coalescer and flows into Two (2) x 100% Pre-Purification Units (PPU) V-220A/B. The PPU vessels are used to remove Tar, Naphthalene, Bulk BTX, compressor oil and small amounts of sulphur compounds from the feedstock.
The two PPU Vessels are operated in a led-lag configuration to provide frequent change out of the silica gel/activated carbon media without disturbing the flow of COG through the PSA plant.

Now that the COG has been cleaned and is in a suitable condition it is passed to the 5 bed Pressure Swing Adsorbers V-201A/B/C/D/E at approximately 406psig and 100^{o}F.
The pressure swing adsorption unit is a series of adsorber vessels connected by a number of pipe manifolds. Flow to each of the adsorbers is controlled by switching valves. Continuous product flow is achieved by cycling adsorber operation between run, depressurisation, purge and repressurisation.
In these units high purity hydrogen is produced (99.9%) using a 5-vessel pressure swing adsorption (PSA) system. Each of the adsorber units selectively adsorbs the impurities from a hydrogen rich feed gas onto a fixed bed of adsorbents.

Further description of the PSA Unit and technology can be found in section 6.1 of this document.

Although the Hydrogen is now at a high purity level due to the composition of the COG feedstock it will still contain a large amount of oxygen. This will need to be removed before it can be used in ammonia synthesis. The Purified Hydrogen is therefore routed to One (1) x 100% Deoxo vessel V – 206 where it is reacted at (109^{o}F) with the oxygen over a Palladium catalyst bed in the following stoichio-metric exothermic reaction;

$$2H_2 + O_2 \rightarrow 2H_2O$$

The temperature is expected to rise by 245^{0}F. The catalyst bed must be protected against excessive temperature rise. This is achieved by an over temperature shutdown system.

The hydrogen product form the Deoxo unit is then cooled by the Hydrogen product cooler E-207 from 354^{0}F to the battery limit of 100^{0}F. As a result of this large amounts of water are condensed. The two phases are separated from each other in the vertical Product separator V - 213.

The Pure Hydrogen (99.9%) product, saturated with water vapour is then delivered to the battery limits under pressure control, (375psig and 100F) for further processing and ammonia synthesis.

6.1 PSA Unit

The plant uses Natco UK Limited fixed bed Pressure Swing Adsorption System to produce a high purity product stream. The adsorption process operates on a repeated cycle with the basic steps of adsorption and regeneration. Although the process is a batch operation, continuous product and offgas flows are achieved by operating the adsorbers in a stepwise manner. No matter how complex the PSA sequence it can always be broken down into the following 5 fundamental steps:

Adsorption
Co-Current Depressurisation
Counter-Current Depressurisation
Purge
Counter-Current Repressurisation

Impurities from the feed are passed into the two offgas drums V-203A/B for further use in the plants fuel gas system. The product pressure control maintains a back pressure in the system and spills over pressure into the vent header. The system offered is a 5 Absorber system

A brief description is given below of the operating cycle that each adsorber goes through.

6.1.1 Adsorption

Impure feed gas flows into the adsorber vessel currently online during the run step at pressure. As the gas is passed over the adsorbent beds, the adsorbents, solid granular materials, selectively adsorb the impurities, leaving a high purity hydrogen product. Feed flow continues through the bed until the bed is just short of being fully saturated with impurities, and the feed gas is then automatically switched to a clean adsorber. The loaded adsorber is taken off line for regeneration.

6.1.2 Regeneration

Regeneration is the process of desorbing the impurities, which were adsorbed during the adsorption step, followed by repressurisation to adsorption pressure so that the cycle can be repeated.

There are 3 basic steps to the regeneration process:

i. Depressurisation,
ii. Purging and,
iii. Repressurisation.

6.1.3 Depressurisation

At the end of the adsorption step, the adsorber vessel contains a significant amount of high purity hydrogen in the void volume of the adsorbent bed. Much of this hydrogen is saved by pressure equalisation with other vessels, after which the adsorber is blown down to low pressure in preparation for the next step.

6.1.4 Purging

The impurities remaining after blow down are removed by passing hydrogen from one adsorber at pressure in a counter current direction through the adsorber which has just been blown down.

6.1.5 Repressurisation

The adsorber is now ready to be repressurised to adsorption pressure ready for a new run step. This is achieved by a combination of pressure equalisation with other vessels and repressurisation with a slipstream of pure hydrogen.

The feed flowmeter is used to compute the PSA's repressurisation gas requirements and hence cycle time. As the feedrate to the plant is reduced so the cycle time is extended to maintain optimum efficiency.

6.1.6 Offgas Drum

Two offgas drums, a configuration selected to provide the required geometric volume in the most cost effective and practical way, complete with internal mixing device is included. With appropriate controls, a steady and continuous offgas flowrate can be maintained.

The offgas drum control system is so designed that the drum runs at the lowest average pressure consistent with requirements of battery limits (10 psig), thus enabling maximum PSA efficiency to be achieved.

6.2 PSA Technology

The design of the Pressure Swing Adsorption System utilises technology developed by Natco UK Limited. The basic design concepts have been well proven in service, in excess of one hundred PSA units having been installed over the past twenty years, operating on a wide variety of hydrogen rich feedstocks.

6.2.1 Reliability

The reliability of the Pressure Swing Adsorption System depends upon the successful operation of the switching logic and the associated switch valves. These switch valves are required to open and close bubble tight at a relatively high frequency of approximately three complete cycles per hour. In order to ensure the tight shut off is maintained, the plug and seat arrangement incorporates a PTFE insert.

Prior to acceptance by Natco UK of valves suitable for this arduous duty the manufacturer is required to successfully carry out a "life" test, whereby a tight shut off is maintained over the test period, representing well in excess of a year's operation of the unit.

6.2.2 Operating Range and Efficiency

The efficiency of Pressure Swing Adsorption Units, in terms of ability to recover hydrogen from the feed stream, is very sensitive to the off-gas pressure specified for the system.

However, turndown to virtually zero product flow is possible whilst still maintaining specified purity, although efficiency will be lost as a consequence of the loss of accuracy of flow measurements at low flow rates.

The PSA is designed for the entire range of 30 – 100% of the product capacity.

6.2.3 Control

The control system controls the sequencing functions and automatic capacity control for a 5 bed, one vessel online PSA System. Timing is critical to the process and to this end the control system design should include consideration of the scan time of the system which is to be implemented.

All PID control loop process variables, Adsorber Vessel pressures and product / feed flow rates shall be available to the operator for historical trending to enable accurate tuning / commissioning and monitoring of the PSA. PID control loop set point adjustment, mode selection, PSA sequence status and Run / Output Inhibit / Auto / Manual mode selection should also be available to the operator.

6.3 Coke Oven Gas Compressor

The COG will be discharged from the Ovens at approximately 20 psig. In order to maximise the recovery of the hydrogen present in the COG high pressure will be required on the inlet to the PSA system. (See general comments below). In addition to this large fluctuations in flow from the COG ovens (±20) means that not only will the compressor have to cope with high pressure but varying flowrates.

Initial contact has been made with KOBELCO EDTI COMPRESSORS INC for the design of such a specialised compressor. From the information supplied 2 (Two) Screw type compressors will be required. The 1st compressor will be 5,347 HP oil-free screw compressor and the 2nd stage, 4,370 oil-injected screw compressor. The pressure outlet from the 2nd stage oil filled compressor will be 470psi(g) sufficient to send the COG to intermediate storage tank.

The indicative price of these 2 COG compressors Units is

$5,000,000 (Five Million US Dollars)

Details of KOBELCO EDTI proposal can be found in Appendix A.

6.4 Intermediate Storage Tank

The PSA system does not lend itself well to significant pressure or flow fluctuation its preferred mode of operation is for steady state conditions. This provides the best opportunity to maximise hydrogen recovery and purity.

The PSA is designed for 38mmscfd maximum working capacity. The maximum flow fluctuations observed over a 10 min period from the COG oven is 38 mmscfd±20%.
From Natco UK calculations a 10,000 cubic foot (ft^3) with dimensions 13'7" i/d x 68'3" Tan/Tan should be sufficient to even the flow of gas prior to reaching the PSA unit.

During high flow a maximum operating pressure of 456.81psi(g) will be observed. This will therefore not exceed the design limitation of the compressor outlined above. The flow can then be delivered to the PSA unit under pressure control.

The calculations for the size of the Intermediate storage tank can be found in Appendix B.

7.0 GENERAL COMMENTS

The statements below are intended to highlight decisions made during the execution of the design study. The points are of interest and may be useful in any future justification of the Ammonia synthesis project.

- A design pressure of 400psig has been selected for the operating pressure of the PSA Unit. This was selected as from Natco PSA calculation runs higher pressures (600-650psig) do not produce an increase in hydrogen recovery. The 400psig pressure is not excessively large as to make the design of the COG complicated and not feasible;

- From Natco UK experience liquids carried through to the PSA absorbents drastically reduced the purity and recovery of hydrogen from the PSA unit. The Feed Coalescer V-212 plays an important part in achieving this objective;

- The recovery of the hydrogen from the COG is approximately 78% producing 17mmsfd;

- The Pre-Purification Units (PPU) vessels are used to remove Tar Naphthalene Bulk BTX and compressor oil from the feedstock. Although Naphthalene does not pose a severe problem and design of the PSA can account for this Naphthalene crystallisation is an issue and must be removed prior to the COG entering the PSA adsorber beds.

- The PPU is also expected to removal small amounts of sulphur compounds and thereby further protecting the PSA absorber beds.

- The Pre-purification Units V-220 use 'fifty-fifty' wide pore silica gel and activated carbon as the media to remove hydrocarbons/sulphur compounds which is non-regenerative and life expectancy is approximately 6 months.

- The Deoxo unit is positioned after the PSA to prevent poisoning of the catalyst from sulphide compounds. Carbon Monoxide will similarly be at low levels (less than 10ppm) and will therefore not act as a Deoxo catalyst inhibitor. A feed temperature of 109^{0}F is sufficient to catalyse reaction.

- The Deoxo Unit V-206 use a Palladium (Pd) based catalyst which has a guaranteed design life of 2 years;

8.0 SCOPE OF SUPPLY

The following schedule outlines the main items of equipment for supply of a COG PSA Unit. The scope of supply includes all necessary equipment in order to achieve maximum reliability purity and recovery.

Details of individual items of equipment and ancillaries are given below;

VESSELS	
Item	**No Required**
V – 212 Feed Coalescer	1-off
V – 220A/B Pre-Purification Units (PPU)	2-off
V – 201A/B/C/D/E PSA Adsorber Vessels	5-off
V – 203A/B Offgas Drum	2-off
V – 206 Deoxo Unit	1-off
V – 213 Product Separator	1-off

Vessels to be designed in accordance with ASME VIII Div1 and 2. Please refer to vessel datasheets in Appendix E.

Heat Exchanger	
Item	**No Required**
E – 207 Product Cooler	1-off

Heat exchangers to be designed in accordance with ASME VIII Div1 and TEMA class R.

PSA SKID	
Item	**No Required**
200 – V Complete skid mounted valve skid	1-off

The plant is complete within battery limits, supplied as a modular unit, prefabricated to the maximum extent thus minimising field installation time and labour. All vessels and major equipment will be installed off module.

Piping for all module-mounted equipment will be prefabricated and installed between items of equipment and from equipment to module edge where the termination will be with a standard flanged connection. Interconnecting pipework between module and off module equipment and pipework to battery limit will either be supplied prefabricated with cutting lengths for fit-up or will be site run.

All on-module electrical and instrument connections will be made in a junction box, with appropriate segregation of electrical circuits, mounted at the edge of the module.

Control of PSA sequencing will be by a new control system programmed to provide the necessary control required by the sequence logic diagrams.

8.1 PSA Unit

8.1.1 Adsorbents

Natco UK Limited will supply the initial charge of all, adsorbents for the five adsorber vessels. Packed in steel or plastic airtight drums to minimise water pick up from the atmosphere.

Approximate quantities per Adsorber vessel	Alumina	5.268	Te
	Carbon	24.129	Te
	Mol Sieve	21.834	Te
Approximate quantities per PPU vessel	WP Silica gel	30.74	Te
	Carbon	19.08	Te
Approximate quantities per Deoxo vessel	Palladium	8.84	Te

8.1.2 Relief Valves

1 full sized safety valve's with inlet and outlet isolation valve (locked) will be supplied and installed on the skid for each adsorber and 2 full sized safety valves with inlet and outlet isolation valves (locked) for the offgas drum.

8.1.3 Vessel Isolation Valves

Isolation valves complete with spectacle blinds are provided for each set of adsorber automatic valves, such that a complete adsorber including instrumentation can be isolated. A hard piped nitrogen connection is included for each absorber.

8.1.4 Instrumentation

The instrumentation provided by Natco UK Limited will be engineered and designed in accordance with the following standards;

Instrumentation will be electronic, certified to North American standards designed for use within a Class 1 Div 2 Group 3 hazardous, Temperature Class T3.

Equipment supplied by Natco UK Limited will include:-

- Automatic switching valves for cycle sequence control, complete with solenoid valves certified or positioner as required by service.
- Interconnecting pipework, wiring and tubing for all items located on module;
- All other local on module instrumentation and devices necessary to make the unit automatic and safe during operation;
- All services such as control stations, instrument air supply and instrument signals will be piped or wired by Natco UK to module edge;
- Switching valve position detection by proximity switch is included indicating closed/not closed, wired to module edge junction box;
- Control System for PSA sequencing functions.

8.1.5 Adsorber Logic System

Natco UK will supply the control system as described below. Built into the system as standard features are the following:-

- Automatic manual/manual step function - Enables system to run on automatic or the sequence to be stepped manually.
- Output Inhibit Function - Enables controller to continue to sequence but all outputs are isolated.
- Vessel State Indication - Outputs from the PLC indicate which vessel is on RUN, PURGE, HOLD, etc.

The control system shall have the capability to automatically close feed, product and purge valves and signal shutdown for the following conditions:

- Long cycle time
- Low product gas pressure
- Power failure
- Low instrument air pressure

8.1.6 Noise Control

A silencer is included in the offgas line to the offgas drum

8.1.7 Insulation and Heat Tracing

Insulation and heat tracing is supplied. No fireproofing has been included.

8.1.8 Painting

Off module piping, equipment and steelwork will be primed only. Module and on module piping, equipment and steelwork will be supplied grit blasted, primed and finish painted in the fabrication shop.

8.1.9 Lighting

Lighting is excluded from Natco UK scope of supply.

8.1.10 Exclusions

- Interconnecting pipework fittings and valves between skid and absorber vessels;
- Interconnecting cable, cable tray and insulation materials between new module and PSA module and control system/panel
- Analysis equipment
- All field installation work
- Any item not specifically mentioned above

8.2 General

The following check list provides a summary of the split in responsibility between Natco UK Limited and the Purchaser for supply and installation of equipment and provision of services.

EQUIPMENT/SERVICE PLANT 1	**NATCO UK**		**PURCHASER**	
	SUPPLY	**INSTALL**	**SUPPLY**	**INSTALL**
V – 212 Feed Coalescer	√			√
V – 220A/B Pre-Purification Units (PPU)	√			√
V – 201A/B/C/D/E PSA Adsorber Vessels	√			√
V – 203A/B Offgas Drum	√			√
V – 206 Deoxo Unit	√			√
V – 213 Product Separator	√			√
2 stage screw compressor			√	√
Prefabricated Switching Valve Module	√			√
PSA Adsorbents	√			√
PPU Activated carbon	√			√
Deoxo Unit Palladium catalyst	√			√
Pipework: *Pipework, Valves and Fittings On Module*	√	√		
Pipework, Valves and Fittings Off Module	√			√
Instrument and Electrics: *Field Instrumentation*	√			√
PLC for Sequence Control	√			
Control Panel	√			√
On Module Interconnections	√	√		
Off Module Interconnections (ISBL)			√	√
Plant to Control Room Interconnections			√	√
Heat Tracing	N/A			
Lighting			√	√
Insulation	Within BL			√
On Module Painting: *Primer*	√	√		
Finish	√	√		
Delivery – FOB	√			
Installation on Prepared Foundations				√
Foundations: *Foundation Loading Diagram*	√			

EQUIPMENT/SERVICE PLANT 1	NATCO UK		PURCHASER	
	SUPPLY	INSTALL	SUPPLY	INSTALL
Design			√	
Civil Work			√	
Anchor Bolts			√	√
Operating & Maintenance Manuals	√			
Commissioning Services per Diem Rates	√			
Spare Parts: *Commissioning*	√			
2 Years' Operation			√	

8.3 Budget cost

Our budget estimate for the design supply of the complete PSA Plant Including pre-purification units, Deoxo unit and product cooler as detailed in PFD's J10556 – 1002/1003 and generally as described above is:

$ 4,500,000 (Four Million Five Hundred Thousand US Dollars)

Please note this is a budget price and not an offer to sell.

9.0 DATA SHEETS AND DRAWINGS

9.1 Material Balance

A material balance for the PSA plant has been generated and is presented together with the PFD's in Appendix C.

9.2 Piping and Instrumentation Diagram P&ID

The Process Flow Diagrams produced give a clear indication of pressure and temperature profile. In addition P&ID's J10556 – 1010/1011/1012/1013/1014 have been generated to show the configuration of equipment that would be required in order for the PSA plant to be built and operated.

The P&ID's are presented in Appendix D.

9.3 Specifications

Datasheets for all Vessels, Product cooler and Adsorbents have been generated to give an indication of the dimensions, mechanical design of the equipment and specification.
The Feed Coalescer V-212 is proprietary equipment and will be sized during detailed engineering.

The specification sheets are presented in Appendix E.

9.4 Plot Plan

On the limited information available and based on advice given by Aker Kvaerner, a preliminary Plot Plan has been created J10556-8001 of the PSA plant. The layout depicts the approximate area and layout required subject to site review.

The Plot Plan is presented in Appendix F.

10.0 STUDY CONCLUSIONS

It is the conclusion of this study that with the Process design and equipment scheduled in section 8.0 of this report, operation with the defined Coke oven gas feedstock is feasible and practical. The recovery of pure hydrogen saturated with water, (99.9%) from coke oven gas will be 78% giving a total flow of 17mmscfd.

Pre-purification Units have been included in the design to prevent large amounts hydrocarbon and sulphur compounds poisoning the absorbents beds present in the PSA.

Due to the large quantities of oxygen present a Deoxo unit will need to be installed after the PSA to provide pure hydrogen (99.9%) at the battery limits of 375psig and 100^0F.

APPENDIX A

OIL SCREW COMPRESSOR

301 N. Smith Ave.
Corona, CA 92880-1742
Ph: 951-279-9400 · Fax: 951-279-9464
ISO 9001 REGISTERED

TITLE: COKE OVEN GAS COMPRESSOR
Q-27150A-00 CUSTOMER: NATCO UK, LTD.
CUSTOMER REF:

DATE: October [illegible] 2007

DESIGN CRITERIA	Inlet Press. P1 (kPa)	34.7
	Outlet Press P2 (kPa)	114.7
	Inlet Temp. T1 (deg C)	104.0
	Outlet Temp. T2 (degC)	Uncooled
	Gas M.W. (Avg.)	10.32
	Gas K Value	1.358
	Main/Aux/Control Voltage (VAC)	4000 / 460 / 120
	Flow Rate at Inlet (M^3/hr)	45.40
COMPRESSOR DATA	Compressor Model	KS50LNZ
	Compressor Stages	One
	Compressor Quantity	One
	Compressor Speed (rpm)	1770
	Compressor Seal	Dry Gas, Non-Contact With Back Up.
	Compressor BHP (kw)	4370
SCOPE OF SUPPLY	Compressor	KS50LNZ
	Motor (kw)	5000, WP II
	Motor Speed (rpm)	1770
	Gear Box	AGMA Class
	No. Of Shafts	2,1770→4567
	Oil Reservoir	8' x 9' x 6' (C.S)
	Lube Oil Piping (Before Oil Filter)	Carbon Steel
	Lube Oil Piping (After Oil Filter)	Stainless Steel
	Oil-Pumps	Dual
	Oil-Coolers	Dual - Shell & Tube - BEM with Transfer Valve
	Oil Filters	Duplex
	After-Cooler	N/A
	Inlet Filters	2 x 42" Dia
	Control System	By customer (JB is provided)
	Silencer	Included (Suction/ Discharge)
	Process Gas Piping / Instruments	Not Included
	Noise Enclosure / Sound Jacket	Not Included
	Vibration Probes	Accelerometer(1) /Axial Probe(2) per Compressor Accelerometer(1) / Axial Probe(0) / Vibration Probe(0) per Gear Box
	Bearing Temperature Detector	Bearing RTD (0) per Gear Box
	Vibration / Bearing Temperature Monitor	Not Included
	Painting	Manufacturer's Standard
	Shipping	Manufacturer's Standard for Domestic
PRICING, DELIVERY DIMENSIONS, ETC.	**COMPLETE SYSTEM (EX- FACTORY) BUDGETARY PRICING** **DIMENSIONS** **DELIVERY**	See Attached
NOTES		

KEC

301 N. Smith Ave.
Corona, CA 92880-1742
Ph: 951-279-9400 Fax : 951-279-9464
ISO 9001 REGISTERED

TITLE: COKE OVEN GAS COMPRESSOR
Q-27150B-00 CUSTOMER: NATCO UK, LTD.
CUSTOMER REF:

DATE: October 2, 2007

		CASE 1
DESIGN CRITERIA	Inlet Press P1 @ Comp Flange (psig)	110.7
	Outlet Press P2 @ Comp Flange (psig)	469.7
	Inlet Temp. T1 (EF)	120.0
	Outlet Temp. T2 (EF)	Uncooled
	Gas M.W. (Avg.)	10.32
	Gas K Value	1.358
	Main/Aux/Control Voltage (VAC)	4000 / 460 / 120
	Flow Rate at Inlet (mmscfd)	42.83
	Oil Carryover Limit (ppmw)	1.0
COMPRESSOR DATA	Compressor Model	KS50MEH
	Compressor Stages	One
	Compressor Quantity	One
	Compressor Speed (rpm)	1770
	Compressor Capacity (mmscfd)	42.83
	Compressor bhp (hp)	5347
	Disch Temp. (EF)	210
	Comp. Oil Flow/Temp. (gpm/EF)	546 / 120
SCOPE OF SUPPLY	Comp. Suction Knockout Drum	By Others
	Compressor	KS50MEH
	Motor (kW)	6,000 WPII (Space Heater, Winding RTD's)
	Bulk Oil Separator (in)	84" Dia
	Coalescing Oil Separator(s) (in)	2 x 42" Dia, Duplex with switchover valving
	Charcoal Adsorber (in)	N/A
	Dust Filter (in)	N/A
	After-Cooler	N/A
	Knockout Drum, Disch. (in)	N/A
	Oil-Pumps	Single, PT, 3 Rotor Screw
	Oil-Coolers	Single, Shell & Tube, BEM Design
	Oil Filters	Duplex
	Control System	PLC (AB), NEMA 4X
	No. of Skids	Three
PRICING, DELIVERY DIMENSIONS, ETC. (Budgetary Basis)	**COMPLETE SYSTEM (Ex-Factory) Net Each.**	$
	COMMISSIONING SPARES	$
	LUBE OIL	$
	INSULATION	$
	NOISE JACKET	$
	DIMENSIONS	See Attached
	DELIVERY	
NOTES		

KOBELCO

OIL-INJECTED SCREW COMPRESSOR DATA SHEET

E7B0458 / Q-27150

SERVICE	: Coke Oven Gas	ITEM NO.	:
MODEL	: KS50LNZ-KS50MEH	TYPE OF DRIVER	: ELECTRIC MOTOR
NO. OF STAGE	: 2	NO. REQUIRED	: 1

ALL DATA ON PER ONE UNIT BASIS

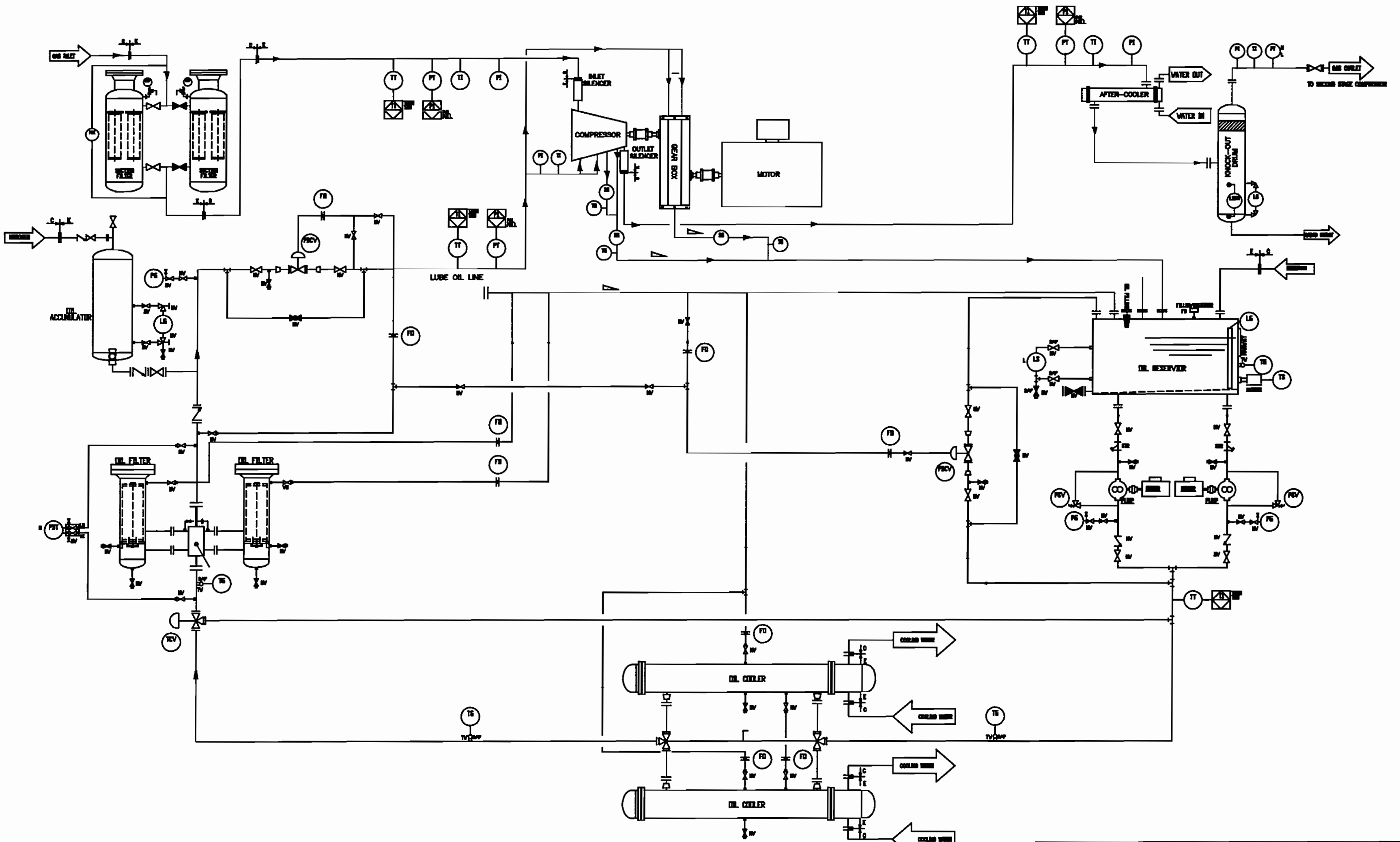
	Design	Design		
	1st stage	2nd stage		
		Full Load		
GAS HANDLED				
FLOW RATE lbm/h WET	54610	50873		
(14.7PSIA & 32 Deg.F) Nm3/h WET	50630	48552		
(14.7PSIA & 32 Deg.F) Nm3/h DRY	49069	47802		
(14.7PSIA & 60 Deg.F) MMSCFD WET	45.36	43.50		
(14.7PSIA & 60 Deg.F) MMSCFD DRY	43.96	42.83		
ATM PRESSURE PSI	14.7	14.7		
SUCTION CONDITIONS				
PRESSURE AT TERMINAL POINT PSIG	20	95		
TEMPERATURE deg.F	104	120		
RELATIVE HUMIDITY %	100	100		
MOLECULAR WEIGHT	10.96	10.32		
SPECIFIC HEAT RATIO (K1=Cp/C\	1.355	1.358		
COMPRESSIBILITY(Z1)	1.000	1.0010		
INLET VOLUME ACFM	14470	4517		
DISCHARGE CONDITIONS				
PRESSURE AT OUTLET FLANGE PSIG	100	470		
TEMPERATURE deg.F	349	210		
TEMP. COOLER OUTLET deg.F	-----	-----		
PRESSURE RATIO	3.304	4.419		
BHP AT COMP. INLET SHAFT HP	4370	5347		
SEPARATE GEAR LOSS HP	109	0		
TOTAL BHP(GEAR LOSS INCL.) HP	4479	5347		
SPEED rpm	4567	1770		
DRIVER RATED HP	5000	5900		
DRIVER SPEED rpm	1770	1770		
SLIDE VALVE VOLUME RATIO %	NA	100.0		

(*1) FLOW RATE SHALL NOT BE LESS THAN 0% OF SPECIFIED FIGURE AT "Design"
(*2) BHP SHALL NOT EXCEED 104% OF QUOTED FIGURE AT "Design"

KOBE STEEL, LTD.

ALL DATA ON PER ONE UNIT BASIS

	Design 1st stage	Design 2nd stage		
GAS COMPOSITION(Mol.%)				
HYDROGEN	55.986	58.415		
CARBON MONOXIDE	5.028	5.246		
CARBON DIOXIDE	1.257	0.012		
OXYGEN	0.774	0.807		
NITROGEN	6.769	7.062		
METHANE	23.207	24.213		
ETHANE	0.387	0.404		
ETHYLENE	1.837	1.917		
PROPANE	0.097	0.101		
PROPYLENE	0.290	0.303		
BENZENE	0.345	0.360		
TOLUENE	0.155	0.161		
O-XYLENE	0.001	0.002		
P-XYLENE	0.001	0.002		
HYDROGEN SULFIDE	0.376	0.392		
HYDROGEN CYANIDE	0.242	0.252		
AMMONIA	0.073	0.076		
SULFUR DIOXIDE	0.037	0.038		
WATER	3.139	0.238		
TOTAL %	100.00	100.00		
RELATIVE HUMIDITY %	100.00	100.00		
AVERAGE MOL. WEIGHT	10.96	10.32		



FIRST STAGE COMPRESSOR SYSTEM

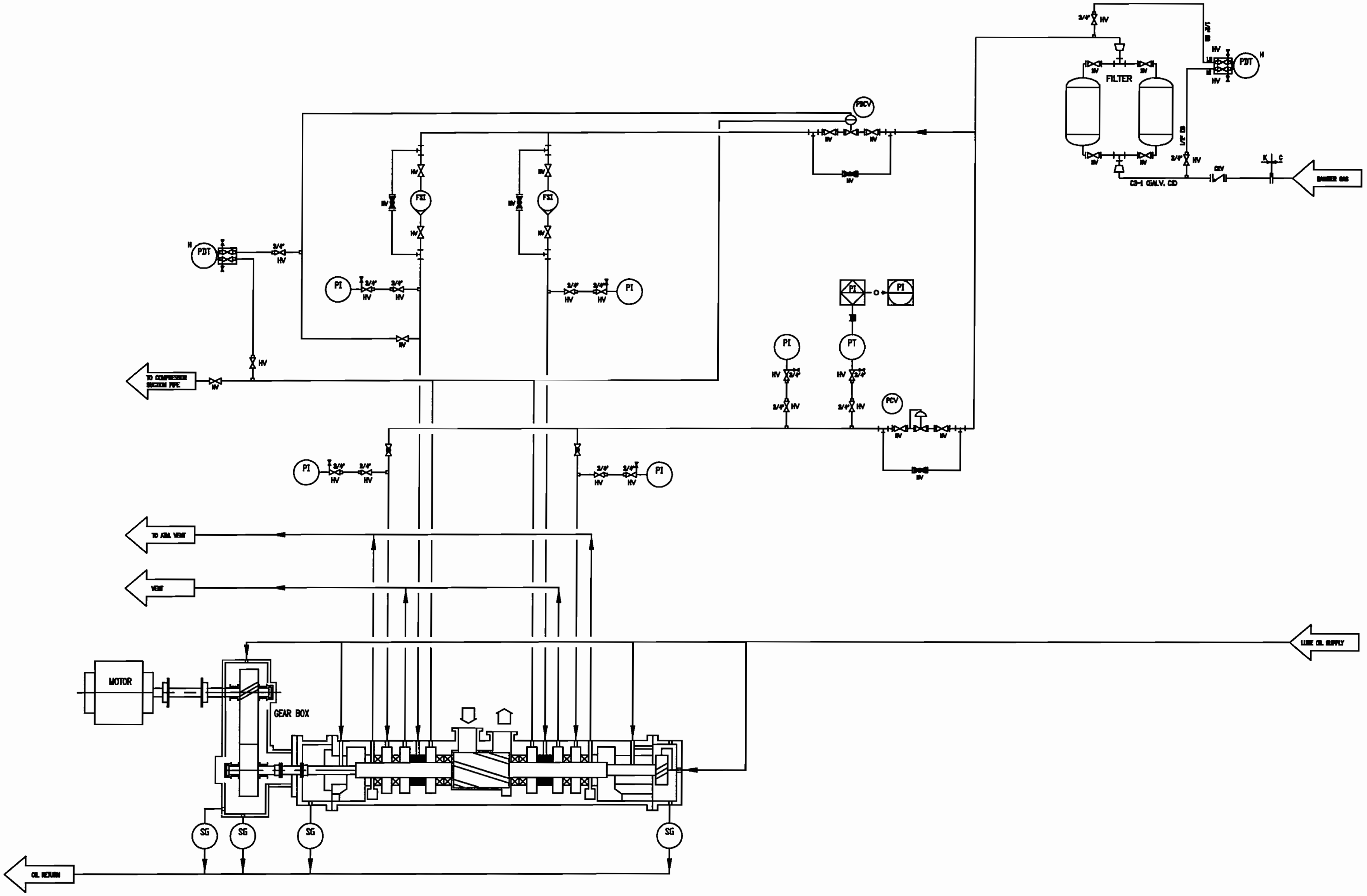
**KOBELCO EDTI
COMPRESSORS INC.**

301 N. SMITH AVE.
CORONA, CA 92880
PH.: (951) 279-9400
FAX.: (951) 279-9464

TITLE: MECHANICAL FLOW DIAGRAM
COKE OVEN GAS COMPRESSOR SYSTEM

		DATE	
DESIGN:	C.C.		SCALE: NONE
DRAWN:	M.M.		
CHECKED:			SHEET 1 OF 2
APPROVED:			

PROJECT NO. Q-27150A
DRAWING NO. Q-27150A-001
REV. A
REVISION DATE :
CAD FILENAME: 27150A0011
LAST PLOT DATE:



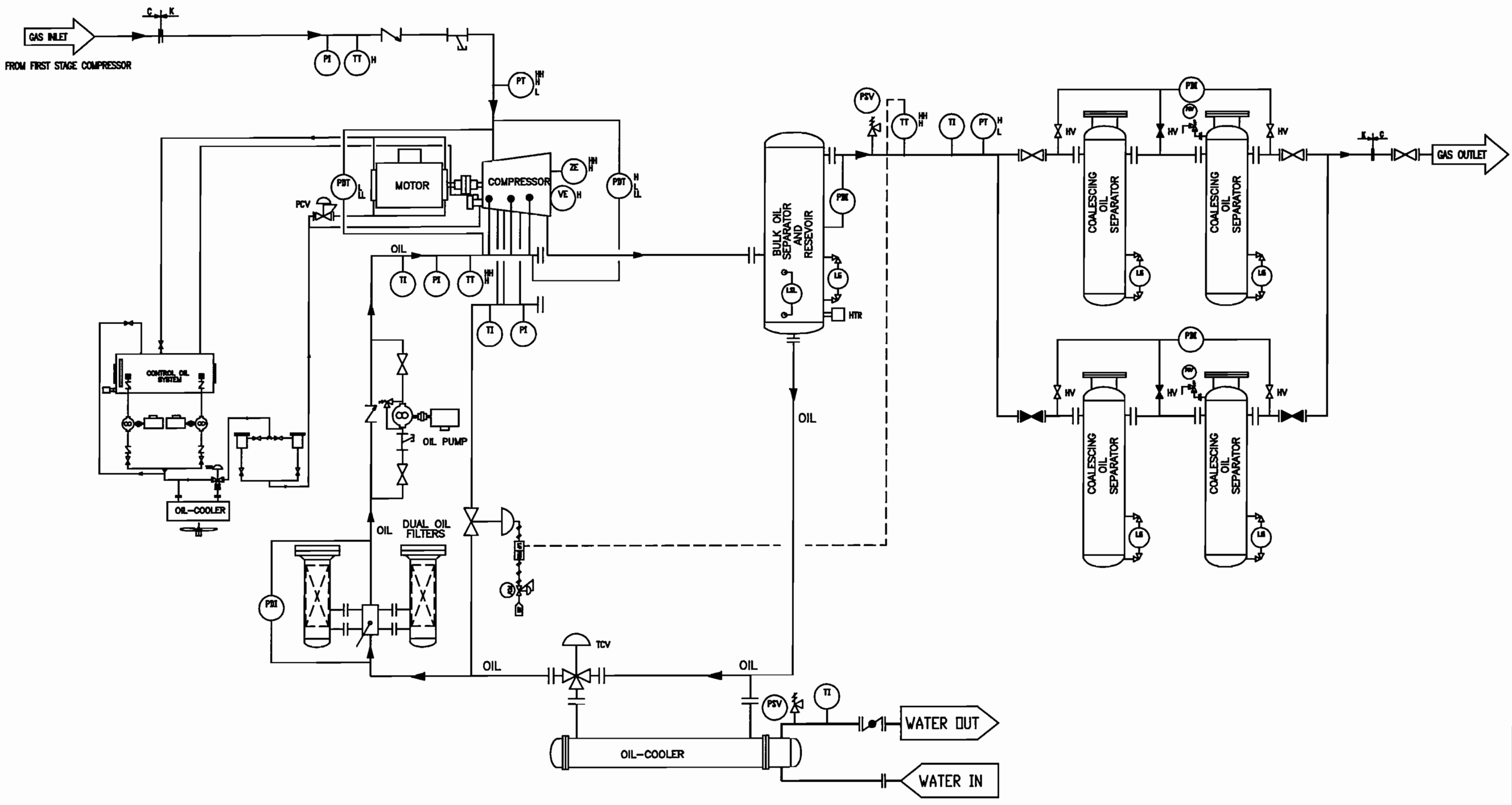
KOBELCO EDTI COMPRESSORS INC.

301 N. SMITH AVE.
CORONA, CA 92880
PH.: (951) 279-9400
FAX.: (951) 279-9464

TITLE:	MECHANICAL FLOW DIAGRAM COKE OVEN GAS COMPRESSOR SYSTEM (SEAL SECTION)	
		DATE
DESIGN:	C.C.	
DRAWN:	MARCUS	
CHECKED:		
APPROVED:		

SCALE: NONE
SHEET 2 OF 2

PROJECT NO. Q-27150A
DRAWING NO. Q-27150A-001
REV. A
REVISION DATE :
CAD FILENAME: 27150A0012
LAST PLOT DATE:



SECOND STAGE COMPRESSOR SYSTEM

KOBELCO EDTI COMPRESSORS INC.

301 N. SMITH AVE.
CORONA, CA 92880
PH.: (951) 279-9400
FAX.: (951) 279-9464

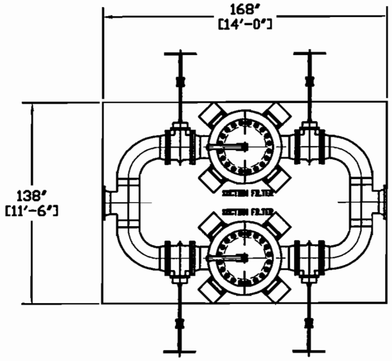
TITLE: MECHANICAL FLOW DIAGRAM COKE OVEN GAS COMPRESSOR SYSTEM			
		DATE	
DESIGN:	M.G.		SCALE:
DRAWN:	MARCUS		NONE
CHECKED:			SHEET 1 OF 1
APPROVED:			

PROJECT NO. Q-27150B

DRAWING NO. Q-27150B-001

REV. A

REVISION DATE :
CAD FILENAME: 27150B0011
LAST PLOT DATE:



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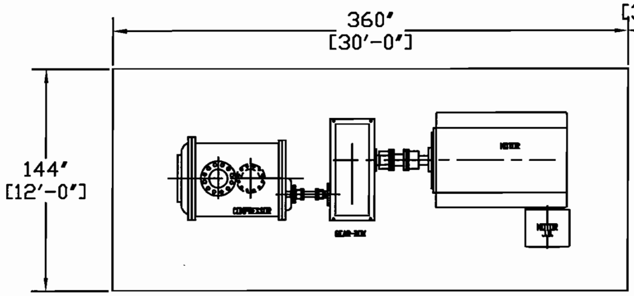

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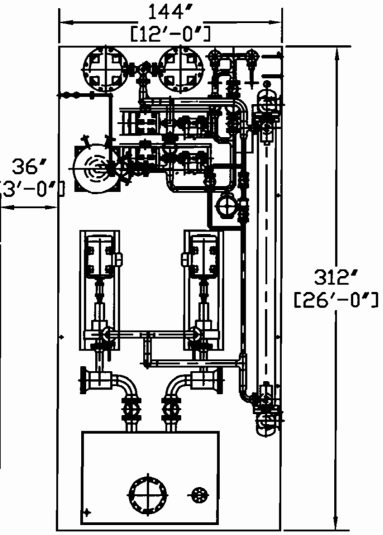

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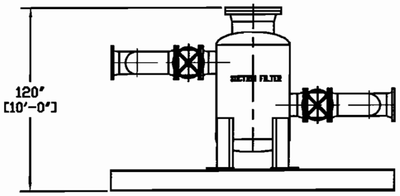
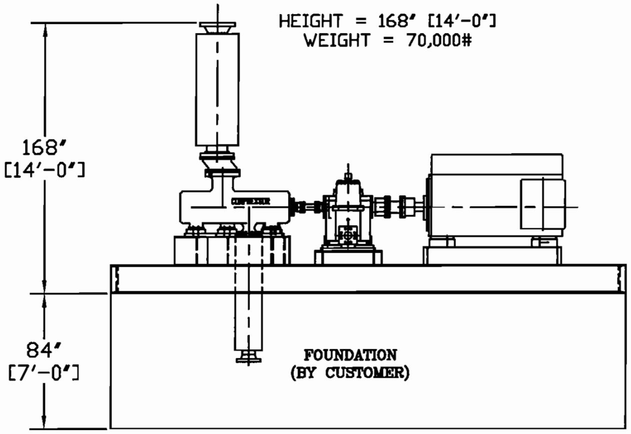
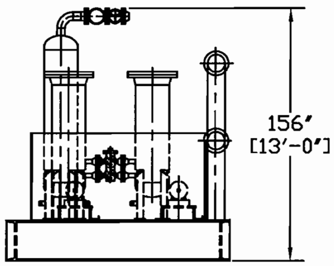






FIRST STAGE COMPRESSOR SYSTEM

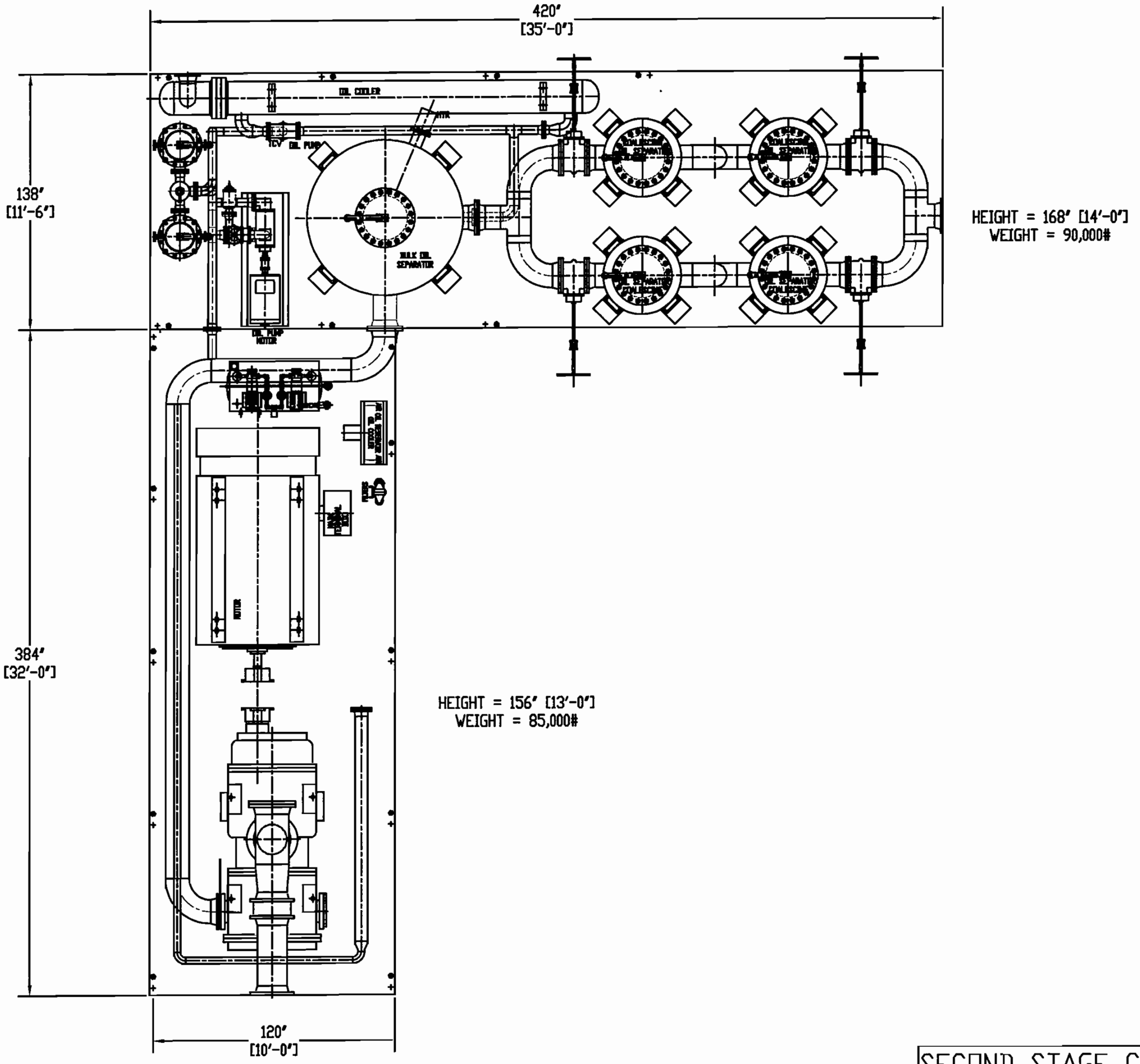
**KOBELCO EDTI
COMPRESSORS INC.**

301 N. SMITH AVE.
CORONA, CA 92880
PH.: (951) 279-9400
FAX.: (951) 279-9464

TITLE: MACHINERY ARRANGEMENT
COKE OVEN GAS COMPRESSOR SYSTEM

		DATE	
DESIGN:	C.C.		SCALE:
DRAWN:	MARCUS		NONE
CHECKED:			SHEET
APPROVED:			1 OF 1

PROJECT NO. Q-27150A
DRAWING NO. Q-27150A-011
REV. A
REVISION DATE :
CAD FILENAME: 27150A0111
LAST PLOT DATE:



SECOND STAGE COMPRESSOR SYSTEM

KOBELCO EDTI COMPRESSORS INC.

301 N. SMITH AVE.
CORONA, CA 92880
PH.: (951) 279-9400
FAX.: (951) 279-9464

TITLE: MACHINERY ARRANGEMENT COKE OVEN GAS COMPRESSOR SYSTEM			
		DATE	
DESIGN:	C.C.		SCALE:
DRAWN:	MARCUS		NONE
CHECKED:			SHEET
APPROVED:			1 OF 1

PROJECT NO. Q-27150B
DRAWING NO. Q-27150B-011
REV. A
REVISION DATE :
CAD FILENAME: 27150B0111
LAST PLOT DATE:

APPENDIX B

STORAGE TANK CALCULATION

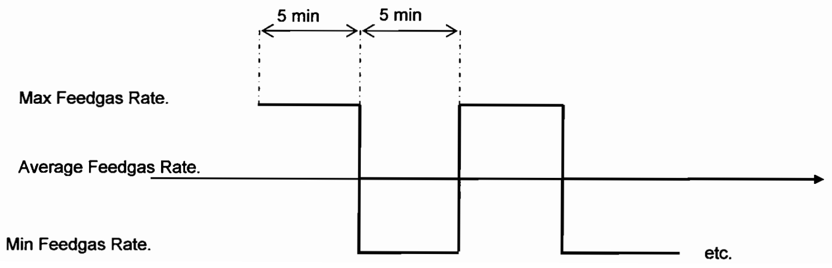
CONSIDER PSA FEED STORAGE

38.0 mScfd

Assumptions			
1. Average Feedgas Rate, Nm3/hr	42,415	4,174.66	Lbmols/hr
2. Maximum Feedgas Rate, Nm3/hr	50,897	5,009.59	Lbmols/hr
3. Temperature, F	100		
4. Minimum storage pressure, psig	415		
5. FCV DP Upstream of PSA, psi	15		
6. PSA Operating Pressure, psig	400		

	Time	Buffer Storage				Storage Flowrate, Lbmols/hr		Net Flow to Storage	Storage Pressure
	Minutes	L/D Ratio	Diameter (ft)	Length (ft)	Cubic Feet	Feed	Product	Lbmols	psig
CASE A									
Max Flow Cycle Start	0.0	5.0	6.3	31.7	1,000	5,009.59	4,174.66	0.00	415.00
Max Flow Cycle End	5.0	5.0	6.3	31.7	1,000	5,009.59	4,174.66	69.58	833.08
Min Flow Cycle End	10.0	5.0	6.3	31.7	1,000	3,339.72	4,174.66	-69.58	415.00
CASE B									
Max Flow Cycle Start	0.0	5.0	10.8	54.2	5,000	5,009.59	4,174.66	0.00	415.00
Max Flow Cycle End	5.0	5.0	10.8	54.2	5,000	5,009.59	4,174.66	69.58	498.62
Min Flow Cycle End	10.0	5.0	10.8	54.2	5,000	3,339.72	4,174.66	-69.58	415.00
CASE C									
Max Flow Cycle Start	**0.0**	**5.0**	**13.7**	**68.3**	**10,000**	**5,009.59**	**4,174.66**	**0.00**	**415.00**
Max Flow Cycle End	**5.0**	**5.0**	**13.7**	**68.3**	**10,000**	**5,009.59**	**4,174.66**	**69.58**	**456.81**
Min Flow Cycle End	**10.0**	**5.0**	**13.7**	**68.3**	**10,000**	**3,339.72**	**4,174.66**	**-69.58**	**415.00**

DESIGN BASIS



APPENDIX C

PRELIMINARY MATERIAL BALANCE

AND

PROCESS FLOW DIAGRAMS (PFD'S)

NATCO UK LIMITED

PRESSURE SWING ADSORPTION UNIT

MASS BALANCE

0		Issued For Design Study	CPG					
REV	**DATE**	**DESCRIPTION**	**Originator.**	**Checked.**	**Mech.**	**Process**	**Instr.**	**Proj. Man.**

PROJECT TITLE: **PRESSURE SWING ADSORPTION UNIT**	SPECIFICATION NUMBER: **J10556 - 3401**
CLIENT: **AKER KVAERNER FOR ENVIRES**	JOB NO.: **J10556** SHEET 1 OF 2

J10556 -3401 38MMSCFD PSA AKER KVAERNER FOR ENVIRES

Stream Number		1	2	3	4	5	6	7	8
Stream Name		H_2 Feed COG	PSA Feed	PSA Product	Offgas	De-Oxo Product	Ex Cooler	H_2 product	Water H_20
Vapor Fraction		1.00	1.00	1.00	1.00	1.00	0.99	1.00	0.00
Temperature	F	100.00	99.95	108.95	90.95	354.47	100.00	99.88	99.88
Pressure	psig	413.00	406.00	401.00	10.00	396.00	391.00	375.00	375.00
Enthalpy	btu/hr	1955089.50	1991120.31	1047572.19	1030352.64	4266108.17	426900.14	905506.66	-478606.49
Entropy	btu/R/hr	-13785.34	-13602.02	-10591.44	6861.02	-5603.63	-11353.14	-10437.40	-763.37
Vapor Density	lb/ft3	0.75	0.74	0.15	0.07	0.11	0.14	0.13	
Liquid 1 Density	lb/ft3	53.86					62.93		62.93
Liquid 1 Specific Gravity	60F@STP	0.88					1.00		1.00
Vapor Cp	btu/lbmol/R	7.68	7.68	6.92	7.99	6.96	6.92	6.92	
Vapor Cv	btu/lbmol/R	5.55	5.56	4.91	5.99	4.96	4.91	4.91	
Liquid 1 Cp	btu/lbmol/R								17.97
Vapor Viscosity	cP	0.01	0.01	0.01	0.01	0.01	0.01	0.01	
Liquid 1 Viscosity	cP	0.57					0.68		0.68
Vapor Thermal Conductivity	btu/ft/hr/F	0.05	0.05	0.11	0.03	0.14	0.11	0.11	
Liquid 1 Thermal Conductivity	btu/ft/hr/F	0.08					0.36		0.36
Vapor Flowrate	mmscf/day@STP	38.08	38.09	17.38	20.71	17.24	17.00	17.00	
Liquid 1 Flowrate	gal/min@STP	0.50					0.96		0.95
Liquid 2 Flowrate	gal/min						0.96		0.95
Molecular Weight		10.64	10.62	2.26	17.63	2.28	2.28	2.05	18.01
Molar Flowrate	lbmol/hr	4184.27	4182.73	1908.87	2273.86	1893.40	1893.40	1866.99	26.41
Mass Flowrate	lb/hr	44534.91	44410.13	4311.95	40098.14	4311.85	4311.85	3836.30	475.60

Note: All Liquid 1 Phase calculations exclude Free Water

J10556 -3401 38MMSCFD PSA AKER KVAERNER FOR ENVIRES

Stream Number		1	2	3	4	5	6	7	8
Stream Name		H_2 Feed COG	PSA Feed	PSA Product	Offgas	De-Oxo Product	Ex Cooler	H_2 product	Water $H_2$0
Molar Flowrate By Component									
HYDROGEN	lbmol/hr	2427.44	2427.44	1893.40	534.04	1862.47	1862.47	1862.46	0.01
CARBON MONOXIDE	lbmol/hr	218.13	218.13	0.00	218.13	0.00	0.00	0.00	0.00
CARBON DIOXIDE	lbmol/hr	54.32	54.32	0.00	54.32	0.00	0.00	0.00	0.00
OXYGEN	lbmol/hr	33.62	33.62	15.47	18.16	0.00	0.00	0.00	0.00
NITROGEN	lbmol/hr	293.57	293.57	0.00	293.57	0.00	0.00	0.00	0.00
METHANE	lbmol/hr	1006.15	1006.15	0.00	1006.15	0.00	0.00	0.00	0.00
ETHANE	lbmol/hr	16.81	16.81	0.00	16.81	0.00	0.00	0.00	0.00
ETHYLENE	lbmol/hr	79.75	79.75	0.00	79.75	0.00	0.00	0.00	0.00
PROPANE	lbmol/hr	4.31	4.31	0.00	4.31	0.00	0.00	0.00	0.00
PROPYLENE	lbmol/hr	12.50	12.50	0.00	12.50	0.00	0.00	0.00	0.00
BENZENE	lbmol/hr	15.09	15.09	0.00	15.09	0.00	0.00	0.00	0.00
TOLUENE	lbmol/hr	6.90	6.90	0.00	6.90	0.00	0.00	0.00	0.00
HYDROGEN SULFIDE	lbmol/hr	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYDROGEN CYANIDE	lbmol/hr	0.02	0.01	0.00	0.01	0.00	0.00	0.00	0.00
AMMONIA	lbmol/hr	1.72	1.72	0.00	1.72	0.00	0.00	0.00	0.00
SULFUR DIOXIDE	lbmol/hr	1.72	0.86	0.00	0.86	0.00	0.00	0.00	0.00
CARBONYL SULFIDE	lbmol/hr	0.43	0.22	0.00	0.22	0.00	0.00	0.00	0.00
WATER	lbmol/hr	11.32	11.32	0.00	11.32	30.93	30.93	4.54	26.40
NAPHTHALENE	lbmol/hr	0.43	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYDROGEN CHLORID	lbmol/hr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NITRIC OXIDE	lbmol/hr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
XYLENE	lbmol/hr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	lbmol/hr	4184.27	4182.73	1908.87	2273.86	1893.40	1893.40	1866.99	26.41

J10556 -3401 38MMSCFD PSA AKER KVAERNER FOR ENVIRES

Stream Number		1	2	3	4	5	6	7	8
Stream Name		H_2 Feed COG	PSA Feed	PSA Product	Offgas	De-Oxo Product	Ex Cooler	H_2 product	Water $H_2$0
Molar Composition By Component									
HYDROGEN	molar %	58.01	58.03	99.19	23.49	98.37	98.37	99.76	0.04
CARBON MONOXIDE	molar %	5.21	5.21	0.00	9.59	0.00	0.00	0.00	0.00
CARBON DIOXIDE	molar %	1.30	1.30	0.00	2.39	0.00	0.00	0.00	0.00
OXYGEN	molar %	0.80	0.80	0.81	0.80	0.00	0.00	0.00	0.00
NITROGEN	molar %	7.02	7.02	0.00	12.91	0.00	0.00	0.00	0.00
METHANE	molar %	24.05	24.05	0.00	44.25	0.00	0.00	0.00	0.00
ETHANE	molar %	0.40	0.40	0.00	0.74	0.00	0.00	0.00	0.00
ETHYLENE	molar %	1.91	1.91	0.00	3.51	0.00	0.00	0.00	0.00
PROPANE	molar %	0.10	0.10	0.00	0.19	0.00	0.00	0.00	0.00
PROPYLENE	molar %	0.30	0.30	0.00	0.55	0.00	0.00	0.00	0.00
BENZENE	molar %	0.36	0.36	0.00	0.66	0.00	0.00	0.00	0.00
TOLUENE	molar %	0.16	0.16	0.00	0.30	0.00	0.00	0.00	0.00
HYDROGEN SULFIDE	molar %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYDROGEN CYANIDE	molar %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
AMMONIA	molar %	0.04	0.04	0.00	0.08	0.00	0.00	0.00	0.00
SULFUR DIOXIDE	molar %	0.04	0.02	0.00	0.04	0.00	0.00	0.00	0.00
CARBONYL SULFIDE	molar %	0.01	0.01	0.00	0.01	0.00	0.00	0.00	0.00
WATER	molar %	0.27	0.27	0.00	0.50	1.63	1.63	0.24	99.96
NAPHTHALENE	molar %	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00
HYDROGEN CHLORID	molar %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NITRIC OXIDE	molar %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
XYLENE	molar %	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total	molar %	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Exhibit 24 U.S. Patent 4,496,369 (4 pages)

United States Patent [19]
Törneman

[11] **Patent Number:** **4,496,369**
[45] **Date of Patent:** **Jan. 29, 1985**

[54] **APPARATUS FOR GASIFICATION OF CARBON**

[75] Inventor: **Björn Törneman,** Vësterås, Sweden

[73] Assignee: **IPS Interproject Service AB,** Stockholm, Sweden

[21] Appl. No.: **505,985**

[22] Filed: **Jun. 20, 1983**

[30] **Foreign Application Priority Data**

Jul. 1, 1982 [SE] Sweden 8204089

[51] **Int. Cl.**^{3} **C10J 3/68;** C21C 5/40
[52] **U.S. Cl.** **48/92;** 48/DIG. 2; 266/155; 266/157
[58] **Field of Search** .... 48/92, 62 R, DIG. 2; 266/155, 157, 195; 75/0.5 BA, 24

[56] **References Cited**

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FOREIGN PATENT DOCUMENTS

296811	5/1971	U.S.S.R.	266/155

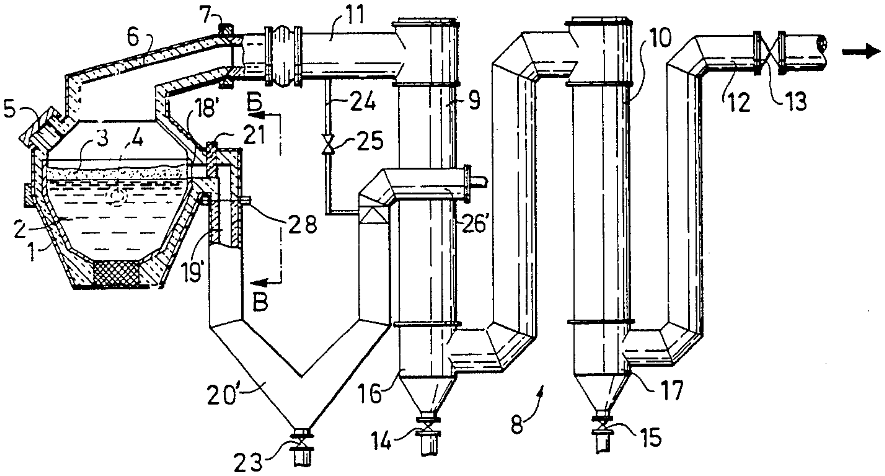
Primary Examiner—Jay H. Woo
Assistant Examiner—Joye L. Woodard
Attorney, Agent, or Firm—Silverman, Cass & Singer, Ltd.

[57] **ABSTRACT**

Apparatus for gasification of carbon (C) in the form of carbon, hydrocarbons and/or hydrocarbon compounds, comprising a reactor (**1**) into which injection of carbon, oxygen gas and iron oxides takes place, beneath the surface of an iron melt, and in which carbon is injected in stoichiometric excess in relation to the amount of oxygen in the form of oxidic compounds contained in the melt, the reactor having a total inner pressure exceeding atmospheric pressure.

According to the invention an exhaust gas pipe (**6**) from a reactor (**1**) makes a gas-tight connection with a cooler (**8**), which together with the reactor (**1**) forms a sealed unit; and a regulating valve (**13**) for adjusting and maintaining an overpressure in said unit is provided and placed on the cool side (**12**) of the cooler (**8**).

4 Claims, 5 Drawing Figures



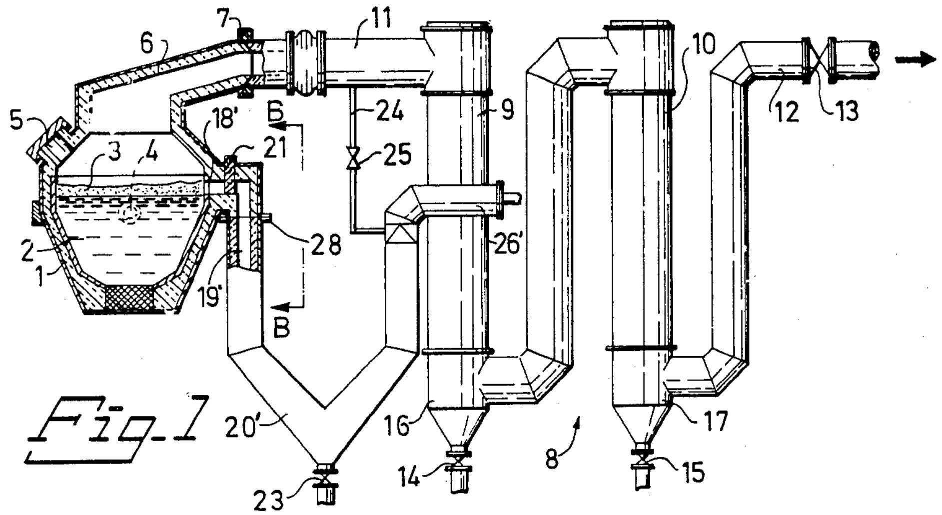


Fig-1

Fig-2

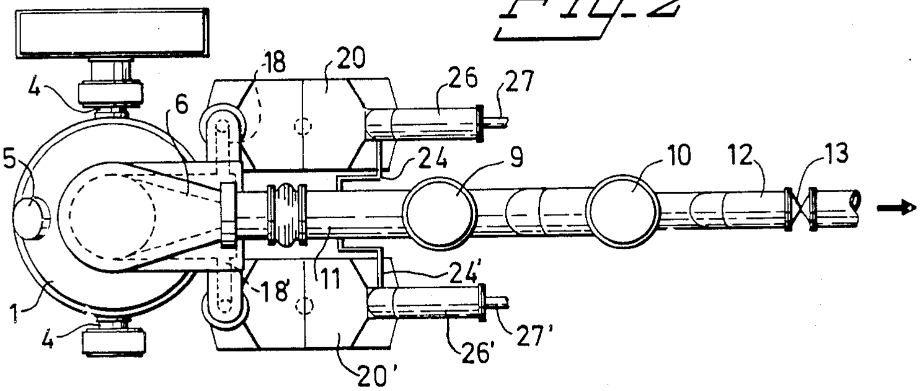


Fig-3

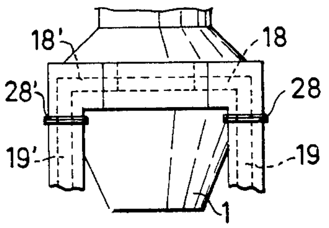


Fig-4

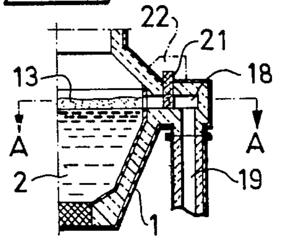
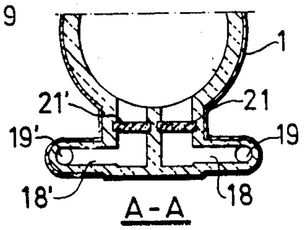


Fig-5



APPARATUS FOR GASIFICATION OF CARBON

The present invention relates to an apparatus for production of gas by gasification of carbon, said apparatus being intended to work at increased pressure.

More specifically the invention relates to an apparatus for production of gas by gasification of carbon in an iron melt into which carbon, oxygen and iron-ore concentrate are injected, carbon being injected in stoichiometric excess in relation to the oxygen in the form of oxide compounds contained in the melt. A gas is then formed, substantially comprising carbon monoxide (CO) and hydrogen (H_2).

Swedish Patent (Swedish patent application No. 7706876-5) describes such a process for production of gas, in which gas as well as crude iron are produced. It is in fact highly advantageous to use iron-ore concentrate as a cooling medium, and replace the melt of metals by continuous or intermittent discharge of melt and slag, whereby the sulphur content in the bath as well as the presence of other contaminants may be kept at a favourably low level.

Swedish Patent (Swedish patent application No. 8103201-3) describes a process in gasification of carbon in the form of carbon, hydrocarbons and/or hydrocarbon compounds, whereby carbon, oxygen and iron oxides, in which the iron oxides act as a cooling medium, are injected into the reactor, containing an iron melt, beneath the surface of the melt. Carbon is injected in stoichiometric excess in relation to the oxygen contained in the melt in the form of oxides. The iron melt has a carbon content such that it dissolves carbon. According to the process the reactor is brought to a total inner pressure of 2 to 50 bar, preferably 4 to 10 bar.

By applying a pressure in the reactor the gas production and the production of crude iron increase, compared to when atmospheric pressure prevails. Further, the amount of dust as well as the consumption of lining decrease substantially.

It is difficult to maintain overpressure in a reactor of the kind used here, especially when a discharge of slag and crude iron is to take place at the same time. In order to reduce dust formation and other unwanted effects the sulphur content should be adjusted to lie within the range 0.5% to 2.5%. The sulphur content is controlled by injecting slag forming compounds. The slag formed by the injection of slag forming compounds should be discharged during operation so that the amount of slag does not become too large. The temperature of the gas produced is high, approximately 1300° C. to 1400° C. (2372° F. to 2552° F.), which also makes it extremely difficult to control the pressure in the reactor.

The present invention relates to an apparatus for carrying out the last-mentioned process, i.e. an apparatus for production of gas and crude iron under increased pressure.

This invention thus relates to an apparatus for gasification of carbon (C) in the form of carbon, hydrocarbons and/or hydrocarbon compounds, comprising a reactor in which injection of carbon, oxygen gas and iron oxides takes place under the surface of the iron melt, and in which carbon is injected in stoichiometric excess in relation to the amount of oxygen in the form of oxide compounds in the melt, the reactor having a total inner pressure exceeding atmospheric pressure. The invention is further characterized in that an exhaust gas pipe from the reactor is closely attached to a cooling device, which together with the reactor forms a sealed unit and in that a regulating valve for controlling and maintaining overpressure in the said unit is placed on the cold side of the cooling device.

The invention will now be further described with reference to an embodiment shown in the attached drawing, where

FIG. **1** is a side view of an apparatus according to the invention, the reactor being shown in cross-section

FIG. 2 shows from above the apparatus seen in FIG. **1**

FIG. **3** is a partial view, seen in the direction of the arrows B in FIG. **1**

FIG. **4** is a section of the right-hand half in FIG. **3**

FIG. **5** is a horizontal section along line A—A in FIG. **4**

FIG. **1** shows a reactor **1**, lined and provided with a steel mantle, which during operation contains a crude iron melt **2**. In FIG. **1**, **3** represents slag floating on top of the crude iron melt. The reactor **1** is preferably designed to be tilted round an axis **4** for discharge of crude iron **2** through opening **5**.

Carbon, iron-ore concentrate, oxygen and slag-forming compounds are injected by means of conventional lances and/or injection pipes.

In the top of the reactor **1** there is an exhaust gas pipe **6** for the gas produced, which is connected by a gas-tight coupling **7** to a device in the direction in which the gas is transported. This device comprises a cooler, generally represented by **8**, which according to this embodiment comprises two conventional steam boilers **9**,**10**. According to a preferred embodiment the cooler contains a dust separator.

The gas produced is thus led through the pipe **6** and another pipe **11** to the first boiler **9**. The gas is then led to the second of the two boilers, **10**, and on to a discharge pipe **12**.

The discharge pipe is provided with a regulating valve **13** for controlling and maintaining the pressure in the reactor and the cooler **8**. The regulating valve **13** is of any suitale kind.

As the gas in the outlet pipe **12** has a considerably lower temperature than before it reaches the cooler, e.g. a temperature of approximately 200° C. (392° F.) a quite conventional regulating valve and conventional pressure units may be used. It is thus possible to avoid the considerable difficulties that would arise if the pressure had to be adjusted on the hot side, i.e. in direct connection with the exhaust gas pipe **6** from the reactor, where the temperature of the exhaust gas is approximately 1300° C. to 1400° C. (2372° F. to 2552° F.).

As the pressure is adjusted after the cooler **8**, this cooler is maintained under pressure and is thus designed to resist any increased pressure in the system.

Dust that has been separated is discharged through valves **14**,**15** at the bottom of the dust deparators **16**,**17**.

As mentioned above it is desirable to be able to tap off slag **3** during operation, i.e. whilst the reactor **1** is pressurized. According to the invention there is a device for tapping slag for this purpose, which is also pressurized at a pressure corresponding to the pressure in the reactor. The device for tapping slag comprises a horizontal slag channel **18** at the same level as the desired slag height, leading to a descending slag channel **19**. The channel **19** is connected to a granulator **20**.

In the horizontal channel **18** there is a flooding valve comprising a stone **21** or a board of a suitable material which in its lower end position closes the slag channel between the reactor and the granulator **20** (See FIG. **4**) and which in its raised position opens the channel mentioned. The stone **21** is sealed to the walls of the slag channel by means of devices not shown. A sealed housing **22** which is marked with dashes in FIG. **4** is placed, according to one embodiment, above the stone **21**. This housing may also comprise a control, not shown, for positioning the stone **21**.

When the level of the slag in the reactor reaches the level of the horizontal slag channel **18**, the stone **21** will be pushed upwards and slag will run out of the reactor **1** down to the granulator **20**. In order to equalize the pressure in the granulator **20** both at this stage and when granulated material is discharged through a valve **23** at the bottom of the granulator, a pressure equalizing pipe **24** which includes a regulating valve **25** is provided. This pipe **24** connects the granulator **20** with the above-mentioned pipe **11**, which leads gas away from the reactor **1**.

With wet granulation, hydrogen sulfide (H_2S) is formed which is allowed to leave the granulator through a pipe **26**. This pipe **26** is also provided with a regulating valve **27** for maintaining pressure in the granulator **20**.

In order to enable discharge of crude iron during operation there is a channel **18′,19′** which corresponds to the above-mentioned channel **18,19** and which connects the reactor with a second granulator **20′** for granulation of crude iron. This channel **18′** is also provided with a flooding valve in the form of a stone **21′** or a board which operates in the same way as the previously mentioned flooding valve **21**. This second granulator **20′** is pressurized and connected to said further pipe **11** by a pressure equalizing pipe **24′**. A pipe **26′** and a regulating valve **27′** are also provided for discharging the gases produced to the atmosphere.

The horizontal channels **18,18′** and the stones **21,21′** are fitted in or adjacent to the wall of the reactor **1**. Thus a very high temperature will prevail at the stones **21,21′**, which will eliminate freezing and blockage by slag and/or crude iron splashes.

Thanks to this and the pressurizing of the granulators **20,20′** slag and crude iron can be discharged continuously or intermittently during operation. Further it is not necessary for the stones **21,21′** to be designed to deal with pressure differences between the horizontal channels **18,18′** and the descending channels **19,19′**.

It is evident from FIG. **5** that the channels **18,18′** are arranged parallel to each other. In FIG. **3** the channels **18,18′** are shown positioned at the same level. The height of the channels **18,18′** may, of course, be varied according to the desired slag level and the thickness of the slag layer. In such a case the channel **18′** for tapping crude iron is preferably positioned at a lower level than a channel **18** for tapping slag.

The descending channels **19,19′** are each provided with a sealed coupling **28,28′**. When all the crude iron is to be discharged, these couplings **28,28′** are released as well as the coupling **7** on the exhaust gas pipe **6** on the reactor and the reactor is then tilted.

An apparatus according to the present invention must, of course, be adapted to the pressures at which it is to be used. Modifications of valves, seals, design of cooler and the like may be made without departing from the main concept of the invention, which is to pressurize both the reactor and the cooler as well as any other auxiliary equipment, for example the tapping devices for slag and crude iron.

The present invention is thus not limited to the embodiment described above but can be varied within the scope of the attached claims.

I claim:

1. Apparatus for gasification of carbon in the form of carbon, hydrocarbons, or hydrocarbon compounds, under total pressure exceeding atmospheric pressure, comprising:

A. reactor means for containing molten iron, said reactor including injection means for injecting carbon, oxygen gas, and iron oxides beneath the surface of the molten iron, and for injection of carbon in stoichiometric excess relative to the amount of oxygen contained in the molten iron in the form of oxide compounds;

B. an exhaust pipe connected to said reactor means for discharge of exhaust gas therefrom;

C. cooling means for cooling said gas connected to said exhaust pipe to form a sealed unit with said reactor means;

D. valve means for regulating and maintaining pressure greater than atmospheric pressure in said unit, said valve means being positioned on said cooling means;

E. first tapping means for discharge of slag from said reactor means, and second tapping means for discharge of crude iron from said reactor means, each of said first and second tapping means connected to said exhaust pipe by a pressure equalizing pipe, in order to maintain said first and second tapping means at the same pressure as said unit.

2. The apparatus of claim **1**, wherein each of said first and second tapping means comprises a granulator means having an inner portion connected to said exhaust pipe.

3. The apparatus of claim **1**, wherein each of said first and second tapping means comprises a horizontal channel connected to said reactor means for discharge therethrough of slag and crude iron, respectively, said channel including a flooding valve comprising a valve member for opening and closing said channel.

4. The apparatus of claim **1**, wherein said cooling means comprises at least one steam boiler connected to at least one dust separator means.

* * * * *

Exhibit 25 U.S. Patent 4,511,372 (6 pages)

United States Patent [19]
Axelsson

[11] **Patent Number:** **4,511,372**
[45] **Date of Patent:** **Apr. 16, 1985**

[54] CARBON GASIFICATION METHOD

[75] Inventor: **Carl-Lennart Axelsson,** Stockholm, Sweden

[73] Assignee: **IPS Interproject Service AB,** Bettna, Sweden

[21] Appl. No.: **574,665**

[22] Filed: **Jan. 27, 1984**

Related U.S. Application Data

[63] Continuation of Ser. No. 379,787, May 19, 1982, abandoned.

[30] **Foreign Application Priority Data**

May 20, 1981 [SE] Sweden 8103201

[51] **Int. Cl.**^{3} **C10J 3/00**
[52] **U.S. Cl.** .... **48/197 R;** 48/92; 48/210; 75/42
[58] **Field of Search** .... 48/92, 197 R, 206, 210; 75/42; 282/373

[56] **References Cited**

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2713864	3/1977	Fed. Rep. of Germany	48/92
2750725	5/1979	Fed. Rep. of Germany	48/92

Primary Examiner—Peter Kratz
Attorney, Agent, or Firm—Silverman, Cass & Singer

[57] **ABSTRACT**

A method of gasifying carbon (C) in the form of coal, hydrocarbons and/or hydrocarbon compounds, comprising the steps of into a reactor vessel holding a molten iron bath to inject carbon, oxygen and iron oxides beneath the surface of the molten iron bath, where the iron oxides constitute a coolant and where carbon is injected in a stoichiometric excess relative to oxygen included in the bath in the form of oxides, and where the molten iron bath has such a carbon content that it solves-in carbon. According to the invention, the reactor vessel is caused to have an inner total pressure of 2 to 50 bar, preferably 4 to 10 bar.

Hereby the gas production and the production of pig iron increase. Furthermore, the dust formation and the lining wear are reduced substantially.

12 Claims, 2 Drawing Figures

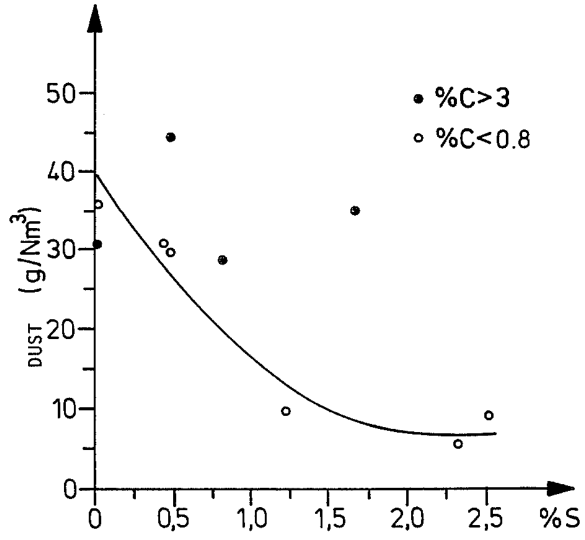


Fig. 1

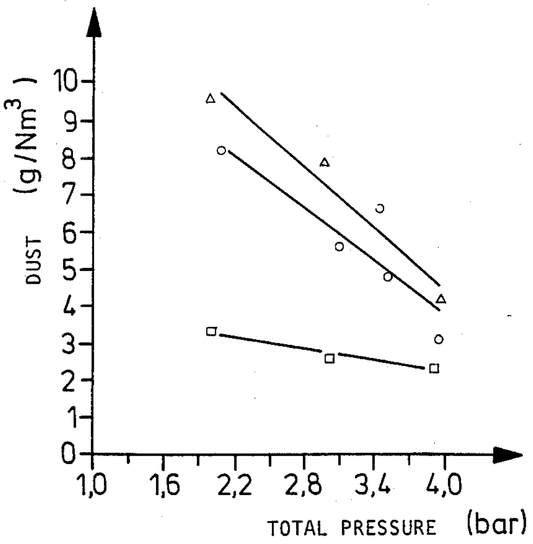
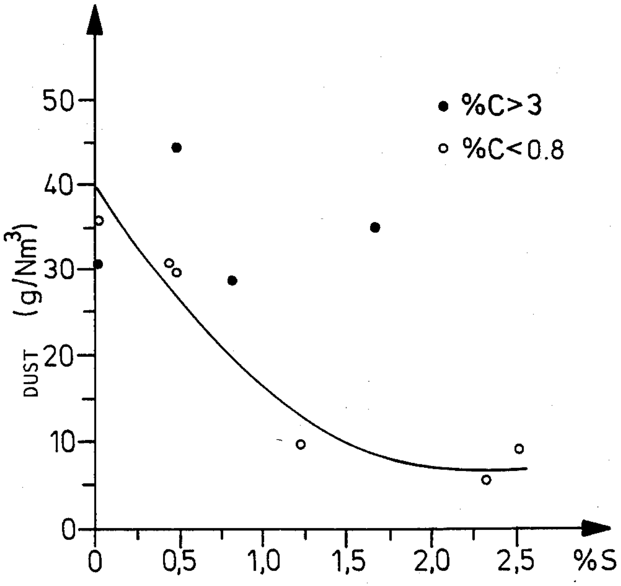

DUST (g/Nm^3)
10
9
8
7
6
5
4
3
2
1
0
1,0
1,6
2,2
2,8
3,4
4,0
TOTAL PRESSURE (bar)

Fig. 2


● %C>3
○ %C<0.8
DUST (g/Nm^3)
50
40
30
20
10
0
0
0,5
1,0
1,5
2,0
2,5
%S

CARBON GASIFICATION METHOD

This application is a continuation of application Ser. No. 379,787, filed May 19, 1982, now abandoned.

This invention relates to a method of gasifying carbon.

The invention, more precisely, relates to a method, at which carbon is gasified in a molten iron bath by injecting carbon beneath the bath surface.

Several methods proposing to gasify carbon in a molten iron bath are known. One such method is disclosed in SE-PS No. (Swedish patent application No. 7706876-5), which describes a method of preparing hydrocarbon compounds from carbon (C) in the form of coal including a certain amount of water, hydrocarbon and/or hydrocarbon compounds. According to said method, carbon is injected into a molten bath in a stoichiometric excess relative to oxygen included in the form of oxidic compounds in the molten bath, together with a coolant. The coolant preferably consists of iron oxides in the form of iron ore concentrate when the molten bath consists of molten iron, whereby iron is reduced in the same process.

Slag-forming compounds, such as CaO, also are added.

The heat required for the reduction of iron oxides is taken from the combustion of injected carbon and injected oxygen, at which large amounts of carbon monoxide (CO) and hydrogen gas (H_2) are formed.

At the method thus described a pig iron process is combined with a carbon gasification process, whereby great advantages, especially economic ones, are obtained.

At tests with the aforesaid methods it was found, however, that many problems arise when carbon is gasified by means of a molten iron bath. The problems are of such nature that the process cannot be adapted to the production unless the problems are solved.

The problems substantially emanate from one difficulty, viz. to produce a large amount of gas per time unit in relation to the size of the reactor vessel, in which the reactions proceed.

The problems, more precisely, are as follows: to effect a high gas production, to avoid heavy wear of the lining, to establish a good thermal balance and to minimize dust formation.

As regards the difficulty of effecting a high gas production, this is connected with the size of the reactor vessel.

The reactants preferably are supplied by means of a pneumatic injection system, which effects the injection at the bottom of the reactor vessel. In a process, at which gas and powder are injected into a bath of molten iron, the maximum flow of injected material is determined by the gas accumulation capacity of the system. Carbon monoxide (CO) and hydrogen gas (H_2) are formed more or less immediately after the injection and thereby give rise to a gas flow, which is disintegrated to small bubbles rising to the bath surface. The height of the bubble column formed increases with increasing supply of reactive components to the system. In the case of a molten iron bath covered with slag, thus, the gas developed must pass through molten metal and slag, whereby both the metal and the slag will increase in height compared with their nominal heights, i.e. when no gas develops. At a certain injection flow the mixture of metal, slag and gas will reach up to the upper edge of the reactor vessel, and metal and slag are thrown out. When this takes place, the upper hydrodynamic limit of the system, as one may call it, is exceeded.

As regards lining wear, this is intimately connected with a high gas production.

A vessel intended to hold a molten iron bath is lined with one or, often, several ceramic materials constituting an insulation. At its contact with metal and slag, the ceramic material is subjected to wear, the mechanisms of which can be divided substantially into chemaical disintegration, erosion and thermal cleavage.

At a process of the kind here concerned the erosion is very substantial and has proved directly responsive to the volumetric gas flow through the reactor vessel. The reason of this is high gas development, i.e. a large volumetric flow yields a forceful stirring of the bath.

The gasification of carbon to CO and H_2 contributes heat energy to the system, while the cleavage of iron oxides is an endothermal reaction. It is, however, desired to produce relatively large amounts of pig iron in the reactor vessel, because this results among other benefits in an advantageous turnover of the molten iron bath.

A high pig iron production is advantageous partly because the molten iron bath absorbs impurities from injected carbon and partly because a relatively high pig iron production is a prerequisite for rendering the process economically justifiable.

The necessary heat energy contribution by the carbon gasification reaction, however, is of such a magnitude that, compared with the bath volume, large amounts of carbon must be gasified for rendering the reduction of necessary iron oxides possible.

The three aforesaid problems, thus, would be solved if the gas production can be maintained high in relation to the bath volume.

A great and in one sense decisive problem at carbon gasification is dust formation. It has been known for a long time that large amounts of iron are vaporized when oxygen is injected into a carbonaceous molten iron bath. At top injection by means of the so-called LD-process, the main part of the dust formation can be explained by the so-called bubble-breaking theory.

When, however, oxygen is injected into the reactor vessel from the bottom or from the side, it was found that iron is evaporated at the phase boundary surfaces between metal and gas, owing to the high temperature arising at the reaction between injected oxygen and carbon. The evaporation of iron occurs at the phase boundary surfaces, which are not covered with iron oxide.

All of the aforesaid problems are eliminated or substantially reduced by the present invention.

The present invention, thus, relates to a method of gasifying carbon (C) in the form of coal, hydrocarbon and/or hydrocarbon compounds, comprising the steps of into a reactor vessel holding a molten iron bath to inject carbon, oxygen and iron oxides beneath the bath surface, which iron oxides constitute a coolant and are intended to be reduced, of injecting carbon in a stoichiometric excess relative to oxygen included in the bath in the form of oxides, which molten iron bath has such a carbon content that it dissolves carbon. The method is characterized in that the reactor vessel is caused to have an inner total pressure of 2 to 50 bar, preferably of 4 to 10 bar.

The reactor vessel is manufactured entirely sealed to the surrounding, with the exception of a gas outlet and injection tuyeres nozzles. The gas outlet preferably is provided with an adjustable throttling for rendering pressure control in the reactor vessel possible.

The invention is described in greater detail in the following, partially with reference to the accompanying drawing, in which

FIG. 1 is a diagram of the dust content plotted against the total pressure in the reactor vessel, and

FIG. 2 is a diagram of the dust content plotted against the sulphur content in the bath.

According to the present invention, the reactor vessel is caused to operate at overpressure, which (total pressure) may be from about 2 bar to 50 bar, depending on the capacity intended, the size of the reactor vessel etc. A preferred pressure range, however, is about 4 to 10 bar and especially about 6 to 8 bar.

The gas volume accumulated in the mixture of metal, slag and gas depends substantially only on the volumetric gas flow. At a constant volumetric gas flow, thus, the mass flow is proportional to the pressure. The amount of carbon injected per time unit, thus, compared with the prevailing of atmospheric pressure, can be increased in direct proportion to the pressure without thereby affecting the size of the accumulated gas volume. This implies that the aforesaid hydrodynamic limit for the reactor vessel, i.e. when metal and slag are thrown out of the reactor vessel, also increases proportionally to the pressure. A substantially higher gas production per time unit, thus, is rendered possible by pressurizing the reactor vessel.

An increased mass flow, as mentioned, can be effected without increasing the volumetric flow. This in its turn implies, that the aforesaid erosion, in spite of increased gas production, can be held constant or is caused to decrease by reducing the volumetric flow, in spite of a mass flow exceeding the mass flow at atmospheric pressure in the reactor vessel, because a decrease in the volumetric flow implies less stirring and thereby lower erosion.

The mass flow is caused to increase by injecting a greater amount of carbon and oxygen. By this greater carbon and oxygen amount a greater heat energy amount is supplied to the bath and is utilized for reducing a greater amount of iron oxides to pig iron. The heat losses through the walls of the reactor vessel are determined by the difference between the inner and outer temperature of the walls, so that a great heat loss does not occur as long as the bath temperature is not increased.

An additional effect on the heat balance is obtained by the increased total pressure. When the volume of a gaseous equilibrium mixture is decreased, the concentration of all components and the total pressure of the mixture increase in a corresponding degree. When the total number of moles of reactants and products according to a reaction formula is different, the numerator and denominator of the concentration fraction are changed in different degrees. The system then is not in equilibrium after the pressure increase. The equilibrium is shifted to that side which represents the smallest number of moles in the reaction formula.

The gas composition obtained by the present process is determined in principle by the reaction

$$C(\text{in Fe})+CO_2(g)\rightleftharpoons 2CO(g) \quad (1)$$

The proportion hydrogen gas/water vapour can be calculated by the so-called shift reaction

$$H_2O(g)+CO(g)\rightleftharpoons H_2(g)+CO_2(g) \quad (2)$$

When the total pressure is caused to increase, the reaction (1) is shifted to the left, which also shifts the reaction (2) to the left.

Outgoing gas, thus, at an increased total pressure will include a greater proportion CO_2 and H_2O than at atmospheric pressure, and thereby will have a higher combustion degree, which implies an additional heat contribution to the reactor. This additional heat contribution yields an extra reduction potential in the reactor.

Instead of an increased iron reduction, however, an increased proportion of water vapour can be added by injection, which implies an increased proportion of hydrogen gas in the outgoing gas and, thus, enriches the chemical heat content of the gas and increases its H_2/CO relation. This latter effect is favourable in addition to other benefits when the gas, for example, is to be used for methanol production.

At carbon gasification processes of the kind here concerned dust formation is a serious problem. It was mentioned above, that iron is evaporated from the phase boundary surfaces between metal and gas, owing to the very high temperature arising at the reaction between oxygen and carbon.

The total phase boundary surface at constant mass flow in the system decreases with increased pressure, owing to a reduced volumetric flow. This in its turn implies a decrease of the evaporation and dust formation.

FIG. 1 shows by way of example a diagram over the dust content expressed in g/Nm^3 plotted against the total pressure expressed in bar (standard atmospheres). The diagram shows three different curves, representing different sulphur contents in the bath and varying amount of injected oxygen. A triangle designates experiments at a sulphur content of 0.92%±0.05% and a carbon content of 0.61%±0.05% and an oxygen flow of 42 Nl/min. A circle designates experiments with the same sulphur content and carbon content, but with an oxygen flow of 2.4 Nl/min. A square designates experiments with a sulphur content of 1.57%±0.19% and a carbon content of 0.11%±0.07% and an oxygen flow of 4.2 Nl/min.

The experiments illustrated in FIG. 1 were carried out on laboratory scale where carbon and oxygen were injected into liquid iron at a temperature of 1550° C.

The diagram shows clearly that the dust formation decreases significantly already at relatively low overpressures. This effect is increased at higher pressures. At a high sulphur content in the bath, the dust formation in general is lower and is affected relatively little by the pressure, compared with when the sulphur content is higher. In the diagram also is shown that at unchanged contents of sulphur and carbon the dust formation decreases with diminishing oxygen flow.

It has been discovered, thus, that a high sulphur content reduces the dust formation significantly at a given carbon content and a given oxygen flow. The sulphur content, isolated from this aspect, must exceed 0.5% to 1.5%, but be lower than 2.0% to 2.5%. A preferred range for the sulphur content is about 0.5% to 2%. FIG. 2 shows the dust content in g/Nm^3 plotted against the sulphur content in % in the bath. Filled circles refer to measurements of a molten iron bath with a carbon content exceeding 3%, and unfilled circles refer to a molten iron bath containing less than 0.8% carbon. FIG. 2 refers to conditions at atmospheric pressure.

According to the present invention it is preferred to operate a reactor in the manner described above while the sulphur content in the bath is caused to be about 0.5% to 2% at the same time as the carbon content in the bath is caused to be lower than 3%, preferably below 2%.

The carbon content in the iron bath is controlled by the amount of injected coal in relation to other reactants. The sulphur content in the iron bath is controlled by the amount and type of slag-forming compounds.

It is fully apparent that all problems mentioned in the introductory portion above are eliminated, or in any case substantially reduced, by carrying out the method while pressurizing the reactor vessel. The improvement is accentuated in that the bath is caused to assume the aforesaid sulphur and carbon contents.

By utilizing the invention, thus, the dust formation and the lining wear are reduced substantially. Furthermore, a considerable pig iron production is rendered possible owing to a greater heat energy development in the bath. One of the most essential advantages, however, is that the gas production can be increased substantially.

The invention must not be regarded restricted to the embodiments stated above, but can be varied within the scope of the attached claims.

I claim:

1. In a method for gasifying carbon in the form of coal, hydrocarbons, and/or hydrocarbon compounds, in which carbon, oxygen and iron oxides are injected beneath the surface of a molten iron bath held in a reactor vessel so that the iron oxides constitute a coolant and are intended to be reduced, and the carbon is dissolved in the molten bath, the carbon being injected in a stoichiometric excess relative to the oxygen present in the bath in the form of oxides, the improvement comprising:

A. maintaining the total pressure in the reactor vessel greater than atmospheric pressure up to 50 bar;

B. maintaining the carbon concentration in the molten iron bath lower than 3% by weight carbon; and

C. maintaining the sulphur concentration in the molten ion bath in the range of about 0.5% to 2.5%, thereby enabling increase in the rate of gas production with reduction in dust formation.

2. The method as claimed in claim **1** wherein the sulphur concentration is in the range of about 0.5% to 2%.

3. The method as claimed in claim **2** wherein said total pressure is within the range of about 4 to 10 bar.

4. The method as claimed in claim **1** wherein said total pressure is within the range of about 4 to 10 bar.

5. The method as claimed in claim **4** wherein the carbon concentration is lower than 2%.

6. The method as claimed in claim **1** wherein the carbon concentration is lower than 2%.

7. The method as claimed in claim **1** wherein said total pressure is within the range of about 2 to 50 bar.

8. In a method for gasifying carbon in the form of coal, hydrocarbons, and/or hydrocarbon compounds, in which carbon, oxygen and iron oxides are injected beneath the surface of a molten iron bath held in a reactor vessel so that the iron oxides constitute a coolant and are intended to be reduced, and the carbon is dissolved in the molten bath, the carbon being injected in a stoichiometric excess relative to the oxygen present in the bath in the form of oxides, the improvement comprising:

A. maintaining the total pressure in the reactor vessel greater than atmospheric pressure up to 50 bar;

B. maintaining the carbon concentration in the molten iron bath lower than 0.8% by weight carbon; and

C. maintaining the sulphur concentration in the molten ion bath in the range of about 0.5% to 2.5%, thereby enabling increase in the rate of gas production with reduction in dust formation.

9. The method as claimed in claim **8** wherein the sulphur concentration is in the range of about 0.5% to 2%.

10. The method as claimed in claim **9** wherein said total pressure is within the range of about 4 to 10 bar.

11. The method as claimed in claim **8** wherein said total pressure is within the range of about 4 to 10 bar.

12. The method as claimed in claim **8** wherein said total pressure is within the range of about 2 to 50 bar.

* * * * *

Exhibit 26 Details of Tasks 1, 2.1 and 2.2 (338 pages)

Exhibit 26

DETAILS OF WORK ON TASK 1, 2.1 & 2.2

EXHIBIT 26 TABLE OF CONTENTS

Table of Figures

Table of Acronyms and Abbreviations

$	Dollars, US
%v	volume percent
%w	weight percent
°C	degrees centigrade
°F	degrees Fahrenheit
bar	10^6 Pascal
CFD	computational fluid dynamics
CIG	Coal Iron Gasification
cm	centimeter
d	day
DOE	United States Department of Energy
eaf	electric arc furnace
gal	gallons, US
GFE	Gibbs Free Energy
HGT	HyMelt Gasification Technology
hr	hour
ID	inside diameter
IGCC	integrated gasification combined cycle
kg	kilogram
kJ	kilo joule
kSCF	thousand standard cubic feet
MEFOS	Swedish acronym for metallurgical research consortium in Lulea, Sweden
min	minute
MIP	Molten Iron Pure Gas
mm	millimeter

MM	million
mt	metric ton, 1000 kg
Nm3	normal cubic meter @ 0°C and 1 ATM
NOx	oxides of nitrogen
OD	outside diameter
Pa	Pascal, a unit of pressure
P-CIG	Pressurized Coal Iron Gasification
ppm	parts per million, volume unless otherwise noted
ppmvd	parts per million, volume dry
PSA	Pressure Swing Adsorption
psig	pounds per square inch, gauge
SCFD	standard cubic feet per day
SWPC	Siemens Westinghouse Power Corporation
ton	short ton, US
UOP	a petroleum and chemical technology development and leasing company formerly Universal Oil Products
USA	United States of America

1 PROJECT OBJECTIVES, SCOPE AND DESCRIPTION OF TASKS

1.1 Introduction

EnviRes and DOE executed the cooperative agreement for this work on September 19, 2002. This document is the final report for task 2.1 under this agreement. Ashland Petroleum Company performed bench scale testing of the HyMelt gasification technology (HGT) from 1992 to 1997. HGT operates by injecting coal and/or other carbonaceous feeds below the surface of molten iron without significant amounts of oxidizers. The resultant gas stream contains as much as 95%v H_2 with the balance consisting of CO, H_2S and CH_4. Most of the carbon in the feed dissolves in the molten iron. The temperature of the molten metal bath drops to provide heat required by the process. The carbonaceous feed is interrupted before carbon saturation of the molten iron occurs. Oxygen is then injected to reduce the carbon content of the molten iron, raise the temperature and produce a gas stream rich in CO. Overall this process is exothermic. Adding the proper amount of a material that reacts endothermicly in the molten iron bath such as steam controls the temperature of the system.

When two or more vessels are operated so that one produces a H_2 rich stream and the other produces a CO rich stream and each vessel switches feed at nearly the same time so that again one vessel produces a H_2 rich stream and the other produces a CO rich stream it becomes possible with appropriate valve operation to continuously produce a H2 rich stream and separate CO rich stream.

Testing at the pilot scale where the feed rate exceeds 1 ton/hr would normally require a facility with a capital cost approaching $50,000,000 and require several years to build. A substantial staff of operators, maintenance personnel, analytical chemists, engineering personnel and support personnel would also be required. The usefulness of such a facility after testing would likely be small. EnviRes elected to subcontract with MEFOS for pilot scale testing to avoid these cost and schedule issues.

MEFOS is a metallurgical research facility located in Lulea, Sweden. A group of approximately 35 Nordic and other European companies support MEFOS. Member companies collectively direct research activities of MEFOS, however, MEFOS also does contract research for non-member companies. MEFOS retains no intellectual property rights relating to the contract research that they do.

MEFOS has equipment and support systems for various types of high temperature metallurgical and gasification projects where the feed rate can go to 3 tons/hr. They have a full compliment of staff in house to perform all aspects of a gasification program. Since 1980 MEFOS has done large scale testing of gasification processes including Molten-Iron-Pure Gas (MIP) by KHD Humboldt, Coal Iron Gasification (CIG) and Pressurized Coal Iron Gasification (P-CIG) by Nippon Steel Corporation and Interproject Service AB.

1.2 Scope of Work

Phase I of the work to be done under this agreement consists of conducting atmospheric gasification of coal using the HyMelt technology to produce separate hydrogen rich and carbon monoxide rich product streams. In addition smaller quantities of petroleum coke and a low value refinery stream will be gasified. DOE and EnviRes will evaluate the results of this work to determine the feasibility and desirability of proceeding to Phase II of the work to be done under this agreement, which is gasification of the above-mentioned feeds at a gasifer pressure of approximately 5 bar. The results of this work will be used to evaluate the technical and economic aspects of producing ultra-clean transportation fuels using the HyMelt technology in existing and proposed refinery configurations.

2 Executive Summary

EnviRes purchased 25 tons of Illinois #6 coal, transported it to Holt, AL where it was pulverized, dried, bagged and loaded into a sea-land container. EnviRes transported the sea-land container to Savannah, GA where it was shipped to MEFOS. Similarly, EnviRes acquired high sulfur petroleum coke and a high sulfur aromatic extract oil . EnviRes prepared, packaged and shipped them to MEFOS.

Experimental testing of coal, petroleum coke and heavy oil began on June 5 and continued through June 13. We believe that these tests represent the first instance of injection of these feeds into molten iron without the concurrent injection of substantial quantities of oxygen and other materials. The tests in June resulted in unacceptably low rates of carbon dissolution in the molten iron. Preliminary results from tests conducted in September indicate that much better carbon dissolution rates result from submerged injection. The improved performance was confirmed when we analyzed the data generated. We scheduled additional atmospheric testing using bottom tuyeres for both oxygen injection and coal or coke injection to begin December 8, 2003. The December testing operated in a commercially practical mode. The December testing demonstrated satisfactory carbon to metal yields at feed rates of up to 27 kg/min for both coal and petroleum coke. No liquid feed was tested in the December campaign.

An economic evaluation by Kvaerner indicated that water gas shifting of carbon monoxide is prohibitively expensive at $2.86 per kscf of incremental hydrogen produced over the fuel value of the feed carbon monoxide. HyMelt, unlike most other coal gasification processes, does not require water gas shifting to produce high purity hydrogen. Detailed flow sheets, equipment sizing, equipment cost, and preliminary operating cost estimates are presented in this report. Kvaerner obtained cost estimates from UOP for Polybed PSA hydrogen purification.

EnviRes and Siemens Westinghouse Power Corporation decided to evaluate catalytic burners for gas turbines using the carbon monoxide rich fuel gas from the HyMelt process. If performance similar to that already demonstrated with natural gas can be achieved with HyMelt fuel gas, we believe that post combustion abatement controls will not be required to meet currently envisioned new source performance standards for NO_x and CO emissions.

3 Experimental Methodology

3.1 Task 1.1Project Management and Planning

Planning, scheduling, risk analysis and other activities associated with this task were integral in accomplising the subsequent tasks. Most activities for this task were reported in the appropriate quarterly report for that period. Many of the plans and schedules were frequently revised as the project progressed. Most of these activities will not be reported here, however, Appendix I contains an example of a planning report to give some insight into the planning process. Some revisions to plans were made during the execution of the experimental program and were not documented as such, but the results of the decisions are given in the experimental reports.

3.2 Task 1.2 Acquisition, Preparation and Shipment of Feed Materials

EnviRes purchased 25 tons of Illinois #6 coal from Old Ben Coal Company's Zeigler #11 mine. EnviRes contracted Beelman Trucking Company to haul the coal to Empire Coke Company in Holt, AL for pulverization. The coal was pulverized, dried to 2% moisture and loaded into 1-ton bulk polypropylene bags on November 9, 2002. A total of 19.3 tons of dried pulverized coal were loaded into a 40' sea-land container on November 12. Page and Jones shipped the container to Savannah, GA on November 12. It was loaded on a ship in Savannah on November 22 in transit to Sweden. MEFOS received the coal on December 20. MEFOS inspected the shipment and found it to be in good order. Section 3.1.1 on page AVI p18 in Appendix VI of this report gives the elemental and mineral analyses of this shipment.

At the request of EnviRes, Marathon Ashland Petroleum Company LLC donated 17 tons of delayed coke from their Garyville, LA refinery. EnviRes contracted with Fore Trucking Company to haul the coke to Holt, AL for pulverization and drying. The coke was pulverized, dried to less than 2% moisture and loaded into bulk bags. A total of 9.8 tons of dried, pulverized coke were loaded onto a 20' sea-land container on November 22. Page and Jones shipped the container to Savannah, GA where it left for Sweden in mid December. The shipment arrived in good order at MEFOS on January 10, 2003. Section 3.1.2 on page AVI p18 in Appendix VI of this report gives the elemental analysis of this shipment.

At the request of EnviRes, Marathon Ashland Petroleum Company LLC acquired 50 – 55 gallon drums and filled them with 325 aromatic extract on January 10, 2003. The drums were loaded into a Sea Land container that left Savannah, GA on January 22. MEFOS received the oil in mid February. Section 3.1.3 on page AVI p18 in Appendix VI of this report gives the elemental analysis of this shipment.

3.3 Task 1.3 Predictive Modeling of the HyMelt Process

The HyMelt process operates at temperatures sufficiently high enough that many reactions will approach thermodynamic equilibrium. While some circumstances such as inadequate mixing and local composition deviations from bulk conditions can cause results far from equilibrium for the bulk conditions, a thermodynamic equilibrium analysis of the system still provides a useful insight into the behavior of the process.

Thermodynamic equilibrium for steady state systems generally implies a Gibbs Free Energy (GFE) minimization. For gas phase systems such an exercise is fairly trivial since sufficient thermodynamic data for all species likely to be found in the gas phase of gasification processes is readily available and the chemical activity of gaseous species at these temperatures is very close to the partial pressure of the species. Many commercially available process simulation software packages possess this capability. Such an endeavor becomes significantly more complex, however, when metal and slag phases are included with the gas phase in a GFE minimization. Typically the activity of species dissolved in the metal or slag phase are very nonlinear with composition. This can be further complicated by the possibility of multiple liquid and/or solid phases occurring in the slag phase. We believe that FactSage is the only commercially available software capable of simulating the above described system.

The FactSage thermochemical software and databases are fully described in refference 1 of Appendix II. It is the only commercially available software and database package that has the capability to model simultaneous gas-metal-slag equilibrium without requiring additional thermodynamic data. The extensive component and solution databases available in FactSage set it apart from most other thermodynamic equilibrium simulation software. FactSage allows incremental reactants to be added to the system and the incremental gases produced in equilibrium with the system to be removed if desired. Detailed phase diagrams of the slag and metal phases can also be generated in nearly any format desired.

While the HyMelt process can appear to be continuous on an overall basis, each reactor operates in a batch mode. One reactor begins a cycle with a low carbon, high temperature bath of molten iron. Carbonaceous feed to the metal bath produces a hydrogen rich gas stream, increases the carbon content of the metal and decreases the temperature of the metal bath as the carbonaceous injection period proceeds. Simultaneously a second reactor begins the other portion of the cycle with a high carbon, low temperature bath of molten iron. Oxygen injected into the metal bath produces a carbon monoxide rich gas stream, decreases the carbon content of the metal bath and increases the temperature of the metal bath as the oxygen injection period proceeds. Repeating these cycles may increase or decrease minor constituents of the metal depending on the composition of the carbonaceous feed and whether other additives are injected. Taken together, both injections result in a net exothermic system. Some of the net exotherm will be consumed by system heat losses and sensible heat required to heat additives such as bunt lime (sensible heat for reactants and products has already been considered). The remaining exotherm will be balanced by an endothermic injectant such as steam to allow temperature to remain fairly constant across cycles. Steam injection, to the extent that it can be practiced, reduces the separately produced oxygen requirement per ton of feed.

MEFOS performed the thermodynamic analysis of the HyMelt process. The MEFOS report appears in Appendix II. The MEFOS analysis examined the change of species in the metal, slag and gas phases of the HyMelt process within a cycle and over many cycles for feeds consisting of a heavy aromatic oil, petroleum coke and Illinois #6 coal. The major conclusions of the analysis are the following:

1. Sulfur removal solely as H_2S is not practical. Approximately 90% of sulfur in feed must be removed by the addition of burnt lime.

2. Higher pressure operation results in higher dissolved oxygen in the metal phase. This causes more CO to dilute the hydrogen rich gas.

3. When feeding petroleum coke with high vanadium and nickel content, the vanadium level in the metal can reach 13% before it starts to oxidize to form vanadium oxides in the slag phase. Nickel does not oxidize, but as it increases in the metal phase, the volume of metal increases. An arbitrary limit of 20% nickel was assumed.

4. During oxygen injection, virtually no CO_2 forms until the carbon content in the metal is less than 0.7 wt%.

5. The relatively high oxygen content of coal results in approximately 20% CO in the hydrogen rich stream compared to 5% CO for petroleum coke and 3% CO for heavy aromatic oil.

EnviRes obtained a license for FactSage and plans to perform additional studies.

3.4 Task 1.4 Combustion Modelling and Analysis

The product gas produced by the HyMelt process differs from typical product gas produced by entrained flow gasifiers and most other proposed gasification process in several significant ways. Because the HyMelt process produces both a hydrogen rich stream and a carbon monoxide rich stream, either stream or both could be the fuel for a combustion turbine. If both streams are combined and used as fuel for a combustion turbine, the resultant mixture is more similar to fuel streams produced by other gasification processes. The most significant differences are the following:

1. The HyMelt fuel stream contains less than 1%v CO_2 compared to other oxygen blown gasifiers with fuel stream CO_2 levels of 2% to 20%v.

2. The HyMelt fuel stream typically contains less H_2 than most other gasifier fuel streams.

3. The HyMelt fuel stream typically contains more CO than most other gasifier fuel streams.

4. The concentration of other contaminants in the fuel stream is largely dependent on downstream cleanup employed by either HyMelt or other gasification processes.

In many situations the hydrogen rich stream has more value as a chemical feed than as a fuel. In this case only the carbon monoxide rich stream serves as fuel. This results in even higher levels of carbon monoxide in the HyMelt fuel stream. We selected the case with maximum CO in the fuel stream to study for combustion modeling because it represented the most extreme departure from typical gasifier fuel streams and because we deemed it to be the most likely outcome in commercial practice.

Most combustion turbines in use today use diffusion burners. Diffusion burners are non-catalytic. They use the combination of temperature and residence time to accomplish combustion. These burners are most often used with natural gas in combustion turbine applications for power generation. Many studies have been made on various aspects of these systems including CFD modeling, combustion reaction modeling, turbine performance, and flue gas concentrations of air emissions. A limited amount of data from coal gasifier fired combustion turbines have also been generated.

Issues related to the impact of fuel type can be broadly grouped into two major categories namely: performance and emissions. Performance issues include overall efficiency in converting the energy content of the fuel into electrical energy, the impact of the fuel on the reliability of the power generating system, maintenance requirements and combustor and turbine modifications necessary to accommodate a different fuel. Emission issues primarily relate to the type and amount of pollutants emitted in the flue gas that are or are anticipated to fall under various regulatory standards.

Several fuel characteristics can affect gas turbine performance. Consider the fuel its self. Natural gas is primarily methane. The simple stoichiometry for combustion of methane in air can be expressed as

$CH_4 + 2O_2 + 7.52N_2 \rightarrow CO_2 + 2\ H_2O + 7.52\ N_2$ $-35{,}736$ kJ/Nm^3 [1] eq.(1)
where the heat release is the net heat of combustion at 0°C.

Similarly the combustion stoichiometry in air for the predominant constituent of HyMelt fuel gas, carbon monoxide, can be expressed as

$CO + 0.5O_2 + 3.76N_2 \rightarrow CO_2 + 3.76N_2$ $-12{,}589$ kJ/Nm^3 [2] eq.(2)
where the heat release is the net heat of combustion at 0°C.

Combustion for gas turbines always requires a substantial amount (typically 3 to 4 times the stoichiometric requirement) of excess air or some other moderating gas to control the inlet temperature to the turbine to approximately 1150°C to avoid over temperature damage to the turbine.

From eq.(1) and eq.(2) the volume of air required to combust a volume of methane is 4 times that required to combust the same volume of carbon monoxide. The net heat released in combusting a volume of methane is 2.839 times the heat released in combusting the same volume of carbon monoxide. This means that on an equivalent heat release basis, methane requires 1.409 times as much combustion air as does carbon monoxide.

Current combustion turbines use an expander inlet pressure of $1.308\text{x}10^6$ Pa (175 psig) to $1.379\text{x}10^6$ Pa (200 psig). The combustion air and moderating gas (usually air) must be available at a somewhat higher pressure. A compressor turbine driven by the expander shaft usually performs this compression. While the amount of excess air or moderating gas may vary with the fuel used, it seems likely that the net power produced by combusting carbon monoxide will be higher than that for methane for the same heat release. Other factors such as the higher molecular weight of the combustion products for carbon monoxide versus those for methane may also play a role in the efficiency of the gas turbine.

Other factors that may affect combustion turbine performance include volatile metals or metal oxides that may deposit on rotating parts causing either erosion or build up on rotating parts resulting in unacceptable imbalance and thus requiring early shutdown for repair. Soot formation or other particulate may have a similar adverse impact on turbine performance perhaps to a lesser degree. Variations in the composition of the fuel to the turbine can cause problems in maintaining the correct combustion air flow to the combustor. Natural gas should not generate any of these problems. The level of problematic contaminants in fuel gas generated by any entrained flow gasification process or the HyMelt process depend to a great extent on the particular feedstock and downstream gas cleanup. The impact of the process itself other than the above mentioned considerations should be minimal.

Most of the activities of Siemens Westinghouse Power Corporation were directed toward the emissions of HyMelt fuel gas compared to Natural Gas. Because extensive cleanup of fuel gas from gasifiers removes most potential pollutants before combustion, only two species are of regulatory concern. They are oxides of nitrogen, NO_x and Carbon monoxide, CO. Carbon dioxide, CO_2 likely will become regulated within the USA in the near future. The SWPC report on page AV-5 in Appendix V discusses the likely emission limits for CO and NO_x and concludes that a limit of 2 ppmv for both CO and NO_x corrected to 0% moisture and 15% oxygen.

SWPC compared the emissions of the anticipated HyMelt fuel gas with natural gas using catalytic combustion in a W501D5A gas turbine. Computational fluid dynamics (CFD) and chemical reactor modeling were used in concert to produce a model of the combustor. This model has been validated with natural gas as the fuel. No experimental data using HyMelt gases have been generated.

The study shows that the expected NO_x production for HyMelt gas is approximately 33% of the NO_x production for natural gas at the same conditions (2 ppmvd vs 6 ppmvd) of 1143 °C (2090°F) combustor exit temperature corrected to 15% oxygen in the flue gas. At the combustor outlet temperature of 1143°C, the carbon monoxide emissions are nearly the same for both natural gas and HyMelt fuel gas. For most other conditions, natural gas has lower emissions of CO. Based on these results both natural gas and HyMelt fuel gas fired gas turbines require some sort of CO abatement while natural gas fired gas turbines also require NO_x abatement and HyMelt fuel gas fired turbines may not require NO_x abatement.

3.5 Design and Fabrication of Pilot Plant Specific Molten Iron Bath Apparatus

Several decades earlier MEFOS designed and buit a large scale test unit called the Universal Converter. Originaly it was used to study basic oxygen steel making. It has a nominal hot metal capacity of 6 mt. This system was fully supported with all the necessary equipment and utilities to charge hot metal to the converter and provide the necessary input streams such as oxygen, argon and various metallurgical addives. An off-gas handling system capable of combusting the product gas, cooling it and scrubbing it to meet Swedish environmental requirements was incorporated into the system. MEFOS modified the Universal Converter in 1982 to study coal gasification. At least three different processes using molten iron gasification were studied in the Universal Converter and are described in 1.1 of this document. MEFOS and EnviRes made modifications to the Universal Converter to test the HyMelt process at a nominal feed rate of 3 mt/hr. These modifications were made to the feed injection system, the product gas sampling system, the product gas analysis system and the product gas particulate sampling system.

EnviRes and MEFOS finalized the design for the Oil injection system, purchased the equipment, and fabricated the system. We successfully hot tested the system (oil was injected into the converter with no metal in the converter, oxygen injection combusted the oil in the converter) on June 4. Figure 1 is a photograph of the oil feed system. The large rectangular shape is the tank for holding the heated oil. Other items (some not visible) include the high-pressure pump, temperature sensors, pressure sensors, flow-metering sensors; electrical heaters, control valves, and recycle piping.

MEFOS began feed injection on June 5. Each day of experimental operation began by melting 5,000 to 5,500 kg of metal in the electric arc furnace (eaf), adjusting the metal composition if necessary, and transferring the metal to the Universal Converter by ladle. Figure 2 shows the metal being transferred to the Universal Converter. After completing the metal transfer, the operator typically decarburized the melt with oxygen to get the metal temperature and carbon content to the desired level. Figure 3 shows the Universal Converter during decarburization. The intense flame shown in the photograph occurs at the gap between the hood and the converter where ambient air flows into the hood and reacts with CO and other decarburization gases. After decarburization and feed injection the operator typically tilted the converter for slag and metal sampling. Metal samples were also taken during decarburization and feed injection, but MEFOS considers tilted samples to be more representative of the melt composition. Figure 4 shows an operator taking a slag sample from the tilted converter. At the end of each day of operation, MEFOS poured metal and slag separately from the converter. Figure 5 shows the operator pouring the metal from the converter. The converter was left over night with a burner inside of it to keep the refractory hot for the next day of testing.

MEFOS continuously sampled converter gas during both feed injection and decarburization for analysis by mass spectrometer. The sample probe had a ceramic filter on the end inside the converter and a finer filter after the gas cooled and before it went to analyzers. Figure 6 shows the ceramic probes use inside the converter. These ceramic filters or the finer filters often became obstructed resulting in a greater vacuum in the sample train than intended. This resulted in significant air infiltration into the samples. MEFOS made corrections for air in the gas samples. Figure 7 shows the Mass Spectrometer that MEFOS temporarily set up to measure converter gas composition.

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[1] "Technical Data Book – Petroleum Refining", Fifth Edition, May 1992, American Petroleum Institute, p 14.9

[2] Ibid

Figure 1 Feed system for liquid injection

Figure 2 Metal transfer to the Univeresal Conveter

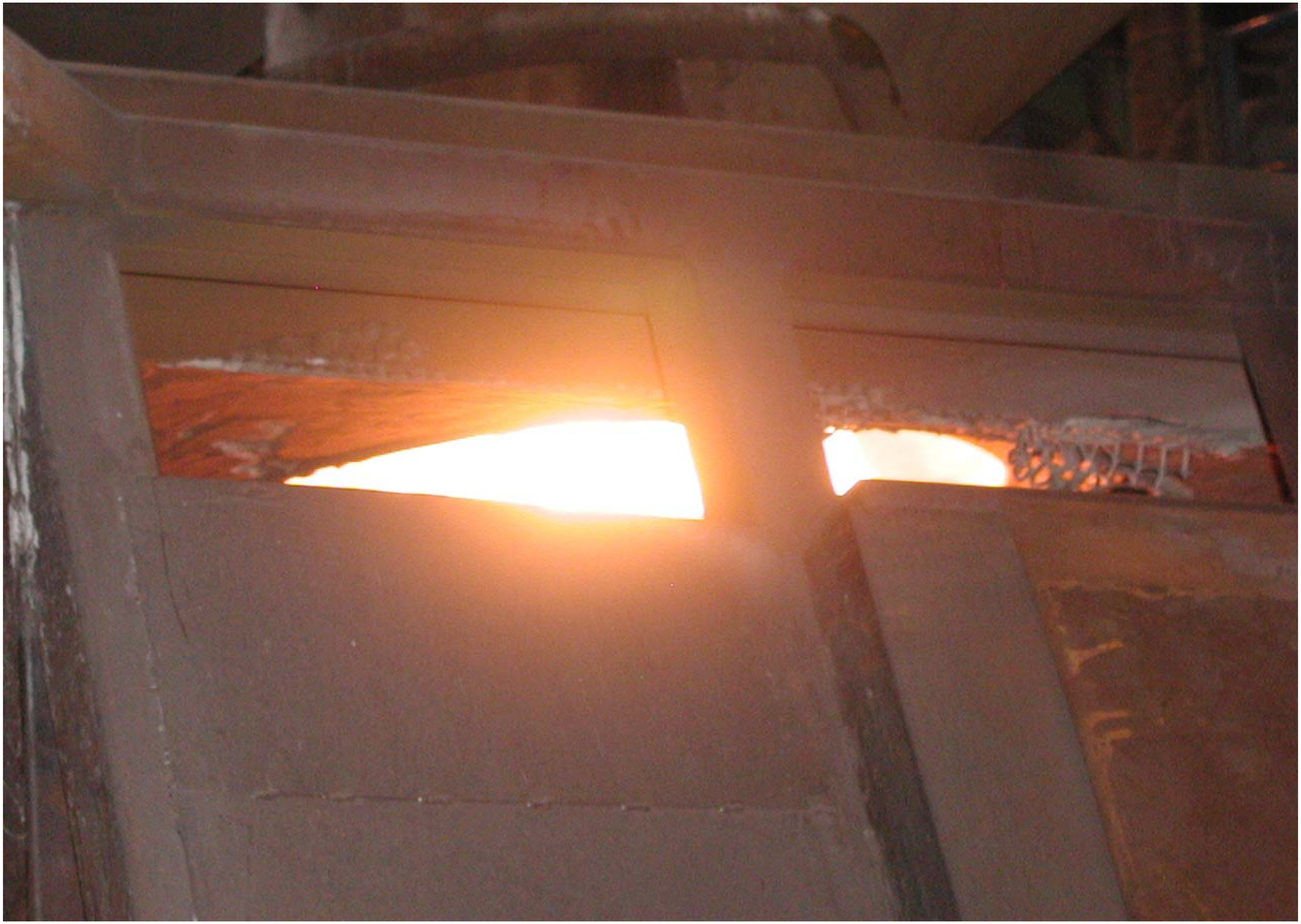

Figure 3 Universal Converter during decarburization

Figure 4 Slag sampling from tilted Universal Converter

Figure 5 Metal pour from Universal Converter at day's end

Figure 6 Used ceramic filters from gas sample probe

Figure 7 On-line mass spectrometer for gas analysis

The MEFOS report in Appendix I points out that some problems in sampling and analyzing streams occurred during the test program. Some of these problems included air infiltration into the process gas sample lines between the sample probe and the analytical equipment, calibration drift for the mass spectrometer, feed misidentification and other problems that were not clearly identified. Most of these problems can be corrected by standard data reconciliation techniques. Since the volume of data is great, data reconciliation represents a long and arduous task that would consume substantial resources and money. As we will describe later, the rate of carbon dissolution into the metal for the June test program was unacceptably low. We decided that additional testing with better feed injection was necessary. We will, therefore, focus attention and resources on test periods that represent commercially attractive operating conditions. Our analysis of the June data will review the useful data generated with greater effort reserved for later work.

The MEFOS report in Appendix I describes the equipment, the materials used, the testing procedure and the heat notes in sufficient detail so that no further comment regarding them will be made. Additional comments on the results will be made in section 4.0 Discussion.

Preliminary analysis of the data generated June 5 to 13 indicated that carbon dissolution rates into the metal were unsatisfactory. MEFOS and EnviRes concluded that the problem was caused by problems associated with top entry lances. We further concluded that although significant improvements could be made to top entry lances and the way they are utilized, most of these improvements were not achievable within the financial and time constraints of this project. MEFOS suggested that we test tuyeres for coal and petroleum coke injection. The quickest, most cost effective, most likely to succeed approach was to use a side entry lance 10 cm from the bottom of the refractory lining. The initial tuyere to be tested was a single lanyard (one tube) design. Argon would transport the solid feed from the feed hopper to the tuyere. Figure 8 is a view of the universal converter with the lance installed. The single rubber hose conveys the pneumatically transported particulate to the tuyere near the center of the figure. The stainless steel tubing connects a pressure gauge (to the top) allowing the inlet pressure to the tuyere to be monitored. The universal converter is tilted to the charging or tapping position in Figure 8. The hood that collects product gases and air for combustion appears at the very top of the figure. A connection for bottom stirring (not connected) appears at the lower left.

On Tuesday, September 2, 2003 we made several injection attempts with coal and petroleum coke. All attempts resulted in an occluded tuyere (the pressure drop across the tuyere was high and there was almost no flow). We observed that a solid accretion had formed on the inside wall of the universal converter at or near the location of the tuyere outlet. Figure 9 shows a dark formation near the tuyere outlet that appears to be a metal accretion.

Figure 8 Initial tuyere installation in the Universal Converter

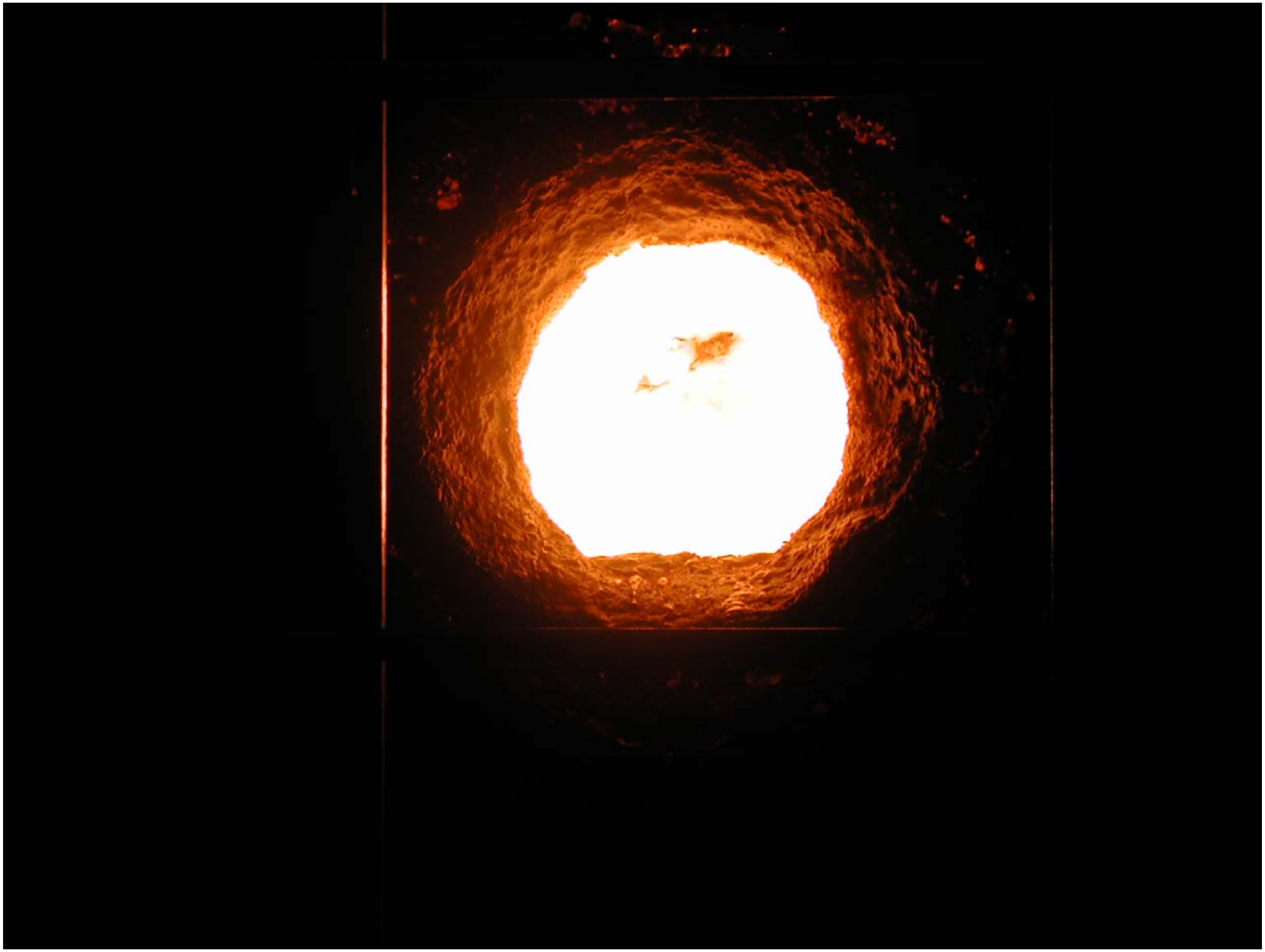

Figure 9 Metal accretion or mushroom on refractory at or near tuyere outlet

We decided to use a slit tuyere in place of the single lanyard tuyere. Figure 10 shows an end view of the slit tuyere. A slit tuyere consists of two concentric pipes with the OD of the inner pipe only slightly smaller than the ID of the outer pipe. Such a design is much more resistant to metal intrusion into the annular space. We decided to inject air in the annular space and coal in the center pipe. The center pipe ID was 8.0 mm. We felt that the slightly exothermic effect of the small amount of injection air would retard or prevent accretion formation. MEFOS worked into the night to install the new tuyere. Figure 11 shows the installation of the slit tuyere in the universal converter. This view is similar to Figure 8. Note that there are two hoses. The original rubber hose still transports the solid feed. The second hose transports the air for the slit tuyere. We resumed testing on the morning of September 3. Little difficulty was encountered with coal or coke injections after installing the slit tuyere.

Figure 12 shows the temperature probe just after its removal from the universal converter. The outer wall of the temperature probe is approximately 8 mm of rolled cardboard. In the absence of oxygen, which is the case in the universal converter, the cardboard lasts for more than 30 seconds even when immersed in molten iron. This is longer than the insertion time of the probe. The temperature probe measures the temperature one time before it is discarded. MEFOS measured the metal temperature approximately once every 2 minutes during feed injection or oxygen injection and at least once, with a different probe, every time the universal converter was tilted.

Figure 13 shows the metal sample probe just after its removal from the universal converter. The sample probe also has a cardboard outer wall. The tip of the sample probe has a hollow ceramic cavity that allows metal to enter and freeze. The Tip is covered with a metal shroud that prevents slag from entering the cavity as the probe passes through the slag layer. The shroud melts in the molten iron. The probe can sample metal from 10 to 20 cm below the metal surface. MEFOS took metal samples using this method approximately once every 10 minutes. MEFOS also took metal samples with a different probe when the converter was tilted. The hopper and chute in the right center of both Figures 12 and 13 allows lime, scrap and fluxing agents to be added to the universal converter during operation.

The work done in September demonstrated that a submerged tuyere gave much better results for feed injection, but a top entry lance still performed the decarburization step. This is not a practical method for commercial operation because a submerged tuyere in a molten iron bath requires a substantial flow through it as long as it is submerged to prevent metal infiltrating the tuyere and occluding the follow path. During the September testing a large flow of nitrogen kept the tuyere open when oxygen blowing through the top entry lance occurred. This is not practical commercially because any gas other than the product gas used to keep the tuyere open would dilute the product gas. Even if the product gas is recycled to the tuyere during decarburization, a substantial heat penalty occurs because the recycle gas must be cooled to less than 250°C to facilitate compression and other handling. This gas then reheats in the melt to 1400° or 1500°C. Greater capital and operating costs ensue to facilitate the recycle stream.

Figure 10 Discharge end view of slit tuyere before installation

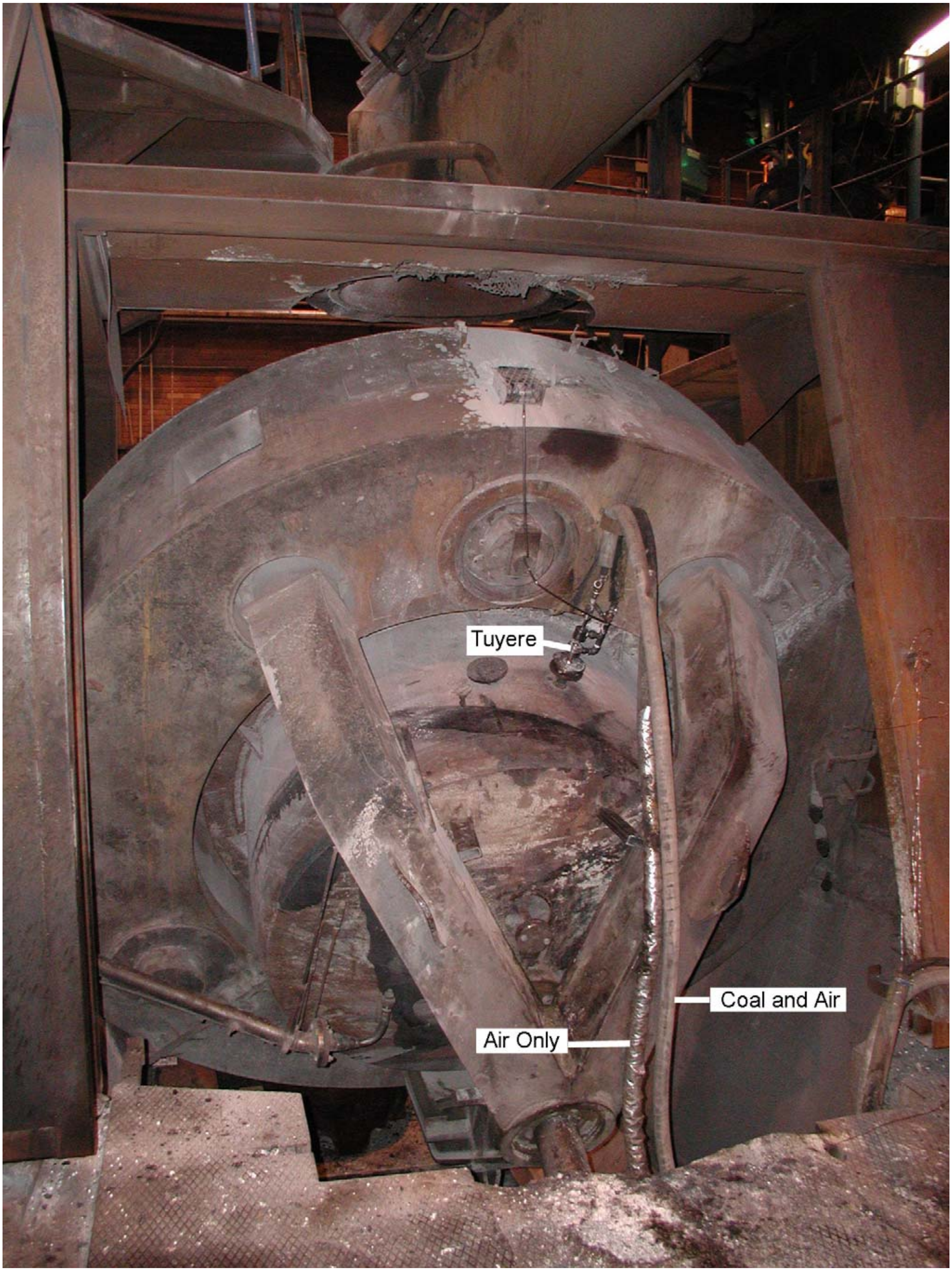

Figure 11 Slit tuyere installed on the Universal Converter

Figure 12 Temperature probe removal during decarburization for Universal Converter

Figure 13 Sample probe removal during decarburization

Normally the universal converter could not be kept in heat balance because it was tipped after each decarburization and each feed injection for slag sampling, metal sampling and inspection. MEFOS kept it in heat balance by adding aluminum bars to the melt before the oxygen blow. Aluminum reacts very exothermically with oxygen. The aluminum oxide reports to the slag. During 2 consecutive cycles on September 4 we were able to stay in heat balance without adding aluminum bars.

Since larger molten iron containing reactor vessels must be used in commercial operation, a second issue of multiple injection tuyeres arises. Generally, multiple injection tuyeres allow higher injection rates for the same level of carbon dissolution because multiple injection tuyeres result in better mixing and spread out the carbon over the vessel. Mutiple injection tuyeres can be more problematic with respect to mechanical arrangement. If one tuyere starts to occlude, more flow goes to the other tuyere(s) and exacerbates the occlusion problem unless separate flow systems are used for each tuyere.

Once we demonstrated that a submerged tuyere gave acceptable performance for feed injection we felt obliged to demonstrate a commercially acceptable method that incorporated submerged tuyere feed injection with an acceptable method for decarburization and useing multiple tuyeres. We developed and demonstrated this configuration in the December 2003 test campaign.

While much better carbon dissolution occurred with the tuyere configuration in the September test campaign we concluded that a third campaign was necessary. The side entry tuyere was not practical for long term operation because it increased sidewall refractory wear in the vicinity of the tuyere. We saw evidence that oxygen injection through a lance produced excessive FeO in the slag resulting in increased refractory wear and increased CO_2 in the off gas during decarburization. The Q-BOP basic oxygen steelmaking process has demonstrated the utility of a bottom entry tuyere. We decided that MEFOS modify the Universal Converter so that both feed and oxygen could be injected through a bottom entry tuyere.

MEFOS observed some refractory erosion in the refractory wall after September testing. The erosion was primarily in the vicinity of where the submerged tuyere had been. This tuyere entered through the side of the vessel near the bottom rather than through the bottom. MEFOS added a course of refractory brick in the lower section of the Universal Converter. Figure 14 depicts the added refractory addition on the left side of the figure only. The refractory was, of course applied to the entire interior of the Universal Converter. This made the Universal Converter id somewhat smaller resulting in a bath height of 800 mm instead of 500 mm for the standard metal charge of 5500 kg.

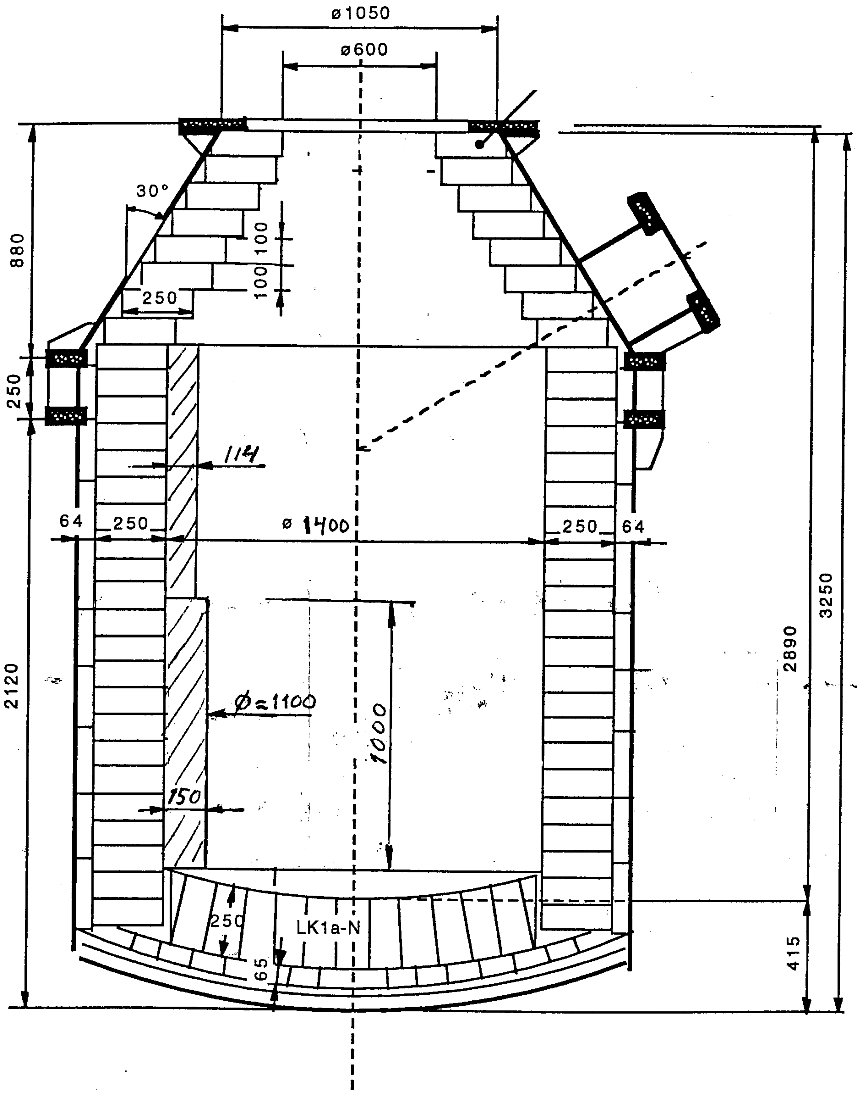

Figure 14 Universal Converter lining showing added refractory on left side

MEFOS performed analysis in the September testing with two mass spectrometers in addition to the infared analyzers for CO, CO_2 and H_2 and a paramagnetic analyzer for O_2. Two mass spectrometers were used because one gave poor results for lower atomic weight species while the other gave poor results for higher atomic weight species. MEFOS used a single mass spectrometer of later design that resolved these problems in December testing.

The first day of operation with the new tuyere system was December 9, 2003. The metal charge for the Universal Converter, as always, must be melted in a separate electric arc furnace (EAF), transported by ladle to the Universal Converter and poured into the tilted Universal Converter. On this day MEFOS experienced hydraulic problems with the EAF. The EAF had melted the charge, but couldn't be tilted to pour the charge into the ladle. The MEFOS maintenance group fixed the problem. The charge metal was poured into the Universal Converter at 1:30 pm, approximately 3 hours later than planned. As usual, we decarburized the melt with an oxygen injection using the new tuyeres. We observed that the maximum oxygen injection rate was 7 to 8 m^3n/min where we had been able to get 10 m^3n/min with the top entry lance. Using a 9 mm id tuyere would solve this problem. After completing oxygen injection we injected coke. We used coke because we felt that it was less likely to stick in the tuyere.. After feed injection, we made a second oxygen injection for decarburization. MEFOS does not normally sample the product gas during decarburization, but on this test we decided to sample the decarburization gas so the sample probe was inserted into the Universal Converter at the beginning of the oxygen injection. After the conclusion of oxygen injection when the operator tilted the vessel for melt sampling, he neglected to remove the sample probe from the Universal Converter before tilting. The sample probe was badly bent. The sample probe is water-jacketed. Straightening the sample probe in this configuration had never been done before. Leaking a large volume of water into the Universal Converter during operation can be dangerous. MEFOS concluded that the sample probe could not be repaired in a reasonable time to allow further testing. We decided to pour the metal out of the Universal Converter. The MEFOS maintenance group worked into the night repairing the sample probe.

MEFOS had the sample probe repaired by the beginning of shift on December 10. After we charged the pig iron from the EAF to the Universal Converter we performed a normal oxygen injection for decarburization and metal heating. We injected coke at 30 kg/min to a target metal carbon of 4%. We performed a second decarburization. At the end of this decarburization, the flow meter for propane going into the annular slit of the tuyere exploded. No other damage or injuries occurred, but no further testing could be performed until we replaced the flow meter. This meant that no further testing could be done on this day. MEFOS found a replacement flow meter and completed installation of it by the beginning of the shift on December 11.

We determined that a leaking check valve in the air line, used during coal injection, caused the flow meter explosion. Air mixed with propane at 7 to 8 bar. The thermal conductivity cells in the flow meter were probably the ignition source. We replaced the check valve with a remotely actuated ball valve to preclude a second failure.

Metal charge was melted in the EAF and transferred uneventfully to the Universal Converter as scheduled on the morning of December 11. We decarburized the metal according to schedule. The initial injection feed for testing was ILL #6 coal. We injected coal for 4 cycles. We followed each coal injection with an oxygen decarburization. This nearly emptied the charge hopper. We emptied the remaining coal and filled the hopper with coke. We planned to inject coke for 2 cycles before the end of the workday. After the first coke injection, where we achieved a maximum injection rate of 27 kg/min, we observed some of the refractory brick, added after September testing, floating on the surface. This was not dangerous because the refractory thickness behind the bricks that came loose was sufficient for safe operation, but continuing to operate with refractory bricks in the slag would result in very viscous slag. We tapped the slag with the bricks still floating in the slag and then we tapped the metal. December 11 was the last scheduled day of testing. MEFOS decided to test on December 12 because we had experienced so much down time. The MEFOS maintenance group gunned castable refractory over the top layer of bricks that were coming loose. This prevented further loss of bricks in subsequent operation. In Figure 15 the refractory bricks float near the bottom of the throat of the Universal Converter as it is tilted for tapping slag.

On the morning of December 12, we charged and decarburized the metal in the Universal Converter as described earlier. We made 3 coal injections and 3 decarburizations after the initial decarburization. We achieved a maximum coal injection rate of 27 kg/min. A problem with the in-blow temperature probe and sampler precluded temperature measurement or sampling during injection. We performed temperature measurement and sampling with the Universal Converter tilted at the end of each injection. We monitored the accretion formation on the bottom of the Universal Converter by visual inspection. While the size of the accretion on each tuyere increased and decreased from injection to injection, we did not observe any general increase in the accretion on either tuyere. The accretions on both tuyeres at the end of testing on December 11 appear in Figure 16.

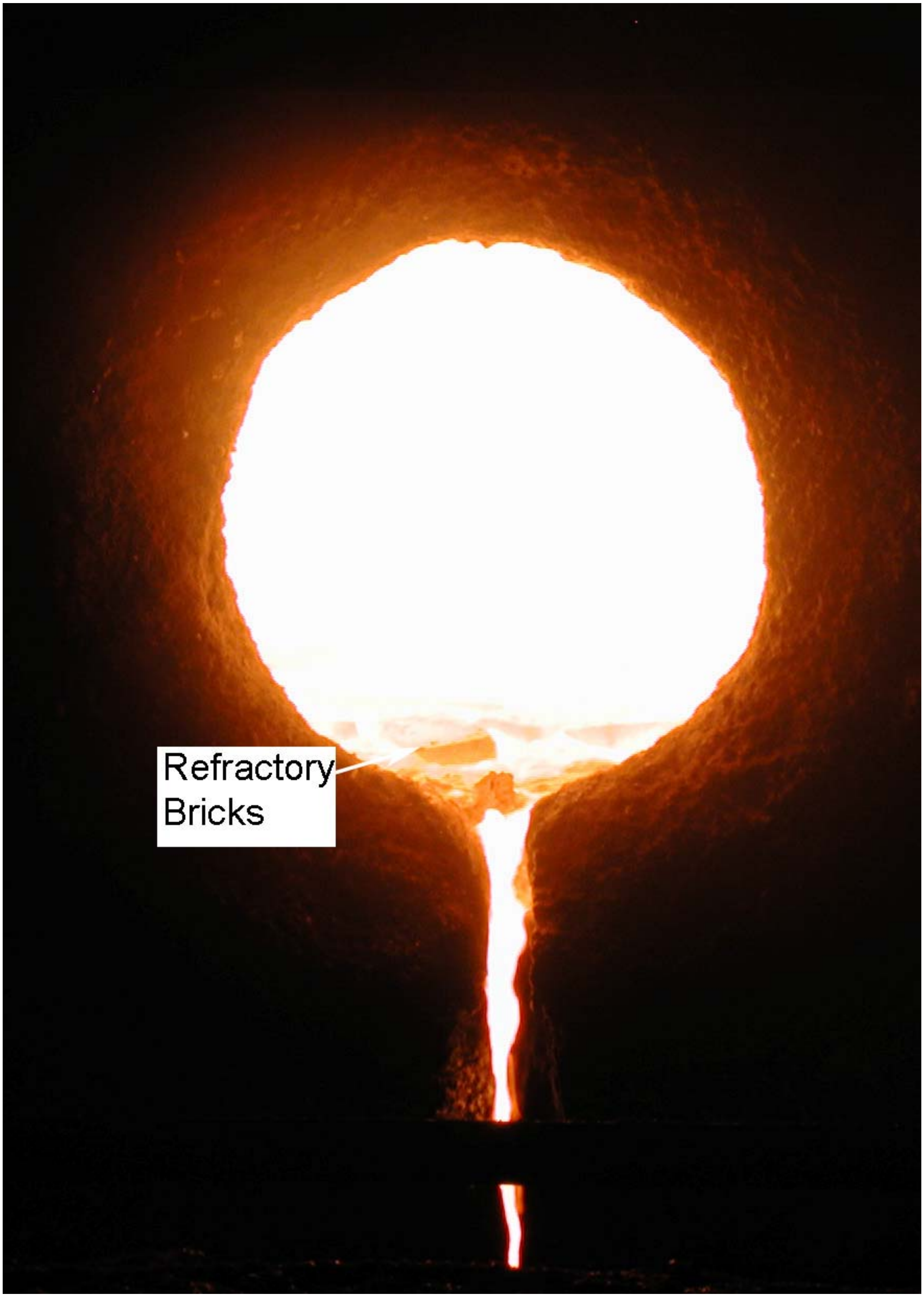

Figure 15 A view of refractory bricks after becoming dislodged

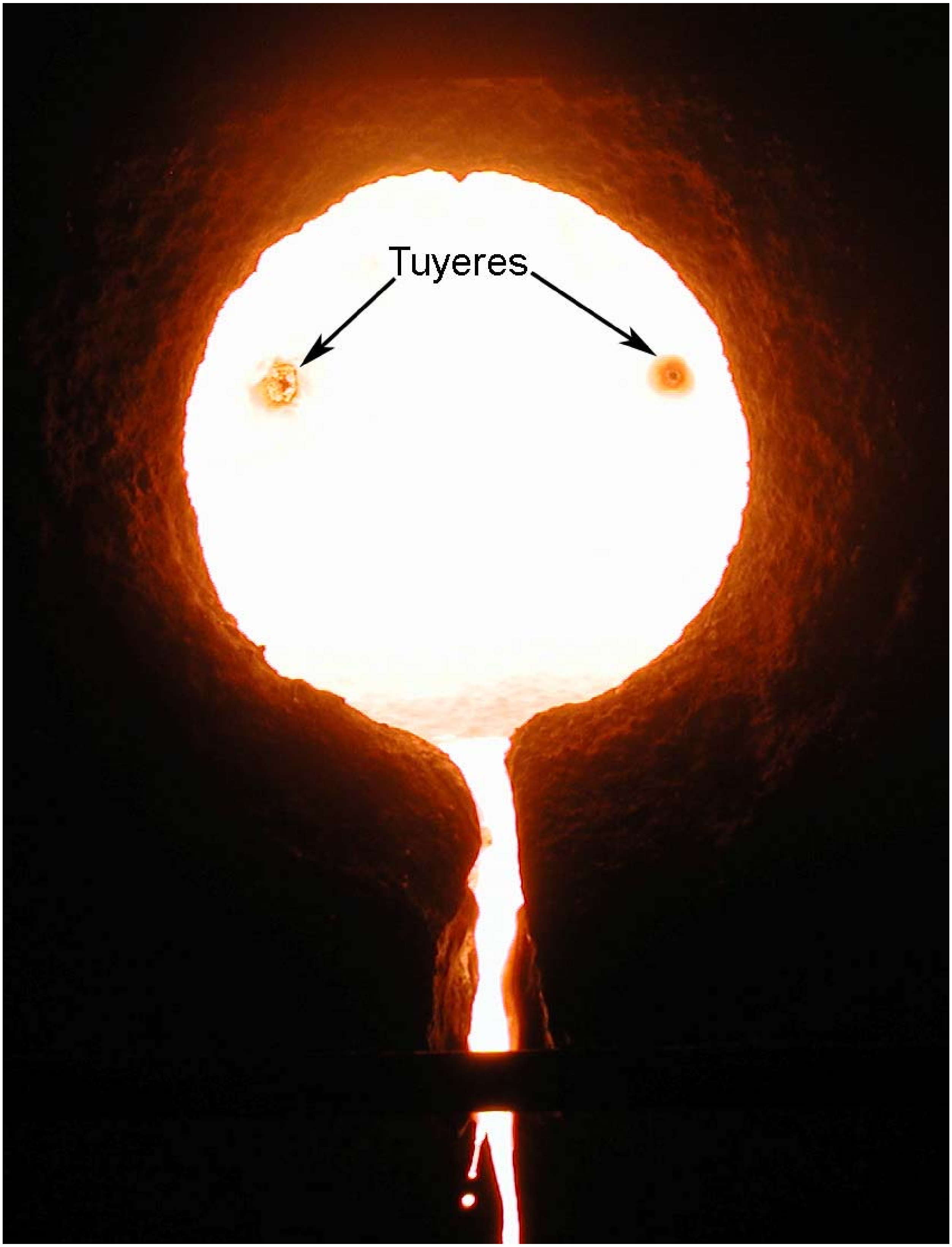

Figure 16 A view of tuyeres and accretions at the end of testing, 11 Dec 03

On September 12, 2005 EnviRes and MEFOS finalized the design of the pressure vessel. Figures 17 and 18 depict this design. A tapered, rotating ceramic plug maintains pressure in the vessel. The tapered plug can be moved closer or farther from the vessel opening. By virtue of its rotation, the problem of slag or metal splashing onto the plug and freezing it to the vessel opening is avoided. The hollow stem of the plug allows product gases to be sampled at pressure. The product gases drop to atmospheric pressure when the gases flow through the annular space between the plug and the vessel. As the gases exit the annular space they are captured by the vessel hood and processed in the same way as gases normally exiting an atmospheric pressure vessel.

We experienced several schedule delays resulting from commitments of MEFOS to their member companies. EnviRes and MEFOS initiated the process safety review of a more detailed pressure vessel design on June 12-13, 2006. The review was completed on June 29, 2006. The vessel, refractory and other components were ordered shortly after this meeting. The complete process safety review and more detailed drawings of the pressure vessel are given in Appendix VIII. Delivery was scheduled for October 20, 2006. Problems with vendor backlog and other issues pushed actual delivery to November 20, 2006. This caused the schedule for the test campaign to slip to April 16, 2007.

EnviRes decided to terminate further experimental activities because of the numerous schedule delays and the inability to determine if additional delays were to come. EnviRes purchased exclusive rights to the P-CIG process. This purchase will be described later.

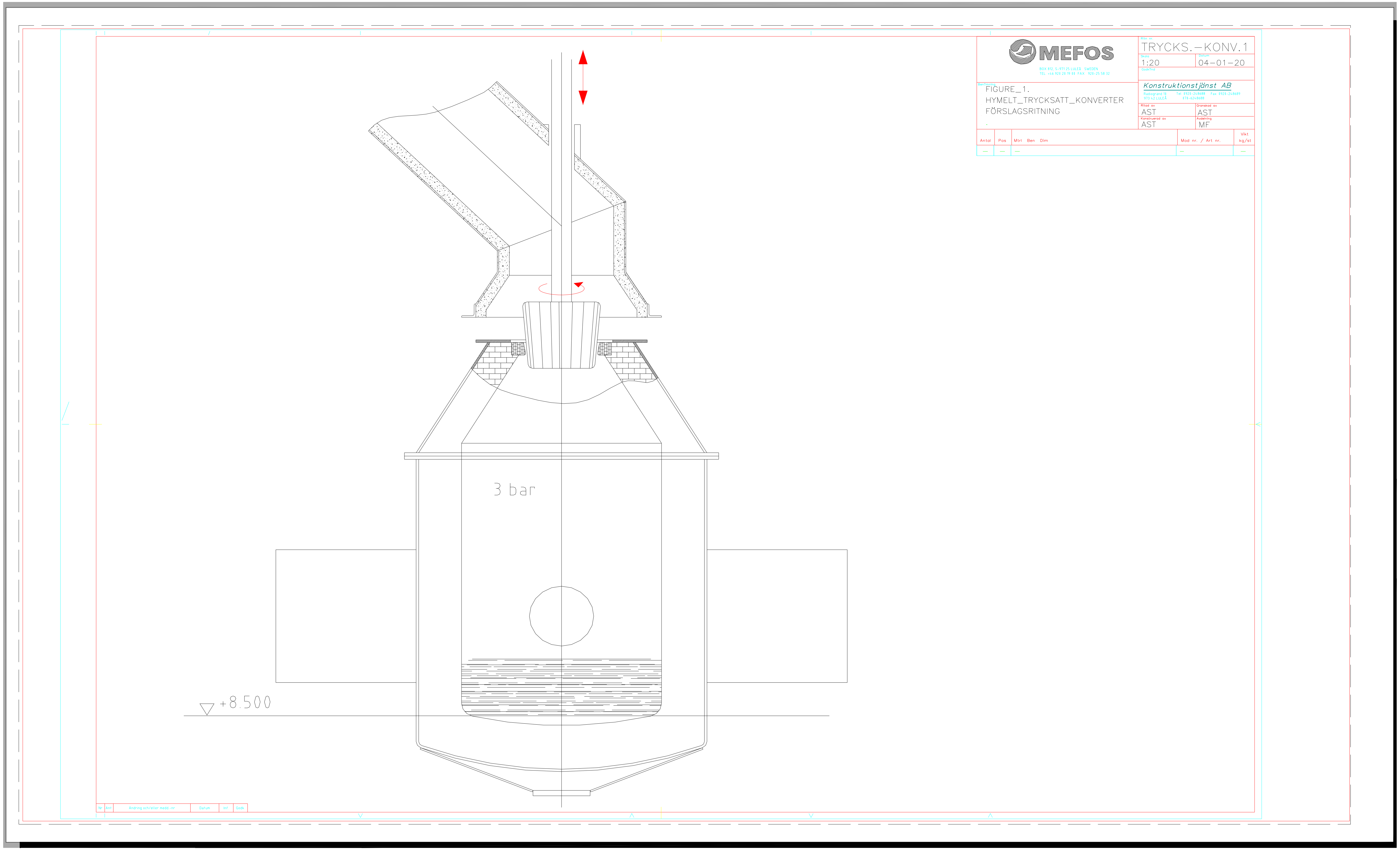

Figure 17 Plan view of Proposed Pressure vessel

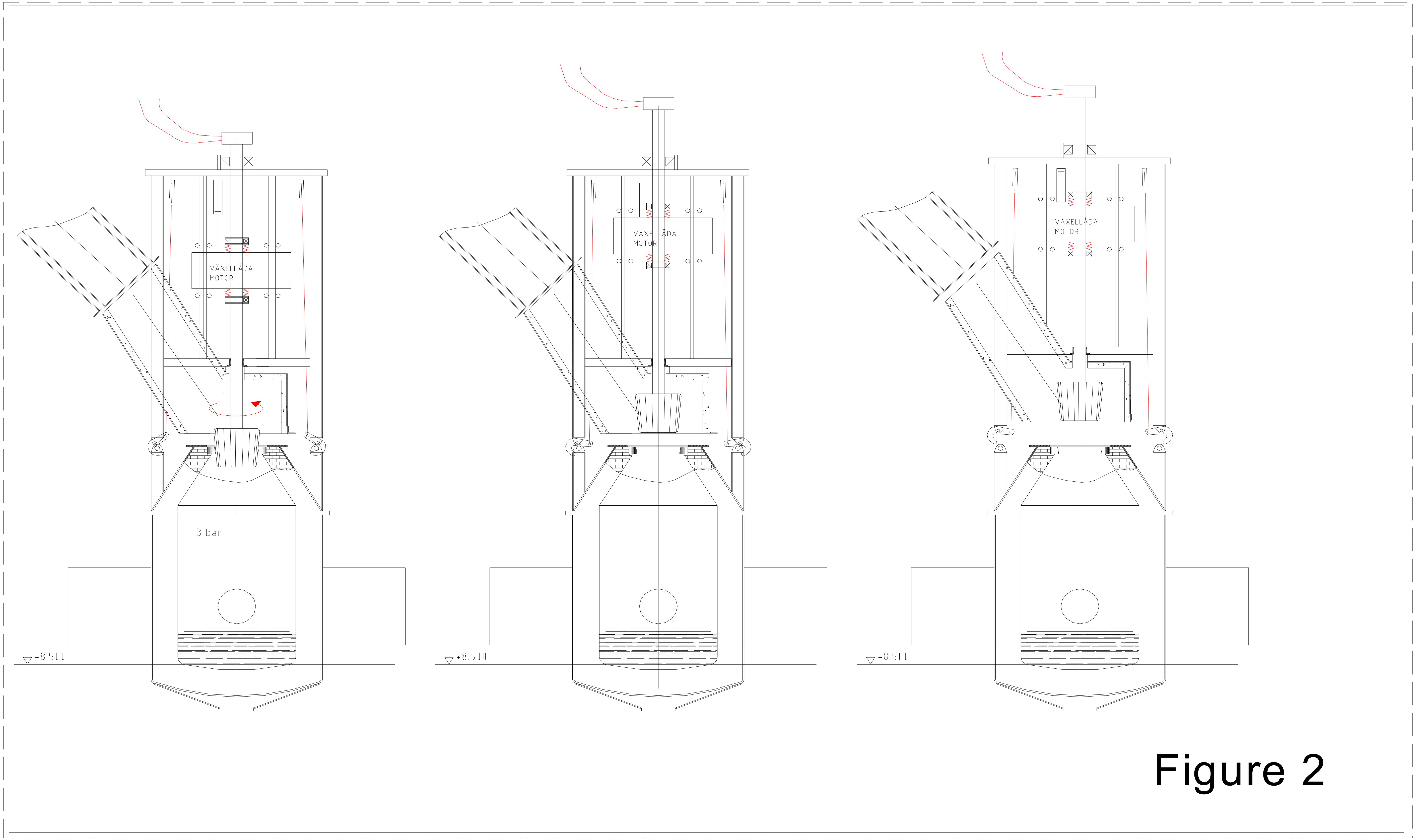

Figure 18 Operating steps in going from normal operating condition to being ready to tilt converter

4 Results and Discussion

4.1 MEFOS Activities

From all data generated and observations of the Universal Converter after feed injection during the June 2003 test campaign, we believe that the top entry lance injection system did not adequately penetrate the slag and metal to give acceptable carbon dissolution in the metal phase. During feed injection significant amounts of carbonaceous material were observed on top of the slag layer. The high levels of methane in the product gas are another indictor of poor feed injection. Methane levels should not exceed 0.5 %v in the product gas. During the tests methane levels often exceeded 6 %v.

Oil injection appeared to produce an unacceptable level of soot. We observed this problem visually and from the rate at which the gas sample ceramic filters became obstructed. We believe that the oil injection lance did not produce enough oil velocity to penetrate the slag layer. Better liquid lance injection designs may be possible that can eliminate this problem, but we decided that the project period was too short to pursue this area of development and design during the project.

No problems with accretions or other solid metal formations were observed. Nitrogen stirring gas and transport injection gas made detection of air leakage into the sample system more difficult to detect and quantify.

For all injections performed in June, the methane content of the product gas was in the range of 5 to 10%. In some tests coke could be seen floating on the slag when the universal converter was tilted after injection. Dust samples contained as much as 90% carbon. Pages AVI 49 to AVI 51 of the MEFOS report in Appendix VI show the carbon yield to metal for coal, petroleum coke and aromatic extract oil. Carbon yield to metal is calculated as the quotient of the change in the total mass of carbon dissolved in the metal divided by the total mass of carbon contained in the injectant for that period. The change in the total mass of carbon in the metal is calculated as the product of the mass of metal in the bath and the change in the weight fraction of carbon in the metal from the beginning to the end of the injection period. Since the yield is expressed as a percentage, the above quotient should be multiplied by 100%.

The maximum value for carbon yield to metal must always be less than 100% for several reasons. First, any oxygen contained in the feed will convert in near quantitative fashion to carbon monoxide. With Illinois #6 coal having 8.26% oxygen, the amount of carbon in the feed not reporting to the metal by this mechanism should be 7 to 10% of the feed carbon. If the coal moisture content increased during storage, this number will be higher. Similarly any methane formed will reduce the amount of carbon reporting to the metal from the feed although the thermodynamic amount of methane should always be less than 1% at these conditions. Second, any FeO present in either the metal or slag from decarburization will react with feed carbon to form carbon monoxide. In this case the value of carbon monoxide produced will have a maximum value near the beginning of the injection period and decrease as oxygen is consumed. Third, any slag reactions such as $CaO + C + S \rightarrow CaS + CO$ will consume carbon that would otherwise report to the metal. Slag reactions should consume very little carbon since the ratio of slag to metal is always small.

Top entry oxygen blowing typically created substantially more FeO in the slag than does tuyere injection of oxygen. Values of FeO in the slag are given in the MEFOS report in Appendix VI. FeO in the slag after oxygen blowing typically ranged from 5 to 15%.

The carbon yield to metal during June testing for coal ranged from 59.6% to 13.7%, for petroleum coke the values ranged from 72.4 to 22.4% and for oil the values ranged from 33.4% to 11.4%. The oil injection differed significantly from the method of injection for coal and petroleum coke. The carbon yield to metal for petroleum coke and coal become nearly equal when the effect of oxygen contained in the coal is considered. For both petroleum coke and coal the carbon yield to metal decreased with increasing feed rate. The decrease in transport gas flow rate with increasing solid flow and thus the velocity of the gas particulate stream impinging on the slag/metal surface may explain at least in part the decrease of carbon to metal with feed rate.

MEFOS discusses many of the trends in product gas compositions. Several problems with sampling and analysis combined with injection problems, described earlier make detailed analysis of the gas compositions questionable without significant effort to correct for these problems. It is unclear whether the high COS values result from the high FeO levels in the slag. It is unclear whether oxygen in air leakage into the sample lines to various analyzers reacted with hydrogen and/or CO.

The results of mercury sampling and analysis show a wide range of mercury levels if the data are correct. We only sampled and analyzed the product gas for mercury three times during June testing.

The hydrogen-purging test for sulfur removal described on page 49 of the MEFOS report shows that much more sulfur disappeared from the metal and slag than could be accounted for by the amount of H_2S appearing in the product gas. Similar unexplained sulfur disappearance from the metal was always experienced in the early bench scale tests.

The vanadium tests show that vanadium has a partition coefficient that is highly dependent on the oxygen potential. This result reasonably agrees with the FactSage thermodynamic studies performed by MEFOS. These tests (page 35 and 43 of the MEFOS report) also show that vanadium in the slag can be reduced causing the vanadium to report back to the metal after it has been oxidized from the metal into the slag for vanadium levels of 0.6 to 0.8% in the metal.

For all injections performed in June, the methane content of the product gas was in the range of 5 to 10%. In September testing the methane content typically remained below 0.5% as shown on pages AVII 12 and AVII 13 of Appendix VII. High values of methane in the product gas indicate poor feed metal contact. The carbon yield to metal ranged from 58% to 88% for petroleum coke while it was fairly steady at 55% for coal. The carbon yield to metal was significantly worse in June testing especially as the feed rate increased

MEFOS gives a detailed presentation of data generated in September testing in Appendix VII. We will provide some analysis of these data in this section. We believe that the hydrogen purity of the product gas during feed injection is perhaps the most important gas parameter. A retractable, water jacketed sample probe with a coarse, castable high alumina plug at its end conveys the sample stream from the upper part of the interior of the Universal Converter, through a more efficient secondary filter and then to the various analyzers. The Universal Converter operated at near atmospheric pressure. This necessitates the use of a suction pump to move the sample stream to the analyzers. MEFOS points out in Appendix VII that they analyze for hydrogen with three different analyzers. As noted the infrared analyzer can read a maximum value of 21% hydrogen.

Figures 9 and 10 on page AVII 13 and AVII 14 of Appendix VII show plots of the readings of these three analyzers versus time. It appears that the two mass spectrographic analyzers give good agreement when the difference in response time between the two analyzers is considered. Raw hydrogen values of 45% to 65% appear in these tables. MEFOS observed that oxygen appears in all of the product gas samples. Oxygen and hydrogen values in the product gas as a function of time appear in figures 7 and 8 on page AVII 12 of Appendix VII. The presence of oxygen in this stream can only be explained by air leaking into the sample stream after cooling since the temperature of the Universal Converter is well above the autoignition temperature for these mixtures. Normalized values for hydrogen ranging from 60 to 80% appear in figures 29 and 30 on page AVII 27 of Appendix AVII. These normalized values still contain 7% to 12% argon, the transport gas for coal and coke. The slit air for the injection tuyere accounts for 2 to 4% of the CO in both figures. Oxygen in coal accounts for approximately 13% CO in the process gas stream. The rest of the CO comes from reaction of FeO in the slag with carbon in the metal. This accounts for the high initial value of CO that decreases with injection time. Note that the CO value for coal injection is 10 to 15% higher that for coke injection in figure 30. This is consistent with the expectation that oxygen in coal converts entirely to CO. Coke contains little oxygen. The first three injections were coal the last three were coke in figure 30.

As noted in Appendix VII, COS values range from 50 to 200 ppm compared to 100 to 300 ppm observed in June testing. Figures 21 and 22 in Appendix VII show that the benzene value in the product gas stays below 100 ppm. Figures 23 and 24 show that acetylene values range around 1500 ppm. Figures 27 and 28 show that HCH values generally stayed below 20 ppm. The H_2S value stays below 0.020%. It does increase with metal sulfur content, but is well below the expected thermodynamic value. We suspect that the highly basic slag captured some of the H_2S from the product gas. Since the sample stream appears to contain up to 50% air, the above values should be multiplied by 2 to be consistent with the treatment of H_2 and CO. Thermodynamic simulation reported earlier gave values for trace constituents similar to these.

Figures 44 and 45 indicate that the slag captured most of the sulfur in the feed. Figures 41 and 42 show that FeO in the slag after decarburization normally ranged from 2 to 5%, but on occasion exceeded 12 %. Figures 47 and 48 show that dust loses range from 5% to 8% of feed. In commercial operation the reactor should operate at up to 30 bar. This will substantially reduce the gas superficial velocity and presumably the dust loss. The commercial design anticipates capturing dust and recycling it. Refractory wear may not be significant since the refractory in the Universal Converter was not optimized for this operation.

We see little difference in trace impurities between coal and coke injection. For the most part this is not surprising since the elemental compositions of the two feeds are similar except for significantly higher values of ash and oxygen for coal and correspondingly higher values for the other major constituents for coke. The one trace constituent value that is surprising is benzene. Coal has more benzene like structures than petroleum coke. One would think that the values for benzene would therefore be higher for coal than for coke if one accounts for the formation of benzene by the incomplete destruction of the feed.

In the following discussion of the December 2003 campaign, the reader should refer to the MEFOS report in Appendix VIII. Only one or two tests of questionable value were made during HyMelt 11 and 12. Testing during HyMelt 13 and 14 exhibited smoother operation and more test periods.

Figure 3 of Appendix VIII shows that feed injection rates were the highest attained to date and approached 30 kg/min for both coal and coke. We did not anticipate that this feed injection rate could be achieved at atmospheric pressure. We expect to be able to achieve a higher feed injection rate as we increase system pressure. PCIG (Pressurized Coal Iron Gasification) tests performed by MEFOS 25 years ago exhibited this behavior. We believe that for the same gas thoughput, higher pressure will result in a longer residence time for the feed.

The small tuyere diameter limited the oxygen injection rate to approximately 8 m^3n/min. Oxygen injection with the top entry lance had been 10 m^3n/min. This lower oxygen injection rate precluded operating the reactor in heat balance as had been done in previous testing.

Figure 8 of the Appendix VIII MEFOS report shows FeO in the slag to be 1 to 2%. In previous testing FeO in the slag averaged 3 to 4%. During coal or coke injection in previous testing, a pronounced spike of CO appeared in the initial minute product gas analysis. We inferred that this spike was the result of FeO in the slag reacting with carbon to from CO. In HyMelt 13 and 14 the CO spike appears to be much smaller and in some tests non-existent.

In each test campaign the analytical equipment and methods were improved. In the December campaign we measured trace constituents much more reliably. Figures 11 to 19 of the Appendix VIII MEFOS report show that the level of HCN seldom rose above 10 ppm during coal or coke injection with a maximum value of approximately 30 ppm. During oxygen blowing the HCN level stayed below 10 ppm. Similarly the concentration of COS in the product gas always stayed below 60 ppm and usually below 20 ppm. The concentration of COS in the product gas during oxygen blowing was generally lower that during feed injection. The concentration of methane in the product gas generally stayed below 1% although it sometimes exceeded 1%. In several injection periods the concentration of methane rose in a near linear fashion during the injection. Thermodynamic equilibrium calculations predict this behavior as the activity of carbon in the metal increases.

Section 6 of the Appendix VIII MEFOS report presents the results of process calculations that show that nearly all of the deviation of gas analysis from that predicted by thermodynamic equilibrium can be accounted for by air leakage into the converter and/or sample train. Figures 21 and 22 present the carbon yield to metal for coke and coal injection as a function of injection rate. These yields do not account for carbon reacting with injection air for either coal or coke, nor do they account for oxygen contained in the feed reacting to remove carbon. For both coal and coke the carbon yield to metal does not seem to fall off as the feed rate increases in this campaign.

It is interesting to note that the carbon content of some dust samples contained more carbon than 1 minus the ash content. If these analyses are correct this implies that carbon must have formed in the gas space of the converter or in the sample train. Carbon formation at reactor temperature is not possible, but if the gas sample remains at approximately 900°C for several seconds, such a reaction is possible. The carbon content of the dust during oxygen injection typically stayed below 5%.

4.2 Kvaerner Activities

Kvaerner initiated simulation activities using Aspen Plus. The HyMelt reactor section process flow sheet appears in Appendix III page 2, the flow sheet for the amine system appears in Appendix III on AIII page 15 stream flows for this flow sheet appear on AIII page 14 and the flow sheet for the water gas shift appears in Appendix III on AIII page16 stream flows for this flow sheet appear on AIII page 17 to 19. Kvaerner obtained cost estimates from Dow for the amine system and UOP for the PSA hydrogen purification system. This information is also given in Appendix III. Kvaerner estimated the differential cost for shifting nearly all of the carbon monoxide produced in a 450 t/d demonstration plant.

Kvaerner completed an economic comparison of using the carbon monoxide rich stream for fuel vs. shifting the carbon monoxide rich stream to hydrogen. Results of this work are given in Appendix III. UOP estimated a cost of $1.7 MM for a Polybed PSA system capable of producing 15.31 MMSCFD of product hydrogen UOP estimated a cost of $2.5 MM for a unit capable of producing 28.39 MMSCFD. Kvaerner obtained or generated detailed flow sheets, material balances, energy balances, equipment sizing and operating costs. Kvaerner obtained or generated similar information from Dow for an amine system to remove H_2S from the product hydrogen. As presented in Appendix III Kvaerner determined that the incremental cost over fuel value for upgrading the carbon monoxide rich HyMelt stream was $2.86 per kSCF of hydrogen produced.

4.3 Siemens Westinghouse Power Corporation Activities

EnviRes and Siemens Westinghouse decided to model and test a catalytic burner instead of a diffusion burner for proposed gas turbines using the carbon monoxide rich stream as fuel. Most if not all combustion systems for IGCC turbines use diffusion burners to combust carbon monoxide rich fuel. These burners simply provide residence time and mixing for combustion to take place. Diffusion burners tend to produce NO_x levels of 25 ppmv when the flue gas is adjusted to a standard value for excess oxygen. Diffusion burners usually produce CO emissions in excess of 5 ppmv. It is likely that new source performance standards will require both NOx and CO emissions to be below 3 ppmv for power plants by the time a commercial HyMelt plant is built. If both of these hypotheses are correct, combustion turbines (including those firing natural gas) will be required to have post combustion abatement controls for both NO_x and CO. While diffusion burners have not been specifically tested with a fuel that is representative of the carbon monoxide rich stream from HyMelt, we believe that the results would be very similar.

Siemens Westinghouse had a catalytic burner program under development before this project began. They have tested a prototype of their catalytic burner with natural gas at commercial conditions. In these test they found that NOx and CO emissions could be kept under 2 ppmv under optimal operating conditions. If similar results can be obtained for the HyMelt carbon monoxide rich stream, gas turbines using catalytic burners may not require post combustion abatement controls for a HyMelt gasifier. This appears to us to be a strong incentive to pursue catalytic burners. If catalytic burners are not feasible for HyMelt carbon monoxide rich gas we can switch to diffusion burners with very little uncertainty.

Modeling activities described by SWPC in Appendix V showed that combustion of carbon monoxide rich fuel such as that produced by the HyMelt process emit slightly more to slightly less carbon monoxide in the flue gas for a combustor outlet temperature of 1127°C (2060°F) to 1149°C (2100°F) with 15% Oxygen in the flue gas compared to natural gas at the same conditions. Oxides of nitrogen were 50% lower for the carbon monoxide rich fuel compared to those from natural gas over the same conditions. The report also gives temperature and velocity profiles within the combustor.

EnviRes and NETL agreed to eliminate experimental combustion tests from the project so that funds could be allocated to additional gasification campaigns and other activities.

5 Conclusions

All testing conducted from June 5 to 13 gave unacceptable carbon dissolution rates. At low feed rates both petroleum coke and coal resulted in approximately 70% of theoretical. At higher feed rates the rate of carbon dissolution dropped rapidly to near 20% of theoretical. Carbon dissolution rates for oil were even worse. Carbon dissolution rates could be improved with better injection lance design, but we feel that the probability of obtaining 98% of theoretical is unlikely with top entry lances.

Preliminary results based on visual observation and preliminary operating data indicate that submerged injection of coal and petroleum coke results in a much better carbon dissolution rate. The carbon dissolution rate also appears to be less dependent on coal or coke feed rate. Subsequent data reported by MEFOS from the September 2003 testing campaign agreed with initial observations. Testing in December 2003 used a more commercial compatible tuyere design. The composition of major gas streams appears to closely approach that predicted by thermodynamic equilibrium.

We significantly improved carbon dissolution rates by injecting feed with a submerged tuyere rather than a top entry lance. It appears that the 5% to 8% dust loss is the only carbon that is not otherwise reacted as thermodynamically predicted or fails to dissolve in the metal. We believe that much less dust loss will occur in pressurized operation. We would capture and recycle most of this material in commercial operation. We attained a maximum feed rate of 10 kg/min for coal and 18 kg/min using petroleum coke with a single tuyere in September testing. In December testing we attained a maximum feed rate of 27 kg/min for coal and 27 kg/min for coke using two submerged injection tuyeres. This leads us to believe that higher carbon dissolution rates could be attained with an additional tuyere or tuyeres.

We were able to measure and quantify trace constituents. We observed gas yields for major and trace constituents to be near thermodynamic equilibrium. Other than increased CO in the product hydrogen stream when coal is fed resulting from oxygen contained in the coal, there is little difference in the product stream compositions for coal compared to that for coke.

We were able to demonstrate a commercially viable tuyere configuration in December testing. We await the technical report from MEFOS on this testing. Getting slag samples analyzed accounts for most of the delay in completing the MEFOS technical report.

Hydrogen purging to remove sulfur does not appear to be attractive, however, during the testing much more sulfur disappeared than could be accounted for by H_2S appearing in the product gas. Further investigation of this phenomenon appears warranted.

Based on the economic analysis by Kvaerner, we believe that shifting carbon monoxide to hydrogen is not economically attractive at an incremental cost of $2.86/kSCF above fuel value. We further conclude that gasification processes that must use water gas shift to produce hydrogen are at a disadvantage to processes that directly produce hydrogen.

The carbon monoxide rich fuel gas produced in the decarburization step appears to be equivalent to or better than natural gas on a heat content basis. Catalytic burners for gas turbines using HyMelt carbon monoxide rich fuel gas may not require post combustion abatement controls. If this possibility comes to fruition, it will produce a significant economic benefit for power generation.

6 References

None

Appendix I

MEFOS Program Plan for Campaign I

MEFOS

Box 812, 971 25 LULEÅ

Dokument:	Försöksprogram	*Reg nummer:*	
Fo-uppgift:		*Datum:*	2003-03-20
Konto:		*Rev datum:*	
Ämnesomr:		*Avdelning:*	MM

HYMELT PILOT PLANT TESTS AT MEFOS

PROGRAMME CAMPAIGN 1

by

Sten Ångström

Projektledare:	Nils-Olov Lindfors	*Sekr:*	acj
Distribution:			

Background

This programme describes planned activities in the HyMelt project at Mefos during the period 2003-02-25 to 2003-06 30

The activities refer to tasks and subtasks in a work program stated in KK01005K:

Subtask 1 Thermodynamic calculations

The work will be executed according to plan

Subtask 2 Design and construction of lances for injection and blowing

The work will be executed according to plan

Subtask 3 Design and construction of an oil feeding system

The work will be completed 1 September

Subtask 4 Design and construction of reactor shell for high pressure operation

The work will be executed according to plan

Subtask 5 Design and construction of water injection system

The activity has lower priority. Final decision will be taken later.

Subtask 6 Preparation work for atmospheric pressure operation

The work will be executed according to plan except for carbon and coke. Oil feed will test in hot condition. Full evaluation including chemistry, mass and heat balances etc will be made in a coming campaign dedicated for oil.

Detailed description of the work follows below in the subsequent chapters.

Subtask 7 Cold tests for atmospheric pressure test

See Subtask 6

Subtask 8

See Subtask 6

Subtask 9

See Subtask 6

Subtask 10 to 15

In accordance with the work programme the activities are planed to be performed after 030630.

Experimental objectives

In Mefos pilot converter pulverized coal, pet-coke and oil shall be feed to an iron melt by top lance injection. The injection period, recarburisation and hydrogen production follows by oxygen blowing in a decarburisation and CO-gas production period.

The objectives are to determine:

- Gas composition
- Dust amount, size distribution and composition
- Sulphur distribution
- Productivity limitations, yields, carbon dissolution etc
- Hot test of HyMelt equipments
- Practical operational experiences

- Heat and mass-balance evaluations

Time schedule and Scope of work

The test will be performed in June 5,6,10,11,12 and 13 2003.

Day 1	Coal tests
Day 2	Coke tests
Day 3	Coal tests
Day 4	Coke tests
Day 5	Rearranging lance system etc for oil injection
Day 6	Oil injection tests
Day 7	Oil injection tests

Operation will be on daytime from 06:00 to 18:00.

Preparation work

Preparation of MEFOS test units and equipment for HyMelt trials and assembly of HyMelt equipment:

EAF refractory work

Universal Converter

- Refractory work
- Installation of bottom purging elements
- Rearranging process gas system

Assembling lances and injection system

- Material injection system including 3 m^3 dispenser on load cells

Assembling material handling system including hopper load cells

- Cooling scrap
- Lime

Oil injection system including barrel recharging, heated tank, pump, flow control and lance

Manual addition of

- Aluminium bars
- Vanadium
- Nickel
- Ferrosulphur
- Dolomite

Measurements

- Gas and dust sampling lance from converter atmosphere
- Set up of standard gas analysers and mass spectrometer of process gas
- Dust sampling in combusted gas for determination of composition and load
- Overhead crane weighing scale
- Metal sampling probes and melt temperature system
- Combusted gas analysis and flow rate measurements
- Process control set up
- Hydrogen flow control

Ladle refractory work

The bag filter line will be used in parallel with the wet venturi.

Raw materials and gas

Pig iron		36 ton
Coal, Illiois #6 in big bags	4,5 ton	19 ton

Pet-coke in big bags	4,5 ton	10 ton
Oil in barrels	4,5 ton	6,2 ton
Lime 10-20 mm	5 ton	
Dolomite 10-20 mm	1 ton	
Cooling scrap small pieces SSAB	2 ton	
Aluminium bars	200 kg	
Ferrosulphur	1000 kg	
Ferrovanadium	? kg	
Nickel	? kg	
Hydrogen supply from gas bottle	? kg	

Measurements and data logging

The composition of ingoing materials will be analysed before start of tests.

Coal	complete elemental analysis, particle size
Coke	complete elemental analysis, particle size
Oil	complete elemental analysis
Lime	complete elemental analysis according to the supplier
Cooling scrap	complete elemental analysis according to the supplier
Aluminium bars	complete elemental analysis according to the supplier
Ferrosulphur 10 – 30 mm	complete elemental analysis according to the supplier
Ferrovanadium 10 – 30 mm	complete elemental analysis according to the supplier
Nickel	complete elemental analysis according to the supplier

Dolomite lime 10 – 20 mm complete elemental analysis according to the supplier

Following measured data will be collected and stored in a process computer. The software platform to be used is LabView.

Continuous measurements:

Gas supply:	range
Oxygen to lance	0 – 20 m^{3}n/min
Nitrogen bottom purging	0 – 1 m^{3}n/min
Nitrogen material transport	0 – 1 m^{3}n/min

Combusted gas

Flow rate, venturi	0 – 20000 m^{3}n/h
bagfilter	0 – 5000 m^{3}n/h

Composition:

CO	0 – 1%
CO_2	0 – 5%
O_2	0 – 23%
SO_2	0 – 0,5%

Materials

Dispenser weight	0 – 3000kg

Bin weights

Cooling scrap	0 – 1000 kg
Lump lime	0 – 1000 kg
Oil feed	0 – 15 l/min

Non continues measurements

Metal temperature 0 – 1800 °C

Metal composition

Process gas composition	Decarb.	Carburisation
CO	0 – 100%	0 – 20%
CO_2	0 – ?%	0 – ?%
H_2	0 – 5%	0 – 100%
H_2S	0 – 0,5%	0 – 2%
COS	0 – 10ppm	0 – 10ppm
CH_4	0 – 0,1%	0 – 2%

Special measurements and sampling not recorded on the process computer:

Metal weight, charging and tapping

Analysis of sampled metal and slag

Poured slag weights

Dust sampling in converter for composition analysis

Dust sampling in combusted gas for composition analysis and load

Manual additions

Process control

During operation all measured parameters can be displayed in real time.

In addition the most essential process parameters are calculated on line for supervising.

1. Material injection flow rate
2. Gas flow rate
3. Carbon balance for recarburisation yield
4. Oxygen balance for oxygen yield during decarburisation

Experimental procedures

Before start of tests the converter and the transfer ladle will dried and preheated.

One test day is planned for 2 hours of melting, 10 hours for operation in the converter. One test cycle is estimated to 1 hour.

For each day:

1) Pig iron is melted and adjusted to hot metal quality:

%C	4 – 4,5
%Si	0,2 -0,5
%Mn	0,2 – 0,5
%S	~0,020
%P	~0,040

2) The hot metal is tapped into a transfer ladle and if necessary, the furnace slag is skimmed off before weighing.

Tapping temperature ~1450°C’

During tapping the metal will be alloyed with vanadium and nickel

%V ?

%Ni ?

3) The hot metal is charged into the converter.

4) Sampling and temperature measurement

Adjusting of sulphur composition to ~1%

Addition of aluminium bars or cooling scrap, target temperature ~1300°C.

Slag skimming if necessary

5) Oxygen blowing to ~0,5%C, ~10 m^3n O_2/min.

Slag former addition after ignition.

CaO/SiO_2 ~?

%MgO~?

Sampling, temperature measurement, adjustment of temperature to ~?°C.

6) Injection of coke or coal to 4% carbon injection flow rate ~10 kg/min.

The procedure 4) – 6) are repeated for approximately 10 times.

During the days separate sulphur refining test shall be made by hydrogen purging through the bottom of the converter for 10 minutes with ? ln/minute.

The melt is tapped into transfer ladle and before casting in sand bed the weight is registered.

Controlled parameters to vary during operation are:

- Temperature, high ? °C
  low ? °C
- Feed, high ? kg/min
  low ? kg/min
- Transition carbon level, high ? %
  low ? %
- Sulphur content, high ? %
  low ? %

Staffing

Raw material handling, tractor driver	1
EAF operator	1
Material, oil injection	1
Crane operator and ladles	1
Converter operator	1
Metal sampling, temperature	
Measurements and manual additives	1
Dust sampling combusted gas	1
Process gas sampling	1
Leco analysis	1
Instrumentation and computer	2
Researcher	2

Account numbers

SAFETY

Appendix II

FactSage Thermochemical Studies

MEFOS

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Dokument:	MEFOS-rapport	*Reg nummer:*	MEF03039SK
Fo-uppgift:		*Datum:*	2003-05-23
Konto:	386420	*Rev datum:*	
Ämnesomr:		*Avdelning:*	MM

SUMMARY OF THE THERMODYNAMIC CALCULATIONS ON THE HYMELT PROCESS USING FACTSAGE 5.1

by

Guozhu Ye

Godkänd av forskningschef: ....   *Slutlig:* Y
Projektledare: Nils-Olov Lindfors   *Sekr:* ta
Distribution: EB, NOL, GY, SÅ, Don Malone (EnviRes)

Summary of the Thermodynamic calculations on the HYMELT process using FACTSAGE 5.1
Guozhu Ye
MEFOS

SUMMARY

This report summarized the calculations carried out under the subproject "Desk study" as part of the EnviRes pilot project at MEFOS. The major conclusions are drawn in the followings.

The H_2-cycle

	Injection time per H_2-cycle, min (10 kg/min and 5 ton iron melt)	Injected material/ton iron melt-ratio for one H_2-cycle, kg/ton
P-coke	22	44
Aromatic extract	21	42
Coal ILL#116	30	60
Spent tyres	22.5	45

The H_2-cycle is thus only related to the C-content in the injected carbon-materials.

The de-C cycle

This is the same as a LD-process where C-content is removed by oxidation except the pressure provided. One interesting point here is that if the cycle time for de-C step will be in the same range as that for the H_2-cycle time the gas system for the CO- and H_2 could be quite different. Since the flow rate of CO will be 2-3 times that of the H_2-gas.

The simulations are based on a variation of carbon content in the metal between 0.5-4 %.

The S-cycle

The S-cycle is mostly determined by the S/C-ratio in the used materials and the H/C-ratio as shown in the following table. Sulphur is assumed to vary between 0.5-1.25 %.

	S/C-ratio	H/C	C-/S-cycle ratio
P-coke	0.075	0.058	3
Aromatic extract	0.045	0.077	6
Coal ILL #6	0.049	0.069	0*
Spent tyres	0.021	0.088	20

*10 % ash in the coal and about 10 % CaO is added. S is thus removed in the slag already. There will not be S-accumulation.

S-removal by H_2- purging

Due to the unfavourably thermodynamical conditions provided for H_2S-formation, the method for S-removal by H_2-purging is highly inefficient. To remove the S dissolved in the iron melt it will consume much more H_2-gas than it has been produced during the H_2-cycles.

S-removal by slag treatment

Slag treatment is efficient. Using a slag with a CaO/SiO_2-ratio of 2 and a minimum amount of 60 kg/ton iron melt, the dissolved S will be removed. The slag used in the calculation consists of 60 % CaO, 30 % SiO_2 and 10 % MgO. This slag could be reused after S-removal of the slag by hot treatment.

The V-cycle

The V iron melt can contain up to 13 % V before V will be oxidised to VOx. This means:

1 V-cycle = 1 360 C-cycles

The Ni-cycle (only P-coke)

Theoretically Ni-solubility in the iron melt is not limited. Practically an iron melt with 20 % Ni is reasonable with regards to the reactor volume. This means:

1 Ni-cycle = 11 V-cycles

Heat balance

The temperature drop for a H_2-cycle is shown in the following table.

	ΔT (FACT), °C	ΔT (HSC), °C
P-coke	285 °C	230 °C
Aromatic	300 °C	260 °C
Coal ILL#6	240 °C	Nd

A temperature increase of about 450 °C is expected during the de-C cycle according to the FACTSage calculations.

A net temperature increase of 150-200 °C is thus expected (H_2-cycle + de-C cycle).

This net energy will cover heat losses of reactor and energy needed for smelting of the added slag for metal protection and S-removal.

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1 INTRODUCTION

The HyMelt process consists mainly of two cycles:

- a H_2-cycle during injection of coal/coke/oil in a hot metal bath where high purity H_2 is produced and carbon is dissolved in the metal phase.

- a de-C cycle where the dissolved carbon is oxidized to CO, as a separate product.

The HyMelt process thus produces two separate gas products directly.

As part of the pilot project at MEFOS, thermodynamic calculations on the HyMelt process have been carried out using the thermodynamic computation program FACTSage 5.1 available at MEFOS.

The aim of the calculations is to thermodynamically determinate the following cycles:

- the H_2-cycles
- the CO-cycle
- the S-cycle
- the V-cycle (only for P-coke)
- the Ni-cycle (only for P-coke)

The cycle range of C and S has been set by EnviRes: 0.5-4 % C and 0.5-1.25 % S respectively.

The calculations include simulations on S-removal by:

- H_2-purging
- slag treatment

The effect of temperature on the S-removal, V-cycle etc has also been considered. Both adiabatic and isothermal equilibrium calculations have been performed. In order to ensure the quality of the calculations results, heat balance calculations were also performed by HSC 5.1(A thermochemical computational program developed by Outokompu, Finland)

The calculations have mainly been performed at conditions of 20 bars but also atmospheric pressure calculations have been made.

Effect of pressure on the equilibria has also been calculated.

According to the project plan three basic materials have been simulated. In addition to these, some calculations on spent tyres were also made.

This report will summarize the most interesting calculation results and some special cases will be highlighted such as V-calculations, S-removal by H_2-purging and by slag treatment.

Some calculations for spent tyres have also been calculated.

2 RESULTS OF THERMODYNAMIC CALCULATIONS BY FACTSAGE 5.1

Following phases are included for all calculations:

- gas phase, ideal gas mixture.
- metal phase, diluted solution model for Fe-liquid.
- slag model, the quasi-chemical slag model developed by the CRCT group (Center for Research in Computational Thermochemistry) at the Ecole Polytechnique de Montreal.
- condensed phases, all condensed phases involved in the considered system are included in the calculations.

The detail of the FACTSage program have been described in a 40-page paper published in Vol 26 of the CALPHAD journal [1]which provide an excellent overview on the program and its various modules.

The calculations have been made according to the MEFOS scale of 5 tons metal and an assumed industrial scale of 10 tons. In case of the MEFOS 5 ton converter, an injection rate of 10 kg coal/coke/oil per minute has been used for the calculation. The 10 ton scale converter, the injection rate of 100 kg/min has been used.

From equilibrium point of view the rate is however not important. It is more interesting to use the ratio of "amount of the injected material/ton of the iron melt" for comparison of the different cycles.

The rate of O_2 during the de-C cycle has been related to the H_2-production rate using the H_2-cycle so that the CO-production rate will be the same as that of H_2. It will be slightly different for the three considered materials.

2.1 P-coke

Table 1 shows the chemical composition of P-coke used for the calculations.

Table 1 - Chemical composition of P-coke.

C	H	N	S	O
86.3	5	1	6.5	1

Table 2 shows the most interesting elements dissolved in the metal during the H_2- and CO-cycles.

Table 2 - Concentration of the major elements in the iron melt during the different cycles.

Cycles	C	S	V	Ni	O
initial	0.5%C	0.5%S	0	0	0
1st H_2-cycle 22 min	4.03%C	0.7636%S	0.0092%V	0.00167%Ni	0.0263%O
1st de-C cycle 65 min	0.52%C	0.751%S	0.00921%V	0.00174%Ni	0.157%O
2nd H_2-cycle 22 min	3.95%C	0.994%S	0.0184%V	0.00334%Ni	0.011%O
2nd de-C cycle 64 min	0.51%C	1.027%S	0.0184%V	0.00346%Ni	0.18%O
3rd H_2-cycle 23 min	4.08%C)	1.255%S	0.0275%V	0.0050%Ni	0.012%O
3rd de-C cycle 64 min	0.50%C	1.286%S	0.0275%V	0.0052%Ni	0.18%O

Table 3 shows the mass balance and distribution of the most interesting elements during injection.

Table 3 - Mass distribution of the major elements in the 5 ton iron melt during the H_2- and de-C cycles.

Cycles	C	S	V	Ni	O
initial	25 kg C	25 kg S	0	0	0
1st H_2-cycle 22 min	211 kg C 97.89% to metal	38.8 kg S 96.50% to metal	0.484 kg V 100% to metal	0.088 kg Ni 100% to metal	0.138 kg O
1st de-C cycle 65 min	26.12	38.74	0.467	0.088	7.96
2nd H_2-cycle 22 min	208 96% to metal	52.35 95.17% to metal	0.967 100% to metal	0.176 100% to metal	0.58
2nd de-C cycle 64 min	25.934	52.271	0.938	0.176	8.495
3rd H_2-cycle 23 min	207 95% to metal	65.73 93.91% to metal	1.45 100% to metal	0.264 100% to metal	0.64
3rd de-C cycle 64 min	25.454	65.63	1.4476	0.2640	9.14

2.1.1 The H_2-cycle

With an injection rate of 10 kg/min, in a reactor with 5 tons iron melt it will take 22 minutes to increase the C-content from 0.5 % to 4 %. Related to the total amount of the iron melt, it is 44 kg P-coke/ton iron, see also Figure 6.

As shown in the tables, theoretically a high carburization rate is expected. Over 95 % of carbon in the P-coke is reported to the metal phase.

For the other elements, 94-96 % of sulphur, 100 % of both V and Ni are reported to the metal phase during the injection (the H_2-cycle).

The adiabatic temperature

Figure 1 shows the temperature decrease during the H_2-cycle. A temperature drop of 285 °C will be expected after injection of 220 kg P-coke into the 5 ton iron melt.

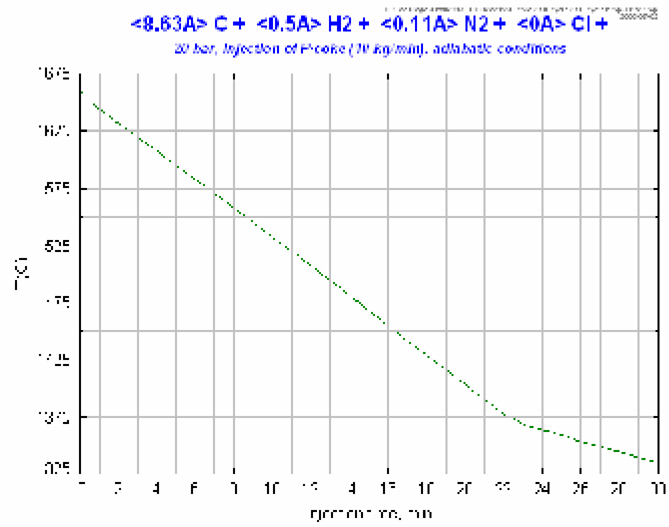


Figure 1 - Temperature drop during the 1st H2-cycle.

The quality of H_2-gas

The purity of the produced H_2 is dependent on the dissolved elements such as O and N in the iron melt and also these elements in the injected P-coke. Figure 2 shows that H_2-content in the gas product from first H_2-cycle is almost 96 %, the minor amount of CO and N_2 is mainly due to the O- and N-content in the P-coke.

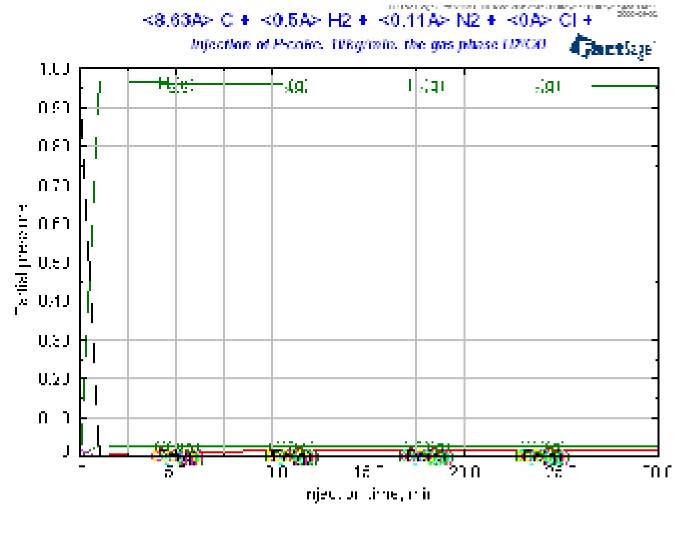


Figure 2 - The purity of H_2-gas produced during the 1st H_2-cycle.

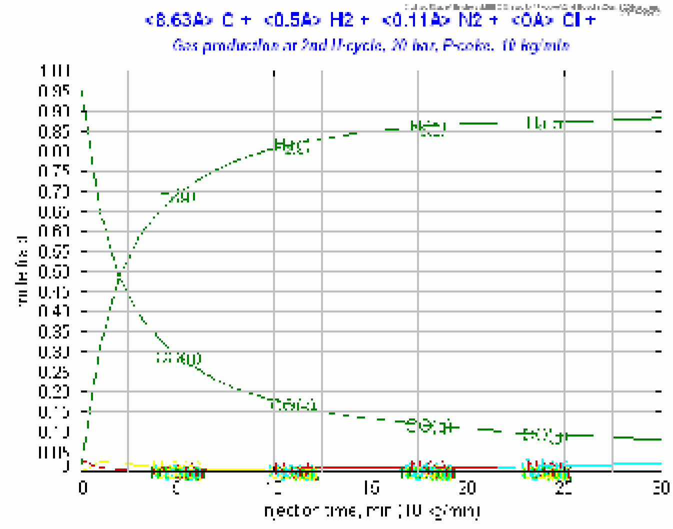


Figure 3 - Purity of H_2-gas produced during the 2nd H_2-cycle.

In the second and third H_2-cycle the H_2-gas quality becomes much poorer. Due of the high pressure of 20 bars applied during the CO-cycles, the O-solubility after de-C process is as high as 0.18 % is the iron melt. The high O-concentration makes a large amount of dissolved oxygen available prior to the C-cycles. As shown in Figures 3-4, the H_2-cycle starts with a gas with up to 95 % CO and gradually the CO-concentration decreases to 28 % after 5 minutes of injection, to 17 % after 10 minutes and 10 % after 20 minutes. The H_2-concentration increases accordingly to about 87 %.

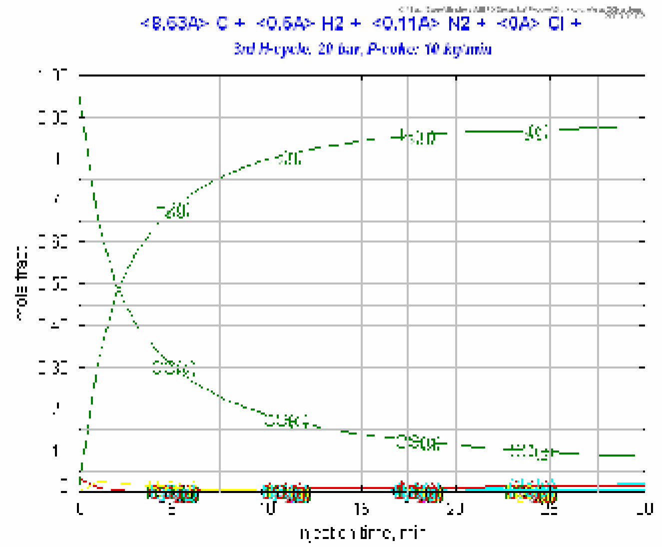


Figure 4 - Purity of H_2-gas produced during the 3rd H_2-cycle.

In reality, the CO-gas produced in the first few minutes will leave the system directly and they should not be available for the coming equilibrium steps. A more precise diagram will be similar to Figure 2, probably a few intensive minutes for CO-generation and then a rather pure H_2-production.

Concentration of the gases of minor amount is shown in Figure 5 (from the second H_2-cycle).

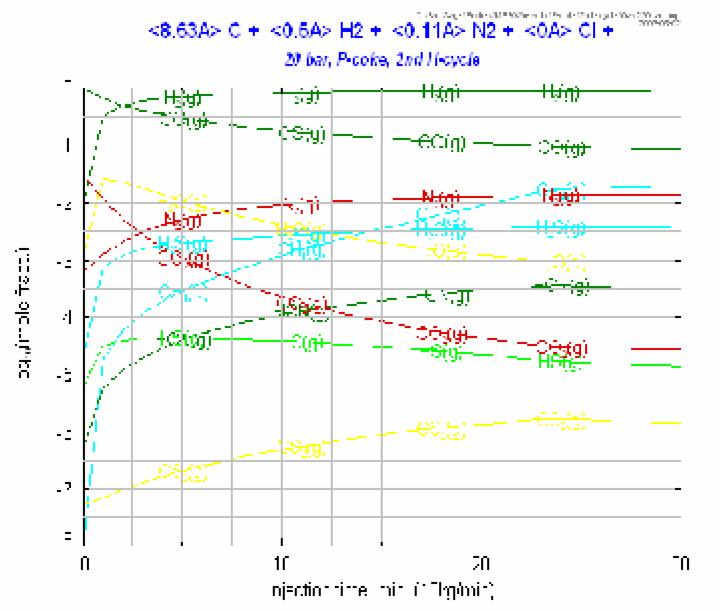
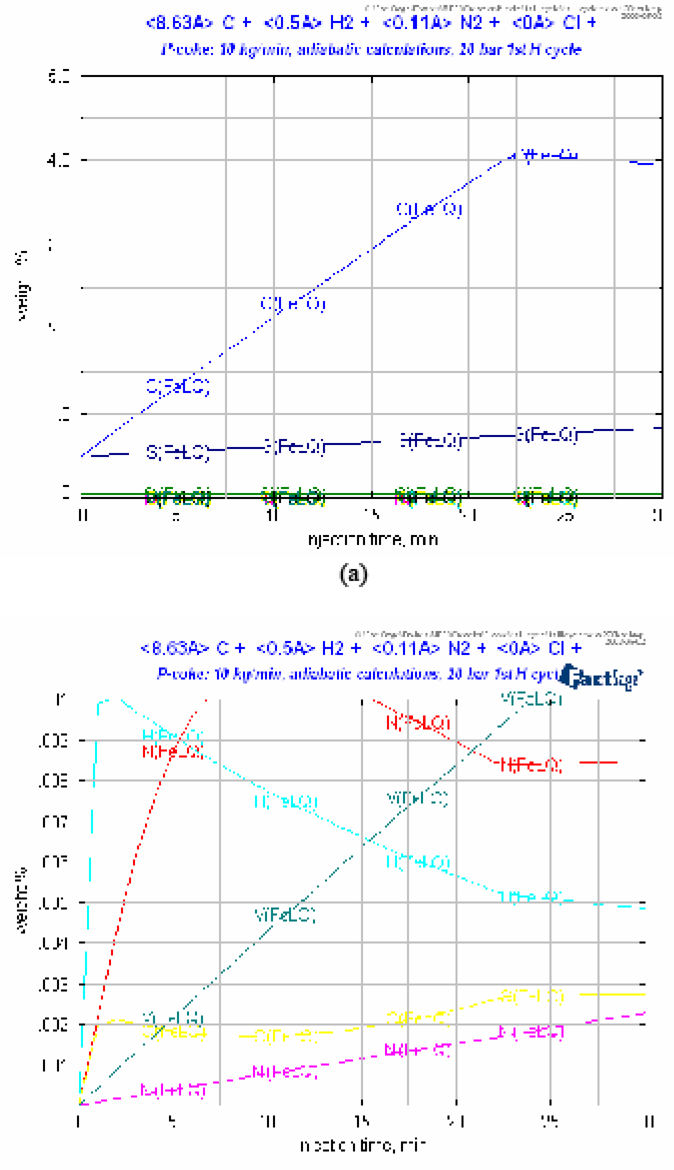


Figure 5 - Gaseous species of minor amount, from 2nd H_2-cycle.

Chemistry of the iron melt

Concentration of the dissolved elements of interest during the first H_2-cycle is shown in Figure 6. As shown, C-content increases to from 0.5 % to 4 % C in 22 minutes of injection, S-, V- and Ni-content increases proportionally with the amount of the injected P-coke. The same trends are observed for the second and third H_2-cycle.



(a)

(b)

Figure 6 - Chemistry of the iron melt, (a) major element, (b) elements of minor amount.

2.1.2 The CO-production cycle

As shown in Table 2 and 3, it he O_2-blowing rate is defined so that the production rate of CO will be in the same range as that for the H_2-production, it will take 65 minutes to remove C-content in the iron melt from 4 % to 0.5 %. See also Figure 8 (from the second cycle).

The adiabatic temperature

According to the adiabatic calculations the iron melt could be heated up to 1 800 °C from 1 350 °C during the oxidation cycle, as shown in Figure 7.

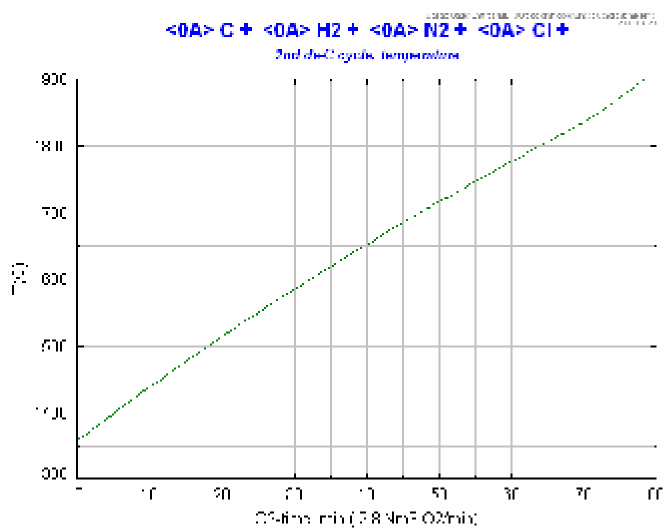


Figure 7 - Temperature increasing during the de-C cycle.

Purity of the CO-gas

During the H_2-cycle, some H is dissolved in the iron melt. The H_2-concentration is about 0.3 % under the pressure of 20 bars. During the first few minutes of the de-C cycle, the dissolved hydrogen will be released and a pure CO-gas will be expected. See Figure 8.

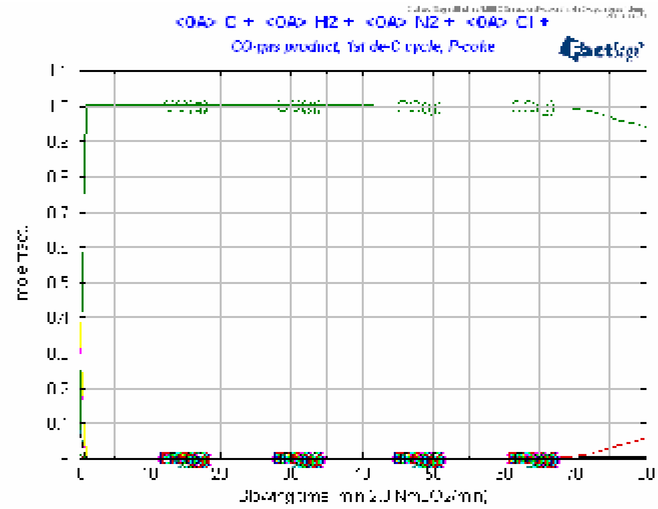


Figure 8 - CO-gas purity during a de-C cycle.

Chemistry of the iron melt

Figure 9 shows the C-content decrease from 0.4 to 0.5 % during O_2-blowing with a rate of 2.8 Nm^3/min.

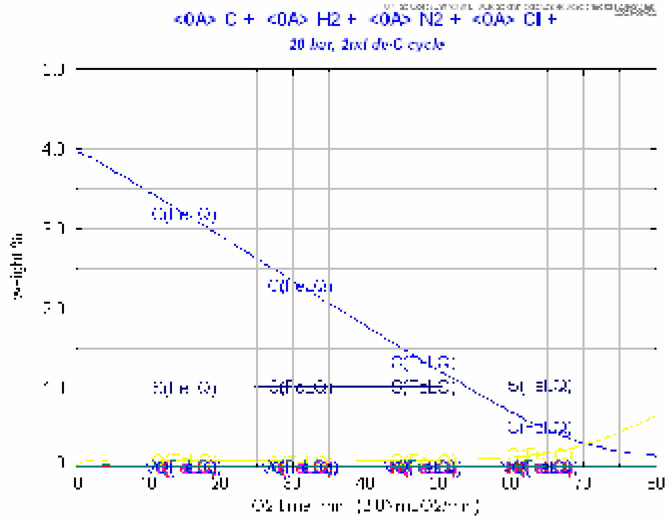


Figure 9 - Change of the concentration of the major elements in a typical de-C process.

As shown in the Figure and Tables 2-3 the S-, V- and Ni-content remain in the iron melt during the de-C cycles.

2.1.3 The S-cycle

As shown in Table 2 and Figure 10, the S-content increases proportionally with the injected material during the H_2-cycle, over 95 % of S is the iron melt. During the de-C cycle, the S-content in the melt remains unchanged. This indicates that H_2-purging is not an efficient way for S-removal.

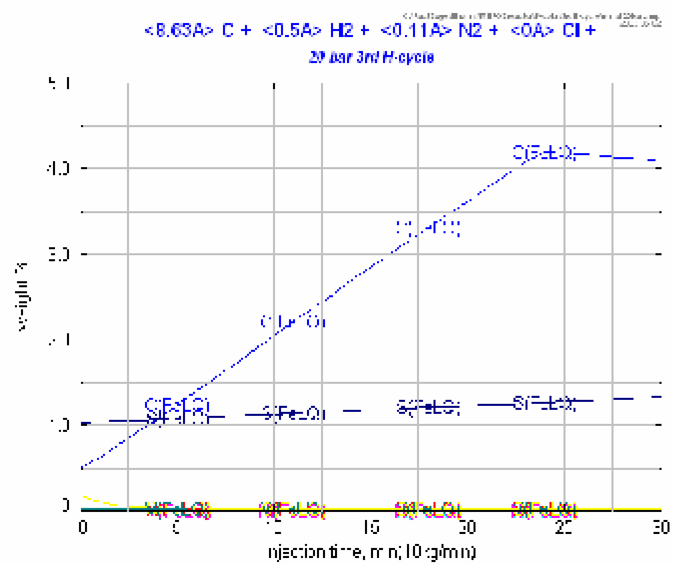


Figure 10 - Major elements in the iron melt during the 3rd H2-cycle.

The S-cycle has been set to 0.5- 1.25 %. After three H_2-cycles (and three de-C cycles), the S-content reaches the upper S-limit.

1 S-cycle = 3 C-cycles

Thus after we have injected totally 660 kg P-coke in 5 ton iron melt, or 132 kg P-coke/ton iron melt, an S-removal step has to be taken.

2.1.4 S-removal by H_2-purging

Using the equilibrium composition of iron melt obtained from the calculations in the third H_2-cycle and various H_2-amount as input. S-removal by H_2-purging has been simulated.

H_2S formation

As shown in Figure 11, the H_2S formation is rather limited. The partial pressure of H_2S is as low as 0.004.

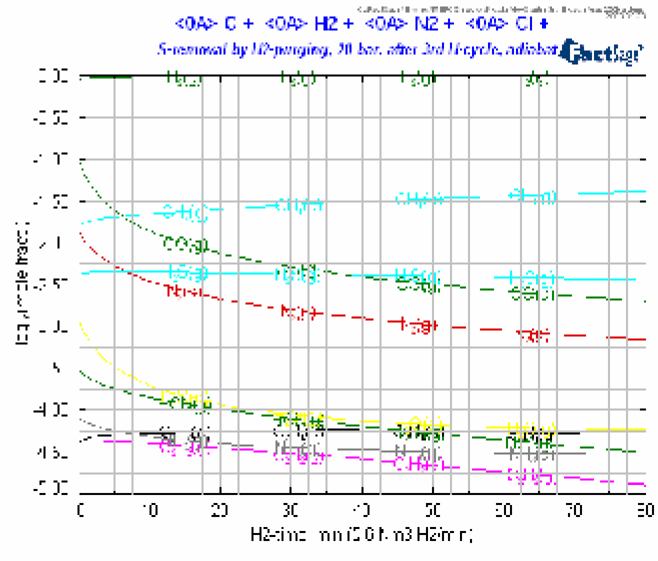


Figure 11 - Formation of H_2S and other gaseous species of minor amount.

S-removal efficiency

With a H_2-purging rate of 5.6 Nm^3/min (which is the same as the H_2-cycle), it will take 80 minutes to reduce S-content in the iron melt from 1.24 % to 1.20 % and it will take over 38 hours to reduce 1 % S in the iron melt. The total amount of H_2 needed will be 12 800 Nm^3 which is about 34-35 times the H_2-gas produced during three H_2-cycles (370 Nm^3/S-cycle), see Figure 12 and Table 4.

Table 4 shows summary calculations of S-removal under various conditions over a treating period of 80 minutes. The best case is having a start S-content of 5 % and treatment at 1 700 °C. For this 2 448 Nm^3 H_2 is required which is 7 times of the H_2 produced. H_2-purging time will be 7.3 hours (with a H_2-feed rate of 5.6 Nm^3/h for a 5 ton reactor).

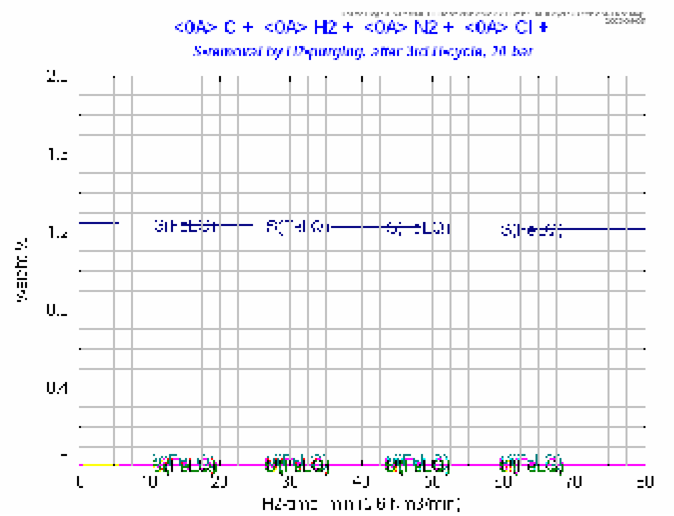


Figure 12 - S-removal by H_2-purging.

Table 4 - S-removal calculations for 4 cases.

De-S by H_2, 5.6 Nm^3 H_2 /min %S=1.255, adiabatic	Temp. drop 1393 to 1248°C 80 min	From 1.246%S to 1.21%S	**12800 Nm^3** H_2 required for removal of 1%S in metal	If 5.6Nm^3 H_2/min it will take **2286 min. (38.10h)**
De-S by H_2, 5.6 Nm^3 H_2 /min %S=4.75, adiabatic	Temp drop 1475 to 1320°C 80 min	From 4.75%S to 4.7%S	**8960 Nm^3** H_2 required for removal of 1%S in metal	If 5.6Nm^3 H_2/min it will take **1600 min. (26.67h)**
De-S by H_2, 5.6 Nm^3 H_2 /min %S=5, 1700°C	1700°C 80 min	From 4.805%S to 4.622%S	**2448 Nm^3** H_2 required for removal of 1%S in metal	If 5.6Nm^3 H_2/min it will take **437 min. (7.29h)**
De-S by H_2, 5.6 Nm^3 H_2 /min %S=1.24, 1700°C,	1700°C 80 min	From 1.25%S to 1.17%S	**5600 Nm^3** H_2 required for removal of 1%S in metal	If 5.6Nm^3 H_2/min it will take **1000 min. (16.67h)**

Temperature

The temperature drop will be about 2 °C/min, meaning we need to put extra energy to keep the reactor hot. The temperature drop will be over 850 °C.

It is concluded from the FACT-calculations that S-removal by H_2-purging is not efficient.

2.1.5 S-removal by slag treatment

The S-removal by slag treatment has been calculated at 20 bars and atmospheric pressure. No differences has been observed (S-bearing gaseous species has been involved).

Figure 13 show that temperature has no effect at all in the S-removal efficiency. The calculation uses a slag of 500 kg (for 5 ton iron melt) consisting of 60 % CaO, 30 % SiO_2 and 10 % MgO.

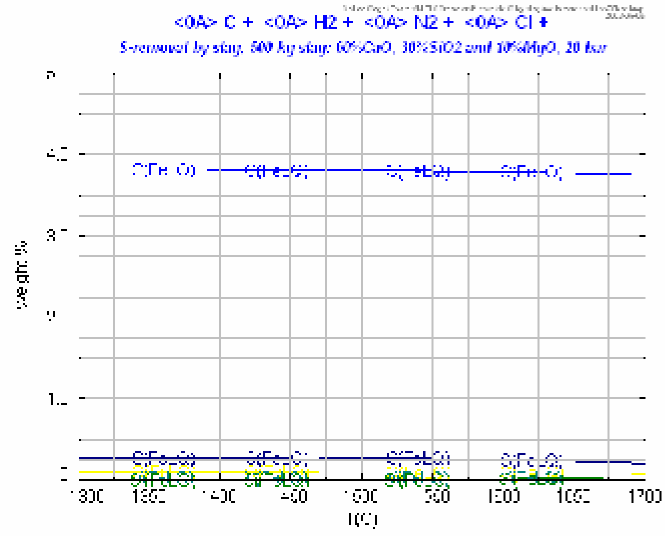
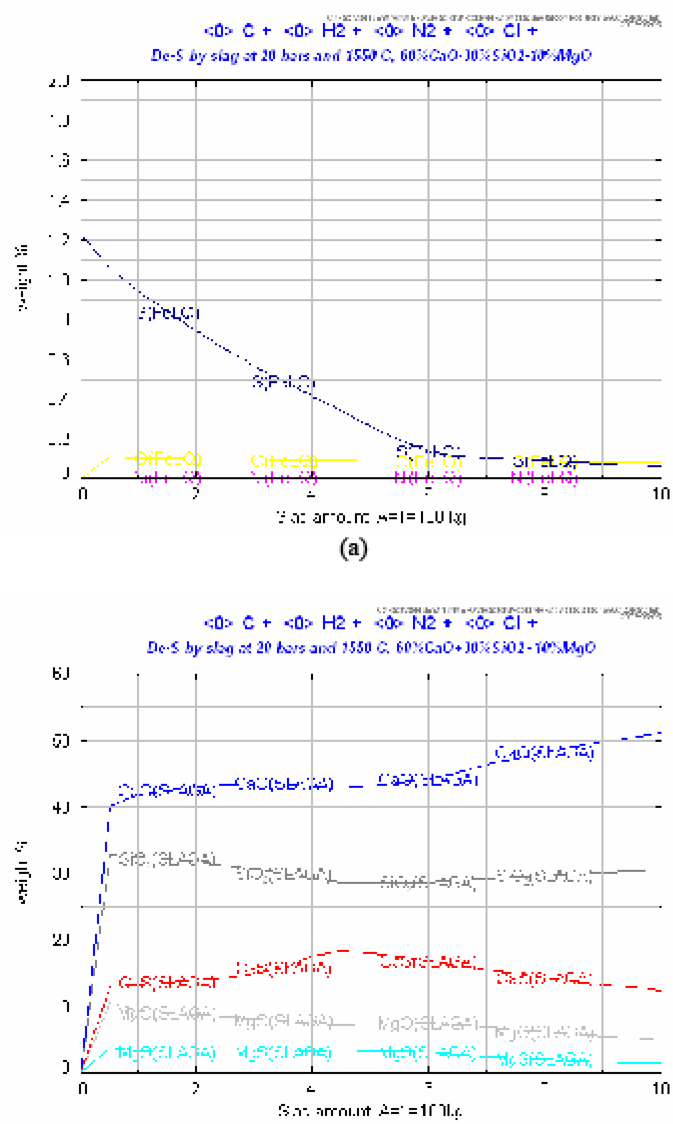


Figure 13 -S-removal by slag at temperature 1300-1700°C; 100 kg slag/ton iron melt.

The minimum slag amount required for S-removal (from 1.25 % to 0.5 % S) at 1 550°C and 20 bars is about 300 kg for the 5 tons iron melt or 60 kg /ton iron melt, or 450 kg slag/ton injected P-coke, see Figure 14.



(a)

(b)

Figure 14 -Minimum slag amount for S-removal at 1 550 °C.
(a) S-content in the iron melt. (b) Slag composition.

This slag could however be recycled after a hot treatment where S in the slag (CaS) is oxidised to SO_2.

2.1.6 The V-cycle

Since the V-content in P-coke is only 0.22 % and almost all V reports to the iron melt in the first cycles. It is decided to calculate at which V-level, vanadium will firstly be oxidised.

Figure 15 shows that when V-content is increased to 13 % the V-oxidation (to VOx) will start. The system used for the equilibration calculations is Fe-V-4 % C - 1.5 % S-VO_x.

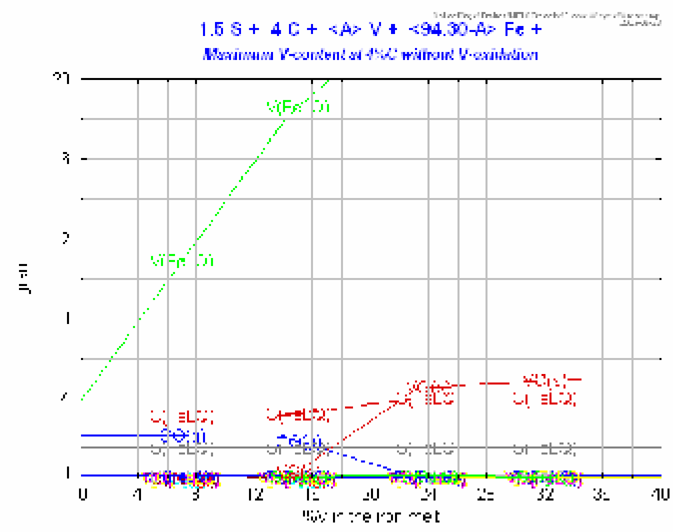


Figure 15 - Maximum V-level in the iron melt before the initial V-oxidation.

For a reactor start with 5 000 kg iron melt the composition at maximum V-content (13 %) will be:

- 5 000 kg Fe
- 240 kg C
- 650 kg V
- 90 kg S

The amount of V (650 kg) in the iron melt corresponding to 300 ton P-coke.

This means:

1 V-cycle = 1 360 C-cycle

The Ni-cycle

It is realistic to assume that Ni-level could increase to 20 % (due to the limitation of the reactor volume, not due to the chemistry). The amount of Ni will be 1 316 kg corresponding to 3 290 ton injected P-coke.

1 Ni-cycle = 11 V-cycles = 15 000 C-cycles

2.2 Aromatic extract

The chemical composition of aromatic extract is shown in the following table.

Table 5 - Chemical composition of aromatic extract.

Carbon	Hydrogen	Nitrogen	Sulfur	Oxygen
90.31	6.99	0.24	4.09	0

2.2.1 The H_2-cycle

The H_2-cycle for aromatic extract is almost the same as that for P-coke. About 21 minutes are needed for the H_2-cycle from 0.5 to 4 % C with a feeding rate of 10 kg/min and 5 ton iron melt. This corresponds to 42 kg Aromatic extract per ton iron melt, see Figure 16 and Table 6.

Table 6 - Concentration of major elements in the iron melt during the different cycles, injection of aromatic extract.

Cycles	Cycle time, min	% C	% S	% O
initial		0.5	0.5	0
1st H_2-cycle	21	4.02	0.63	0.02
1st de-C cycle	47	0.50	0.65	0.154
2nd H_2-cycle	21	3.96	0.78	0.066
2nd de-C cycle	46	0.52	0.81	0.171
3rd H_2-cycle	21	3.97	0.93	0.07
3rd de-C cycle	47	0.48	0.96	0.172
4th H_2-cycle	23	4.07	1.07	0.08
4th de-C cycle	48	0.50	1.11	0.172
5th H_2-cycle	22	4.09	1.22	0.08
5th de-C cycle	48	0.51	1.26	0.172
6th H_2-cycle	21	3.94	1.36	0.08

Table 6 shows the most interesting elements dissolved in the metal during the H_2- and CO-cycles.

Table 7 shows the mass balance and distribution of the most interesting elements during injection.

Table 7 - Mass distribution of C and S in the 5 ton iron melt during the H_2- and de-C cycles, injection of aromatic extract (190 kg input C /cycle).

Cycles	Cycle time, min	C in iron melt, kg	S in iron melt, kg
Initial		25	25
1st H_2-cycle	21	212	33
1st de-C cycle	47	25.5	33
2nd H_2-cycle	21	208	41
2nd de-C cycle	46	26.3	41
3rd H_2-cycle	21	209	49
3rd de-C cycle	47	24.1	49
4th H_2-cycle	23	215	57
4th de-C cycle	48	25.4	57
5th H_2-cycle	22	216	65
5th de-C cycle	48	26.13	64
6th H_2-cycle	21	216	72

Table 7 shows that over 95 % of C and over 90 % of S in the aromatic extract will be reported to iron melt during the injection period.

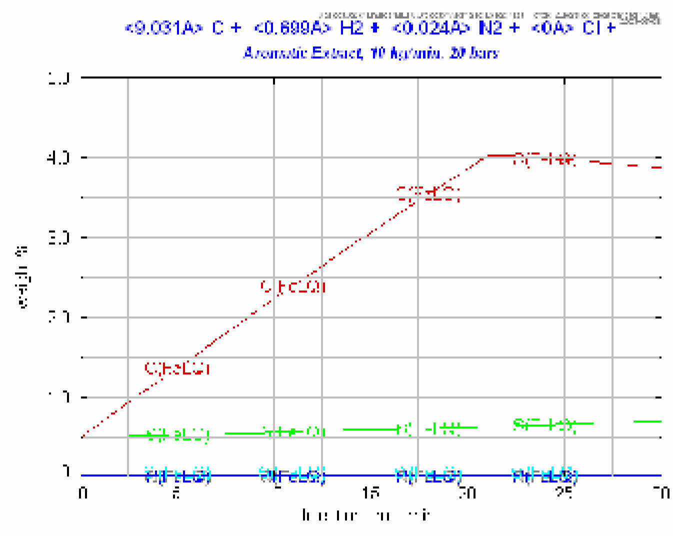


Figure 16 - C- and S-content in the iron melt during injection of aromatic extract.

The adiabatic temperature

Figure 17 shows the adiabatic temperature during a injection period. The temperature drop over a H_2-cycle is 300 °C.

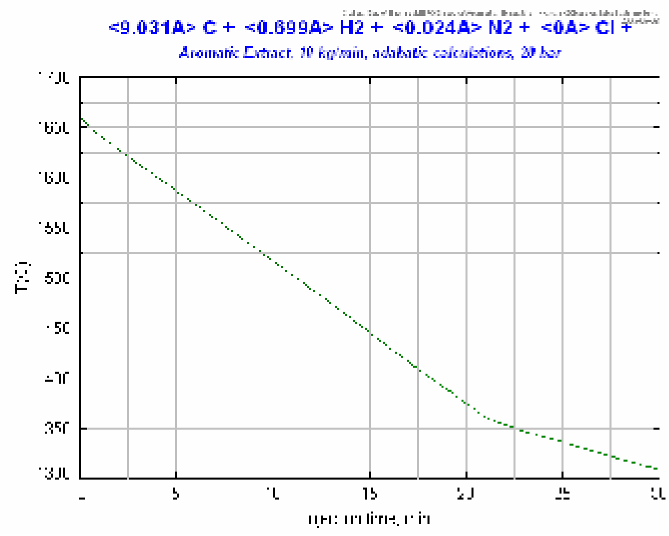


Figure 17 - Temperature drop during injection of aromatic extract.

The quality of H_2

As for P-coke, during the de-C cycle some oxygen will dissolve in the iron melt due to the oxidation step and the high pressure of 20 bars. This will affect the quality of H_2-gas in the beginning of each H_2-cycle. See Figure 18.

Chemistry of the iron melt

As shown in Tables 6-7 about 90 % of the input S is reported in the iron melt, about 10 % of S leaves the reactor as H_2S. The S-content increases proportionally with the injection, see Figure 16.

2.2.2 The de-C cycle

The de-C cycle is the same as for P-coke and will not be repeated here.

2.2.3 The S-cycle

Due to the lower S/C ratio, the S-cycle for aromatic extract is much longer compared to that of P-coke. As shown in Table 6 after fifth H_2-cycle, the S-content reaches 1.22 % S and after fifth de-C cycle 1.28 % S after sixth H-cycle 1.38 % S.

This means for aromatic extract:

1 S-cycle = 6 C-cycles

After we have injected totally 1 260 kg aromatic extract to the 5 ton reactor, a S-removal step is needed.

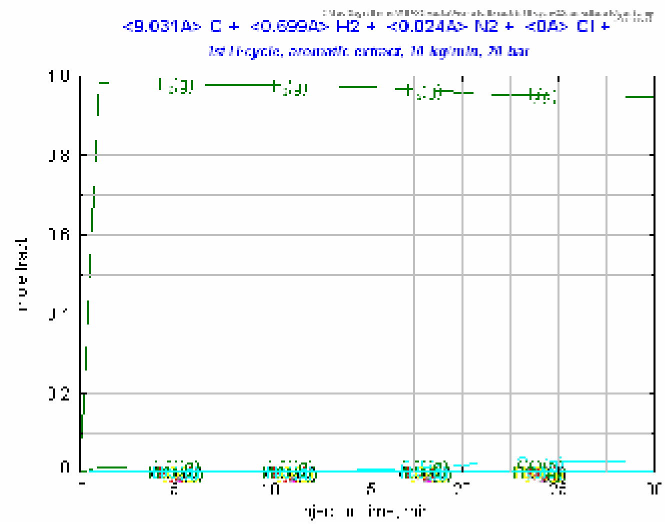


Figure 18 - H_2-production by injection of aromatic extract, the 1st H_2-cycle.

2.3 Coal ILL #6

The chemical composition of coal is shown in Table 8 and Table 9.

Table 8 - Chemical composition of coal ILL #6.

C	H	N	Cl	S	O	Ash
71.14	4.91	1.48	0.13	3.48	8.26	10.81

Table 9 - Mineral analysis of ash.

SiO_2	Al_2O_3	TiO_2	CaO	K_2O	MgO	Na_2O	Fe_2O_3	RO_5	SO_3
50.65	20.15	0.96	4.01	2.16	1	1.25	16.25	0.28	2.95

Coal ILL #6 is a special material since it has high contents of oxygen and ash compared to the other two materials.

The H_2-cycle

As shown in Figure 19 the H_2-cycle (C from 0.5 to 4 %) is about 30 minutes with an injection rate of 10 kg/min.

The temperature drop will be 240 °C, see Figure 20.

Due to the high content of ash, about 1 kg CaO/min is added together with the coal to balance the SiO_2 in the ash. The purpose of CaO addition is to have a CaO/SiO_2-ratio equal to 2.

As shown in Figure 19, the generated slag amount (CaO + ash) seems to be able to pick up all sulphur in the injected coal. S-removal is thus not necessary.

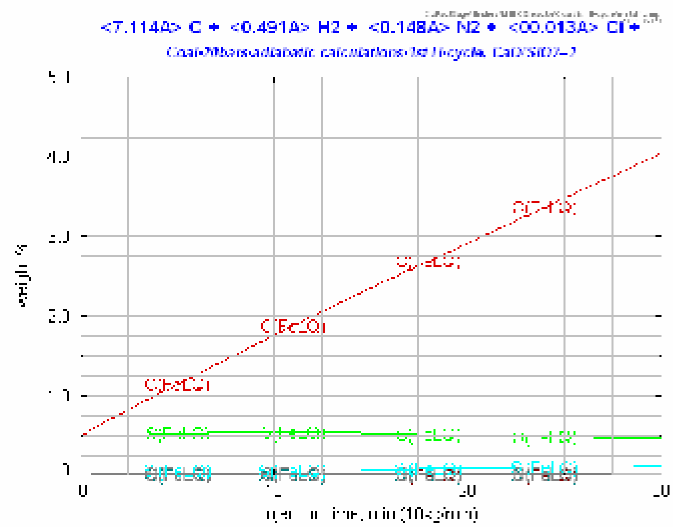


Figure 19 - Major elements in the iron melt during injection of coal.

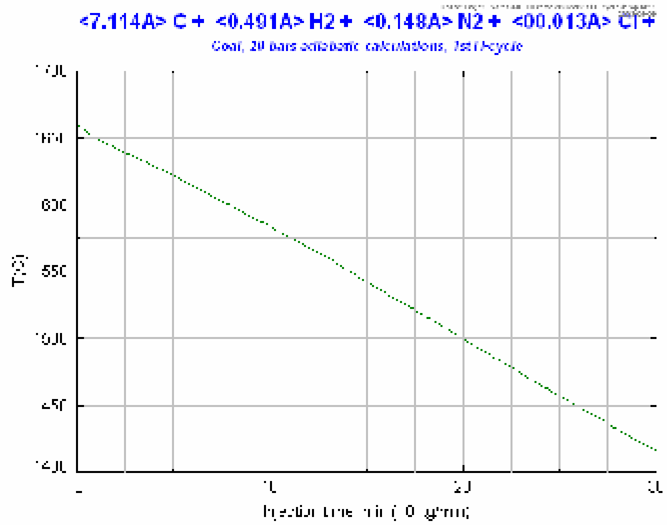
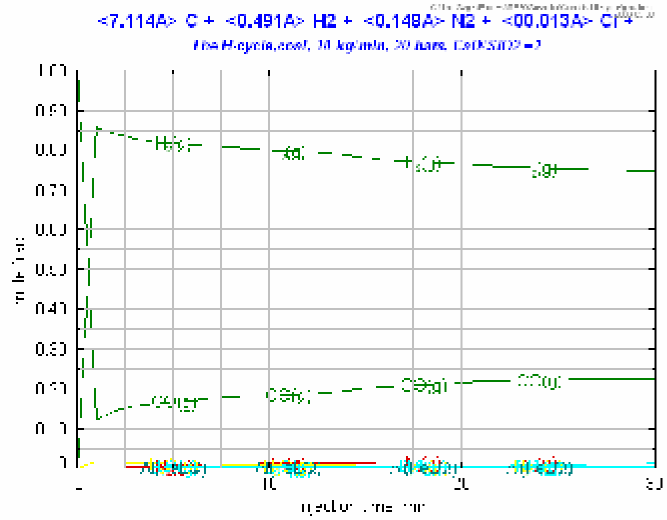
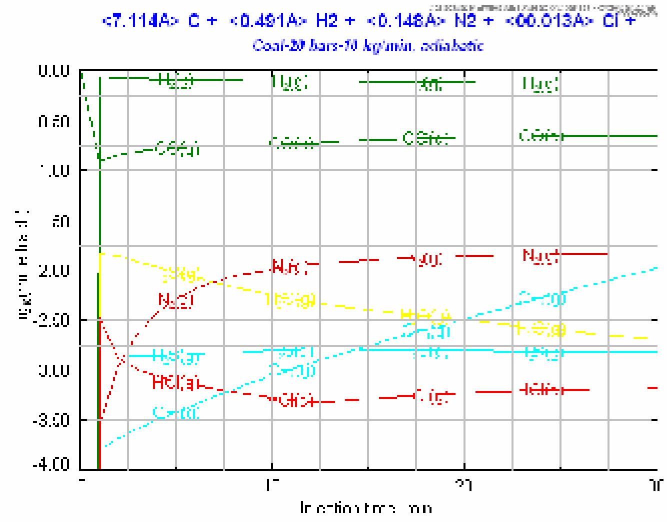


Figure 20 - Temperature drop during injection of coal.

Due to the high oxygen in the coal, the gas produced contains about 20 % CO as shown in Figure 21. The high Cl-content results in the formation of HCl.



(a)



(b)

Figure 21 -The gas composition during injection of coal.
(a) Purity of the H_2-production.
(b) Concentration of gaseous components of minor amount.

2.4 Calculation on spent tyres

In addition to the three materials from EnviRes some calculations on spent tyres have also been calculated .

The C-cycle: 45 kg tyres/ton iron melt

The S-cycle: 1 S-cycle = 20 H_2-cycles

The calculations are quite similar as those for the EnviRes materials except the S/C-ratio and the high content of Zn. Zn is recovered in the H_2-gas system.

The complete analysis of spent tyres is shown in Appendix I.

3 SUMMARY OF THE CALCULATIONS

The H_2-cycle

Based on 10 kg/min injection rate and a 5 ton iron melt the H_2-cycle for the three EnviRes materials and spent tyres have been calculated and the shown results are summarized in the following table.

	Injection time per H_2-cycle, min	Injected material/ton iron melt-ratio for one H_2-cycle, kg/ton
P-coke	22	44
Aromatic extract	21	42
Coal ILL#116	30	60
Spent tyres	22.5	45

The H_2-cycle is thus only related to the C-content in the injected carbon-materials.

The de-C cycle

This is the same as a LD-process where C-content is removed by oxidation except the pressure provided. One interesting point here is that if the cycle time for de-C step will be in the same range as that for the H_2-cycle time the gas system for the CO- and H_2 could be quite different. Since the flow rate of CO will be 2-3 times that of the H_2-gas.

The S-cycle

The S-cycle is mostly determined by the S/C-ratio in the used materials and the H/C-ratio as shown in the following table.

	S/C-ratio	H/C	C-/S-cycle ratio
P-coke	0.075	0.058	3
Aromatic extract	0.045	0.077	6
Coal ILL #6	0.049	0.069	0*
Spent tyres	0.021	0.088	20

* 10 % ash in the coal and about 10 % CaO is added. S is thus removed in the slag already. There will not be S-accumulation.

During the injection time, over 90 % of input S will dissolve in the iron melt, the rest will leave the reactor as H_2S together with the produced H_2. The higher the S/C-ratio the shorter the S-cycle will be, the higher the H/C-ratio, the longer the S-cycle will be. Higher H/C means more specific H_2-production and more removal of S from the iron melt (to H_2S).

S-removal by H_2- purging

Due to the unfavourably thermodynamical conditions provided for H_2S-formation, the method for S-removal by H_2-purging is highly inefficient. To remove the S dissolved in the iron melt it will consume much more H_2-gas than it has been produced during the H_2-cycles.

S-removal by slag treatment

Slag treatment is efficient. Using a slag with a CaO/SiO_2-ratio of 2 and a minimum amount of 60 kg/ton iron melt, the dissolved S will be removed. The slag used in the calculation consists of 60 % CaO, 30 % SiO_2 and 10 % MgO. This slag could be reused after S-removal of the slag by hot treatment.

The V-cycle

The V iron melt can contain up to 13 % V before V will be oxidised to VOx. This means:

1 V-cycle = 1 360 C-cycles

The Ni-cycle (only P-coke)

Theoretically Ni-solubility in the iron melt is not limited. Practically an iron melt with 20 % Ni is reasonable with regards to the reactor volume. This means:

One Ni-cycle = 11 V-cycles

Heat balance

Most of the calculations presented here are under adiabatic condition. The temperature drop for a H_2-cycle is shown in the following table.

	ΔT (FACT), °C	ΔT (HSC), °C
P-coke	285 °C	230 °C
Aromatic	300 °C	260 °C
Coal ILL#6	240 °C	Nd

The lower temperature drop of coal injection is due to the high oxygen content in the material which reacts with carbon in the H_2-cycle and produces extra energy to the system. The control calculation with HSC-program shows about 30-40 °C lower temperature drop than the FACTSage results. HSC-calculations are based on pure compounds and FACTSage calculations include the heat of mixing (dissolution of elements to the iron melt.

FACTSage shows a temperature increase of about 450 °C during the de-C cycle whereas HSC-heat balance shows a much lower temperature rise, about 330 °C.

The heat balance shows that it will be a net temperature increase of 150-200 °C based on the calculations (H_2-cycle + de-C cycle).

This net energy will cover heat losses of reactor and energy needed for smelting of the added slag for metal protection and S-removal.

4 REFERENCES

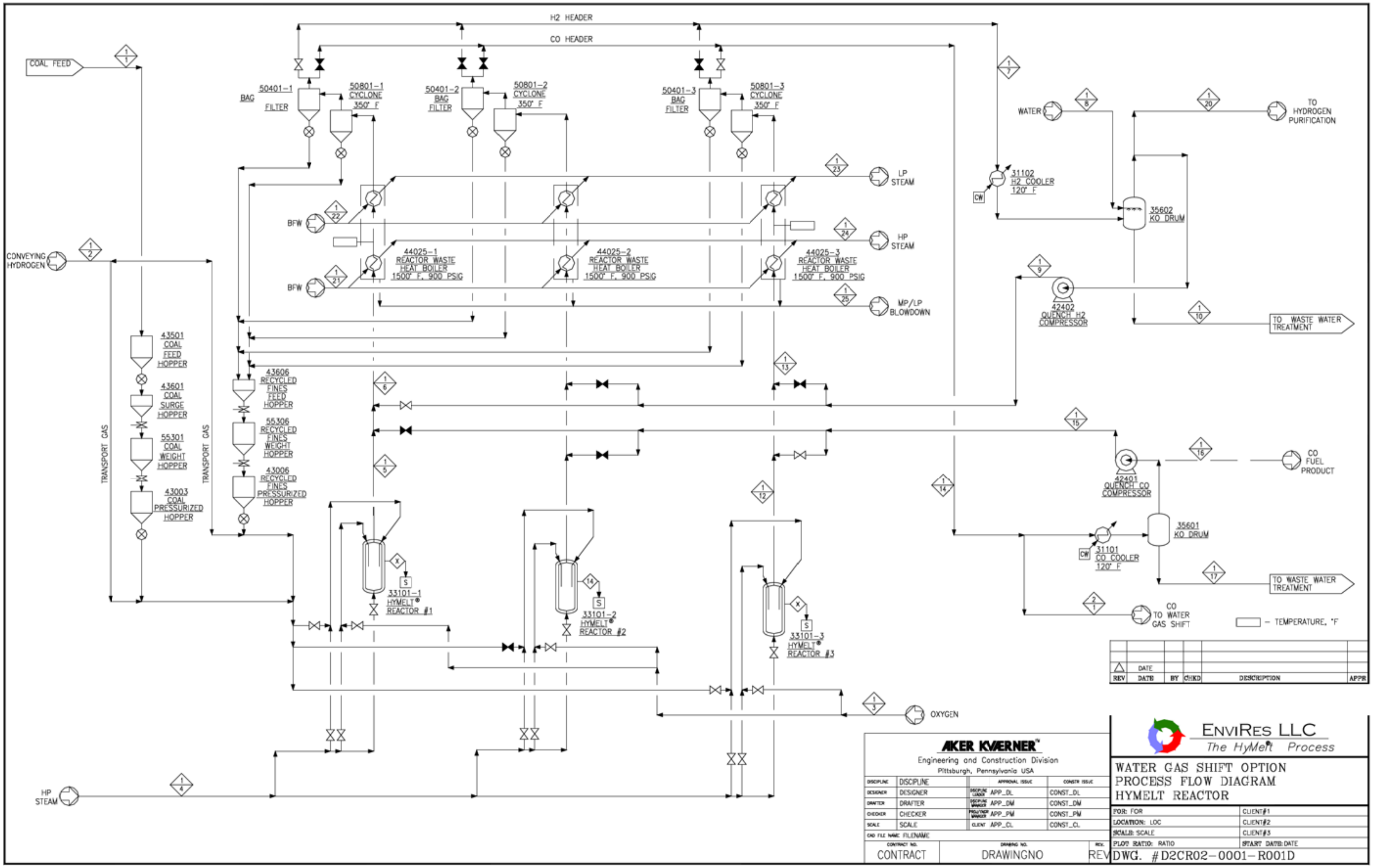
[1] FACTSAGE Thermochemical Software and Databases, C.W. Bales, and co-workers, CALPHAD 26 (2), 2002, pp 189-228.

Analysis of Swedish spent tyres

Parameter	**Content (cut)**	**Powder**
Moisture	2.2	< 0.01
Ash, %	8.2	7.7
Heat value, MJ/kg	32.48	35.41
Volatile, %	61.7	68.9
C, %	82.1	0.5
H (total), %	7.2	
IV, %	0.2	0.3
S, %	1.69	2.07
Cl, %	0.09	0.5
Pb, µg/g	31	68
Zn, %	1.6	18
Cd, µg/g	2.5	4.5
Cr, µg/g	2.2	3.7
Ni, µg/g	1.7	4.9
Fe, µg/g	240	4.0
Hg, µg/g	0.09	0.07

Appendix III

Kvaerner Process Flow, Hydrogen Purification, Amine and CO-Water Gas Shift Studies



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July 9, 2003

Email: mike.friedrich@akerkvaerner.com

Mr. Mike Friedrich

Aker Kvaerner

1200 Penn Avenue

Pittsburgh, PA 15222

SUBJECT: UOP Polybed PSA Unit

EnviRes, Kentucky

UOP Proposal P3H038 Rev. 4

Dear Mike,

In reply to your request, two budgetary designs and price estimates are provided for a UOP Polybed PSA Unit that produces a hydrogen product for the Hymelt Process.

Case 1 produces 15.31 MMSCFD of product hydrogen and Case 2 produces 28.39 MMSCFD of product hydrogen.

If there are any questions, please contact me at 713-744-2863 or email: Eugene.kuchta@uop.com.

Sincerely,

Eugene Kuchta

Process Technology & Equipment

EAK:rk

UOP POLYBED™PSA UNIT

for

Kvaerner

EnviRes / Hymelt Process

Project No: P3H038 July 9, 2003

Case 1 : 15.31 MM SCFD Product

		Feed	Product		Tail Gas	
Flowrate,	MM SCFD	19.08	15.31		3.76	
	lb-mol/hr	2,095	1,681		413	
Pressure,	psig	500	490		5	(Ex ST)
Temperature,	°F	120	130		110	
	°C	49	54		43	
Composition, mol%						
Hydrogen		93.24	99.9		66.15	
Nitrogen		1.13	Balance		5.32	
Carbon Monoxide		3.69	10	ppmv	18.70	
Carbon Dioxide		0.01	--		0.05	
Methane		0.86	Balance		4.36	
Acetylene		0.01	--		0.05	
Water		0.01	--		0.05	

Hydrogen Sulfide	1.00	--	5.07
Hydrogen Cyanide	0.05	--	0.25

Design Hydrogen Recovery:	86%
PSA Price (± 20% FCA USA. Shop):	$1,700,000 USD
PSA Approximate Plot Size:	50 ft. x 30 ft.

PSA Utilities:

Instrument Air	1,400 SCFH @ 85 psig
Electric Power	5.0 kW @ 120 VAC, 1 ph, 60 Hz
Nitrogen (Startup only)	
Leak Test	120,000 SCF @ 500 psig
Purge	60,000 SCF @ 85 psig

UOP POLYBED™PSA UNIT

for

Kvaerner

EnviRes / Hymelt Process

Project No: P3H038 July 9, 2003

Case 2 : 28.39 MM SCFD Product

		Feed	Product		Tail Gas	
Flowrate,	MM SCFD	46.19	28.39		17.80	
	lb-mol/hr	5,072	3,118		1,954	
Pressure,	psig	491	481		5	(Ex ST)
Temperature,	°F	120	130		110	
	°C	49	54		43	
Composition, mol%						
Hydrogen		71.40	99.9		25.94	
Nitrogen		0.60	Balance		1.40	
Carbon Monoxide		5.20	10	ppmv	13.49	
Carbon Dioxide		21.70	--		56.31	
Methane		0.40	Balance		1.04	
Water		0.20	--		0.52	

Hydrogen Sulfide	0.40	--	1.04
Hydrogen Cyanide	0.10	--	0.26

Design Hydrogen Recovery: 86%

PSA Price (± 20% FCA USA Shop): $2,500,000 USD

PSA Approximate Plot Size: 70 ft. x 40 ft.

PSA Utilities:

Instrument Air	3,400 SCFH @ 85 psig
Electric Power	5.0 kW @ 120 VAC, 1 ph, 60 Hz
Nitrogen (Startup only)	
Leak Test	360,000 SCF @ 491 psig
Purge	180,000 SCF @ 85 psig

UOP POLYBED™PSA UNIT

for

Kvaerner

EnviRes / Hymelt Process

Project No: P3H038 July 9, 2003

UOP Scope of Supply includes	Adsorber Vessels
	Off-Gas Drum(s)
	Valve and Piping Skid
	Initial Adsorbent Charge
	Engineering
	Control Panel with CRT
	Relief Valves for Adsorber Vessels and Off-Gas Drum
	Block Valves
	Interconnecting Piping from Adsorber Vessels to Skid
Customer Scope of Supply includes but is not limited to	Foundation including Anchor Bolts
	Installation of All UOP Supplied Equipment
	Piping from Valve and Piping Skid to Off-Gas Drum
	Adsorbent Loading Under UOP Supervision

Performance Test

Piping To/From PSA Battery Limits

Wiring between Skid and Control Cabinet/CRT

Supply of Utilities

Leak and Pressure Test of the PSA Unit

Design and Supply of Peripheral Controls

- Product Back Pressure Control Valve
- Feed KO Drum
- Feed Flow Control
- Block Valves on All Piping To/From Unit
- Feed and Tail Gas Vent
- Tail Gas Flow/Pressure Control

Analyzer

Finish Paint

Notes:

1. The price is quoted exclusive of taxes, crating, insurance, or freight costs, and is based upon UOP standard fabrication and third quarter, 2003, costs.
2. The typical U.S. installation cost for Polybed™ PSA Units similar to the proposed system has been approximately 15% of UOP's quoted purchase price.

DOW

SPECIALTY ALKANOLAMINES

Gas Treating Products

Products, Technology and Service from Dow

AkerKvaerner PSA TGU

Contents: **Page Number**

AkerKvaerner PSA TGU

Simulation Summary

Absorber Feed Gas Conditions

Gas Flow Rate:	22.09	MM SCFD
Pressure:	5.00	Psig
Temperature:	110.0	Deg F

Composition	Feed Mol %	LB MOL/HR	Product Mol%	LB MOL/HR
H2S	0.86%	20.98	0.00%	0.02
CO2	65.29%	1,583.19	60.56%	1,424.87
H2	20.10%	487.47	20.72%	487.44
CO	11.40%	276.52	11.75%	276.50
N2	1.02%	24.69	1.05%	24.69
CH4	0.75%	18.09	0.77%	18.09
C2H6	0.02%	0.58	0.02%	0.58
C3H8	0.05%	1.16	0.05%	1.16
H2O	0.51%	12.32	5.08%	119.47
UCARSOL	0.00%	0.00	0.00%	0.00
TOTAL	100.00%	2,425.00	100.00%	2,352.82

Treated Gas Conditions

GAS FLOW RATE:	21.43	MM SCFD
H2S	10	PPMV
CO2	63.8	%(V/V) DRY
CO2 Slippage	90.0	%

Solvent

Name	UCARSOL HS	103
Lean Solvent Flow	560.0	GPM
Amine Strength	50.00	%(W/W)
Internals - Number of Contact Trays	10	TRAYS

Solution Conditions

Lean Solvent Temperature	100.0	Deg F
Lean Loading	0.005	Mol/Mol
Rich Loading	0.159	Mol/Mol

Regenerator Conditions:

Tower Internals - Number of Trays	20	TRAYS
Rich Amine Feed Temp	213.3	Deg F
Reboiler Press	13.0	Psig
Reflux Flow	31.8	GPM

Exchanger Data:

Lean Cooler Duty	13.681	MM BTU/HR
Lean - Rich Exch'r	27.269	MM BTU/HR
Reflux Cond'r Duty	17.221	MM BTU/HR
Reboiler Duty	32.619	MMBTU/HR

AkerKvaerner PSA TGU

Major Equipment Summary

Absorber

Absorber Internals	10	TRAYS
Absorber Diameter	7.6	FT
Lean Loading	0.005	Mol/Mol
Rich CO2 Loading	0.141	Mol/Mol
Rich H2S Loading	0.019	Mol/Mol
Atmospheric Pressure	14.7	Psia
Treated Gas H2S	10.0	PPMV
Treated Gas CO2	63.8	%(V/V) DRY

Regenerator

Regenerator Internals	20	TRAYS
Regenerator Diameter	6.3	FT
O/H Reflux Ratio	5.00	Mol H2O/Mol AG
Regenerator Heat to Acid Gas Ratio	181.954	M BTU/Mol Acid Gas
Steam to Feed Ratio	1.077	LB/GAL

Reboiler

Heat Duty	32.619	MMBTU/HR	**U**	145.0	BTU/HR-FT2-DEGF
Steam Rate	35.8	M LB/HR	**LMTD**	41.8	Deg F
Reboiler Temperature	253.3	Deg F	**Fn**	1.00	
Reboiler Steam Pressure	50.0	Psig	**Area**	5,384	SQFT

Lean/Rich Exchanger

			U	120	BTU/HR-FT2-DEGF
Heat Duty	27.269	MM BTU/HR	**LMTD**	41.6	Deg F
Rich Inlet Temp	110.0	Deg F	**Fn**	0.80	
Rich Outlet Temp	213.3	Deg F	**Area**	6,836	SQFT
Lean Inlet Temp	253.3	Deg F			
Lean Outlet Temp	153.1	Deg F			

Lean Solvent Cooler

			U	90	BTU/HR-FT2-DEGF
Type	AIR		**LMTD**	15.4	Deg F
Heat Duty	13.681	MM BTU/HR	**Fn**	0.80	
Lean Inlet Temp	153.1	Deg F	**Area**	12,309	SQFT
Lean Outlet Temp	100.0	Deg F			

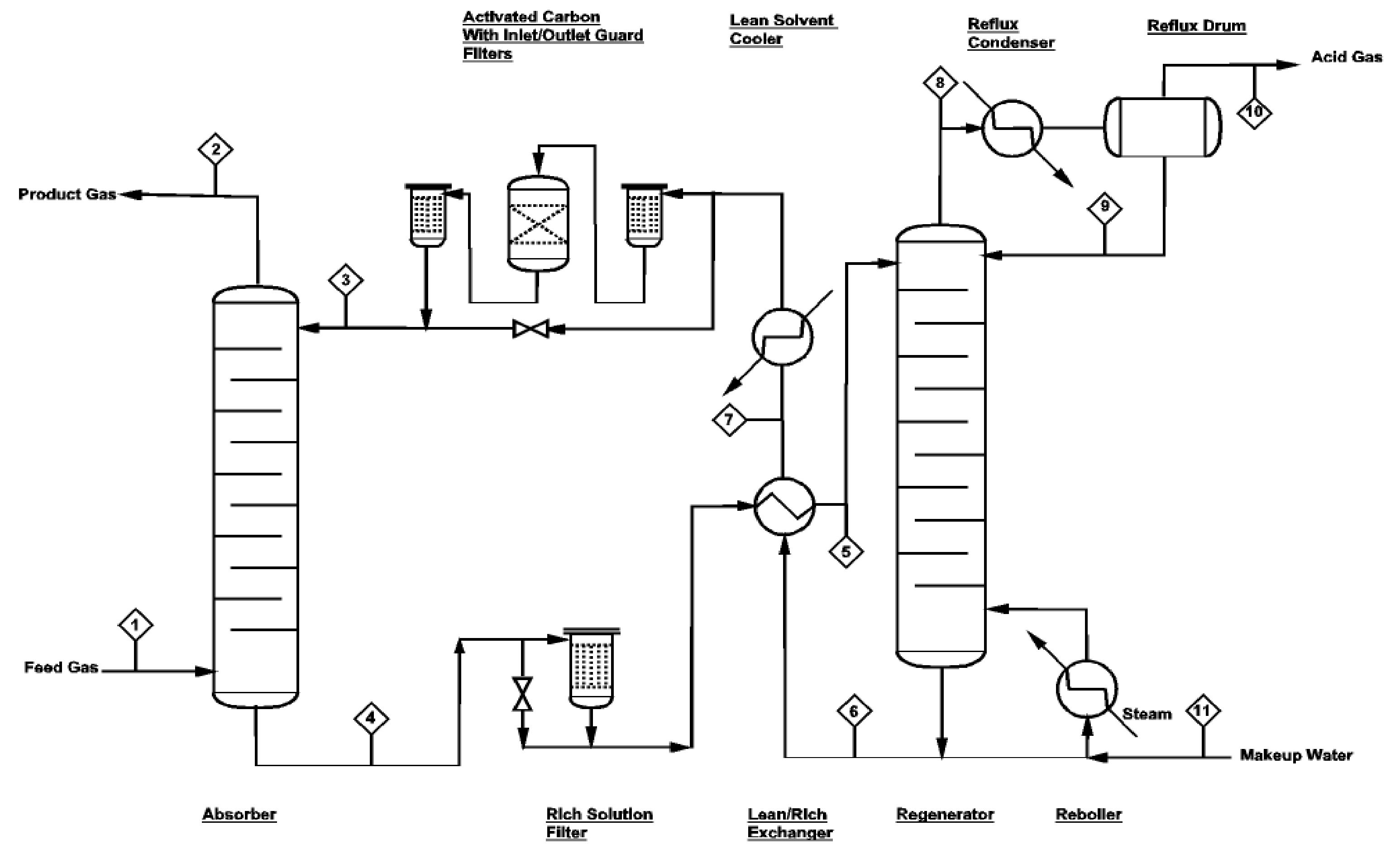
Reflux Condenser

			U	64	BTU/HR-FT2-DEGF
Type	AIR		**LMTD**	49.7	Deg F
Heat Duty	17.221	MM BTU/HR	**Fn**	0.80	
Inlet Temp	231.6	Deg F	**Area**	6,759	SQFT
Outlet Temp	120.0	Deg F			
Reflux Flow Rate	31.8	GPM			

The Dow Chemical Company assumes no obligation or liability resulting from the use of this information. No warranty, expressed or implied, is given nor is freedom from any patent owned by Dow or others to be inferred. Equipment sizes are estimated and should be confirmed by normal rigorous engineering methods.

AkerKvaerner PSA TGU

Stream Summary		Feed Gas 1	Product Gas 2	Lean UCARSOL 3	Cool Rich UCARSOL 4	Hot Rich UCARSOL 5	Hot Lean UCARSOL 6	Warm Lean UCARSOL 7	Stripper Overhead 8	Reflux Liquid 9
Temperature	Deg F	110.0	100.0	100.0	110.0	213.3	253.3	153.1	231.6	120.0
Pressure	Psig	5.0	4.0	4.0	5.0	.0	13.0		11.0	10.0
Gas Flow	MM SCFD	22.1	21.4						9.80	
Liquid Flow	GPM			560.0	573.2	-	594.4	570.4		31.8
Lean Solution Density	LB/GAL			8.8	8.7	8.4	8.3	8.6		8.7
Lean Solution Viscosity	cP			5.35			0.96	2.25		
Lean Solution Specific Heat	BTU/LB-F			0.858			0.956	0.889		
Lean Solution Surface Tension	DYNE/CM			38.8			30.3	35.9		
Lean Solution Thermal Conductivity	BTU/HR-FT-F			0.27			0.328	0.298		
H2S	LB MOL/HR	20.98	0.02	0.68	21.63	21.63	0.68	0.68	20.95	
CO2	LB MOL/HR	1,583.19	1,424.87	5.13	163.45	163.45	5.13	5.13	158.32	
H2	LB MOL/HR	487.47	487.44		0.03	0.03			0.03	
CO	LB MOL/HR	276.52	276.50		0.02	0.02			0.02	
N2	LB MOL/HR	24.69	24.69		0.00	0.00			0.00	
CH4	LB MOL/HR	18.09	18.09		0.00	0.00			0.00	
C2H6	LB MOL/HR	0.58	0.58		0.00	0.00			0.00	
C3H8	LB MOL/HR	1.16	1.16		0.00	0.00			0.00	
H2O	LB MOL/HR	12.32	119.47	8,184.82	8,077.67	8,077.67	8,184.82	8,184.82	896.36	883.17
UCARSOL HS	LB MOL/HR		0.003	1,161.02	1,161.02	1,161.02	1,161.02	1,161.02	0.379	0.379
TOTAL	LB MOL/HR	2,425.00	2,352.82	9,351.64	9,423.82	9,423.82	9,351.64	9,351.64	1,076.07	883.55
TOTAL	LB/HR	80,391.4	74,640.1	295,147.8	300,899.1	300,899.1	295,147.8	295,147.8	23,830.3	15,958.5
M/H A.G.	LB MOL/HR	1,604.16	1,424.89	5.81	185.08	185.08	5.81	5.81	179.27	



The Dow Chemical Company
Process Flow Diagram

AkerKvaerner PSA TGU

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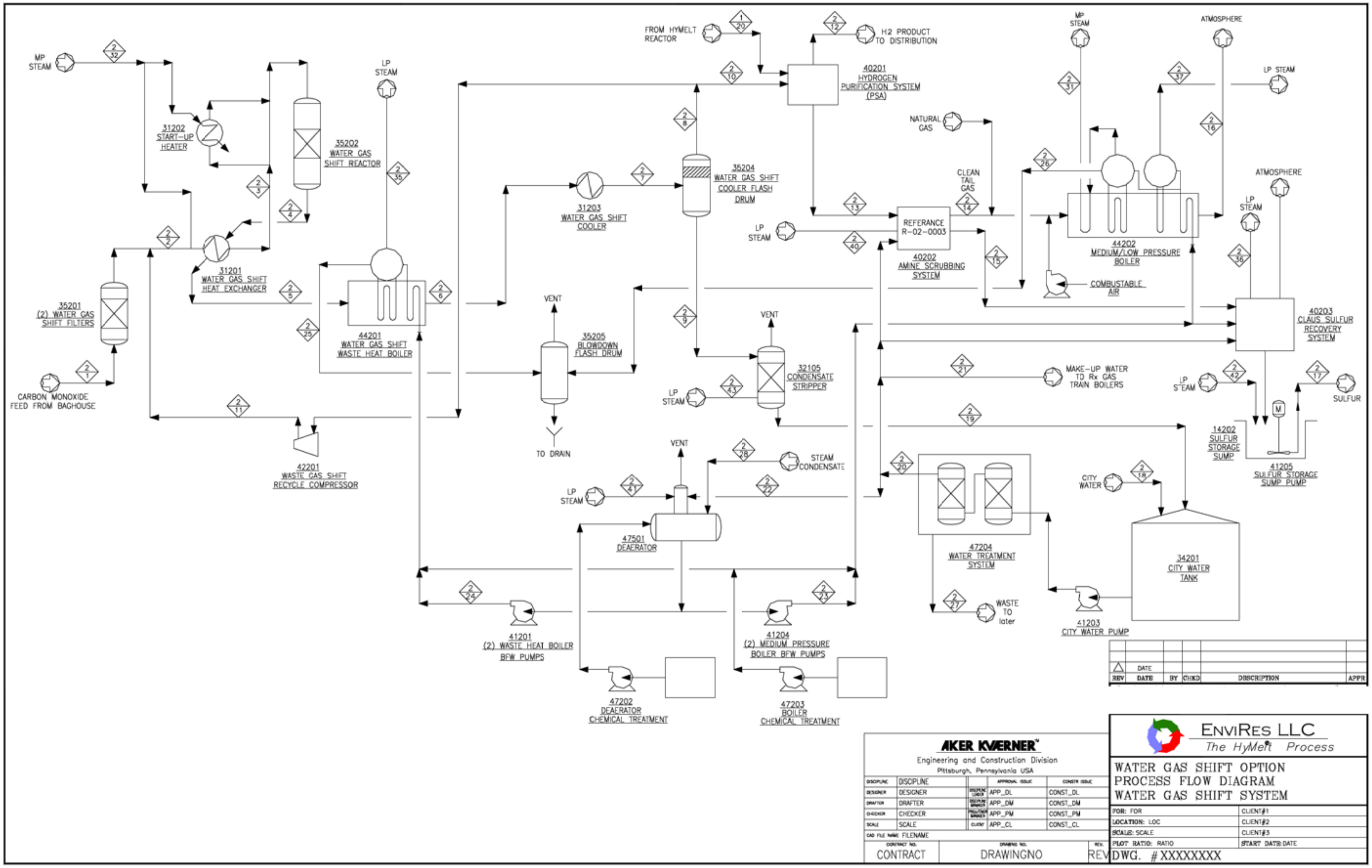
MP STEAM
31202 START-UP HEATER
35202 WATER GAS SHIFT REACTOR
LP STEAM
31201 WATER GAS SHIFT HEAT EXCHANGER
35201 (2) WATER GAS SHIFT FILTERS
CARBON MONOXIDE FEED FROM BAGHOUSE
44201 WATER GAS SHIFT WASTE HEAT BOILER
42201 WASTE GAS SHIFT RECYCLE COMPRESSOR
31203 WATER GAS SHIFT COOLER
35204 WATER GAS SHIFT COOLER FLASH DRUM
VENT
35205 BLOWDOWN FLASH DRUM
TO DRAIN
FROM HYMELT REACTOR
H2 PRODUCT TO DISTRIBUTION
40201 HYDROGEN PURIFICATION SYSTEM (PSA)
NATURAL GAS
CLEAN TAIL GAS
REFERANCE R-02-0003
40202 AMINE SCRUBBING SYSTEM
32105 CONDENSATE STRIPPER
STEAM CONDENSATE
47501 DEAERATOR
41201 (2) WASTE HEAT BOILER BFW PUMPS
41204 (2) MEDIUM PRESSURE BOILER BFW PUMPS
47202 DEAERATOR CHEMICAL TREATMENT
47203 BOILER CHEMICAL TREATMENT
MP STEAM
ATMOSPHERE
44202 MEDIUM/LOW PRESSURE BOILER
COMBUSTIBLE AIR
40203 CLAUS SULFUR RECOVERY SYSTEM
MAKE-UP WATER TO Rx GAS TRAIN BOILERS
47204 WATER TREATMENT SYSTEM
WASTE TO later
CITY WATER
34201 CITY WATER TANK
41203 CITY WATER PUMP
14202 SULFUR STORAGE SUMP
41205 SULFUR STORAGE SUMP PUMP
M
SULFUR
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The HyMelt Process
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WATER GAS SHIFT SYSTEM
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PRELIMINARY MATERIAL BALANCE - Water Gas Shift Option

Stream Number	2-1	2-2	2-3	2-4	2-5	2-6	2-7	2-8	2-9	2-10	2-11	2-12	2-13				
Description	COFEED	HTRIN1	COFEED2	WGOUT	WHBIN	WGWHB OUT	FLASHIN	FLASHOUT	FLCOND	WGSOUT	REC	PSAPROD	TAILGAS			Convey. H2	H2 PRODUCT
Temperature F	350	192.4	600	842.5	694.9	390.3	120	120	120	119.9	126.1	130	110			130	130
Pressure psia	500	500	497	496	493	490	487	486	486	485	500	475	19.7			475	475
Vapor Frac	1	1	1	1	1	1	0.646	1	0	1	1	1	1			1	1
Mole Flow lbmol/hr	1816.315	5537.209	10912.55	10912.55	10912.55	10912.55	10912.553	7045.592	3866.961	3324.701	3720.891	2994.447	2424.883			1400	1594.447
Mass Flow lb/hr	51524.224	139485.15	236323.5	236323.5	236323.5	236323.5	236323.49	166555.9	69767.546	78595.05	87960.9	6038.129	80368.87			2823.019	3215.111
Volume Flow cuft/hr	32111.641	77404.455	245686	307933	273443.6	197321.5	89632.643	88311.34	1503.461	41755.83	45844.97	40665.93	750683.8			19012.626	21653.31
Enthalpy MMBtu/hr	-91.849	-402.652	-921.167	-921.125	-936.191	-966.694	-1065.708	-588.848	-476.859	-277.868	-310.803	1.136	-282.267			0.531	0.605
Mole Flow lbmol/hr																	
CO	1702.668	1925.713	1925.713	422.348	422.348	422.348	422.348	422.347	0.001	199.299	223.048	0.028	276.508			0.013	0.015
H2	25.356	1736.241	1736.241	3239.606	3239.606	3239.606	3239.606	3239.594	0.012	1528.712	1710.882	2994.375	487.456			1399.966	1594.409
H2O	3.051	16.546	5391.891	3888.525	3888.525	3888.525	3888.525	25.552	3862.973	12.058	13.495	0	12.326			0	0
CH4	0.163	0.346	0.346	0.346	0.346	0.346	0.346	0.346	0	0.163	0.183	0.018	18.098			0.008	0.01
C2H2	0.272	0.577	0.577	0.577	0.577	0.577	0.577	0.577	0	0.272	0.305	0	0.584			0	0
N2	1.108	2.348	2.348	2.348	2.348	2.348	2.348	2.348	0	1.108	1.24	0.025	24.673			0.012	0.013
CO2	83.55	1855.13	1855.13	3358.495	3358.495	3358.495	3358.495	3354.521	3.974	1582.944	1771.577	0	1583.099			0	0
H2S	0.031	0.065	0.065	0.065	0.065	0.065	0.065	0.064	0.001	0.03	0.034	0.002	20.974			0.001	0.001
COS	0.114	0.242	0.242	0.242	0.242	0.242	0.242	0.242	0	0.114	0.128	0	0.12			0	0
HCN	0	0	0	0	0	0	0	0	0	0	0	0	1.043			0	0
HG	0	0	0	0	0	0	0	0	0	0	0	0	0.001			0	0
*** VAPOR PHASE ***																	
Enthalpy Btu/lb	-1782.636	-2886.704	-3897.905	-3897.728	-3961.479	-4090.553	-3535.439	-3535.439		-3535.446	-3533.423	188.158	-3512.138			188.158	188.158
Heat Cap Btu/lb-R	0.261	0.327	0.415	0.436	0.429	0.421	0.36	0.36		0.36	0.361	3.448	0.254			3.448	3.448
Conductivity Btu-ft/hr-sqf	0.022	0.035	0.041	0.065	0.058	0.042	0.039	0.039		0.039	0.04	0.112	0.021			0.112	0.112
Density lb/cuft	1.605	1.802	0.962	0.767	0.864	1.198	1.89	1.886		1.882	1.919	0.148	0.107			0.148	0.148
Viscosity cP	0.024	0.019	0.024	0.029	0.027	0.02	0.017	0.017		0.017	0.017	0.01	0.016			0.01	0.01
VVSTDMX @ 60 F MMcuft/day	16.543	50.432	99.389	99.389	99.389	99.389	99.389	64.170		30.281	33.889	27.273	22.085			12.751	14.522
*** LIQUID PHASE ***																	
Enthalpy Btu/lb							-6834.935		-6834.971								
Heat Cap Btu/lb-R							1.146		1.146								
Conductivity Btu-ft/hr-sqf							0.335		0.335								
Density lb/cuft							46.404		46.405								
Viscosity cP							0.564		0.564								
Surface Ten dyne/cm							68.034		68.036								
Flowrate gpm																	

C99168

PRELIMINARY MATERIAL BALANCE - Water Gas Shift Option

Stream Number	2-14	2-15	2-16	2-17 *	1-20		2-18	2-19	2-20	2-21	2-22	2-23	2-24	2-25	2-26	2-27	2-28
Description	CLEAN TAIL GAS	CLAUS FEED	BOILER FLUE	SULFUR PRODUCT	H2FEED		CITY WATER	STRIPPED COND	DEMIN MAKE-UP	DEMIN TO Rx GAS TRAIN BOILERS	DEMIN TO WGS BOILERS	MED PRES BFW	WATER GAS SHIFT WHB BFW	WATER GAS SHIFT WHB BDOWN	MED PRES BDOWN	DEMIN PLANT WASTE	STEAM COND RETURN
Temperature F	100	120	465		120		60	212	100	100	100	250	250	308	474	100	298
Pressure psia	18.7	24.7	14.7		500		90	15	65	65	65	715	215	75	535	65	65
Vapor Frac	1	1	1		1		0	0	0	0	0	0	0	0	0	0	0
Mole Flow lbmol/hr	2352.714	192.502	6520		2094.63		2006.97	4219.37	6164.08	856.73	5187.01	6097.81	1772.97	17.76	120.34	62.26	1985.57
Mass Flow lb/hr	74618	7919	204170	670	7811.948		36155	76012	111046	15434	93444	109852	31940	320	2168	1122	35770
Volume Flow cuft/hr					26584.86												
Enthalpy MMBtu/hr					-3.749												
Mole Flow lbmol/hr																	
CO	276.489	0.019			77.237												
H2	487.427	0.029			1953.119												
H2O	119.470	13.190	928.77		0.268		2006.97	4219.37	6164.08	856.73	5187.01	6097.81	1772.97	17.76	120.34	62.26	1985.57
CH4	18.098	0.000			17.953												
C2H2	0.584	0.000			0.312												
N2	24.673	0.000	3505.48		23.59												
CO2	1424.789	158.310	1872.48		0.155												
H2S	0.021	20.953	SO2 - 22 ppmv		20.946												
COS	0.120	0.000			0.006												
HCN	1.043	0.000			1.043												
HG	0.001	0.000			0.001												
*** VAPOR PHASE ***																	
Enthalpy Btu/lb					-479.868												
Heat Cap Btu/lb-R					1.877												
Conductivity Btu-ft/hr-sqf					0.099												
Density lb/cuft					0.294												
Viscosity cP					0.011												
VVSTDMX @ 60 F MMcuft/day	21.428	1.753	59.383		19.077												
*** LIQUID PHASE ***																	
Enthalpy Btu/lb																	
Heat Cap Btu/lb-R																	
Conductivity Btu-ft/hr-sqf																	
Density lb/cuft							62.37	59.81	62	62	62	58.8	58.8	50.2	55	62	55.6
Viscosity cP																	
Surface Ten dyne/cm																	
Flowrate gpm							72.3	158.6	223.5	31.1	188.1	233.2	67.8	0.8	4.9	2.3	80.3

C99168

PRELIMINARY MATERIAL BALANCE - Water Gas Shift Option

Stream Number		2-31	2-32		2-35	2-36 *		2-37		2-40 *	2-41	2-42 *	2-43				
Description		SUPHT MPSTM	MPSTM TO PROCESS		LPSTM from WHB	LPSTM from Claus	LPSTM from Rx gas trains	LPSTM from Med Pres Boiler		LPSTM to Amine Plant	LPSTM to Deaerator	LPSTM to Sulfur Pit	LPSTM to Condensate Stripper	LPSTM to Rx gas train deaerator		NG to BOILER	
Temperature F		700	700		308	308	308	308		298	298	298	298	298		20	
Pressure psia		520	520		75	75	75	75		65	65	65	65	65		50	
Vapor Frac		1	1		1	1	1	1		1	1	1	1	1		1	
Mole Flow lbmol/hr		5375.41	5375.43		1755.20	194.28	814.99	407.77		1985.57	720.40	83.26	360.81	22.20		142.63	
Mass Flow lb/hr		96838	96838.34		31620	3500	14682	7346		35770	12978	1500	6500	400		2580	
Volume Flow cuft/hr			121088														
Enthalpy MMBtu/hr			-533.581														
Mole Flow lbmol/hr																	
CO			0														
H2			0														
H2O		5375.41	5375.43		1755.20	194.28	814.99	407.77		1985.57	720.40	83.26	360.81	22.20			
CH4			0														
C2H2			0														
N2			0														
CO2			0														
H2S			0														
COS			0														
HCN			0														
HG			0														
*** VAPOR PHASE ***																	
Enthalpy Btu/lb			-5510.013														
Heat Cap Btu/lb-R			0.566														
Conductivity Btu-ft/hr-sqf			0.032														
Density lb/cuft			0.8														
Viscosity cP			0.023														
VVSTDMX @ 60 F MMcuft/day																1.299	
*** LIQUID PHASE ***																	
Enthalpy Btu/lb																	
Heat Cap Btu/lb-R																	
Conductivity Btu-ft/hr-sqf																	
Density lb/cuft																	
Viscosity cP																	
Surface Ten dyne/cm																	
Flowrate gpm																	

Water Gas Shift Equipment List
C99268
EnviRes LLC HyMelt Process

Equipment Number	Quantity	Operating/Standby	Description	Capacity/Size	Motor Hp operating/ connected
14202	1	1/0	Sulfur Storage Pit	10,000 gallon	
31201	1	1/0	WGS Heat Exchanger	15.1 MM Btu/h; Shell: 0.5 Mo; Tube: 316 SS	
31202	1	1/0	Start-up Heater	5 MM Btu/h; Shell: CS; Tube: CS	
31203	1	1/0	WGS Cooler	99.0 MM Btu/h; Shell&Tube: 316 SS	
32105	1	1/0	Condensate Stripper	3 ft dia. X 20' T/T; 10' packed section; Shell SS	
34201	1	1/0	City Water Storage Tank	400,000 gallons, CS	
35201	2	1/1	WGS Filter	2 ft dia. X 10 ft high, 500 psig, 120 F	
35202	1	1/0	Water Gas Shift Reactor	10 ft dia x 20 ft high, 1.0 Cr, 0.5 Mo	
35204	1	1/0	WGS Cooler Flash Drum	9 ft.x 18 ft high	
35205	1	1/0	Blowdown Flash Drum	1.5 ft.dia X 3 ft. high	
35212	1	1/0	WGS Reactor Catalyst	1050 ft3 each reactor bed	
40201	1	1/0	H2 Purification System	28 million SCFD H2 Product	
40202	1	1/0	Amine Scrubbing System	22 MM SCFD feed	
40202.01	1	1/0	Absorber	7.6 ft dia. X 35' T/T; 10 SS trays; Shell CS	
40202.02	1	1/0	Regenerator	6.5 ft dia. X 55' T/T; 20 SS trays; Shell CS	
40202.03	1	1/0	Lean/ Rich Exchanger	27.3 MM Btu/hr; Plate&Frame: 316 SS	
40202.04	1	1/0	Lean Solvent Cooler	13.7 MM Btu/h; Plate&Frame: 316 SS	
40202.05	1	1/0	Reflux Condenser	17.2 MM Btu/h; Tubes: 316SS; Shell: CS	
40202.06	1	1/0	Reboiler	32.6 MM Btu/h; Tubes: SS; Shell: CS	
40202.07	1	1/0	Reflux Drum	3 ft dia. X 6' T/T; SS	
40202.08	1	1/0	Activated Carbon Bed	8 ft dia. X 14' T/T; CS; 530 cu ft activated carbon	
40202.09	1	1/0	Rich Solution Filter	650 gpm; 50 micron; 8" line	
40202.10	1	1/0	Activated Carbon Inlet Guard Bed	200 gpm; 10 micron; 4" line	
40202.11	1	1/0	Activated Carbon Outlet Guard Bed	200 gpm; 10 micron; 4" line	
40202.12	2	1/1	Lean Solvent Pump	700 gpm @ 50 psi; Shaft: SS	40 / 80
40202.13	2	1/1	Rich Solvent Pump	650 gpm @ 50 psi; Shaft: SS	30 / 60
40202.14	2	1/1	Reflux Pump	40 gpm @ 100 ft TDH ; SS	2 / 4
40202.15	2	1/1	Make-up Pump	150 gpm @ 100 ft TDH	7.5 / 15
40202.16	1	1/0	Amine Storage Tank	20,000 gal; underground	
40203	1	1/0	Claus Sulfur Recovery Plant	8 tons/day skid mounted	
40203.01	1	1/0	Claus Plant Incinerator	Operation at 1000 F w/ recuperator; 0.83 MM Btu/h fuel	
40205	1	1/0	CO Power Generation Plant	Not included in this option as produce 14.5 MM SCFD Hydrogen (9.5 MM SCFD more than base case)	
41201	2	1/1	WH Boiler Feedwater Pump	80 gpm x 200 psi TDH	20 / 40
41203	2	1/1	City Water Pump	300 gpm x 100 ft. TDH	15 / 30
41204	2	1/1	MP BFW Pump	250 gpm x 700 psi TDH	150 / 300
41205	2	1/1	Sulfur Storage Pump	100 gpm x 30 psi TDH	5 / 10
41501	2	1/1	Cooling Tower Pump	13,000 gpm x 50 psi TDH	500 / 1000
42201	1	1/0	Water Gas Shift Recycle Compressor	800 acfm x 25 psi pressure rise, 500 psig discharge	150 / 150
44201	1	1/0	WGS Waste Heat Boiler	31,600 lbs/hr (60 psig)	
44202	1	1/0	Medium/ Low Pressure Boiler	97,000 lbs/hr (505 psig/700 F) & 7,300 lbs/hr (60 psig) Est. one 75 Hp comb air fan	75 / 75
44301	1	1/0	Cooling Tower	130 MM Btu/hr; 13,000 gpm circulation Est. three fans @ 125 Hp ea.	375 / 375
47202	1	1/0	Deaerator Chemical Treatment System	Est. two 1/2 Hp metering pumps	0.5 / 1
47203	1	1/0	Boiler Chemical Treatment System	Est. two 1/2 Hp metering pumps	0.5 / 1
47204	1	1/0	Water Treatment System	250 gpm demin plant w/ inlet filter, regeneration Est. two 15 Hp demin pumps, two 20 Hp blowers; two 15 Hp pumps for regen,etc.	35 / 100
47501	1	1/0	Deaerator	350 gpm; Storage Section - 6.5 ft dia. X 21 ft T/T	

Water Gas Shift Equipment List
C99268
EnviRes LLC HyMelt Process

Project Direct Cost Comparison to Base Case

Equipment, Material Costs & Field labor			
Areas	Base Case	WGS Cost	WGS Delta
Feed Prep			$0
Reactor Area			$0
WGS Area	----	3113700	$3,113,700
Hydrogen Purification	1998200	2961400	$963,200
Amine Scrubbing	1593000	2371500	$778,500
Claus Plant	2888500	3247000	$358,500
Steam Generation			$3,511,700
Power Generation		----	$0
Utilities			$2,800,000
			$11,525,600

Results:

1.) WGS option ---> $22,083,050 Project Total
Produce 9.5 MM SCFD more of hydrogen than base.

2.) Base Power Options (from CO)

Simple Cycle:	Generate 17.8 MW for	$15,200,000
Combined Cyc:	Generate 27 MW for	$30,600,000

Water Gas Shift Equipment List
C99268
EnviRes LLC HyMelt Process

Preliminary Economics of Water Gas Shift Option (Differential to Base Case)

Capital Cost Multiplier	**1**	
Basis:		
Avg. On-stream Factor	**90%**	
Amortization Parameters		
Annual Interest Rate	**10%**	
Payoff Period	**20**	years

Labor Rates (all-up):

Engineering	**80**	$/hr
Field Labor	**70**	$/hr
Constr. Mgt	**85**	$/hr

Estimated Differential Capital Costs:

Major Equipment Cost	6,206,000			
Installed Equipment Cost	5,319,800	Field Hrs	**49300**	
Direct Totals	11,525,800			
Constr Equip & Indirects	$2,305,160	% Directs	**20%**	
Constr. Mgt. Staff Supv	$794,100	% Field Hrs	**18.95%**	9342
Freight	$366,520	% Directs	**3.18%**	
Taxes & Permits	$504,830	% Directs	**4.38%**	
Engineering	$2,545,600	Manhours	**31820**	
Other Project Costs (Ovhd & GA)	$1,342,339	% Above Indirects	**20.60%**	
Contingency	$3,420,768	% Total	**15.00%**	
Indirect Totals	$11,279,317			
Total Capital Cost	$22,805,117			

Differential Operating & Maintenance Costs, $ per year:

Natural Gas @ $ / MM Btu	**5**	$2,135,250	MM SCFD	**1.3**	Btu/SCF	**1000**
Electricity @ cents / kwh	**0.04**	$443,081	kwh	**1405**		
Cooling Water Chem @ cents/kgal	**0.02**	$122,990	gpm	**13000**		
BFW Chem @ cents/kgal	**0.08**	$12,488	gpm	**330**		
LP Stm (from Reactor) @ $ / k lb	**0**	$0	lb/hr consumed	**14300**		
Operation/ Maint @ $ / manhr	**50000**	$150,000	No. of addnl	**3**		
Insur & Taxes @ 1% Capital/yr		$228,051				
O & M Mgt Fees		**$400,000**				
Spare Parts @ 5% Major Equip/yr		$310,300				
Total O & M Cost		$3,802,161				
Amortization Cost @ % capital/ yr	11.75	$2,678,680				
Total Yearly Costs		6,480,841				

Differential Sales, $ per year:

CO Fuel Lost @ $ / MM Btu	**2.5**	-$4,142,960	MM SCFD	**-16.54**	Btu/SCF	**305**
PSA TailGas Fuel Lost @ $ / MM Btu	**1.5**	-$648,459	MM SCFD	**-3.76**	Btu/SCF	**350**
Total Sales		-$4,791,419				
Net Hydrogen Production Cost, $ per year		$11,272,260				
Net Hydrogen Production Cost, $ per k scf		$ 2.86	MM SCFD	**12**		

Appendix IV

Siemens Project Specifications

EnviRes High-CO Gas Turbine Study Specification

This document describes the key parameters that form the boundary conditions, for the conceptual design of a gas turbine operating with HyMelt off-gas. This is intended to be a working document that can be updated throughout the project by Siemens Westinghouse.

Contents

1 Revisions

Rev.	Date	Description of Change
A	22 Oct 03	Original Issue

2 Syngas Composition

The composition, temperature, and pressure of HyMelt syngas from Illinois #6 Coal are shown in Table 1. The syngas from petroleum coke will be virtually identical to that from coal. The contaminants listed in Table 1 are all expected to be less than 1 ppmv.

Table 1
Illinois #6 Coal Syngas Composition

Composition

CH_4	0.07	%(vol)
CO	75.72	%(vol)
CO_2	3.92	%(vol)
COS [1]	-	%(vol)
H_2	19.96	%(vol)
H_2O	0.30	%(vol)
H_2S [1]	-	%(vol)
N_2	0.03	%(vol)
Total	100.00	%(vol)

Properties

Temperature	160 or lower	°F	71 or lower	°C
Pressure	365 to 415	psia	25 to 29	bar
HHV	309	Btu/scf	12.16	MJ/Nm^3
HHV	4,995	Btu/lb	11.61	MJ/kg
LHV	298	Btu/scf	11.76	MJ/Nm^3
LHV	4,832	Btu/lb	11.23	MJ/kg

Contaminants

Barium (Ba)	ppm(w)
Calcium (Ca)	ppm(w)
Chlorides (Cl)	ppm(w)
Copper (Cu)	ppm(w)
Iron (Fe)	ppm(w)
Lead (Pb)	ppm(w)
Magnesium (Mg)	ppm(w)
Manganese (Mn)	ppm(w)
Nickel (Ni) [1]	ppm(w)
Phosphorus (P) [1]	ppm(w)
Potassium (K)	ppm(w)
Silica (SiO2)	ppm(w)
Silicon (Si)	ppm(w)
Sodium (Na)	ppm(w)
Vanadium (V)	ppm(w)
Zinc (Zn)	ppm(w)
Other trace metals	ppm(w)

[1] These constituents may be harmful to catalysts.

3 Gas Turbine Size

The original proposal assumed that the HyMelt® process module would produce about 1157 million Btu/hr of CO-rich gas, which was slightly less than the fuel requirements of a W501D5A gas turbine. The actual gasification module may produce more gas, which would match the fuel requirements of a larger turbine or turbines.

Table 2 lists the approximate syngas consumption of the three W-class gas turbines in 1x1 and 2x1 combined cycle arrangements. More detailed calculations performed during the project will determine the actual syngas requirements.

Table 2
Estimated Gas Turbine Syngas Consumption

Combined Cycle Plant	Gas fuel,	Syngas, Million	Gas Turbine Power,	Combined Cycle Power,

Designation	Million Btu/h	scf/h[1]	MW	MW
1x1.W501D5A	1,169	3.9	121	173
1x1.W501FD	1,726	5.8	190	283
1x1.W501G	2,146	7.2	253	365
2x1.W501D5A	2,338	7.8	241	346
2x1.W501FD	3,452	11.6	379	567
2x1.W501G	4,292	14.4	506	730

[1] Estimated consumption of syngas with an LHV of 298 Btu/scf.

4 Use of Natural Gas

Natural gas is the preferred fuel for start-up and, if necessary during shutdown.

5 Emission Limits

The two tentative plant sites are

A. East St. Louis, Illinois

B. Decatur, Illinois

In the absence of specific information about emission limits at these sites, the values of 2 ppmv for both CO and NOx seem to be the best choice. In the near future, stack emissions are projected to be as low as 2 ppmv NOx and 2 ppmv CO when corrected to 0% moisture and 15% oxygen. These projections are based on (1) current limits in California, Massachusetts, New York, and New Hampshire of 2.5 to 3.5 ppmv NOx, and (2) the current best available emission control technology (BACT) can achieve 2-3 ppmv for both NOx and CO. These limits are not expected to be relaxed during the next 15 years.

If the gas turbine exhaust contains NOx and CO emissions higher than the target levels, some exhaust gas treatment, such as selective catalytic reduction, will have to be added.

Appendix V

Siemens Westinghouse Power Corporation

Combustion Analysis and Modeling

Results of Subtask 6.1, Combustion Analysis/Modeling

Chemical Reactor Modeling of Siemens Westinghouse Catalytic Combustors

Prepared by

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Columbia, MD 21045

Principal Investigators

Diwakar Vashishat

Dr. Richard Joklik

July 25, 2005

Table of Contents

Figures and Tables

Acronyms

AFR	Air-Fuel Ratio
CET	Combustor exit temperature
CFD	Computational fluid dynamics
CRM	Chemical Reactor Modeling
CSE	Combustion Science and Engineering, Inc.
GRI	Gas Research Institute
GTE	Gas Turbine Engine
NG	Natural Gas
NO_x	Oxides of Nitrogen, nitric oxide and nitrogen dioxide
PFR	Plug Flow Reactor
PMP	Pre-Mixed Pilot
PSR	Perfectly Stirred Reactor
SNR	Syngas combustion with No catalytic Reaction
SR	Syngas combustion with catalytic Reaction
SWPC	Siemens Westinghouse Power Corporation
UHC	Unburned hydrocarbons

Summary

The objective of Subtask 6.1 is to determine the catalytic combustion characteristics of HyMelt syngas burned in a W501D5A gas turbine. This analytical task was accomplished by modeling the partial combustion in the catalytic zone and the complete combustion of the remaining gases in downstream zones. The analytical approach included the following steps.

1. Conceptually divide the geometry of the combustor into a pilot zone, a catalytic combustion zone, and hot, warm, and cold downstream zones.
2. Represent the fluid flow and chemical reactions in each zone as analytical models consisting of plug-flow reactors, perfectly stirred reactors, and mixers.
3. Calibrate the analytical models using data from previous natural gas combustion tests. Establish the flow rates in each zone for fuel, combustion air, cooling air, and combustion products.
4. Model the partial combustion of HyMelt syngas in the catalytic zone.
5. Using the combustion products from the catalytic model and downstream combustion parameters determined in the calibration step, calculate the combustion characteristics of HyMelt syngas, including emissions.
6. Repeat the syngas combustion calculations, except without any combustion in the catalytic section, to see the effects of this “worst case” on catalytic combustor performance.

The analytical results from Task 1 showed satisfactory combustion performance with HyMelt syngas in a catalytic combustor. Figure 1 and Figure 2 show the estimated NOx and CO emissions, respectively, for combustor exit temperatures between 2080 and 2170 ^{o}F (1140 to 1190 ^{o}C). Each chart contains a dotted line representing expected performance, a solid line near the dotted line representing “worst case” performance without catalytic reactions, and a solid line to the left representing calibration with natural gas combustion. The expected combustor exit temperature is around 2130 to 2140 ^{o}F (1165 to 1170 ^{o}C), with 6-7 ppmvd NOx and 40-45 ppmvd CO.

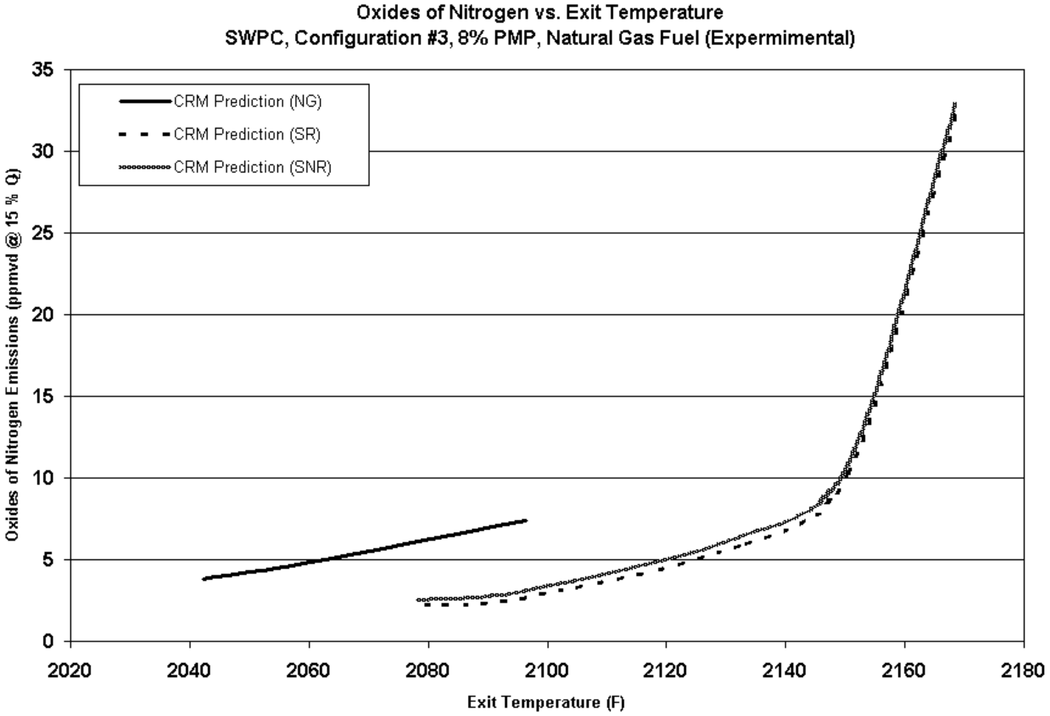


Figure 1 – Calculated NOx Emissions from Catalytic Combustion of HyMelt Syngas

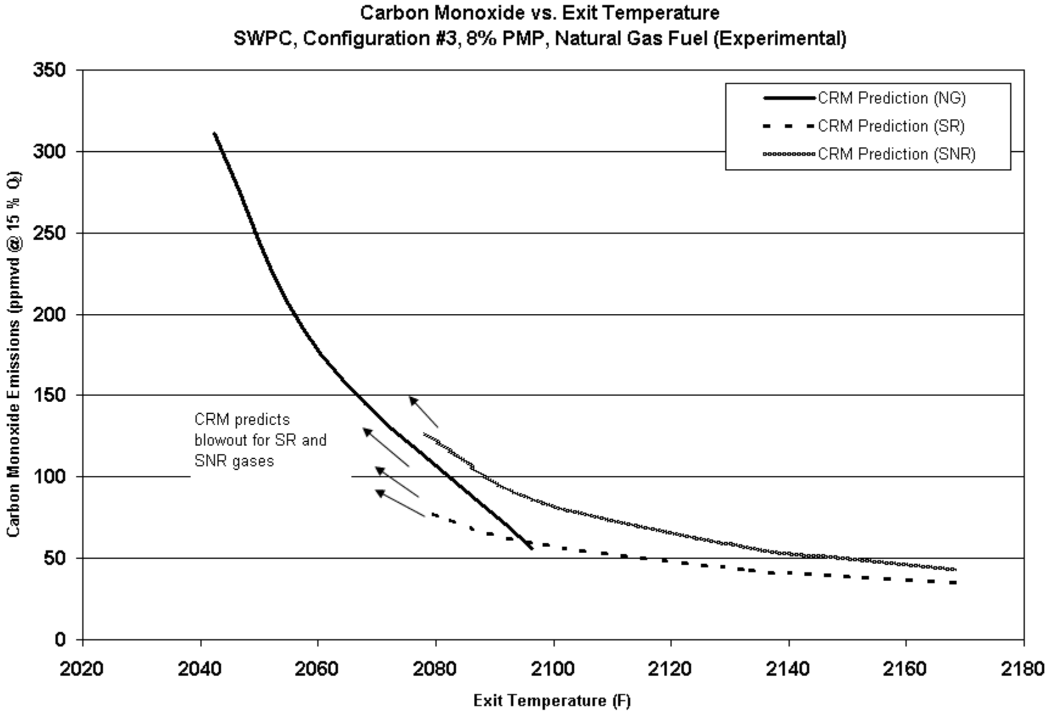


Figure 2 – Calculated CO Emissions from Catalytic Combustion of HyMelt Syngas

Introduction

The goal of this project is to study the effects of fuel switching on emissions of carbon monoxide (CO) and oxides of nitrogen (NOX). Computational fluid dynamics (CFD) and chemical reactor modeling (CRM) are used in concert to form a model of the SWPC combustor. Although CFD is a useful tool in predicting fluid structures, it is not robust enough to incorporate a detailed chemical kinetics model. The use of a detailed chemical kinetics model is necessary to accurately predict emissions, because it takes into consideration the multitude of pathways in which combustion reactions occur. Through the CRM model, detailed chemical kinetics is used to predict emissions from the SWPC combustor. A CRM model approximates the combustor fluid dynamics as a network of perfectly stirred (PSR) and plug flow (PFR) reactors. The CRM model allows rapid design studies, but the CRM must be tuned to some experimental data, in this case provided by SWPC.

CRM Modeling Process

The CRM process uses mathematical models that approximate sections of a combustor as chemical reactors. The CRM model is built using a network of PSR, PFR, and non-reacting flow mixers. PSR and PFR are commonly used to describe the re-circulation and CO burnout zones, respectively, of a combustor. The theory of operation of each reactor is described below, and their application to the SWPC combustor is also explained.

PSR: Perfectly Stirred reactors

A PSR is one in which stirring is so efficient that the contents are always uniform in composition and temperature throughout the reactor [1]. The initial part of a gas turbine combustor, where fuel is locally burned using a re-circulation zone, can be readily described as a PSR. PSR inlet conditions are characterized by temperature, pressure and inlet composition, and the reactor is characterized by residence time, temperature and pressure. PSRs are considered to be controlled by the flow parameters. In the SWPC combustor the pressure is constant throughout the combustor. All PSRs in the SWPC combustor are assumed to be adiabatic. Residence times of PSRs are determined through particle tracking post processing from a CFD solution.

PFR: Plug Flow Reactors

A PFR is one in which elements of the homogeneous fluid reactant move through a tube as a uniform mass parallel to the tube axis. It is assumed that no mixing occurs in the axial (flow) direction, but that mixing is perfect in the transverse direction [1]. The CO burnout zone of a combustor can be accurately described as a PFR. PFR inlet conditions are characterized by temperature, pressure and inlet composition and the reactor is characterized by residence time, physical dimensions, heat loss rate, wall temperature profile, and pressure. PFRs are considered to be controlled by the kinetic rates of the chemical reactors. All PFR's in the SWPC combustor are assumed to be adiabatic. The residence times are approximated by the following equation: distance / average bulk velocity = time.

MIX Subroutine

MIX subroutine solves for the mass and energy balances when two or more streams of non-reacting fluids mix. Mass, temperature and species composition inputs are specified.

Subroutines for PSR and PFR calculations can be found through Sandia National Laboratories. Manuals on the CHEMKIN suite of subroutines used to build the CRM model are available at http://www.ca.sandia.gov/chemkin/docs.html.

CFD: Computational Fluid Dynamics

Previously, CSE has performed detailed CFD analysis on the SWPC combustor using reduced chemical kinetics with large-eddy-breakup combustion sub-model. The results from the CFD modeling process are used as a starting point for the CRM modeling of the SWPC combustor. CFD results provide detailed information about the fluid dynamics inside the combustor. In the case of the SWPC combustor, we can locate the recirculation zone around the PMP by looking at a velocity vector plot created through CFD. Throughout the combustor, air is added at locations as prescribed in the Configuration #3 to cool the combustor liner. Particle tracking is used to determine the penetration depths of various flow streams.

Kinetic Submodel

The CRM uses GRI Mechanism 3.0 to model the detailed chemical kinetics. GRI Mechanism 3.0 is a detailed chemical kinetics mechanism for combustion of methane, comprising of 325 elementary chemical reactions utilizing 53 species. This mechanism can be found at http://www.me.berkeley.edu/gri_mech/. GRI Mechanism 3.0 has sub-mechanisms for CH_4, C_3H_8, CO, and H_2 combustion.

SWPC CRM Model

Previous CFD modeling of the SWPC combustor was used to gain detailed information about the fluid dynamics inside the combustor. Figure 3 shows the axial velocity profile in the combustor. By analyzing temperature, velocity, species concentration, and species production rates, the combustor can be divided into zones that are represented by PSRs and PFRs in a CRM model, as shown in Figure 4. Recirculation zones, such as the premixed pilot zone, are represented as PSRs. Dilution and quench air feeds match those used in the March 7, 2003 test run with Configuration #3.

The downstream portion of the combustor is represented as a network of interconnected PFRs. These PFRs allow for bulk transport of mass from center of the combustor to the edge of the combustor and vice versa. The CRM model theorizes three zones in the combustor. The innermost zone, along the axial centerline of the combustor, is the hottest zone. As flow from the catalyst exit reacts with the premixed pilot, the centerline of the combustor generates the hot (the hottest) products of combustion. Penetration of cold air streams into the hot zone is accounted for in the model. The outermost zone contains cold air from various dilution flows and some of the hot flow (from the inner hot zone) that has migrated to the outer edge of the combustor. In the outermost zone, the hot flow mixes with the cold flow, lowering the temperature to levels below which CO oxidation to CO_2 can take place. Therefore, the outermost zone is the main source of the CO emissions.

Figure 4 shows the CRM network model for the SWPC combustor. The three catalyst flows and the three core flows leaving the head end are connected to the inner, middle, and outer sections downstream, as indicated by the shape symbols shown near the streams. The catalyst flow is added in stages, percentages of which were determined through tracing the catalyst flow from the catalyst exit to the turbine inlet. Figure 5 shows the CRM overlay on the CFD temperature solution and the spatial orientation of the reactors.

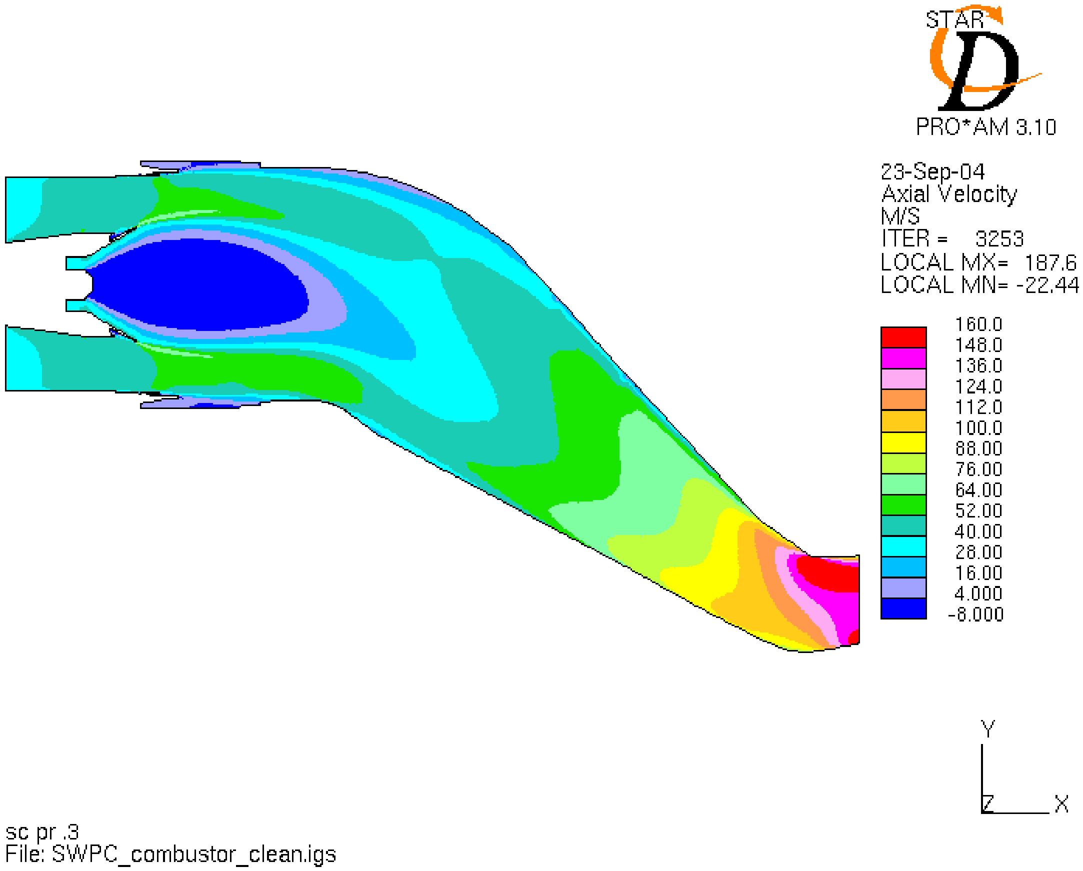
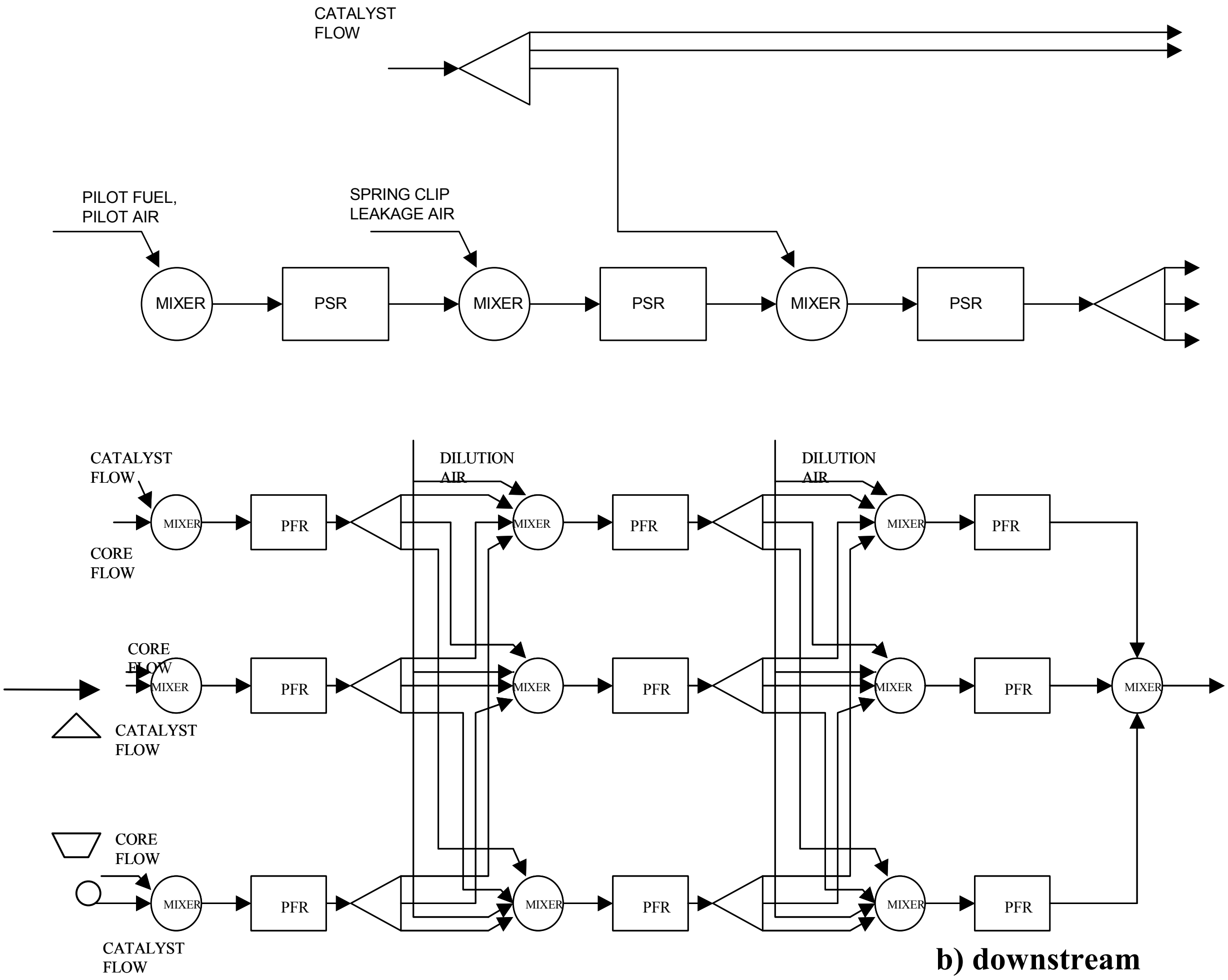


Figure 3. Axial Velocity Profile Created Through CFD Modeling of the SWPC Combustor



b) downstream

DOWNSTREAM OF PILOT ZONE, COOLIING AIR AND DILUTION AIR IS ADDED, INTERNAL FLOW SPLITS DETERMINED FROM CFD SOLUTION, 3 TIERS OF PFR's REPRESENT THE HOT, WARM AND COLD ZONES

Figure 4. CRM Model Representation of the SWPC Combustor.

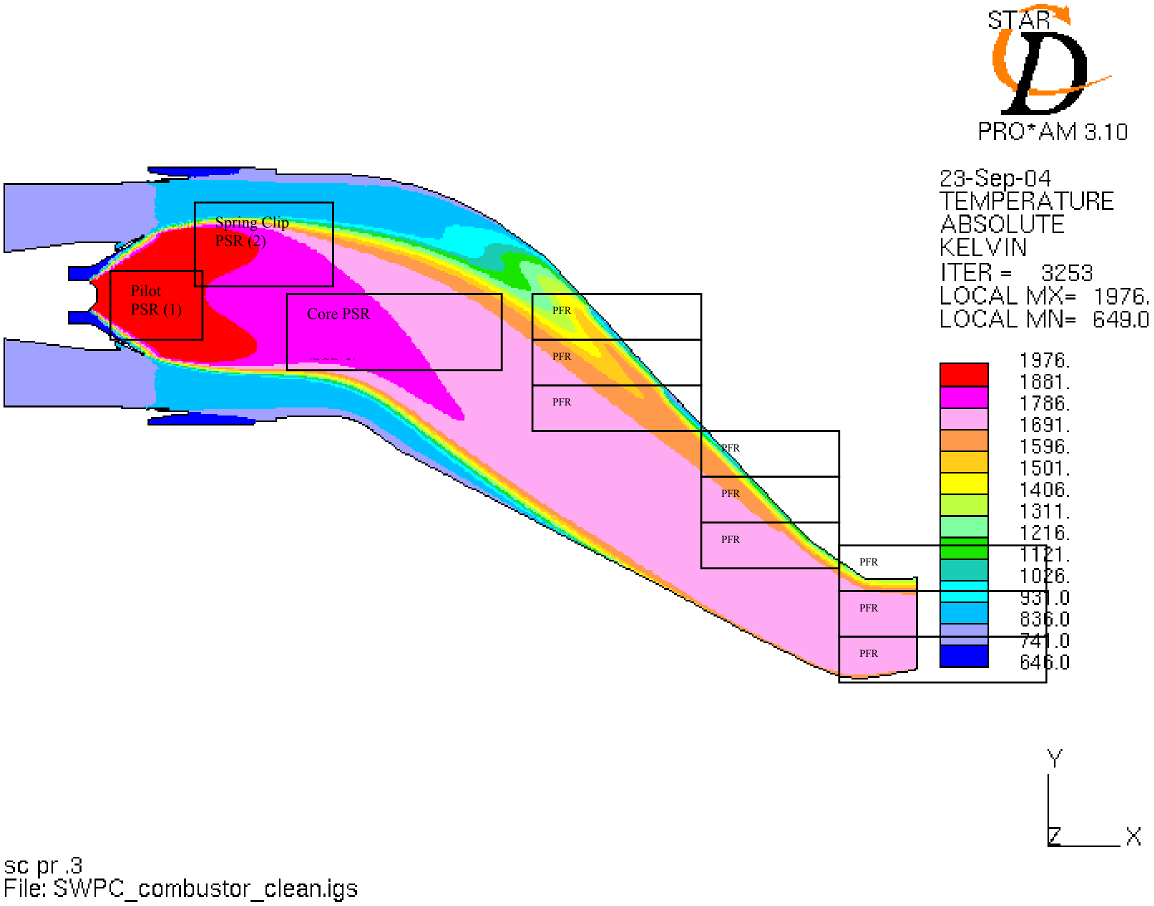


Figure 5. CRM Overlay on CFD Temperature Solution

Boundary Conditions

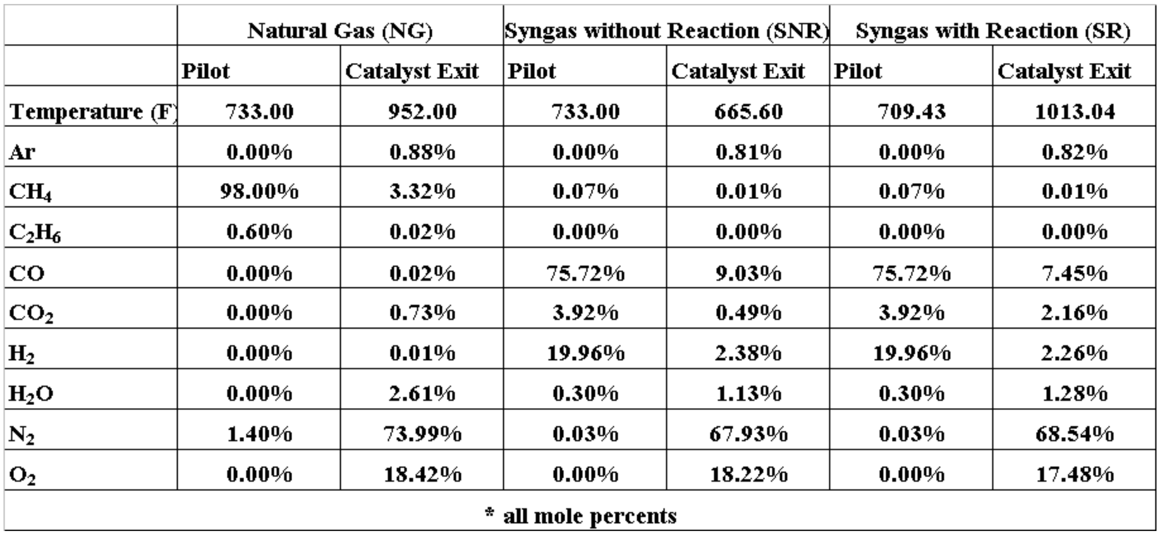
The combustor inlet conditions are specified below:

- Pressure = 14.2 atm, (208.7 psi)
- Air Temperature = 649.5 K (709.4 °F)
- Catalytically Combusted Fuel Temperature = See Table 1
- 8% Fuel split to the premixed pilot
- Dilution along the combustor
- Fuel = natural gas, syngas with reaction, syngas without reaction

Fuel Properties

Fuel properties are provided in the table below. The mole percentage of each component of the fuel is provided, as well as the temperature of each stream (added with the appropriate air stream). Note the lower SNR catalyst exit temperature, since the SR has reacted through the catalyst and heat has been liberated through the reaction with the catalyst.

Table 1. Fuel Composition and Temperatures Specified by SWPC

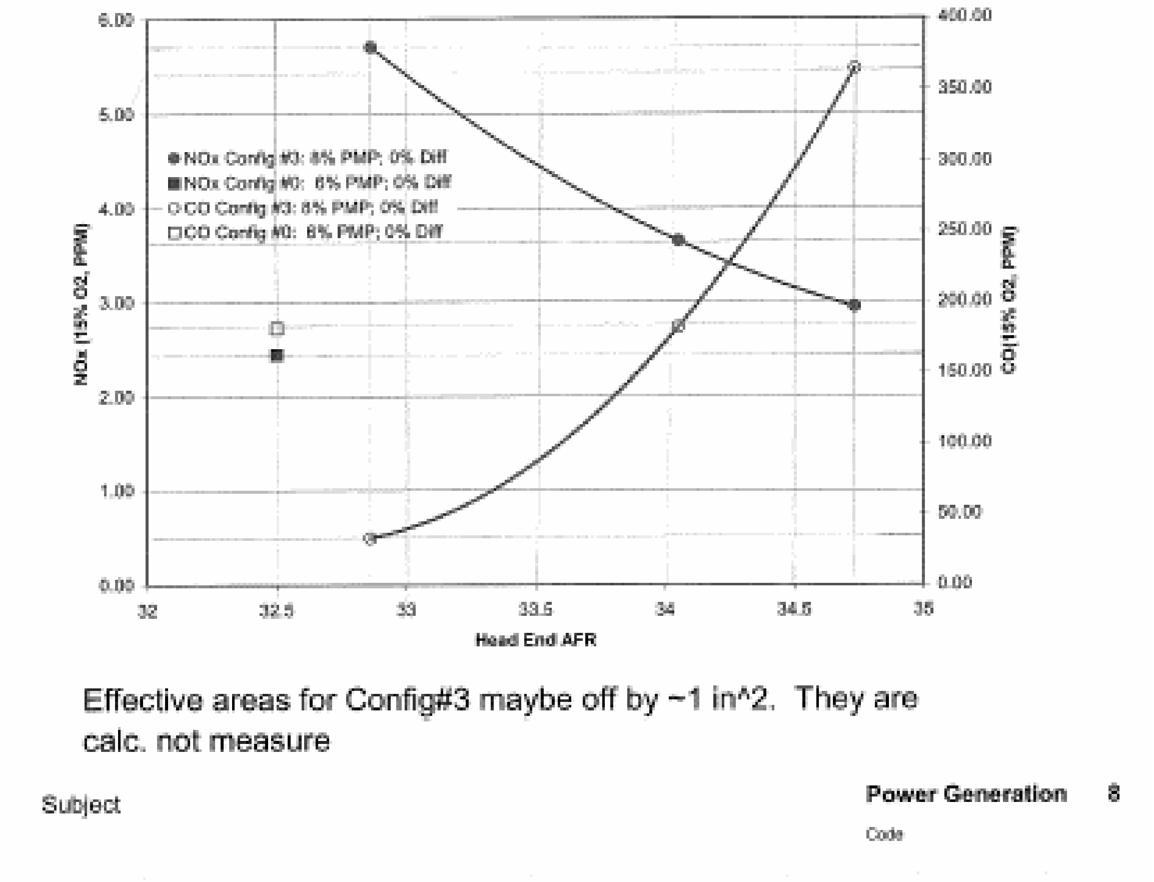


	Natural Gas (NG)		Syngas without Reaction (SNR)		Syngas with Reaction (SR)	
	Pilot	**Catalyst Exit**	**Pilot**	**Catalyst Exit**	**Pilot**	**Catalyst Exit**
Temperature (F)	**733.00**	**952.00**	**733.00**	**665.60**	**709.43**	**1013.04**
Ar	**0.00%**	**0.88%**	**0.00%**	**0.81%**	**0.00%**	**0.82%**
CH_4	**98.00%**	**3.32%**	**0.07%**	**0.01%**	**0.07%**	**0.01%**
C_2H_6	**0.60%**	**0.02%**	**0.00%**	**0.00%**	**0.00%**	**0.00%**
CO	**0.00%**	**0.02%**	**75.72%**	**9.03%**	**75.72%**	**7.45%**
CO_2	**0.00%**	**0.73%**	**3.92%**	**0.49%**	**3.92%**	**2.16%**
H_2	**0.00%**	**0.01%**	**19.96%**	**2.38%**	**19.96%**	**2.26%**
H_2O	**0.00%**	**2.61%**	**0.30%**	**1.13%**	**0.30%**	**1.28%**
N_2	**1.40%**	**73.99%**	**0.03%**	**67.93%**	**0.03%**	**68.54%**
O_2	**0.00%**	**18.42%**	**0.00%**	**18.22%**	**0.00%**	**17.48%**

*** all mole percents**

Experimental Data

The experimental data is provided in Figure 6.



Effective areas for Config#3 maybe off by ~1 in^2. They are calc. not measure

Subject

Power Generation 8

Code

Figure 6. Experimental CO and NO_X Emissions data for the 8% PMP, Configuration #3

The experimental data provided by the testing of Configuration #3 (a representative case) is shown in Figure 6. Natural gas fuel properties, combustor temperature and pressure listed in the boundary conditions section, and internal gas flow splits determined from CFD analysis provide all other pertinent boundary conditions.

Results

Figure 7 shows the CO emissions as a function of the head-end air-fuel ratio, which is the total amount of air to the catalyst and the pilot divided by the total amount of fuel to the catalyst and the pilot. The CRM predicts the absolute values and trends close to experimental CO emissions fairly well over the range of head-end air-fuel ratios modeled. An increase in load (corresponding to a higher exit temperature) facilitates the higher temperature required for a faster rate of CO burnout. The calculated theoretical combustor exit temperature (CET) is also listed for each experimental point. The CET is used to compare the results of the natural gas with the syngas, which will be discussed later.

Figure 8 shows the NO_X emissions as a function of the head-end air-fuel ratio. As with CO emissions, experimental NO_X trend and absolute values are matched by the CRM model. The CET is also listed. The trend in NO_X emissions is due to changing head-end air-fuel ratio. An increase in air-fuel ratio results in a lower primary zone temperature for the primary premixed pilot, which causes lower NO_X emissions.

Figure 9 compares the CO emissions from the three fuels modeled. Based on the current CRM model, a higher CO emissions output is predicted for the syngas fuels, when compared to the natural gas. This can be attributed to the freezing of CO in the outer boundary layer where cold air for dilution and quenching is introduced. When comparing the two syngas fuels, syngas without reaction is predicted to have higher CO emissions. A higher mole fraction of CO at the exit of the catalyst (syngas without reaction, Table 1) translates to a higher CO emissions value at the exit of the combustor. The figure also shows that syngas fuels reach blowout at a higher CET than natural gas fuel.

Figure 10 compares the NO_X emissions from the three combustion gases modeled. Syngas with reaction has slightly higher NO_X emissions than syngas with reaction. Natural gas has higher NO_X emissions than syngas for the same exit temperature. The premixed pilot has a higher flame temperature for natural gas due to the changes in fuel mass required to balance exit temperature, therefore NO_X production in the premixed zone is higher for the natural gas fuel.

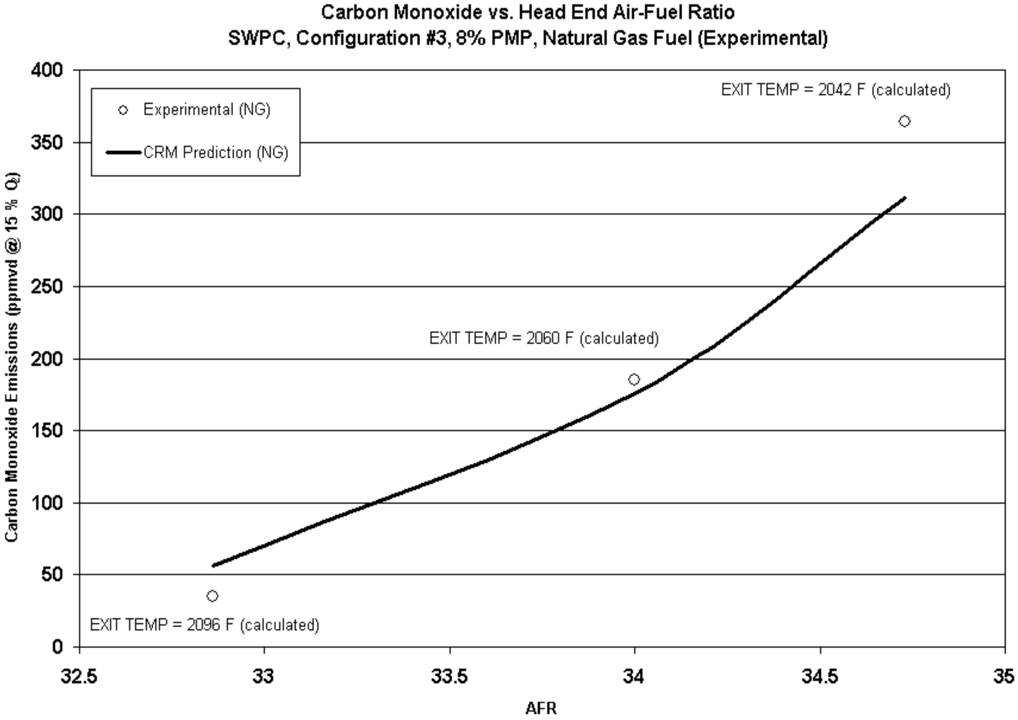


Figure 7. CO vs. Head-End Air-Fuel Ratio for Natural Gas: Experimental vs. CRM Model

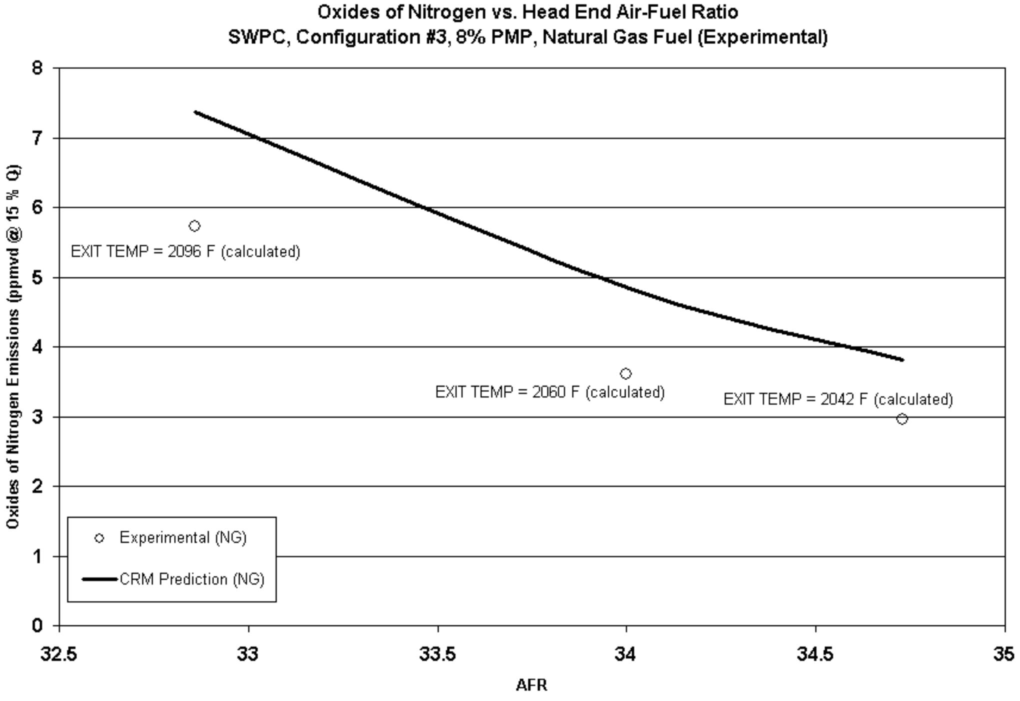


Figure 8. NO$_X$ vs. Head-End Air-Fuel Ratio for Natural Gas: Experimental vs. CRM Model

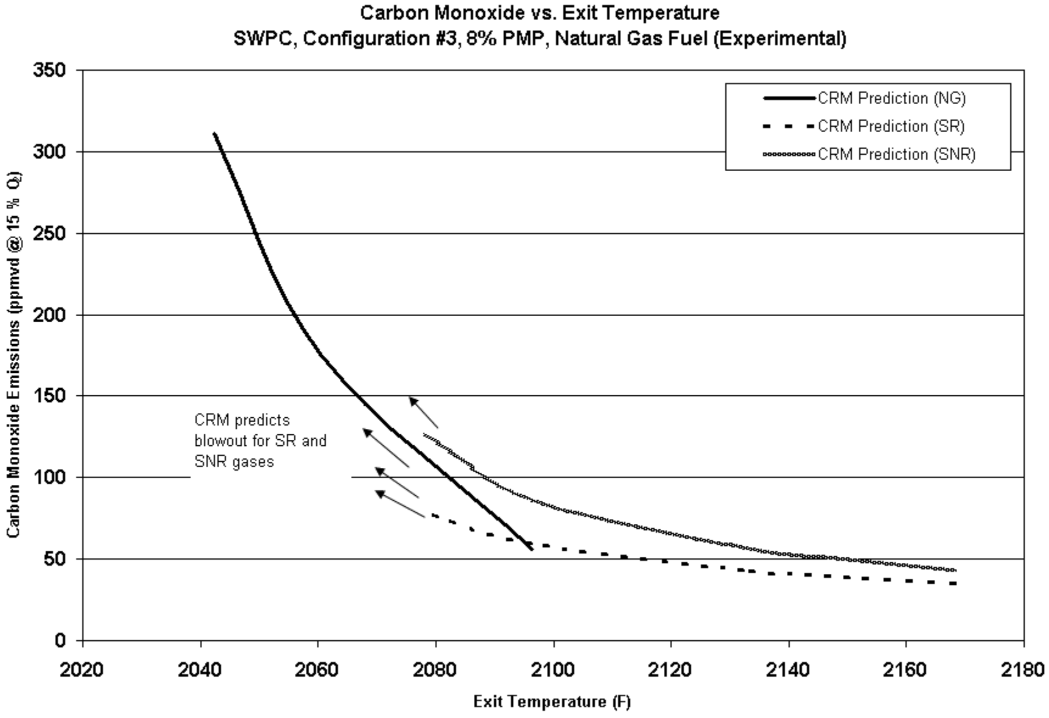


Figure 9. CO vs. Combustor Exit Temperature for All Fuels: CRM Model

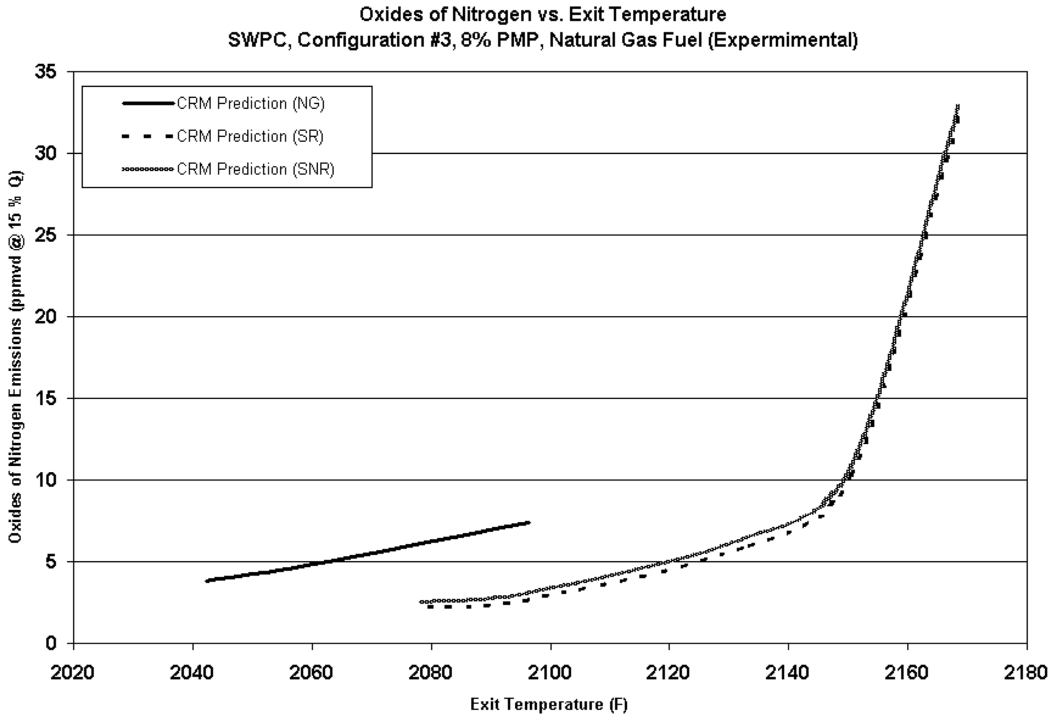


Figure 10. NO_X vs. Combustor Exit Temperature for All Fuels: CRM Model

Conclusions

A CRM tool is created to perform parametric studies aiding in the combustor design cycle. Through the CRM model, full chemical kinetics analysis is used to predict emissions from a SWPC engine.

Good agreement with the 8% premixed pilot experimental data is found with the natural gas fuel. Syngas fuel with reaction (SR) gives lower CO emissions than syngas fuel without reaction (SNR) for the same CET. Syngas fuels (both SNR and SR) give lower NO_X emissions than natural gas for the same CET. Blowout is predicted to occur at a higher CET temperature for syngas fuels than for natural gas fuel. These conclusions are based on modeling the combustor for a limited set of experimental data collected for natural gas combustion.

Reference

1. Hill, Charles, G. *An Introduction to Chemical Engineering Kinetics and Reaction Design.* New York, Wiley, 1977.

APPENDIX VI

MEFOS DATA, Campaign 1, June 5-13, 2003

MEFOS

Box 812, 971 25 LULEÅ

Dokument:	Tekniskt meddelande	*Reg nummer:*	TM03037K
Fo-uppgift:		*Datum:*	2003-08-20
Konto:	386550	*Rev datum:*	
Ämnesomr:		*Avdelning:*	MM

HYMELT CAMPAIGN 1,

5-13 JUNE 2003

by

Sten Ångström

Godkänd av forskningschef:		*Slutlig:*	Y
Projektledare:	Nils-Olov Lindfors	*Sekr:*	acj
Distribution:	EB, NOL, SÅ, Don Malone-EnviRes		

TABLE OF CONTENTS **Page**

1 Introduction

The first test campaign in the development of the EnviRes HyMelt process has been performed at MEFOS. The tests have been made in the 6 ton universal converter equipped with facilities for injection of hydro-carbides and oxygen.

The technical objective was to make preliminary evaluation the process and functional test of the equipment and measuring systems.

The tests were made for:

- Solid feed injection for Illinois #6 (coal) and Pet-coke (coke)
- Liquid feed injection for 325 Aromatic extract (oil)
- Oxygen blowing
- Gas measurement
- Dust sampling
- Process control
- Process strategies

The campaign was carried out for six days in the period from June 5 to 13, 2003.

This document is a completion of collected data and a preliminary evaluation of the operational results and performance of process equipment and measuring systems.

2 Equipment

2.1 MEFOS standard equipment

2.1.1 Electric arc furnace

The electric arc furnace is a fully ceramic lined AC furnace suitable for melting 4 to 10 ton of steel or hot metal. In the project the furnace was used for production of high carbon iron melt in charges of 5 - 6 ton.

Technical data:

Heat size	4 – 10 ton
Trafo	4,9 MVA
Shell diameter	2800 mm
Diameter lined	2100 mm

2.1.2 Universal converter

The experiments were carried out in MEFOS universal converter. The converter has a nominal max capacity of 6 ton and can be altered into a variety of converter pro??cesses for metal refining. In the experiment the converter was used as a 5,5 ton, top blown vessel with bottom purging of inert gas.

Technical data:

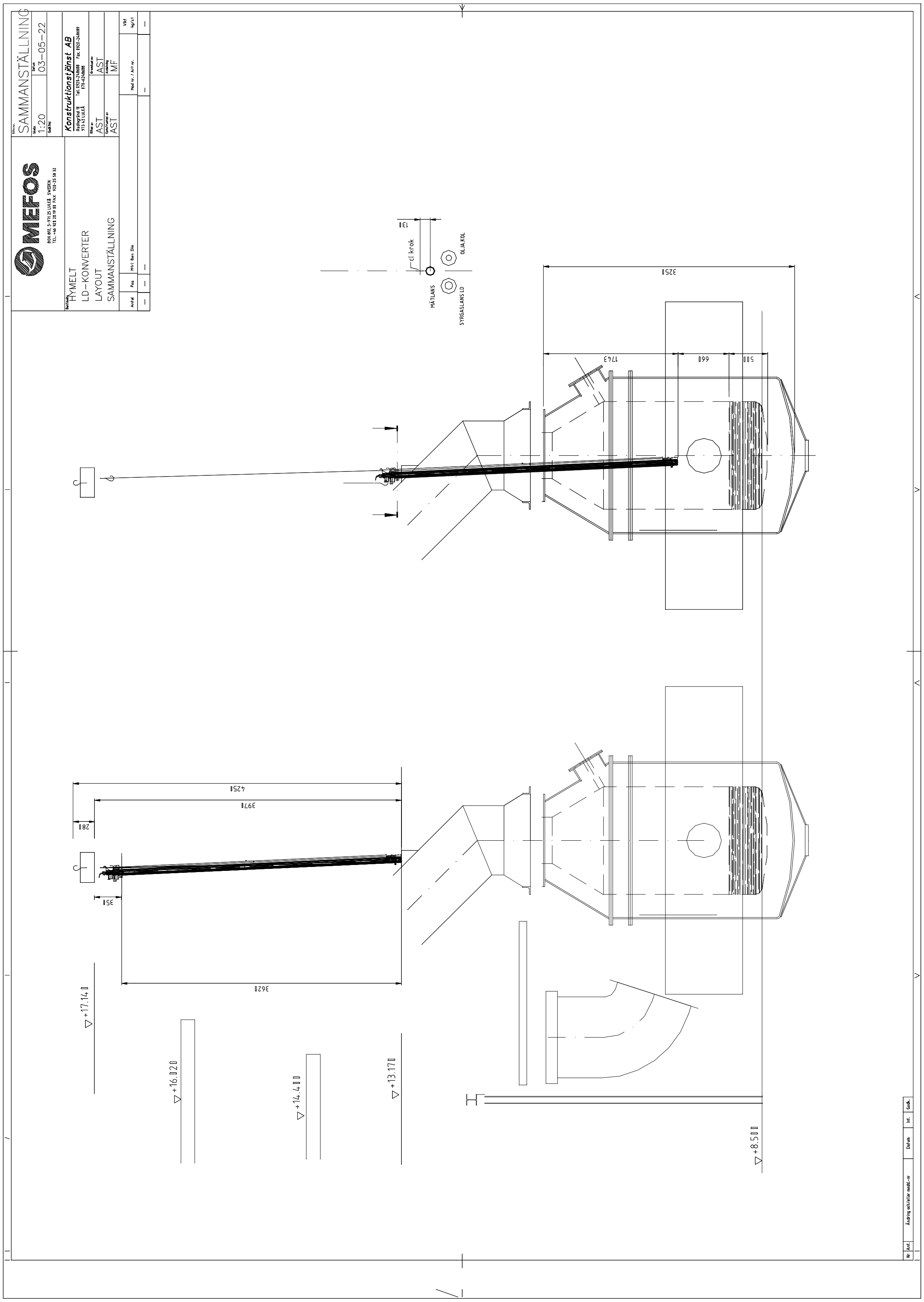
Shell diameter	2000 mm
Diameter lined	1410 mm
Height lined	2893 mm
Lining	Far impregnated magnetite Radex ST

Two hoppers above the converter were erected for slag former and cooling scrap addition.

Totally four top lances was mounted:

- Oxygen lance for decarburisation
- Lance for solid injection alternatively lance for liquid injection
- Sub lance for metal sampling and temperature measurements
- Gas suction lance for sampling of process gas from converter gas atmosphere

In the converter bottom, on the half radius from the wall, a bottom tuyere was mounted for inert gas or hydrogen purging.


MEFOS
BOX 812, S-971 25 LULEÅ SWEDEN
TEL. +46 920 20 19 00 FAX 920-25 58 32
Benämning
HYMELT
LD-KONVERTER
LAYOUT
SAMMANSTÄLLNING
Ritnr.
SAMMANSTÄLLNING
Skala
1:20
Datum
03-05-22
Godkänd
Konstruktionstjänst AB
Radiogränd 11
973 42 LULEÅ
Tel. 0921-248688
070-6248688
Fax. 0921-248689
Ritad av
AST
Granskad av
AST
Konstruerad av
AST
Avdelning
MF
Antal
Pos
Mtrl Ben Dim
Mod nr. / Art nr.
Vikt kg/st
cl krok
130
MÄTLANS
SYRGASLANS LD
OLJA,KOL
3250
1743
660
500
4250
3970
280
350
3620
+17.140
+16.020
+14.400
+13.170
+8.500
Ändring och/eller modd.-nr
Nr
Ant.
Datum
Int.
Godk.

AVI-6

Figure – 1 MEFOS universal converter Hy-Melt, 5 ton, set up

The MEFOS venturie scrubber was used for gas treatment. Before gas cleaning the process gas has to be completely combusted by sufficient amount of air above the converter mouth.

Technical data, venturie scrubber:
Gas flow rate 21 000 m^3n/h
Gas temperature inlet 650 ^oC
Pressure drop across venturie 500 – 1900 mm wq

2.1.3 Material injection system

For injection of coal and pet-coke a 3 m^3 powder dispenser system was selected. The system has advantages in flexibility regarding blowing conditions and allows handling and charging of fine grained material from "big bags" by use of suction.

Technical data:

Dispenser volume	3 m^3
Spec. transport gas	~0, 05 m^3n/kg
Outlet diameter	variable
Max pressure	10 bar

2.1.4 Measurements, sampling and automation

For process control a set of selected measurements were sampled and evaluated by an in-house system for converter automation that runs on a LabView platform. The system includes, data logging, standard closed loop regulation and modules for real time evaluation of fundamental process parameters.

Measurements:

Gas supply: range
- Oxygen to lance, line C 0 – 20 m^3n/min
- Nitrogen bottom purging, line D 0 – 1 m^3n/min
- Nitrogen material transport 0 – 1 m^3n/min (Operator notes)

Combusted gas

- Flow rate, venturi 0 – 20000 m^3n/h
- Composition:
  - CO 0 – 5%
  - CO_2 0 – 20%
  - O_2 0 – 23%
  - SO_2 0 – 0, 5%

Materials
- Dispenser weight 0 – 3000kg

Bin weights

Cooling scrap	0 – 1000 kg
Lump lime	0 – 1000 kg
Oil feed	0 – 20 kg/min

Oxygen lance pos	mm above metal surface
Injection lance pos	mm above metal surface

Non-continuous measurements:

Metal temperature	0 – 1800 °C
Metal composition	

Process gas composition conventional

CO	0 – 100%
CO_2	0 – 20%
H_2	0 – 20%

Process gas composition mass spectrometer MS 127

H_2	0 – 100%

Process gas composition mass spectrometer AIR SENSE 2000

H_2	0 – 100%
H_2S	0 – 2%
COS	0 – 100 ppm
CH_4	0 – 4%

Special measurements and sampling not recorded on the process computer:

Metal weight, charging and tapping
Analysis of sampled metal and slag
Poured slag weights
Dust sampling in converter for composition analysis
Dust sampling in combusted gas for composition analysis and load
Manual additions of Al-bars, FeSi, FeV and FeS
Hydrogen gas for bottom purging

In blow metal sampling was made by use of a sub-lance system. Sampling during process stop in tilted converter was manually made. In both cases the samples were either analysed for carbon and sulphur by use of a Leco combustion analyser or sent to SSAB for spark emission spectrometry giving almost a complete analysis. All samples were stored for reference and further evaluations.

Slag sampling was manually made when the converter was tilted. All samples were stored and selected samples were analysed by X-ray at SSAB.

Dust sampling was made by two methods:

1. Process dust from the filter of the converter gas.
2. Iso-kinetic sampling of combusted dust from the duct.

Process parameters calculated on-line for supervising were:

5. Material injection flow rate
6. Gas flow rate, supply and combusted gas
7. Carbon balance for carburisation yield
8. Oxygen balance for oxygen yield during decarburisation
9. Carbon content in liquid metal

2.2 HyMelt equipment

2.2.1 Injection lance for coal and pet-coke

A water-cooled lance for solid material injection was designed and constructed.
Technical data:

Total length	4800 mm
Diameter	76 mm
Outlet nozzle diameter	7,0 mm, other dimensions were also tested

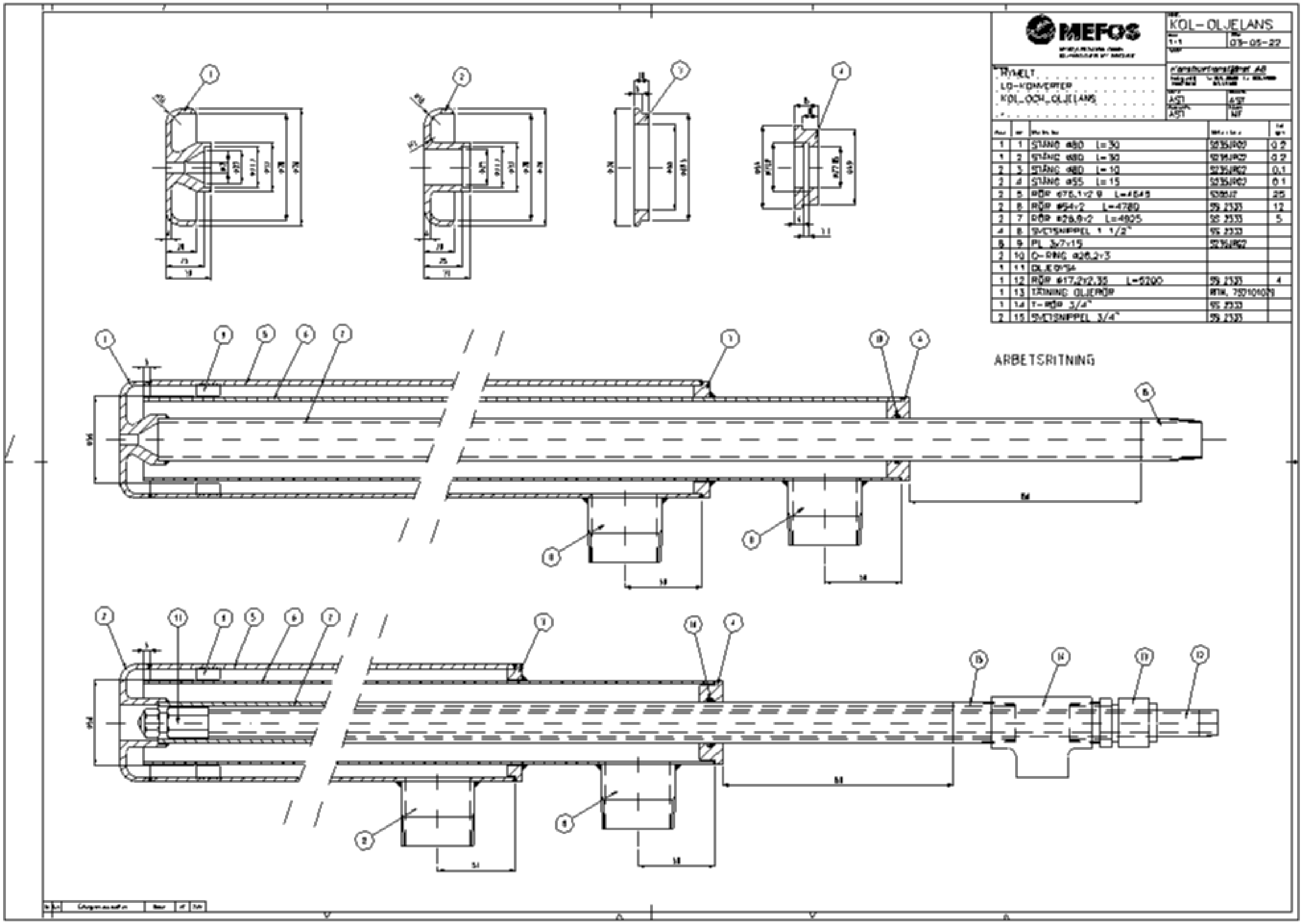
For transport of material from dispenser to the lance a flexible rubber hose was selected. The hose quality has reasonable abrasive wear resistance and can, with proper heat protections, be used in metallurgical environment.

2.2.2 Injection lance for oil feed

A water-cooled lance for oil injection was designed and constructed.

Technical data:

Total length	4800 mm
Diameter	76 mm
Outlet nozzle diameter	1,9 mm


MEFOS
KOL-OLJELANS
1:1
09-05-22
RYMELT
LD-KONVERTER
KOL_OCH_OLJELANS
AST
AST
NF
1 1 STÅNG ø80 L=30 SS2172 0.2
1 2 STÅNG ø80 L=30 SS2172 0.2
2 3 STÅNG ø80 L=10 SS2172 0.1
2 4 STÅNG ø55 L=15 SS2172 0.1
2 5 RÖR ø76,1x2.9 L=4545 SS2172 25
2 6 RÖR ø54x2 L=4780 SS 2333 12
2 7 RÖR ø26,9x2 L=4925 SS 2333 5
4 8 SVETSNIPPEL 1 1/2" SS 2333
6 9 PL 3x7x15 SS2172
2 10 O-RING ø26,2x3
1 11 OLJEDYSA
1 12 RÖR ø17,2x2,35 L=5200 SS 2333 4
1 13 TÄTNING OLJERÖR RTK 7570101071
1 14 T-RÖR 3/4" SS 2333
2 15 SVETSNIPPEL 3/4" SS 2333
ARBETSRITNING
1
2
3
4
5
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7
8
9
10
11
12
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14
15

Figure 2 – Water-cooled injection lances for solids and oil

2.2.3 Injection system for aromatic extract

A special designed oil injection system was set up for low viscosity oil. The demand for short transport distance of the oil called for special safety arrangements and it was found that the storage tank with heating and the pump were to be mounted in a steel container. The set-up gives sufficient safety for spitting and slag splashing that accidentally generates from oxygen converters.

Technical data:

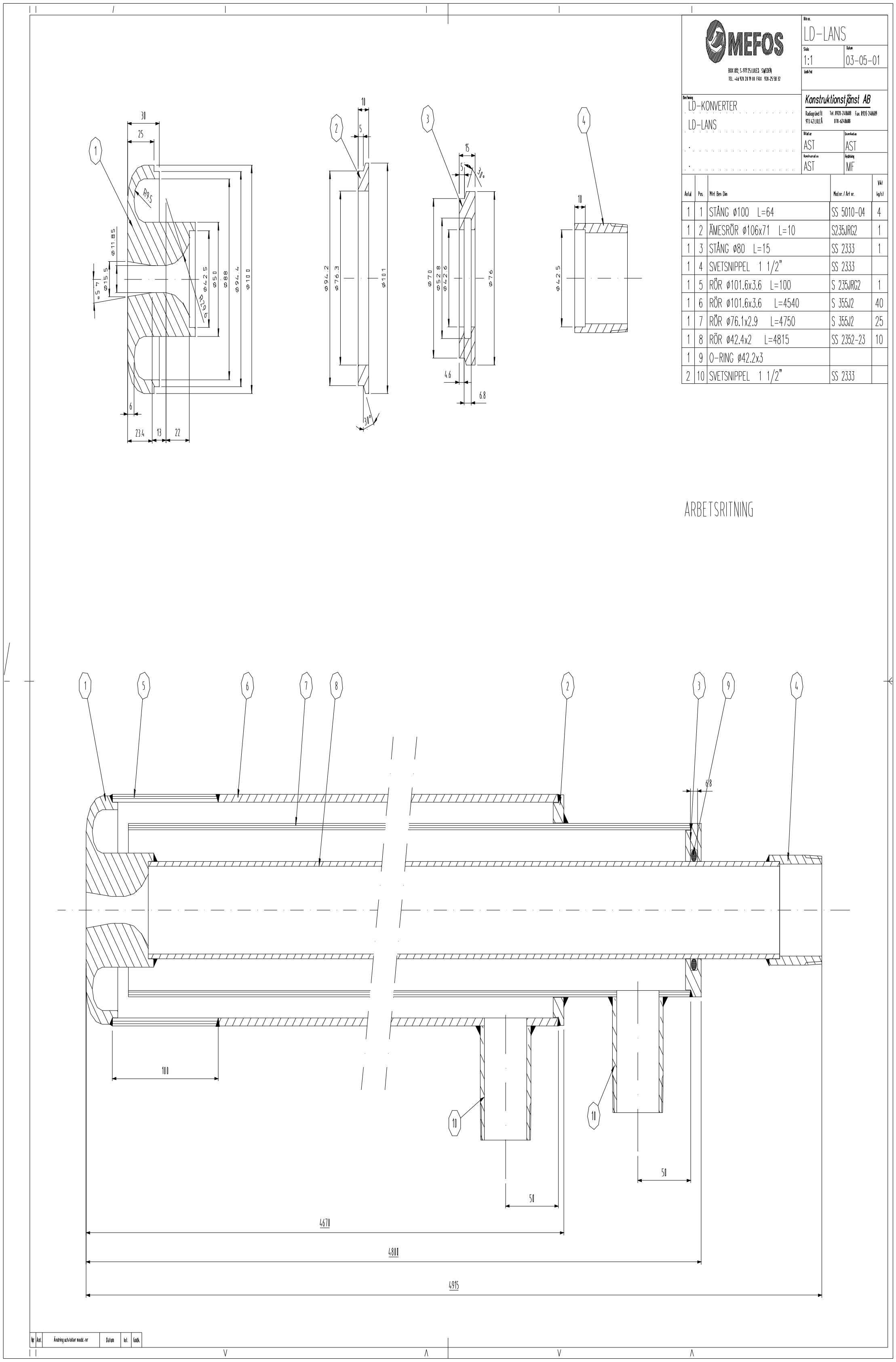
Storage volume	3 m^3
Max pressure	22 bar
Nominal oil feed rate	10 kg/minute

2.2.4 Lance for oxygen blowing

The oxygen lance was designed as a water cooled single Laval nozzle for BOF converters.

Technical data:

Total length	4800 mm
Diameter	76 mm
Nominal flow rate	10 m^{3}n/min
Outlet nozzle diameter	15, 5 mm
Mach No	2



MEFOS
BOX 812, S-971 25 LULEÅ SWEDEN
TEL. +46 921 20 19 00 FAX 921-25 58 32

Ritn nr. LD-LANS
Skala 1:1
Datum 03-05-01
Godkänd

Benämning
LD-KONVERTER
LD-LANS

Konstruktionstjänst AB
Radiogränd 11 Tel. 0920-248688 Fax. 0920-248689
973 42 LULEÅ 070-6248688

Ritad av AST
Granskad av AST
Konstruerad av AST
Avdelning MF

Antal	Pos	Mtrl Ben Dim	Mod nr. / Art nr.	Vikt kg/st
1	1	STÅNG ø100 L=64	SS 5010-04	4
1	2	ÄMESRÖR ø106x71 L=10	S235JRG2	1
1	3	STÅNG ø80 L=15	SS 2333	1
1	4	SVETSNIPPEL 1 1/2"	SS 2333	
1	5	RÖR ø101.6x3.6 L=100	S 235JRG2	1
1	6	RÖR ø101.6x3.6 L=4540	S 355J2	40
1	7	RÖR ø76.1x2.9 L=4750	S 355J2	25
1	8	RÖR ø42.4x2 L=4815	SS 2352-23	10
1	9	O-RING ø42.2x3		
2	10	SVETSNIPPEL 1 1/2"	SS 2333	

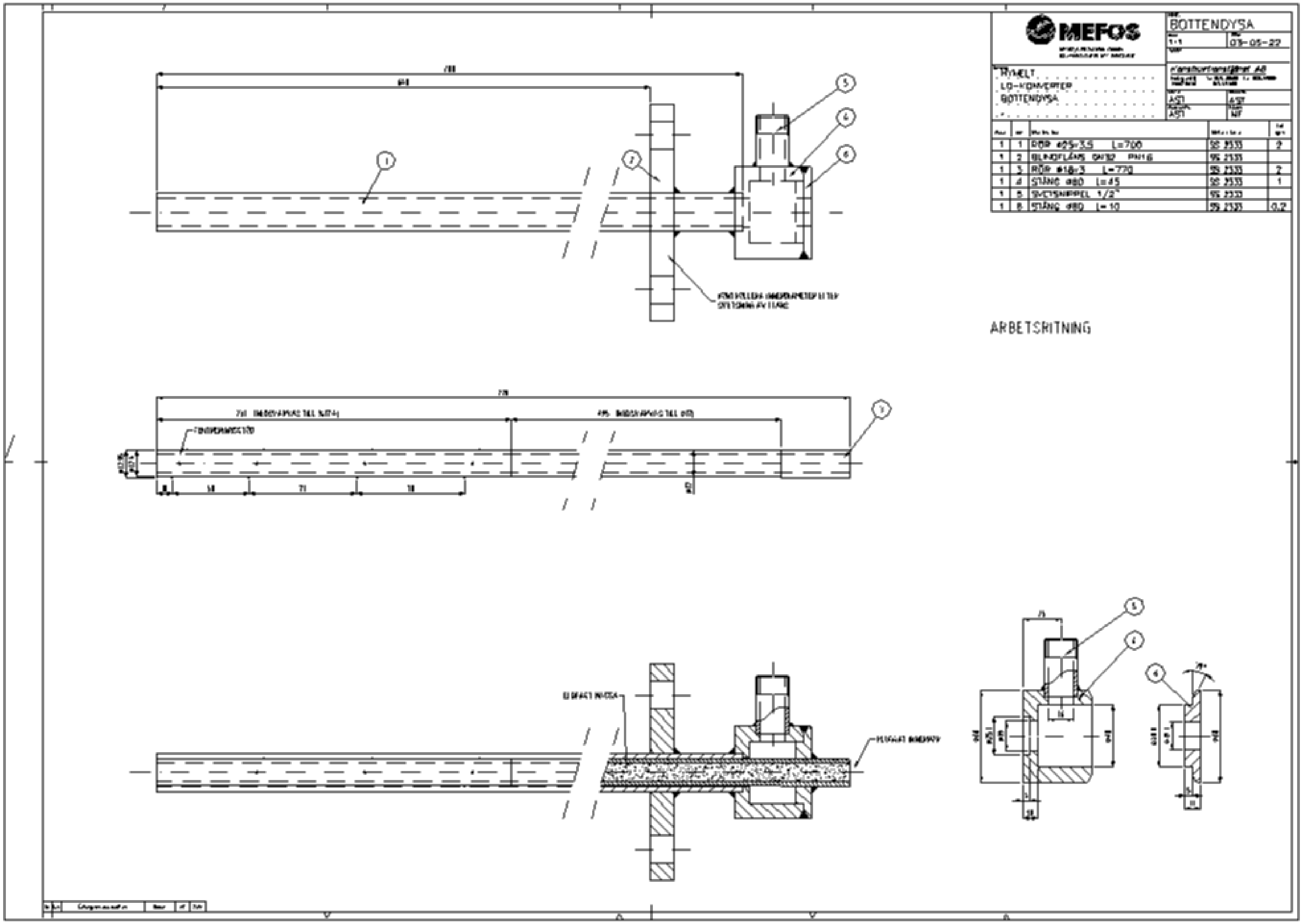
Figure 3 – Oxygen lance

2.2.5 Bottom purging tuyere

Top blown converters suffer from low metal stirring resulting in low mass transport rates witch thereby sets a limit for material trough put. A simple and efficient solution is to install a gas purging element in the bottom of the converter. For the experiment a double eccentric pipe tuyere was selected for injection of nitrogen and hydrogen.

Technical data:

Length	700 mm
Outlet slit, diameters	17,40 – 17,95 mm
Nominal gas flow rate	0,5 m^3n/minute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03-05-22
RYMELT
LD-KONVERTER
BOTTENDYSA
AST
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1 2 BLINDFLÄNS DN32 PN16 SS 2333
1 3 RÖR ø18x3 L=770 SS 2333 2
1 4 STÅNG ø80 L=45 SS 2333 1
1 5 SVETSNIPPEL 1/2" SS 2333
1 6 STÅNG ø80 L=10 SS 2333 0.2
ARBETSRITNING
1
2
3
4
5
6
700
610
770
SEPARAT INKOPPLAT

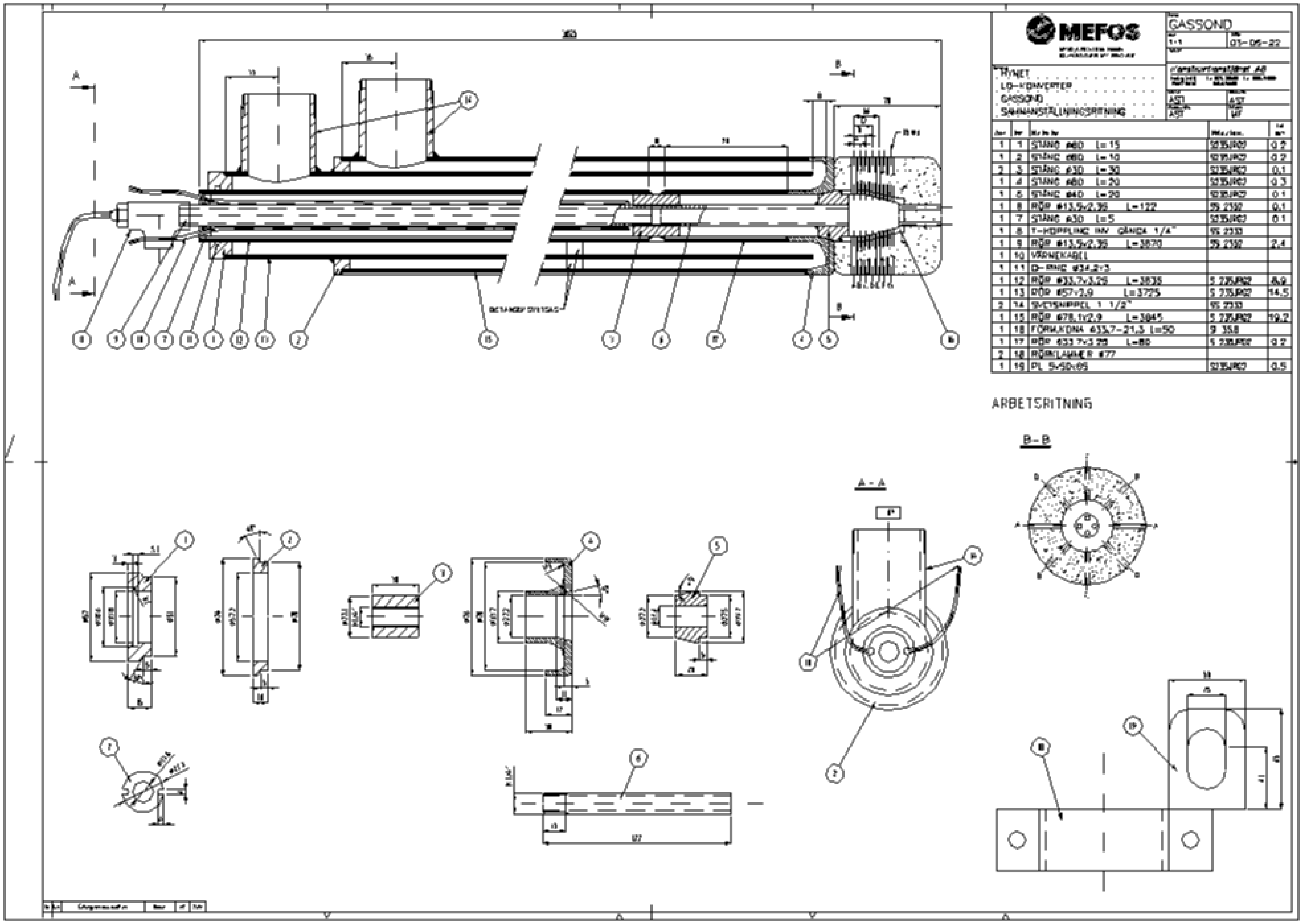
Figure 4 – Bottom tuyere

2.2.6 Gas and dust sampling lance for converter atmosphere

Process gas and dust was collected by a suction lance that could be lowered into the converter in parallel with the injection lance. The lance tip was made as an exchangeable ceramic probe of castable high alumina.

Technical data:

Length	3825
Diameter	76 mm



Ant	Nr	Benämning	Mtrl./Dim.	Vikt kg
1	1	STÅNG ø80 L=15	S235JRG2	0.2
1	2	STÅNG ø80 L=10	S235JRG2	0.2
2	3	STÅNG ø30 L=30	S235JRG2	0.1
1	4	STÅNG ø80 L=20	S235JRG2	0.3
1	5	STÅNG ø40 L=20	S235JRG2	0.1
1	6	RÖR ø13,5x2,35 L=122	SS 2332	0.1
1	7	STÅNG ø30 L=5	S235JRG2	0.1
1	8	T-KOPPLING INV GÄNGA 1/4"	SS 2333	
1	9	RÖR ø13,5x2,35 L=3870	SS 2332	2.4
1	10	VÄRMEKABEL		
1	11	O-RING ø34,2x3		
1	12	RÖR ø33,7x3,25 L=3835	S 235JRG2	8.9
1	13	RÖR ø57x2,9 L=3775	S 235JRG2	14.5
2	14	SVETSNIPPEL 1 1/2"	SS 2333	
1	15	RÖR ø76,1x2,9 L=3845	S 235JRG2	19.2
1	16	FÖRM.KONA ø33,7-21,3 L=50	SS 338	
1	17	RÖR ø33,7x3,25 L=80	S 235JRG2	0.2
2	18	RÖRKLAMMER ø77		
1	19	PL 5x50x85	S235JRG2	0.5

Figure 5 – Lance for gas sampling in converter

3 Material

3.1 Injectants

Materials used for the tests supplied by EnviRes.

3.1.1 Illinois #6

C	71, 14%
H	4, 91%
N	1, 48%
Cl	0, 13%
S	3, 48%
O	8, 26%

Ash	10, 81%
SiO_2	50, 65%
Al_2O_3	20, 15%
CaO	4, 01%
Fe_2O_3	16, 25%

3.1.2 Pet-Coke

C	86, 3%
H	5, 0%
N	1, 0%
S	6, 5%

3.1.3 325 Aromatic extract

C	90, 31%
H	6, 99%
N	0, 24%
S	4, 09%

3.2 Additives

Locally supplied material

3.2.1 Lime mix

The slag former used was a pre mix of burned lime and burned dolomite in 9 to 1 ratio.

Lime

Fraction	3 – 14 mm
CaO	92, 5%
SiO_2	1, 6%
MgO	1, 4%
LOI	2%
CO_2	1, 5%

Dolomite

Fraction 10 – 40 mm

CaO	58%
SiO_2	0, 25%
MgO	40%
CO_2	0, 25%

3.2.2 Aluminium bars

Aluminium bars of ~5 kg were used as fuel additives for compensation of the heat balance. The addition was made before start of oxygen blowing.

Al	96, 57%
Si	0, 62%
Mg	1, 41%
Fe	0, 65%

3.2.3 Ferro silicon

Ferro silicon was used as fuel additives for compensation of the heat balance. The addition was made before start of oxygen blowing.

Si	92%

3.2.4 Ferro sulphur

Ferro sulphur was used in the last heat S1787 in order to drastically increase operational sulphur level in slag and metal. The test included purging of hydrogen through bottom the tuyere.

S	29, 18%
P	0, 01%
C	0,047%

3.2.5 Ferro vanadium

In order to indicate the material balance for vanadium the concentration of vanadium was increased in the last heat S1787.

V	81, 88%
C	0,016%
S	0,023%
Si	1, 23%
Al	0, 46%
P	0,016%

4 Test procedure

4.1 Melting

Charging of pig iron was made the day before the test. The melting procedure followed standard routines for production of synthetic hot metal, ~4 % C and ~0, 2 % Si. Before tapping to a hot metal transfer ladle, the temperature was adjusted to ~1600 ^{o}C.

4.2 Decarburisation of hot metal

The converter operation started with oxygen blowing, 10 m^3n/min, to ~1650 ^{o}C. During blowing, about 20 minutes, all silicon and some carbon from the metal were oxidised. To maintain a slag with reasonable fluid ability and melting temperature, the formed SiO_2 was neutralised by the double amount of lime mix. The lime mix consisted of 90% burned lime and 10% burned dolomite.

The oxygen lance and lime feed program was simplified to:

Time	*Operation*	*Lance position above metal surface*
0 min	Ignition	400 mm
1 min	Lime feed	800 mm
3 min		600 mm

During blowing the metal temperatures were measured and samplings were made approximately every second minute. The samples taken were analysed for C and S by use of a Leco analyser.

4.3 Carburisation H_2 production

The oxygen blowing was followed by carburisation and H_2 production. The operation was made by top lance injection, ~10 kg/min, at a distance of about 400 mm above the metal surface. Temperature measurements and sampling were made as for oxygen blowing. The operation was stopped when desired carbon content was achieved or if the metal temperature became too low.

During blowing a probe for gas sampling was lowered into the converter, 700 mm above metal surface. The sampled gas was analysed for CO, CO_2, H_2, H_2S, COS, and CH_4. Alternatively the sampled gas was collected in a liquid for later Hg analysis. A filter, placed back of the lance, was changed after each blowing period and the collected dust was saved for later analysis. Dust sampling was also made by isokinetic suction from combusted gas in the off gas duct.

After the injection period the converter was tilted and the slag and metal could be inspected and sampled. The metal samples were of spectrometer quality for full chemical determination. If necessary some slag was skimmed of.

4.4 De-carburisation CO production

The procedure for de-carburisation followed mainly the routines for classical BOF blowing. Compensation for heat losses were made by addition of additional fuel, aluminium bars and FeSi before blowing start. To maintain reasonable slag properties the formed Al_2O_3 and SiO_2 was compensated by lime mix.

The procedure was followed by a new injection period or by tapping in case of the last trial for the day.

4.5 Tapping

Before tapping the metal temperature was adjusted to about $120^{\circ}C$ super heat. This was made by oxygen blowing in combination with scrap or aluminium addition. After slag skimming, tapping was made into a steel ladle or hot metal ladle and cast into sand beds. The following day slag and metal was separated and weights were recorded.

5 Heat notes

5.1 HyMelt 1

Un-alloyed pig iron was melted in the EAF, tapping and charging of 5500 kg of hot metal was made without only small disturbances.

5.1.1 Heat ID S1782

Coal was selected for injection.
Totally five period of injection were made and initial problems were detected on:

- Level control of the lances had a poor function because of mechanical interference between cooling rubber tubes and malfunction of chain for the oxygen lance
- Sub-lance system had to be tuned for dipping time and sampling level
- O_2 flow-rate control and routines for the MEFCON system had to be tuned
- The dust load indicated that the complete system for process gas had to be cleaned after each injection period.
- The temperature drop during injection was unexpected high about 10 °C
- Low temperature injection <1400°C gave "unreacted coke" on top of the slag

Tapping and casting could be made without any problems.

New routines for data collection and conducting the test must be made for the coming day.

5.2 HyMelt 2

5.2.1 Heat ID S1783

Operation could be performed under good control. Totally five periods of coal injection and one period of coke were made.

- The "unreacted coke" on top of the slag could almost be completely avoided by operation at higher temperatures, melt temperature was maintained above 1400°C.
- The poor heat balance was managed by aluminium addition and by avoiding tilting of the converter between oxygen blowing and injection.
- 4 periods of process gas sampling was possible.
    - 2 gas analysis coal injection
    - 1 Hg-sampling coal injection
    - 1 gas analyse coke injection
- From the start of gas suction the pressure drop increased giving a continuously increased amount of leakage air to the analysers.

- Sculling, narrowing the converter mouth gave some problems with lance movements
- The last injection was made with coke giving strong indications of an improved carbon yield and an improved heat balance.
- The feeding rate was reduced during coke injection. It was later found that some rubber material was blocking the outlet.

5.3 HyMelt 3

5.3.1 Heat ID S1784

Pet-coke was used for all injections periods. Totally five periods was made and gas suction of process gas was possible for all periods. An overall improved heat balance gave drastically reduced aluminium addition. This in combination with no ash in the material gave a low slag trough put and a stiff and dry slag. It was understood that the slag has been saturated with MgO from refractory wear during the day.

Moderate feed rate 10 kg/min gave in first two injection periods excellent result. Attempt to increase the rate up to 20 kg/min was only possible by reducing the carrying gas from 0,55 m^3n/min to 0,35 m^3n/min and by increasing the nozzle outlet diameter from 7,0 to 7,5 mm at ~12:00. Both these action caused a lower impulse of material jet to the bath. It was later found that coal was by mistake charged to the dispenser during the day.

- Large amount of coke was trapped in the slag giving flames spontaneously or when the slag was skimmed.
- The dry slag gave problems to measure in blow temperatures.
- The heat was tapped when water leakage occurred on the oxygen lance.
- Remaining problem with increased amount of leakage air during sampling of process gas. The analysed components must be corrected by use of an oxygen balance. Argon content is therefore included from this day in the database. Clogging is mainly caused by dust in the filter in top of the lance and in the ceramic head.
- The standard hydrogen analyser was closed before the start of the tests.
- Recalibration of MS hydrogen was made after that calibration gas of 100% responded only 85%. Can be seen in the data base.

5.4 HyMelt 4

5.4.1 Heat ID S1785

Pet-coke injection was made for 5 periods, gas analysis was possible for all. During the day the confusion between coal and pet-coke was detected.

A new slag was tested, the purpose was to achieve good fluid ability down to $1400^{o}C$. The slag was made of oxides from FeSi98 and aluminium bars fluxed with lime and dolomite mix. The result was acceptable and slag skimming could be made after the injections.

The injection nozzle was drilled to 8 mm to allow higher feeding rate up to 20 kg/min. However at this rate the transport gas had to be lowered to 0, 3 m^3n/min giving a lower impulse from the gas/material jet into the melt. This was during the day compensated with higher gas flows 0, 7 m^3n/min and a lower material flow rate.

The operational lance distance was measured with a steel bar placed on the material lance nozzle. The result confirmed calibration 400 mm indicated metal up to 280 mm. The difference is caused by unstable metal surface from bottom stirring.

Preliminary mass balance shows low carbon yield to the melt, the losses to combusted gas was typically 3 kg/min and coke in the slag was found in the same magnitude. High CH_4 % was also reported from process gas analysis.

Sculling on the oxygen lance was detected for the first time and had to be cleaned several times. It was also found that the nozzle of the material lance was clogged in home position during oxygen blowing. It was easily detected when carbon injection was started with the material plume in the slit between converter mouth and the hood. This small scull was removed before all tests except from the first injection which was operated with a poor plume.

The moderate carbon yield can be caused by:

- Particles not solute directly in the jet-metal interface will float up on slag surface giving only small possibilities to contact with metal. With a stiffer slag it is more likely that metal surface and coal particles in direct contact.
- Lower jet impulse from the larger nozzle diameter.

Later note: material confusion caused the main problems with C-yield.

5.5 HyMelt 5

5.5.1 Heat ID S1786

Injection of oil was made for the first 4 periods, the remaining day coal was injected for 3 periods. Oil seems to be a more difficult source than solids. Large amount of CO_2 was detected in the combusted gas indicating severe soot formation.

The coal tests showed similar results as previous heats, moderate carbon yield, tendency for build up of coal on top of slag and a weak heat balance. The lance was made with a 7 mm nozzle.

At 14:30 it was discovered that one of the coke bags was confused with coal. Until then coal has been injected as coke. This can explain the problems to repeat the good results achieved earlier with coke. Experiments made at HyMelt 4 must be rechecked.

Good gas suction of process gas for analyse. The last two periods was used for mercury sampling.

5.6 HyMelt 6

5.6.1 Heat ID S1787

Totally 6 injection periods with pet-coke were made at controlled conditions.
Tests at higher V and S levels.
Hydrogen purging at high sulphur level was performed

6 Result

The complete data base and the individual test periods have been distributed separately. Below is supplementary data presented as graphs. Detailed information on individual test periods can be found in Appendix 1.

6.1 Process gas analysis

In Appendix 2 is an overview of measured components in the process gas presented. Detailed graphs for individual injection periods are presented separately and comments made do also refer to those.

A general difficulty was clogging of the sampling probe giving an increased amount of leakage air in the gas sample during the measuring periods. For the evaluation the recorded values have been balanced by use of the measured oxygen for compensating the amount of air dilution

Isolated peak values are related to calibration and frequent peaks especially on CO are caused from partial combustion of sub-lance probes.

6.1.1 CO

The recordings show significant difference between the injectants.

- Coal gives stabile CO concentration in the range of 20 – 30%.
- Coke gives a decreasing CO concentration during injection starting around 20% down to 10%.
- Oil shows the same behaviour as coke but on a lower CO concentration down below 5%.

The measurements seem to mirror the oxygen content in the material and that we have to consider declining reduction of oxides in the slag during injection.

6.1.2 CO_2

It is not expected to have significant amount of CO_2 in the process gas. The presence can be due to leakage air into the converter atmosphere or to leakage in the sampled volume. The readings are generally below 5% and frequently below 1%.

6.1.3 H_2

The H_2 measurement has a long response time, up to 5 minutes when calibration with a fixed concentration and it is accordingly to be expected an increased reading during the injection period. Coal and coke generates a gas of 50% to 60% H_2, occasionally 10% higher or lower, while oil shows about 70% H_2.

6.1.4 CH_4

Coal and coke give gases of 5 to 7 % CH_4 while oil gives 8 to 12%.

The accuracy is not perfect since the component gives a stronger signal than recommended for optimal performance.

6.1.5 H_2S

The process gas has a content of 0,2 to 0,4 % H_2S independent of injectant. At higher sulphur level in metal the H_2S content in the gas is somewhat higher, 0,5%. (0,8 to 1,0 %S compared to normal level 0,1 to 0,3 %S)

It has not been shown that purging with H_2 will effect the H_2S concentration.

6.1.6 COS

The graphs shown in the Appendix 2 are based on the spectrometer data base, since the records in the Lab View system do not mach. Unexpected high values have been measured, frequently more than 500 ppm, more typical recordings are in the range 100 to 300 ppm.

The data base in the spectrometer operates with complete different format and it is preferred if all future measurements are transferred to the Lab View system.

6.1.7 O_2

No oxygen is expected to be in the gas, the presence is most likely due to leakage into the cooled gas sample.

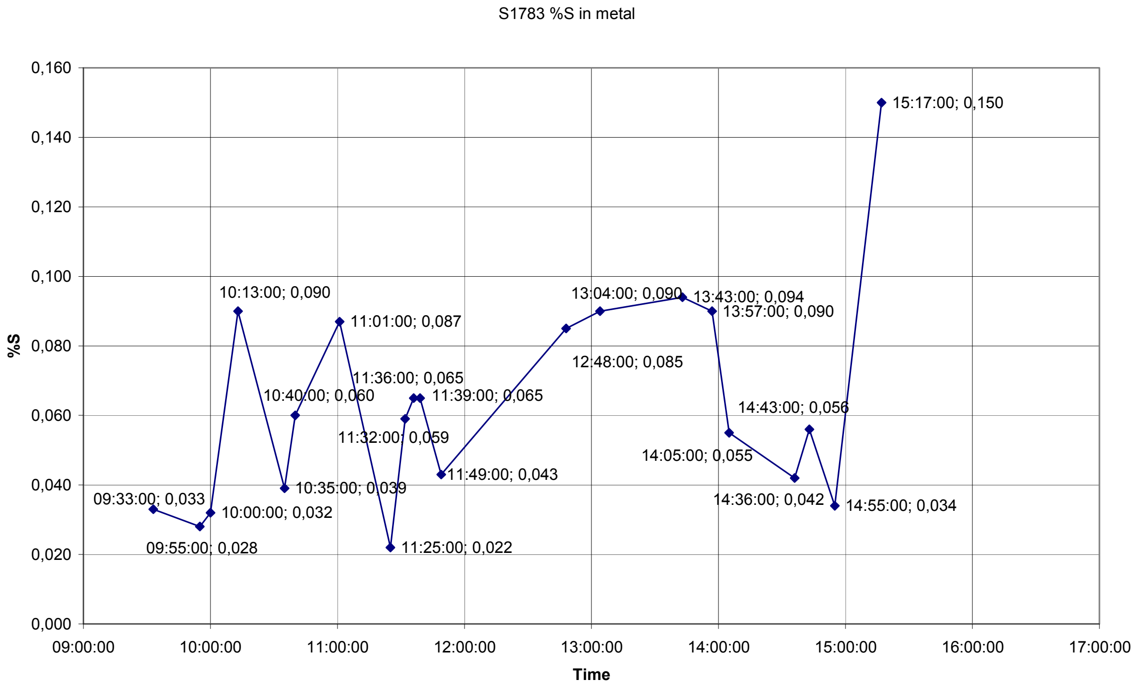
6.2 Metal analysis

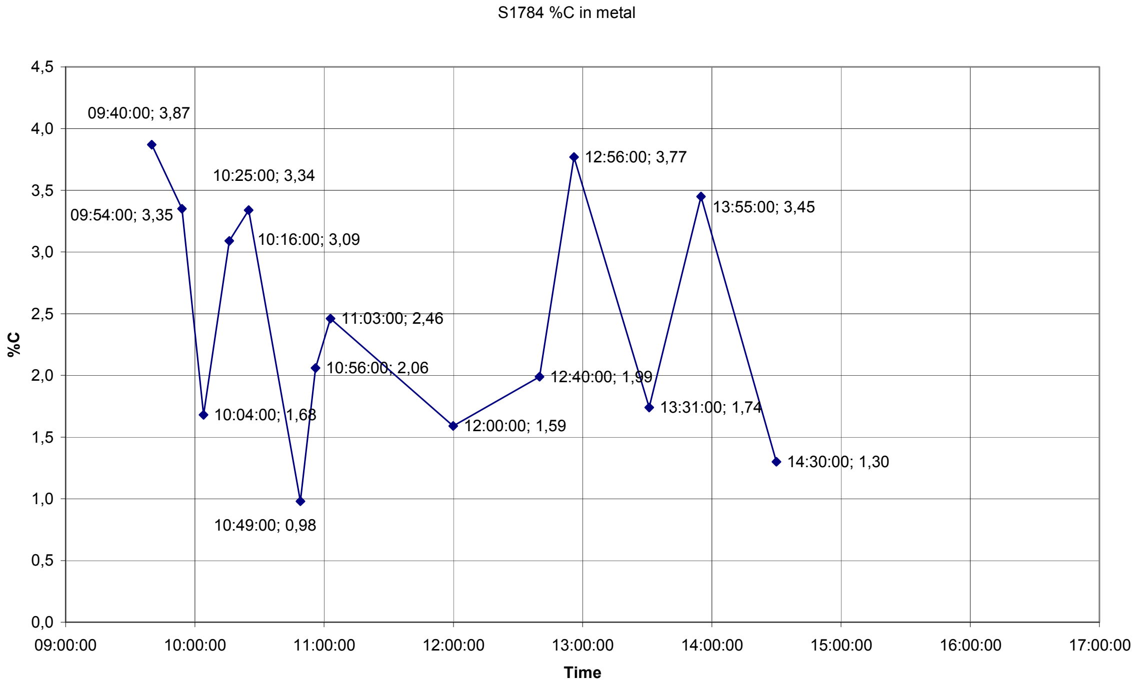
Below are the metal analysis presented for each element of interest. The analyses are generally believed to be good enough for the coming campaigns. However, the in-blow samples of spectrometer quality are few and the sampling procedure must be improved. Carbon and sulphur were analysed on the Leco system which operates with samples of lower quality.

Complete analysis of metal and slag is shown in Appendix 3

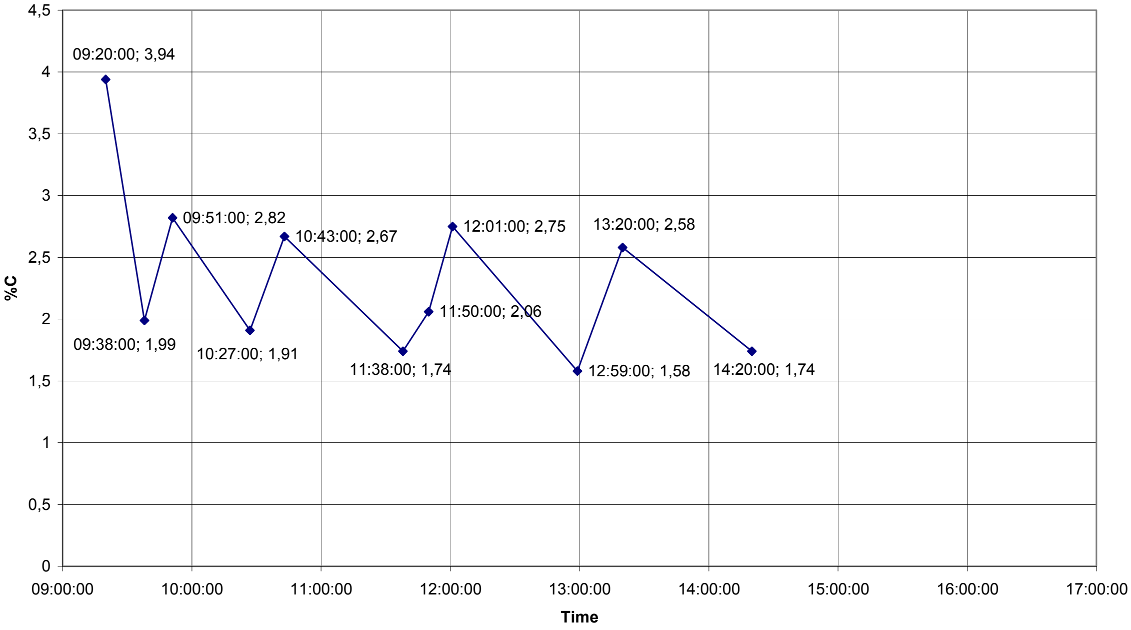
6.2.1 Carbon

S1783

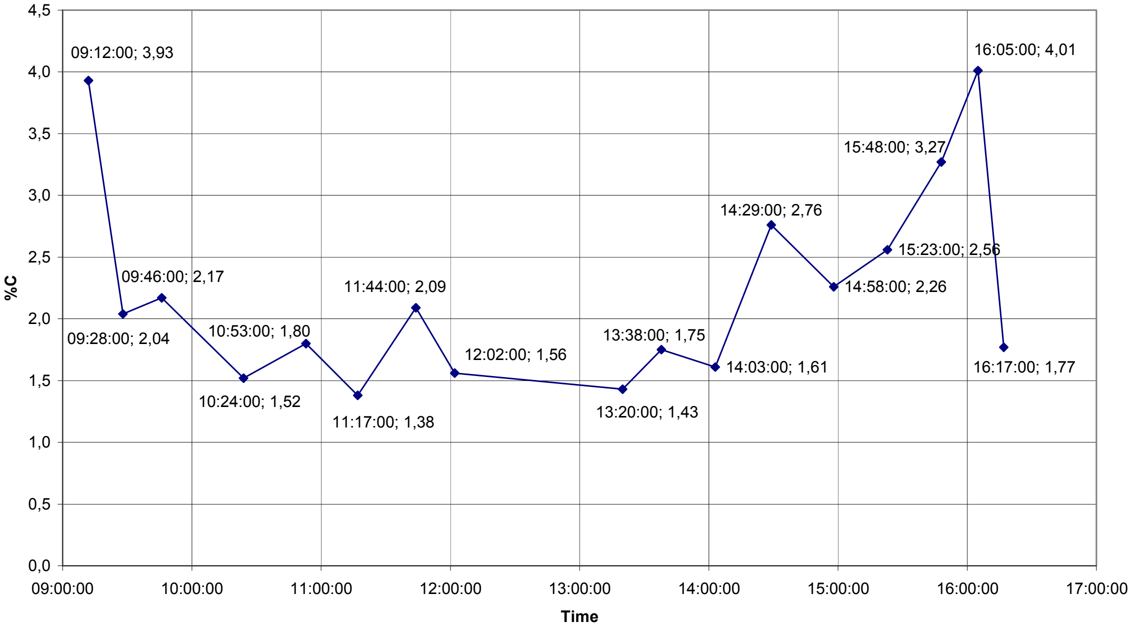




S1785 %C in metal



S1786 %C in metal



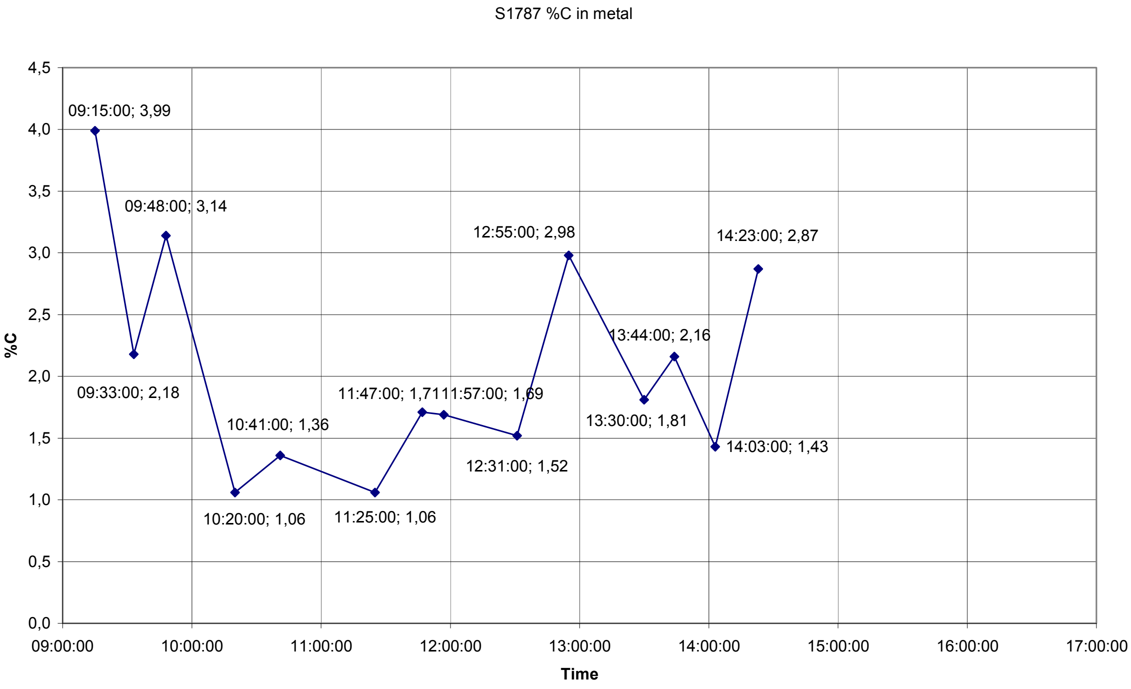
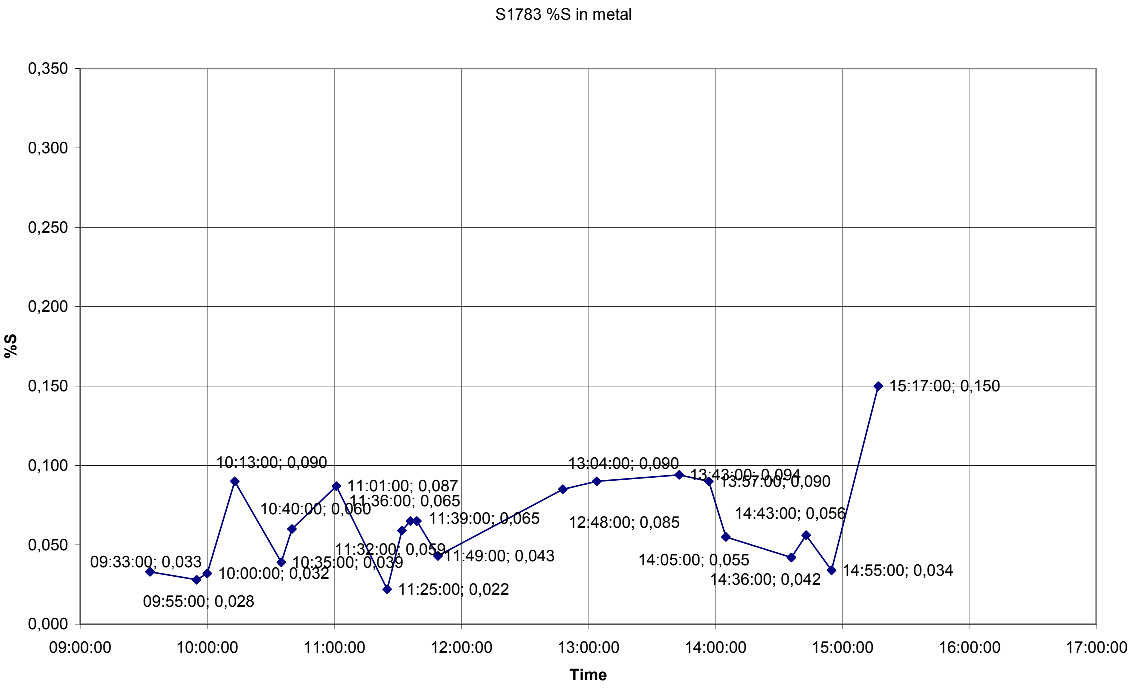
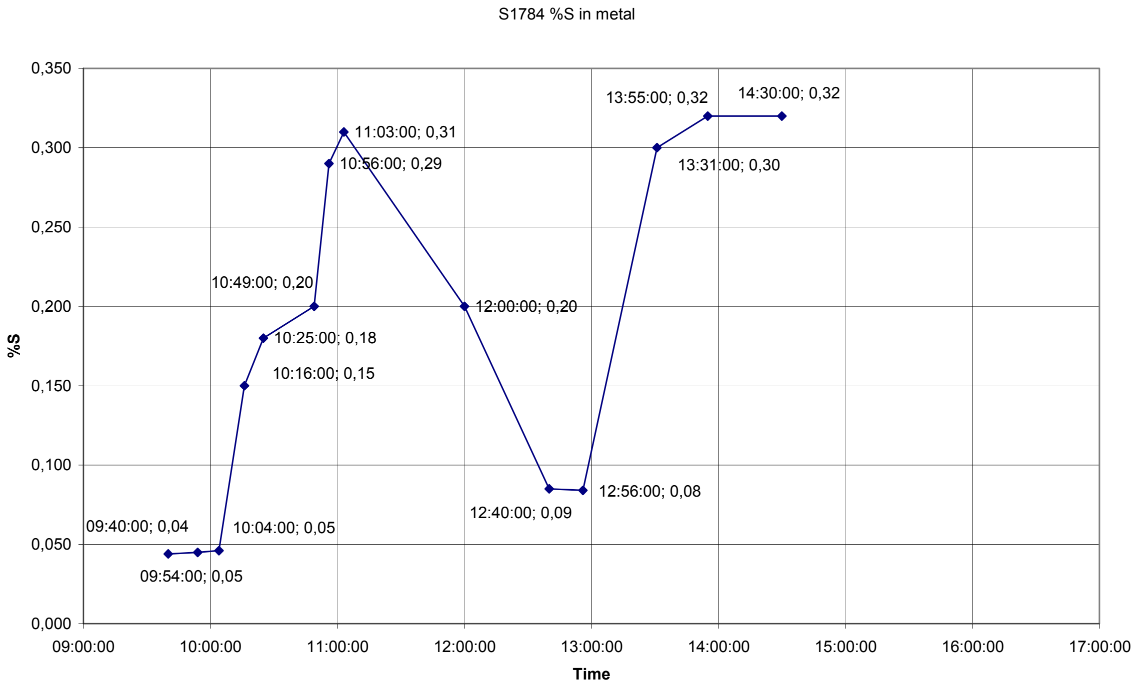
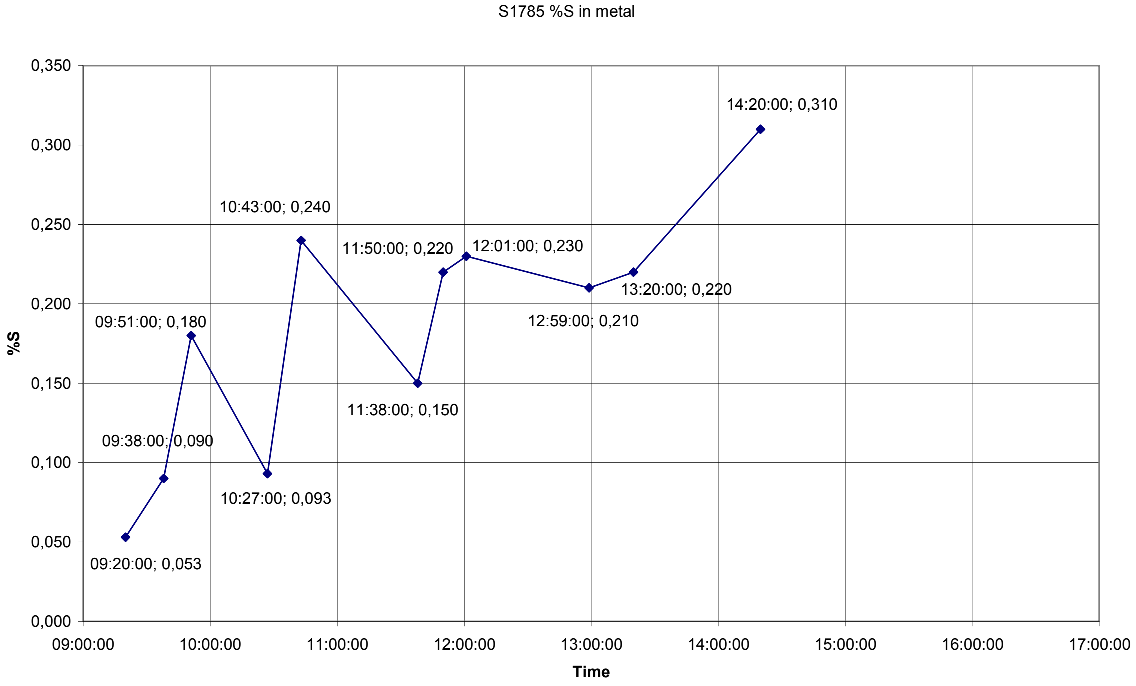


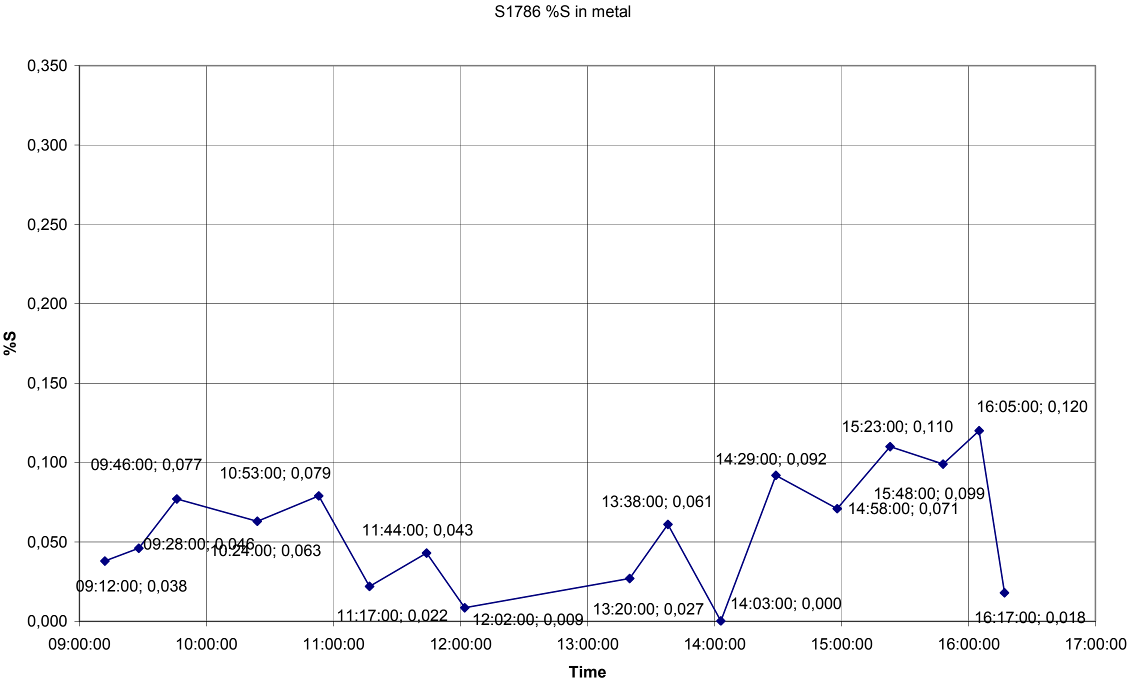
Figure 6 – C analysis in liquid metal HyMelt 2 to 6

6.2.2 Sulphur




S1784 %S in metal
%S
Time
0,350
0,300
0,250
0,200
0,150
0,100
0,050
0,000
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
09:40:00; 0,04
09:54:00; 0,05
10:04:00; 0,05
10:16:00; 0,15
10:25:00; 0,18
10:49:00; 0,20
10:56:00; 0,29
11:03:00; 0,31
12:00:00; 0,20
12:40:00; 0,09
12:56:00; 0,08
13:31:00; 0,30
13:55:00; 0,32
14:30:00; 0,32


S1785 %S in metal
%S
Time
0,350
0,300
0,250
0,200
0,150
0,100
0,050
0,000
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
09:20:00; 0,053
09:38:00; 0,090
09:51:00; 0,180
10:27:00; 0,093
10:43:00; 0,240
11:38:00; 0,150
11:50:00; 0,220
12:01:00; 0,230
12:59:00; 0,210
13:20:00; 0,220
14:20:00; 0,310



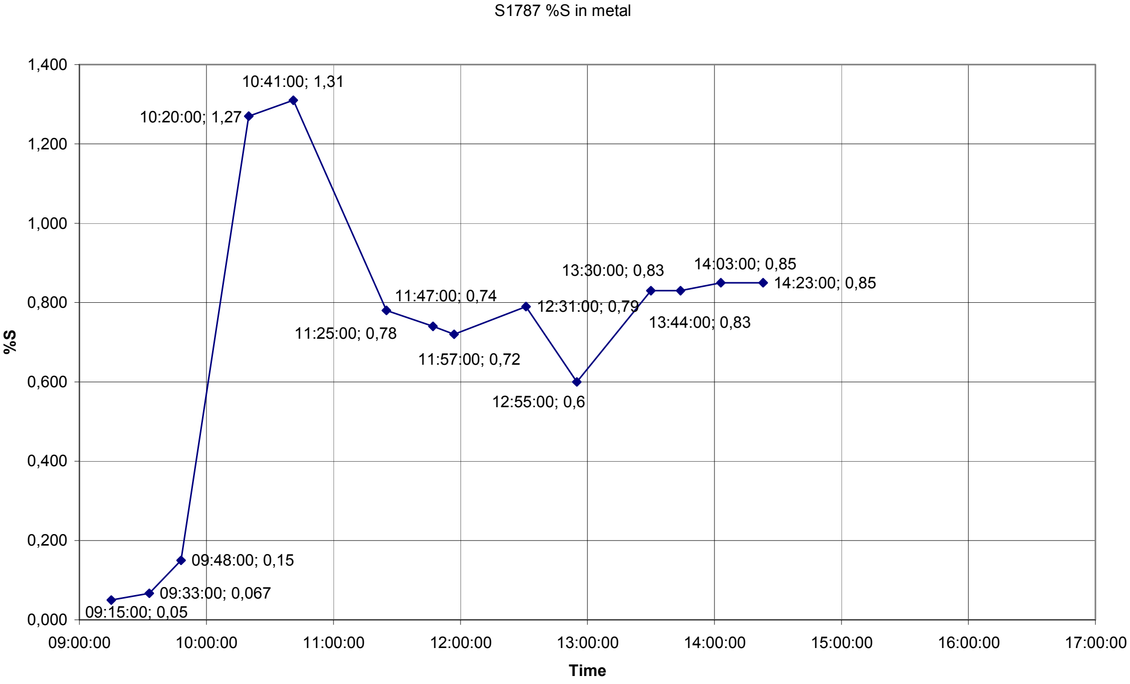
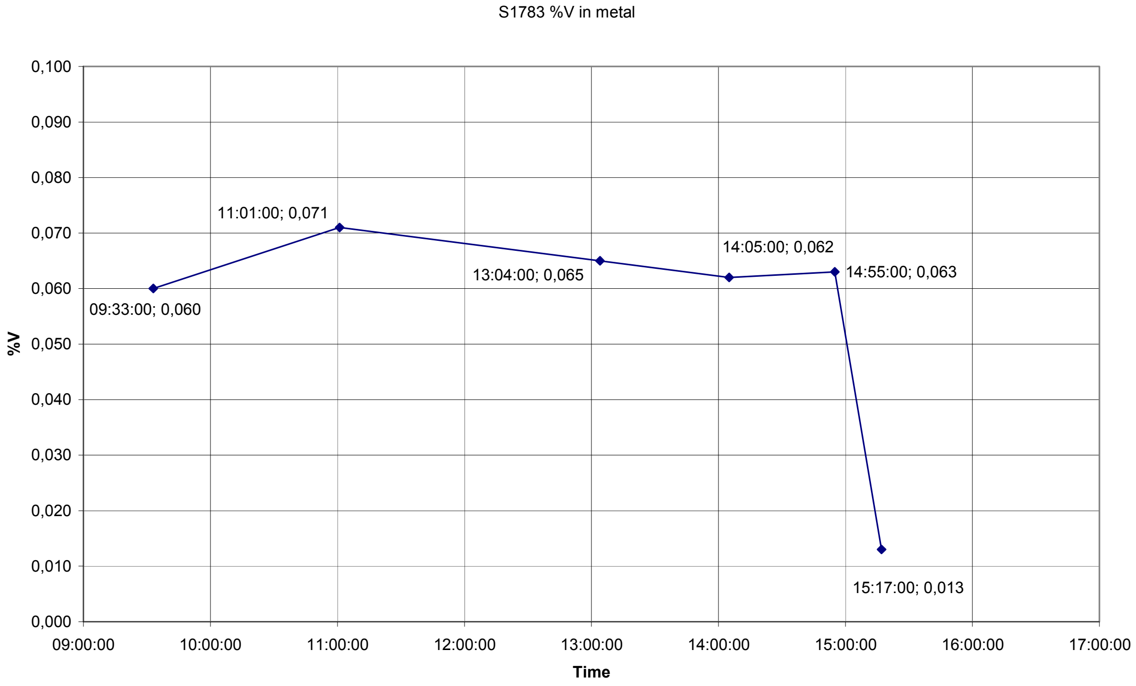
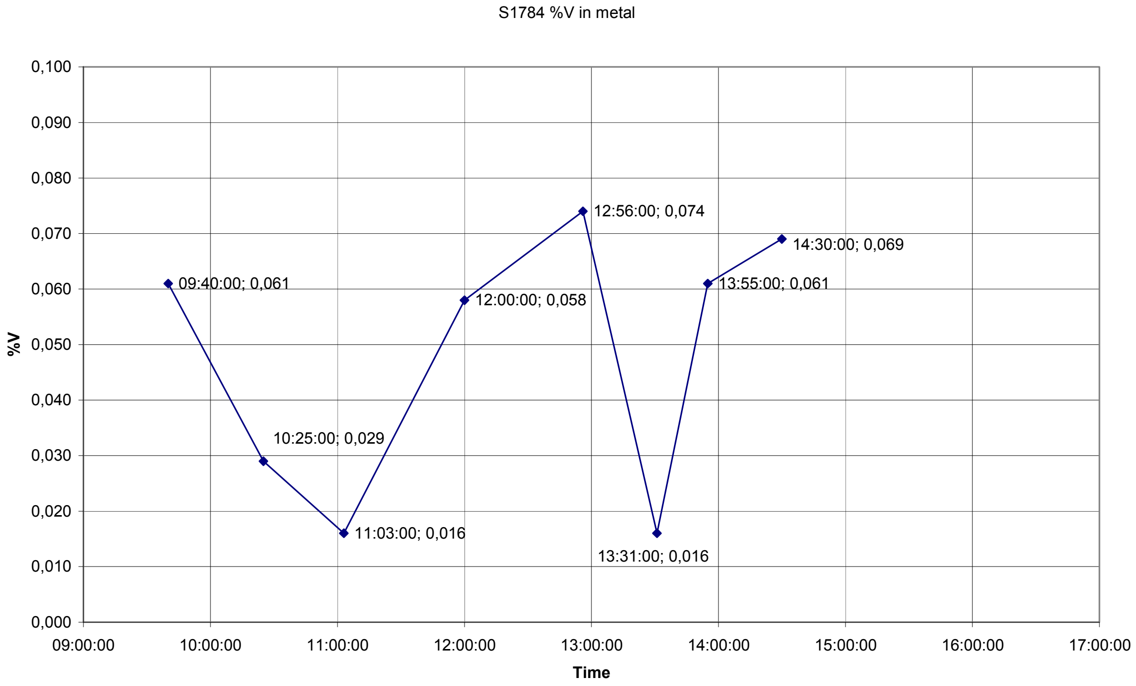
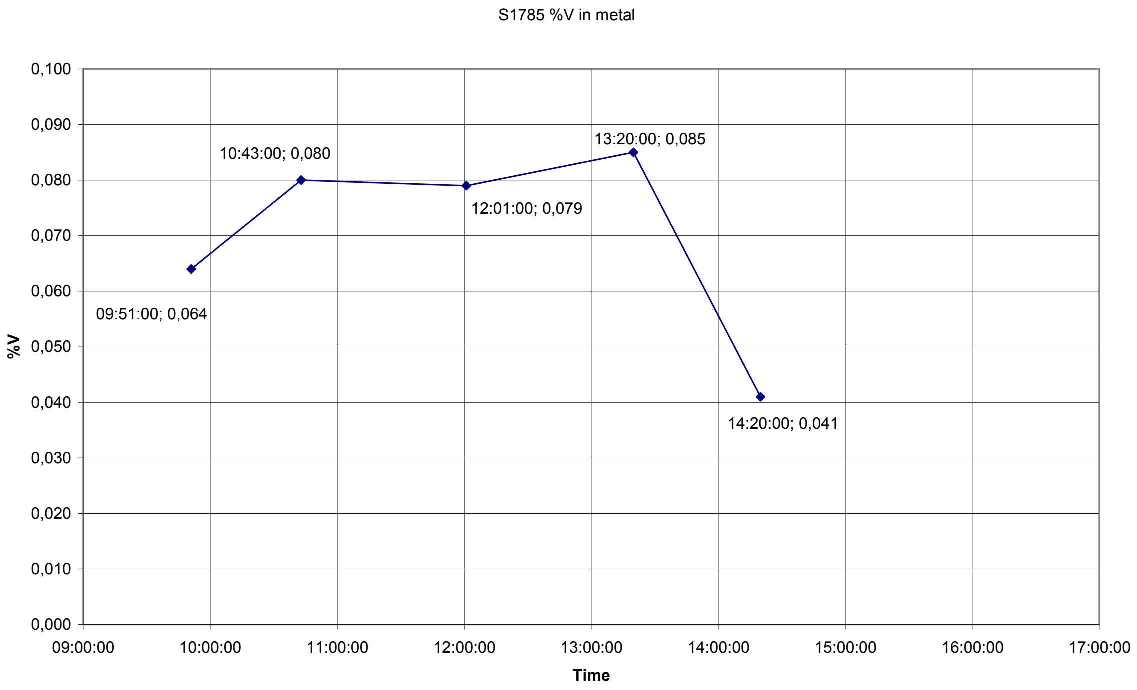


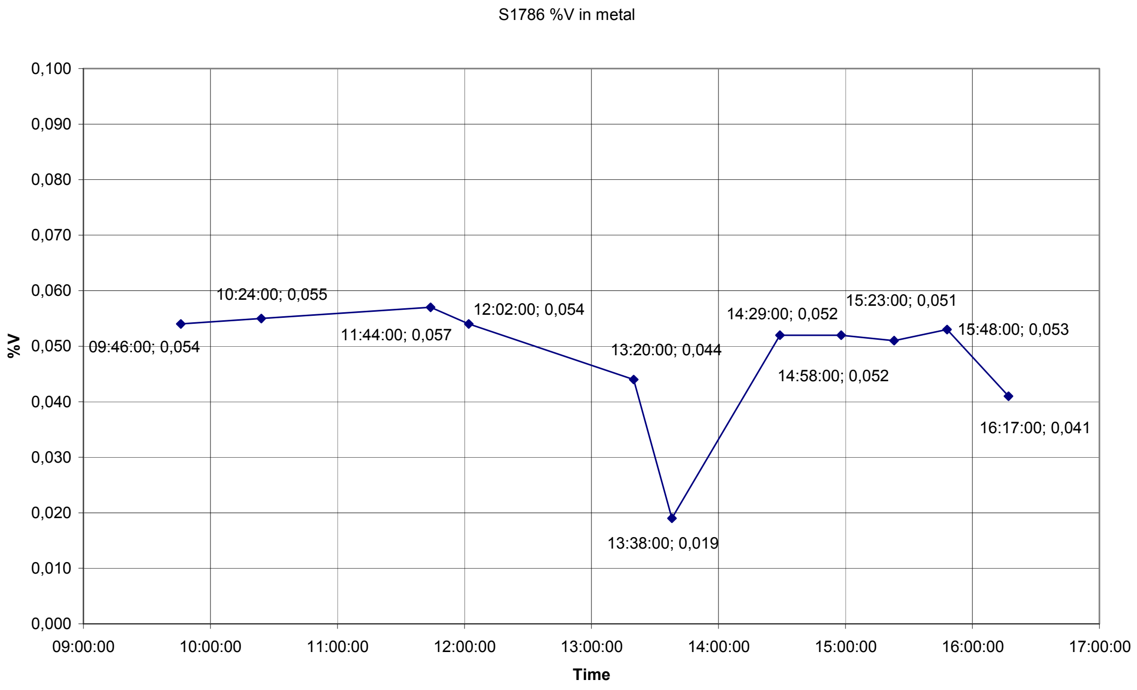
Figure 7 – S analysis in liquid metal HyMelt 2 to 6

6.2.3 Vanadium






S1785 %V in metal
%V
0,100
0,090
0,080
0,070
0,060
0,050
0,040
0,030
0,020
0,010
0,000
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
Time
09:51:00; 0,064
10:43:00; 0,080
12:01:00; 0,079
13:20:00; 0,085
14:20:00; 0,041


S1786 %V in metal
%V
0,100
0,090
0,080
0,070
0,060
0,050
0,040
0,030
0,020
0,010
0,000
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
Time
09:46:00; 0,054
10:24:00; 0,055
11:44:00; 0,057
12:02:00; 0,054
13:20:00; 0,044
13:38:00; 0,019
14:29:00; 0,052
14:58:00; 0,052
15:23:00; 0,051
15:48:00; 0,053
16:17:00; 0,041

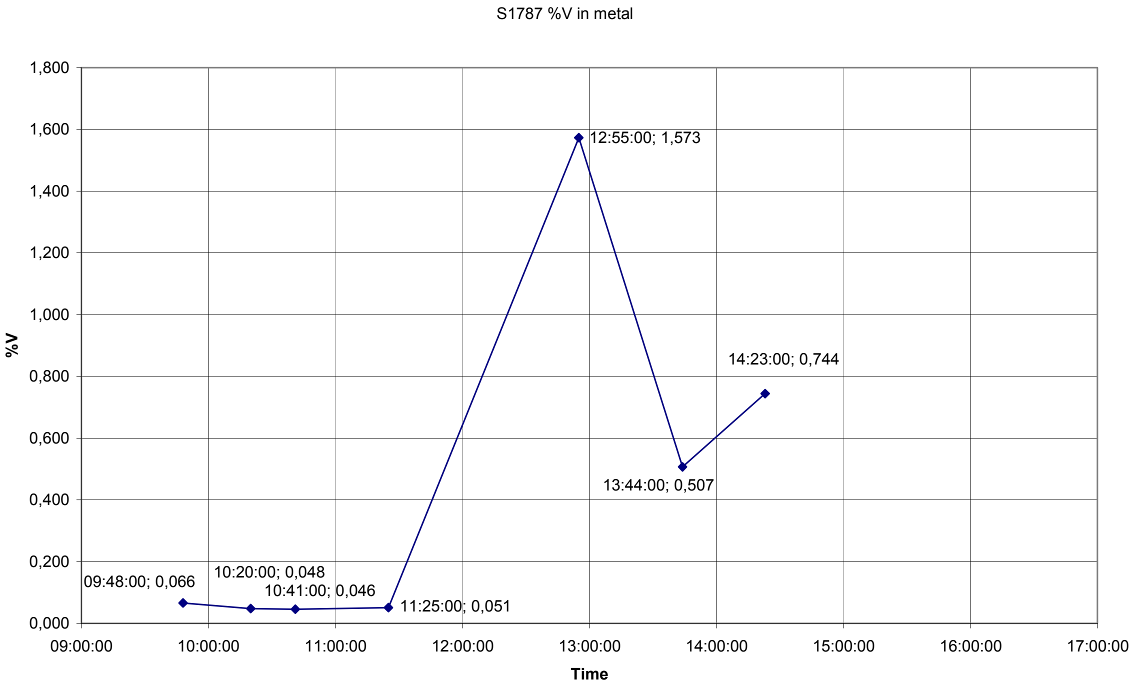


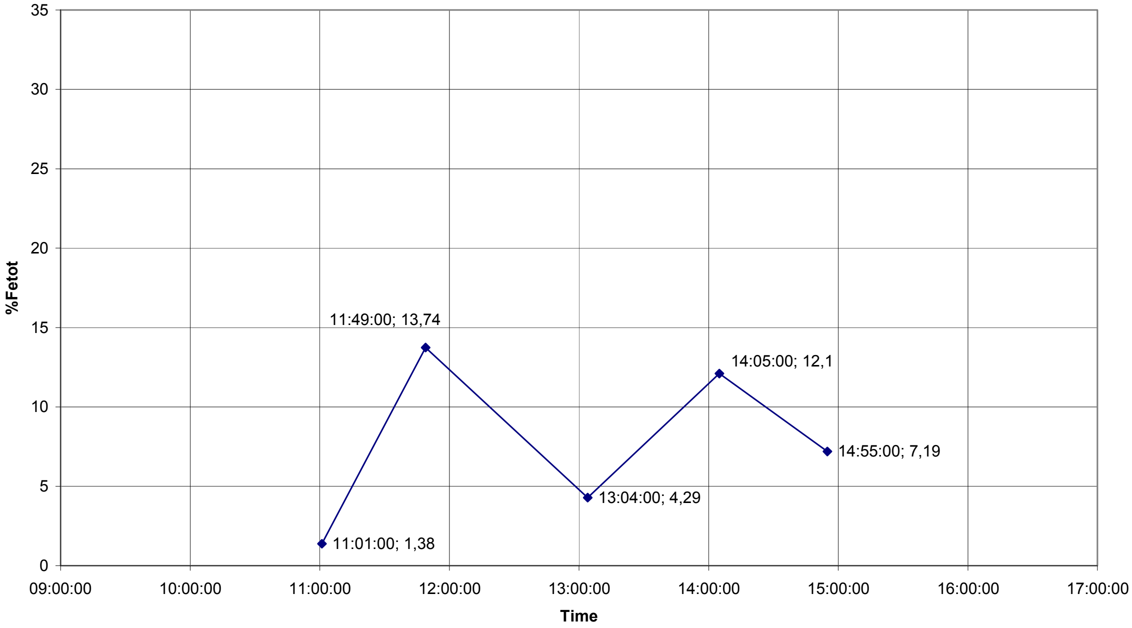
Figure 8 - V analysis in liquid metal HyMelt 2 to 6

6.3 Slag analysis

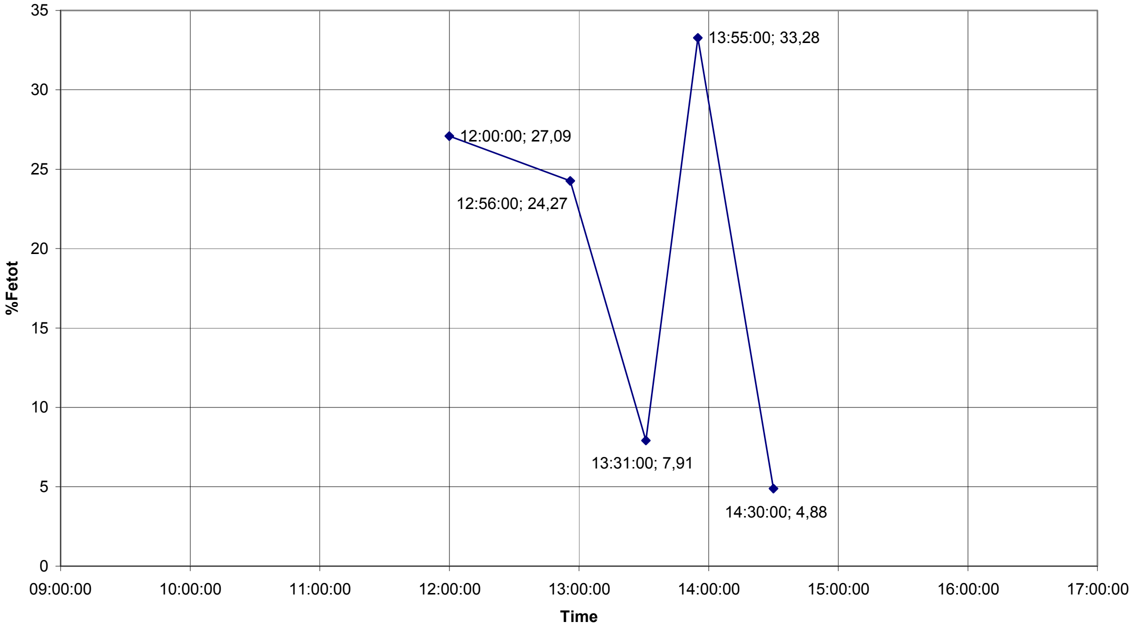
Slag samples are only possible to collect from tilted converter. The method can be used in coming campaigns.

6.3.1 Iron oxides

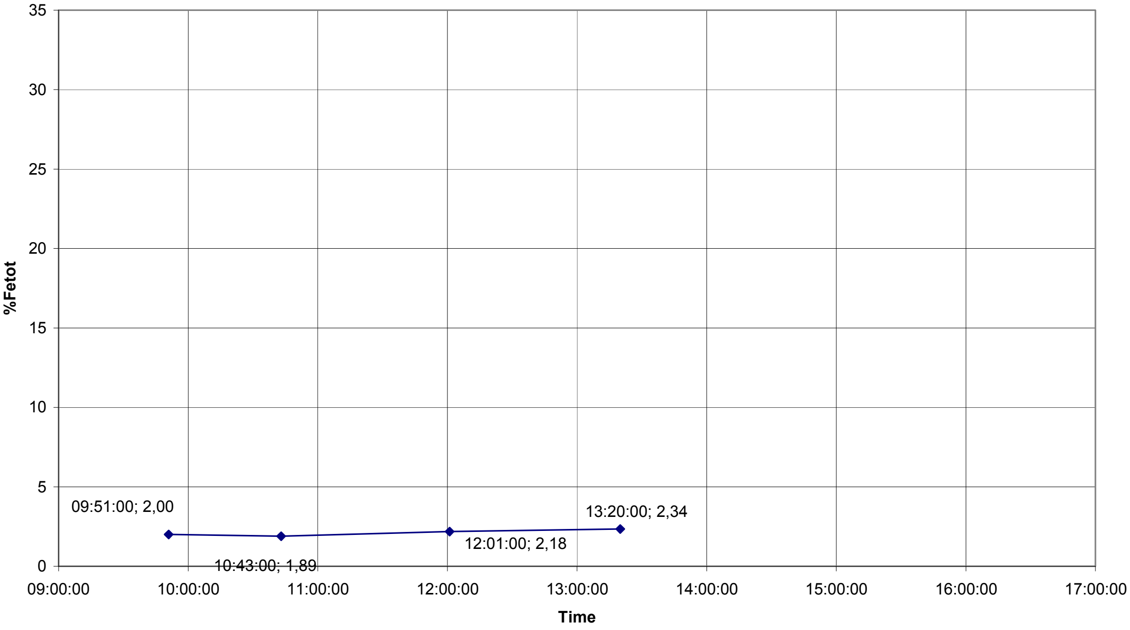
S1783 %Fetot in slag



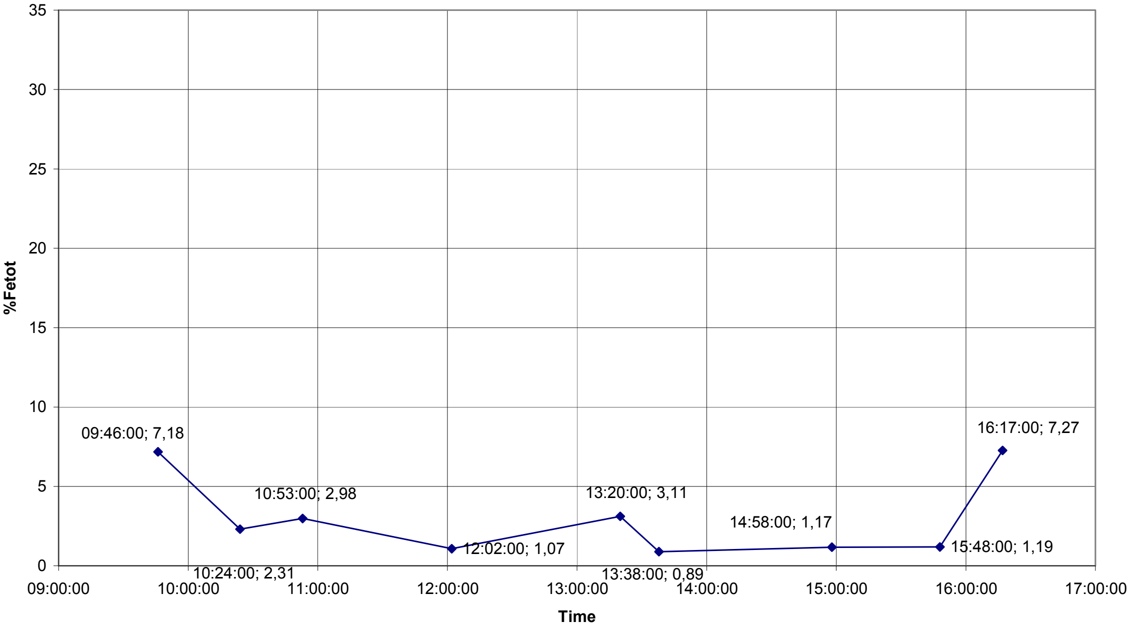
S1784 % Fetot in slag



S1785 %Fetot in slag



S1786 %Fetot in slag



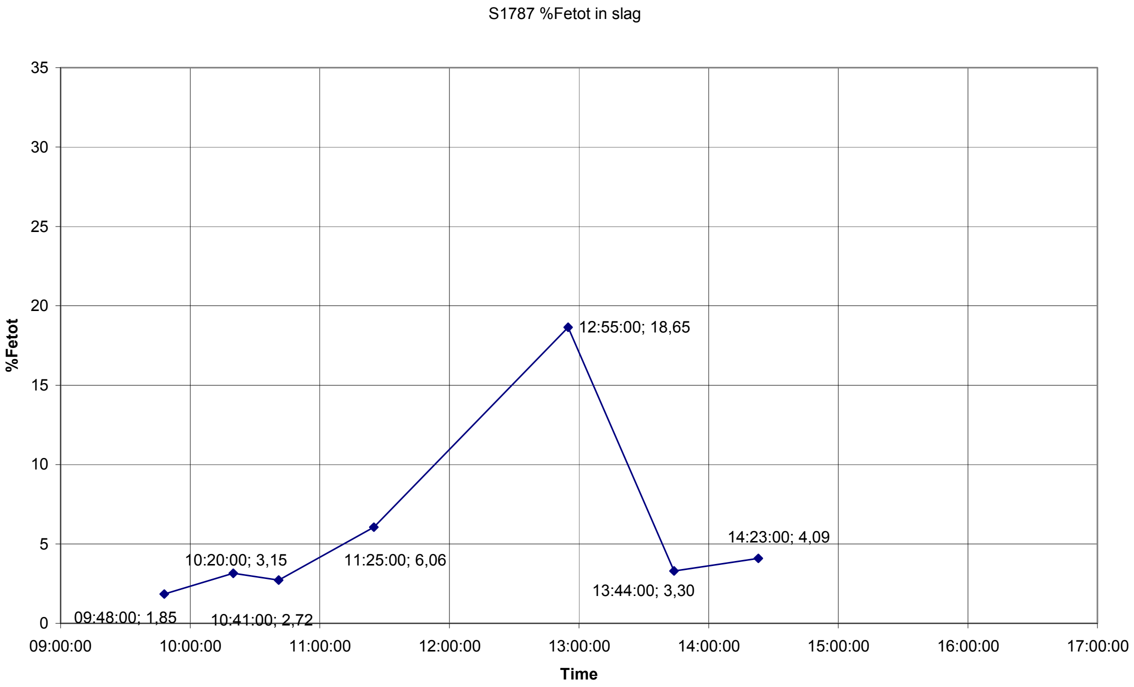
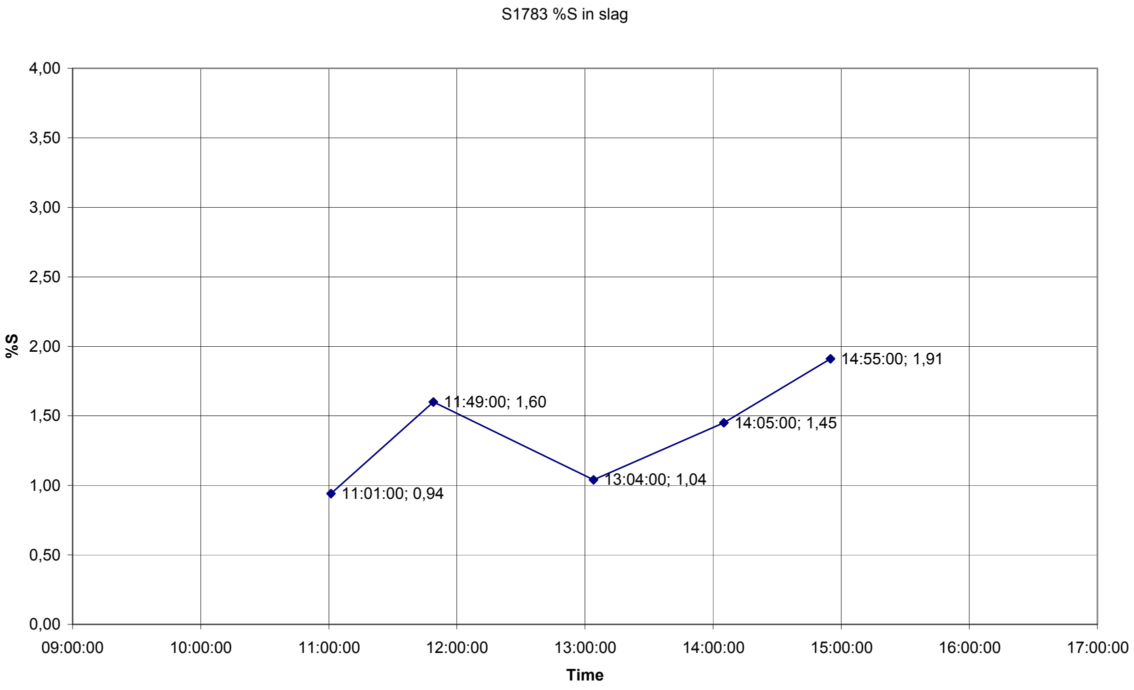
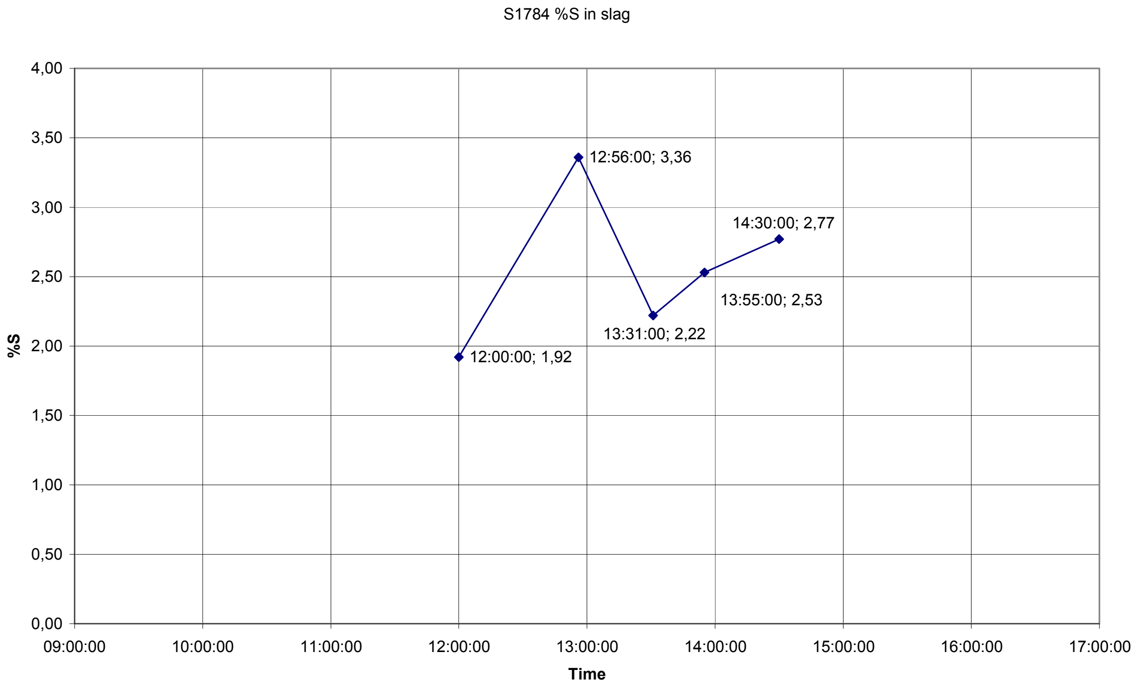
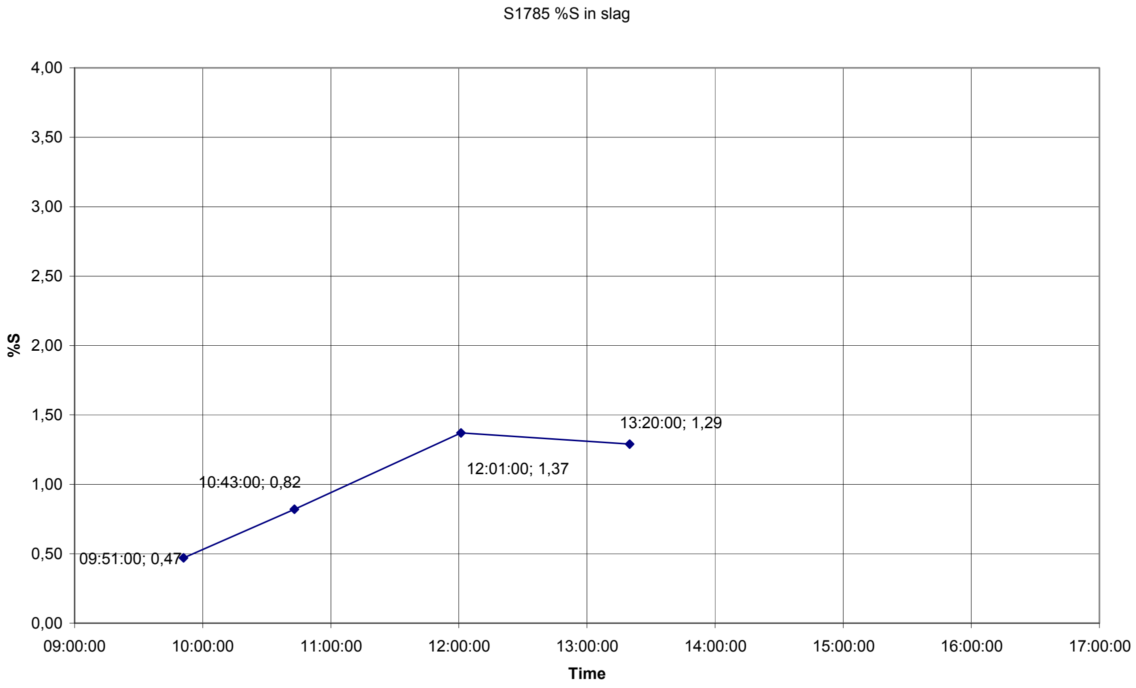


Figure 9 – Fe_{tot} in slag HyMelt 2 to 6

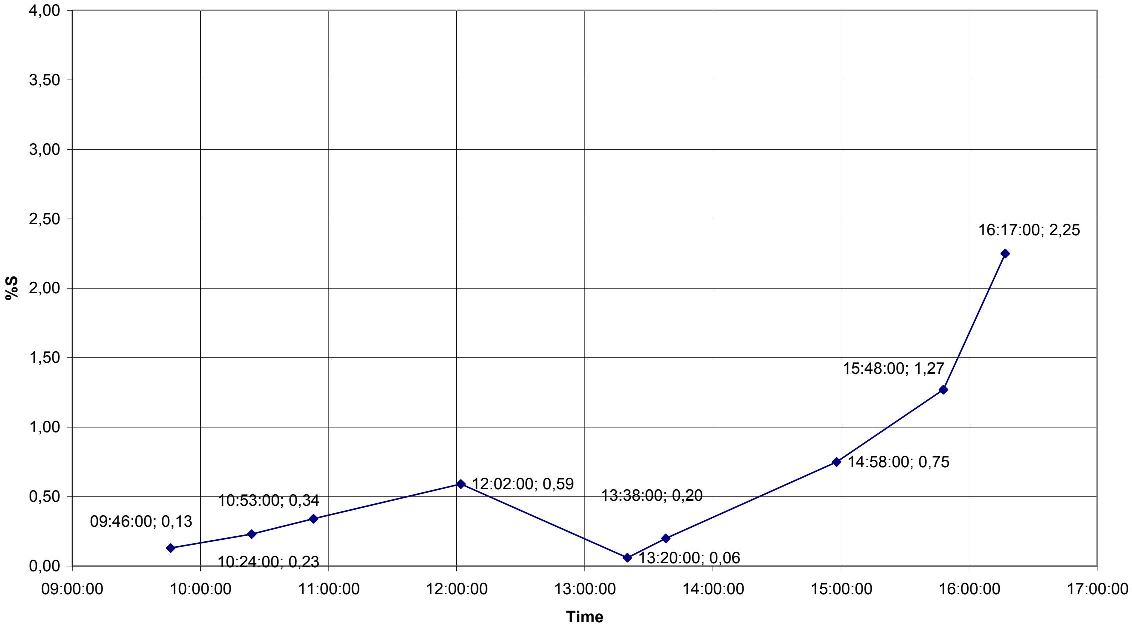
6.3.2 Sulphur




S1784 %S in slag
%S
Time
4,00
3,50
3,00
2,50
2,00
1,50
1,00
0,50
0,00
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
12:00:00; 1,92
12:56:00; 3,36
13:31:00; 2,22
13:55:00; 2,53
14:30:00; 2,77


S1785 %S in slag
%S
Time
4,00
3,50
3,00
2,50
2,00
1,50
1,00
0,50
0,00
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
09:51:00; 0,47
10:43:00; 0,82
12:01:00; 1,37
13:20:00; 1,29

S1786 %S in slag



S1787 %S in slag

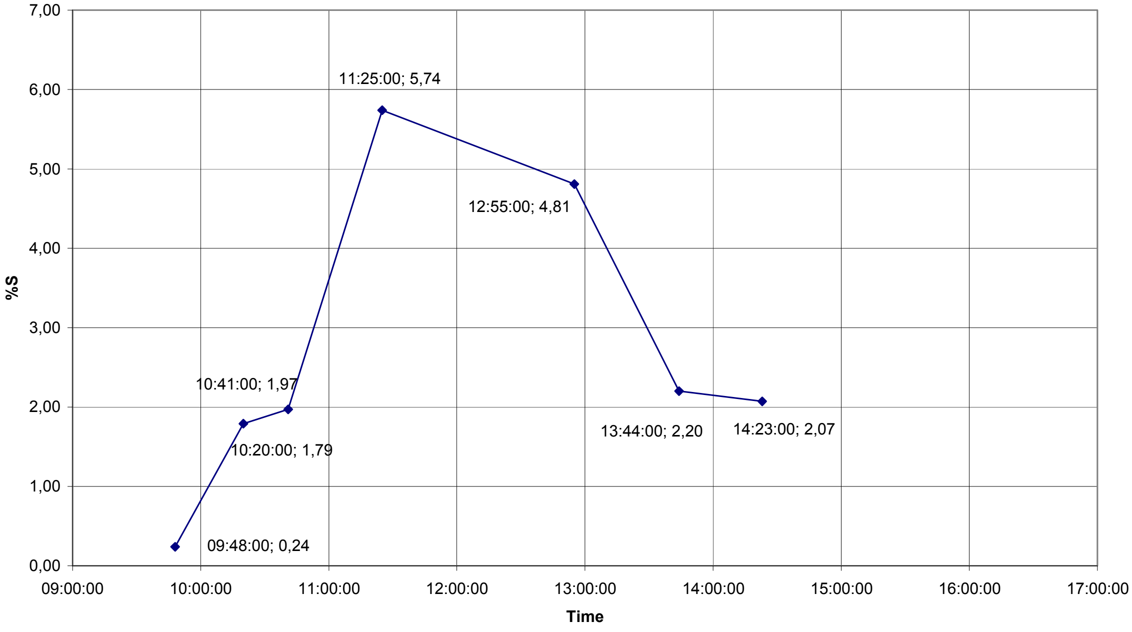
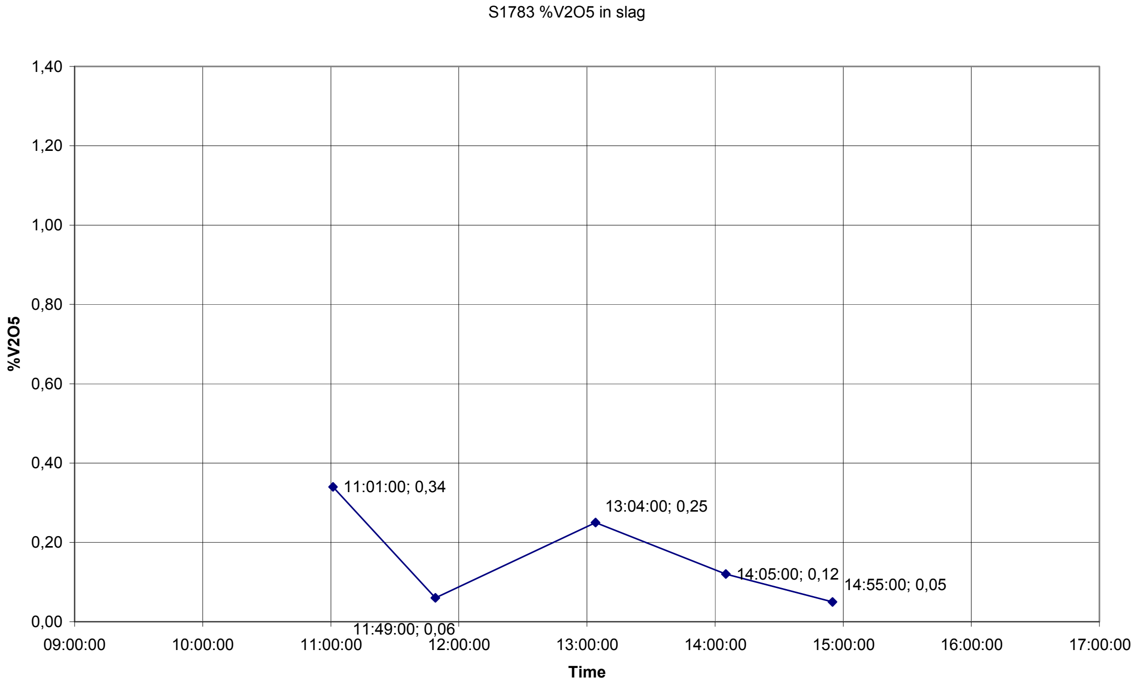
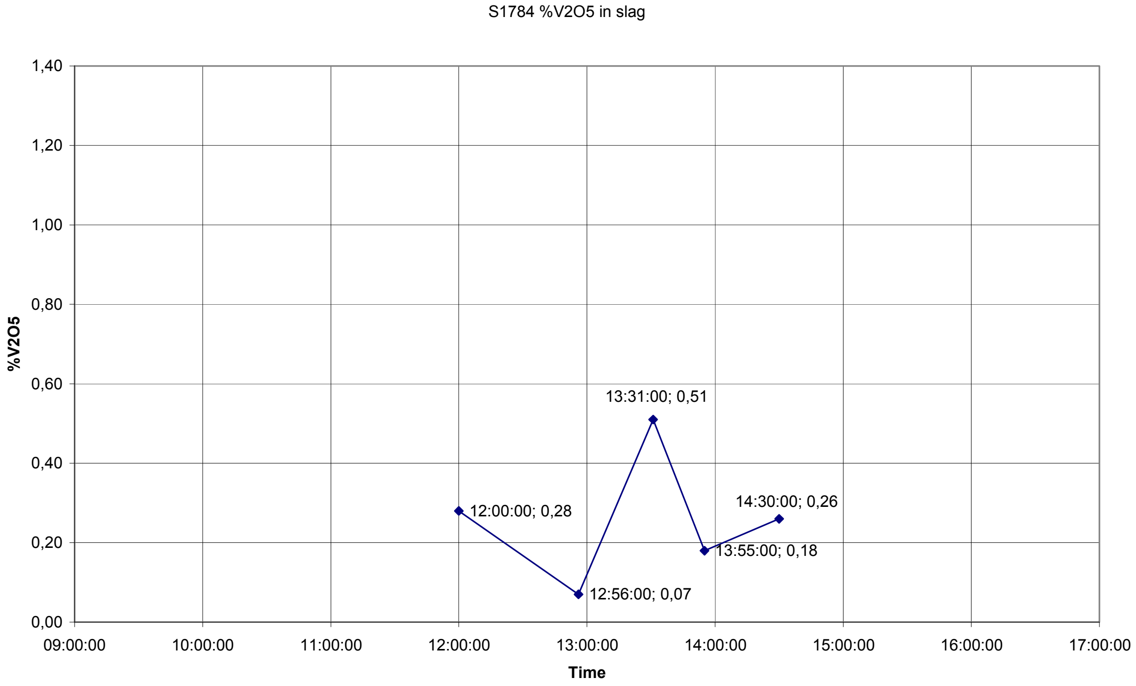
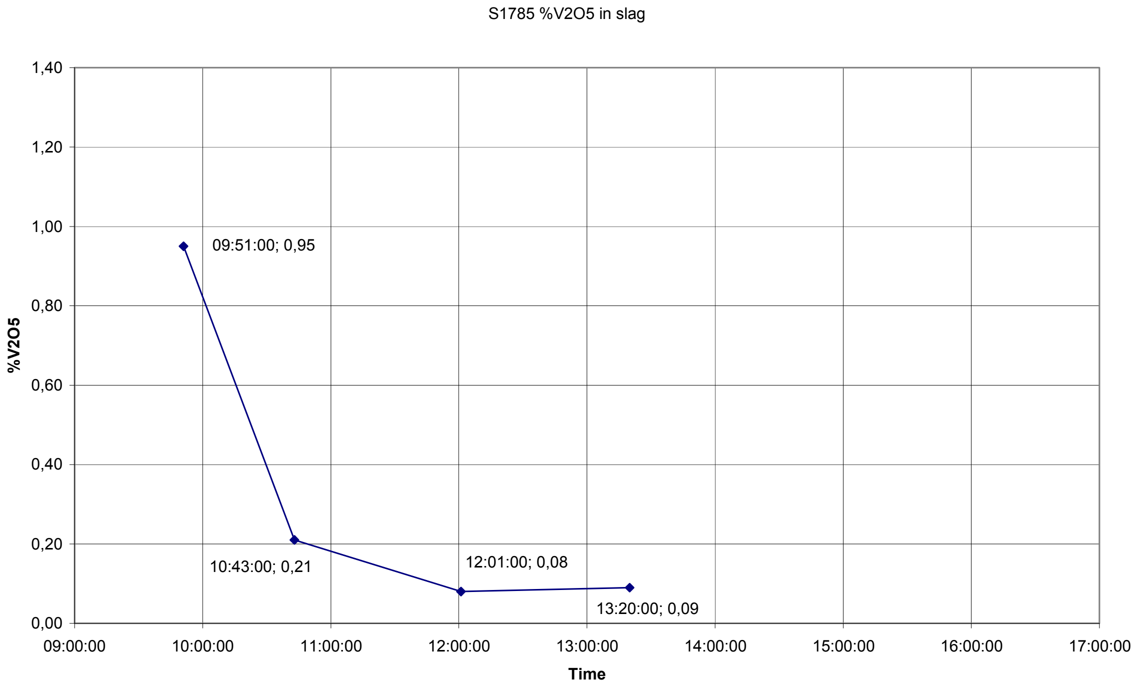


Figure 10 - S in slag HyMelt 2 to 6

6.3.3 Vanadium oxides






S1785 %V2O5 in slag
%V2O5
1,40
1,20
1,00
0,80
0,60
0,40
0,20
0,00
09:51:00; 0,95
10:43:00; 0,21
12:01:00; 0,08
13:20:00; 0,09
09:00:00
10:00:00
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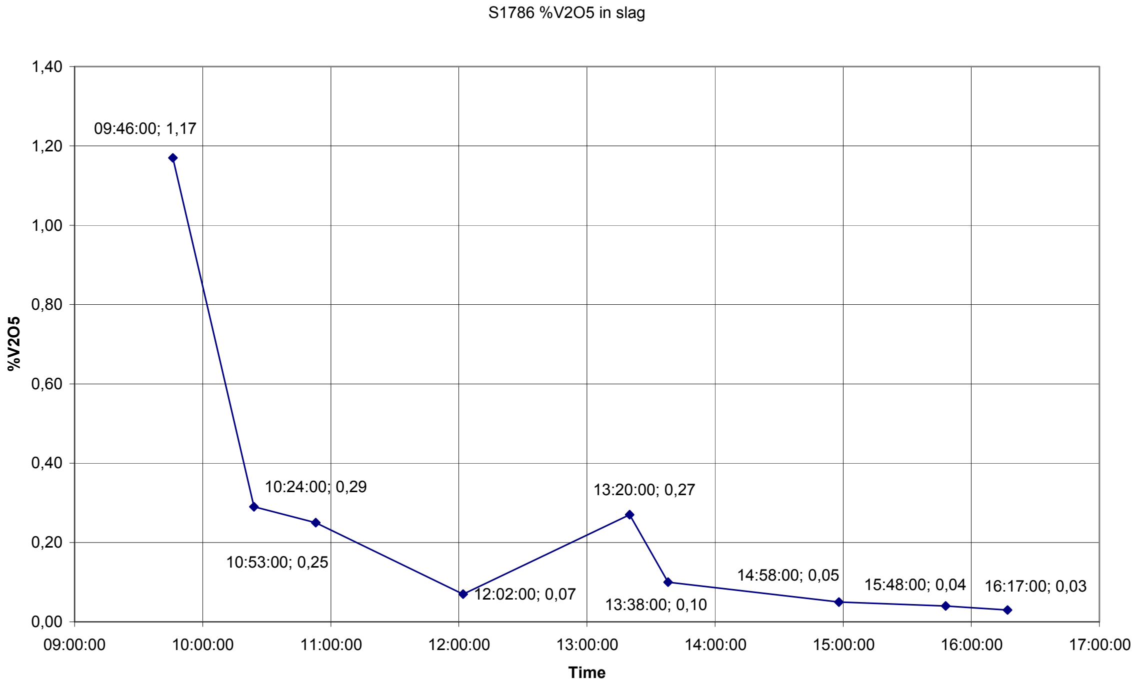
14:00:00
15:00:00
16:00:00
17:00:00
Time


S1786 %V2O5 in slag
%V2O5
1,40
1,20
1,00
0,80
0,60
0,40
0,20
0,00
09:46:00; 1,17
10:24:00; 0,29
10:53:00; 0,25
12:02:00; 0,07
13:20:00; 0,27
13:38:00; 0,10
14:58:00; 0,05
15:48:00; 0,04
16:17:00; 0,03
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
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16:00:00
17:00:00
Time

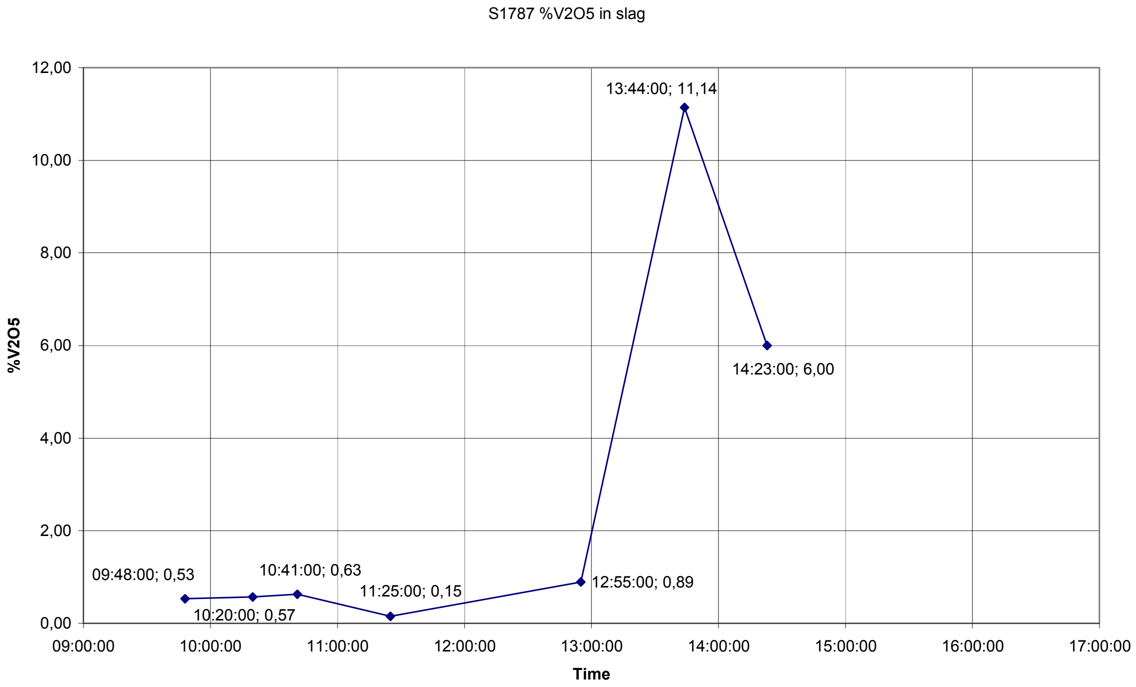
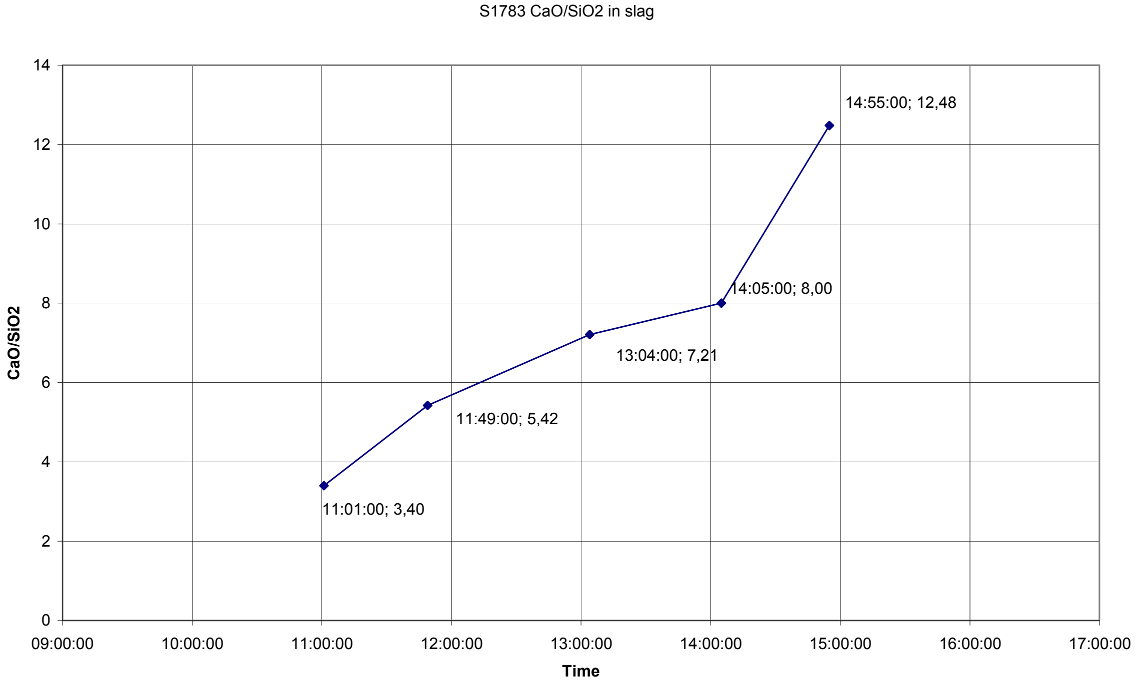
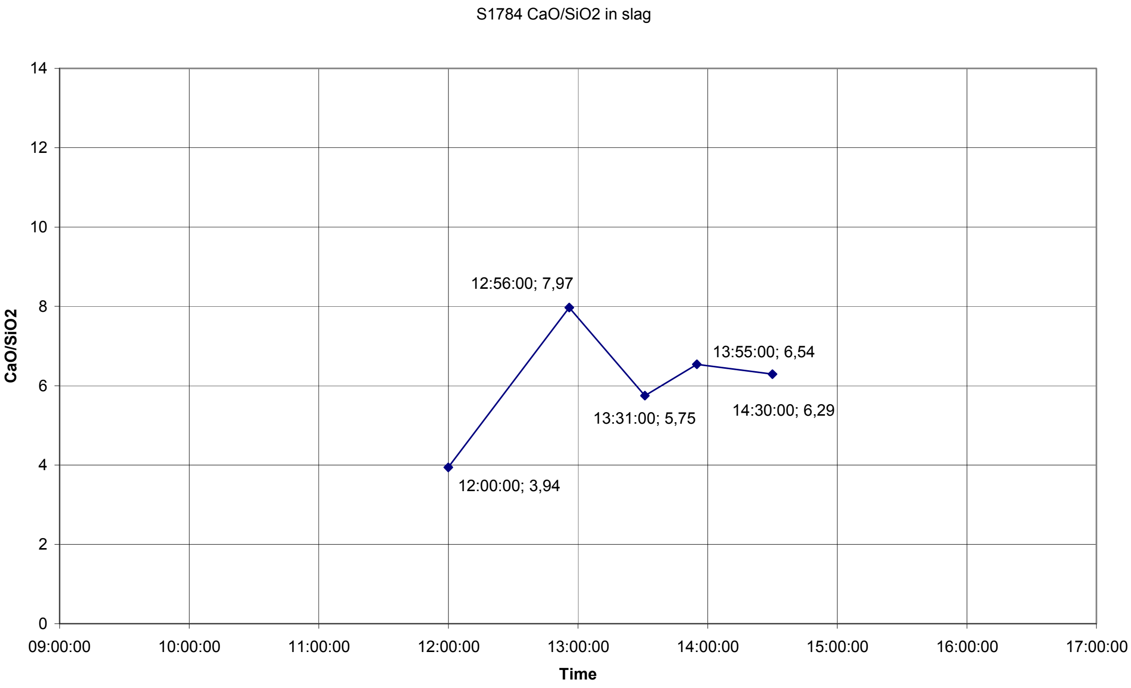
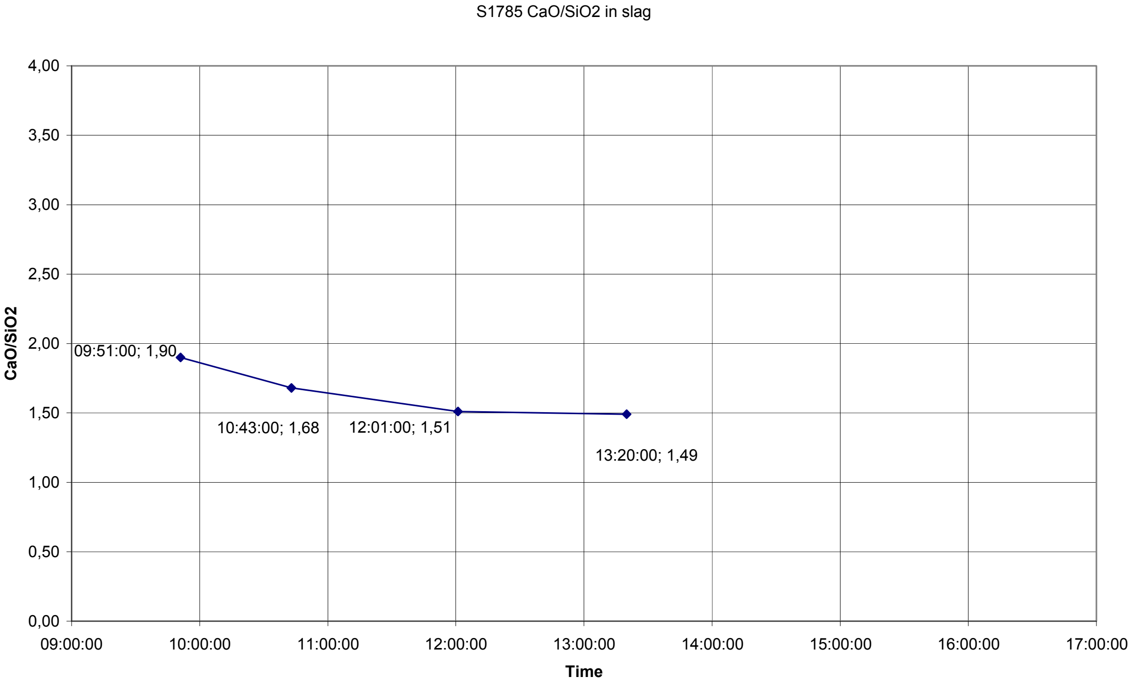


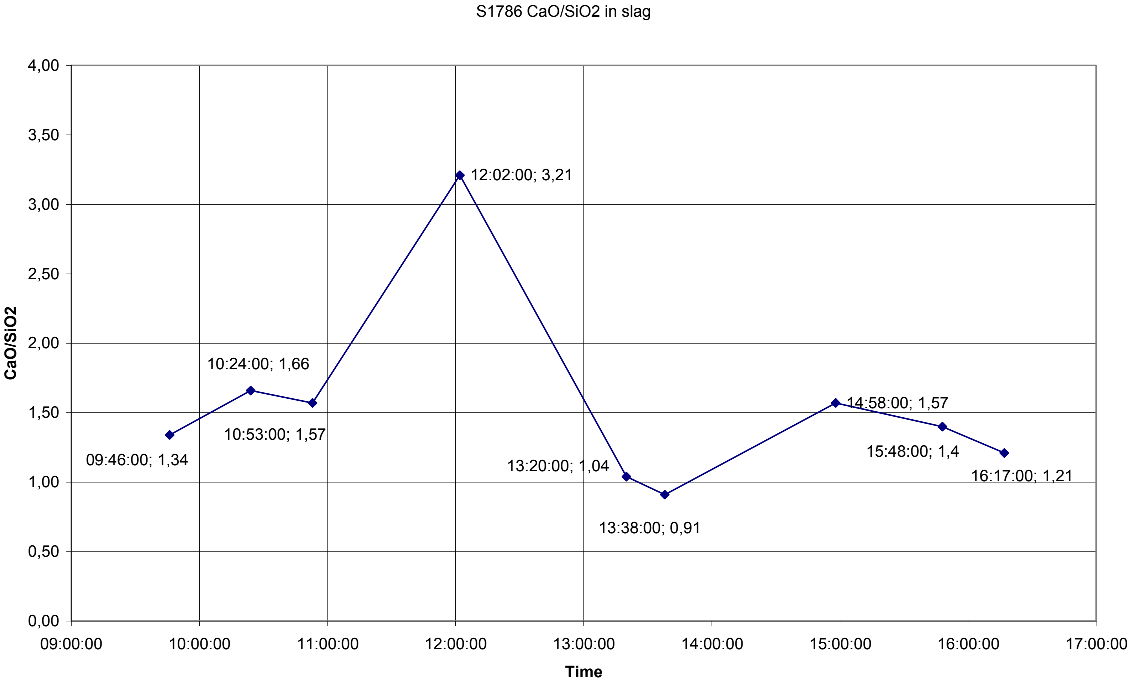
Figure 11 – V-oxides in slag HyMelt 2 to 6

6.3.4 Bas CaO/SiO$_2$




S1784 CaO/SiO2 in slag
CaO/SiO2
0
2
4
6
8
10
12
14
12:00:00; 3,94
12:56:00; 7,97
13:31:00; 5,75
13:55:00; 6,54
14:30:00; 6,29
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
Time


S1785 CaO/SiO2 in slag
CaO/SiO2
0,00
0,50
1,00
1,50
2,00
2,50
3,00
3,50
4,00
09:51:00; 1,90
10:43:00; 1,68
12:01:00; 1,51
13:20:00; 1,49
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
Time



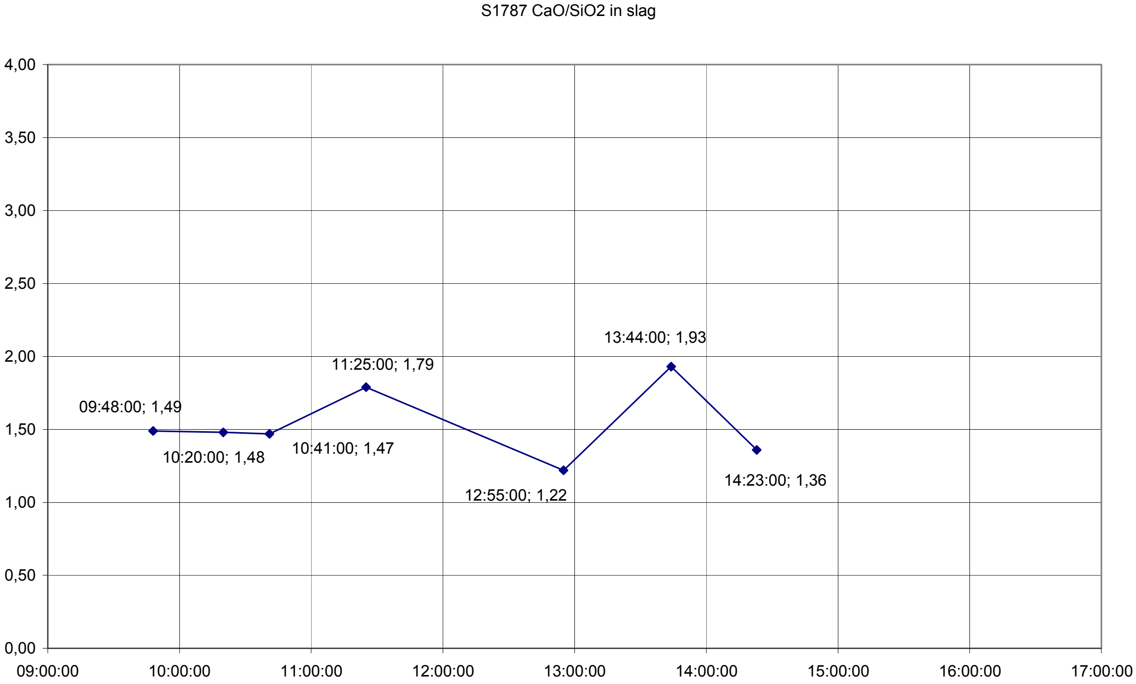
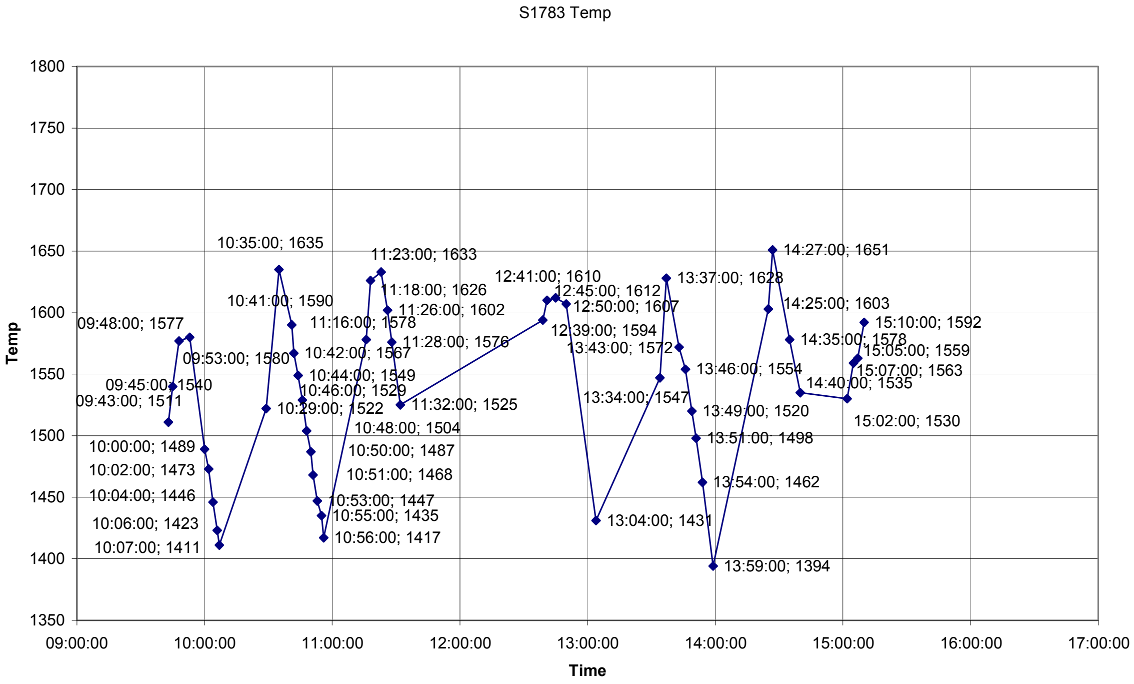
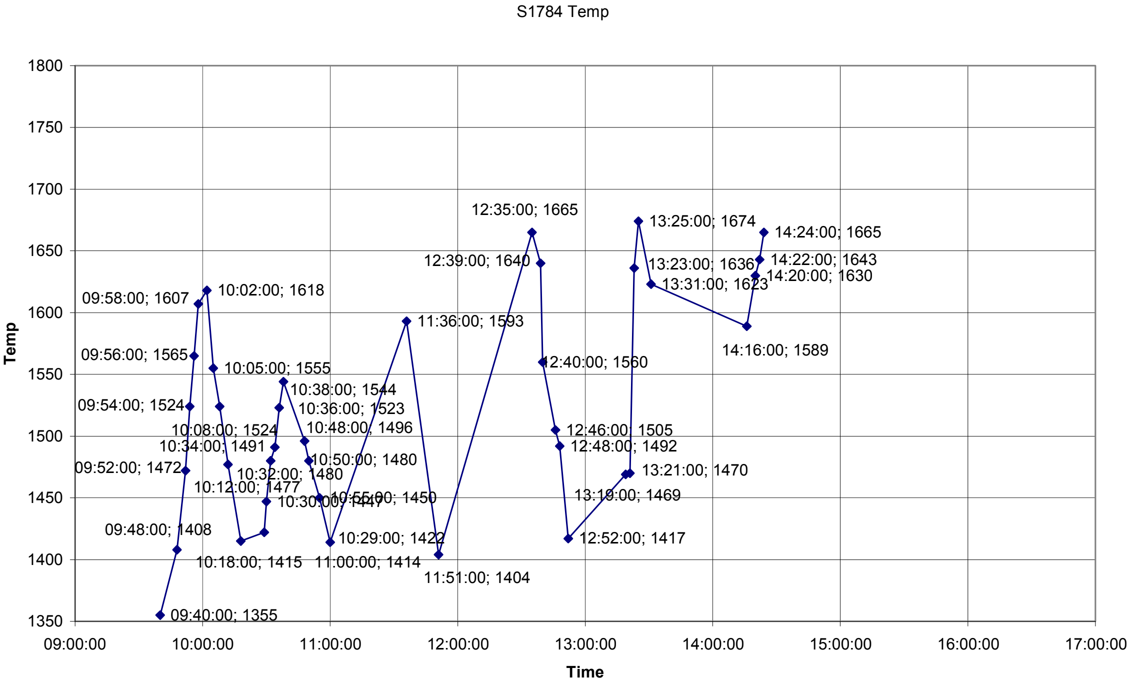


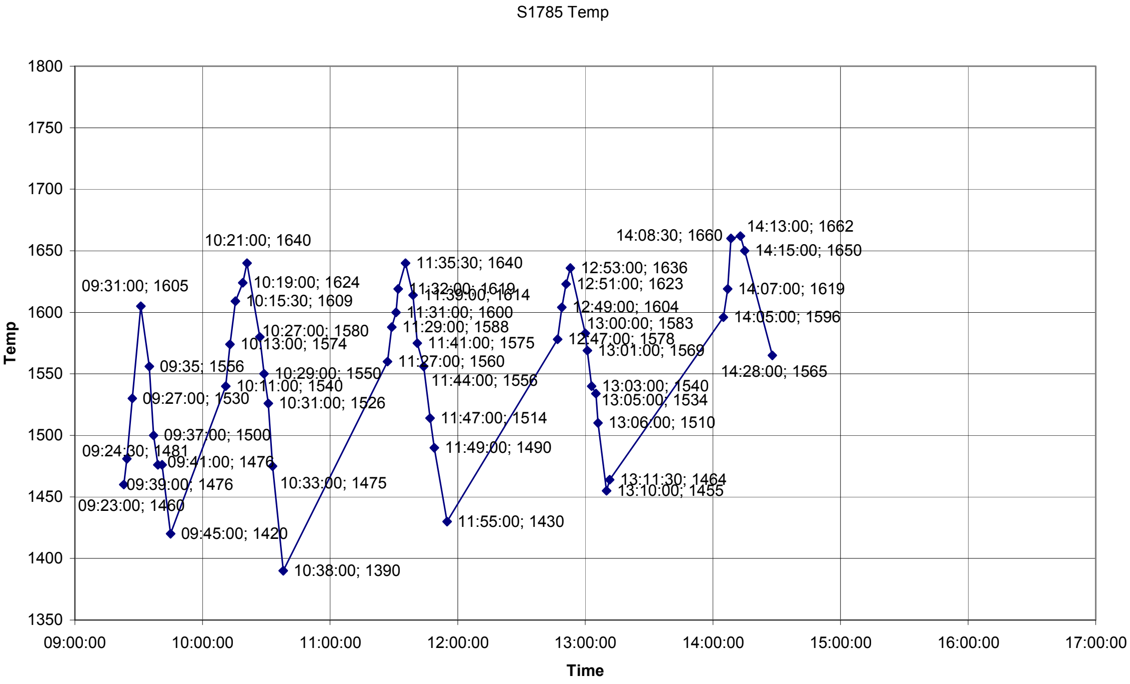
Figure 12 – CaO/SiO_2 ratio in slag HyMelt 2 to 6

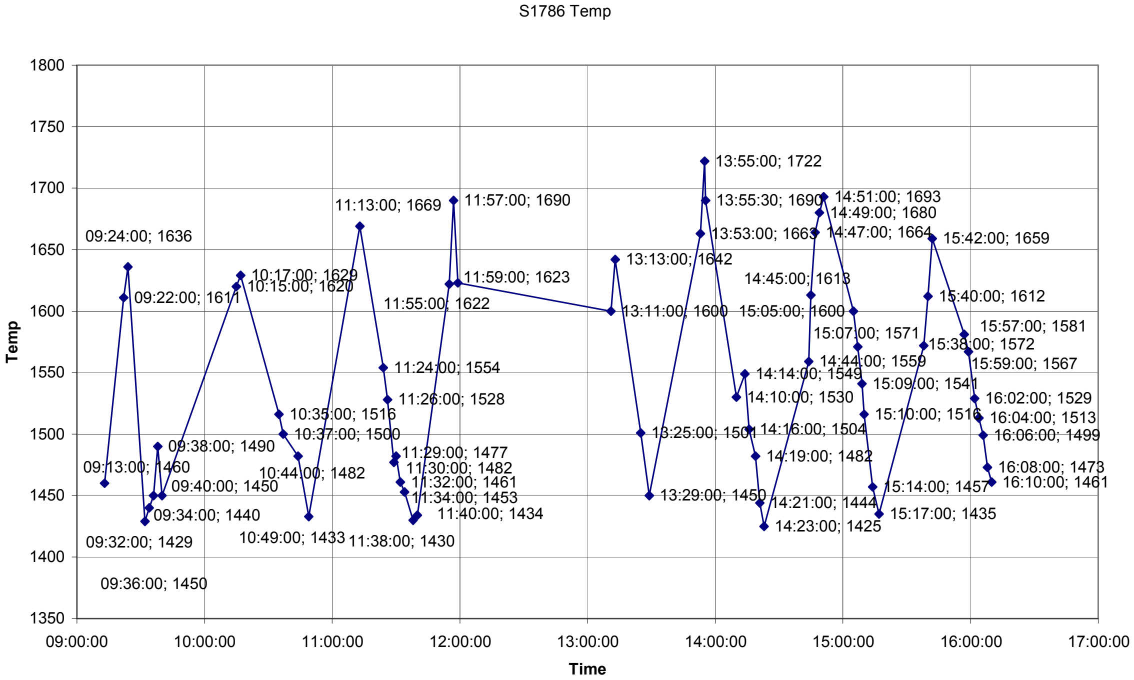
6.4 Temperatures

The metal temperatures refer either from sub-lance measurements or manual lance measurements. The system and code for evaluation of the EMK must be improved in the Lab View system, presented values are manually evaluated.




S1784 Temp
Temp
Time
1800
1750
1700
1650
1600
1550
1500
1450
1400
1350
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
09:40:00; 1355
09:48:00; 1408
09:52:00; 1472
09:54:00; 1524
09:56:00; 1565
09:58:00; 1607
10:02:00; 1618
10:05:00; 1555
10:08:00; 1524
10:12:00; 1477
10:18:00; 1415
10:29:00; 1422
10:30:00; 1447
10:32:00; 1480
10:34:00; 1491
10:36:00; 1523
10:38:00; 1544
10:48:00; 1496
10:50:00; 1480
10:55:00; 1450
11:00:00; 1414
11:36:00; 1593
11:51:00; 1404
12:35:00; 1665
12:39:00; 1640
12:40:00; 1560
12:46:00; 1505
12:48:00; 1492
12:52:00; 1417
13:19:00; 1469
13:21:00; 1470
13:23:00; 1636
13:25:00; 1674
13:31:00; 1623
14:16:00; 1589
14:20:00; 1630
14:22:00; 1643
14:24:00; 1665


S1785 Temp
Temp
Time
1800
1750
1700
1650
1600
1550
1500
1450
1400
1350
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
09:23:00; 1460
09:24:30; 1481
09:27:00; 1530
09:31:00; 1605
09:35; 1556
09:37:00; 1500
09:39:00; 1476
09:41:00; 1476
09:45:00; 1420
10:11:00; 1540
10:13:00; 1574
10:15:30; 1609
10:19:00; 1624
10:21:00; 1640
10:27:00; 1580
10:29:00; 1550
10:31:00; 1526
10:33:00; 1475
10:38:00; 1390
11:27:00; 1560
11:29:00; 1588
11:31:00; 1600
11:32:00; 1619
11:35:30; 1640
11:39:00; 1614
11:41:00; 1575
11:44:00; 1556
11:47:00; 1514
11:49:00; 1490
11:55:00; 1430
12:47:00; 1578
12:49:00; 1604
12:51:00; 1623
12:53:00; 1636
13:00:00; 1583
13:01:00; 1569
13:03:00; 1540
13:05:00; 1534
13:06:00; 1510
13:10:00; 1455
13:11:30; 1464
14:05:00; 1596
14:07:00; 1619
14:08:30; 1660
14:13:00; 1662
14:15:00; 1650
14:28:00; 1565



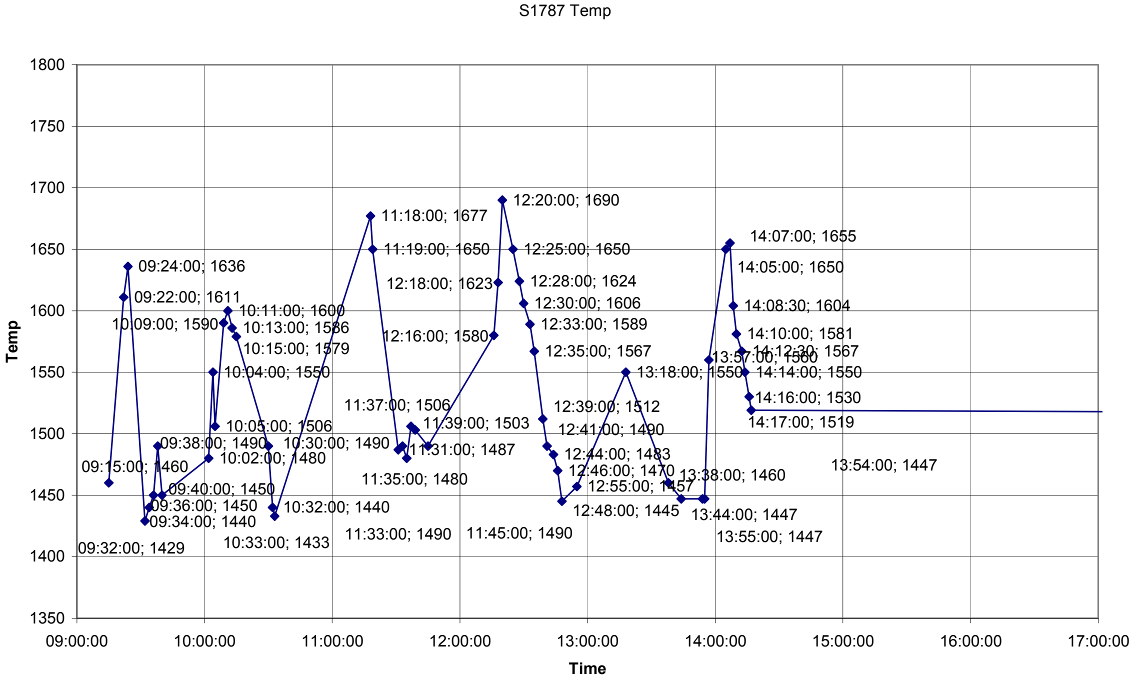


Figure 13 – Temperature in liquid metal HyMelt 2 to 6

6.5 Carbon yield to metal

The carbon yield has been calculated for all injection periods. The calculation is based on the first and last metal analysis in the period and the injected amount of carbon during the time between sampling. Details are shown in Appendix 4.

The best results were archived for pet-coke at moderate feeding rate. A rather strong dependence between yield and feeding rate can be seen. The expected relation between nozzle diameter and yield can not be detected.

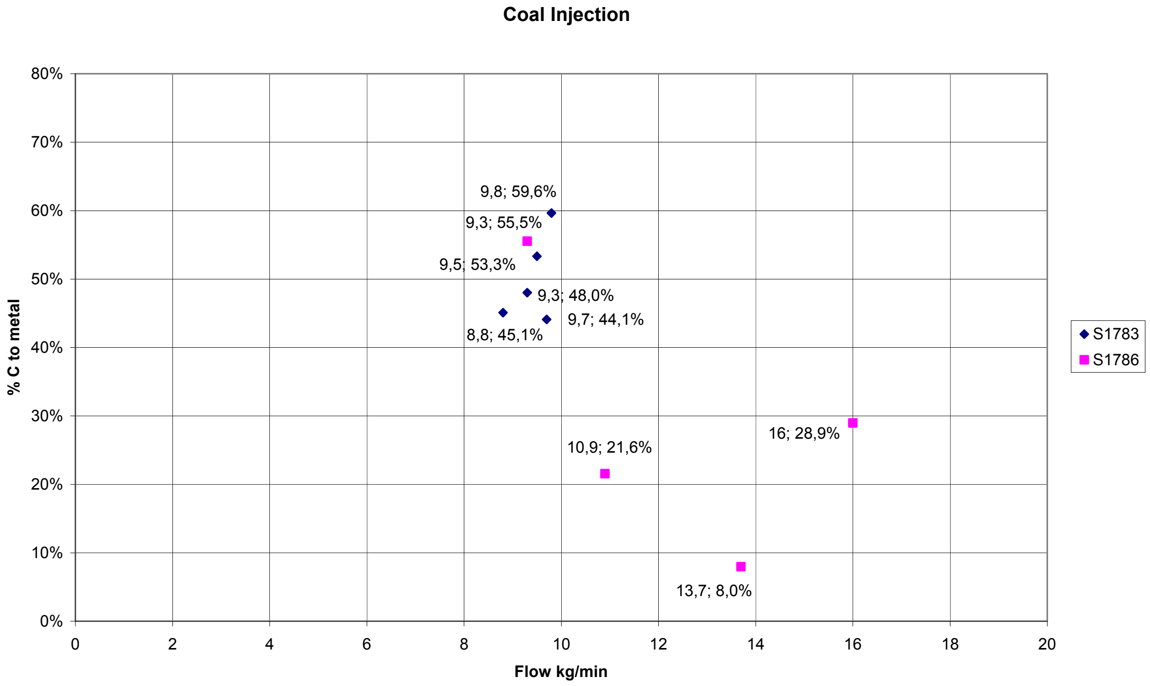


Figure 14 - C yield for coal injection

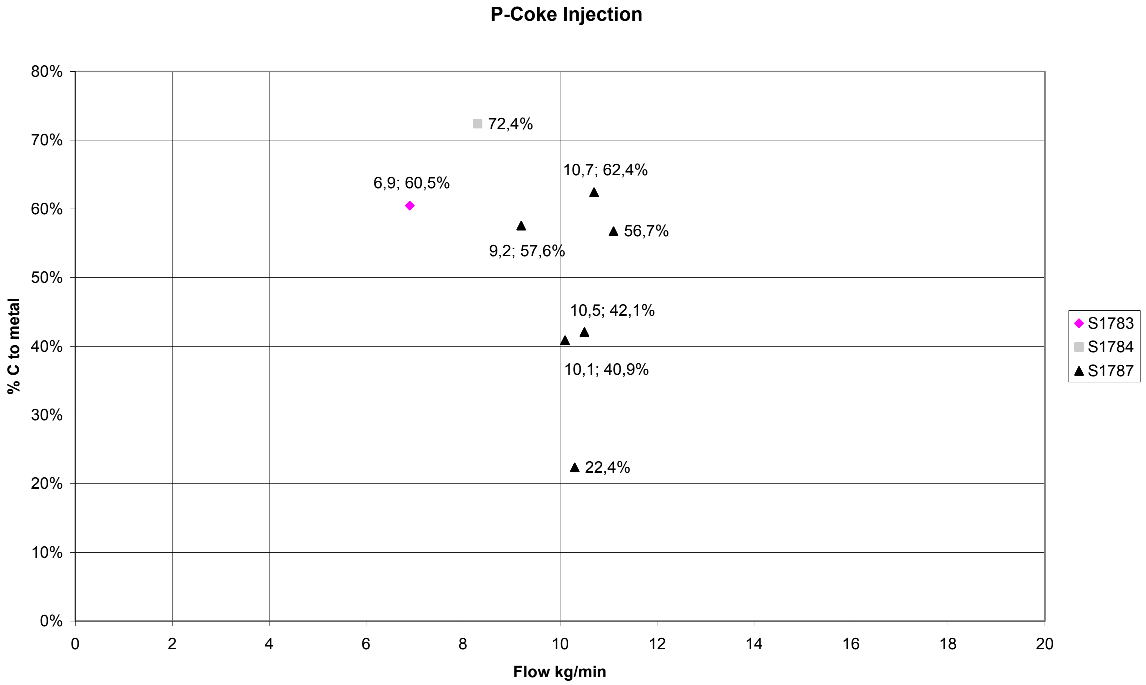


Figure 15 - C yield for coke injection

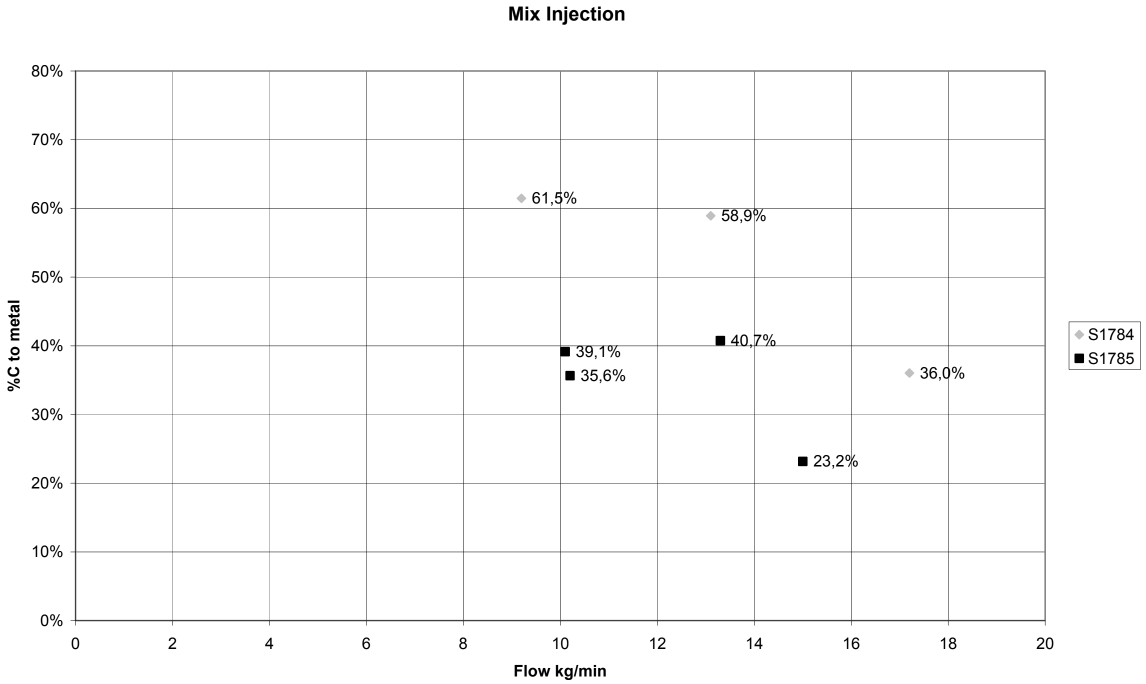


Figure 16 - C yield for coal/coke mix injection

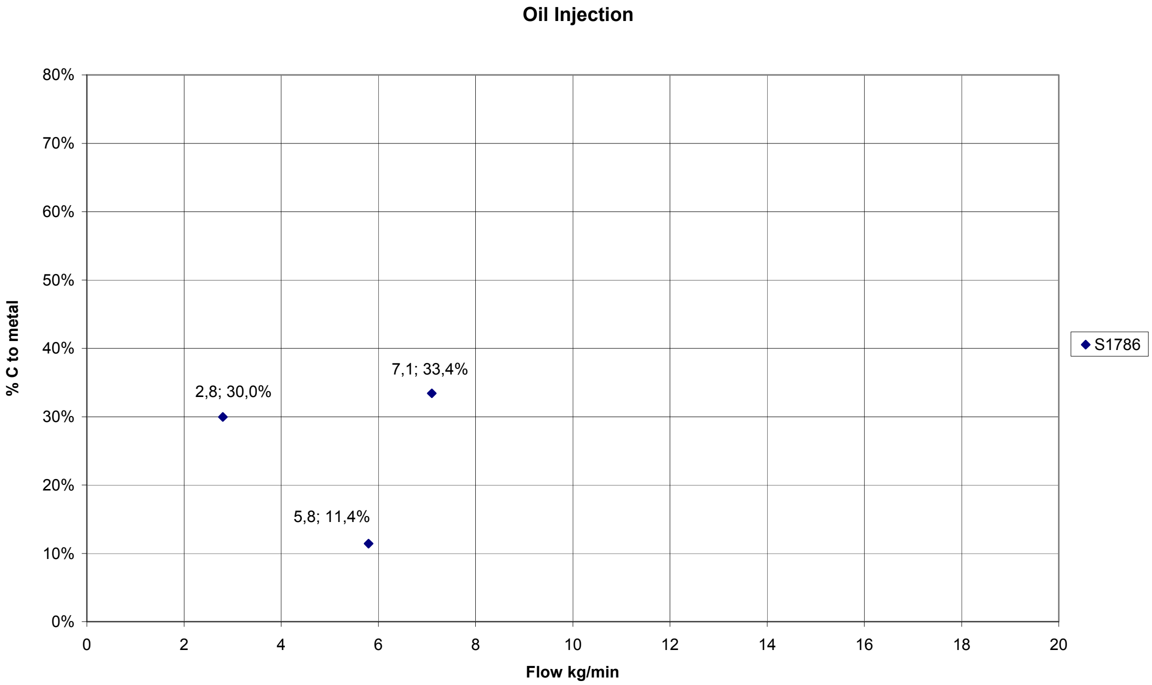


Figure 17 - C yield for oil injection

6.6 Vanadium balance

During HyMelt 6, 80 kg ferro vanadium was added, equal to 65, 5 kg pure V. As can be seen in the table the vanadium is distributed between metal and slag. The concentration ratio is strongly depending on oxygen potential. The response in metal analysis after addition is higher than expected indicating some error in the background data for calculation.

Table 1 – Vanadium balance data

S1787

	Metal			Slag				Calculation	
Time	Weight kg	%C	%V	%Fe	%CaO	%SiO2	%V2O5	CaO/SiO2	[V2O5]/(V)
11:25	5376	1,06	0,051	6,06	37,82	21,09	0,15	1,79	2,94
12:12	5331	Addition of 80 kg FeV (81,88 %V)							
12:55	5207	2,98	1,573	18,65	9,67	24,32	0,89	0,40	0,57
13:44	5082	2,16	0,507	3,3	39,46	20,47	11,14	1,93	21,97
14:23	5082	2,27	0,744	4,09	36,24	26,72	6,00	1,36	8,06

6.7 Hydrogen purging

During HyMelt 6 hydrogen was purged trough the bottom tuyere for 17 minutes. The purpose was to investigate the possibility to remove S to the gas phase.

Before gas purging
Metal 0,8 % S
Slag 5,74 % S

After gas purging
Metal 0,60 % S
Slag 4,81 % S

About 12 kg sulphur has been removed from metal and slag. This corresponds to 44 % efficiency if creation of H_2S is assumed. However, this can not be confirmed by the gas analysing. Further studies must be made to fully understand the chemical mechanisms.

6.8 Dust analysis

6.8.1 Dust sampled from process gas

Dust from the ceramic filter have been analysed, the results are shown in Appendix 5.

Label “Prov K7” refers to coal injection
Label “Prov K21” refers to oil injection
Label “Prov K25” refers to coke injection

The lab has problem to determine carbon because of the small sample amount.

6.8.2 Dust sampled from combusted gas

Estimation by iso-kinetic sampling of the dust load has been made from the injection periods, Appendix 6. The results show a load less than 10 gram/m^{3}n dry gas in average.

Three samples have been analysed and the result are presented in Appendix 7.

Label "Prov 7" refers to coal injection
Label "Prov 21" refers to oil injection
Label "Prov 25" refers to coke injection

The lab has problem to determine carbon because of the small sample amount.

6.9 Mercury in process gas

Three samples for mercury determination in the process gas have been analysed, Appendix 8, The result differs very much in spite of that all three samples refers to coal injection. Obviously there are severe problems with the procedure and must be drastically improved. In future it will be necessary to have one dedicated suction line for the mercury sampling.

"Prov 1", "Prov2" and "Prov 3" are sampled liquids while "Prov 0" is a reference on clean liquid.

6.10 Refractory wear

The converter lining was measured before and after the campaign. As can be seen in the table no severe wear has occurred. Typical erosion in the level of the slag can be seen.

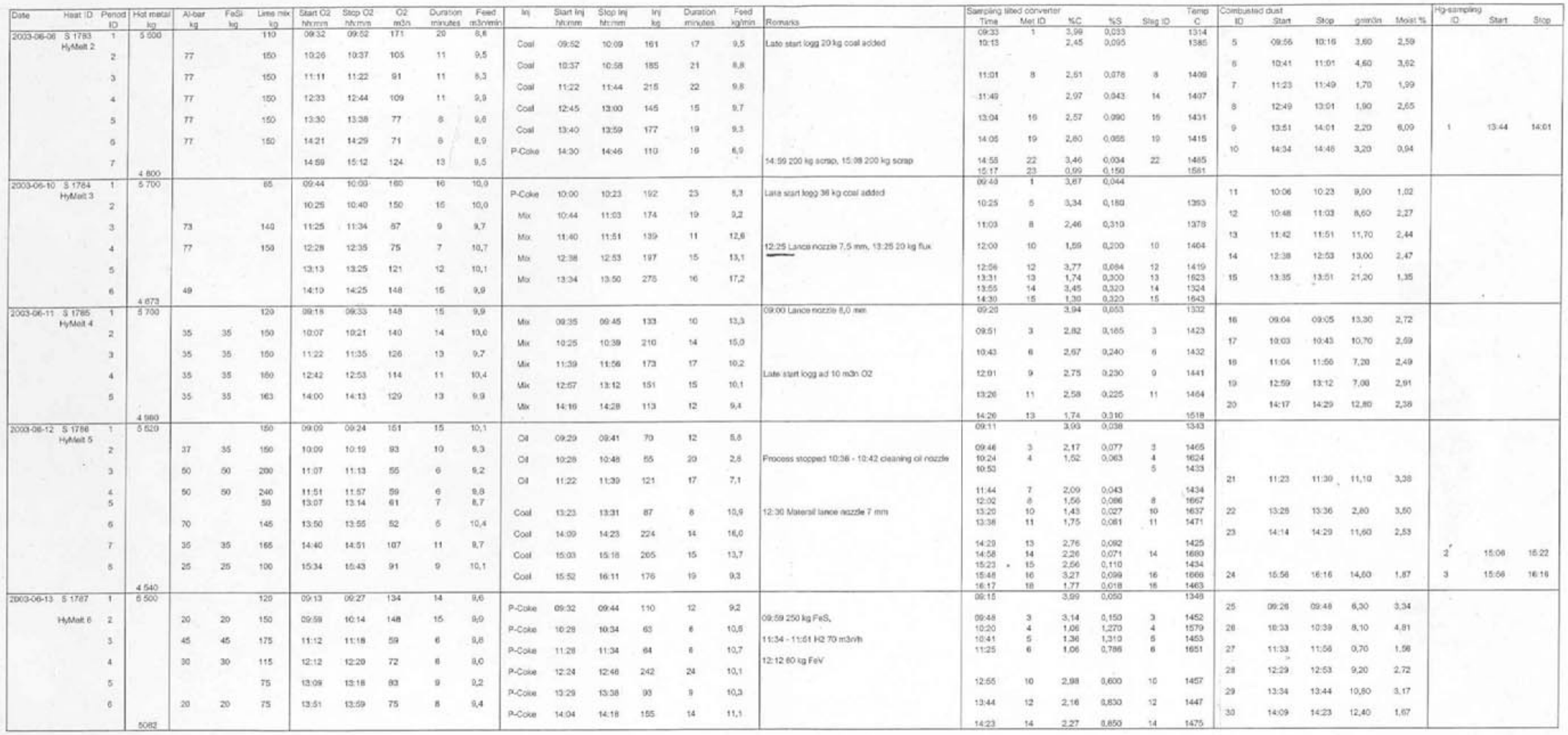
Table 2 – Lining wear

	New lining		After HyMelt 6		Wear
Level	N/S	E/W	N/S	E/W	
Cone	1410	1410	1360	1420	-10
1500	1410	1410	1440	1440	15
1250	1410	1410	1460	1460	25
1000	1410	1410	1460	1460	25
750	1410	1410	1450	1460	23
500	1410	1410	1480	1470	33
250	1410	1410	1500	1460	35
0	1410	1410	1423	1413	4
Hight	2893		2990		97

The lining can stand a wear up to 150 mm and can consequently be used for further campaigns. Minor repair work will be necessary on local spots.

HyMelt Periods over-view

APPENDIX 1



Date	Heat ID	Period ID	Hot metal kg	Al-bar kg	FeSi kg	Lime mix kg	Start O2 hh:mm	Stop O2 hh:mm	O2 m3n	Duration minutes	Feed m3n/min
2003-06-06	S 1783 HyMelt 2	1	5 500			110	09:32	09:52	171	20	8,8
		2		77		150	10:26	10:37	105	11	9,5
		3		77		150	11:11	11:22	91	11	8,3
		4		77		150	12:33	12:44	109	11	9,9
		5		77		150	13:30	13:38	77	8	9,6
		6		77		150	14:21	14:29	71	8	8,9
		7					14:59	15:12	124	13	9,5
			4 800								
2003-06-10	S 1784 HyMelt 3	1	5 700			65	09:44	10:00	160	16	10,9
		2					10:25	10:40	150	15	10,0
		3		73		140	11:25	11:34	87	9	9,7
		4		77		150	12:28	12:35	75	7	10,7
		5					13:13	13:25	121	12	10,1
		6		49			14:10	14:25	148	15	9,9
			4 673								
2003-06-11	S 1785 HyMelt 4	1	5 700			120	09:18	09:33	148	15	9,9
		2		35	35	150	10:07	10:21	140	14	10,6
		3		35	35	150	11:22	11:35	126	13	9,7
		4		35	35	150	12:42	12:53	114	11	10,4
		5		35	35	163	14:00	14:13	129	13	9,9
			4 980								
2003-06-12	S 1786 HyMelt 5	1	5 620			150	09:09	09:24	151	15	10,1
		2		37	35	150	10:09	10:19	93	10	9,3
		3		50	50	200	11:07	11:13	55	6	9,2
		4		50	50	240	11:51	11:57	59	6	9,8
		5				50	13:07	13:14	61	7	8,7
		6		70		145	13:50	13:55	52	5	10,4
		7		35	35	165	14:40	14:51	107	11	9,7
		8		25	25	100	15:34	15:43	91	9	10,1
			4 540								
2003-06-13	S 1787 HyMelt 6	1	6 500			120	09:13	09:27	134	14	9,6
		2		20	20	150	09:59	10:14	148	15	9,0
		3		45	45	175	11:12	11:18	59	6	9,8
		4		30	30	115	12:12	12:20	72	8	9,0
		5				75	13:09	13:18	83	9	9,2
		6		20	20	75	13:51	13:59	75	8	9,4
			5082								

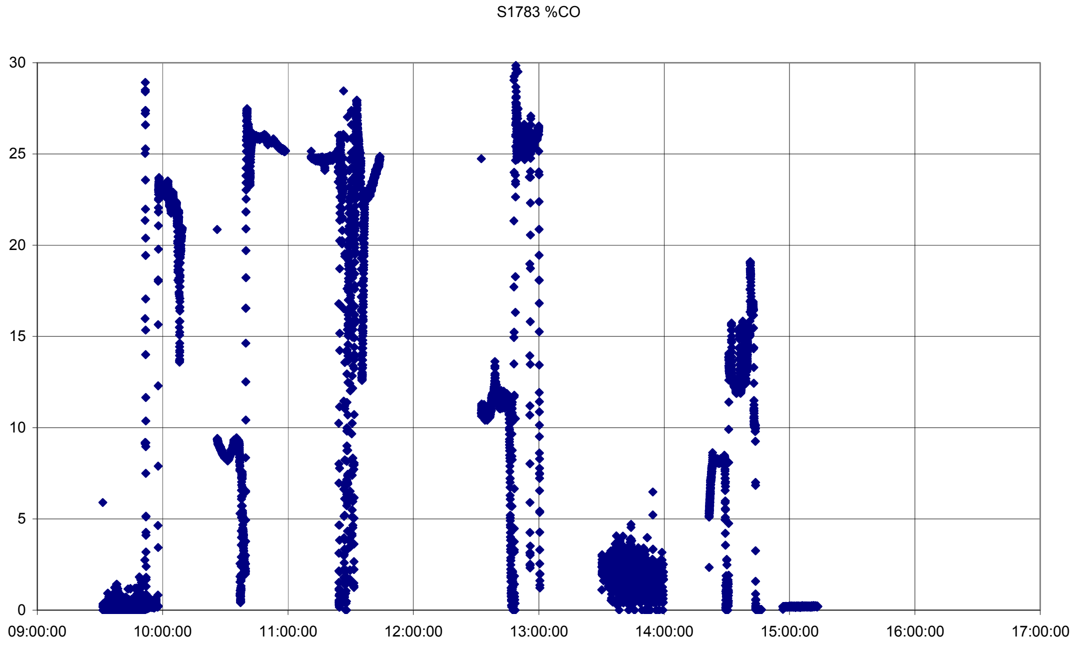
Date	Heat ID	Inj	Start Inj hh:mm	Stop Inj hh:mm	Inj kg	Duration minutes	Feed kg/min	Remarks
2003-06-06	S 1783 HyMelt 2	Coal	09:52	10:09	161	17	9,5	Late start logg 20 kg coal added
		Coal	10:37	10:58	185	21	8,8	
		Coal	11:22	11:44	215	22	9,8	
		Coal	12:45	13:00	145	15	9,7	
		Coal	13:40	13:59	177	19	9,3	
		P-Coke	14:30	14:46	110	16	6,9	
								14:59 200 kg scrap, 15:08 200 kg scrap
2003-06-10	S 1784 HyMelt 3	P-Coke	10:00	10:23	192	23	8,3	Late start logg 36 kg coal added
		Mix	10:44	11:03	174	19	9,2	
		Mix	11:40	11:51	139	11	12,6	12:25 Lance nozzle 7,5 mm, 13:25 20 kg flux
		Mix	12:38	12:53	197	15	13,1	
		Mix	13:34	13:50	275	16	17,2	
2003-06-11	S 1785 HyMelt 4							09:00 Lance nozzle 8,0 mm
		Mix	09:35	09:45	133	10	13,3	
		Mix	10:25	10:39	210	14	15,0	
		Mix	11:39	11:56	173	17	10,2	Late start logg ad 10 m3n O2
		Mix	12:57	13:12	151	15	10,1	
		Mix	14:16	14:28	113	12	9,4	
2003-06-12	S 1786 HyMelt 5	Oil	09:29	09:41	70	12	5,8	
		Oil	10:28	10:48	55	20	2,8	Process stopped 10:36 - 10:42 cleaning oil nozzle
		Oil	11:22	11:39	121	17	7,1	
		Coal	13:23	13:31	87	8	10,9	12:30 Materail lance nozzle 7 mm
		Coal	14:09	14:23	224	14	16,0	
		Coal	15:03	15:18	205	15	13,7	
		Coal	15:52	16:11	176	19	9,3	
2003-06-13	S 1787 HyMelt 6	P-Coke	09:32	09:44	110	12	9,2	
		P-Coke	10:28	10:34	63	6	10,5	09:59 250 kg FeS,
		P-Coke	11:28	11:34	64	6	10,7	11:34 - 11:51 H2 70 m3n/h
		P-Coke	12:24	12:48	242	24	10,1	12:12 60 kg FeV
		P-Coke	13:29	13:38	93	9	10,3	
		P-Coke	14:04	14:18	155	14	11,1	

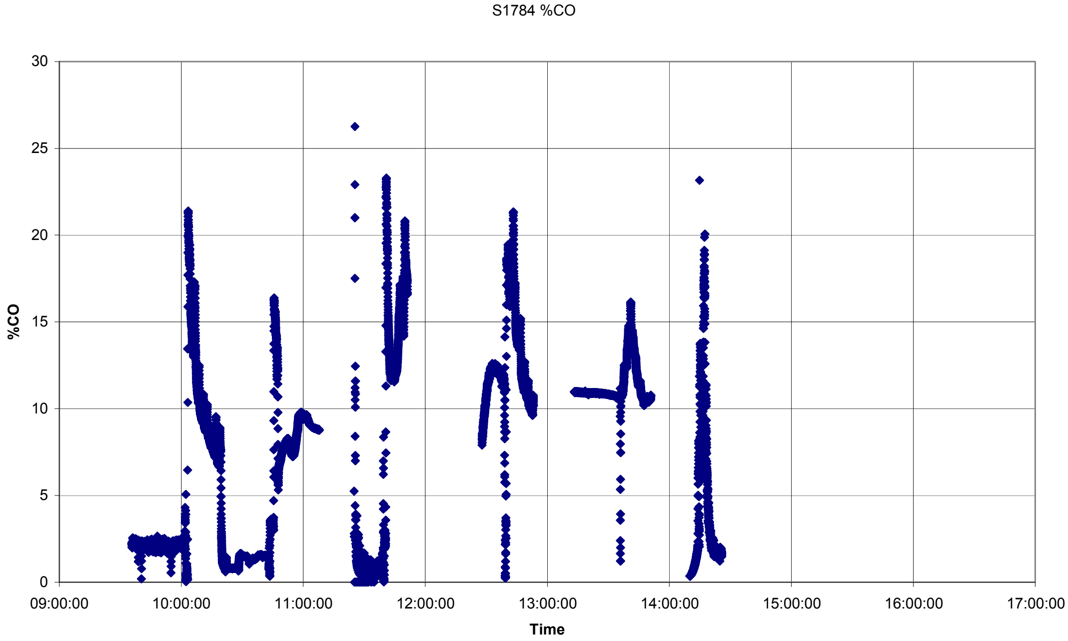
Date	Heat ID	Sampling tilted converter Time	Met ID	%C	%S	Slag ID	Temp C
2003-06-06	S 1783 HyMelt 2	09:33	1	3,99	0,033		1314
		10:13		2,45	0,095		1385
		11:01	8	2,51	0,078	8	1409
		11:49		2,97	0,043	14	1407
		13:04	16	2,57	0,090	16	1431
		14:05	19	2,80	0,055	19	1415
		14:55	22	3,46	0,034	22	1485
		15:17	23	0,99	0,150		1581
2003-06-10	S 1784 HyMelt 3	09:43	1	3,67	0,044		
		10:25	5	3,34	0,180		1393
		11:03	8	2,46	0,310		1378
		12:00	10	1,59	0,200	10	1404
		12:56	12	3,77	0,084	12	1419
		13:31	13	1,74	0,300	13	1623
		13:55	14	3,45	0,320	14	1324
		14:30	15	1,30	0,320	15	1643
2003-06-11	S 1785 HyMelt 4	09:20		3,94	0,053		1332
		09:51	3	2,82	0,165	3	1423
		10:43	6	2,67	0,240	6	1432
		12:01	9	2,75	0,230	9	1441
		13:26	11	2,58	0,225	11	1464
		14:26	13	1,74	0,310		1518
2003-06-12	S 1786 HyMelt 5	09:11		3,93	0,038		1343
		09:46	3	2,17	0,077	3	1465
		10:24	4	1,52	0,063	4	1624
		10:53				5	1433
		11:44	7	2,09	0,043		1434
		12:02	8	1,56	0,086	8	1667
		13:20	10	1,43	0,027	10	1637
		13:38	11	1,75	0,081	11	1471
		14:29	13	2,76	0,092		1425
		14:58	14	2,26	0,071	14	1680
		15:23	15	2,56	0,110		1434
		15:48	16	3,27	0,099	16	1666
		16:17	18	1,77	0,018	18	1463
2003-06-13	S 1787 HyMelt 6	09:15		3,99	0,050		1348
		09:48	3	3,14	0,150	3	1452
		10:20	4	1,06	1,270	4	1579
		10:41	5	1,36	1,310	5	1453
		11:25	6	1,06	0,786	6	1651
		12:55	10	2,98	0,600	10	1457
		13:44	12	2,16	0,830	12	1447
		14:23	14	2,27	0,850	14	1475

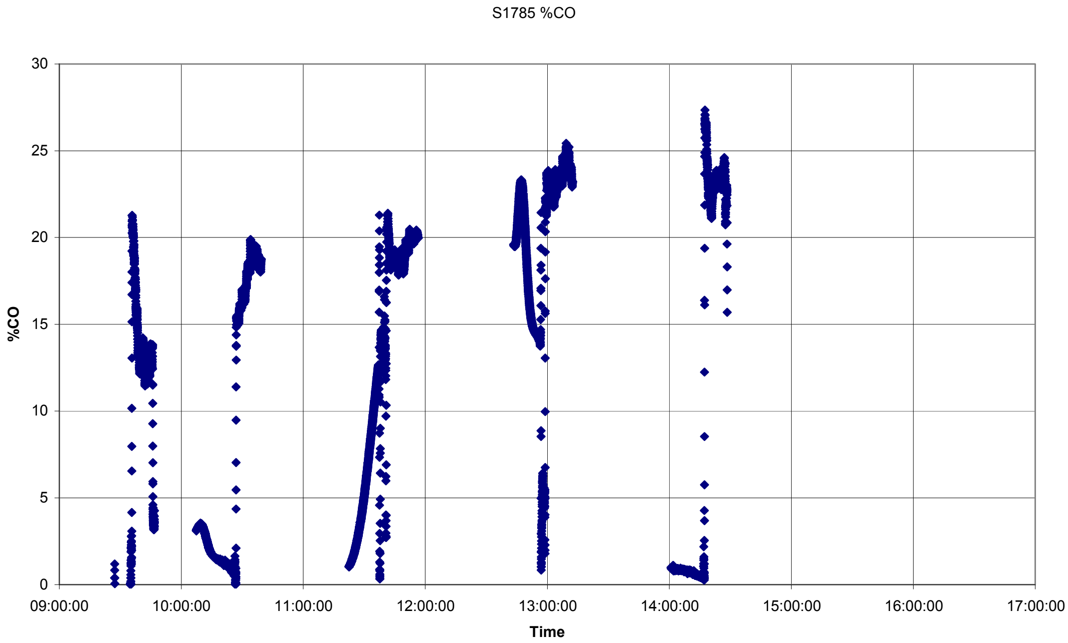
Date	Heat ID	Combusted dust ID	Start	Stop	g/m3n	Moist %
2003-06-06	S 1783 HyMelt 2	5	09:56	10:16	3,60	2,59
		6	10:41	11:01	4,60	3,62
		7	11:23	11:49	1,70	1,99
		8	12:49	13:01	1,90	2,65
		9	13:51	14:01	2,20	6,09
		10	14:34	14:46	3,20	0,94
2003-06-10	S 1784 HyMelt 3	11	10:06	10:23	9,00	1,02
		12	10:48	11:03	8,60	2,27
		13	11:42	11:51	11,70	2,44
		14	12:38	12:53	13,00	2,47
		15	13:35	13:51	21,20	1,35
2003-06-11	S 1785 HyMelt 4	16	09:04	09:05	13,30	2,72
		17	10:03	10:43	10,70	2,69
		18	11:04	11:56	7,20	2,49
		19	12:59	13:12	7,08	2,91
		20	14:17	14:29	12,80	2,38
2003-06-12	S 1786 HyMelt 5	21	11:23	11:30	11,10	3,38
		22	13:28	13:36	2,80	3,50
		23	14:14	14:29	11,60	2,53
		24	15:56	16:16	14,60	1,87
2003-06-13	S 1787 HyMelt 6	25	09:26	09:48	6,30	3,34
		26	10:33	10:39	8,10	4,81
		27	11:33	11:56	0,70	1,56
		28	12:29	12:53	9,20	2,72
		29	13:34	13:44	10,80	3,17
		30	14:09	14:23	12,40	1,67

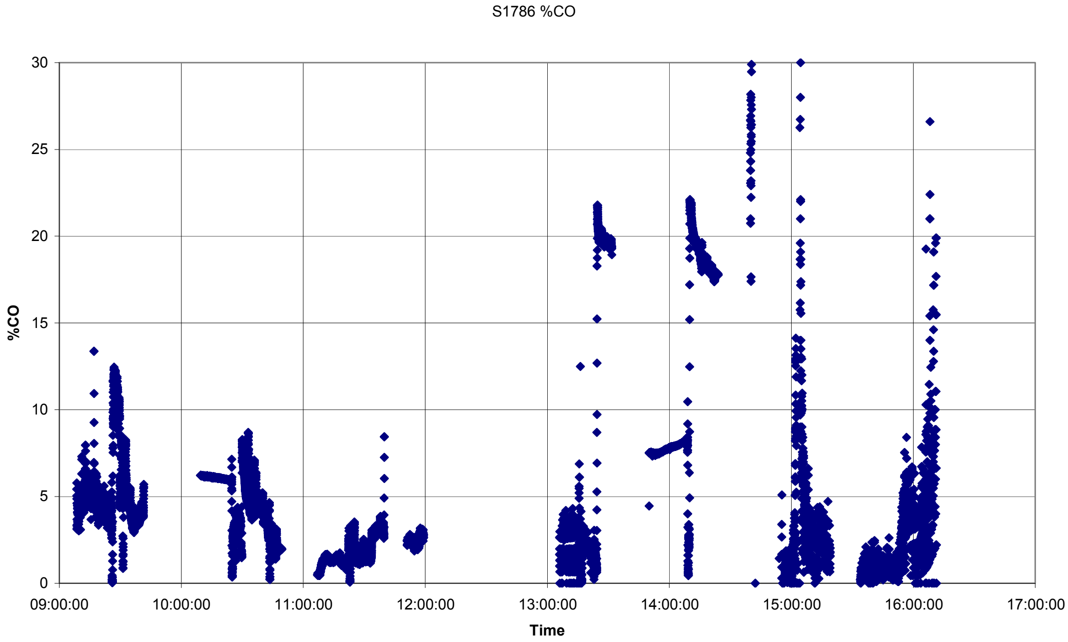
Date	Heat ID	Hg-sampling ID	Start	Stop
2003-06-06	S 1783 HyMelt 2	1	13:44	14:01
2003-06-12	S 1786 HyMelt 5	2	15:06	16:22
		3	15:56	16:16

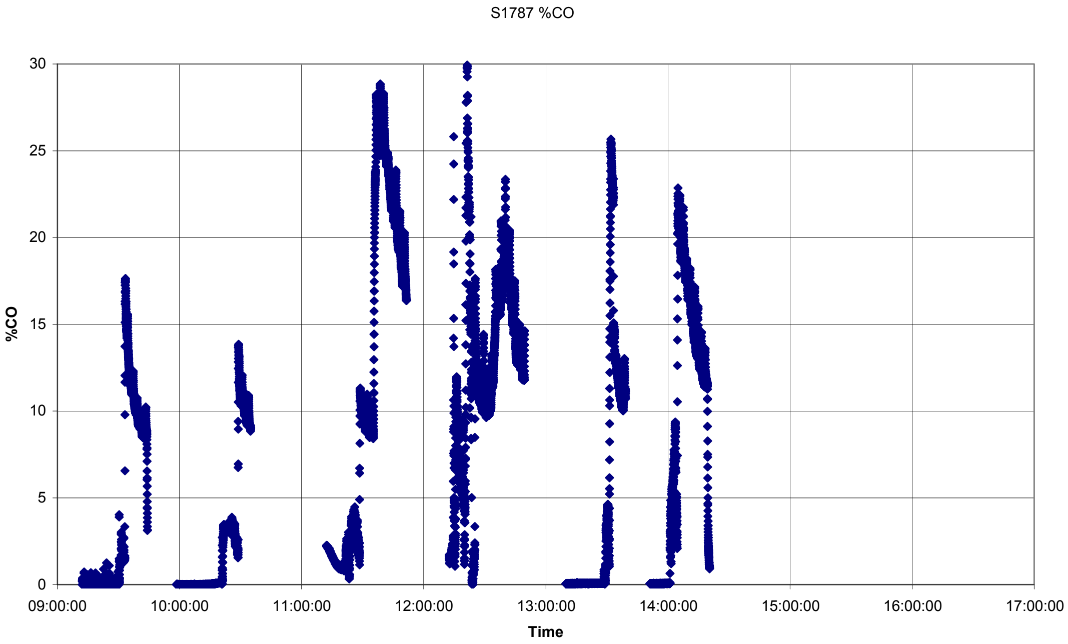
CO gas analysis



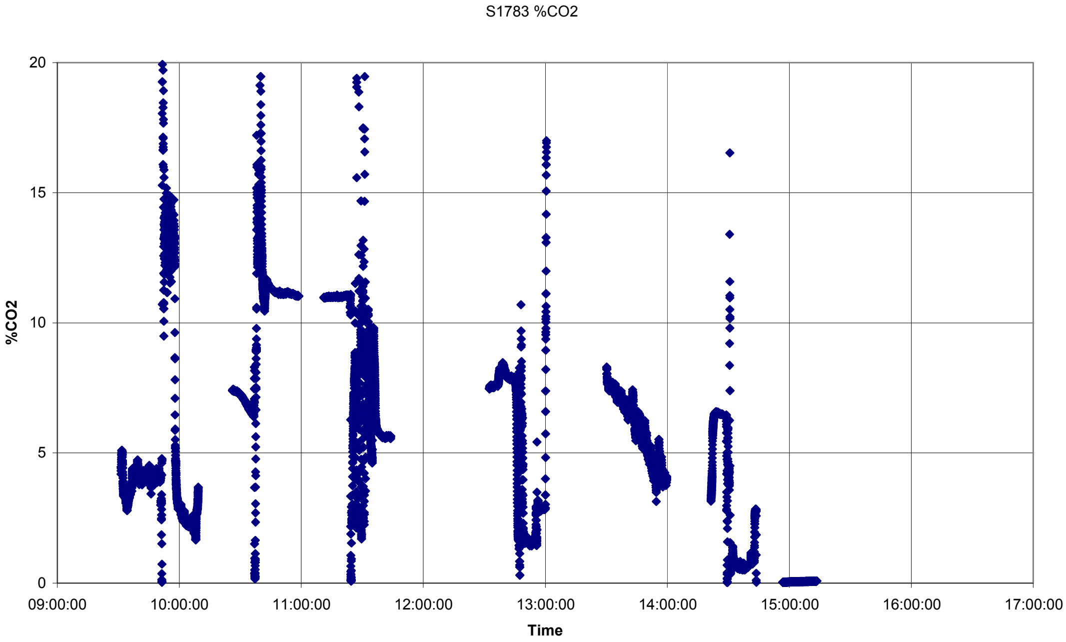


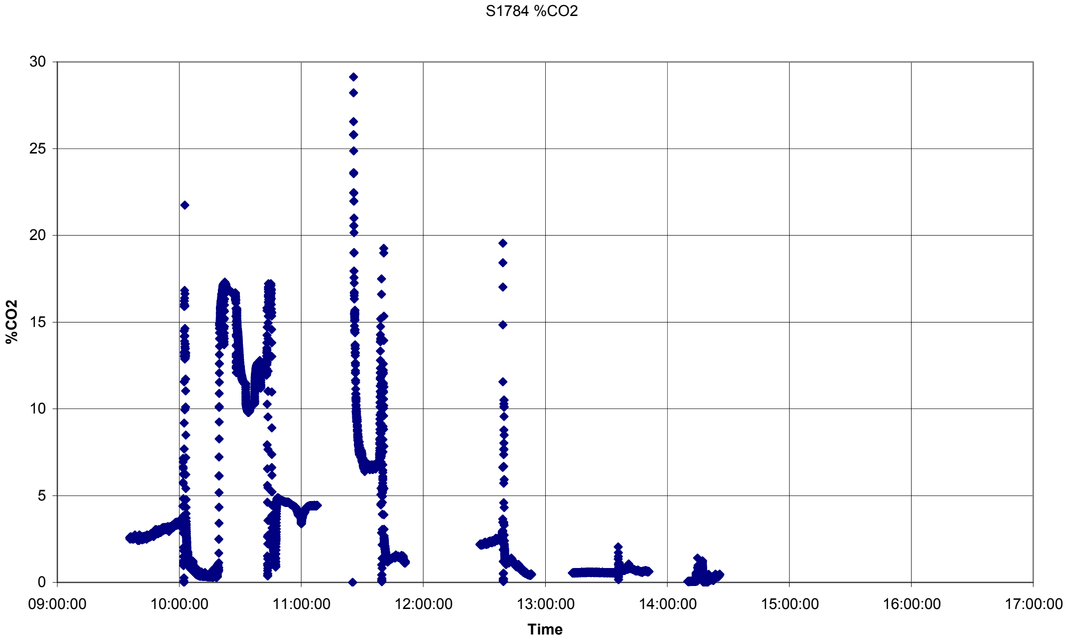

S1785 %CO
%CO
30
25
20
15
10
5
0
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
Time

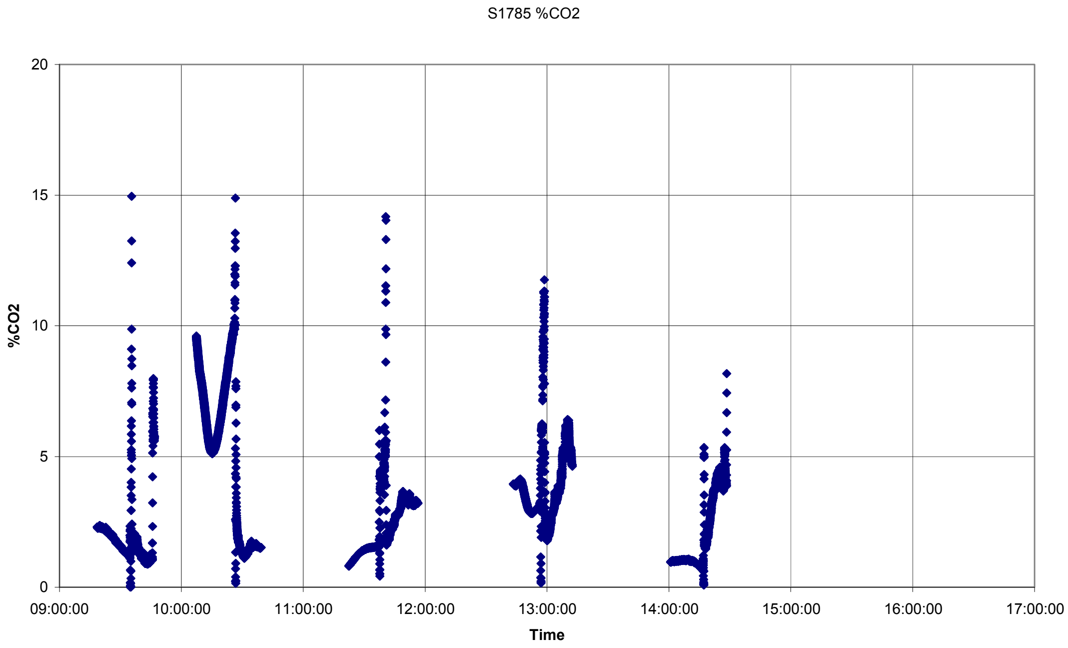

S1786 %CO
%CO
30
25
20
15
10
5
0
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
Time

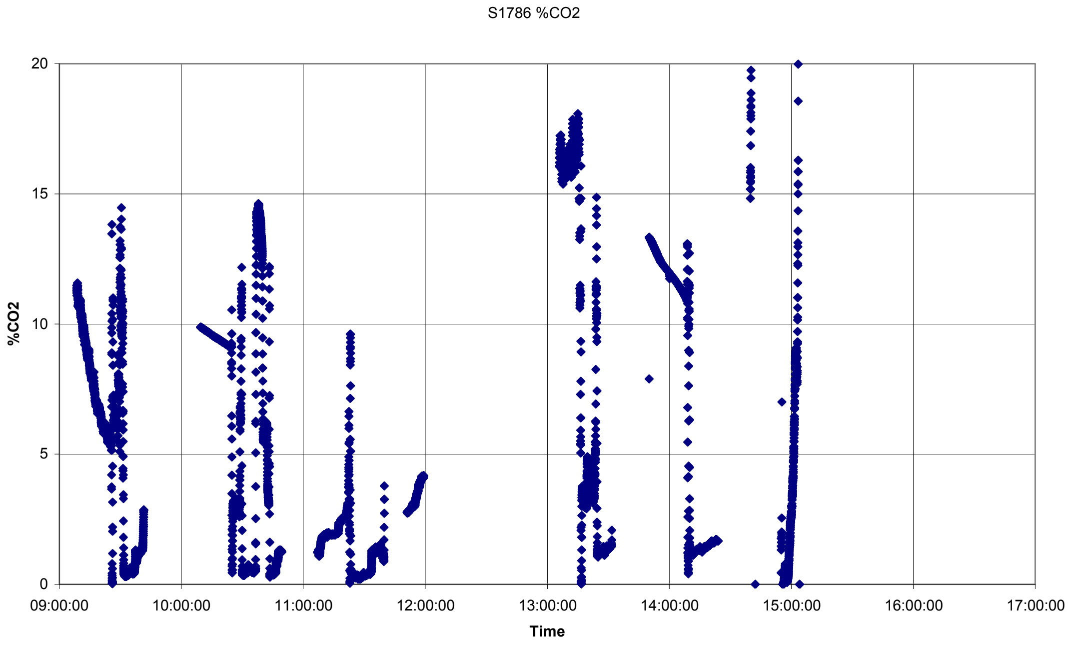

S1787 %CO
%CO
30
25
20
15
10
5
0
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
Time

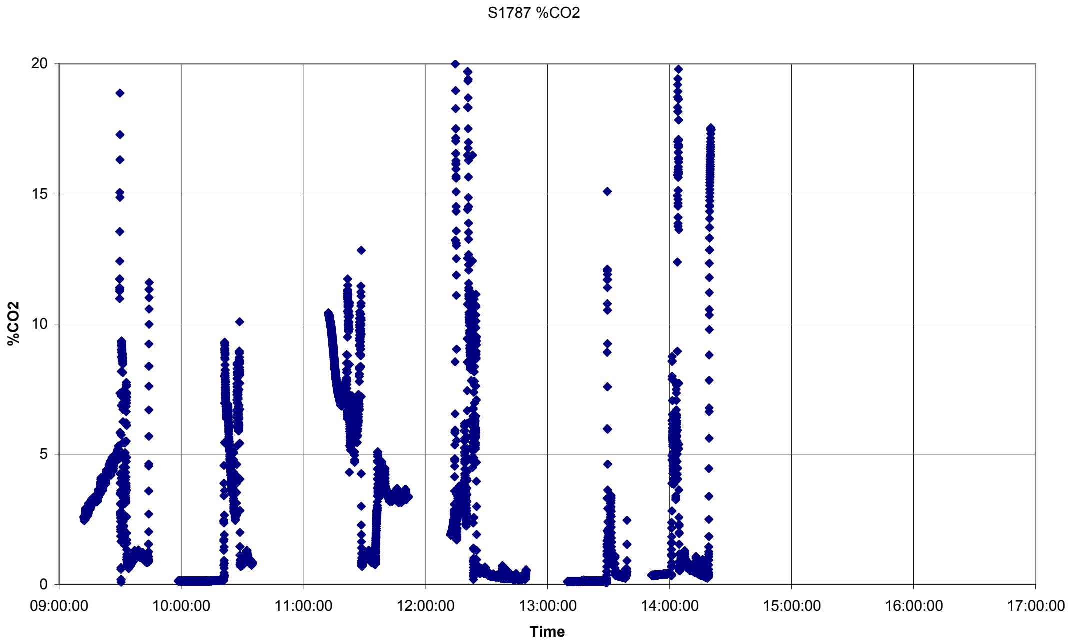
CO_2 gas analysis



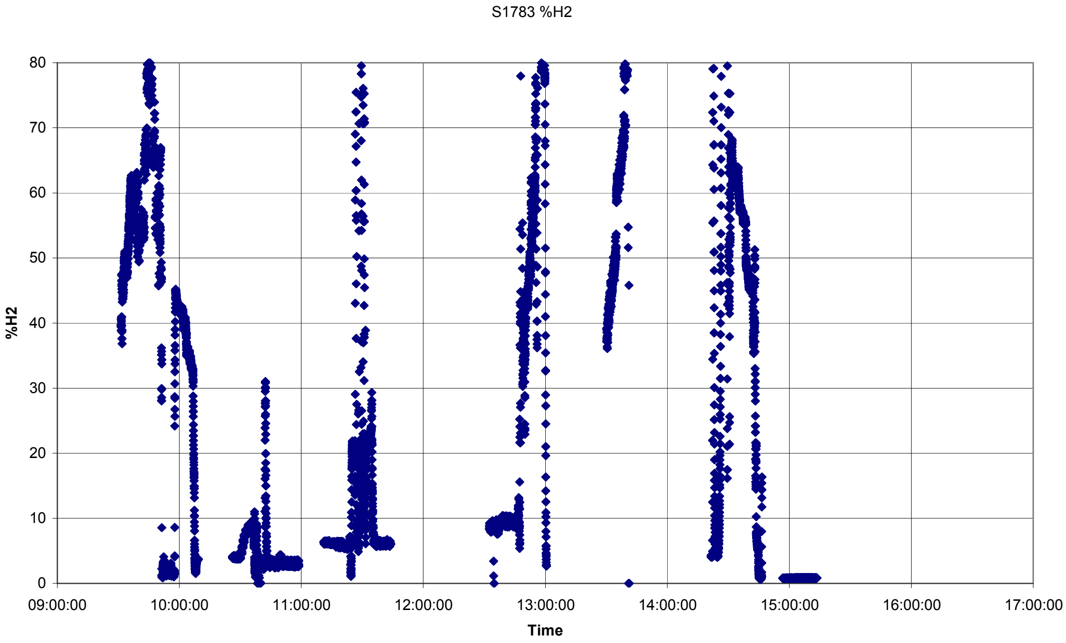


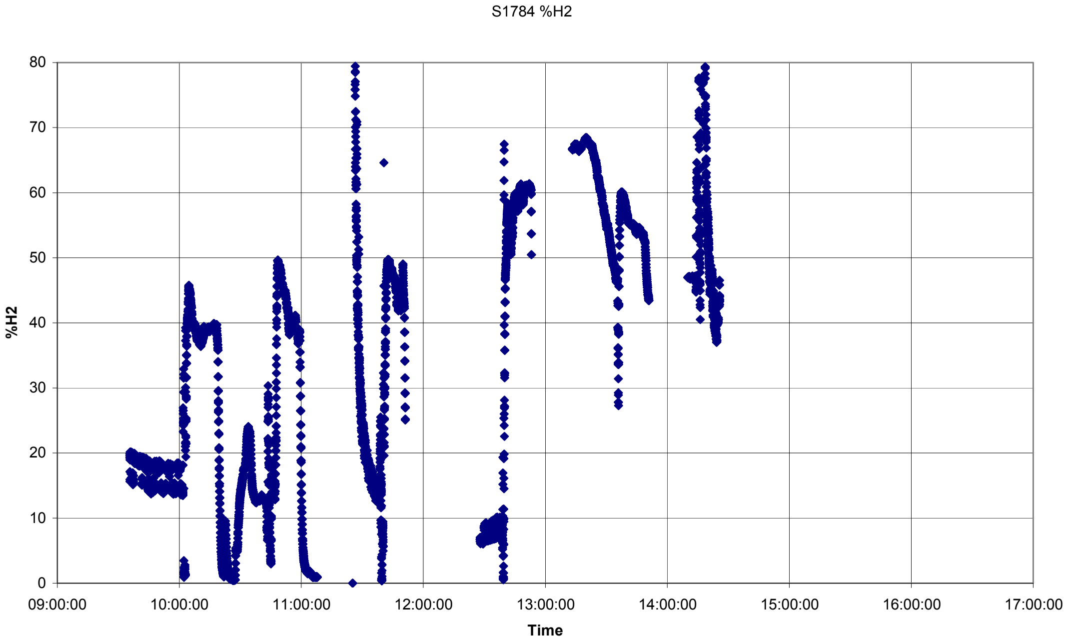

S1785 %CO2
%CO2
20
15
10
5
0
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
Time

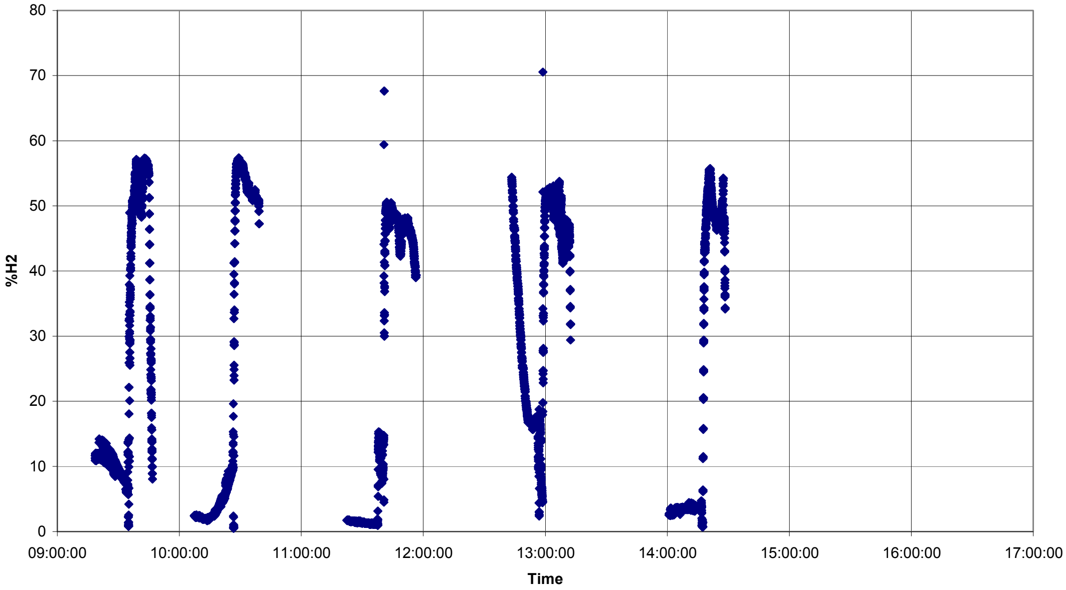

S1786 %CO2
%CO2
20
15
10
5
0
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
Time


S1787 %CO2
20
15
10
5
0
%CO2
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
Time

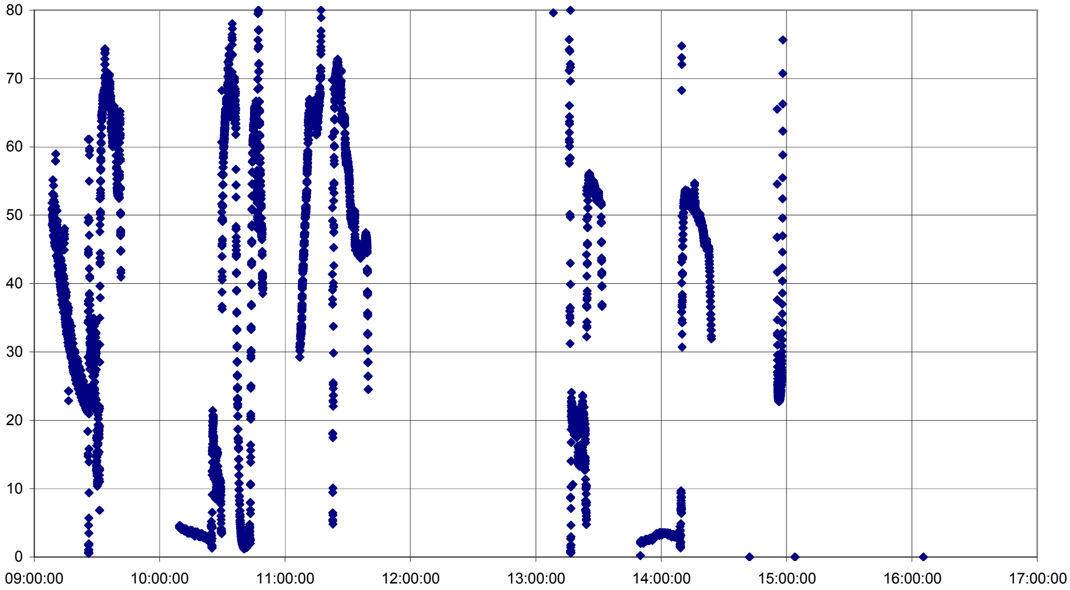
H_2 gas analysis



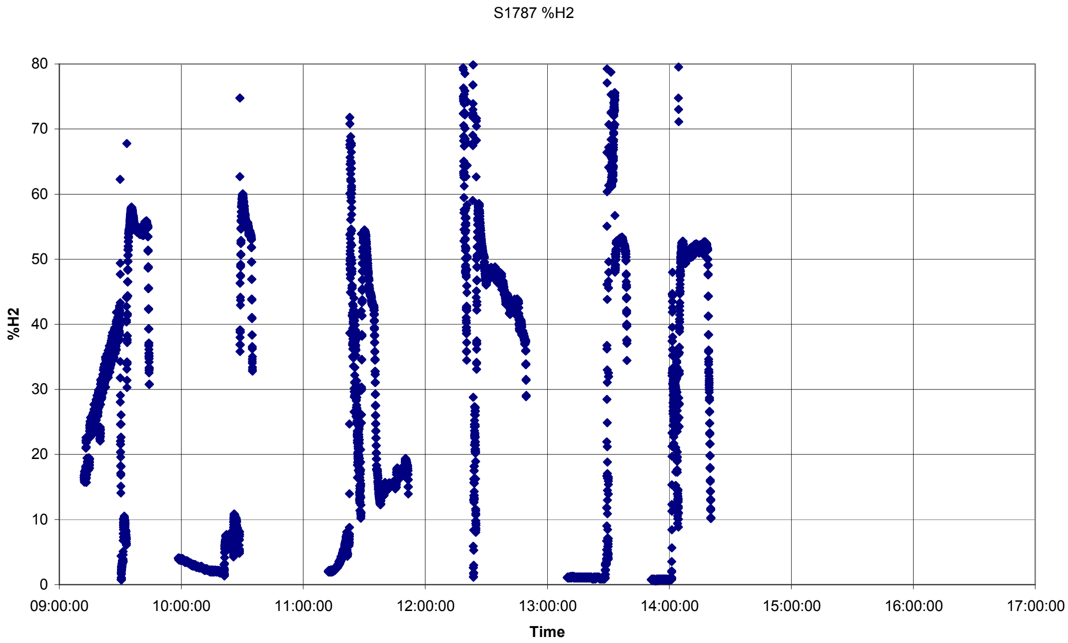




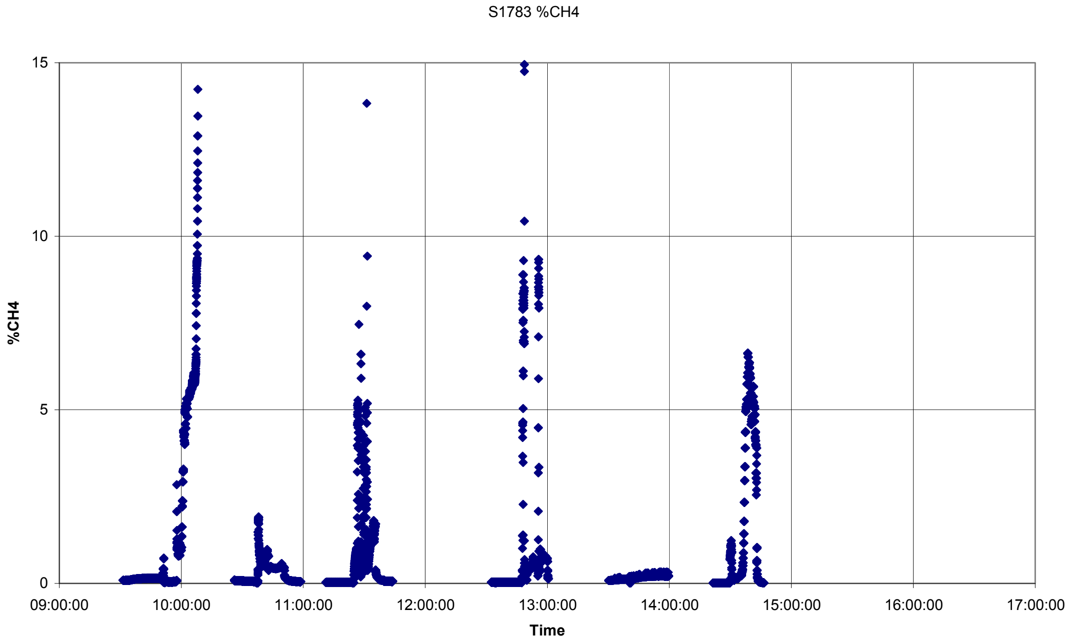
S1785 %H2

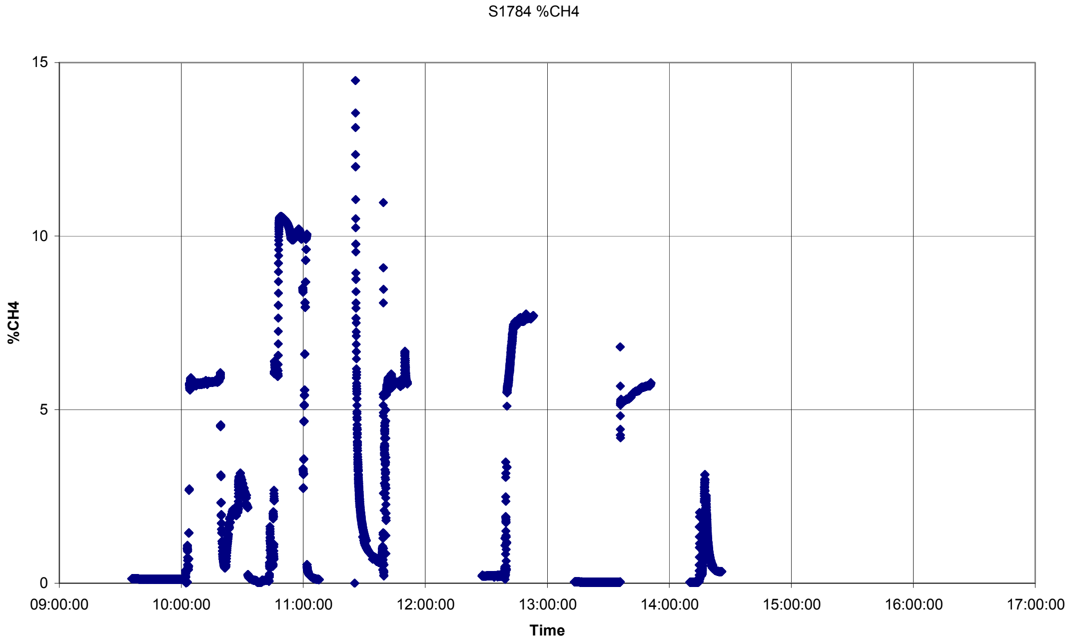


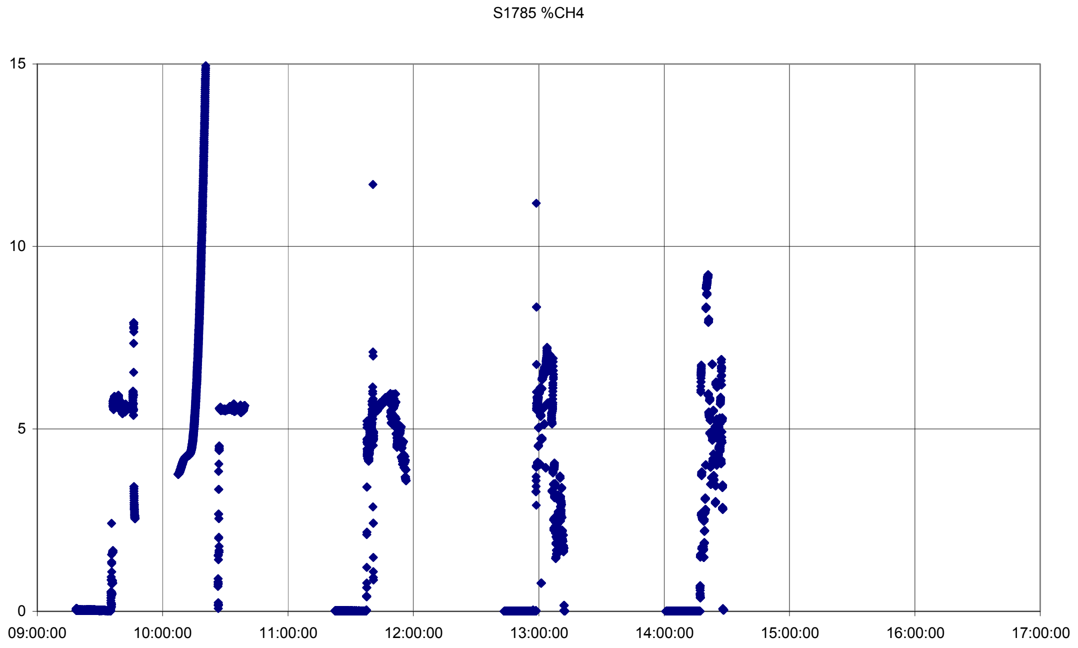
S1786 %H2

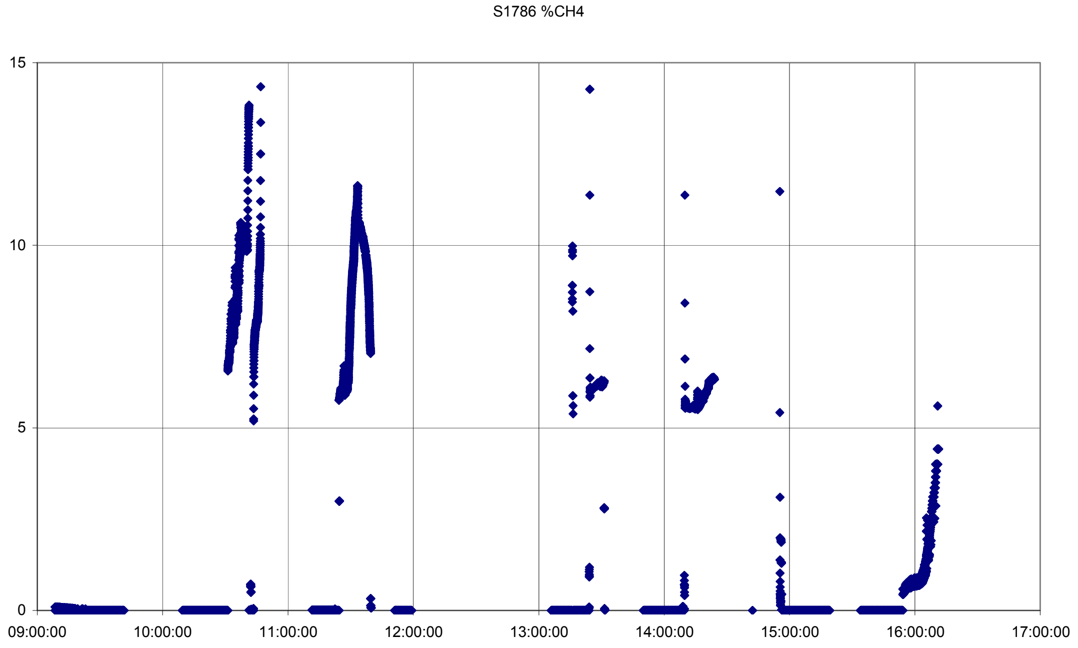

S1787 %H2
%H2
0
10
20
30
40
50
60
70
80
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
Time

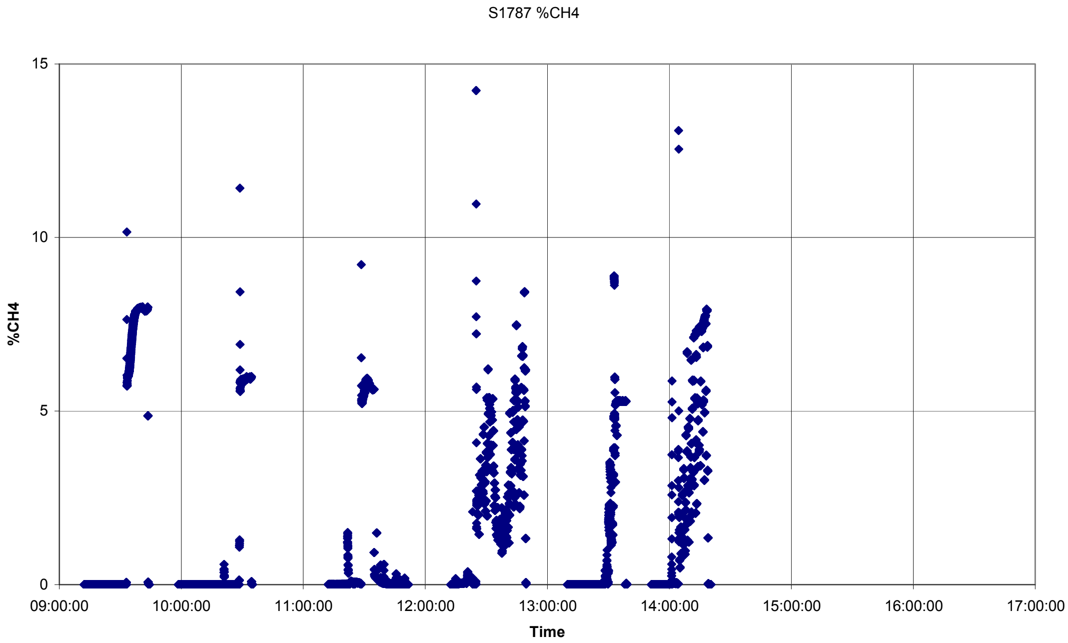
CH$_4$ gas analysis



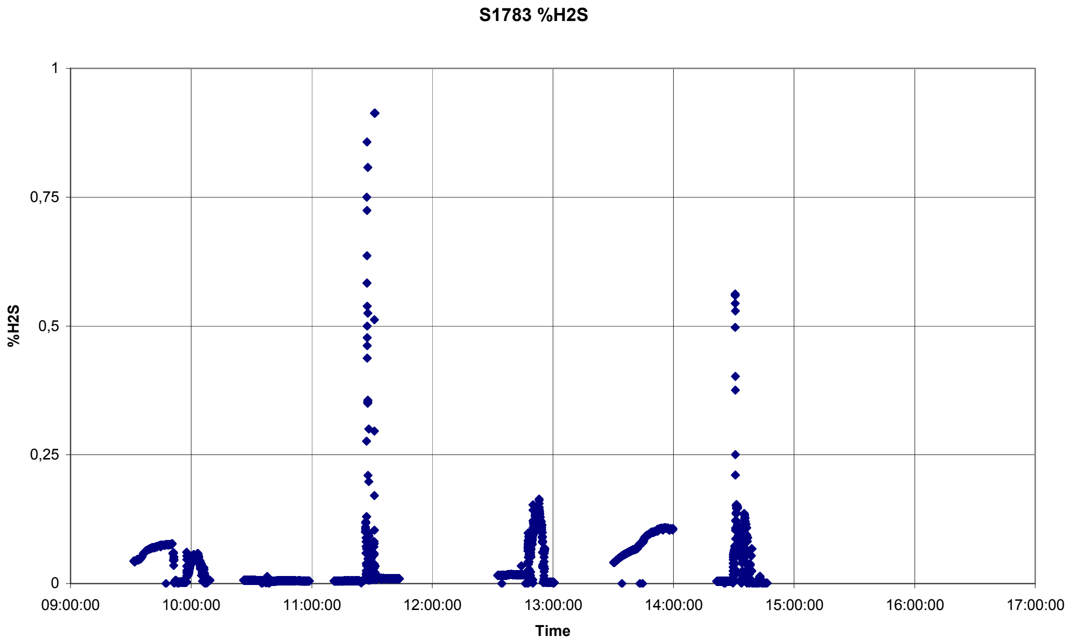


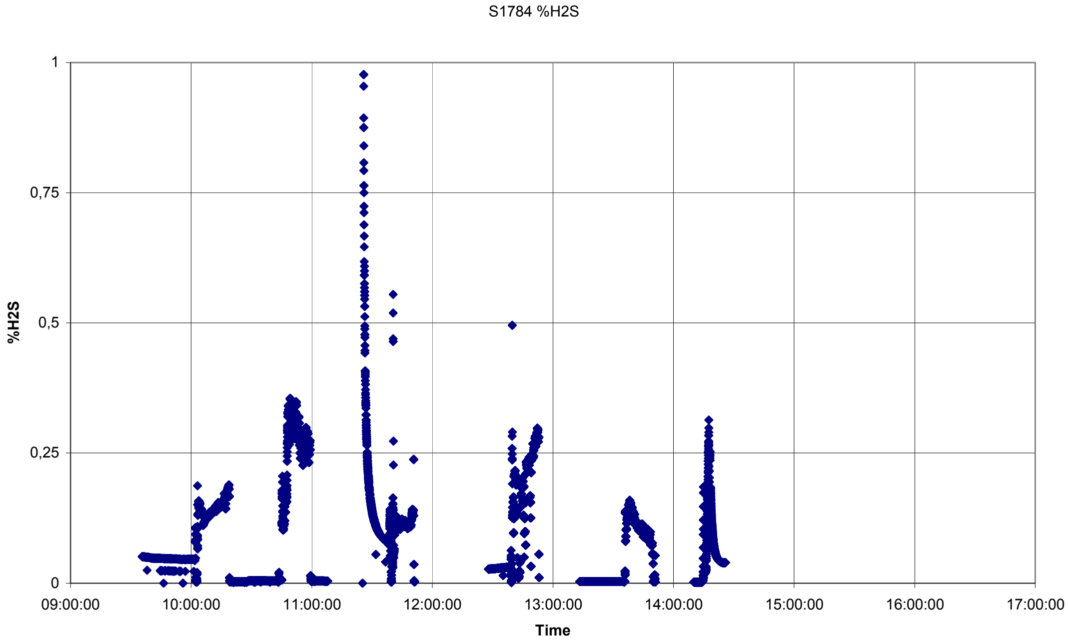

S1785 %CH4
15
10
5
0
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00

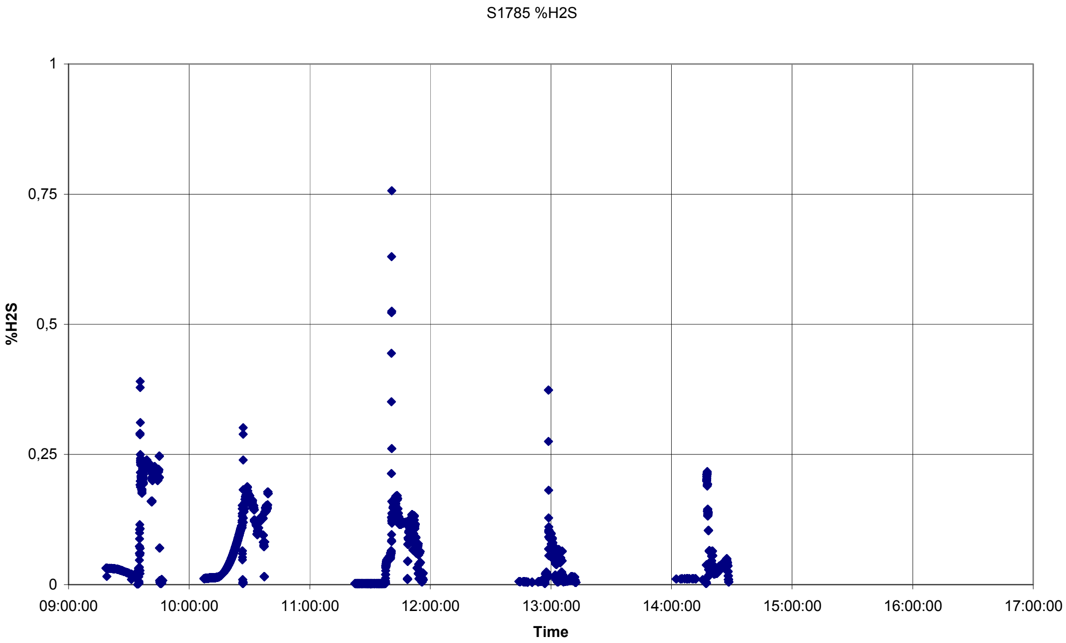

S1786 %CH4
15
10
5
0
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00

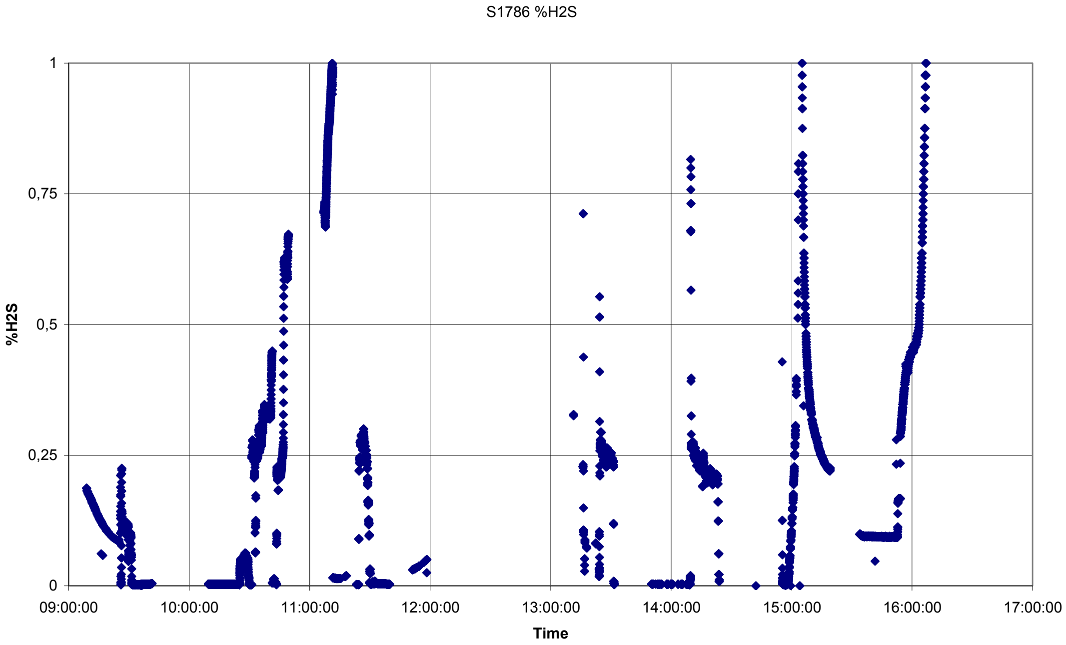

S1787 %CH4
15
10
5
0
%CH4
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
Time

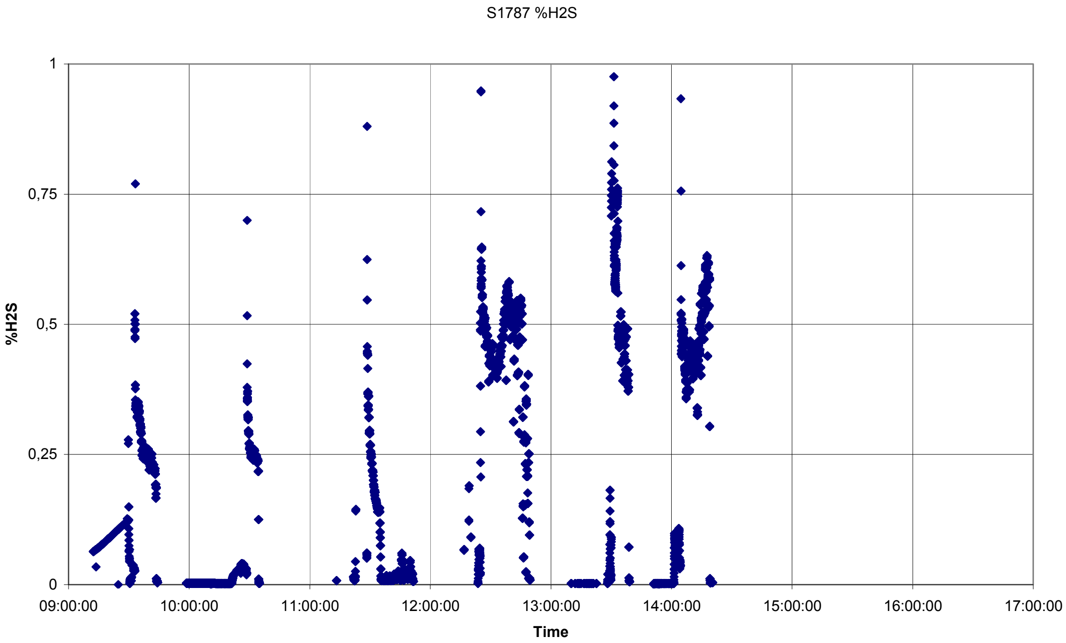
H$_2$S gas analysis



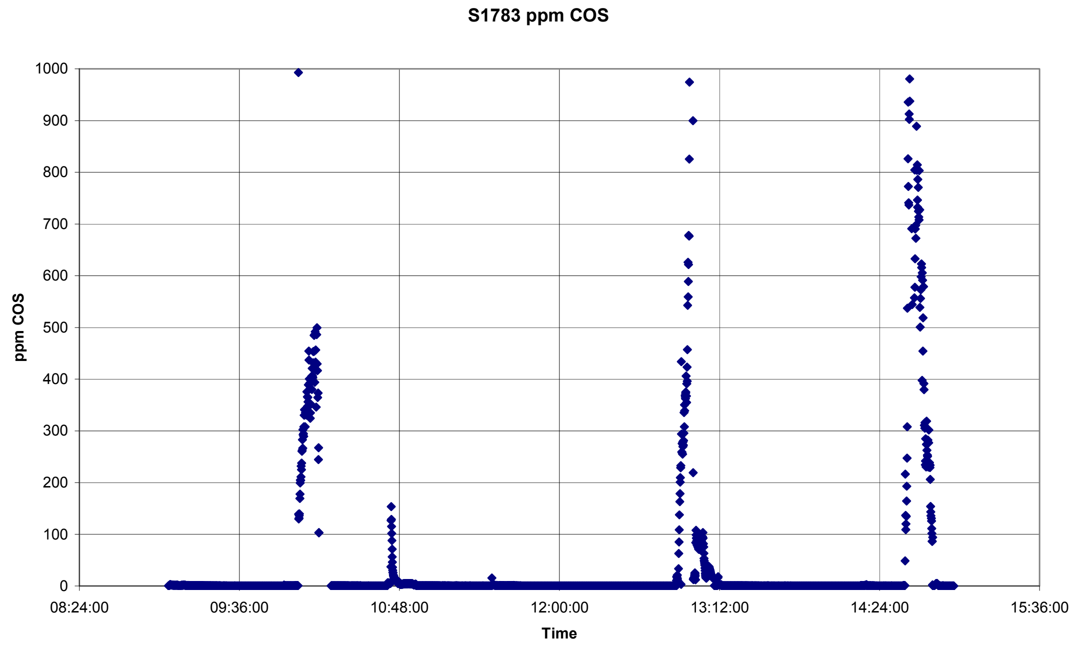


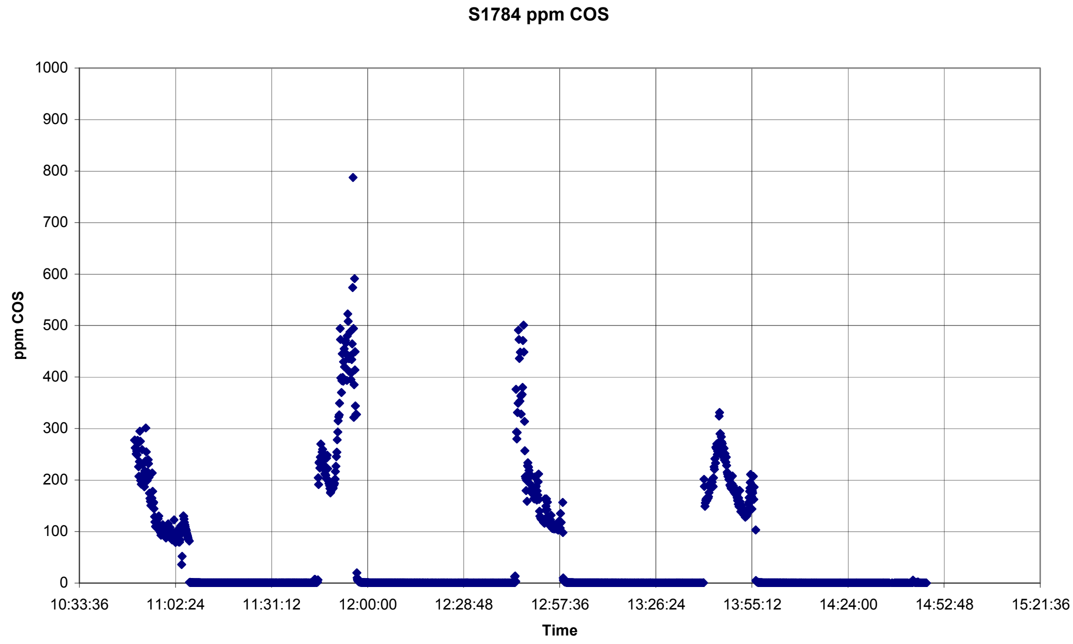

S1785 %H2S
%H2S
1
0,75
0,5
0,25
0
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
Time

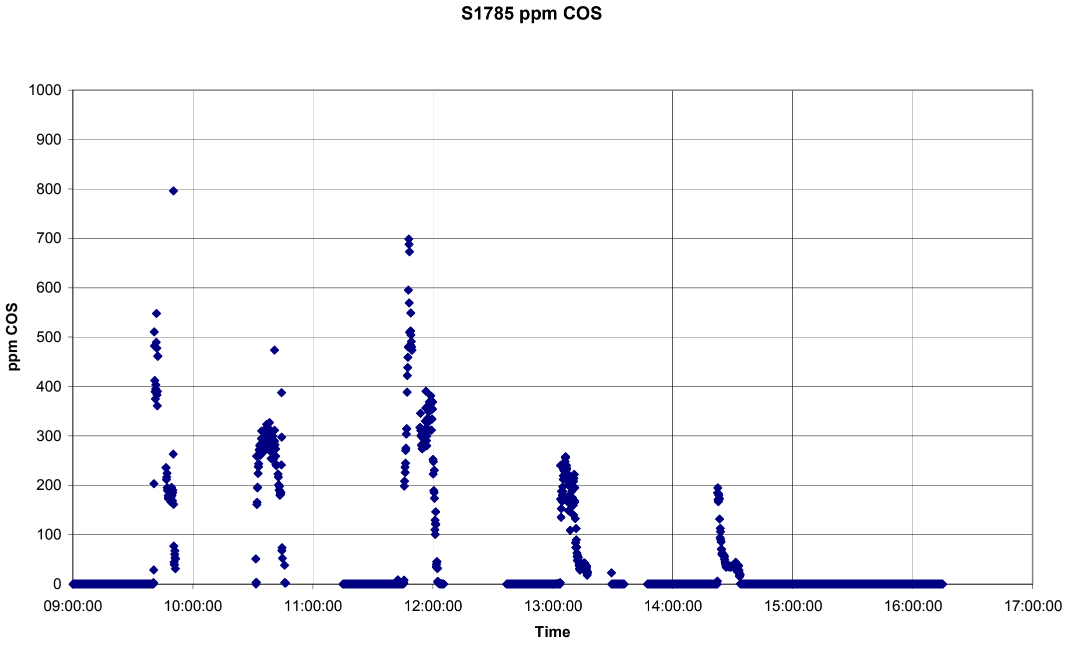

S1786 %H2S
%H2S
1
0,75
0,5
0,25
0
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
Time

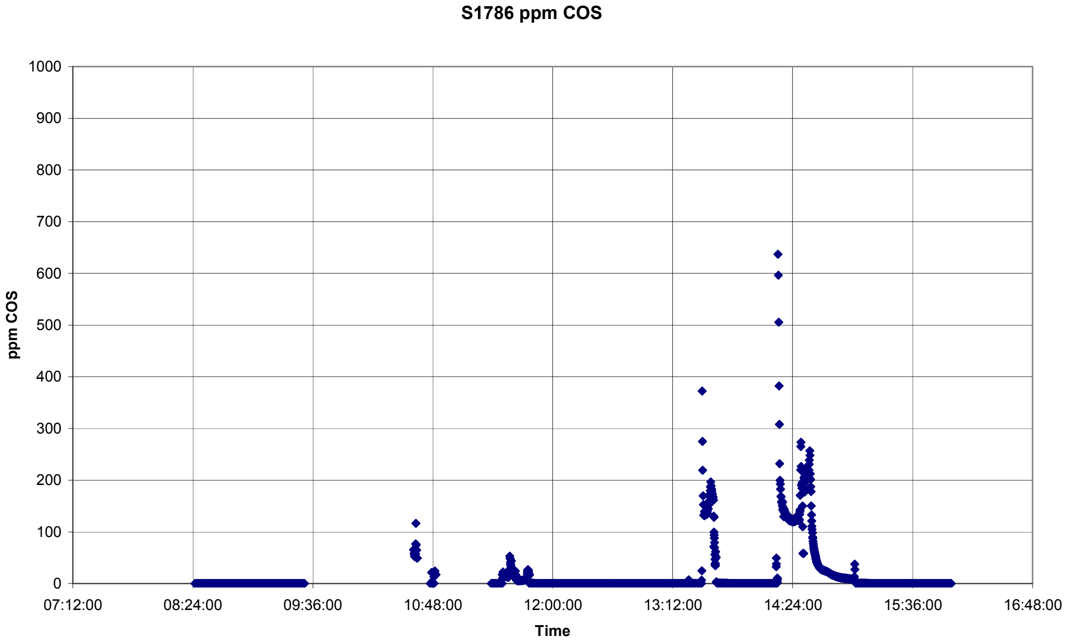

S1787 %H2S
%H2S
1
0,75
0,5
0,25
0
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
Time

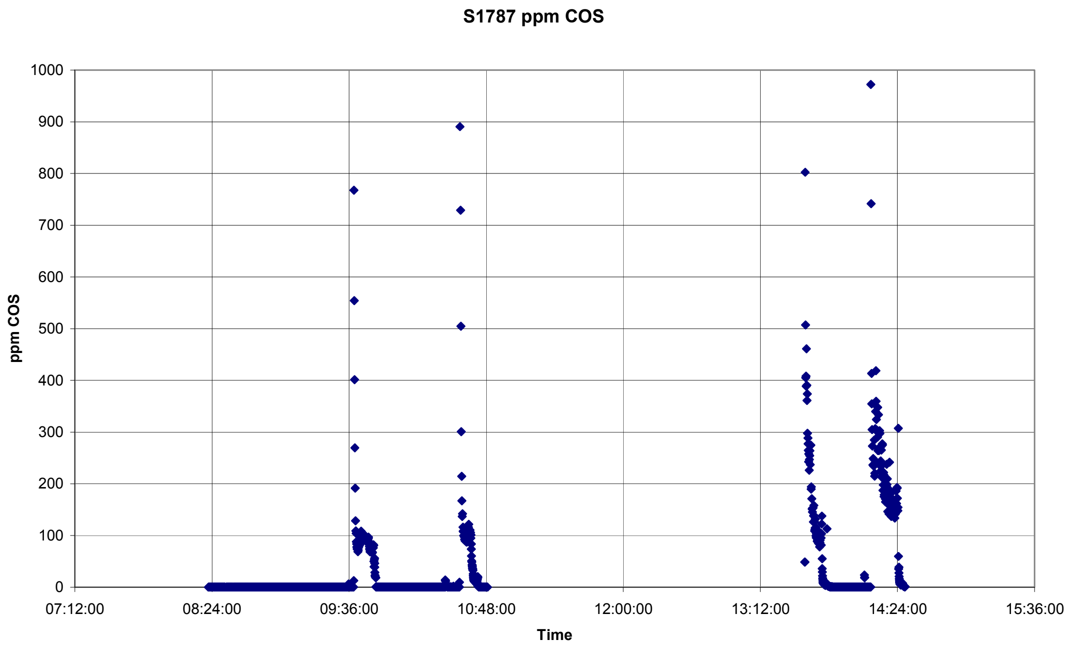
COS gas analysis



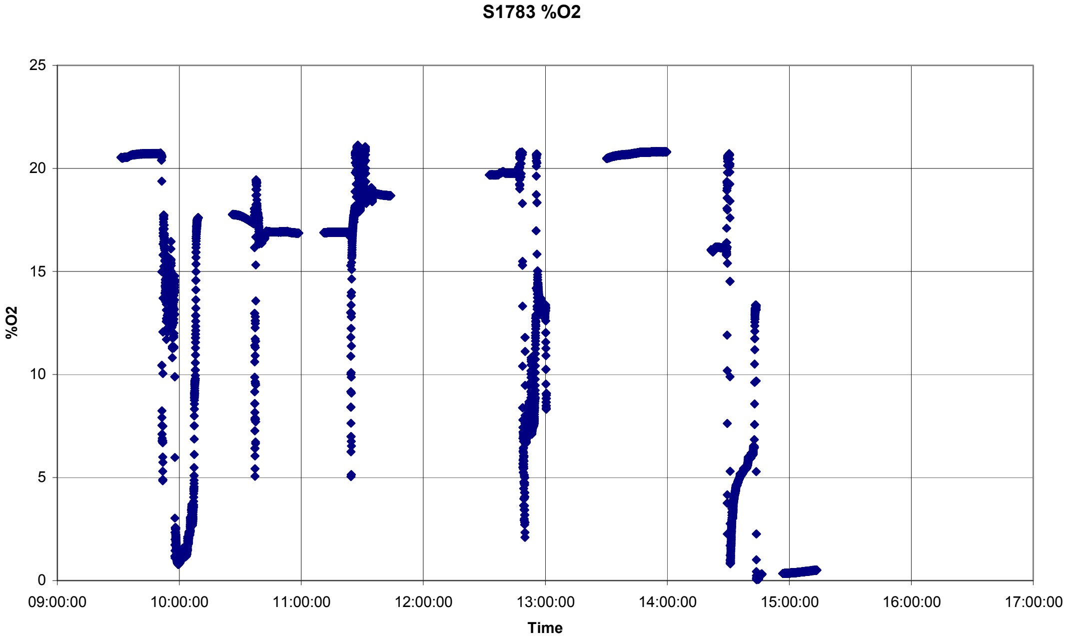


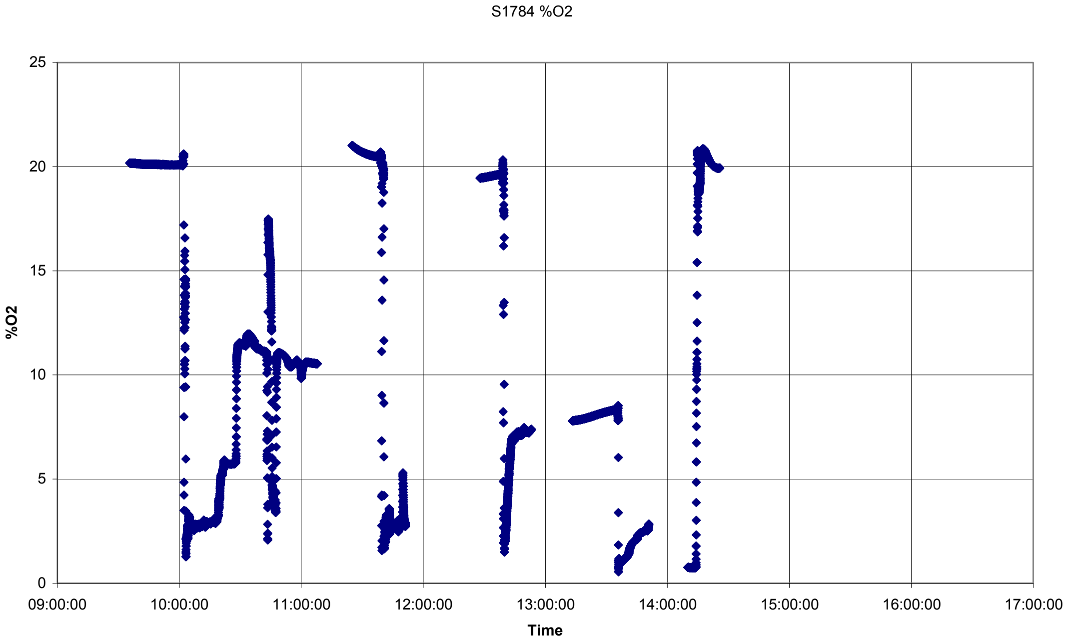

S1785 ppm COS
ppm COS
1000
900
800
700
600
500
400
300
200
100
0
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
Time

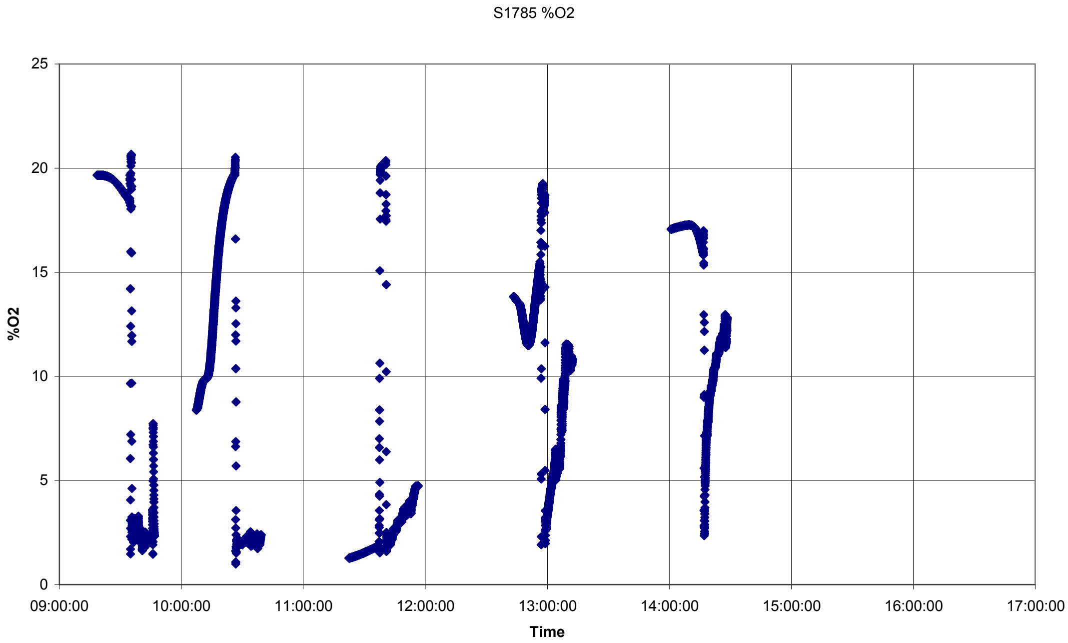

S1786 ppm COS
ppm COS
1000
900
800
700
600
500
400
300
200
100
0
07:12:00
08:24:00
09:36:00
10:48:00
12:00:00
13:12:00
14:24:00
15:36:00
16:48:00
Time

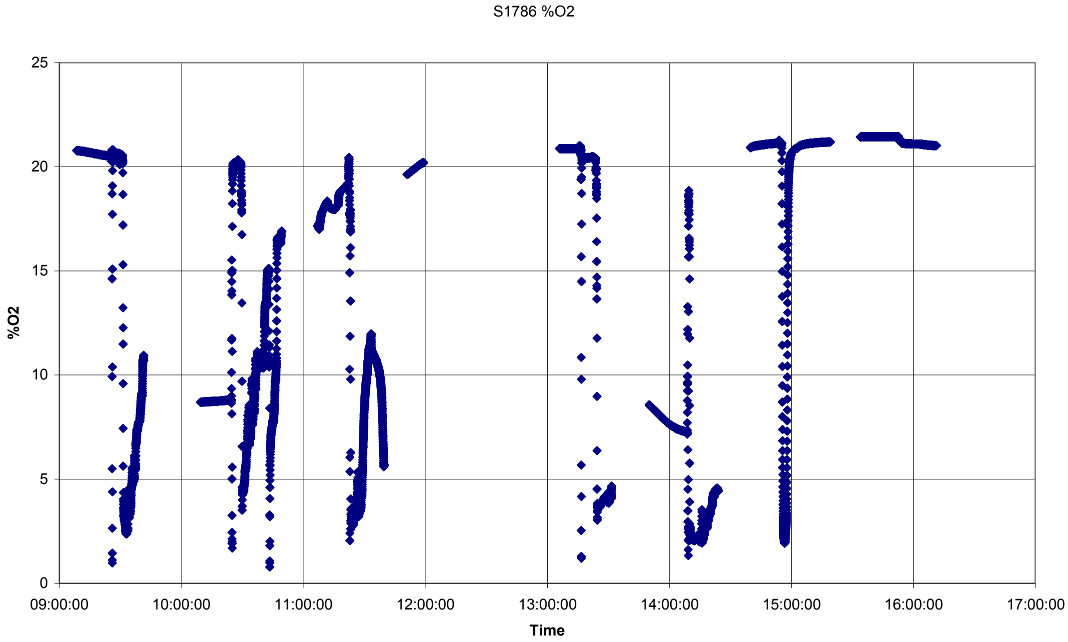

S1787 ppm COS
ppm COS
1000
900
800
700
600
500
400
300
200
100
0
07:12:00
08:24:00
09:36:00
10:48:00
12:00:00
13:12:00
14:24:00
15:36:00
Time

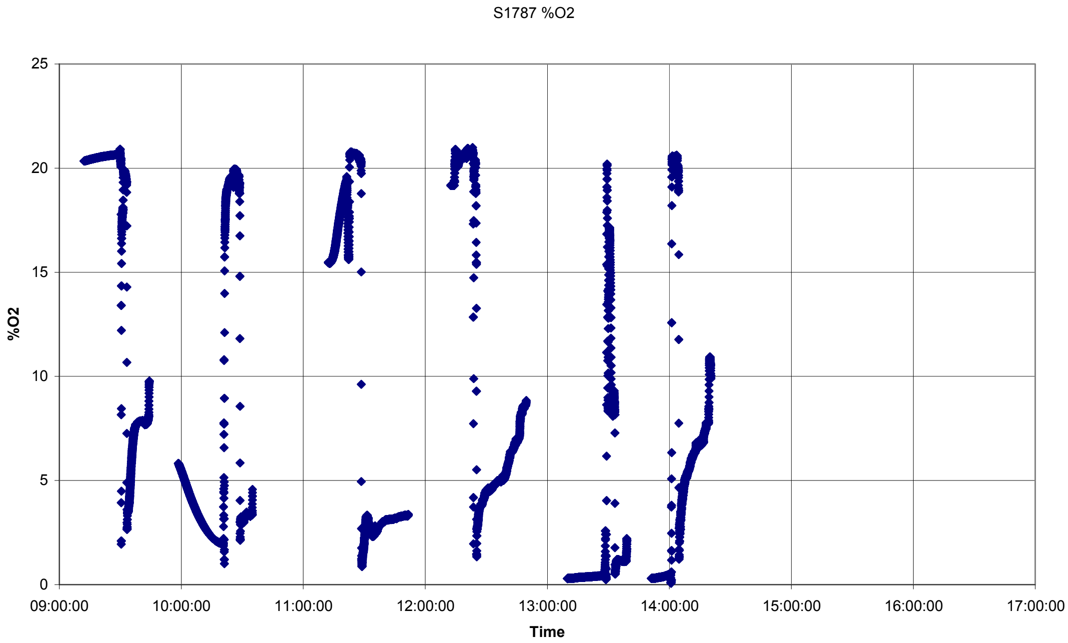
O$_2$ gas analysis






S1785 %O2
%O2
Time
0
5
10
15
20
25
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00


S1786 %O2
%O2
Time
0
5
10
15
20
25
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00


S1787 %O2
25
20
15
10
5
0
%O2
09:00:00
10:00:00
11:00:00
12:00:00
13:00:00
14:00:00
15:00:00
16:00:00
17:00:00
Time

Metal		C	Si	Mn	P	S	Cr	Ni	Cu	V	Al	Mo	Ti
S1783	1	3,99	0,38	0,14	0,05	0,033	0,046	0,039	0,003	0,06	0,002	0,004	0,031
	3	2,89				0,028							
	4	1,53				0,032							
	5	2,45				0,09							
	6	2,31				0,039							
	7	1,5				0,06							
	8	2,61	0	0,12	0,055	0,078	0,048	0,04	0,009	0,071	0,009	0,004	0
	10	2,31				0,022							
	11	1,58				0,059							
	12	1,9				0,065							
	13	2,16				0,065							
	14	2,97				0,043							
	15	1,67				0,085							
	16	2,57	0	0,12	0,055	0,09	0,05	0,042	0,023	0,065	0,004	0,003	0
	17	1,54				0,094							
	18	2,35				0,09							
	19	2,8	0	0,12	0,054	0,055	0,05	0,042	0,03	0,062	0,007	0,003	0
	20	2,26				0,042							
	21	3,02				0,056							
	22	3,46	0	0,13	0,052	0,034	0,05	0,042	0,035	0,063	0,01	0,004	0
	23	0,99	0	0,09	0,042	0,15	0,069	0,08	0,035	0,013	0,055	0,012	0

Slag		Fe	CaO	SiO2	MnO	P2O5	S	Al2O3	MgO	Na2O	K2O	V2O5	TiO2	Cr2O3
S1783	8	1,38	45,97	13,51	0,56	0,04	0,94	30,91	9,99	0,03	0,03	0,34	0,73	0,03
	14	13,74	39,89	7,36	0,22	0,02	1,6	38,03	12,31	0,02	0,05	0,06	0,28	0,03
	16	4,29	43,65	6,05	0,49	0,03	1,04	41,5	10,32	0,02	0,02	0,25	0,22	0,03
	19	12,1	41,44	5,18	0,32	0,04	1,45	41,57	9,97	0,01	0,02	0,12	0,16	0,04,
	22	7,19	43,07	3,45	0,21	0,02	1,91	43,06	10,18	0	0,01	0,05	0,1	0,03

Metal		C	Si	Mn	P	S	Cr	Ni	Cu	V	Al	Mo	Ti
S1784	1	3,87	0,3	0,07	0,05	0,044	0,045	0,042	0,002	0,061	0,027	0,003	0,012
	2	3,35				0,045							
	3	1,68				0,046							
	4	3,09				0,15							
	5	3,34	0	0,06	0,032	0,18	0,047	0,05	0,004	0,029	0,041	0,004	0
	6	0,98				0,2							
	7	2,06				0,29							
	8	2,46	0	0,07	0,041	0,31	0,051	0,051	0,003	0,016	0,017	0,003	0
	10	1,59	0,02	0,07	0,048	0,2	0,054	0,054	0,009	0,058	0,11	0,005	0
	11	1,99				0,085							
	12	3,77	0	0,09	0,046	0,084	0,058	0,054	0,017	0,074	0,032	0,005	0
	13	1,74	0	0,06	0,055	0,3	0,052	0,057	0,018	0,016	0,016	0,004	0
	14	3,45	0	0,06	0,048	0,32	0,054	0,055	0,016	0,061	0,132	0,004	0
	15	1,3	0	0,07	0,057	0,32	0,052	0,059	0,024	0,069	0,008	0,004	0

Slag		Fe	CaO	SiO2	MnO	P2O5	S	Al2O3	MgO	Na2O	K2O	V2O5	TiO2	Cr2O3
S1784	10	27,09	32,95	8,36	0,41	0,06	1,92	26,13	23,4	0,01	0,01	0,28	0,3	0,07
	12	24,27	34,66	4,35	0,18	0,02	3,36	36,58	17,6	0	0,01	0,07	0,15	0,05
	13	7,91	40,08	6,97	0,46	0,06	2,22	32,03	16,7	0	0,01	0,54	0,31	0,05
	14	33,28	30,41	4,65	0,28	0,04	2,53	32,42	19,45	0	0,01	0,18	0,14	0,08
	15	4,88	28,51	4,53	0,33	0,02	2,77	34,98	27,39	0,02	0	0,26	0,19	0,15

Metal		C	Si	Mn	P	S	Cr	Ni	Cu	V	Al	Mo	Ti
S1785	1	3,94				0,053							
	2	1,99				0,09							
	3	2,82	0	0,09	0,052	0,185	0,043	0,041	0,004	0,064	0,008	0	0
	5	1,91				0,093							
	6	2,67	0	0,09	0,054	0,24	0,044	0,042	0,007	0,08	0,006	0	0
	7	1,74				0,15							
	8	2,06				0,22							
	9	2,75	0	0,09	0,054	0,23	0,046	0,042	0,008	0,079	0	0	0
	10	1,58				0,21							
	11	2,58	0	0,08	0,057	0,22	0,047	0,042	0,013	0,085	0,015	0	0
	13	1,74	0,04	0,05	0,057	0,31	0,04	0,048	0,018	0,041	0,059	0	0

Slag		Fe	CaO	SiO2	MnO	P2O5	S	Al2O3	MgO	Na2O	K2O	V2O5	TiO2	Cr2O3
S1785	3	2	40,54	21,35	1,08	0,15	0,47	19,92	17,2	0,01	0,01,	0,95	1,01	0,05
	6	1,89	36,64	21,87	0,47	0,02	0,82	19,77	24,65	0,02	0,01	0,21	0,42	0,04
	9	2,18	36,8	24,34	0,31	0,01	1,37	19,05	22,43	0,02	0,01	0,08	0,24	0,03
	11	2,34	36,28	24,36	0,28	0,01	1,29	18,39	23,69	0,02	0,02	0,09	0,17	0,03

Metal		C	Si	Mn	P	S	Cr	Ni	Cu	V	Al	Mo	Ti
S1786	1	3,93				0,038							
	2	2,04				0,046							
	3	2,17	0	0,08	0,056	0,077	0,04	0,039	0,003	0,054	0,018	0	0
	4	1,52	0,02	0,09	0,063	0,063	0,043	0,038	0,006	0,055	0,008	0	0
	5	1,8				0,079							
	6	1,38				0,022							
	7	2,09	0,6	0,1	0,063	0,043	0,039	0,041	0,01	0,057	0,03	0	0
	8	1,56	1,24	0,09	0,066	0,0086	0,039	0,041	0,012	0,054	0,173	0	0
	10	1,43	0,14	0,05	0,062	0,027	0,041	0,039	0,009	0,044	0,008	0	0
	11	1,75	0,12	0,06	0,064	0,061	0,041	0,04	0,009	0,019	0,003	0	0
	12	1,61				0,00028							
	13	2,76	0,21	0,06	0,057	0,092	0,039	0,039	0,013	0,052	0,038	0	0
	14	2,26	0,11	0,06	0,063	0,071	0,04	0,04	0,012	0,052	0,007	0	0
	15	2,56	0,11	0,06	0,053	0,11	0,041	0,04	0,011	0,051	0,026	0	0
	16	3,27	0,14	0,06	0,057	0,099	0,041	0,041	0,011	0,053	0,286	0	0
	17	4,01				0,12							
	18	1,77	0,13	0,05	0,046	0,018	0,026	0,024	0,008	0,041	0	0	0

Slag		Fe	CaO	SiO2	MnO	P2O5	S	Al2O3	MgO	Na2O	K2O	V2O5	TiO2	Cr2O3
S1786	3	7,18	42,6	31,91	1,98	0,29	0,13	4,41	8,79	0,03	0,05	1,17	1,27	0,1
	4	2,31	44,26	26,61	0,55	0,04	0,23	15,08	13,76	0,01	0,04	0,29	0,55	0,05
	5	2,98	42,15	26,86	0,45	0,06	0,34	14,66	17,43	0	0,02	0,25	0,52	0,05
	8	1,07	50,18	15,64	0,2	0,01	0,59	26,46	9,02	0	0,06	0,07	0,07	0,03
	10	3,11	34,68	33,36	0,83	0,01	0,06	15,69	16,53	0	0,03	0,27	0,1	0,05
	11	0,89	32,26	35,48	0,37	0,01	0,2	15,17	21,77	0,03	0,04	0,1	0,13	0,03
	14	1,17	37,67	24,2	0,18	0,01	0,75	20,85	20,25	0,02	0,04	0,05	0,09	0,03
	16	1,19	34,57	24,67	0,17	0,01	1,27	20,98	22,08	0,03	0,04	0,04	0,07	0,03
	18	7,27	31,62	26,04	0,12	0,01	2,25	18,49	24,3	0,02	0,01	0,03	0,06	0,04

Metal and slag analysis

APPENDIX 3

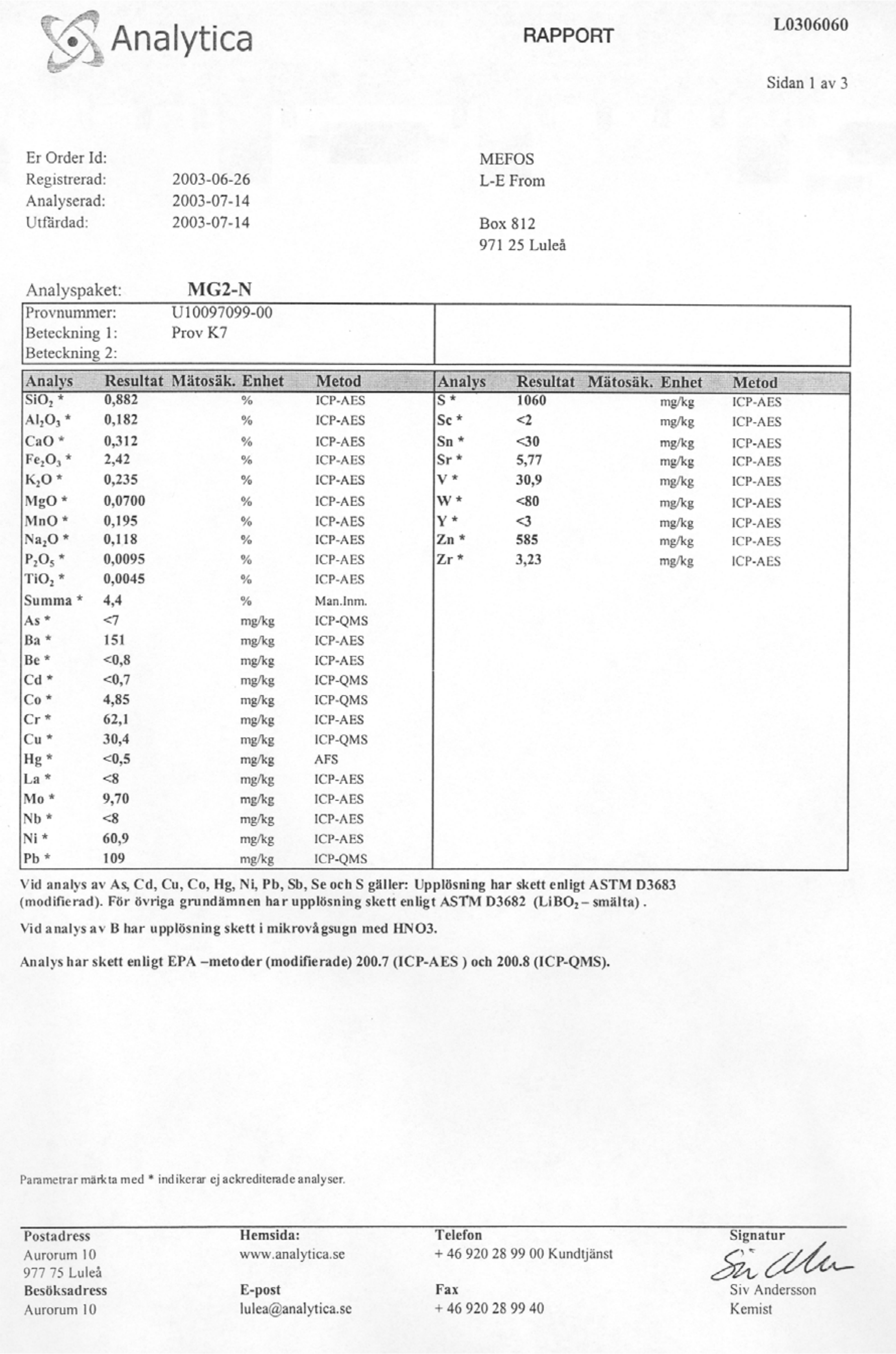
Metal		C	Si	Mn	P	S	Cr	Ni	Cu	V	Al	Mo	Ti
S1787	1	3,99				0,05							
	2	2,18				0,067							
	3	3,14	0,39	0,09	0,053	0,15	0,046	0,042	0,003	0,066	0,331	0	0,002
	4	1,06	0	0,07	0,056	1,27	0,044	0,014	0,002	0,048	0,234	0	0
	5	1,36	0	0,06	0,055	1,31	0,044	0,04	0,003	0,046	0,333	0	0
	6	1,06	0,26	0,08	0,058	0,78	0,046	0,012	0,003	0,051	0,306	0	0
	7	1,71				0,74							
	8	1,69				0,72							
	9	1,52				0,79							
	10	2,98	0,03	0,09	0,055	0,6	0,041	0,043	0,007	1,573	0,299	0	0
	11	1,81				0,83							
	12	2,16	0	0,04	0,056	0,83	0,038	0,043	0,005	0,507	0,245	0	0
	13	1,43				0,85							
	14	2,87	0	0,04	0,054	0,85	0,041	0,043	0,006	0,744	0,257	0	0

Slag		Fe	CaO	SiO2	MnO	P2O5	S	Al2O3	MgO	Na2O	K2O	V2O5	TiO2	Cr2O3
S1787	3	1,85	48,71	32,69	1,24	0,12	0,24	5,92	9,46	0	0,03	0,53	1,12	0,04
	4	3,15	40,36	27,26	0,97	0,04	1,79	11,58	16,32	0,01	0,03	0,57	0,75	0,05
	5	2,72	39,14	26,66	1,06	0,05	1,97	11,48	18,51	0,01	0,02	0,63	0,74	0,06
	6	6,06	37,82	21,09	0,45	0,03	5,74	19,15	11,94	0	0,04	0,15	0,3	0,04
	10	18,65	29,67	24,32	0,38	0,02	4,81	17,52	17,24	0	0,01	0,89	0,16	0,06
	12	3,3	39,46	20,47	0,77	0,09	2,2	14,55	12,21	0	0	11,14	0,17	0,05
	14	4,09	36,24	26,72	0,56	0,03	2,07	16,31	13,77	0,02	0,01	6	0,21	0,06

Heat	HyMelt	Period	Injection period Computer time		Injected C "AS"		Est. Metal	Sample ID					Acc. C in WG "AE"			Injected	To metal	To WG	Rest	To metal	To WG	Rest	Remarc
ID			Start	Stop	Start	Stop		Start Man	Start Comp	%C	Stop Man	Stop Comp	%C	Start	Stop	kg	kg	kg	kg	%	%	%	
S1783	2	1	09:52	10:09	2,6	97,5	5500	10:00	09:56	1,53	10:13	10:09	2,45	151,1	187,3	94,9	50,6	36,2	8,1	53,3	38,1	8,5	Coal Injection
S1783	2	2	10:37	10:58	0	127,7	5186	10:40	10:36	1,5	11:01	10:57	2,61	53,4	121,6	127,7	57,6	68,2	1,9	45,1	53,4	1,5	Coal Injection
S1783	2	3	11:22	11:44	33,9	151,1	5029	11:32	11:28	1,58	11:49	11:45	2,97	70,0	123,9	117,2	69,9	53,9	-6,6	59,6	46,0	-5,6	Coal Injection
S1783	2	4	12:45	13:00	0	99,3	4871	12:48	12:44	1,67	13:04	13:00	2,57	72,0	122,5	99,3	43,8	50,5	5,0	44,1	50,9	5,0	Coal Injection 7 mm
S1783	2	5	13:40	13:59	0	123,7	4714	13:43	13:39	1,54	14:05	14:01	2,80	44,9	106,0	123,7	59,4	61,1	3,2	48,0	49,4	2,6	Coal Injection
S1783	2	6	14:30	14:46	7,68	64,9	4557	14:36	14:32	2,26	14:43	14:39	3,02	38,9	46,2	57,22	34,6	7,3	15,3	60,5	12,8	26,7	P-Coke Injection
S1784	3	1	10:00	10:23	0	130,7	5700	10:04	10:00	1,68	10:25	10:21	3,34	128,3	155,8	130,7	94,6	27,5	8,6	72,4	21,0	6,6	P-Coke Injection
S1784	3	2	10:44	11:03	0	130,3	5412	10:49	10:45	0,98	11:03	10:59	2,46	146,0	163,6	130,3	80,1	17,6	32,6	61,5	13,5	25,0	Mix Injection
S1784	3	4	12:38	12:53	0	155,6	5149	12:40	12:36	1,99	12:56	12:52	3,77	41,8	70,3	155,6	91,7	28,5	35,4	58,9	18,3	22,8	Mix Injection 7.5
S1784	3	5	13:34	13:50	0	237,9	5011	13:31	13:27	1,74	13:55	13:51	3,45	107,8	155,1	237,9	85,7	47,3	104,9	36,0	19,9	44,1	Mix Injection
S1785	4	1	09:35	09:45	0	116,1	5700	09:38	09:34	1,99	09:51	09:47	2,82	117,2	139,3	116,1	47,3	22,1	46,7	40,7	19,0	40,2	Mix Injection 8.0
S1785	4	2	10:25	10:39	0	177,3	5412	10:27	10:23	1,91	10:43	10:39	2,67	101,4	143,3	177,3	41,1	41,9	94,3	23,2	23,6	53,2	Mix Injection
S1785	4	3	11:39	11:56	0	149,3	5268	11:38	11:34	1,74	12:01	11:57	2,75	69,8	128,8	149,3	53,2	59	37,1	35,6	39,5	24,8	Mix Injection
S1785	4	4	12:57	13:12	0	130,8	5124	12:59	12:55	1,58	13:20	13:16	2,58	71,1	113,6	130,8	51,2	42,5	37,1	39,2	32,5	28,3	Mix Injection 8,0
S1786	5	1	09:29	09:41	0	63	5520	09:28	09:24	2,04	09:46	09:42	2,17	107,3	147,9	63	7,2	40,6	15,2	11,4	64,4	24,2	Oil Injection
S1786	5	2	10:28	10:48	0	49,4	5275	10:24	10:20	1,52	10:53	10:49	1,8	46,9	67	49,4	14,8	20,1	14,5	29,9	40,7	29,4	Oil Injection
S1786	5	3	11:22	11:39	0	109,5	5153	11:17	11:13	1,38	11:44	11:40	2,09	9,6	59,9	109,5	36,6	50,3	22,6	33,4	45,9	20,7	Oil Injection, three feed rates
S1786	5	5	13:23	13:31	0	72,8	4908	13:20	13:16	1,43	13:38	13:34	1,75	31,8	63	72,8	15,7	31,2	25,9	21,6	42,9	35,6	Coal Injection
S1786	5	6	14:09	14:23	0	190	4785	14:03	13:59	1,61	14:29	14:25	2,76	14,1	74,1	190	55,0	60,0	75,0	29,0	31,6	39,5	Coal Injection 7,0
S1786	5	7	15:03	15:18	0	176,1	4663	14:58	14:54	2,26	15:23	15:19	2,56	69,4	112,7	176,1	14,0	43,3	118,8	7,9	24,6	67,5	Coal Injection
S1786	5	8	15:52	16:11	0	60,5	4540	15:48	15:44	3,27	16:05	16:01	4,01	59,6	77,2	60,5	33,6	17,6	9,3	55,5	29,1	15,4	Coal Injection
S1787	6	1	09:32	09:44	0	91,7	5500	09:33	09:29	2,18	09:48	09:44	3,14	110,4	123,5	91,7	52,8	13,1	25,8	57,6	14,3	28,1	P-Coke Injection
S1787	6	2	10:28	10:34	0	54,4	5501	10:20	10:16	1,06	10:41	10:37	1,36	120,6	129,3	54,4	16,5	8,7	29,2	30,3	16,0	53,7	P-Coke Injection
S1787	6	3	11:28	11:34	0	55,9	5376	11:25	11:21	1,06	11:47	11:43	1,71	24,0	34,6	55,9	34,9	10,6	10,4	62,5	19,0	18,5	P-Coke Injection
S1787	6	4	12:24	12:48	17,7	208	5331	12:31	12:27	1,52	12:55	12:51	2,98	31,1	84,9	190,3	77,8	53,8	58,7	40,9	28,3	30,8	P-Coke Injection
S1787	6	5	13:29	13:38	0	81,3	5207	13:30	13:26	1,81	13:44	13:40	2,16	66,8	95,1	81,3	18,2	28,3	34,8	22,4	34,8	42,8	P-Coke Injection
S1787	6	6	14:04	14:18	0	129	5082	14:03	13:59	1,43	14:23	14:19	2,87	45,7	99,5	129	73,2	53,8	2,0	56,7	41,7	1,6	P-Coke Injection

Analyzed dust from process gas

APPENDIX 5



Analytica

RAPPORT

L0306060

Sidan 1 av 3

Er Order Id:	
Registrerad:	2003-06-26
Analyserad:	2003-07-14
Utfärdad:	2003-07-14

MEFOS
L-E From

Box 812
971 25 Luleå

Analyspaket: **MG2-N**

Provnummer:	U10097099-00
Beteckning 1:	Prov K7
Beteckning 2:	

Analys	Resultat	Mätosäk.	Enhet	Metod
SiO_2 *	0,882		%	ICP-AES
Al_2O_3 *	0,182		%	ICP-AES
CaO *	0,312		%	ICP-AES
Fe_2O_3 *	2,42		%	ICP-AES
K_2O *	0,235		%	ICP-AES
MgO *	0,0700		%	ICP-AES
MnO *	0,195		%	ICP-AES
Na_2O *	0,118		%	ICP-AES
P_2O_5 *	0,0095		%	ICP-AES
TiO_2 *	0,0045		%	ICP-AES
Summa *	4,4		%	Man.Inm.
As *	<7		mg/kg	ICP-QMS
Ba *	151		mg/kg	ICP-AES
Be *	<0,8		mg/kg	ICP-AES
Cd *	<0,7		mg/kg	ICP-QMS
Co *	4,85		mg/kg	ICP-QMS
Cr *	62,1		mg/kg	ICP-AES
Cu *	30,4		mg/kg	ICP-QMS
Hg *	<0,5		mg/kg	AFS
La *	<8		mg/kg	ICP-AES
Mo *	9,70		mg/kg	ICP-AES
Nb *	<8		mg/kg	ICP-AES
Ni *	60,9		mg/kg	ICP-AES
Pb *	109		mg/kg	ICP-QMS

Analys	Resultat	Mätosäk.	Enhet	Metod
S *	1060		mg/kg	ICP-AES
Sc *	<2		mg/kg	ICP-AES
Sn *	<30		mg/kg	ICP-AES
Sr *	5,77		mg/kg	ICP-AES
V *	30,9		mg/kg	ICP-AES
W *	<80		mg/kg	ICP-AES
Y *	<3		mg/kg	ICP-AES
Zn *	585		mg/kg	ICP-AES
Zr *	3,23		mg/kg	ICP-AES

Vid analys av As, Cd, Cu, Co, Hg, Ni, Pb, Sb, Se och S gäller: Upplösning har skett enligt ASTM D3683 (modifierad). För övriga grundämnen har upplösning skett enligt ASTM D3682 ($LiBO_2$ – smälta) .

Vid analys av B har upplösning skett i mikrovågsugn med HNO3.

Analys har skett enligt EPA –metoder (modifierade) 200.7 (ICP-AES) och 200.8 (ICP-QMS).

Parametrar märkta med * indikerar ej ackrediterade analyser.

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977 75 Luleå
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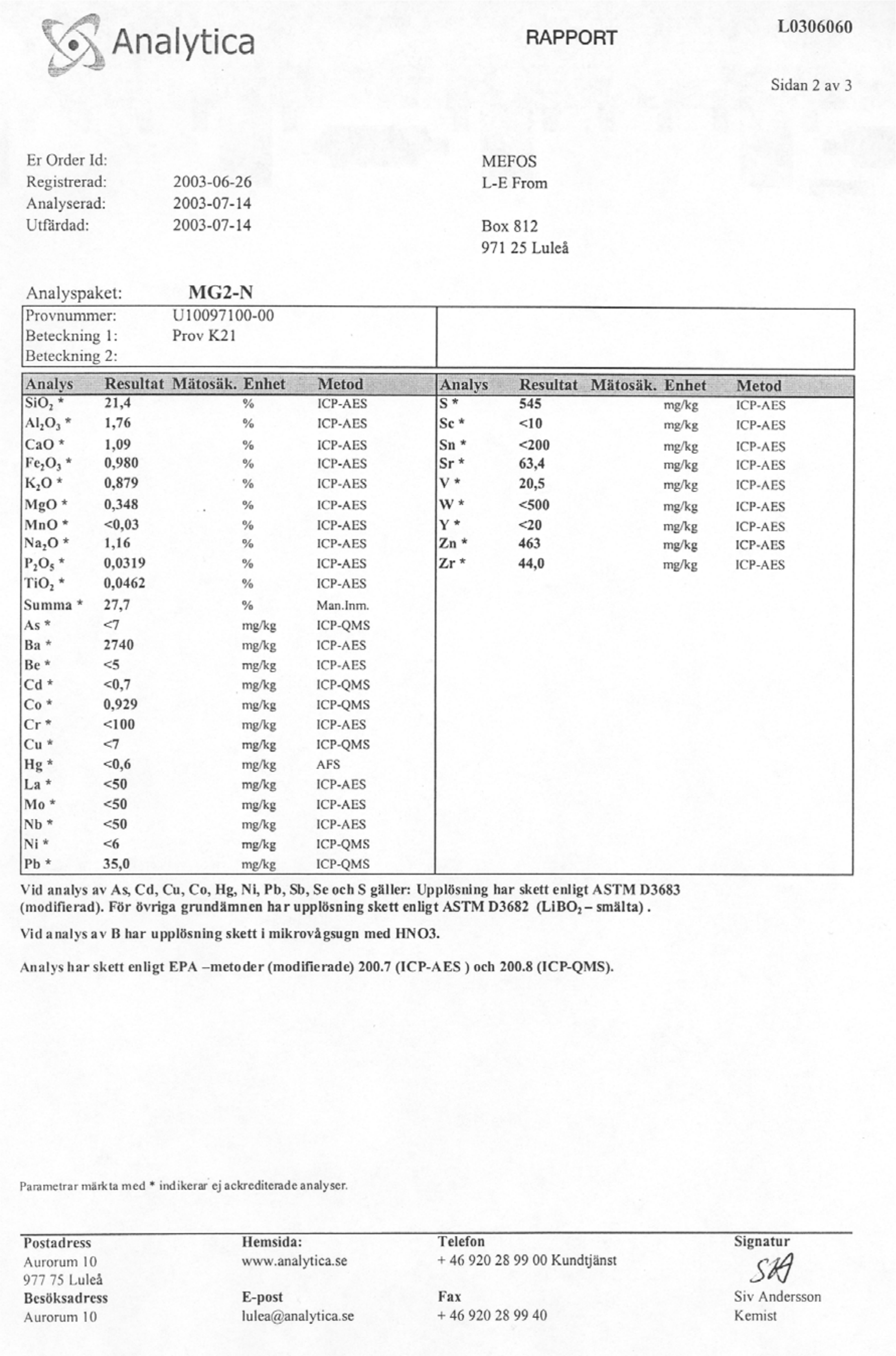
Signatur
Siv Andersson
Kemist



Analytica

RAPPORT

L0306060

Sidan 2 av 3

Er Order Id:
Registrerad: 2003-06-26
Analyserad: 2003-07-14
Utfärdad: 2003-07-14

MEFOS
L-E From

Box 812
971 25 Luleå

Analyspaket: **MG2-N**

Provnummer:	U10097100-00
Beteckning 1:	Prov K21
Beteckning 2:	

Analys	Resultat	Mätosäk.	Enhet	Metod
SiO_2 *	21,4		%	ICP-AES
Al_2O_3 *	1,76		%	ICP-AES
CaO *	1,09		%	ICP-AES
Fe_2O_3 *	0,980		%	ICP-AES
K_2O *	0,879		%	ICP-AES
MgO *	0,348		%	ICP-AES
MnO *	<0,03		%	ICP-AES
Na_2O *	1,16		%	ICP-AES
P_2O_5 *	0,0319		%	ICP-AES
TiO_2 *	0,0462		%	ICP-AES
Summa *	27,7		%	Man.Inm.
As *	<7		mg/kg	ICP-QMS
Ba *	2740		mg/kg	ICP-AES
Be *	<5		mg/kg	ICP-AES
Cd *	<0,7		mg/kg	ICP-QMS
Co *	0,929		mg/kg	ICP-QMS
Cr *	<100		mg/kg	ICP-AES
Cu *	<7		mg/kg	ICP-QMS
Hg *	<0,6		mg/kg	AFS
La *	<50		mg/kg	ICP-AES
Mo *	<50		mg/kg	ICP-AES
Nb *	<50		mg/kg	ICP-AES
Ni *	<6		mg/kg	ICP-QMS
Pb *	35,0		mg/kg	ICP-QMS
S *	545		mg/kg	ICP-AES
Sc *	<10		mg/kg	ICP-AES
Sn *	<200		mg/kg	ICP-AES
Sr *	63,4		mg/kg	ICP-AES
V *	20,5		mg/kg	ICP-AES
W *	<500		mg/kg	ICP-AES
Y *	<20		mg/kg	ICP-AES
Zn *	463		mg/kg	ICP-AES
Zr *	44,0		mg/kg	ICP-AES

Vid analys av As, Cd, Cu, Co, Hg, Ni, Pb, Sb, Se och S gäller: Upplösning har skett enligt ASTM D3683 (modifierad). För övriga grundämnen har upplösning skett enligt ASTM D3682 ($LiBO_2$ – smälta).

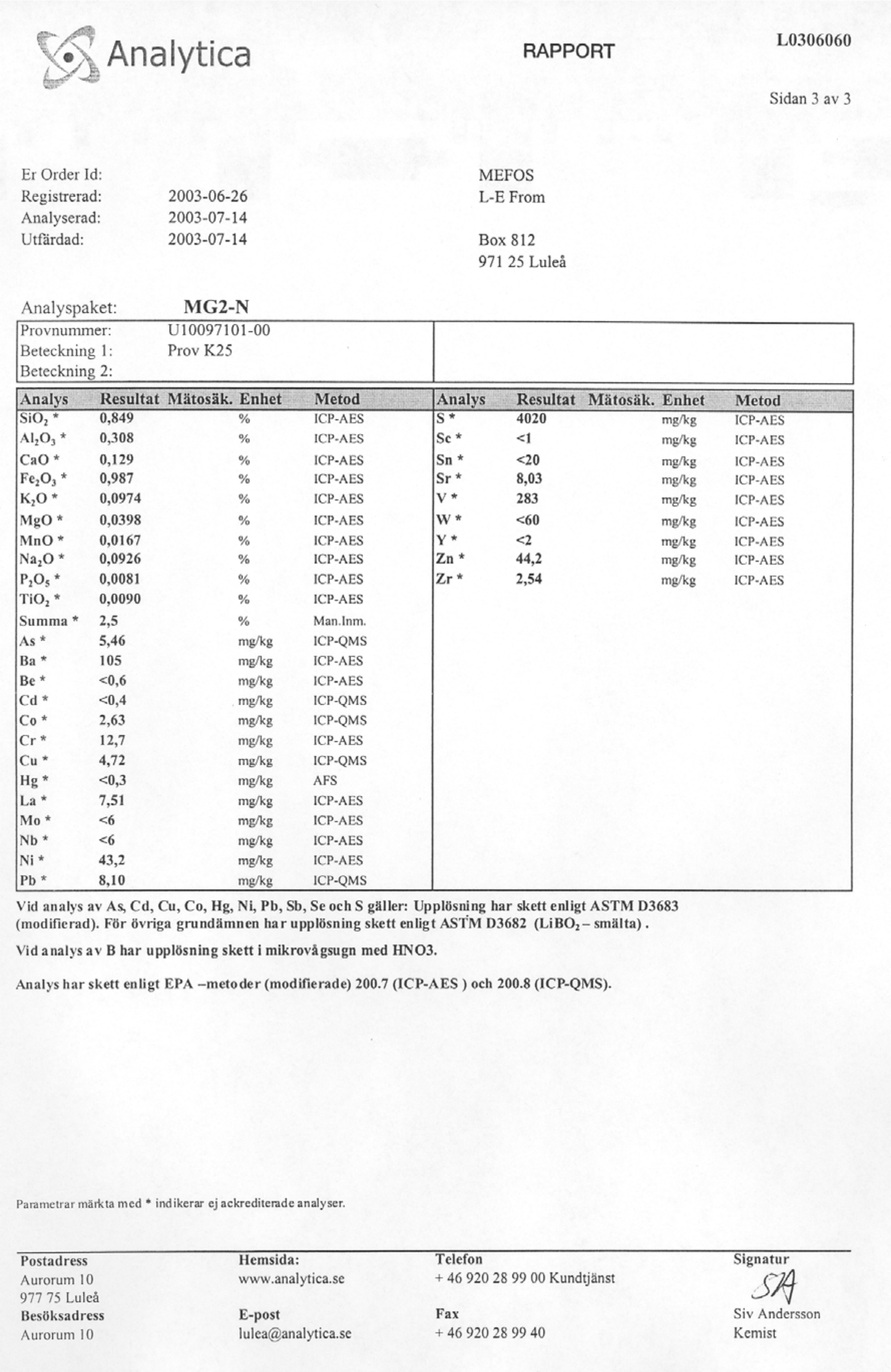
Vid analys av B har upplösning skett i mikrovågsugn med HNO3.

Analys har skett enligt EPA –metoder (modifierade) 200.7 (ICP-AES) och 200.8 (ICP-QMS).

Parametrar märkta med * indikerar ej ackrediterade analyser.

Postadress	**Hemsida:**	**Telefon**	**Signatur**
Aurorum 10 977 75 Luleå	www.analytica.se	+ 46 920 28 99 00 Kundtjänst	SA
Besöksadress	**E-post**	**Fax**	Siv Andersson
Aurorum 10	lulea@analytica.se	+ 46 920 28 99 40	Kemist

APPENDIX 5



Analytica **RAPPORT** **L0306060**

Sidan 3 av 3

Er Order Id:	
Registrerad:	2003-06-26
Analyserad:	2003-07-14
Utfärdad:	2003-07-14

MEFOS
L-E From

Box 812
971 25 Luleå

Analyspaket: **MG2-N**

Provnummer:	U10097101-00
Beteckning 1:	Prov K25
Beteckning 2:	

Analys	Resultat	Mätosäk.	Enhet	Metod	Analys	Resultat	Mätosäk.	Enhet	Metod
SiO_2 *	0,849		%	ICP-AES	S *	4020		mg/kg	ICP-AES
Al_2O_3 *	0,308		%	ICP-AES	Sc *	<1		mg/kg	ICP-AES
CaO *	0,129		%	ICP-AES	Sn *	<20		mg/kg	ICP-AES
Fe_2O_3 *	0,987		%	ICP-AES	Sr *	8,03		mg/kg	ICP-AES
K_2O *	0,0974		%	ICP-AES	V *	283		mg/kg	ICP-AES
MgO *	0,0398		%	ICP-AES	W *	<60		mg/kg	ICP-AES
MnO *	0,0167		%	ICP-AES	Y *	<2		mg/kg	ICP-AES
Na_2O *	0,0926		%	ICP-AES	Zn *	44,2		mg/kg	ICP-AES
P_2O_5 *	0,0081		%	ICP-AES	Zr *	2,54		mg/kg	ICP-AES
TiO_2 *	0,0090		%	ICP-AES					
Summa *	2,5		%	Man.Inm.					
As *	5,46		mg/kg	ICP-QMS					
Ba *	105		mg/kg	ICP-AES					
Be *	<0,6		mg/kg	ICP-AES					
Cd *	<0,4		mg/kg	ICP-QMS					
Co *	2,63		mg/kg	ICP-QMS					
Cr *	12,7		mg/kg	ICP-AES					
Cu *	4,72		mg/kg	ICP-QMS					
Hg *	<0,3		mg/kg	AFS					
La *	7,51		mg/kg	ICP-AES					
Mo *	<6		mg/kg	ICP-AES					
Nb *	<6		mg/kg	ICP-AES					
Ni *	43,2		mg/kg	ICP-AES					
Pb *	8,10		mg/kg	ICP-QMS					

Vid analys av As, Cd, Cu, Co, Hg, Ni, Pb, Sb, Se och S gäller: Upplösning har skett enligt ASTM D3683 (modifierad). För övriga grundämnen har upplösning skett enligt ASTM D3682 ($LiBO_2$ – smälta) .

Vid analys av B har upplösning skett i mikrovågsugn med HNO3.

Analys har skett enligt EPA –metoder (modifierade) 200.7 (ICP-AES) och 200.8 (ICP-QMS).

Parametrar märkta med * indikerar ej ackrediterade analyser.

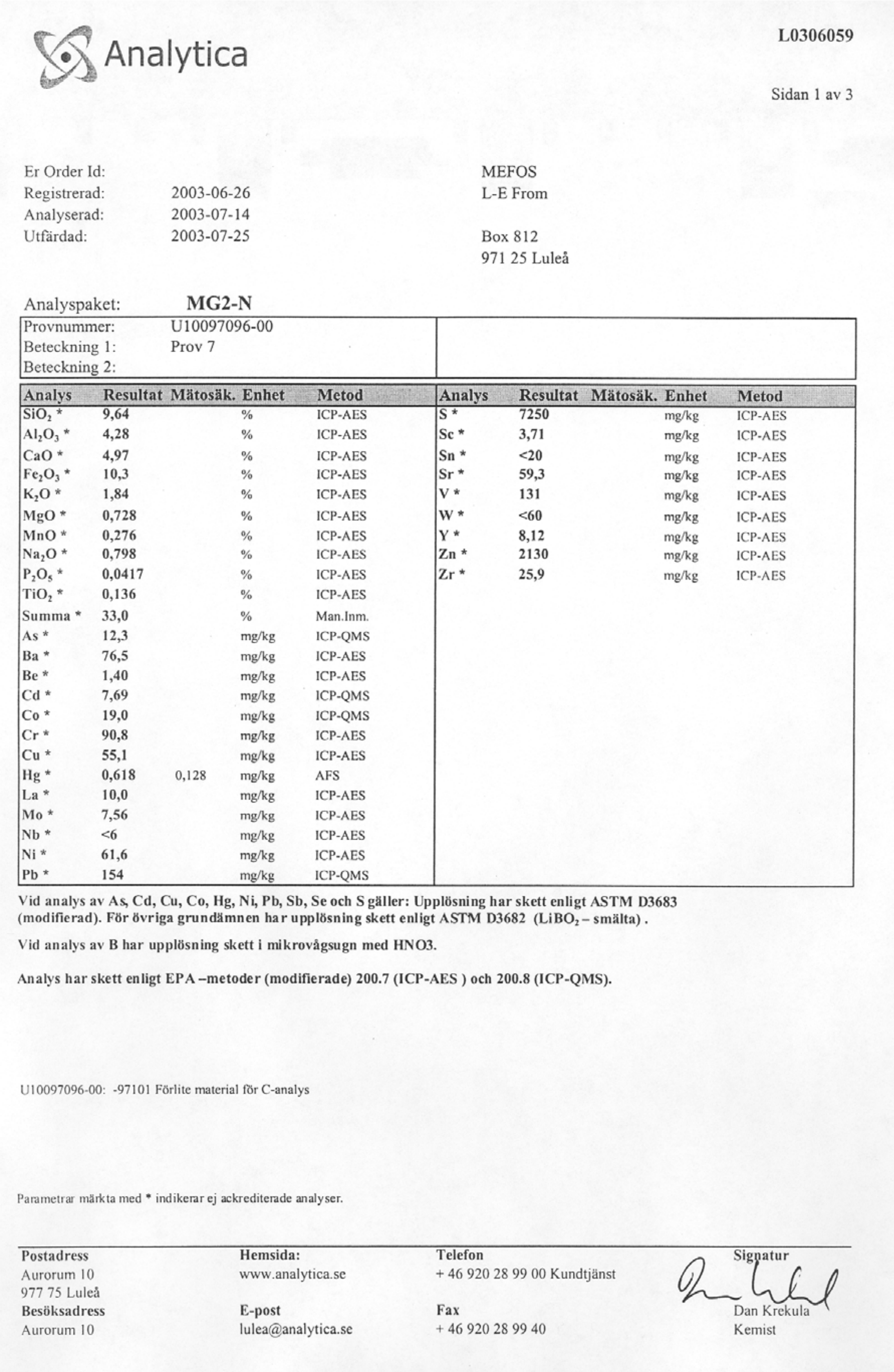
Postadress	**Hemsida:**	**Telefon**	**Signatur**
Aurorum 10 977 75 Luleå	www.analytica.se	+ 46 920 28 99 00 Kundtjänst	
Besöksadress	**E-post**	**Fax**	Siv Andersson
Aurorum 10	lulea@analytica.se	+ 46 920 28 99 40	Kemist

DUST SAMPLES-Preliminary 2003-06-18

Sample No	**Sampling place**	**Date**	**Starttime** hhmm	**Stoptime** hhmm	**Meas.Time** min	**Dust content** g/m3n dry gas	**Moisture** %
1	Before wet venturie, off gas	2003-06-05	11,41	11,55	14,00	9,80	2,04
2	Before wet venturie, off gas	2003-06-05	12,38	12,47	9,00	2,40	3,40
3	Before wet venturie, off gas	2003-06-05	14,03	14,29	26,00	3,60	1,22
4	Before wet venturie, off gas	2003-06-05	14,53	15,10	17,00	2,90	2,82
5	Before wet venturie, off gas	2003-06-06	9,56	10,16	20,00	3,60	2,59
6	Before wet venturie, off gas	2003-06-06	10,41	11,01	20,00	4,60	3,62
7	Before wet venturie, off gas	2003-06-06	11,23	11,49	26,00	1,70	1,99
8	Before wet venturie, off gas	2003-06-06	12,49	13,01	12,00	1,90	2,65
9	Before wet venturie, off gas	2003-06-06	13,51	14,01	10,00	2,20	6,09
10	Before wet venturie, off gas	2003-06-06	14,34	14,48	14,00	3,20	0,94
11	Before wet venturie, off gas	2003-06-10	10,06	10,23	17,00	9,90	1,02
12	Before wet venturie, off gas	2003-06-10	10,48	11,03	15,00	8,60	2,27
13	Before wet venturie, off gas	2003-06-10	11,42	11,51	9,00	11,70	2,44
14	Before wet venturie, off gas	2003-06-10	12,38	12,53	15,00	13,00	2,47
15	Before wet venturie, off gas	2003-06-10	13,35	13,51	16,00	21,20	1,35
16	Before wet venturie, off gas	2003-06-11	9,40	9,50	10,00	13,30	2,72
17	Before wet venturie, off gas	2003-06-11	10,30	10,43	13,00	10,70	2,59
18	Before wet venturie, off gas	2003-06-11	11,40	11,56	16,00	7,20	2,49
19	Before wet venturie, off gas	2003-06-11	12,59	13,12	13,00	7,00	2,91
20	Before wet venturie, off gas	2003-06-11	14,17	14,29	12,00	12,80	2,38
21	Before wet venturie, off gas	2003-06-12	11,23	11,39	16,00	11,10	3,38
22	Before wet venturie, off gas	2003-06-12	13,28	13,36	8,00	2,80	3,50
23	Before wet venturie, off gas	2003-06-12	14,14	14,29	15,00	11,60	2,53
24	Before wet venturie, off gas	2003-06-12	15,56	16,16	20,00	14,60	1,87
25	Before wet venturie, off gas	2003-06-13	9,26	9,48	22,00	6,30	3,34
26	Before wet venturie, off gas	2003-06-13	10,33	10,39	6,00	8,10	4,81
27	Before wet venturie, off gas	2003-06-13	11,33	11,56	23,00	0,70	1,56
28	Before wet venturie, off gas	2003-06-13	12,29	12,53	24,00	9,20	2,72
29	Before wet venturie, off gas	2003-06-13	13,34	13,44	10,00	10,80	3,17
30	Before wet venturie, off gas	2003-06-13	14,09	14,23	14,00	12,40	1,67

Analyzed dust from combusted gas

APPENDIX 7



Analytica

L0306059

Sidan 1 av 3

Er Order Id:
Registrerad: 2003-06-26
Analyserad: 2003-07-14
Utfärdad: 2003-07-25

MEFOS
L-E From

Box 812
971 25 Luleå

Analyspaket: **MG2-N**

Provnummer:	U10097096-00
Beteckning 1:	Prov 7
Beteckning 2:	

Analys	Resultat	Mätosäk.	Enhet	Metod	Analys	Resultat	Mätosäk.	Enhet	Metod
SiO_2 *	**9,64**		%	ICP-AES	**S ***	**7250**		mg/kg	ICP-AES
Al_2O_3 *	**4,28**		%	ICP-AES	**Sc ***	**3,71**		mg/kg	ICP-AES
CaO *	**4,97**		%	ICP-AES	**Sn ***	**<20**		mg/kg	ICP-AES
Fe_2O_3 *	**10,3**		%	ICP-AES	**Sr ***	**59,3**		mg/kg	ICP-AES
K_2O *	**1,84**		%	ICP-AES	**V ***	**131**		mg/kg	ICP-AES
MgO *	**0,728**		%	ICP-AES	**W ***	**<60**		mg/kg	ICP-AES
MnO *	**0,276**		%	ICP-AES	**Y ***	**8,12**		mg/kg	ICP-AES
Na_2O *	**0,798**		%	ICP-AES	**Zn ***	**2130**		mg/kg	ICP-AES
P_2O_5 *	**0,0417**		%	ICP-AES	**Zr ***	**25,9**		mg/kg	ICP-AES
TiO_2 *	**0,136**		%	ICP-AES					
Summa *	**33,0**		%	Man.Inm.					
As *	**12,3**		mg/kg	ICP-QMS					
Ba *	**76,5**		mg/kg	ICP-AES					
Be *	**1,40**		mg/kg	ICP-AES					
Cd *	**7,69**		mg/kg	ICP-QMS					
Co *	**19,0**		mg/kg	ICP-QMS					
Cr *	**90,8**		mg/kg	ICP-AES					
Cu *	**55,1**		mg/kg	ICP-AES					
Hg *	**0,618**	0,128	mg/kg	AFS					
La *	**10,0**		mg/kg	ICP-AES					
Mo *	**7,56**		mg/kg	ICP-AES					
Nb *	**<6**		mg/kg	ICP-AES					
Ni *	**61,6**		mg/kg	ICP-AES					
Pb *	**154**		mg/kg	ICP-QMS					

Vid analys av As, Cd, Cu, Co, Hg, Ni, Pb, Sb, Se och S gäller: Upplösning har skett enligt ASTM D3683 (modifierad). För övriga grundämnen har upplösning skett enligt ASTM D3682 ($LiBO_2$ – smälta) .

Vid analys av B har upplösning skett i mikrovågsugn med HNO3.

Analys har skett enligt EPA –metoder (modifierade) 200.7 (ICP-AES) och 200.8 (ICP-QMS).

U10097096-00: -97101 Förlite material för C-analys

Parametrar märkta med * indikerar ej ackrediterade analyser.

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977 75 Luleå
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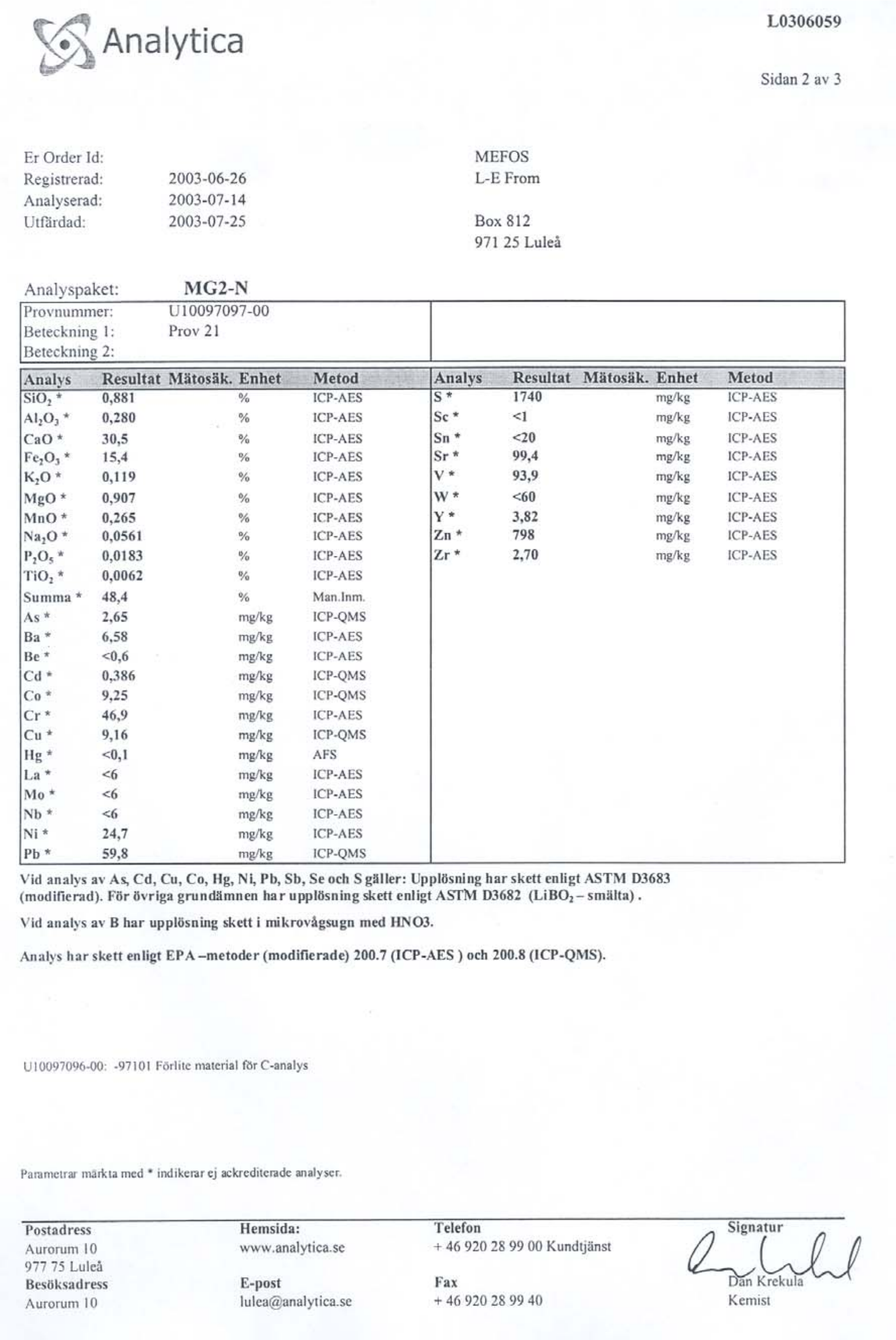
Fax
+ 46 920 28 99 40

Signatur
Dan Krekula
Kemist

Analyzed dust from combusted gas

APPENDIX 7



Analytica

L0306059

Sidan 2 av 3

Er Order Id:		MEFOS
Registrerad:	2003-06-26	L-E From
Analyserad:	2003-07-14	
Utfärdad:	2003-07-25	Box 812
		971 25 Luleå

Analyspaket: **MG2-N**

Provnummer:	U10097097-00
Beteckning 1:	Prov 21
Beteckning 2:	

Analys	Resultat	Mätosäk.	Enhet	Metod
SiO_2 *	0,881		%	ICP-AES
Al_2O_3 *	0,280		%	ICP-AES
CaO *	30,5		%	ICP-AES
Fe_2O_3 *	15,4		%	ICP-AES
K_2O *	0,119		%	ICP-AES
MgO *	0,907		%	ICP-AES
MnO *	0,265		%	ICP-AES
Na_2O *	0,0561		%	ICP-AES
P_2O_5 *	0,0183		%	ICP-AES
TiO_2 *	0,0062		%	ICP-AES
Summa *	48,4		%	Man.Inm.
As *	2,65		mg/kg	ICP-QMS
Ba *	6,58		mg/kg	ICP-AES
Be *	<0,6		mg/kg	ICP-AES
Cd *	0,386		mg/kg	ICP-QMS
Co *	9,25		mg/kg	ICP-QMS
Cr *	46,9		mg/kg	ICP-AES
Cu *	9,16		mg/kg	ICP-QMS
Hg *	<0,1		mg/kg	AFS
La *	<6		mg/kg	ICP-AES
Mo *	<6		mg/kg	ICP-AES
Nb *	<6		mg/kg	ICP-AES
Ni *	24,7		mg/kg	ICP-AES
Pb *	59,8		mg/kg	ICP-QMS

Analys	Resultat	Mätosäk.	Enhet	Metod
S *	1740		mg/kg	ICP-AES
Sc *	<1		mg/kg	ICP-AES
Sn *	<20		mg/kg	ICP-AES
Sr *	99,4		mg/kg	ICP-AES
V *	93,9		mg/kg	ICP-AES
W *	<60		mg/kg	ICP-AES
Y *	3,82		mg/kg	ICP-AES
Zn *	798		mg/kg	ICP-AES
Zr *	2,70		mg/kg	ICP-AES

Vid analys av As, Cd, Cu, Co, Hg, Ni, Pb, Sb, Se och S gäller: Upplösning har skett enligt ASTM D3683 (modifierad). För övriga grundämnen har upplösning skett enligt ASTM D3682 ($LiBO_2$ – smälta).

Vid analys av B har upplösning skett i mikrovågsugn med HNO3.

Analys har skett enligt EPA –metoder (modifierade) 200.7 (ICP-AES) och 200.8 (ICP-QMS).

U10097096-00: -97101 Förlite material för C-analys

Parametrar märkta med * indikerar ej ackrediterade analyser.

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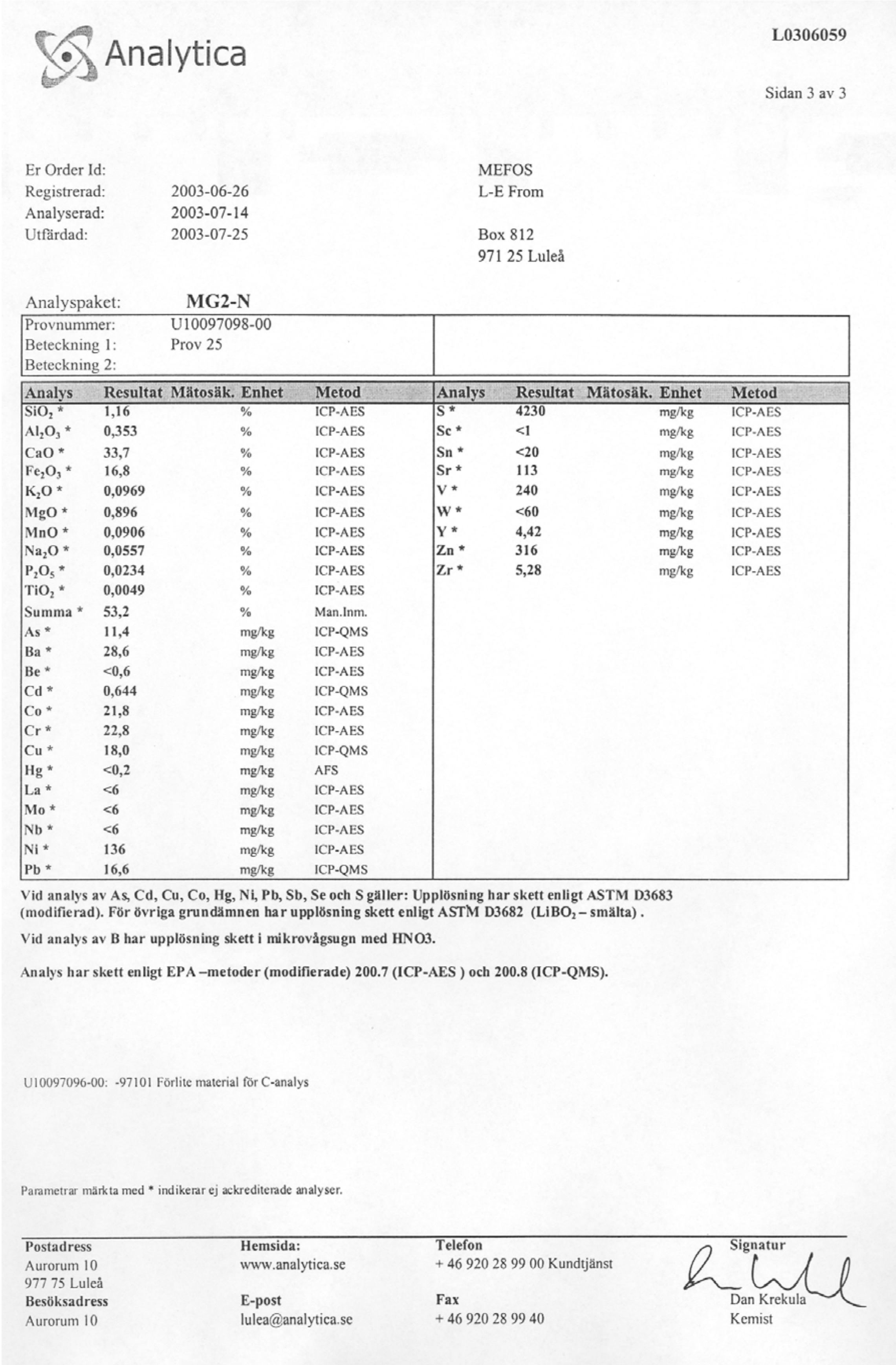
Besöksadress	E-post	Fax	Dan Krekula
Aurorum 10	lulea@analytica.se	+ 46 920 28 99 40	Kemist

Analyzed dust from combusted gas

APPENDIX 7



Analytica

L0306059

Sidan 3 av 3

Er Order Id:			MEFOS
Registrerad:	2003-06-26		L-E From
Analyserad:	2003-07-14		
Utfärdad:	2003-07-25		Box 812
			971 25 Luleå

Analyspaket: **MG2-N**

Provnummer:	U10097098-00
Beteckning 1:	Prov 25
Beteckning 2:	

Analys	Resultat	Mätosäk.	Enhet	Metod	Analys	Resultat	Mätosäk.	Enhet	Metod
SiO_2 *	1,16		%	ICP-AES	S *	4230		mg/kg	ICP-AES
Al_2O_3 *	0,353		%	ICP-AES	Sc *	<1		mg/kg	ICP-AES
CaO *	33,7		%	ICP-AES	Sn *	<20		mg/kg	ICP-AES
Fe_2O_3 *	16,8		%	ICP-AES	Sr *	113		mg/kg	ICP-AES
K_2O *	0,0969		%	ICP-AES	V *	240		mg/kg	ICP-AES
MgO *	0,896		%	ICP-AES	W *	<60		mg/kg	ICP-AES
MnO *	0,0906		%	ICP-AES	Y *	4,42		mg/kg	ICP-AES
Na_2O *	0,0557		%	ICP-AES	Zn *	316		mg/kg	ICP-AES
P_2O_5 *	0,0234		%	ICP-AES	Zr *	5,28		mg/kg	ICP-AES
TiO_2 *	0,0049		%	ICP-AES					
Summa *	53,2		%	Man.Inm.					
As *	11,4		mg/kg	ICP-QMS					
Ba *	28,6		mg/kg	ICP-AES					
Be *	<0,6		mg/kg	ICP-AES					
Cd *	0,644		mg/kg	ICP-QMS					
Co *	21,8		mg/kg	ICP-AES					
Cr *	22,8		mg/kg	ICP-AES					
Cu *	18,0		mg/kg	ICP-QMS					
Hg *	<0,2		mg/kg	AFS					
La *	<6		mg/kg	ICP-AES					
Mo *	<6		mg/kg	ICP-AES					
Nb *	<6		mg/kg	ICP-AES					
Ni *	136		mg/kg	ICP-AES					
Pb *	16,6		mg/kg	ICP-QMS					

Vid analys av As, Cd, Cu, Co, Hg, Ni, Pb, Sb, Se och S gäller: Upplösning har skett enligt ASTM D3683 (modifierad). För övriga grundämnen har upplösning skett enligt ASTM D3682 ($LiBO_2$ – smälta) .

Vid analys av B har upplösning skett i mikrovågsugn med HNO3.

Analys har skett enligt EPA –metoder (modifierade) 200.7 (ICP-AES) och 200.8 (ICP-QMS).

U10097096-00: -97101 Förlite material för C-analys

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Analyzed dust from combusted gas

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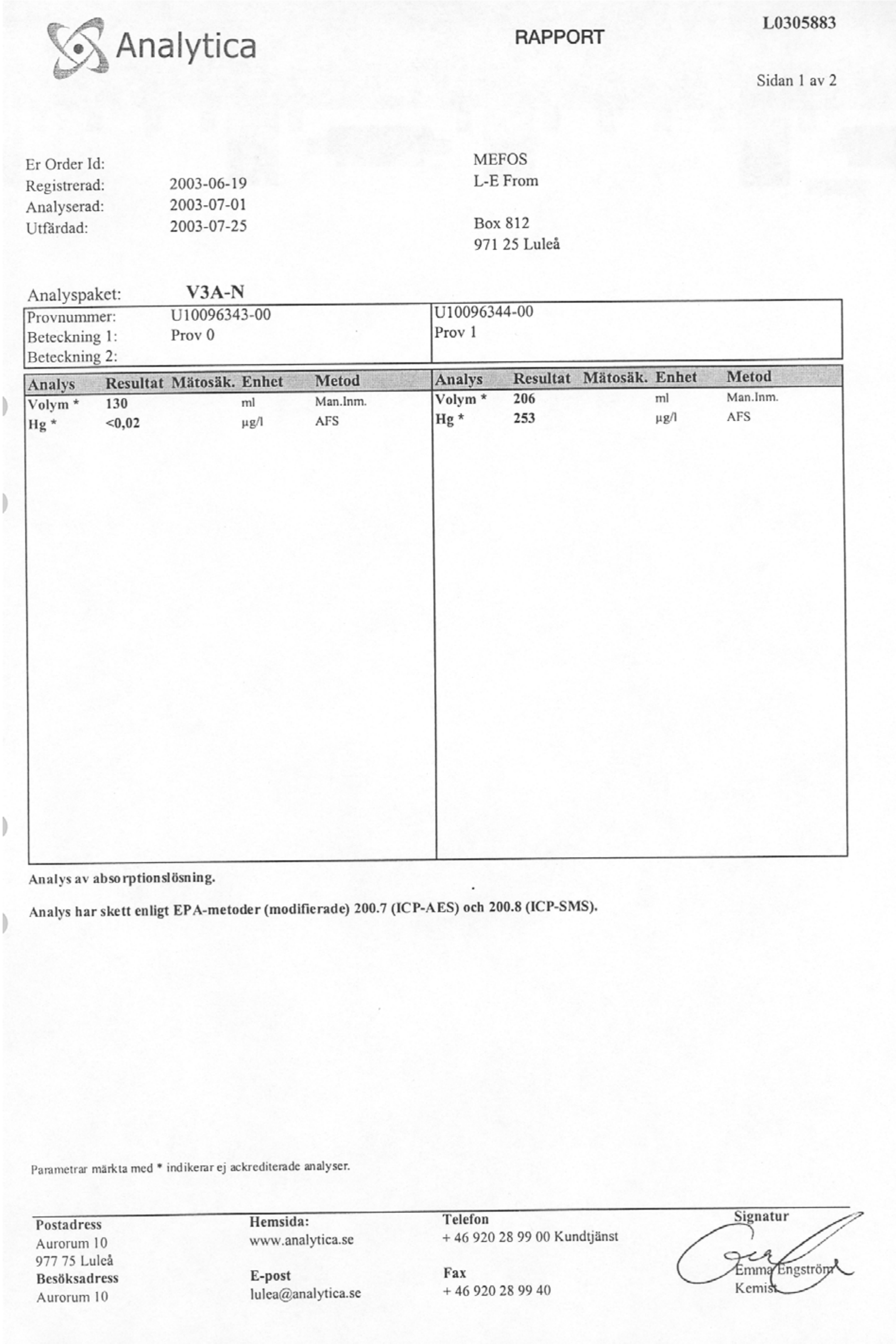

Analytica

RAPPORT

L0305883

Sidan 1 av 2

Er Order Id:
Registrerad: 2003-06-19
Analyserad: 2003-07-01
Utfärdad: 2003-07-25

MEFOS
L-E From

Box 812
971 25 Luleå

Analyspaket: **V3A-N**

Provnummer:	U10096343-00	U10096344-00
Beteckning 1:	Prov 0	Prov 1
Beteckning 2:		

Analys	Resultat	Mätosäk.	Enhet	Metod
Volym *	**130**		ml	Man.Inm.
Hg *	**<0,02**		µg/l	AFS

Analys	Resultat	Mätosäk.	Enhet	Metod
Volym *	**206**		ml	Man.Inm.
Hg *	**253**		µg/l	AFS

Analys av absorptionslösning.

Analys har skett enligt EPA-metoder (modifierade) 200.7 (ICP-AES) och 200.8 (ICP-SMS).

Parametrar märkta med * indikerar ej ackrediterade analyser.

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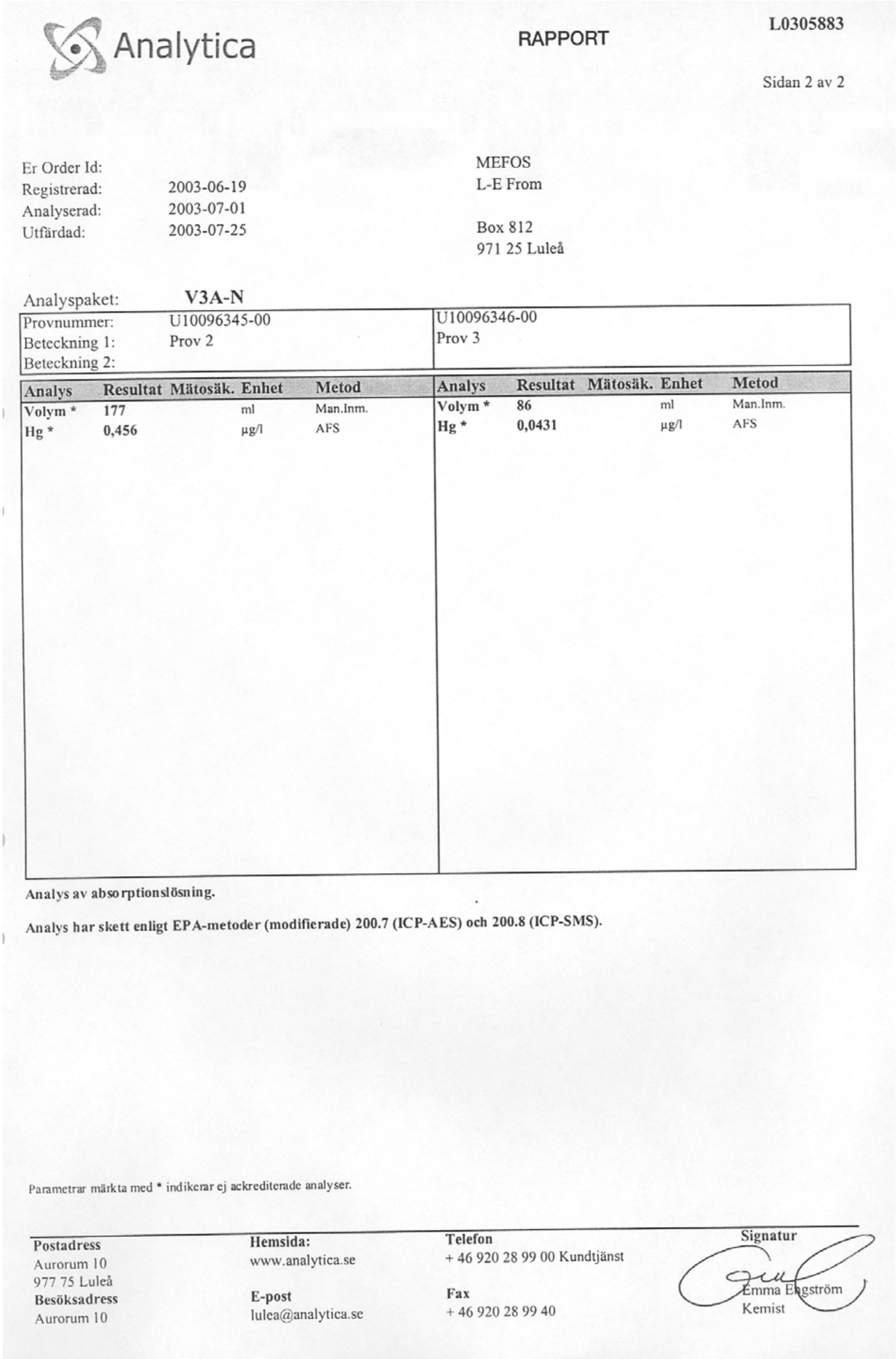
Fax
+ 46 920 28 99 40

Signatur
Emma Engström
Kemist

Analyzed dust from combusted gas

APPENDIX 7



Analytica

RAPPORT

L0305883

Sidan 2 av 2

Er Order Id:	
Registrerad:	2003-06-19
Analyserad:	2003-07-01
Utfärdad:	2003-07-25

MEFOS
L-E From

Box 812
971 25 Luleå

Analyspaket: **V3A-N**

Provnummer:	U10096345-00	U10096346-00
Beteckning 1:	Prov 2	Prov 3
Beteckning 2:		

Analys	Resultat	Mätosäk.	Enhet	Metod
Volym *	**177**		ml	Man.Inm.
Hg *	**0,456**		µg/l	AFS

Analys	Resultat	Mätosäk.	Enhet	Metod
Volym *	**86**		ml	Man.Inm.
Hg *	**0,0431**		µg/l	AFS

Analys av absorptionslösning.

Analys har skett enligt EPA-metoder (modifierade) 200.7 (ICP-AES) och 200.8 (ICP-SMS).

Parametrar märkta med * indikerar ej ackrediterade analyser.

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+ 46 920 28 99 40

Signatur
Emma Engström
Kemist

Appendix VII

Hymelt campaign II,

2-4 September 2003

MEFOS

Box 812, 971 25 LULEÅ

Dokument:	Tekniskt meddelande	*Reg nummer:*	TM03054K
Fo-uppgift:		*Datum:*	2003-10-27
Konto:	387460	*Rev datum:*	
Ämnesomr:		*Avdelning:*	MM

HYMELT CAMPAIGN II,

2-4 SEPTEMBER 2003

by

Sten Ångström, Anders Persson

Projektledare: Nils-Olov Lindfors *Sekr:* acj

Distribution: SÅ, APe, NOL, Don P Malone-EnviRes LLC (dpmalone@alltel.net)

SUMMARY

A second camping has been made in the development of the HyMelt process. The equipment set up was, compared to the first campaign, rearranged. The most important modification was that the top lance injection was replaced by a side wall tuyere injection.

Two test days with stable operation and measurements were made. The first tuyere tested had to be replaced to a tuyere with an annular slit for air injection. The new design showed good performance for the rest of the camping.

Important results achieved compared to top lance injection:

- Improved carbon yield to metal, especially for petroleum coke
- Higher concentrations of hydrogen in the process gas and reduced amounts of hydrocarbons
- More stable operation and generally better routines for sampling and measurements

Remaining process difficulties:

- Metal sculling on the lance
- Not sufficient yield for coal
- Reducible oxides in the slag after oxygen blowing

Introduction

This document describes tests and results from the HyMelt II campaign at MEFOS, 2-4 September 2003. Campaign I is reported in MEFOS document TM03037K, and conditions equal to Campaign I are not be repeated.

Remaining issues from the HyMelt campaign I concerned:

- Carbon yield to metal during carburisation
- Evaluation of melt temperature in the process computer
- System and code for calculation of coal/coke flow rate
- Leakage air in sampled process gas for measurement
- Improved in blow metal sampling system

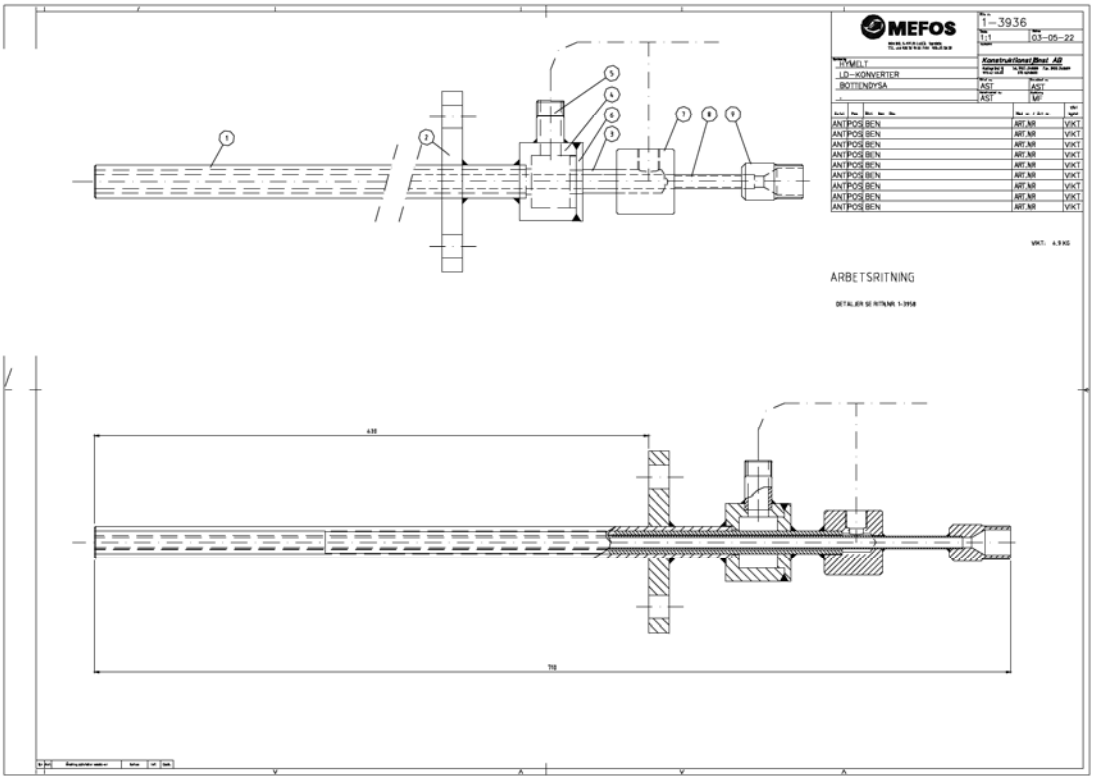
Equipment

Rearrangements made:

- Material injection through a wall tuyere replaced the top lance
- The bottom tuyere was plugged and not used.
- Argon was used as material carrier gas replacing nitrogen.
- A new set up of gas analysers were arranged

Tuyere design

The first tuyere tested was a single pipe tuyere with 8 mm inner diameter. Severe problem with blocking occurred early and made a replacement to a tuyere with an annular slit, Figure 1. In the slit, actually two slits, dried air was blown to prevent metal freezing and mushroom formation in the tuyere outlet. The tuyere design is optimised for other applications and it can for this process most likely be simplified to only one slit.


MEFOS
1–3936
1:1
03–05–22
HYMELT
LD–KONVERTER
BOTTENDYSA
Konstruktionsteknik AB
AST
AST
AST
MF
ANT POS BEN ART.NR VIKT
ANT POS BEN ART.NR VIKT
ANT POS BEN ART.NR VIKT
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ANT POS BEN ART.NR VIKT
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ANT POS BEN ART.NR VIKT
VIKT: 4.9 KG
ARBETSRITNING
DETALJER SE RITN.NR. 1-3958
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6
7
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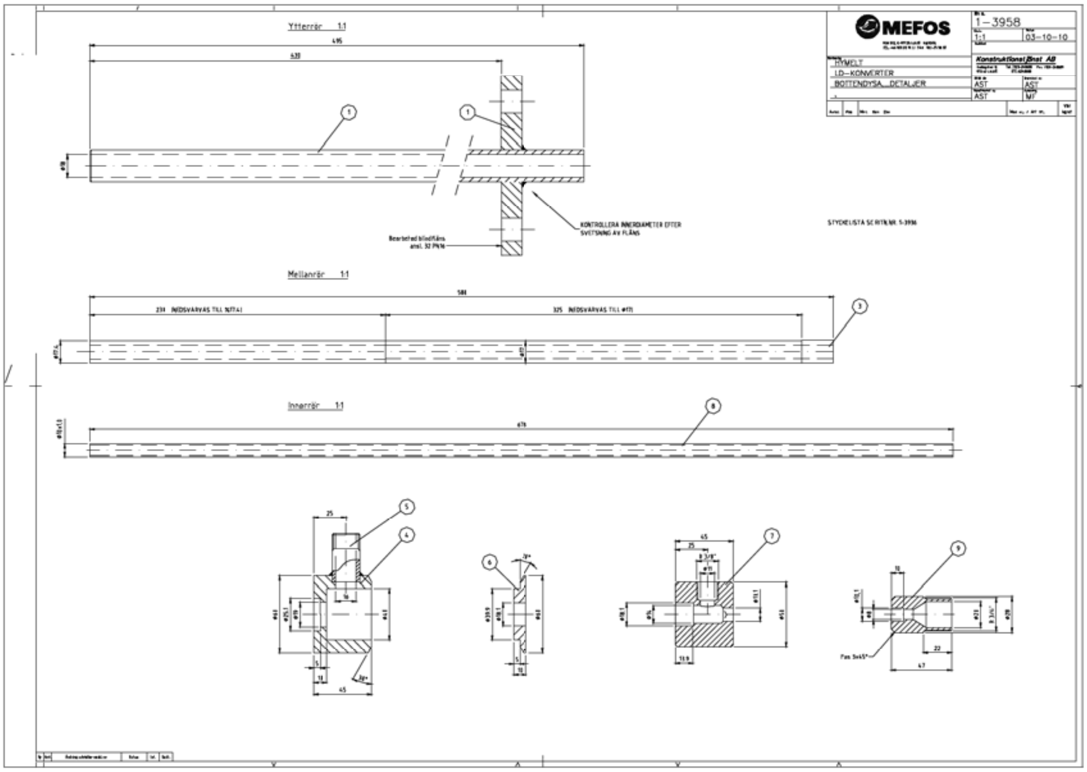
9
430
710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03–10–10
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LD–KONVERTER
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Konstruktionsteknik AB
AST
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Ytterrör 1:1
495
430
1
KONTROLLERA INNERDIAMETER EFTER SVETSNING AV FLÄNS
Bearbetad blindfläns ansl. 32 PN16
STYCKELISTA SE RITN.NR. 1-3936
Mellanrör 1:1
588
234 NEDSVARVAS TILL
325 NEDSVARVAS TILL
3
Innerrör 1:1
676
8
25
5
4
45
6
45
25
7
9
22
47
Fas 5x45°

Figure 1 – Annular slit tuyere

Set up of gas analysing system

The modified set up for process gas analysers is schematically shown in Figure 2. For detail information of H-Sence and AS200 (AirSence) see Appendix 1 and 2,

The option for Hg sampling was not used in this campaign.

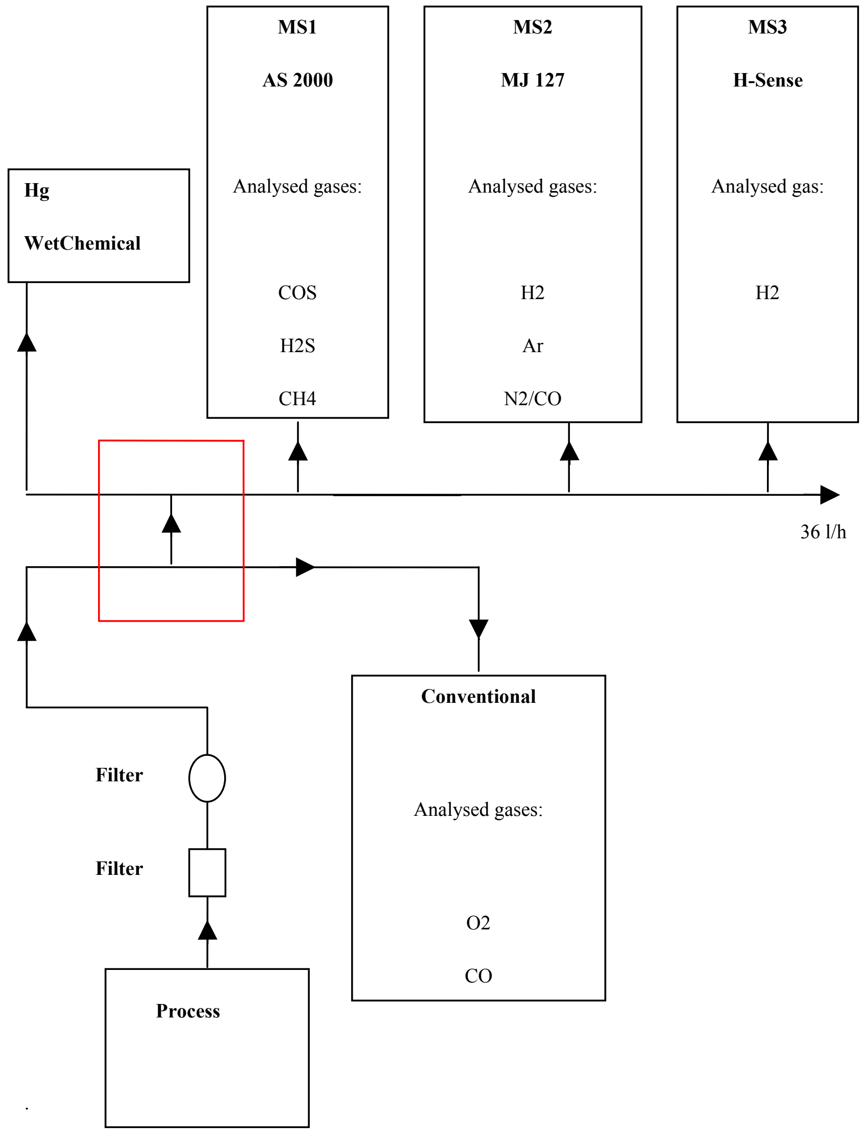

Figure 2 – Schematic set up of gas analysers

From the figure it can be seen that hydrogen was analysed by three methods. This arrangement was a result from the previous campaign in which both response time, linearity and accuracy was discussed.

Figure 3 and 4 demonstrate the problem where known mixtures of argon and hydrogen have been measured by two of the instruments.

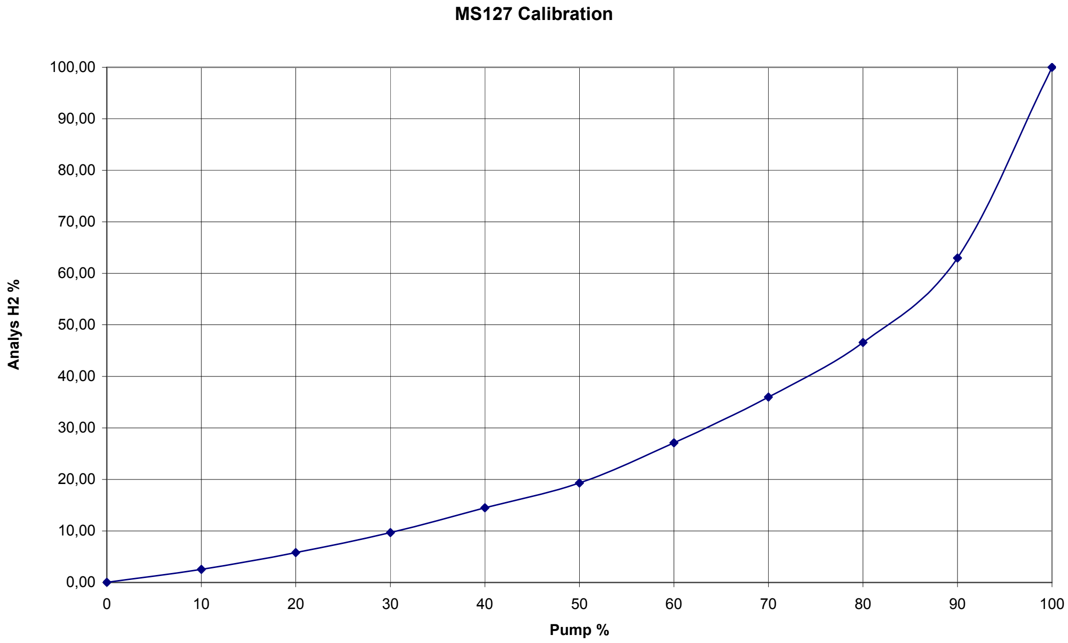

Figure 3 – MS127 results from known gas mixes

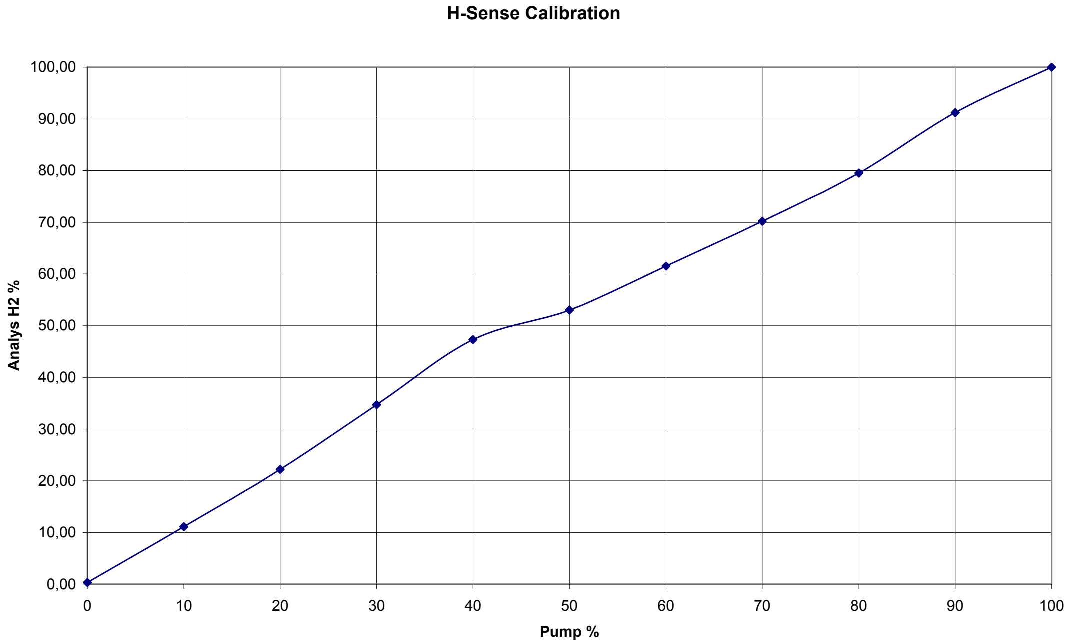

Figure 4 – H-Sense, results from known gas mixes

The H-Sense instrument is gives more reliable data and has a faster response which is of great importance due to short measuring periods.

Material

The same materials as for previous test were used, for information see TM03037K.

Test procedure

The tests were carried out according to the same routines as for the previous test, for information see TM03037K.

Heat notes

HyMelt 7, 2 September 2003

The test was interrupted after a water leakage from the oxygen lance during initial decarburisation. The steel was tapped and transferred to the EAF.

HyMelt 8, 2 September 2003

The wall tuyere was immediately blocked during the first coal injection period. After tapping it was removed and replaced by a concentric tuyere. In the outer slits dried air was blown. The idea was to avoid freezing of metal, mushroom formation, in front of the tuyere by a balanced oxygen feed. The air flow supply was arranged in a separate system, manually controlled and logged.

HyMelt 9, 3 September 2003

Five coke injection tests were made during the day. Sampling of metal, slag, gases and dust could be made for all periods.

HyMelt 10, 4 September 2003

Three coal and tree coke injection periods where made. Sampling of metal, slag, gases and dust could be made for all periods.

An obvious higher part of injected carbon is transferred to metal from coke compared to coal.

Results

Test periods

Evaluation has been made for HyMelt 9 and HyMelt 10. HyMelt 7 and 8 are not evaluated because of short tests and unstable conditions.

HyMelt 9

For all injection periods coke were used. The injection rate varied between 6 to 14 kg/minute.

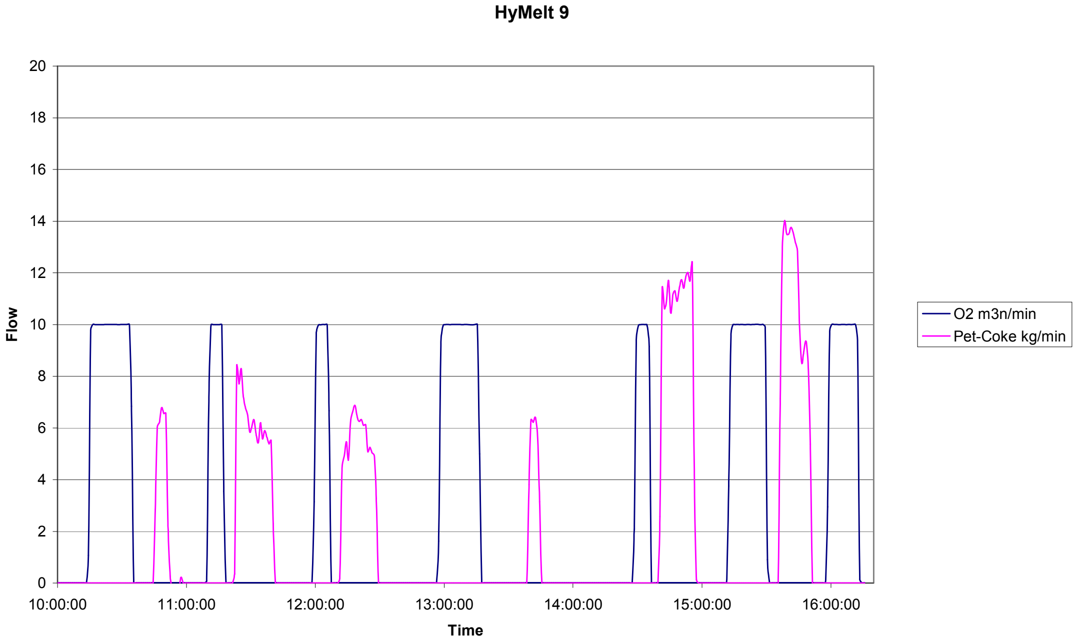

Figure 5 - Injection periods and oxygen blowing periods for HyMelt 9

HyMelt 10

For the first three periods coal were injected and for the remaining three coke were used. The injection rate varied between 6 to 18 kg/minute.

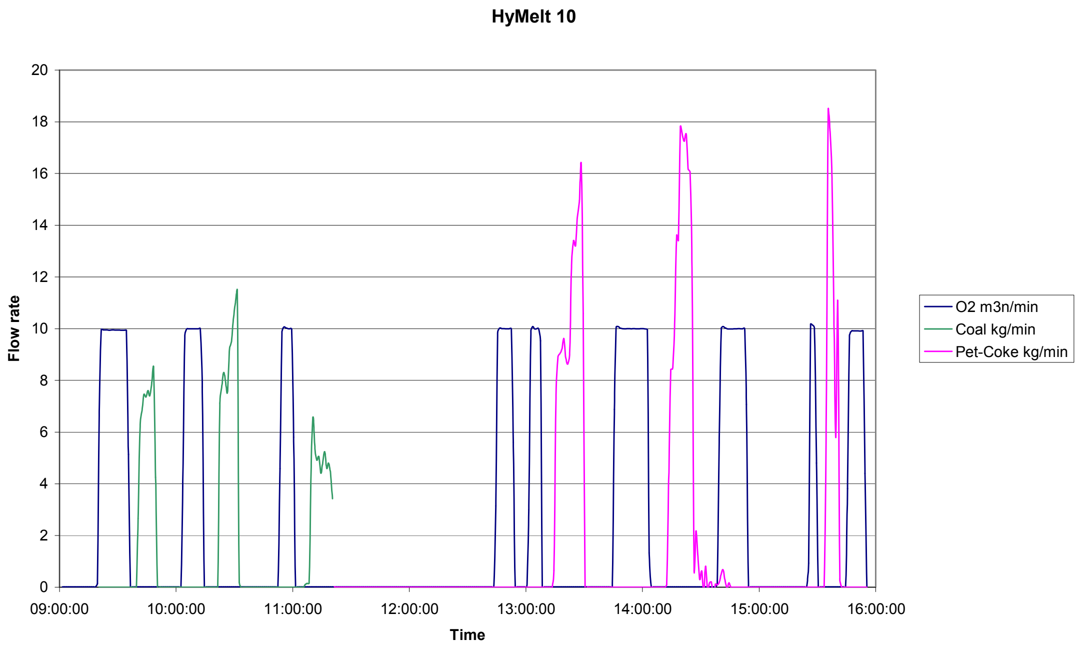

Figure 6 - Injection periods and oxygen blowing periods for HyMelt 10

Generated gas

The recorded gas analysis shows a common tendency for all the periods.

A peak value for H_2 and CO occurs immediately when gas sampling starts followed by a slow decrease of CO and finally a shift of CO to CO_2.

The presence of O_2 and CO_2 are not thermodynamically motivated and must be explained by leakage of air into the converter atmosphere or into the sampling system. Leakage air will also dilute other components than N_2 and O_2.

H_2 and O_2

The dilution of process gas by air is indicated in the graphs where H_2 and O_2 can be compared. The leakage increases during the period probably because of clogging of the sampling lance. A concentration of 10% O_2 shows that the analysed gas is composed of about 50% air and 50% process gas. Consequently if 10% of O_2 is found the measured H_2 concentration corresponds to approximately the double concentration in the process gas.

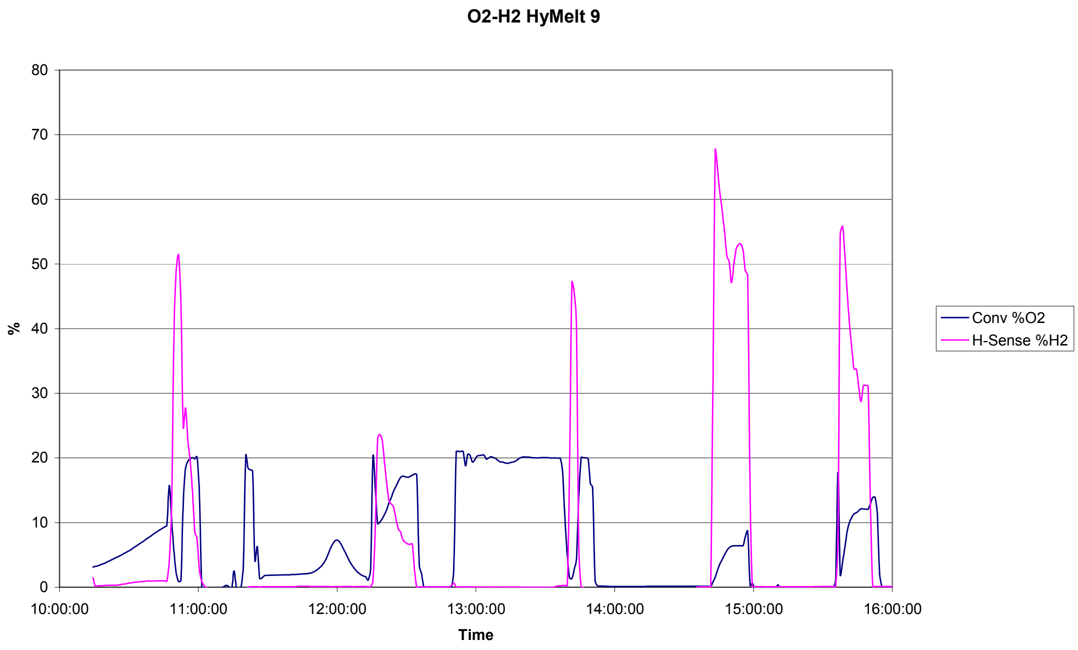

Figure 7 – H_2 and O_2 analysis of process gas HyMelt 9

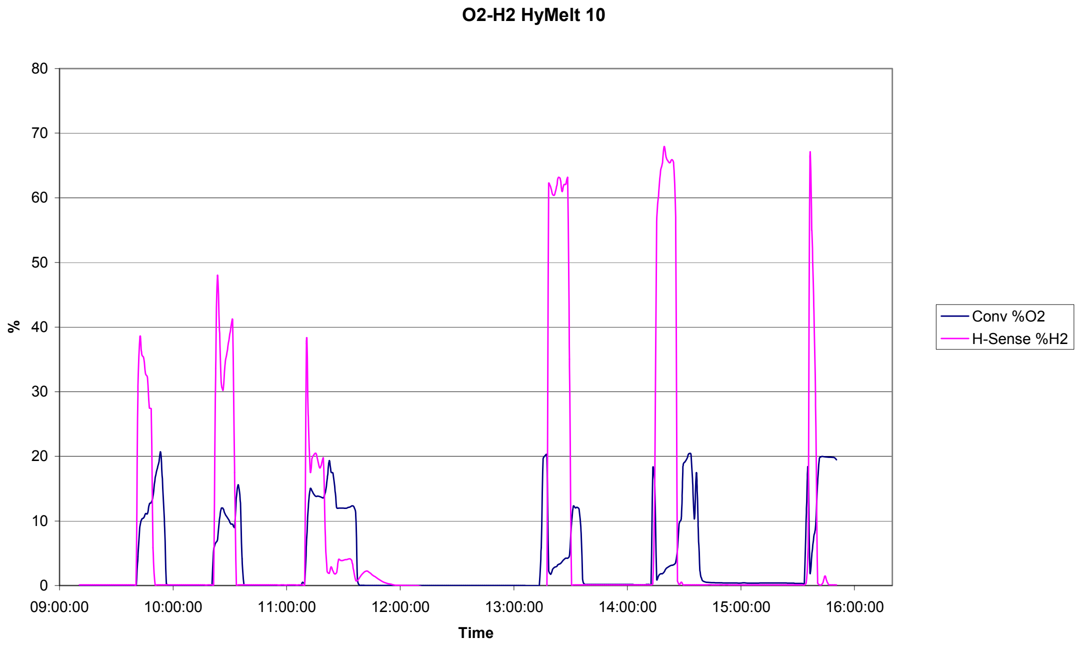

Figure 8 – H_2 and O_2 analysis of process gas HyMelt 10

H_2

Three principals for H_2 analysis were used. The conventional method can only measure up to 20% H_2 and MS127 shows, as expected, lower concentration than the H-sense device. The H-sense system has also a shorter response time and a better linearization and can be considered as most correct.

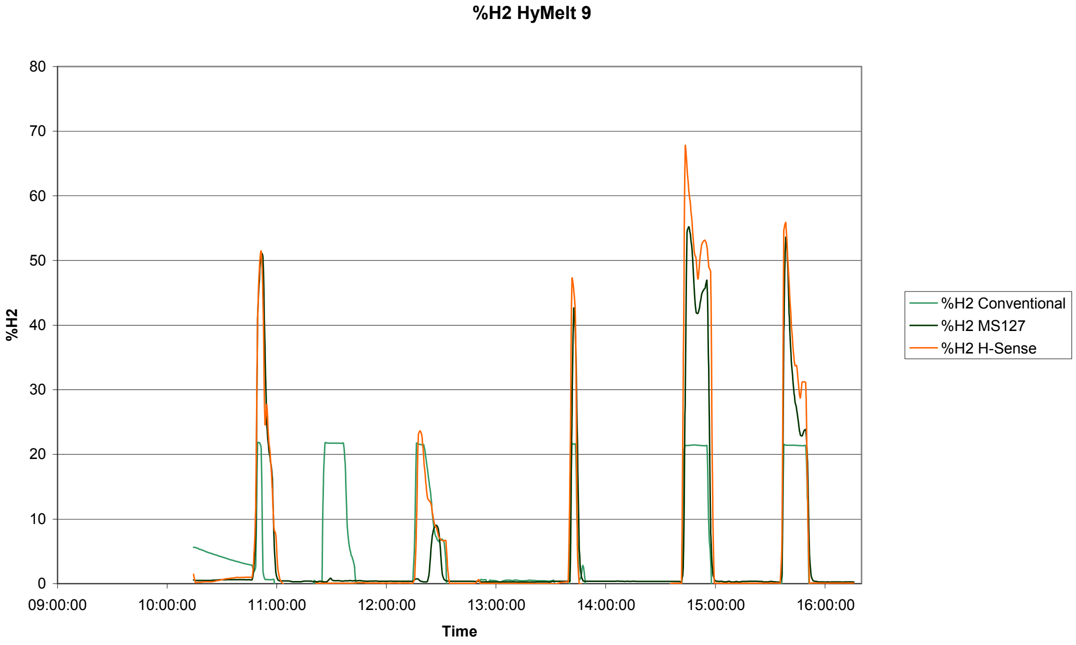

Figure 9 – Alternative methods for H_2 analysis of process gas HyMelt 9

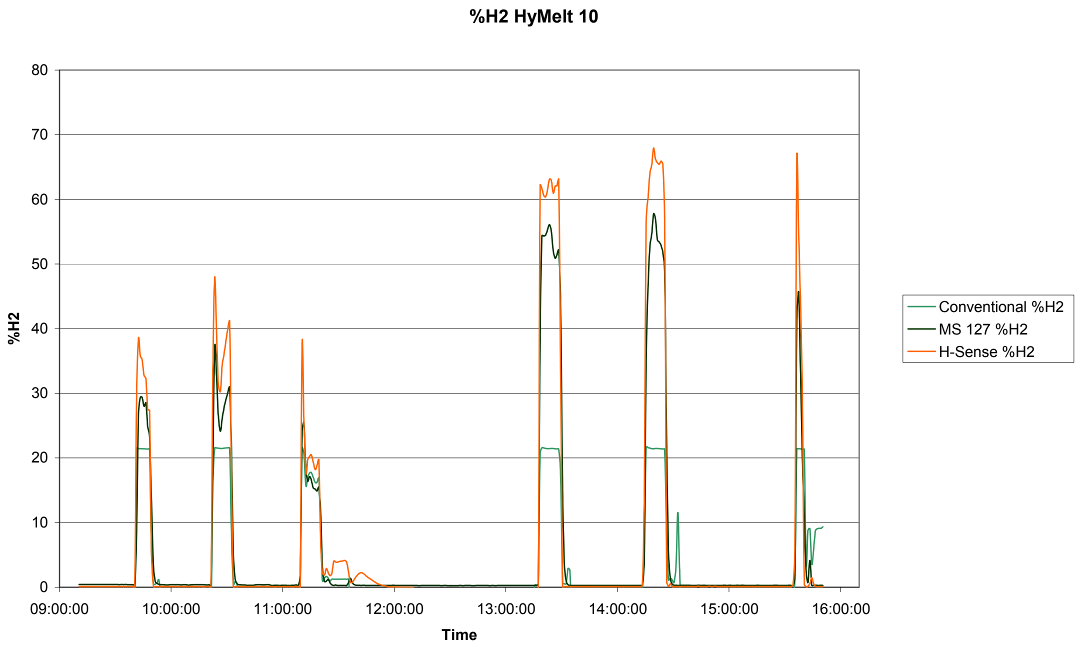

Figure 10 – Alternative methods for H_2 analysis of process gas HyMelt 10

CO and CO_2

The major part of injected carbon solutes into metal, however a fraction is reacting with oxygen to CO. Possible oxygen sources are reduction of metal oxides of the slag and ash or from air injection in the tuyere slits. The air flow rate was in the range of 600 ln/minute or 125 ln O_2 /minute forming 250 ln CO /minute. This flow rate contributes with about 2 – 4 % CO.

The presence of CO_2 is unexpected and can only be explained by air leakage. The highest values are also found, with some exceptions, in the end of the measuring period. Leakage air can effect the CO_2 concentration in two ways, reaction with CO and by dilution.

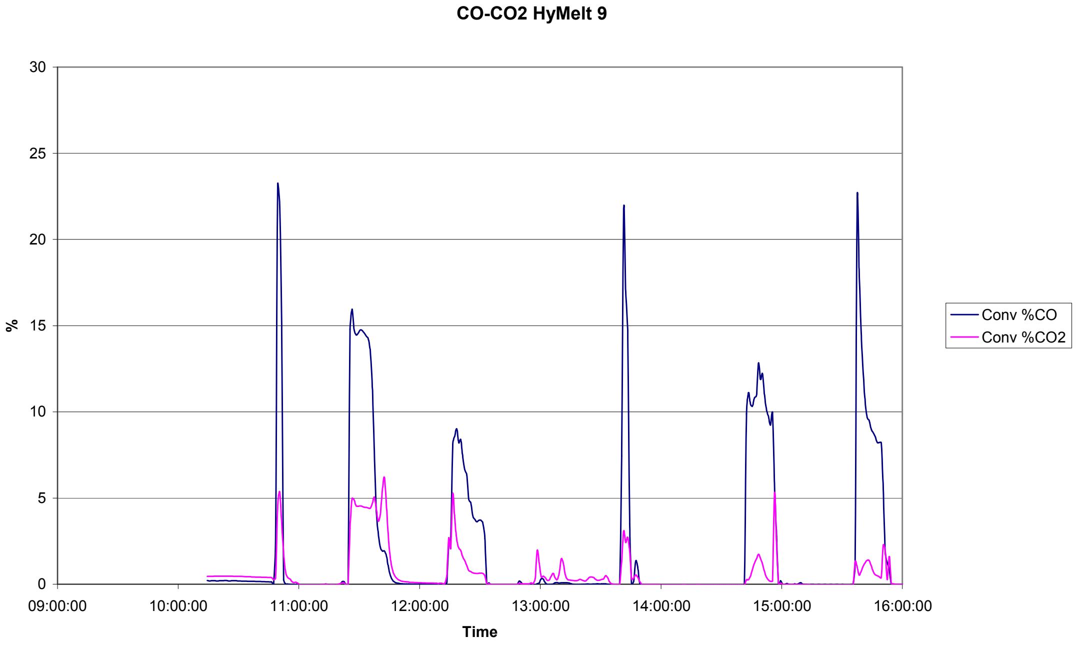

Figure 11 – CO and CO_2 analysis of process gas HyMelt 9

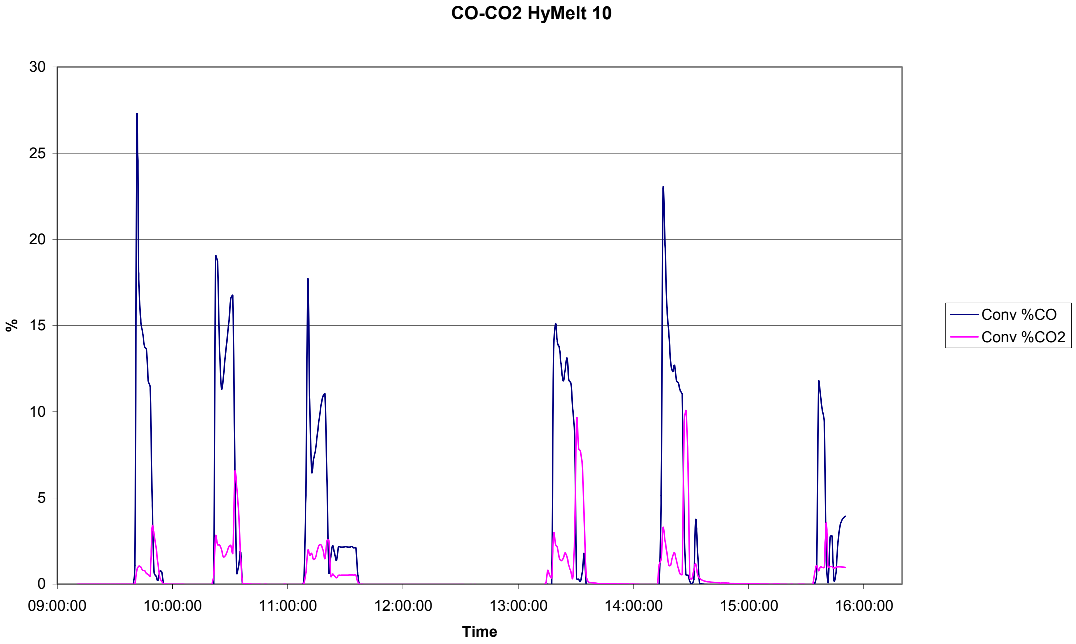

Figure 12 – CO and CO_2 analysis of process gas HyMelt 10

CH_4

The methane concentration is below 0.5 %, considerably lower than the previous trials by top injection, 5– 12% CH_4.

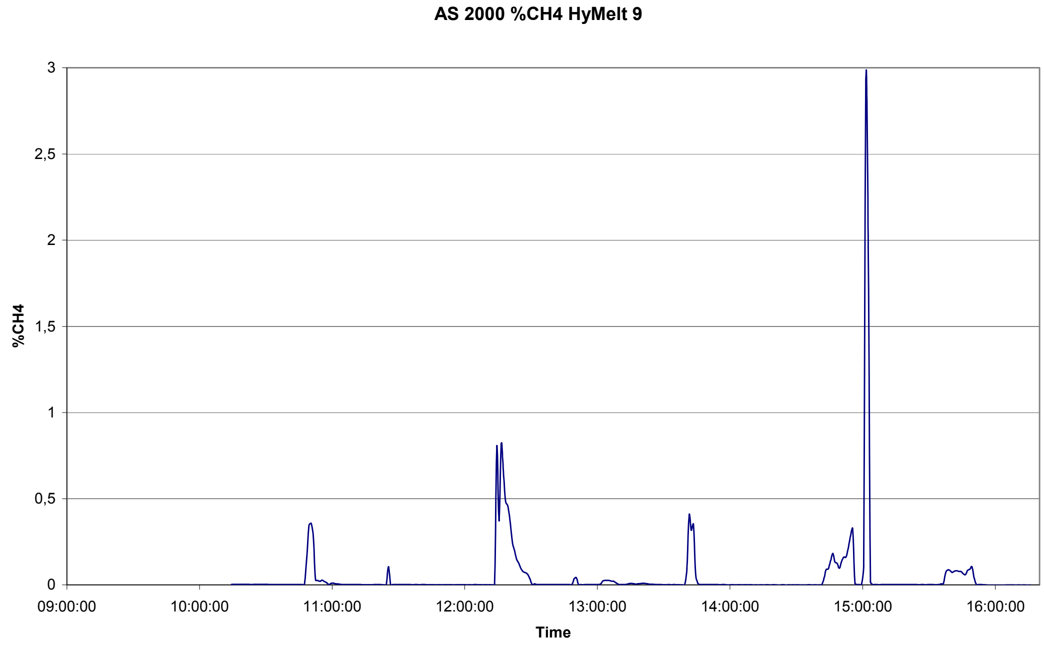

Figure 13 – CH_4 analysis of process gas HyMelt 9

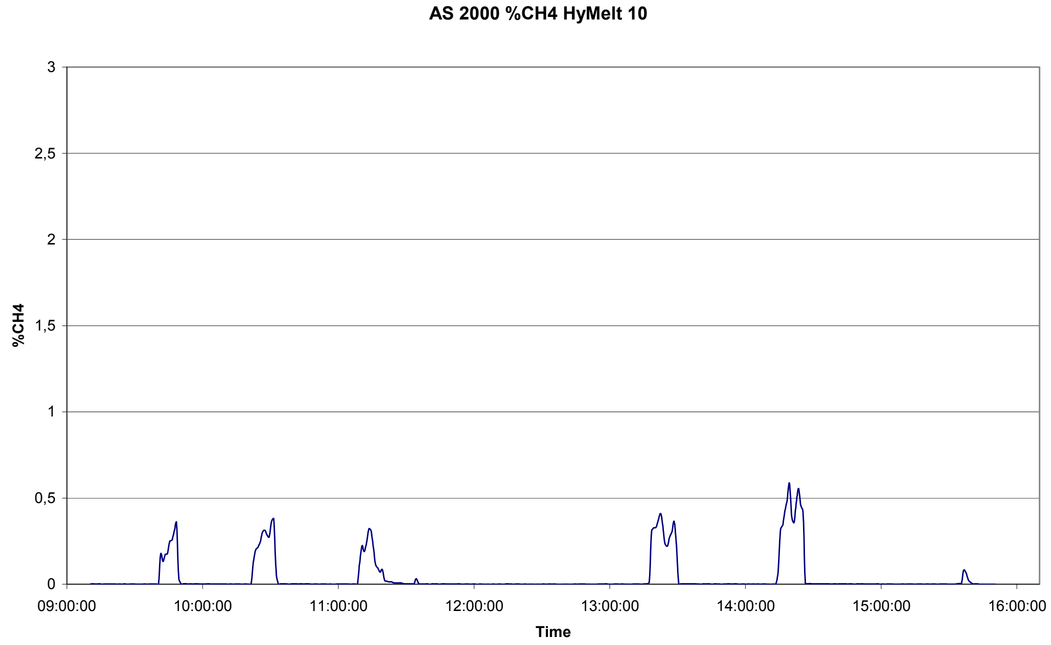

Figure 14 – CH_4 analysis of process gas HyMelt 10

COS

The measured COS is also lower than in previous campaign, typical 50 to 200 ppm compared to 100 to 300 ppm.

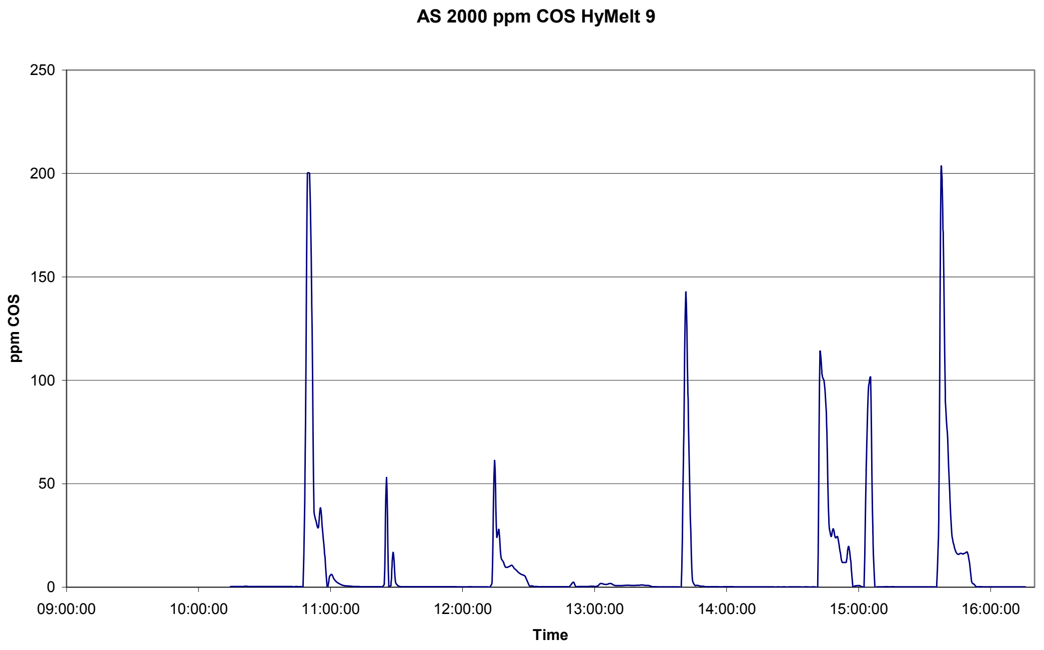

Figure 15 – COS analysis of process gas HyMelt 9

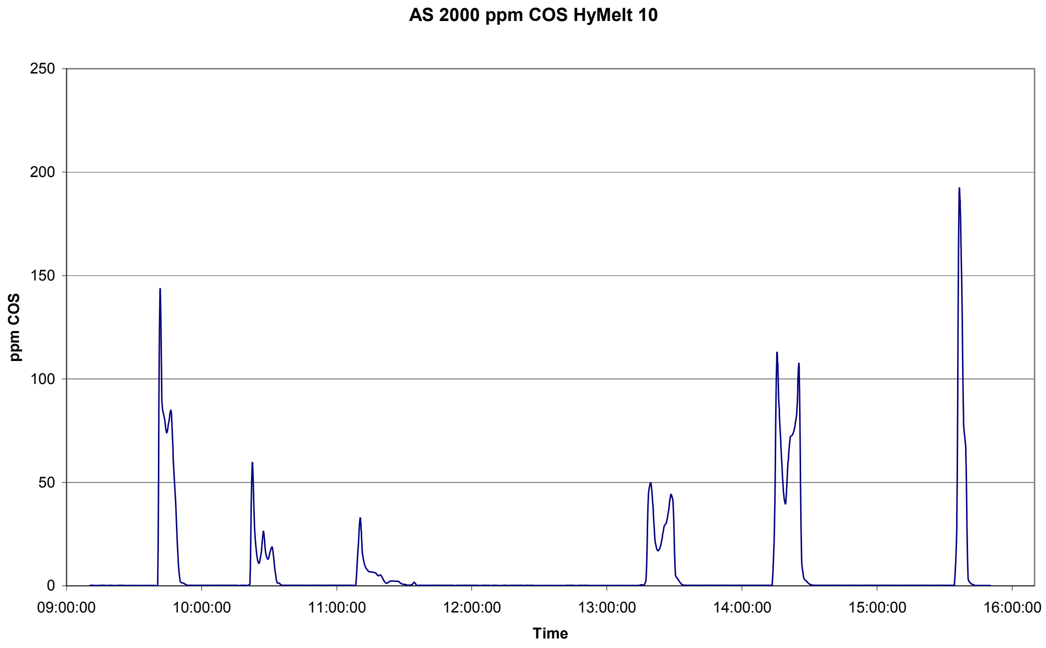

Figure 16 – COS analysis of process gas HyMelt 10

Ar

Argon was used as cleaning gas in the probe between the measurements. The source for readings during operation is originated from carrier gas.

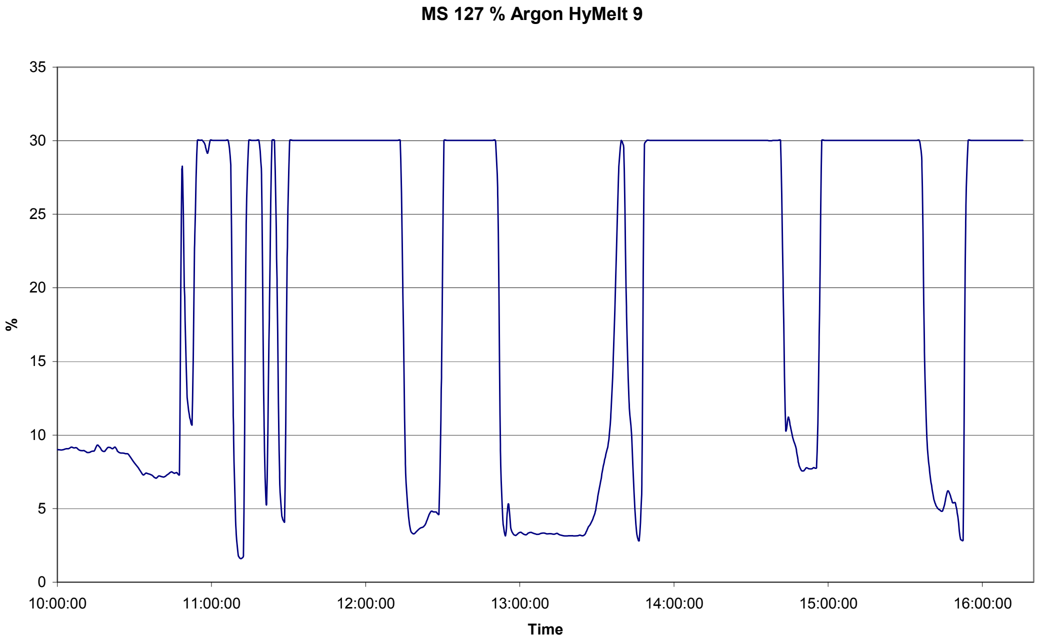

Figure 17 – Ar analysis of process gas HyMelt 9

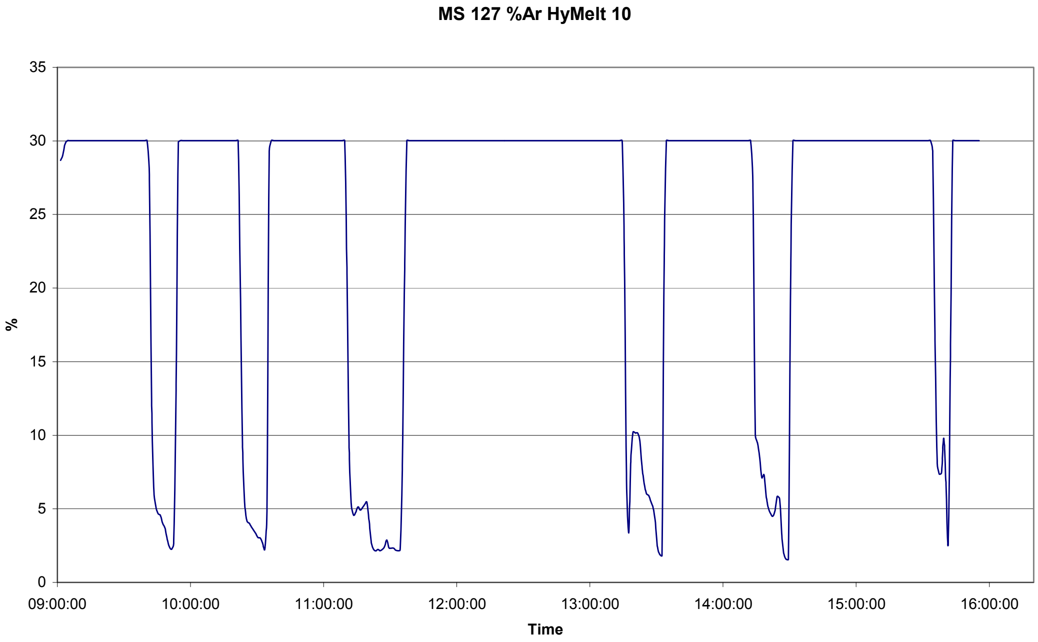

Figure 18 – Ar analysis of process gas HyMelt 10

Mass 28

By detecting mass weight 28 it was tested whether N_2 could be calculated by compensation for separately analysed CO concentration. Both compounds have the same mass but the analyser senility is different. However, a simple linear algorithm does not give any realistic results for N_2 determination.

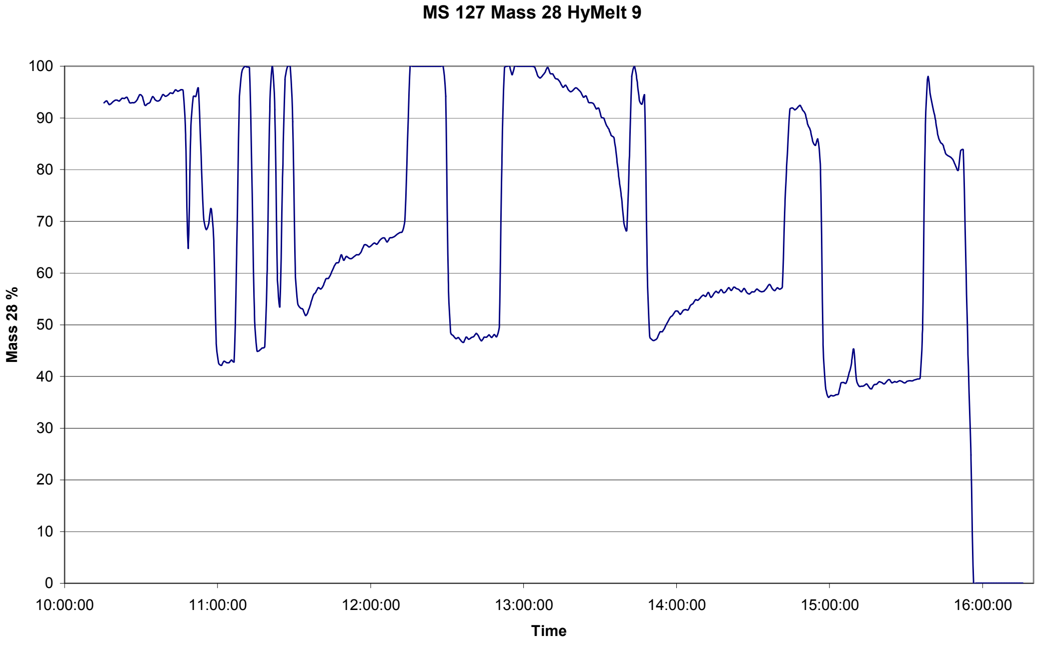

Figure 19 – Mass 28 analysis of process gas HyMelt 9

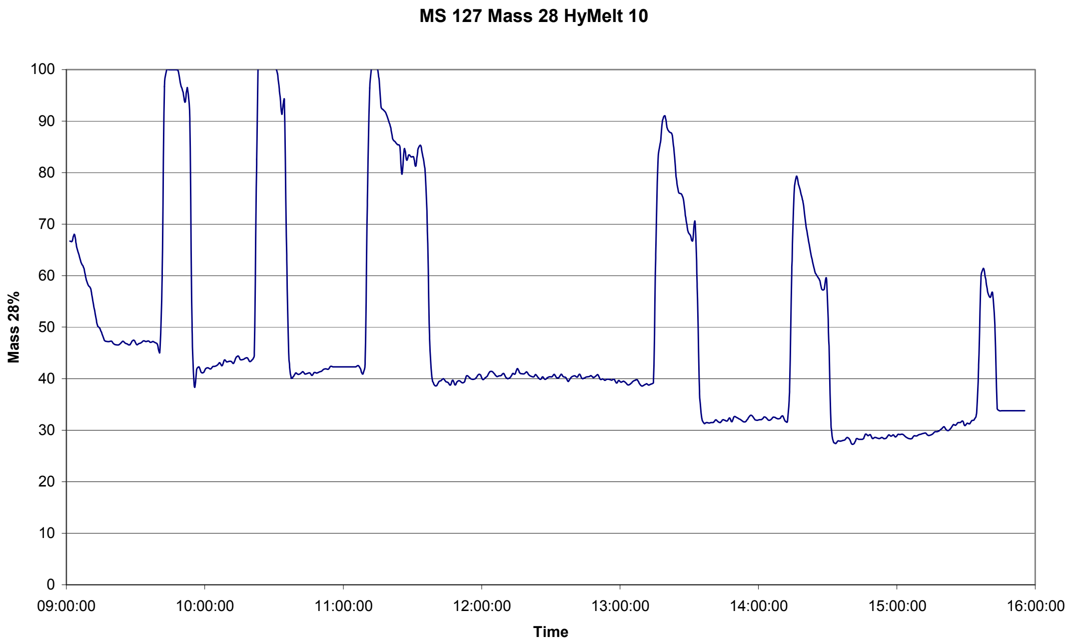

Figure 20 – Mass 28 analysis of process gas HyMelt 9

Benzene

Benzene was not analysed for top injection, results from submerged injection shows typical concentrations below 100 ppm.

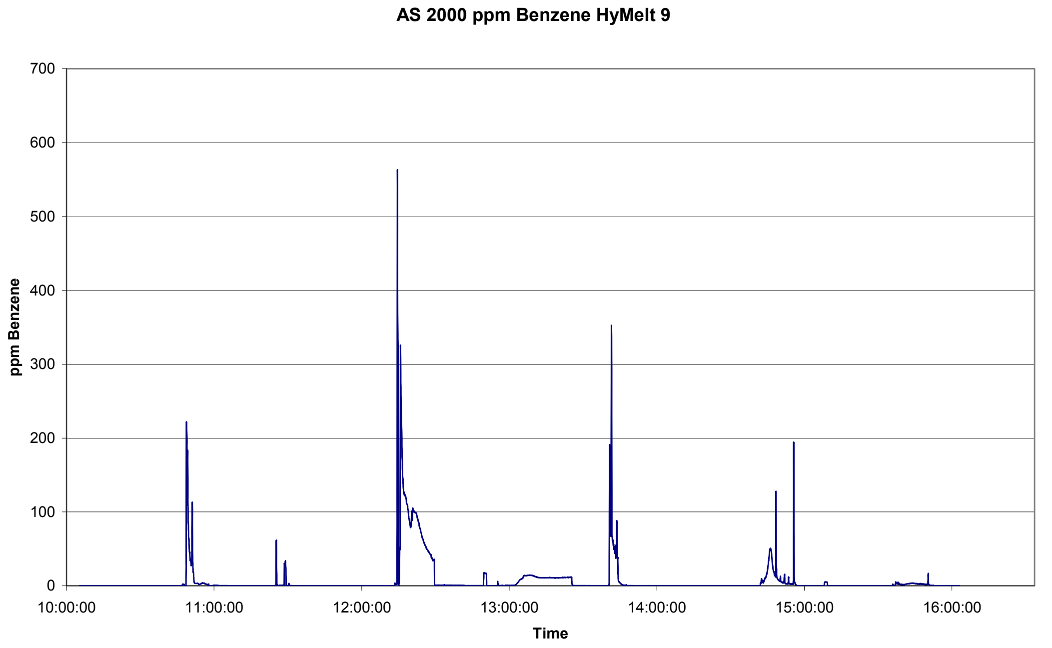

Figure 21 – C_6H_6 analysis of process gas HyMelt 9

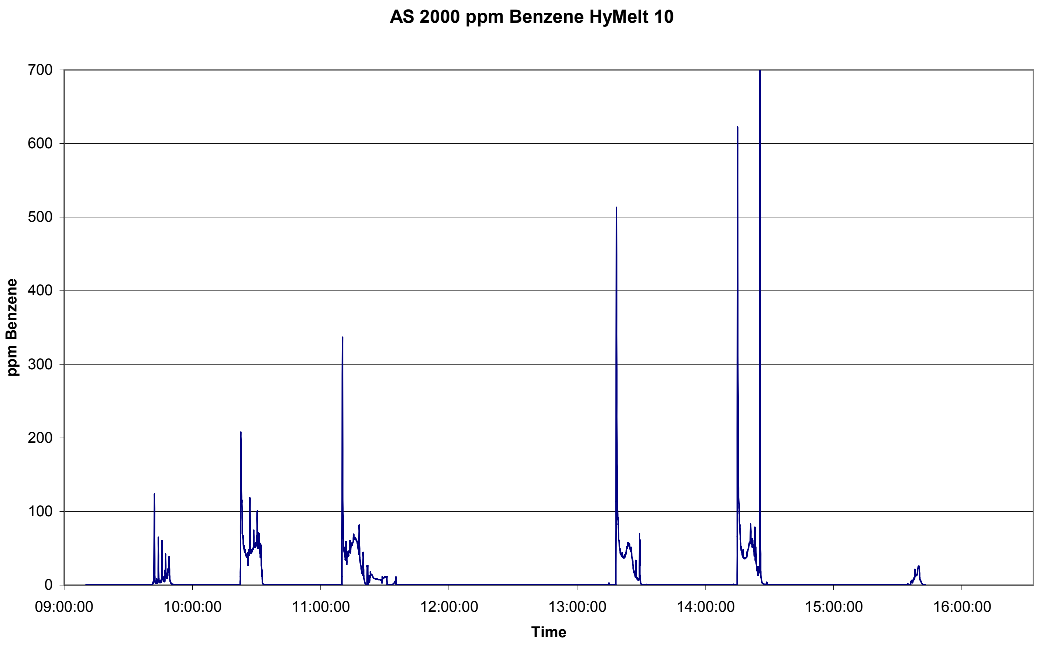

Figure 22 – C_6H_6 analysis of process gas HyMelt 10

C_2H_2

The compound was not analysed for top injection. Result from this campaign shows peak values of more than 1500 ppm. More typical values are below 1000 ppm.

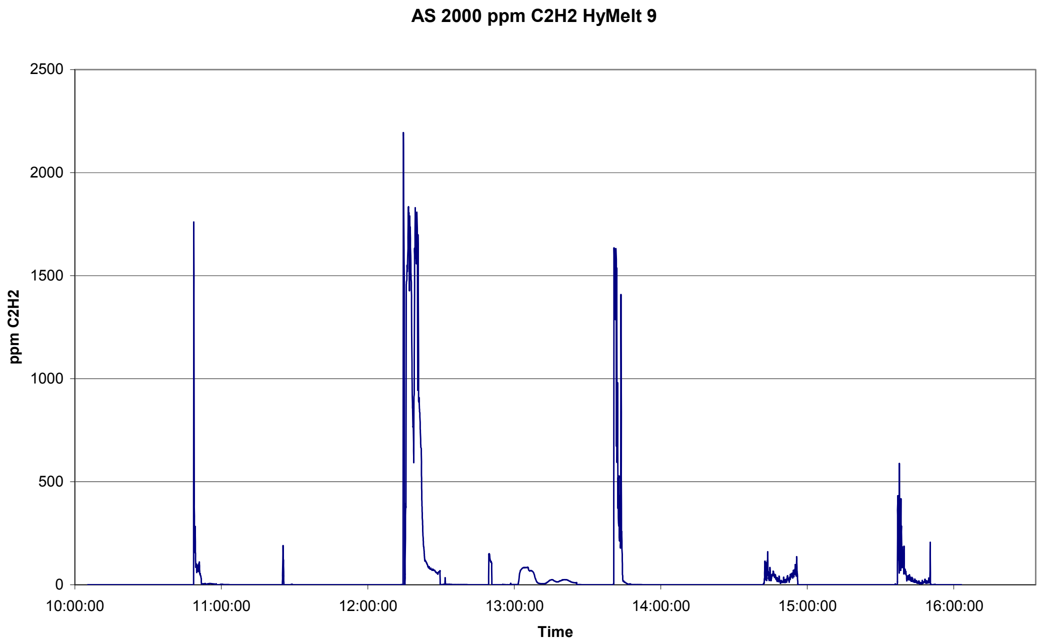

Figure 23 – C_2H_2 analysis of process gas HyMelt 9

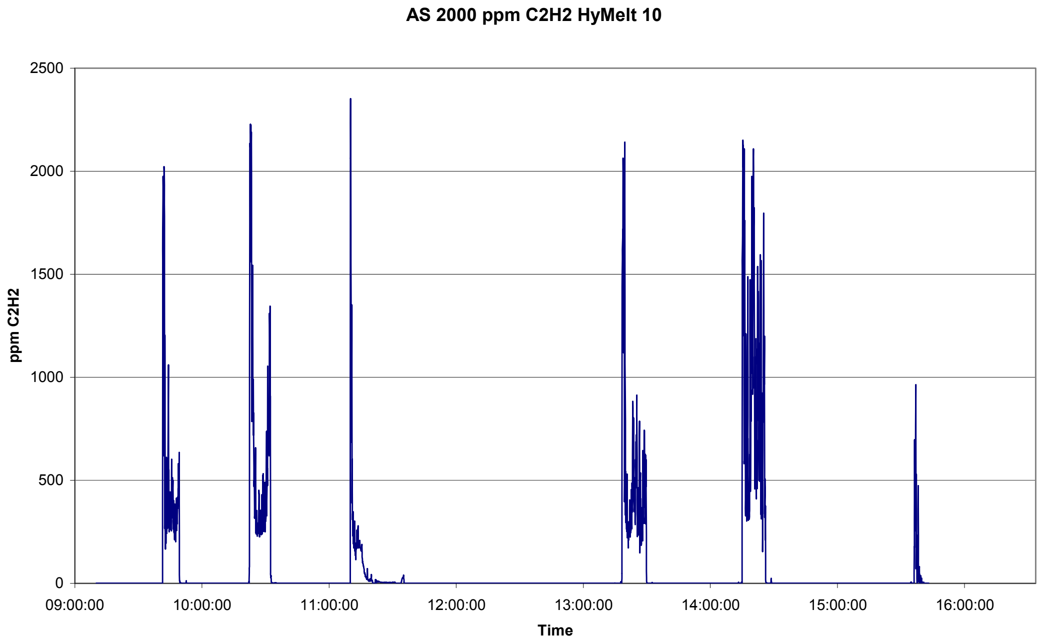

Figure 24 – C_2H_2 analysis of process gas HyMelt 10

H_2S

The level is lower than for top injection, 0,2 – 0,4 %. The reading increases during the day and correlate to the sulphur content of the metal.

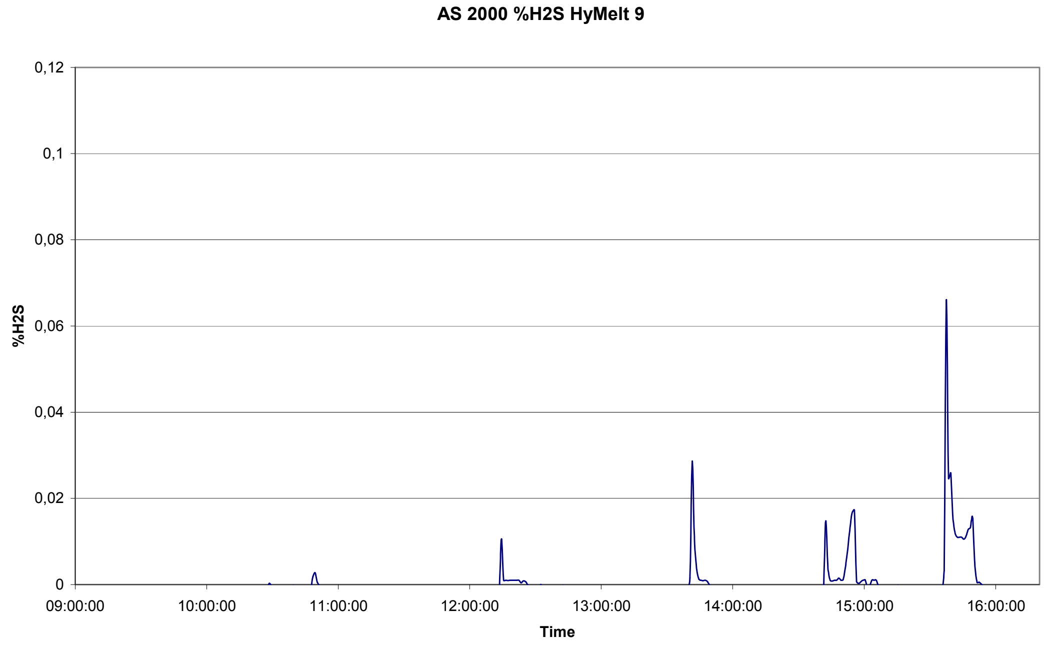

Figure 25 – H_2S analysis of process gas HyMelt 9

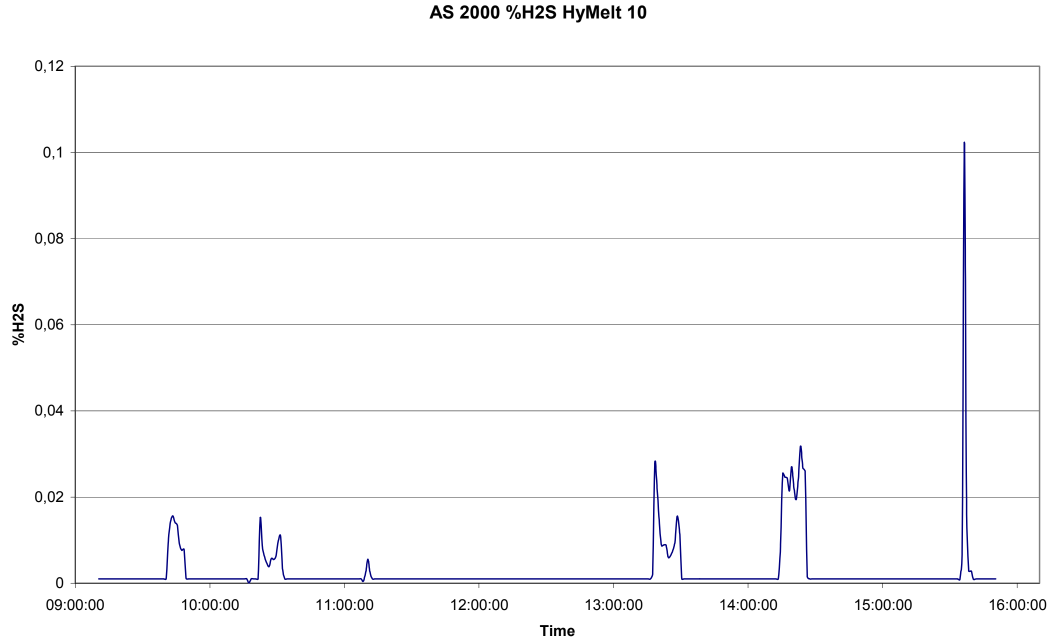

Figure 26 – H_2S analysis of process gas HyMelt 10

HCN

Cyanide concentrations are analysed in concentrations typically below 20 ppm. The compound was not analysed in previous campaign.

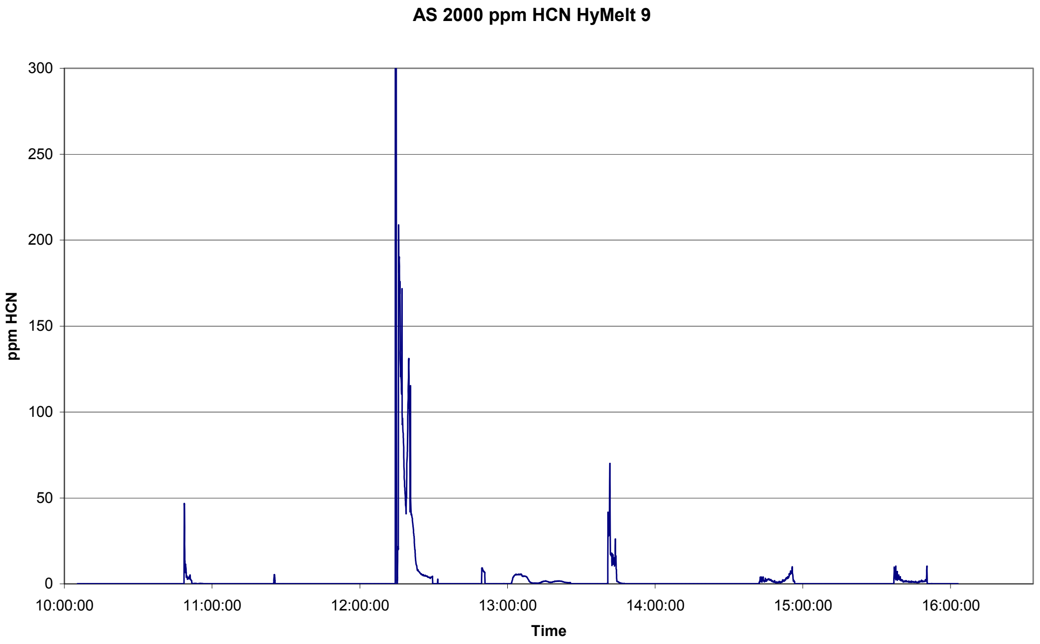

Figure 27 – HCN analysis of process gas HyMelt 9

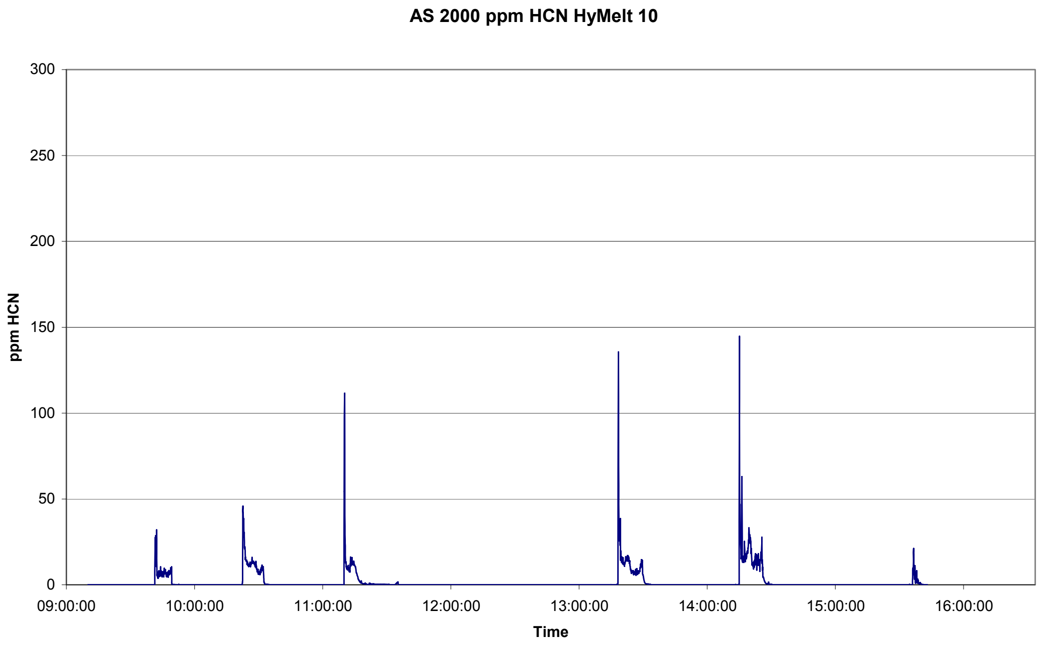

Figure 28 – HCN analysis of process gas HyMelt 10

Normalized gas composition

The partly confusing gas analysis can be presented in an alternative way based on a few assumptions:

- CO_2 can not be present together with an iron melt and the fraction of CO_2 can be consider as CO by ignoring post combustion
- The major part of N_2 originates from leakage air either directly into the converter gas atmosphere or into the gas sampling system.
- O_2 can not be present in an environment of liquid iron

If the gas components of low concentration, <1%, are neglected normalized process gas mixtures of H_2, ($CO+CO_2$) and Ar can be calculated as in Figure 29 and 30.

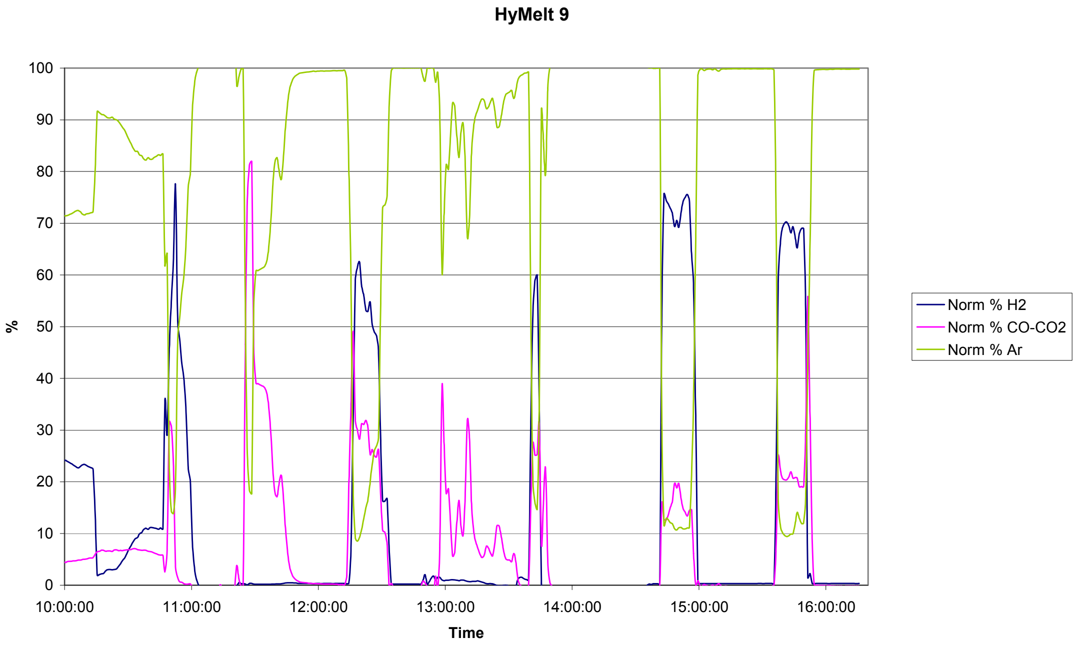

Figure 29 – Normalized gas composition, HyMelt 9

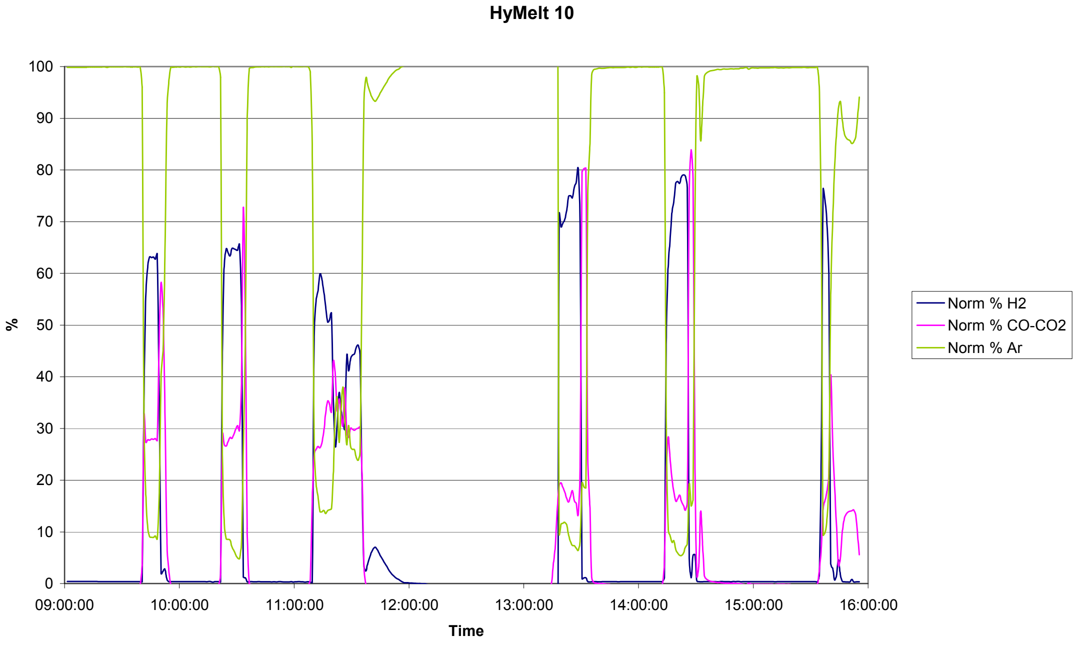

Figure 30 - Normalized gas composition, HyMelt 10

The variations of gas composition can be explained:

- CO has the highest value in the start of injection period when slag reduction takes place. The peaks in the end of periods are not likely to have process signification.
- The H_2 increases until clogging of the probe, a consequence of reduced amount of CO.
- Injection of coal gives higher CO analysis than coke injection because of oxides in the ash.

By comparing Ar concentration with Ar feed rate a normalized process gas flow rate can be estimated and an in-out mass balances of C and H can be made.

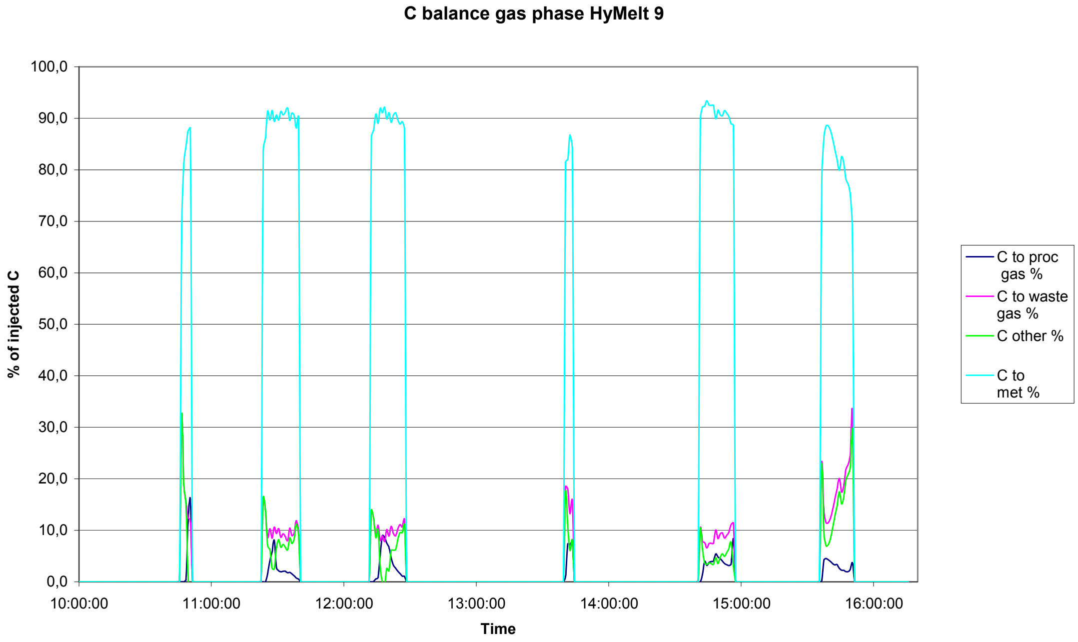

Figure 31 – Gas phase carbon balance HyMelt 9

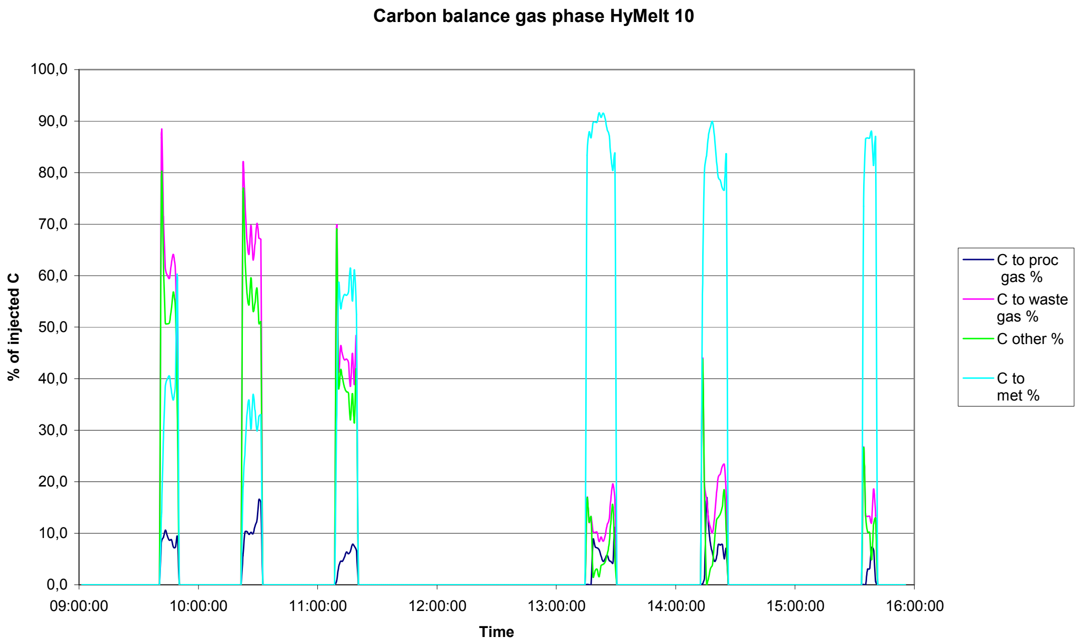

Figure 32 – Gas phase carbon balance HyMelt 10

There are some obvious differences between coal and coke injection:

- The C amount for balance, in this case assumed to be found in metal, are lower in case of coal, 35 – 65% compared to 80 – 90% for coke.
- By assuming that the amount of CO_2 detected in the combusted gas is equal to the total amount of coal compounds including dust in the process gas, it can be concluded that coal generates more dust or soot.

Hydrogen balances

There are significant difference between the hydrogen yield between HyMelt 9 and 10, the difference is greater than between coal and coke. Until now, no explanation has been found, most likely it indicates the accuracy of measuring and the method for evaluation

It shall also be observed that the calculated H yield can reach values above 100%, one possible explanation is different delay time times for measurements.

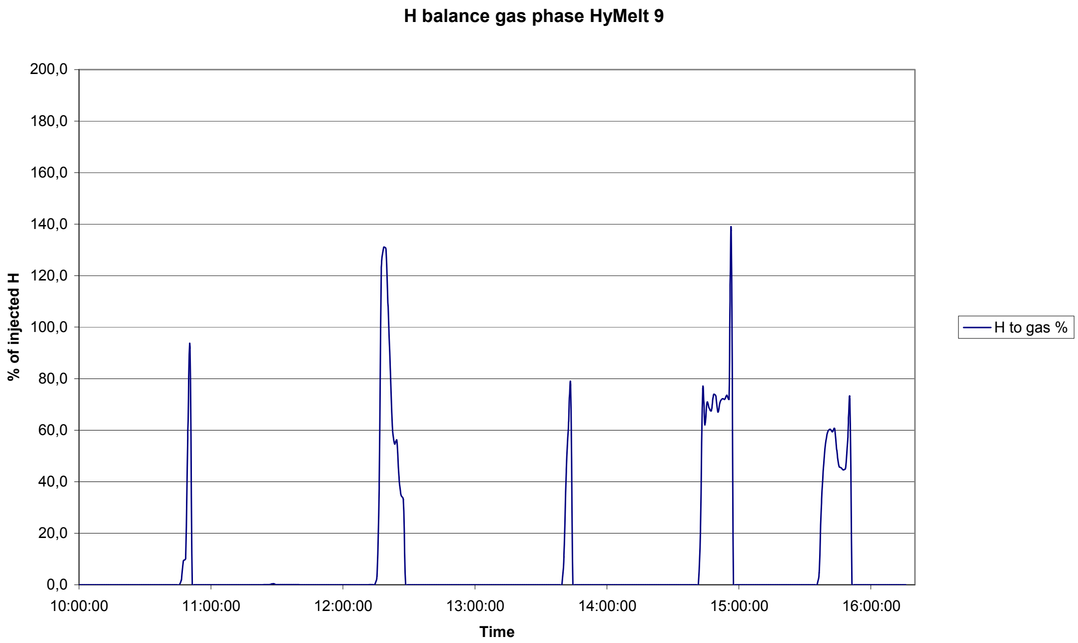

Figure 33 – Gas phase hydrogen balance HyMelt 9

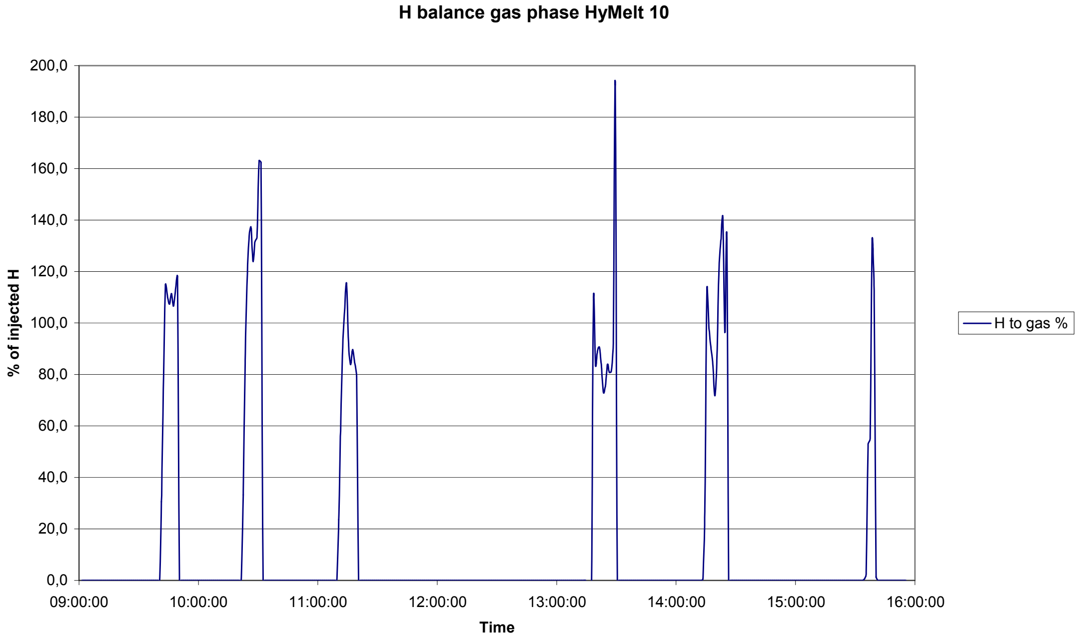

Figure 34 – Gas phase hydrogen balance HyMelt 10

Temperature and melt analysis

Temperature

The temperature variation is a consequence of the heat balance between the cooling gasification period and heating during decarburisation. The target was set to be in the range of 1400 °C to 1650 °C.

Heat losses during replacement of the gas probe, sampling of slag etc gave non operational times resulting in a need for excess fuel of FeSi and Al for the oxidation period. In an industrial process this will not be necessary. The trials when coke were injected indicated almost a balanced process already for 5 ton scale.

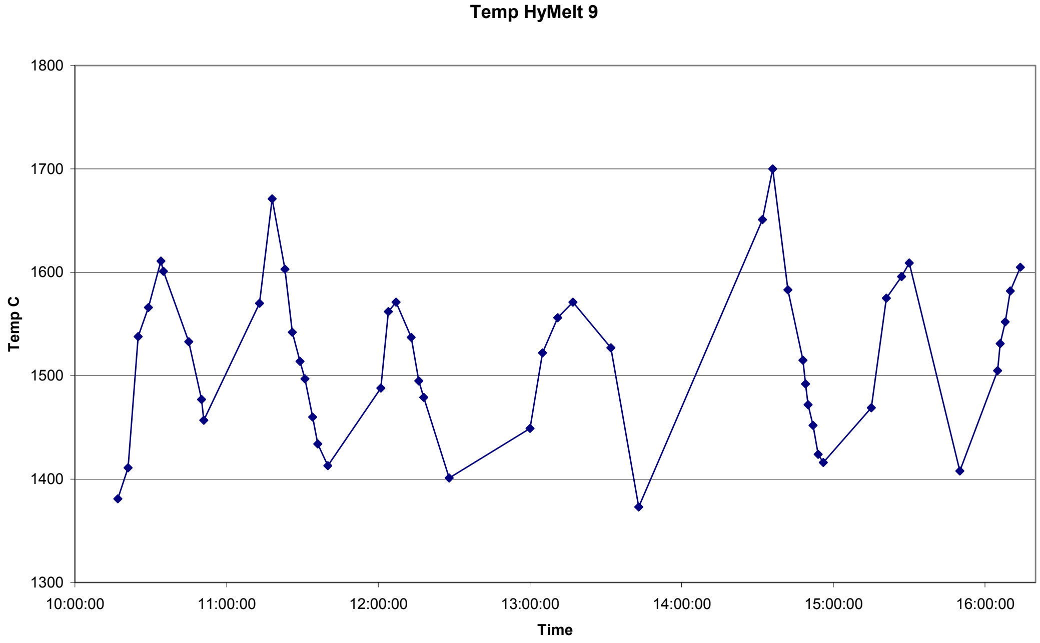

Figure 35 – Metal temperature HyMelt 9

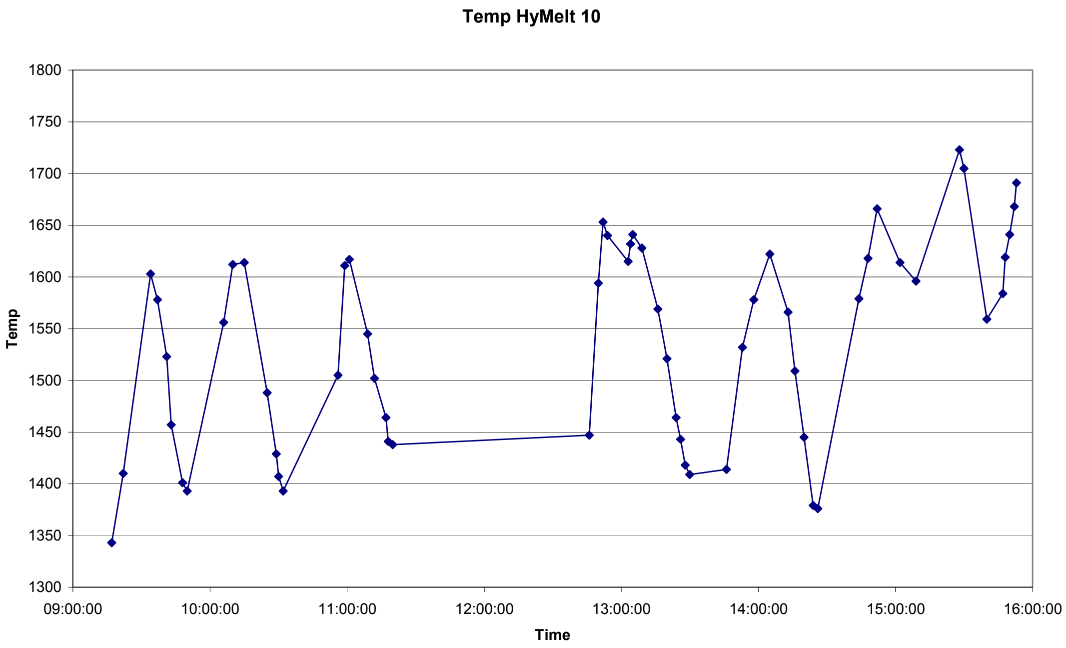

Figure 36 – Metal temperature HyMelt 10

C-metal

The operational carbon content in the metal was set to 0,5 to 4,0 %C. To simplify the tests the temperature was selected for primary control and the carbon content came out as variable.

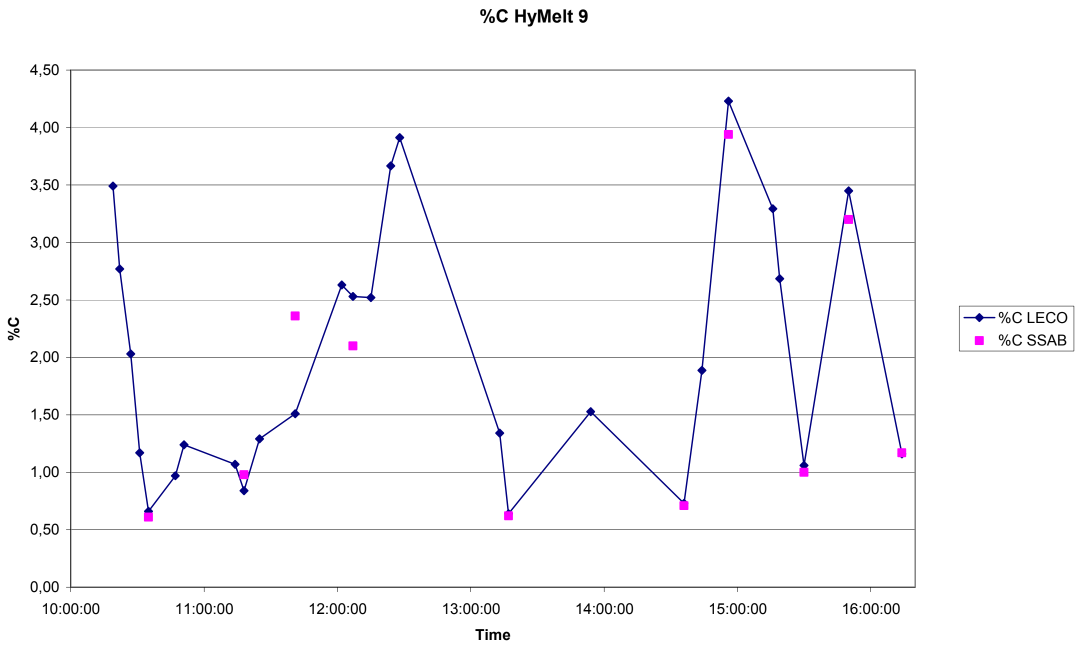

Figure 37 – Carbon content in metal HyMelt 9

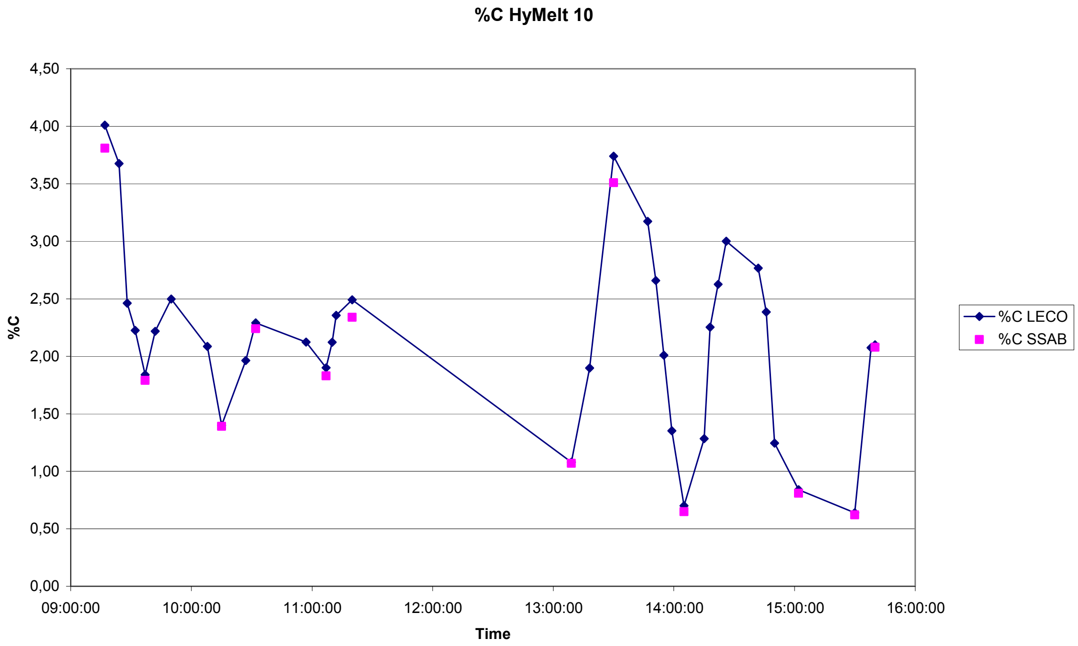

Figure 38 – Carbon content in metal HyMelt 10

S-metal

The sulphur in the metal confirm the relation of total load of sulphur by additions, oxygen potential of the slag (% FeO) and the CaO/SiO$_2$-ratio of the slag.

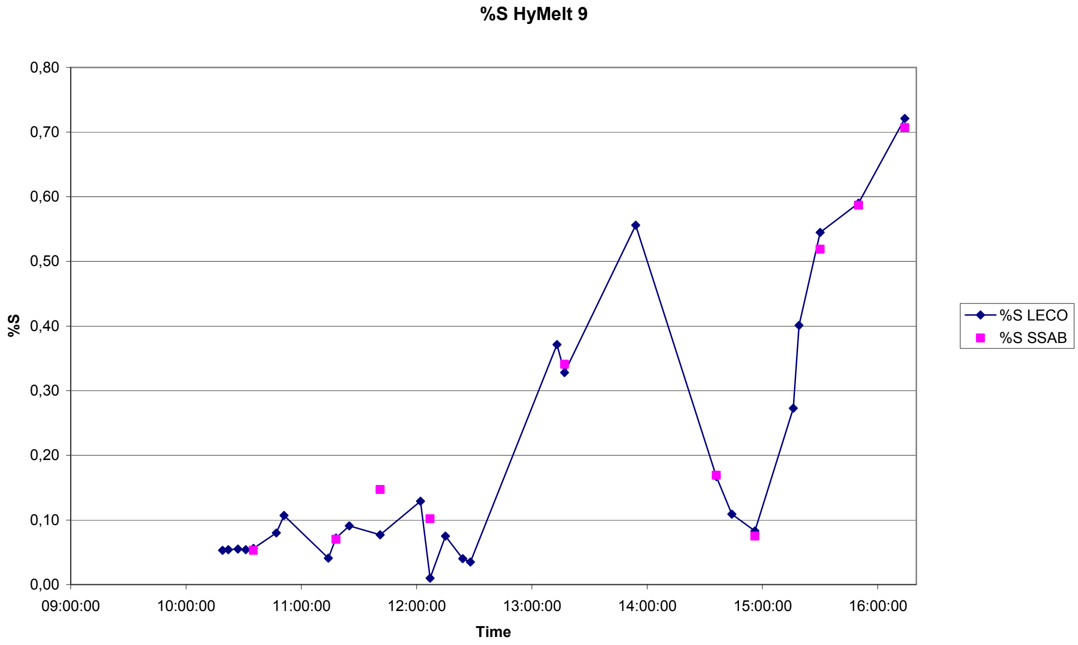

Figure 39 – Sulphur content in metal HyMelt 9

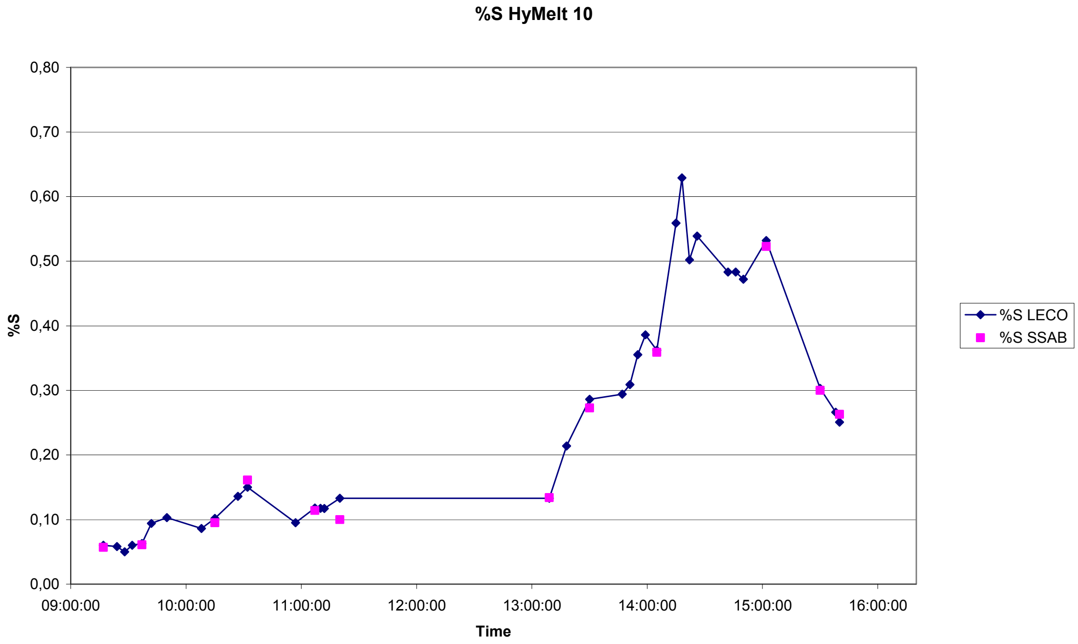

Figure 40 – Sulphur content in metal HyMelt 10

FeO-slag

To achieve a rich H_2 gas it is of interest to keep FeO content in the slag low. The FeO content is a consequence of oxidation which is pronounced by low carbon content of the metal, soft bottom stirring in combination with top blowing. The Fe_{tot} given in the figure can be calculated to FeO by multiplication with 1.28.

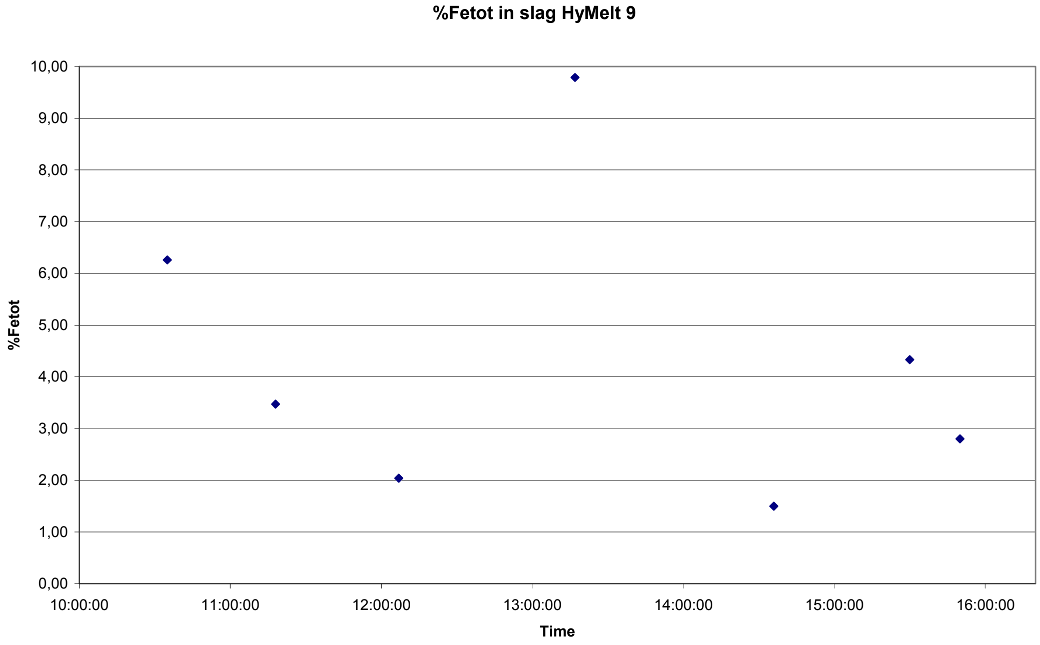

Figure 41 – Fe_{tot} of slag HyMelt 9

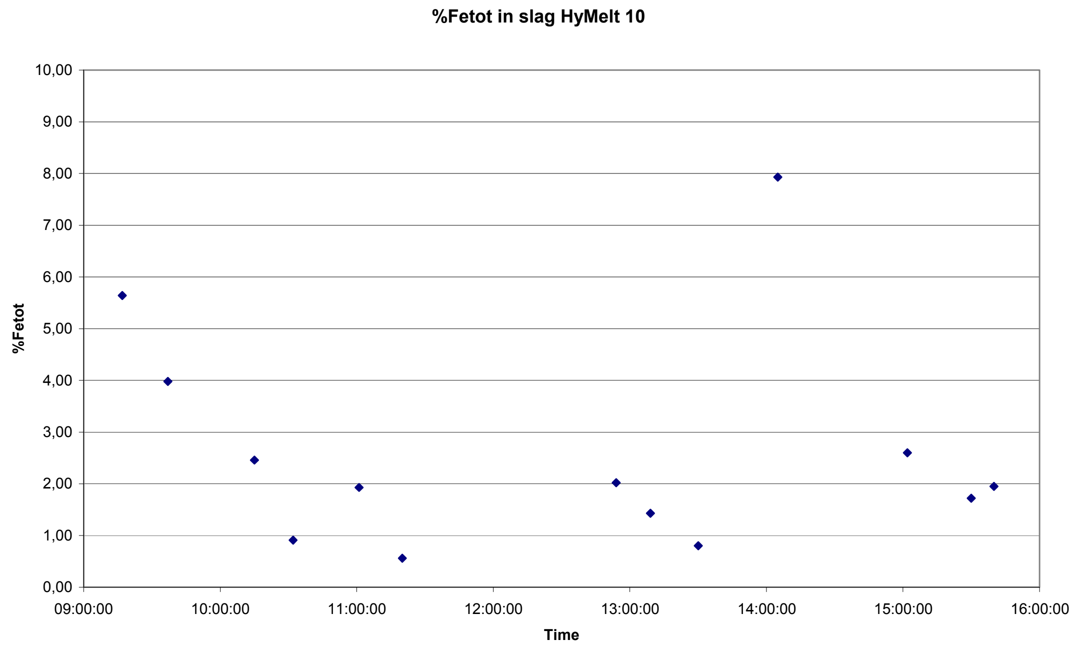

Figure 42 – Fe_{tot} of slag HyMelt 10

CaO/SiO_2-slag

The CaO/SiO_2-ratio was mainly controlled by fuel and lime addition. The process itself generates only small amount of slag depending of ash content and desired slag composition. Stable ratios were achieved for both HyMelt 9 and 10, however the refractory wear is reduced for ratios above 2 which is preferred.

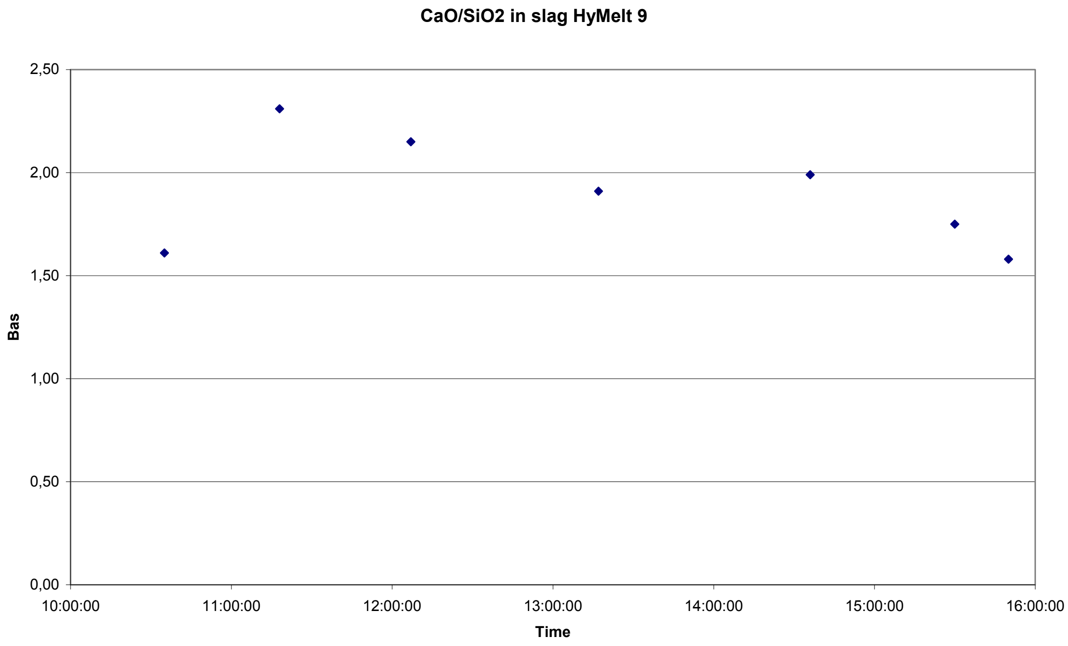

Figure 43 – CaO/SiO_2 of slag HyMelt 9

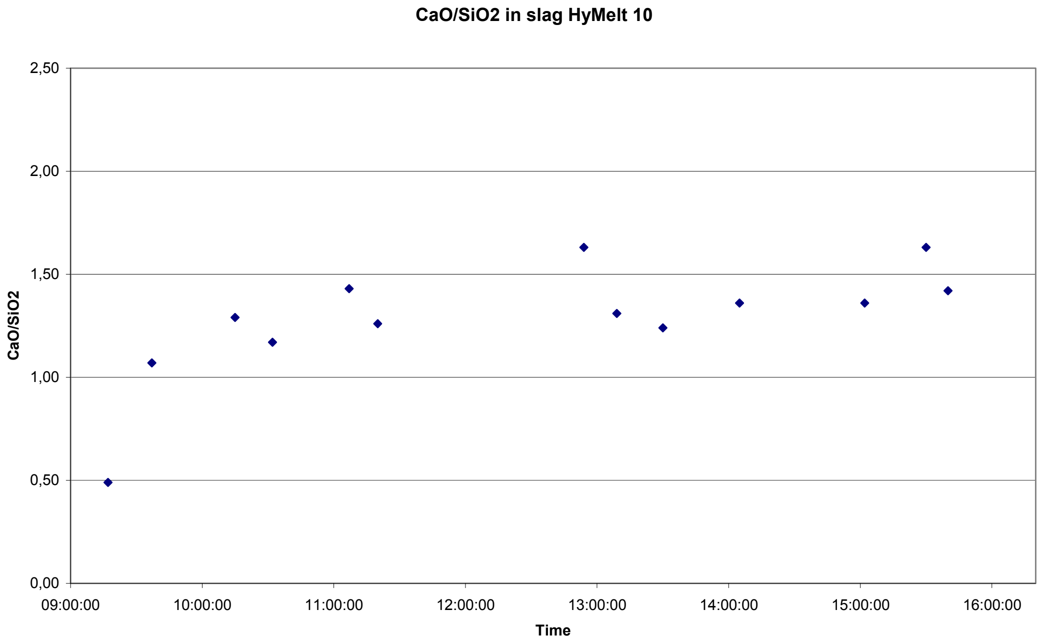

Figure 44 – CaO/SiO_2 of slag HyMelt 10

S-slag

The sulphur in slag is to a large existent the inverse of sulphur of metal and it is obvious that the element can easily be transferred between the liquid phases.

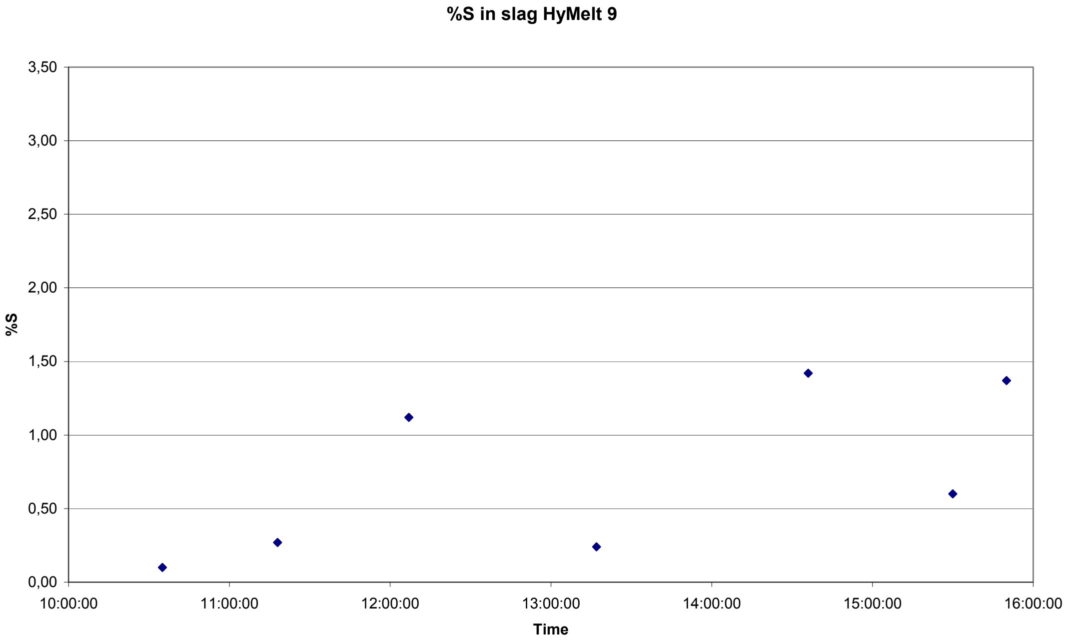

Figure 45 – Sulphur analysis of slag HyMelt 9

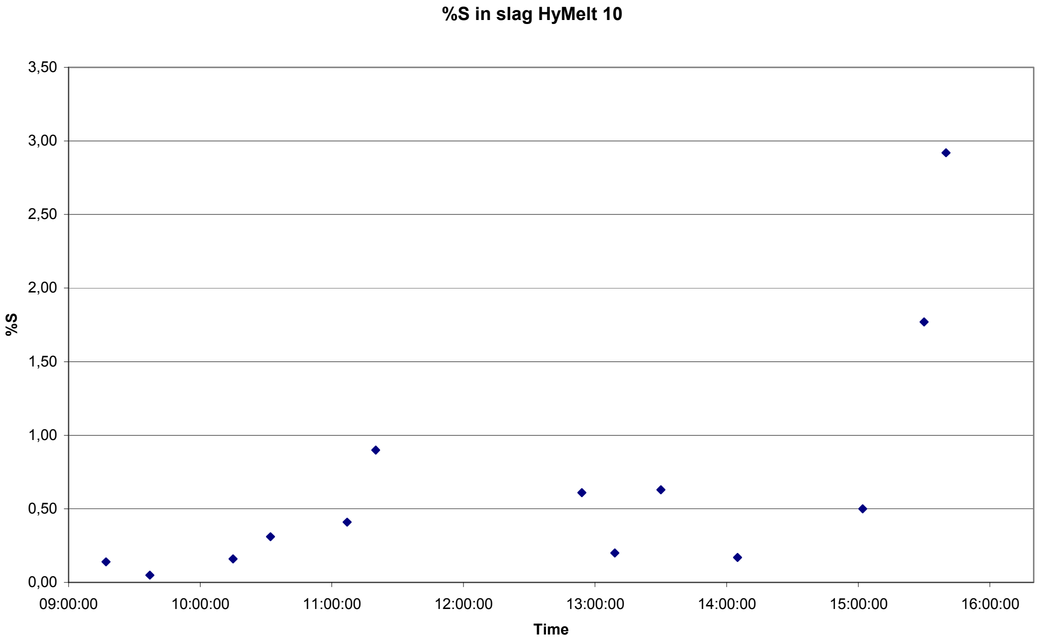

Figure 46 – Sulphur analysis of slag HyMelt 10

Generated dust

Dust samples were collected from the filter in the gas probe for process gas analysis and from the combusted gas. In the later also the amount of dust could be estimated.

Both types of dust were analysed for total carbon according to DIN ISO 10694 by the laboratory Analytica in Täby.

Dust in process gas

Results from process dust indicate high concentrations of carbon 80 to 90 % C independent of injected material.

Table 1 – Carbon in dust coke injection

Charge	%C
S1790-1	83
S1790-2	85
S1790-3	89
S1790-4	83
S1790-5	83
S1790-6	100
S1791-4	87
S1791-5	81
S1791-6	not avail

Table 2 – Carbon in dust coal injection

Charge	%C
S1791-1	90
S1791-2	94
S1791-3	84

Dust in combusted gas

It is a strong relation between amount of dust in the combusted gas and material feed rate. The correlation is expected and seems to be valid for both coal and coke.

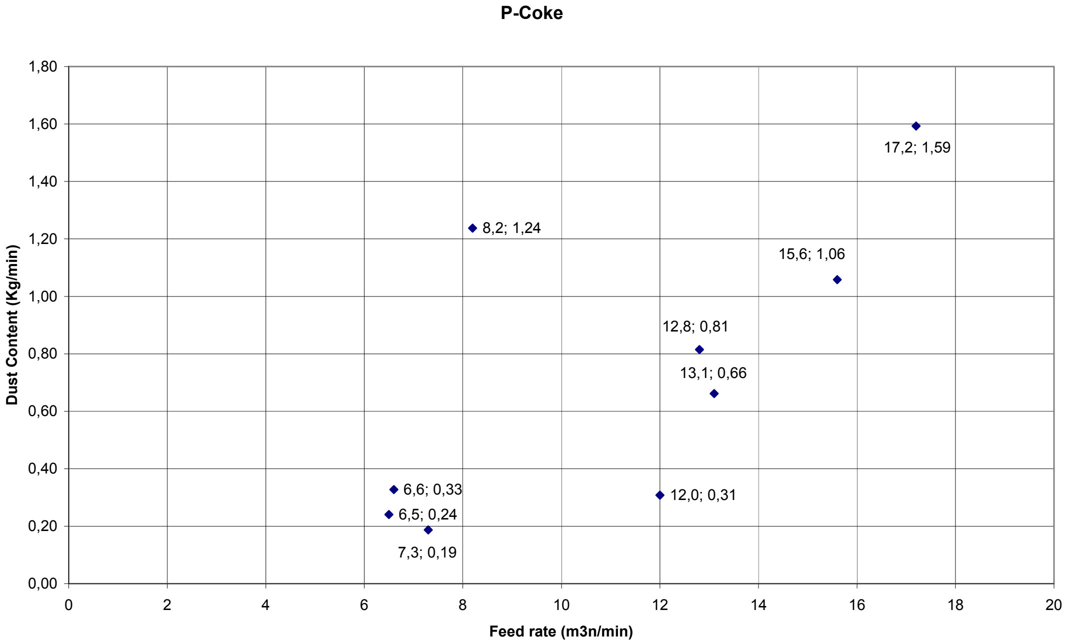

Figure 47 – Dust content of combusted gas at coke injection

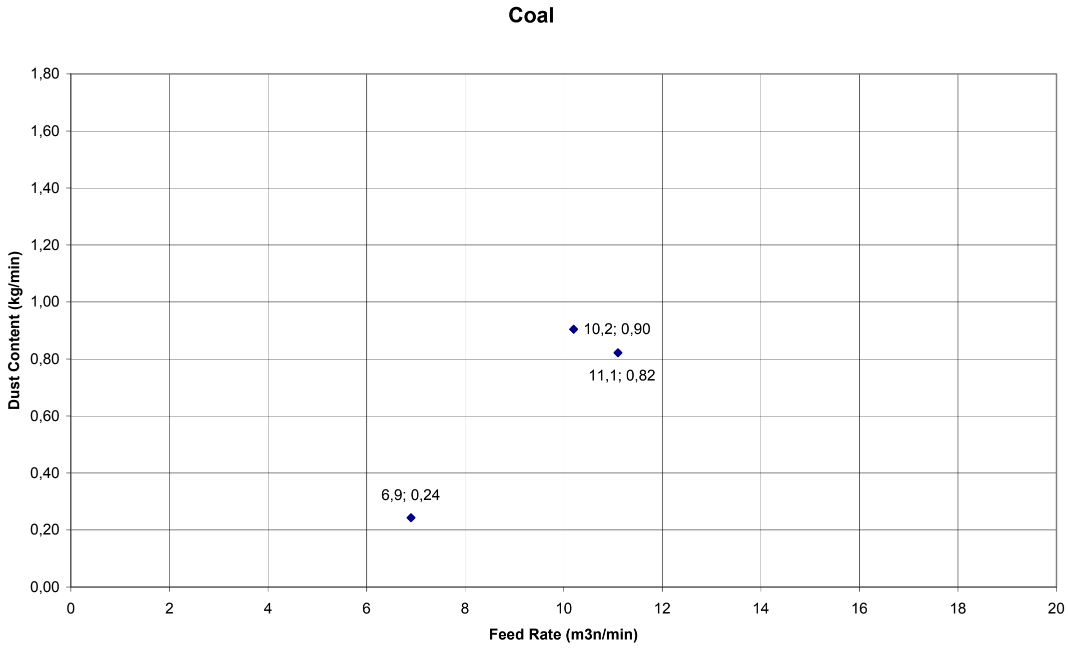

Figure 48 – Dust content of combusted gas at coal injection

Process gas and dust in the process gas are combusted above the converter mouth before reaching the waste gas cleaning system. While the gas components are completely combusted some carbon remains un oxidised in the dust. The amount is low compared to the total throughput low as can be seen in the table 3 and 4.

Table 3 – Carbon amount in combusted dust for coke feed

Charge	Dust Content (g/m3n)	Waste gas (m3n)	Dust Content (gr)	Dust comp %C	Carbon in dust (kg)
S1790-1	5,30	1404	7,4	2,4	0,2
S1790-2	0,80	4206	3,4	not avail	
S1790-3	1,03	3972	4,1	13	0,5
S1790-4	1,40	1398	2,0	22	0,4
S1790-5	1,32	4200	5,5	43	2,4
S1790-6	3,49	3498	12,2	79	9,6
S1791-4	2,98	3330	9,9	18	1,8
S1791-5	7,17	2664	19,1	68	13,0
S1791-6	4,76	1554	7,4	26	1,9

Table 4 – Carbon amount in combusted dust for coal feed

Charge	Dust Content (g/m3n)	Waste gas (m3n)	Dust (kg)	Dust comp %C	Carbon in dust (kg)
S1791-1	3,14	2886	9,1	2,8	0,3
S1791-2	2,67	3684	9,8	1,6	0,2
S1791-3	1,11	2820	3,1	61	1,9

Carbon balances

The carbon yield calculated by gas balance can be compared with calculation based on carbon content in the metal and the methods have rather good agreement.

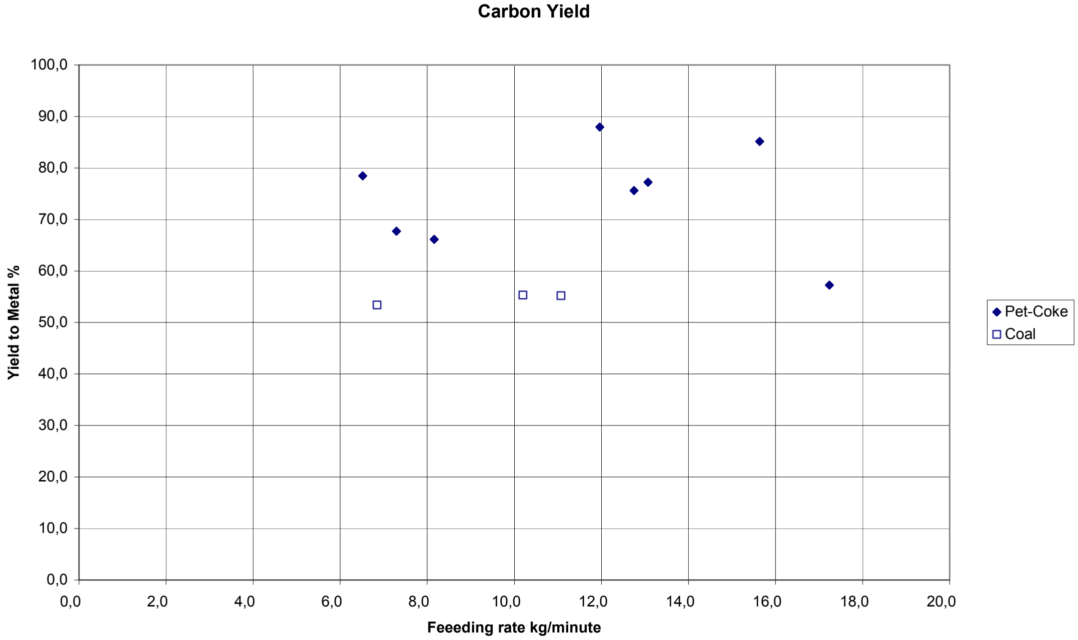

Figure 49 – Carbon to metal yield

Refractory wear

Severe wear was found in the area for injection which must be repaired. The overall lining can be used for further trials.

Table 5 – Refractory wear

	New lining		After HyMelt 10		Wear
Level	N/S	E/W	N/S	E/W	
Cone	1410	1410	1430	1375	-4
1500	1410	1410	1485	1430	24
1250	1410	1410	1490	1490	40
1000	1410	1410	1520	1510	53
750	1410	1410	1510	1520	53
500	1410	1410	1540	1525	61
250	1410	1410	1510	1525	54
0	1410	1410	1380	1400	-10
Hight	2893		2970		77

PMS AB

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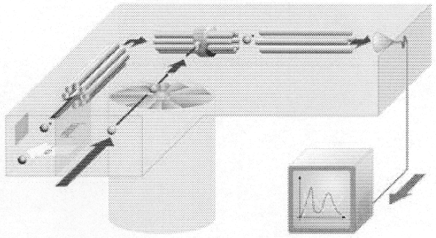
Phone +46 90 122026
Fax +46 90 122027

Homepage **www.pmsab.se** **Contact us:** **info@pmsab.se**

Airsense

Trace Mass Spectrometer



Higher demands for cost reduction, enhanced process control efficiency, coupled with increased environmental awareness is pushing the development of faster and more sensitive next generation analyzers. With years of advanced technical development and process monitoring experience these demands have been met with the Airsense series.

Instrument operation is based on quadrupole mass spectrometry with soft ionization. This combination allows for unrivalled performance in sensitivity, speed, selectivity and robust and reliable operation in industrial use.

Application and system control run under Windows and can be completely automated with pre-programmed methods. Extension to other applications with additional compounds is easily performed.

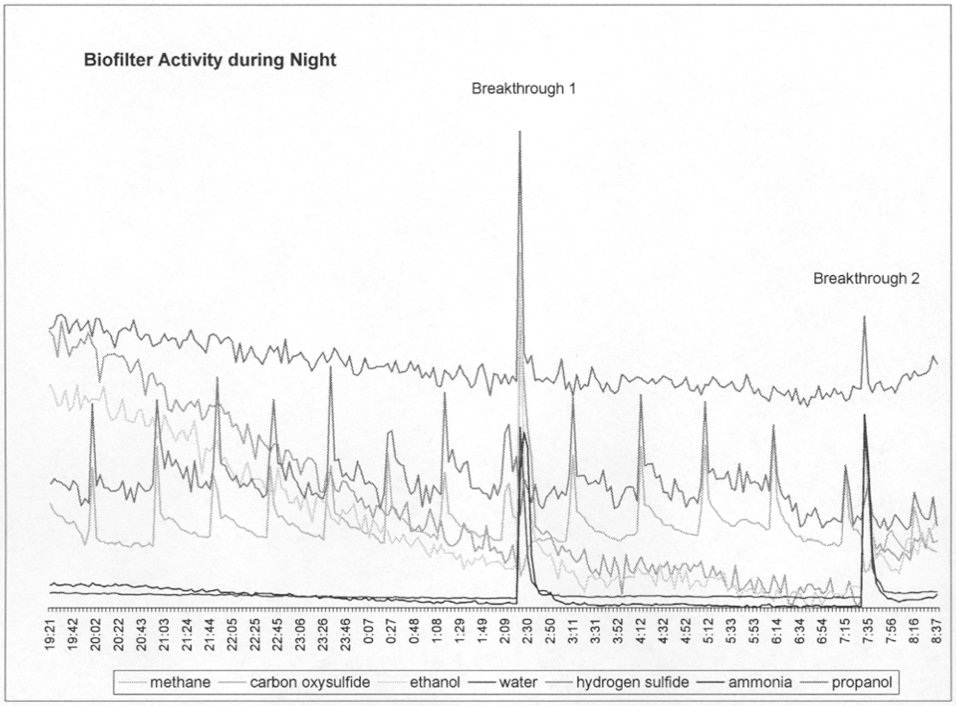
Technical Specification and Rating Data

Mass Range	0 – 500 amu
Analysis Time	10 – 6500 msec/amu
Measuring Range	10^6 with automatic compensation of inlet pressure
Response Time	T 90 < 50 msec
Detection Limit	< 10 ppb benzene in exhaust gas < 1 ppb benzene in air
Zero Drift	≥ 2 ppb over 24 h for benzene
Linearity	10^4
Reproducibility	< +/- 3 % over 24 h for benzene
Accuracy	< +/- 2 % over 24 h for benzene
Temperature	20°C – 40°C
Inlet Temperature	80 – 190°C, adjustable
Humidity	80 % max., non condensing
Gas Consumption	30 – 250 ml/min
Power Supply	220 V / 50 Hz or 115 V / 60 Hz, 800 W
Dimension	590 x 650 x 730 mm
Weight	87 kg
Service Interval	Preventative maintenance once / year
Software	SCP for Windows or ACP for Windows

The Airsense is used in the following applications:

- Incineration Stack Gas
- Fuel Cell
- Fast Pre/Post Catalyst Converter
- DeNO$_x$ Converter
- Sulphur Components in Engine Exhaust
- Catalyst Efficiency
- CO$_2$ Quality Control
- Online PET Bottle Control
- Environmental Monitoring
- Aircraft Emission in Ambient Air
- Gas Phase Analysis of Human Breath
- Workplace Control
- Fast Measurement of non regulated Hydrocarbons
- Desulphuration
- Steel Converter Control
- Cement Industry

- Multi Component Analysis in %, ppm and ppb area
- Soft ionization provides a high level of confidence for component identification in complex gas streams
- Excellent response and reproducibility
- Simple extension of the molecule database
- Typical detection limit in the ppb area
- 3 to 4 decades dynamic range
- Fast sampling rate
- Compact design for mobile operation
- Low annual operating costs



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Phone +46 90 122026
Fax +46 90 122027

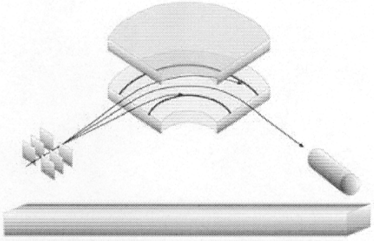
Homepage www.pmsab.se Contact us: info@pmsab.se

HSense

High Resolution Hydrogen Mass Spectrometer

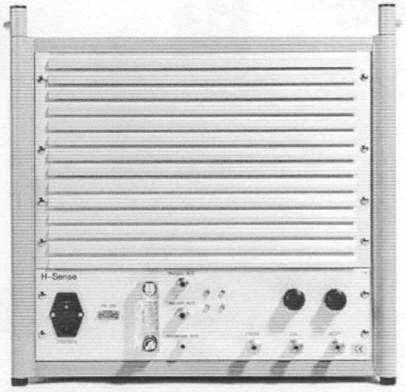
The instrument comprises of a magnetic sector mass spectrometer for the analysis of hydrogen concentrations in the vehicle exhaust. Gas samples are ionized by electron impact ionization. Ions generated are separated by magnetic sector according to their molecular mass. Only hydrogen or helium is analyzed for their concentrations. The well proven gas inlet system automatically compensates for pressure fluctuations. Oil free vacuum pump supply ensures minimal service requirements with only one single routine maintenance per year.

The system is ideal for on-line analysis of hydrogen and helium in vehicle exhaust gas, process control and environmental monitoring.

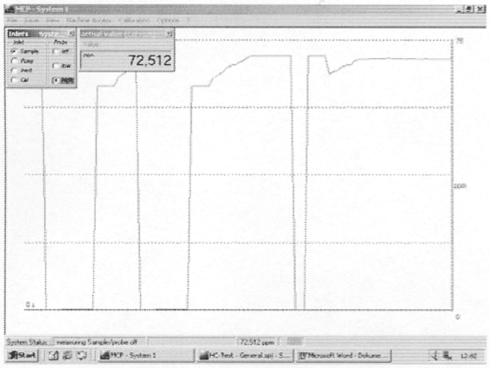


Technical Specification and Rating Data

Mass Range	2 – 4 amu
Mass Separation	min. 1 amu over the mass range
Cycle Time	100 msec min.
Dynamic Range	1 – 10000 ppm / 0,1 – 100 %
Response Time	< 300 msec
Dynamic	10^6
Linearity	± 3%
Drift	< 2% over one hour – measured with 100 ppm H_2
Inlet Pressure Compensation	200 mbar – 2 bar
Gas Consumption	20 ml/min
Calibration Cycle	Automatically controlled, adjustable by the software
Calibration Time	Typical 120 sec.
Analog Output	2-channel on-line outputs
Supply Voltage	220 V / 50 Hz or 115 V / 60 Hz, max. 500 W
Temperature	10°C – 40°C
Humidity	90 % max., non condensing
Weight	67 kg
Dimensions	590 x 650 x 640 mm
Service Interval	Preventative maintenance once / year
Software	MCP for Windows



- Single Component Analysis in ppm and % area
- Excellent response and reproducibility
- Typical detection limit in the ppm area
- 3 to 4 decades dynamic range
- Fast sampling rate
- Easy to use software
- Datastorage in ASCII format
- Low annual operating costs



System Status: measuring Sample/probe off

72,512 ppm

Appendix VIII

HYMELT, CAMPAIGN III,

9-12 DECEMBER 2003

MEFOS

Box 812, 971 25 LULEÅ

Dokument:	MEFOS-rapport	*Reg nummer:*	MEF04010K
Fo-uppgift:		*Datum:*	2004-02-27
Konto:	388160	*Rev datum:*	
Ämnesomr:		*Avdelning:*	MM

HYMELT, CAMPAIGN III,

9-12 DECEMBER 2003

by

Sten Ångström

Godkänd av forskningschef:		*Slutlig:*	Y
Projektledare:	Nils-Olov Lindfors	*Sekr:*	acj
Distribution:	NOL, SÅ, Don P Malone-EnviRes LLC (dpmalone@alltel.net)		

HYMELT, Campaign III, 9-12 December 2003

Sten Ångström

MEFOS

SUMMARY

A third HyMelt pilot campaign has been performed at Mefos.

Compared to previous campaigns the converter profile had a narrower lining to achieve an increased metal height. The injection feed was further split into two bottom tuyeres. The arrangement showed that prolonged residence time of coal/coke particles in the melt improves the process performances. The feeding rate can, compared to previous campaigns, be almost doubled at maintained or improved material yields.

The top lance was removed and oxygen blowing was also made by use of the bottom tuyeres. The process is thereby more stable and lower amounts of reducible slag oxides decrease the initial CO formation in the coke/coal feeding period.

A new system for process gas analysis together with a tighter sampling system improved the sampled gas quality and simplified the evaluation.

The expected number of tests could not be made because of equipment failures. The problems occurred do not influence the HyMelt development and were partly compensated by an additional test day.

TABLE OF CONTENTS **Page**

1 Introduction

In the HyMelt II campaign, TM03054K, it was demonstrated that side wall injection improved the generated gas quality compared to the results the from top lance injection in the HyMelt I, TM03037K. The results also indicated a possibility for further improvements if the injected particles could be kept submerged in the melt for longer time and if a more intense particle contact with the melt could be established

Thus, HyMelt III was designed with two bottom tuyeres and the metal bath height was increased by a reduced lining diameter of the converter.

The tuyeres were also used for oxygen injection. The oxygen lance was removed because of scull problem. Bottom blowing is further expected to decrease the amount of reducible oxides in the slag and thereby shortening the turn-around time between oxygen blowing and hydrogen gas production.

2 Equipment

The set up was focused on residence time of the material in the metal and two major changes were made:

- The injection flow was split into two bottom tuyeres of new design
- Increased metal bath depth

Further modifications were:

- The oxygen lance was removed and replaced by oxygen injection through the two bottom tuyeres.
- The mass spectrometers for gas analysis were replaced by a single instrument of later design.
- A new lance, in parallel with the gas sampling lance, was dedicated for larger dust samples from the process gas
- Nitrogen was used as material transport gas

2.1 Converter lining

The converter lining was made with an inner layer decreasing the diameter to 1100 mm. The bath height at 5,5 ton was thereby increased from approximately 500 to 800 mm. The design was a compromise between an increased bath height and the necessity to keep the tuyeres above the melt surface at tilted position. The refractory used was MagCarbon Radex PLE12.

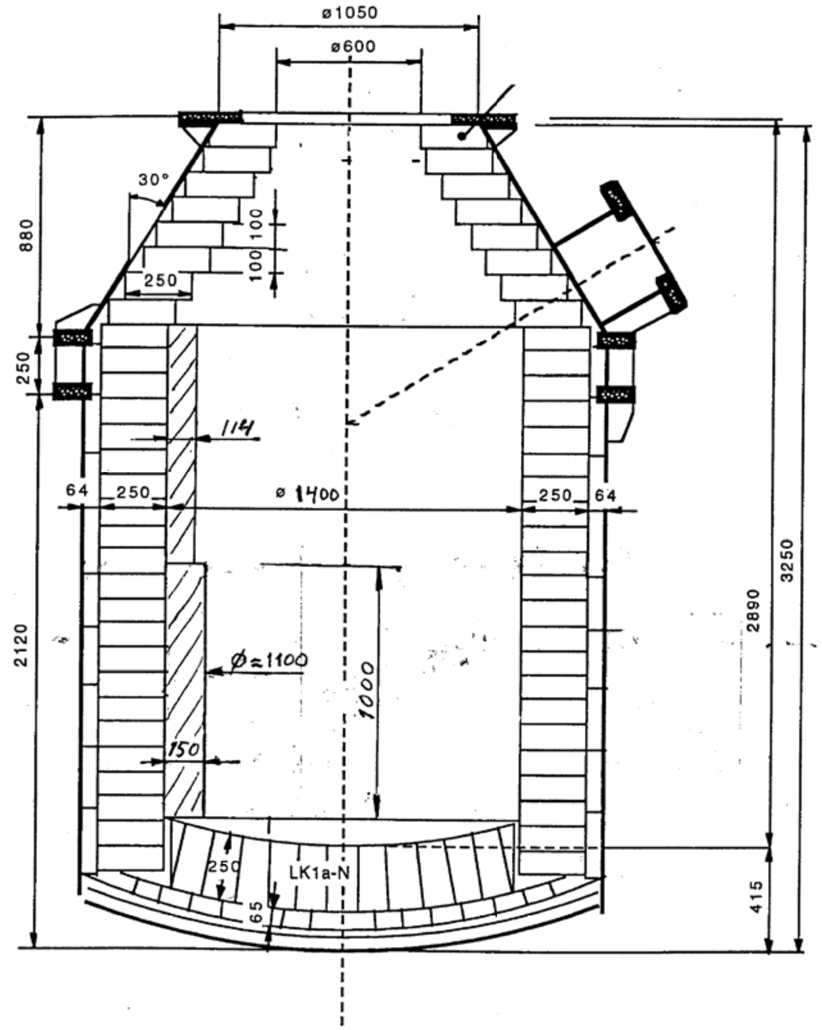


Figure 1 – Converter lining

2.2 Tuyere design

Note: This information was deleted since it is confidential.

2.3 Process gas analysis

The process gas was analysed by mass spectrometer (AirSense Compact) and for comparison by conventional CO, CO_2 and H_2 analysers.

2.4 Dust collection system

Since the oxygen lance was removed it was possible to separate the dust sampling from the process gas sampling and to use a dedicated dust sampling lance. Thus, larger dust samples could be collected.

3 Material

The same materials as for previous tests were used. For detailed information see TM03037K.

4 Test Procedure

Differently from previous tests, described in TM03037K, the converter was tilted for rearrangement of connecting hoses to the tuyeres between oxygen and material feed.

5 Results

5.1 Heats

5.1.1 HyMelt 11

Date 031209

Heat S1792

Failure in the tilting function of the EAF delayed start of tests. Two injection periods with coke was made.

5.1.2 HyMelt 12

Date 031210

Heat S1793

One coke injection period was made. A smaller explosion in gas feeding pipes damaged the propane measuring device.

5.1.3 HyMelt 13

Date 031211

Heat S1794

Four periods with coal and one with coke were made.

5.1.4 HyMelt 14

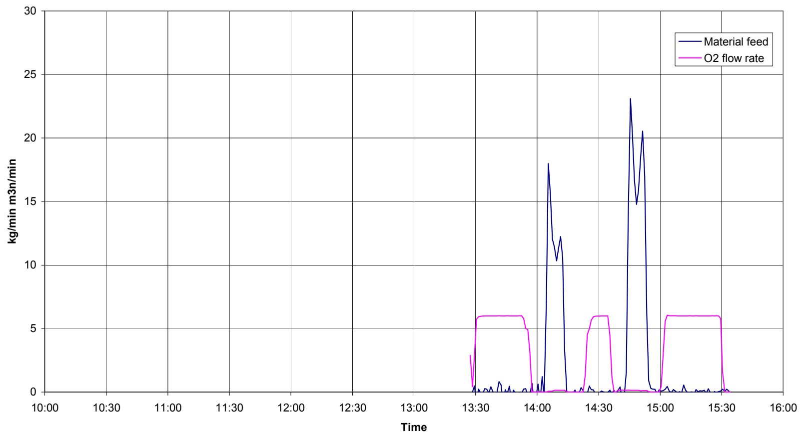
Date 031212

Heat S1795

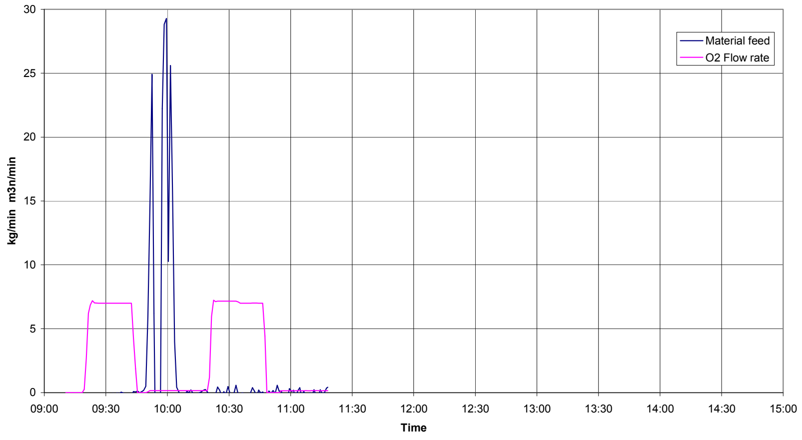
Three periods with coal were made. The operation was mainly made without in-blow temperatures and samples.

Figure 3 – Feed of material and O_2 flow rate HyMelt 11-14

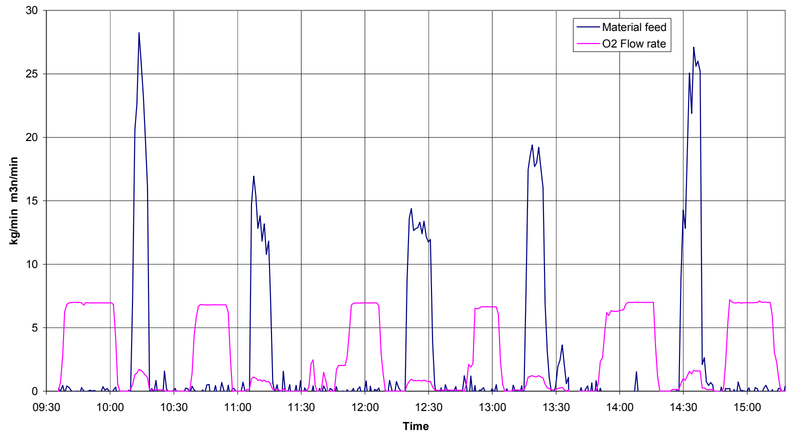
HyMelt 11

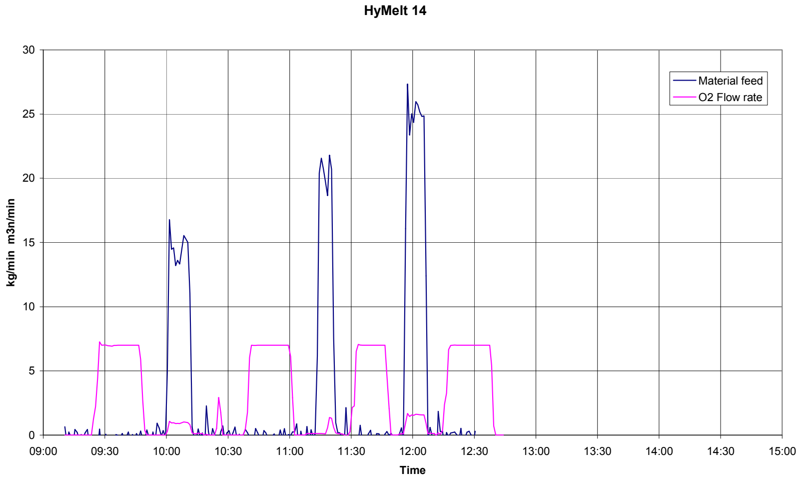


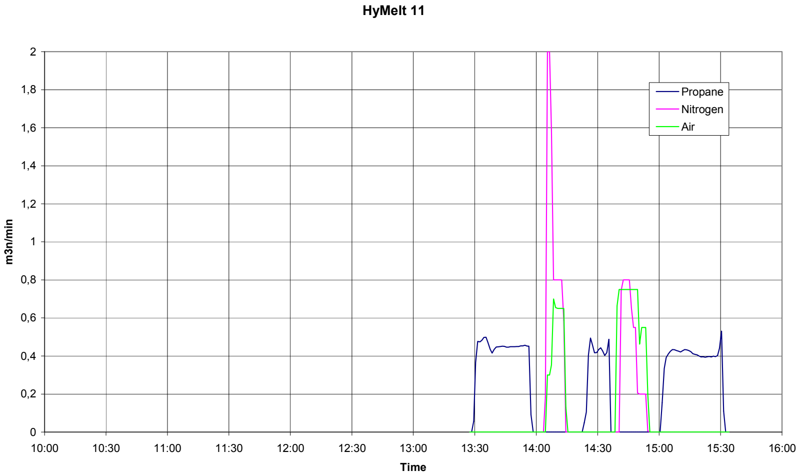
HyMelt 12



HyMelt 13




HyMelt 14
kg/min m3n/min
30
25
20
15
10
5
0
09:00
09:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
Time
Material feed
O2 Flow rate


HyMelt 11
m3n/min
2
1,8
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
15:30
16:00
Time
Propane
Nitrogen
Air

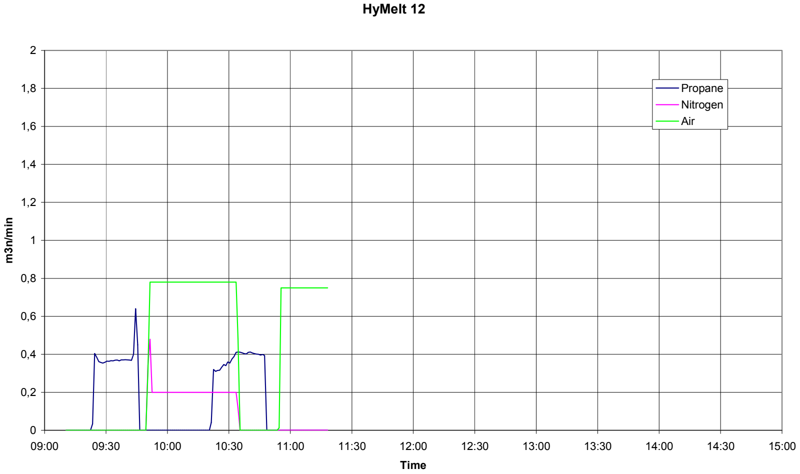
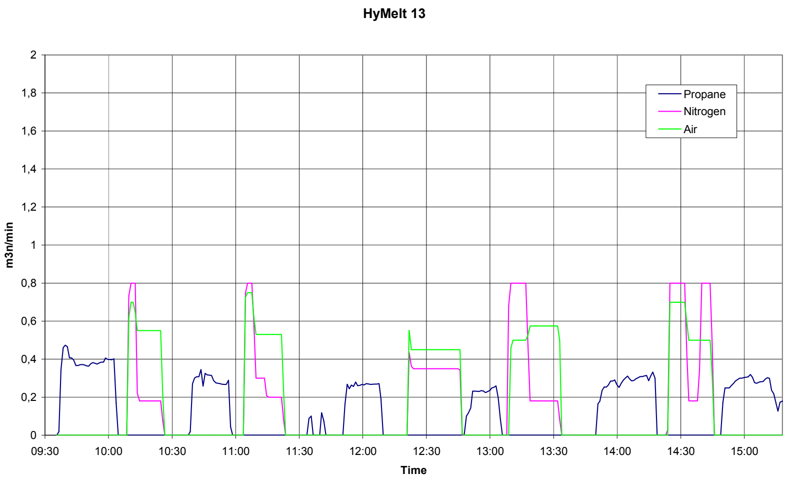
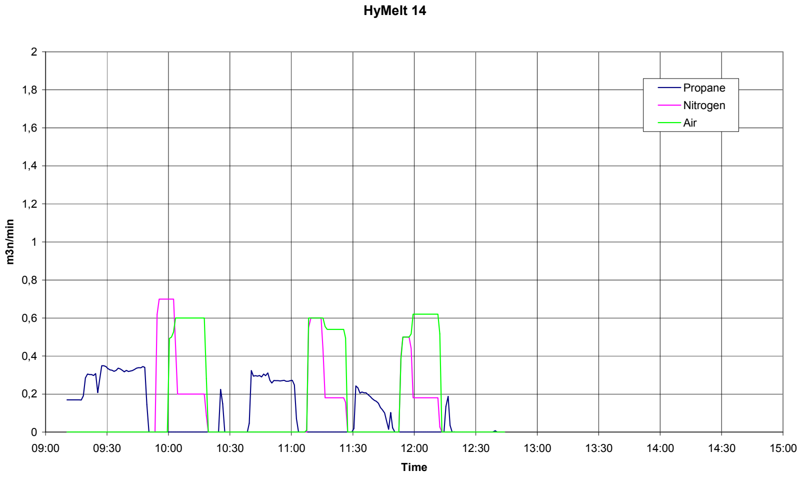

HyMelt 12
m3n/min
2
1,8
1,6
1,4
1,2
1
0,8
0,6
0,4
0,2
0
09:00
09:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
Time
Propane
Nitrogen
Air

Figure 4 – Injected nitrogen, propane and air HyMelt 11-14



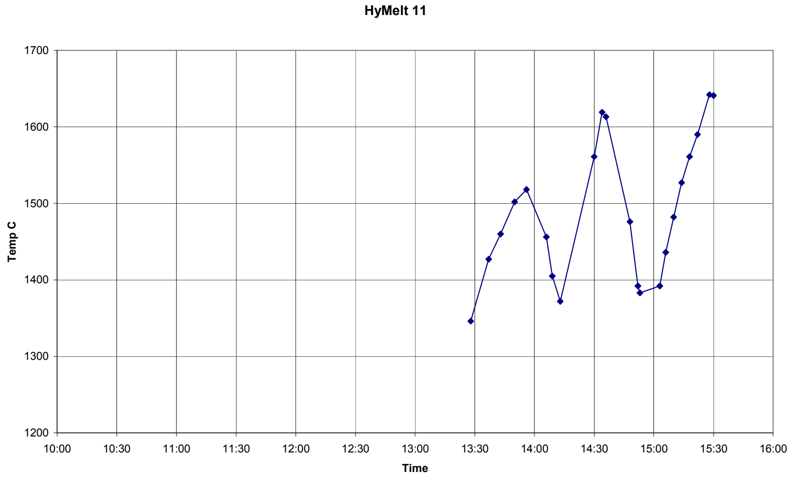


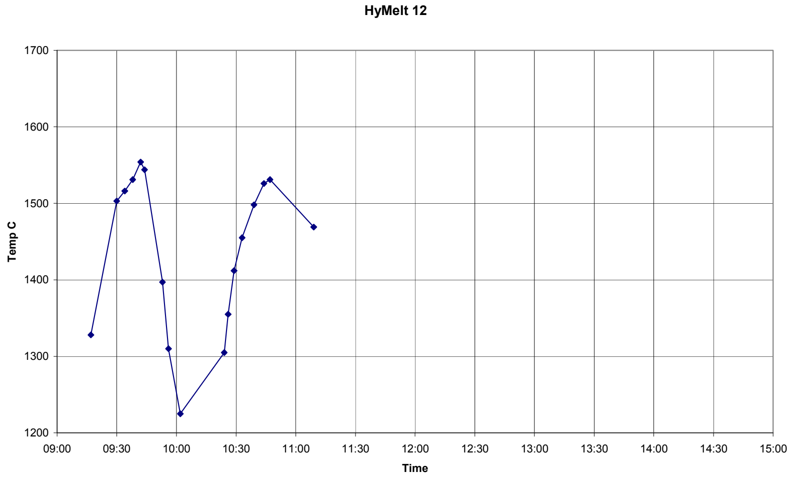
5.2 Metal

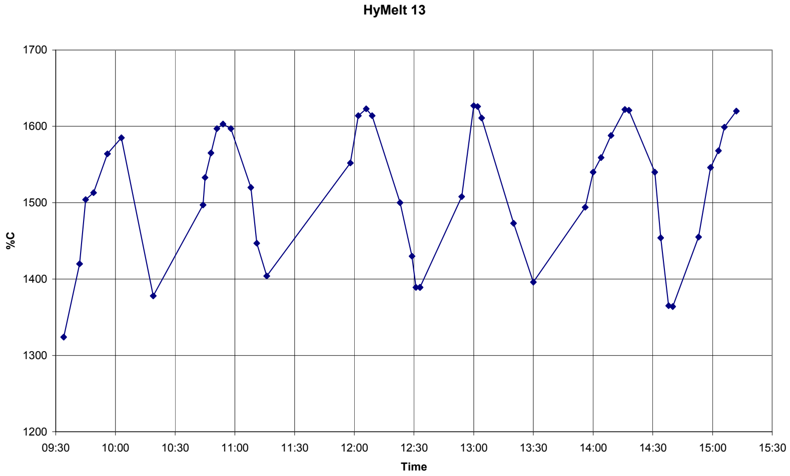
5.2.1 Metal temperature

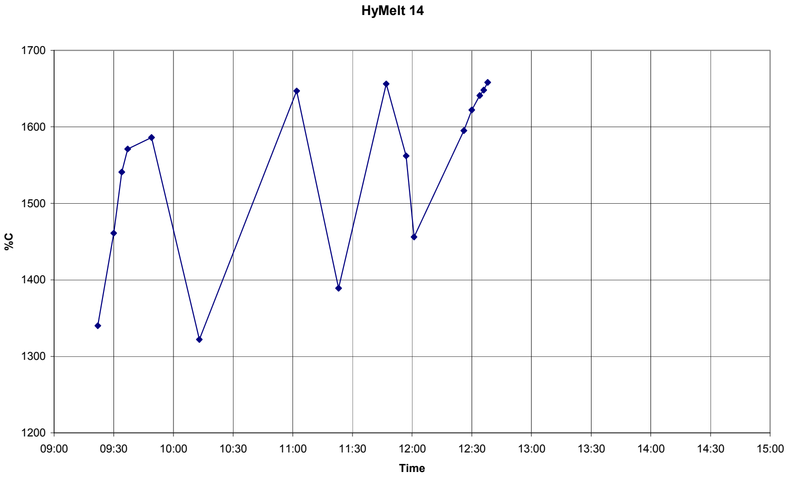
The metal temperature was a primary controlled parameter and mainly kept between 1350 to 1650°C. Oxygen blowing for decarburization was made until the desired temperature was achieved and injection was considered possible above 1350°C. Lowest recommended operational temperature can however be discussed since it seems to be a relation between gas composition and metal temperature.

Figure 5 – Melt temperatures HyMelt 11-14





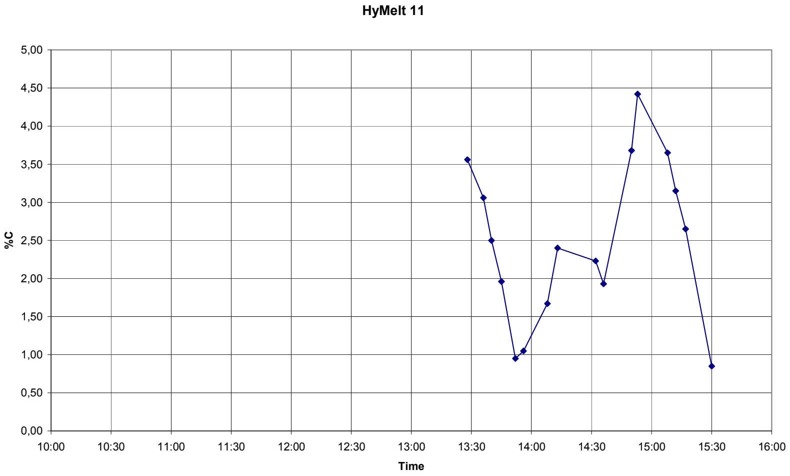


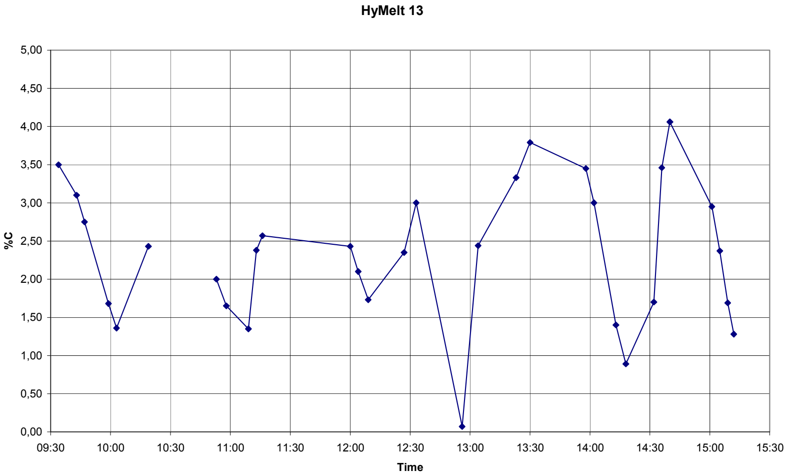

HyMelt 14
%C
1700
1600
1500
1400
1300
1200
09:00
09:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
Time

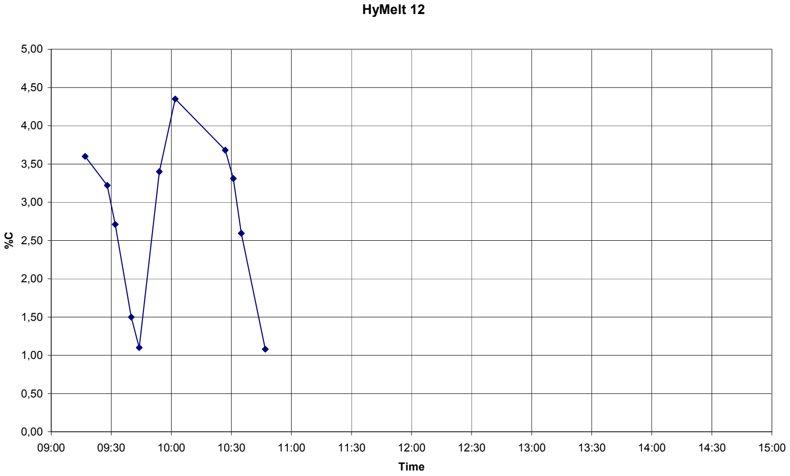
5.2.2 Metal %C

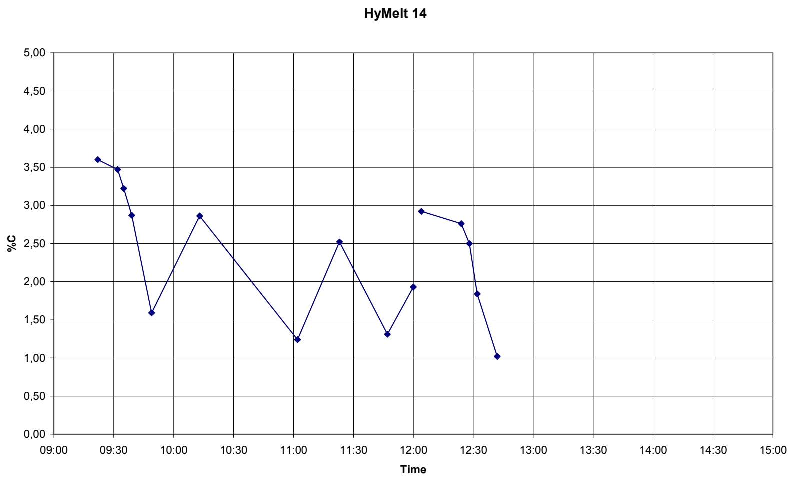
The carbon content was varied between 1 and 4,5 %. The lower limit is a consequence of the relation to oxides in the slag and the upper limit is set by the temperature and available energy for solution of carbon.

Figure 6 – Carbon content HyMelt 11-14





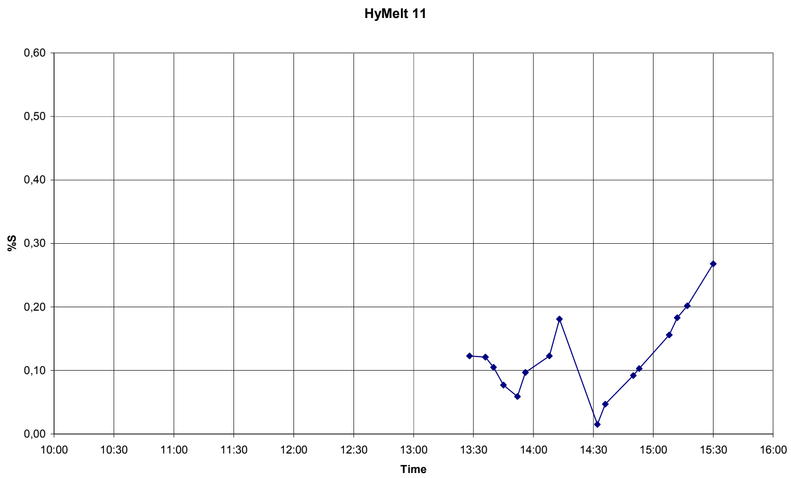


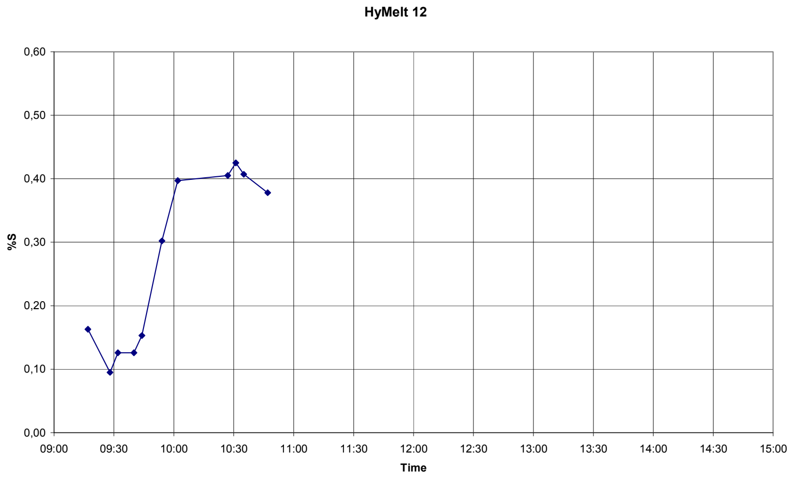

HyMelt 14
%C
5,00
4,50
4,00
3,50
3,00
2,50
2,00
1,50
1,00
0,50
0,00
09:00
09:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
Time

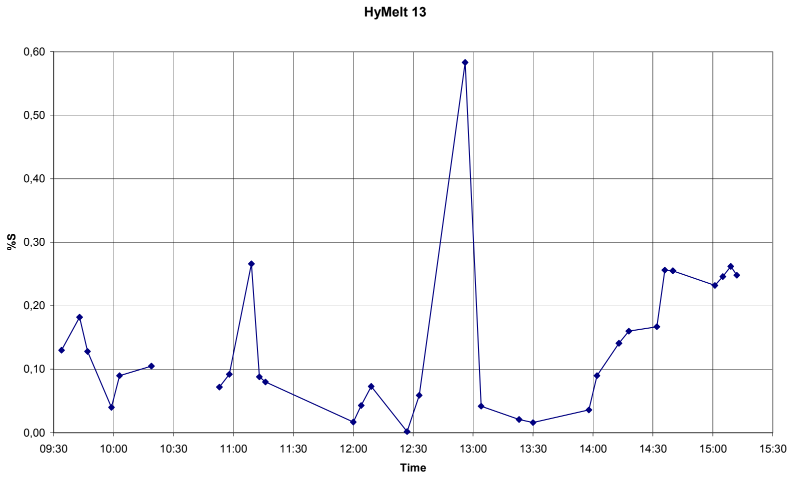
5.2.3 Metal %S

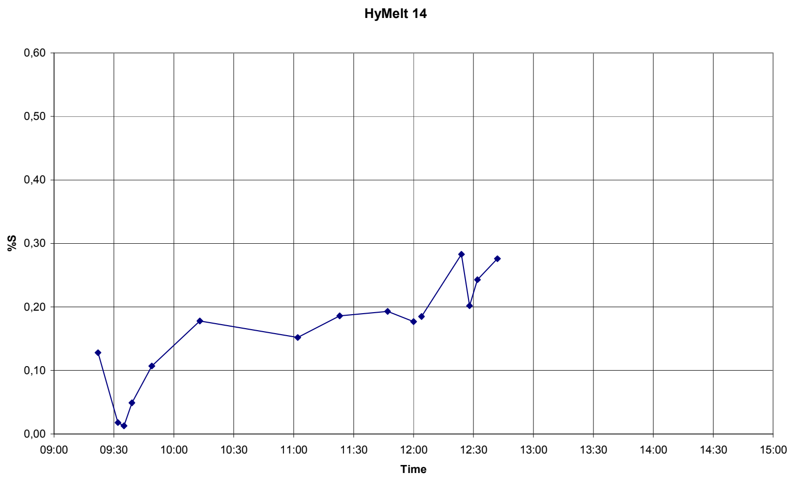
Sulphur is an element of great importance in metallurgy and has consequently been studied for several reasons. The distribution between slag and metal is well known and has a strong relation to CaO/SiO_2-ratio and the oxygen potential, i.e. Fe_{tot}. and % C. A fundamental aspect in the HyMelt process is the variation of the carbon content in the metal and it is expected that the sulphur content in the metal will vary accordingly.

Figure 7 – Sulphur content HyMelt 11-14








HyMelt 14
%S
0,60
0,50
0,40
0,30
0,20
0,10
0,00
09:00
09:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
Time

5.3 Slag

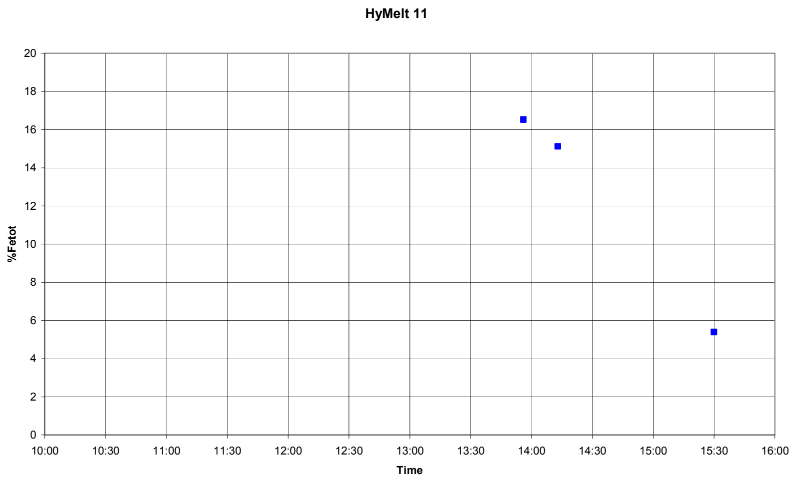
5.3.1 Slag % Fe_{tot}

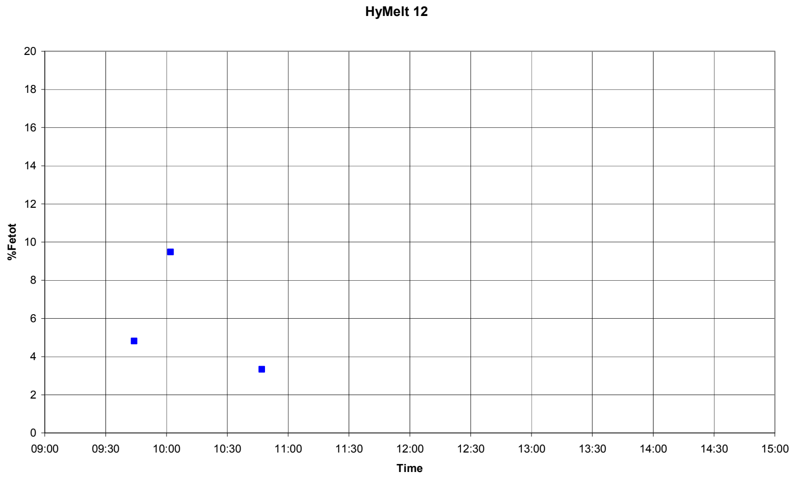
There are at least two good reasons to keep Fe_{tot} as low as possible in the slag:

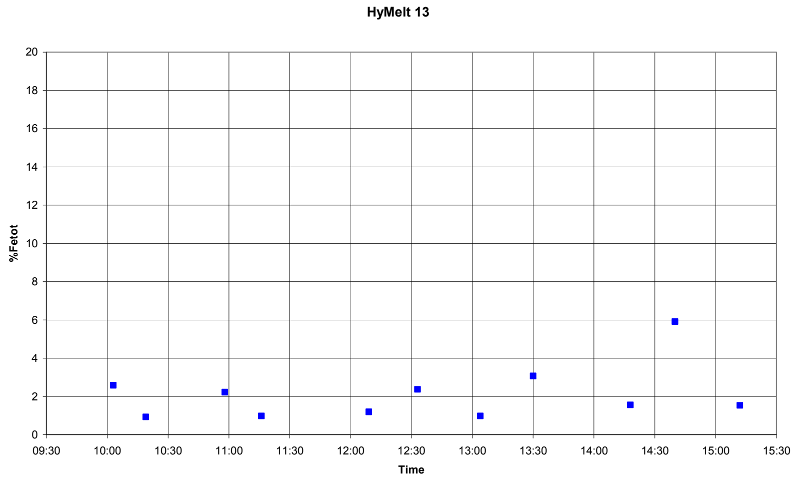
1. Fe_{tot} is for HyMelt conditions a description of the FeO content in the slag and will at higher levels influence the time between start of material injection and the point where gas of good quality can be produced.
2. Fe_{tot} does also directly influence the solidification temperature of the slag and thereby the refractory wear

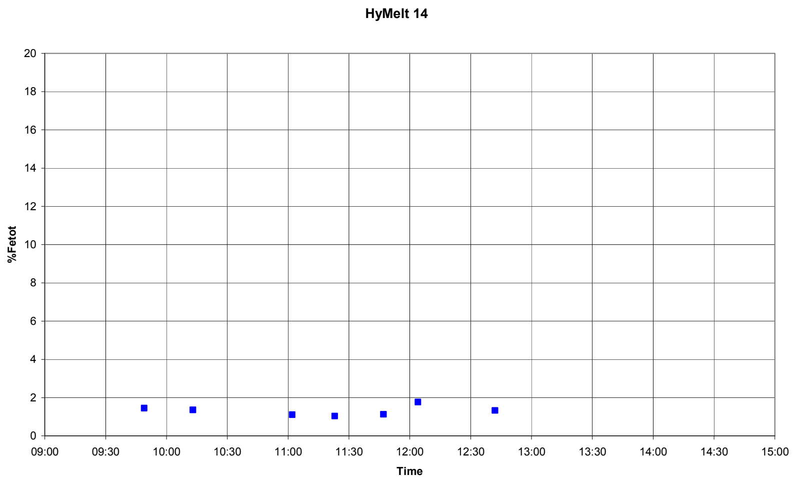
Bottom blowing promotes lower Fe_{tot} at comparable carbon contents and compared to previous top blown campaigns. The most reliable samples are shown in HyMelt 13 and 14.

Figure 8 – Fe_{tot} HyMelt 11-14





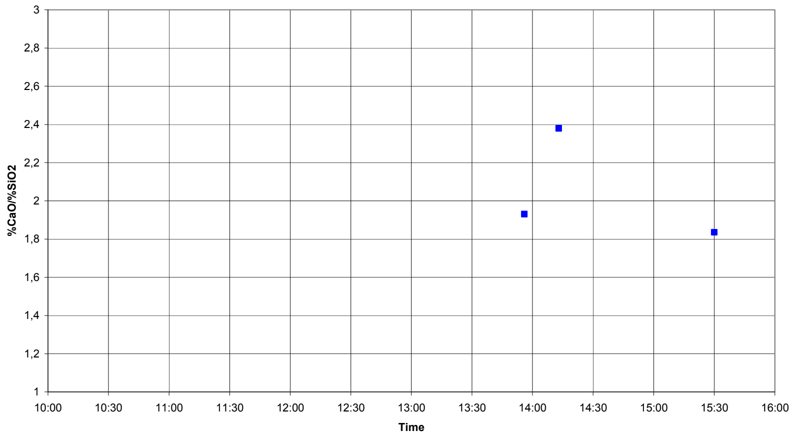


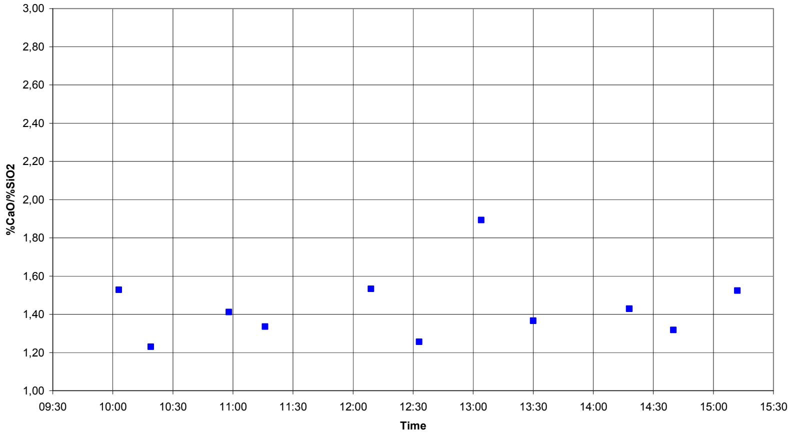

HyMelt 14
%Fetot
0
2
4
6
8
10
12
14
16
18
20
09:00
09:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
Time

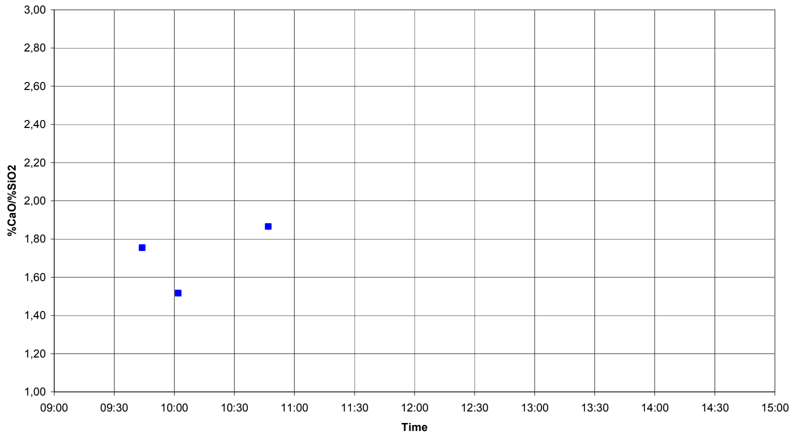
5.3.2 Slag %CaO/%SiO$_2$

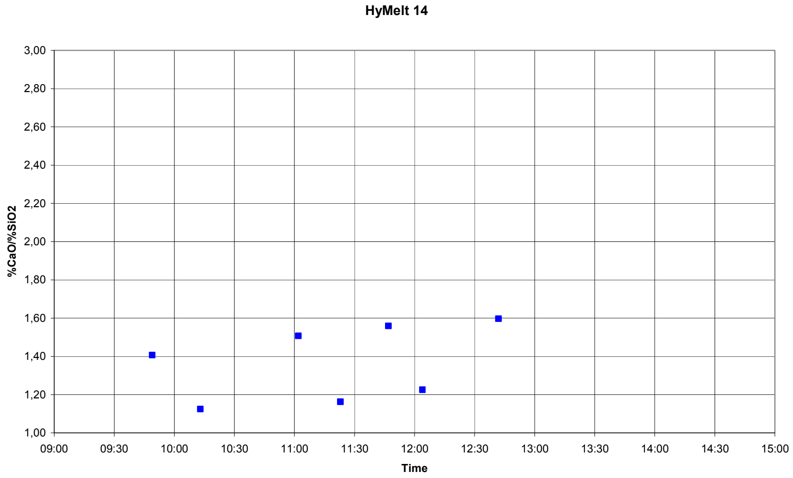
The % CaO/ % SiO$_2$-ratio is a simplified indication of solidification temperature and sulphur capacity of the slag. The optimal ratio for the HyMelt has so far not been investigated but it is likely that improved performances can be achieved at levels higher than 2.

Figure 9 – % CaO/% SiO_2 HyMelt 11-14


HyMelt 11


HyMelt 13

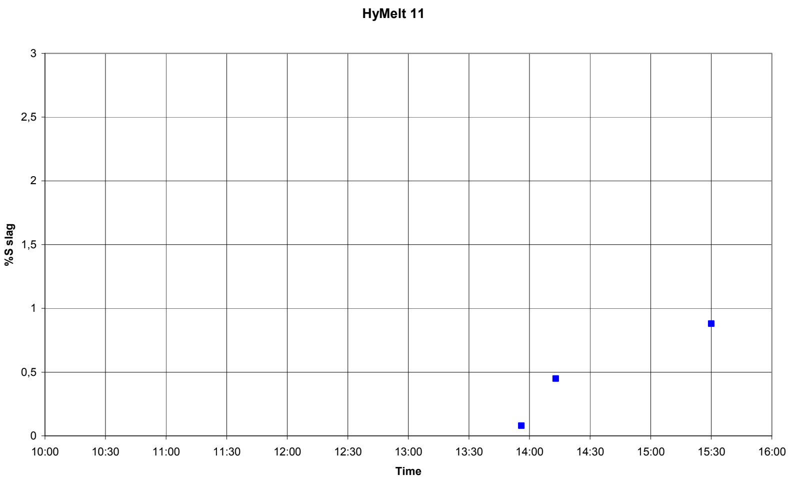

HyMelt 12

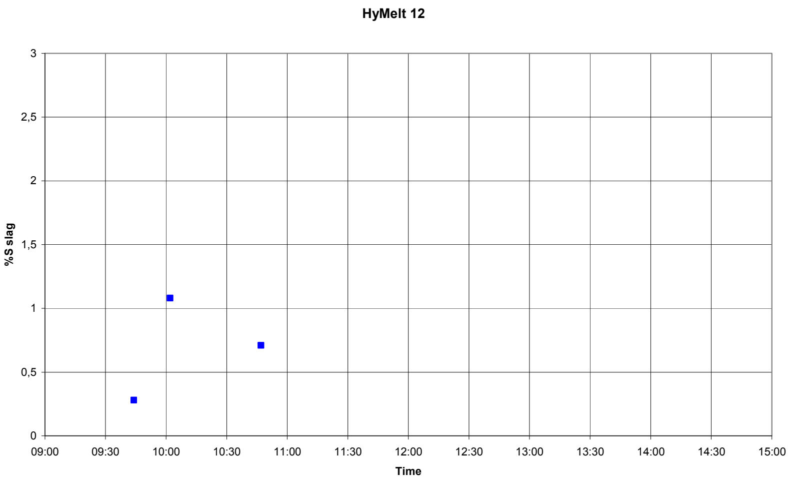

HyMelt 14
%CaO/%SiO2
3,00
2,80
2,60
2,40
2,20
2,00
1,80
1,60
1,40
1,20
1,00
09:00
09:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
Time

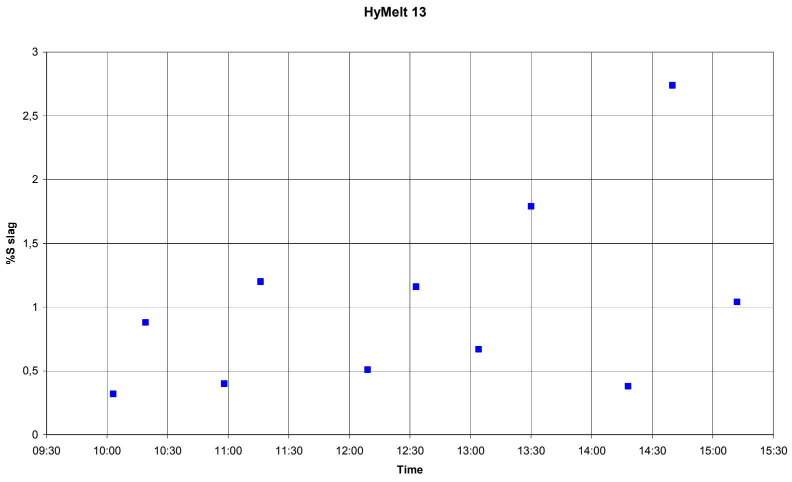
5.3.3 Slag % S

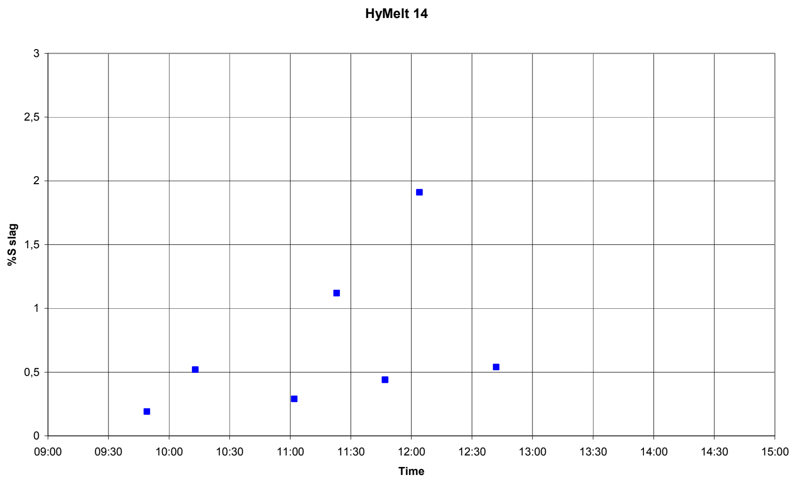
The concentration of sulphur in the slag is a mirror of the concentration in the metal. Saturation is expected at levels somewhere above 3 % and has not been achieved in any of the heats since the concentration is increasing during the entire campaign.

Figure 10 – % S slag HyMelt 11-14








HyMelt 14
%S slag
3
2,5
2
1,5
1
0,5
0
09:00
09:30
10:00
10:30
11:00
11:30
12:00
12:30
13:00
13:30
14:00
14:30
15:00
Time

5.4 Generated gas

For reference the gas composition are shown as in the previous reports and obtained analysis confirm mainly the earlier reported composition.

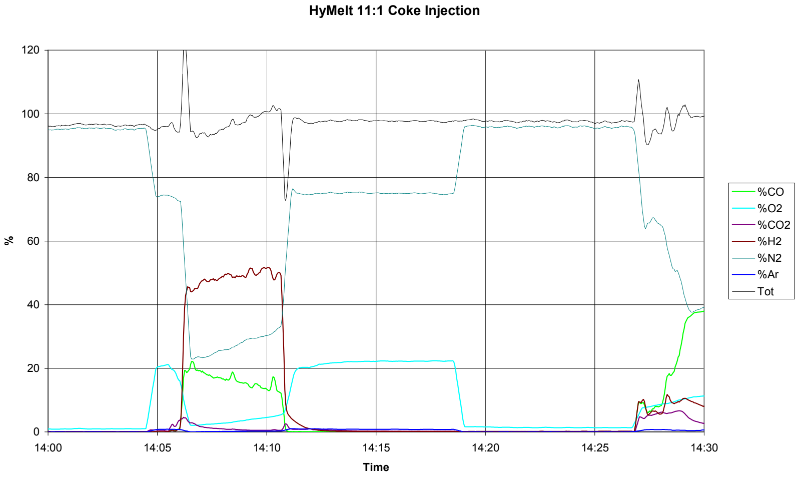
The sampling system was improved after HyMelt 11 and the leakage of air was decreased.

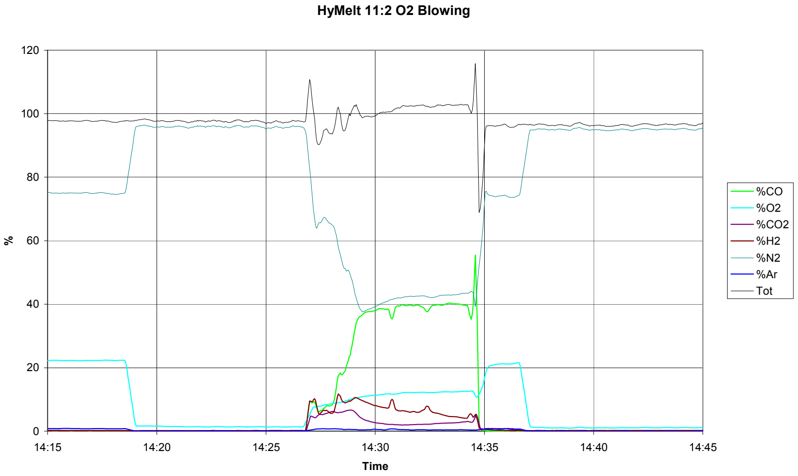
H_2	Up to 60 %.
CO	15 – 30 % Lower for coke and higher for coal.
CO_2	0,5 – 5 % CH_4 typically below 1%
C_2H_2	50 – 200 ppm, significantly lower than HyMelt II 1000 ppm
H_2S	200 ppm
COS	10 – 60 ppm, significantly lower than HyMelt II 50 – 200 ppm
C_2S	10 – 20 ppm
HCN	10 – 30 ppm
O_2	<2 %
N_2	Unstable instrument function
Ar	No significance for the experimental set up

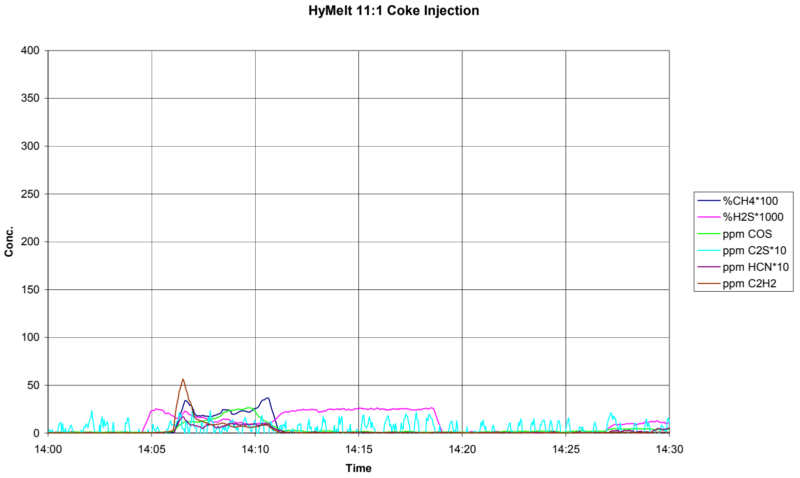
In addition to gas generated at coal and coke feeding some periods with oxygen blowing were analysed in this campaign.

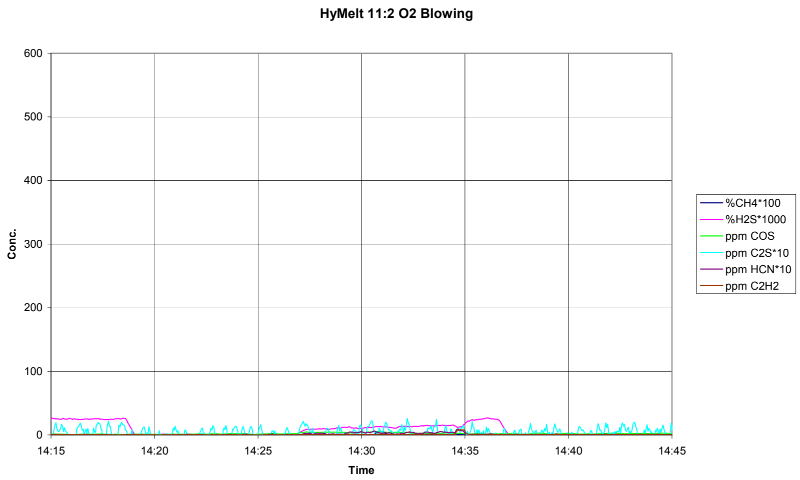
CO, CO_2 and H_2 shows expected values but for several periods CH_4 C_2S C_2H_2 etc. are present and for others not. For the moment no definitive explanation can be given. A likely explanation could be remaining contamination in the sampling system or remaining coal/coke in the slag.

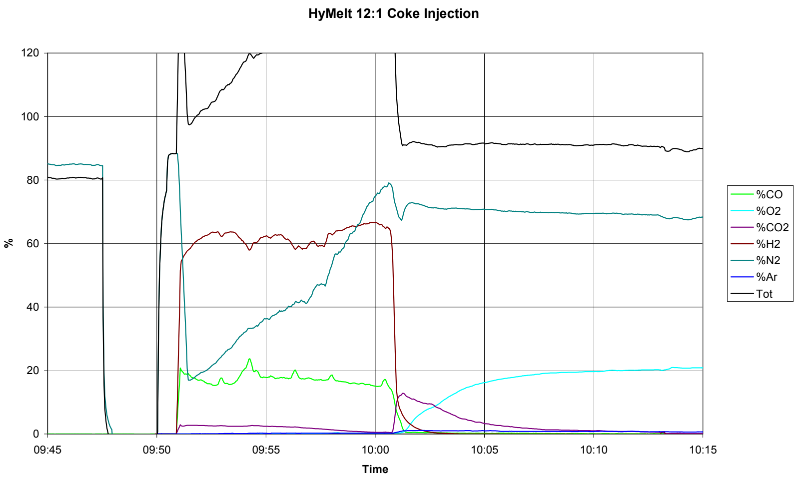
Figure 11 – Process gas HyMelt 11








HyMelt 11:2 O2 Blowing
Conc.
600
500
400
300
200
100
0
14:15
14:20
14:25
14:30
14:35
14:40
14:45
Time
%CH4*100
%H2S*1000
ppm COS
ppm C2S*10
ppm HCN*10
ppm C2H2


HyMelt 12:1 Coke Injection
%
120
100
80
60
40
20
0
09:45
09:50
09:55
10:00
10:05
10:10
10:15
Time
%CO
%O2
%CO2
%H2
%N2
%Ar
Tot

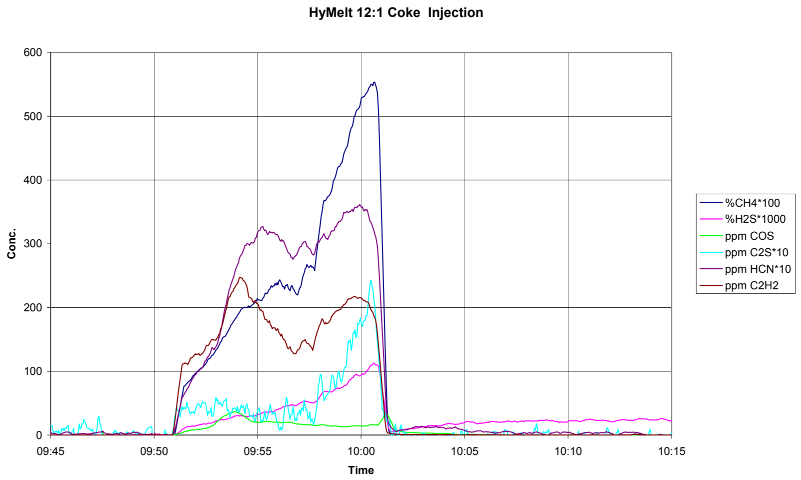
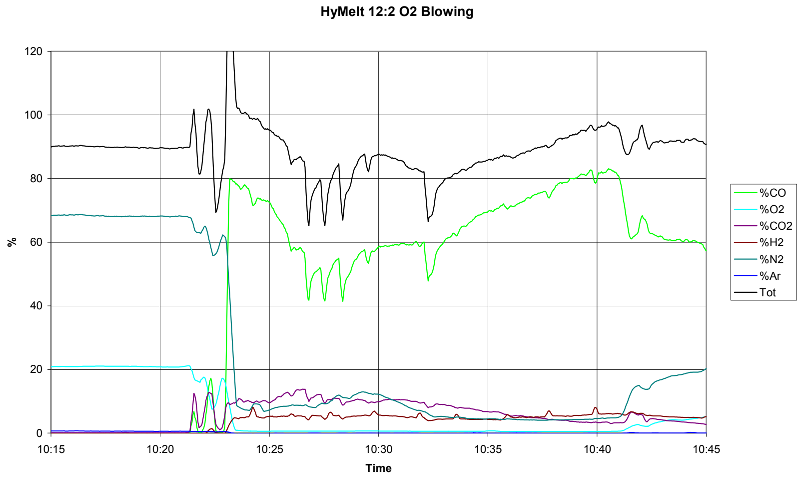

HyMelt 12:1 Coke Injection
Conc.
600
500
400
300
200
100
0
09:45
09:50
09:55
10:00
10:05
10:10
10:15
Time
%CH4*100
%H2S*1000
ppm COS
ppm C2S*10
ppm HCN*10
ppm C2H2

Figure 12 – Process gas HyMelt 12



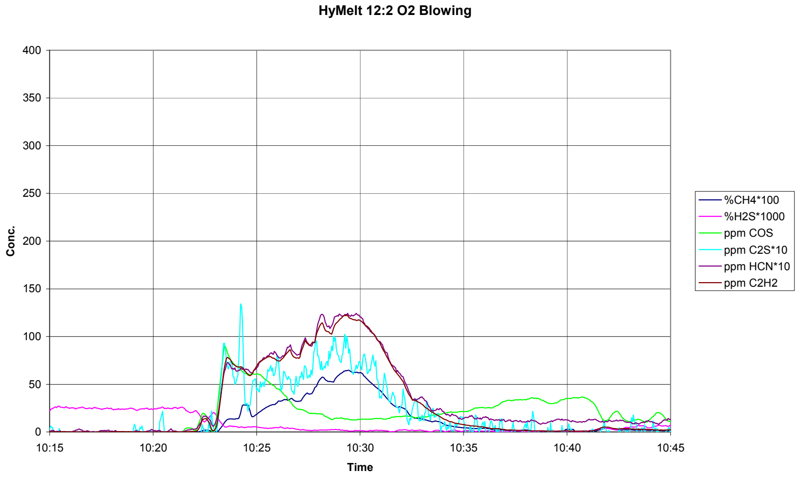
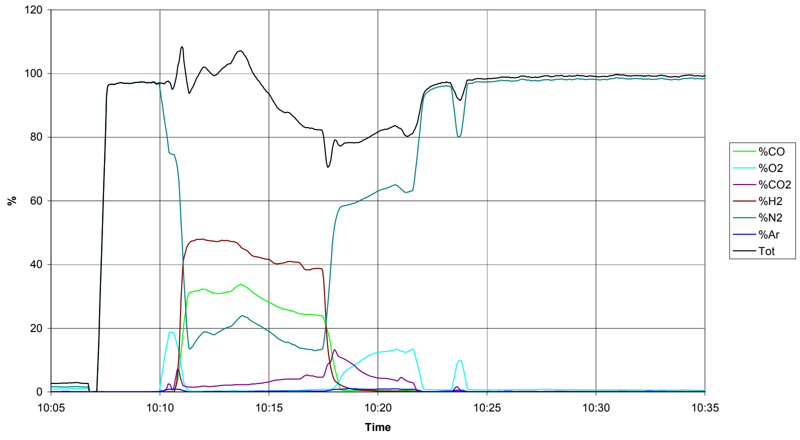
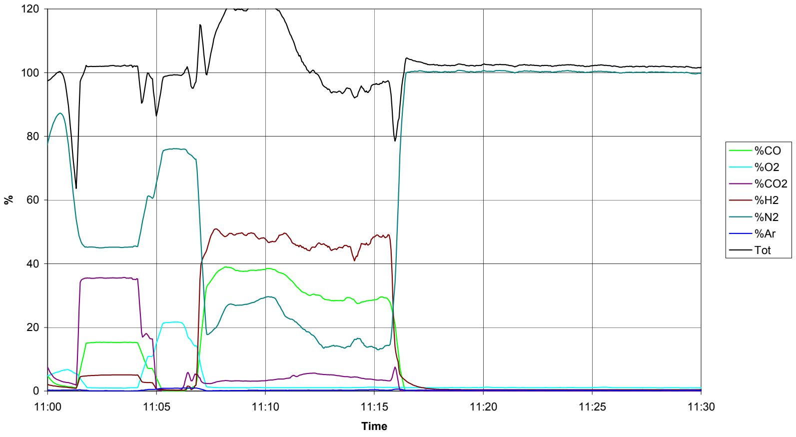
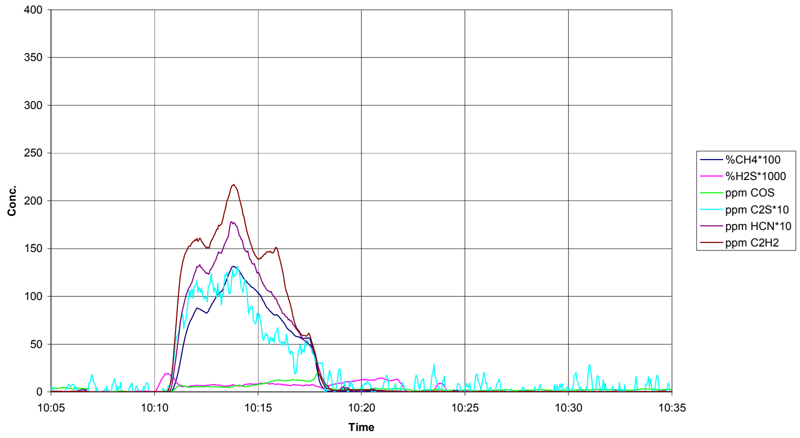
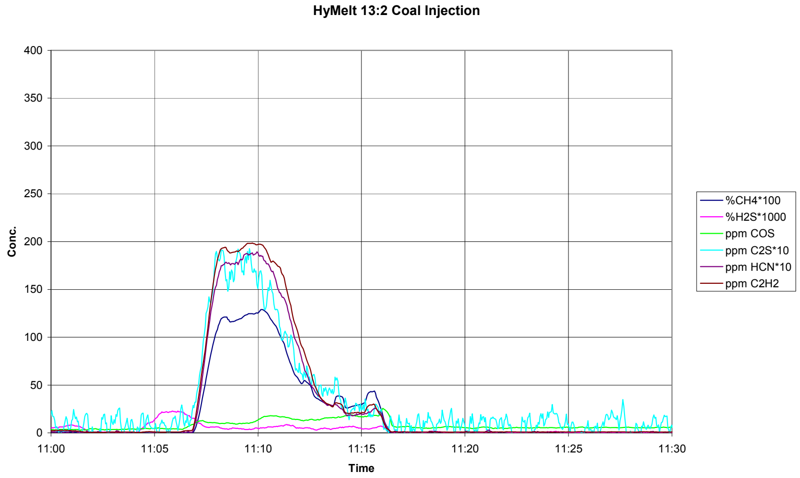


Figure 13 – Process gas HyMelt 13

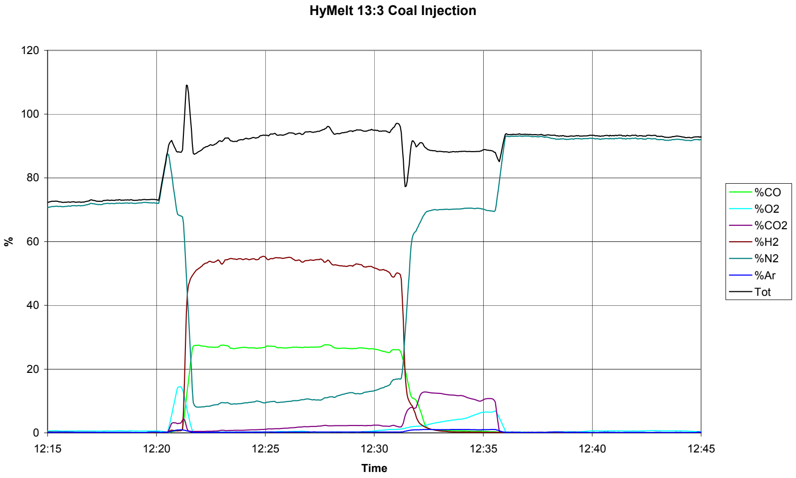

HyMelt 13:1 Coal Injection


HyMelt 13:2 Coal Injection

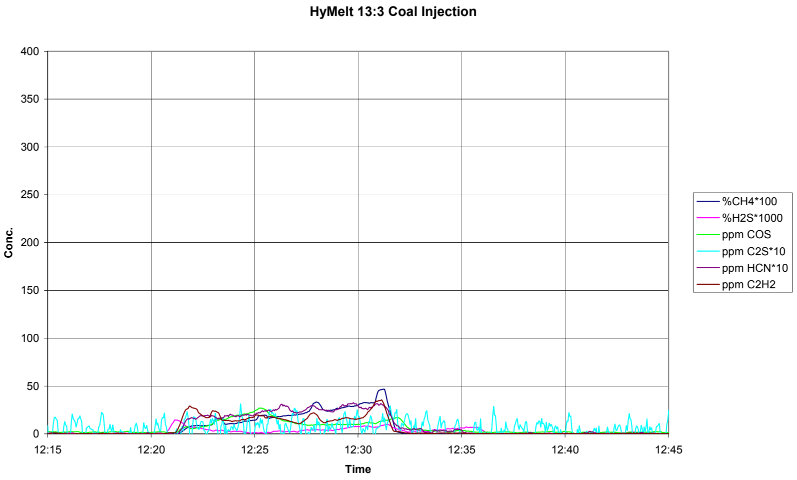

HyMelt 13:1 Coal Injection



HyMelt 13:2 Coal Injection

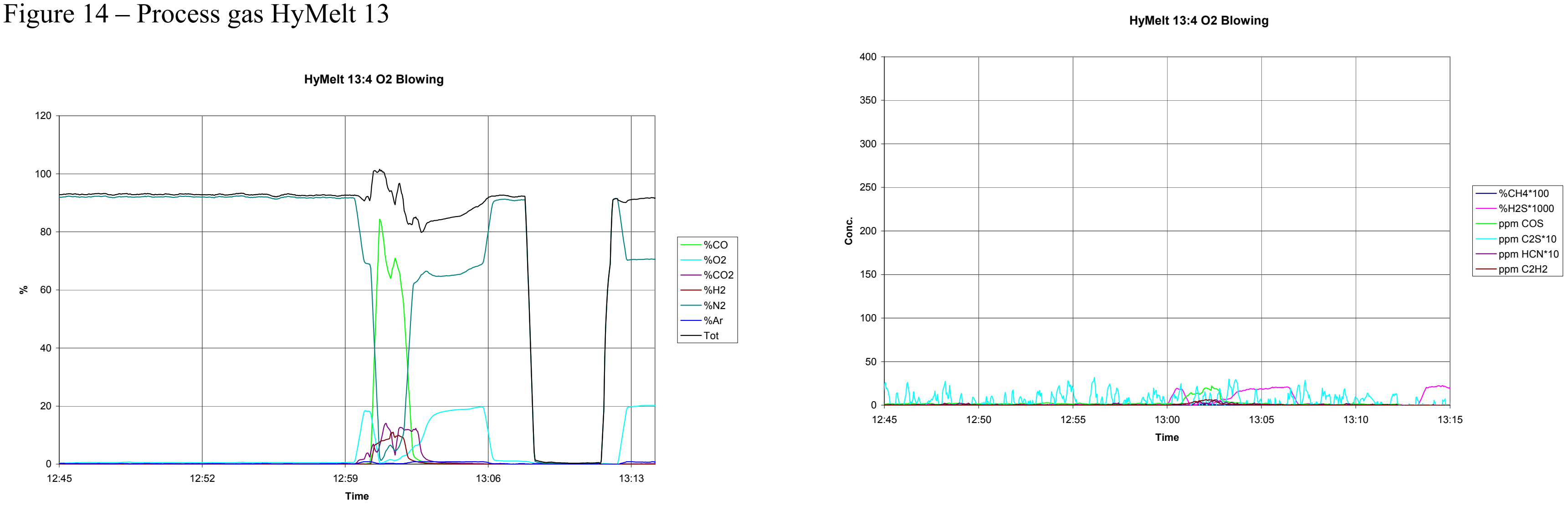


HyMelt 13:3 Coal Injection



HyMelt 13:3 Coal Injection

Figure 14 – Process gas HyMelt 13



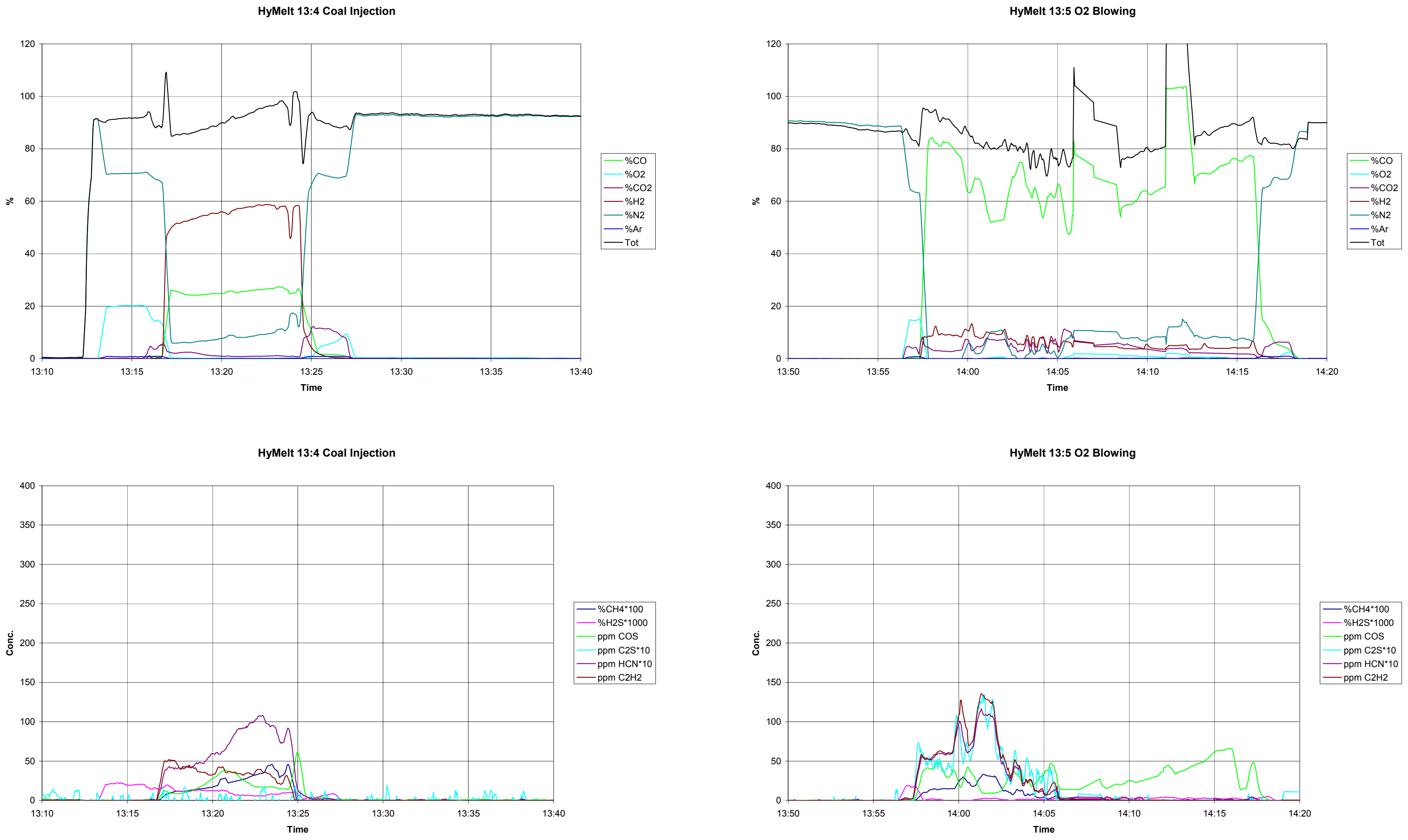
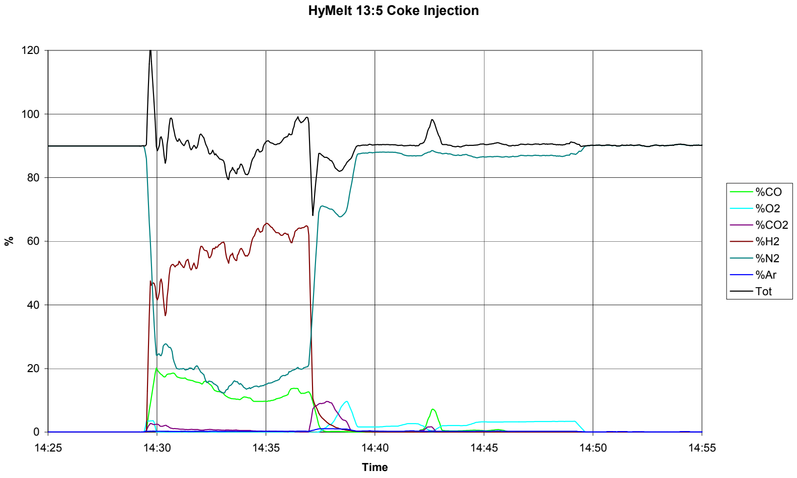


Figure 15 – Process gas HyMelt 13



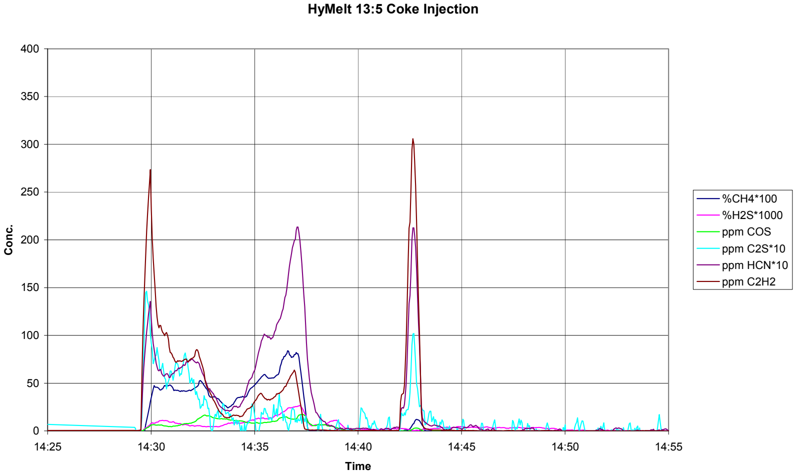
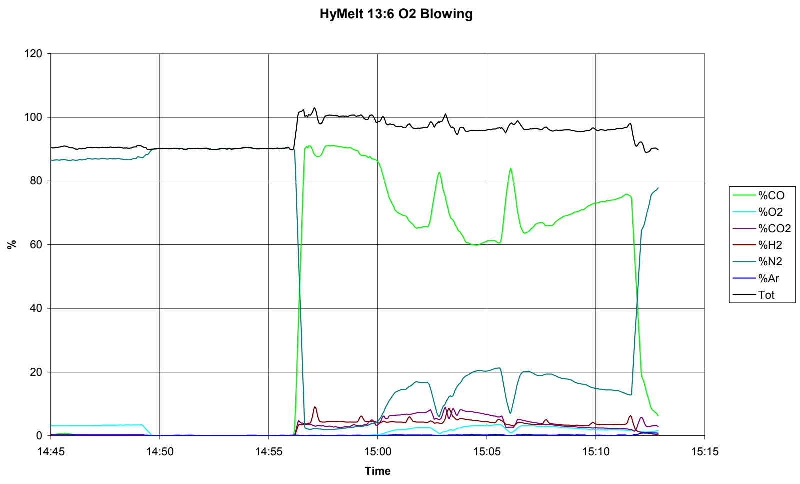
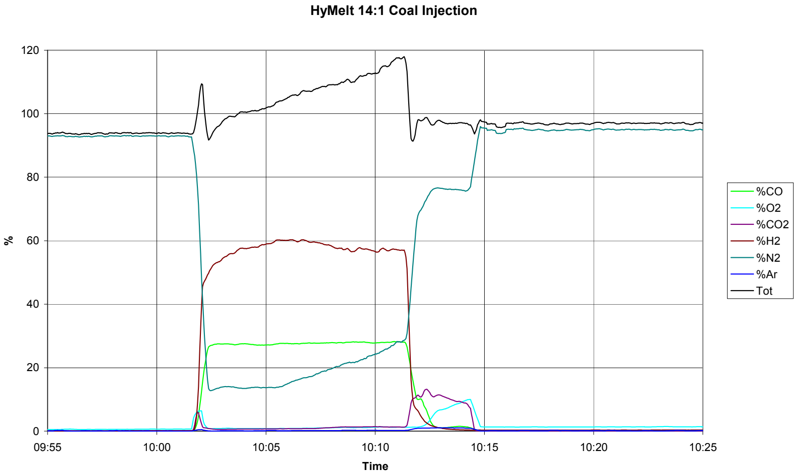
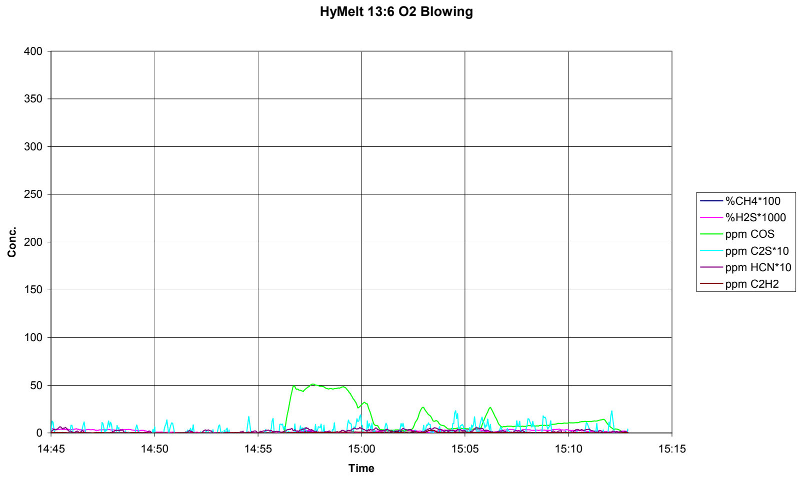


Figure 16 – Process gas HyMelt 13


HyMelt 13:6 O2 Blowing
120
100
80
60
40
20
0
%
14:45
14:50
14:55
15:00
15:05
15:10
15:15
Time
%CO
%O2
%CO2
%H2
%N2
%Ar
Tot


HyMelt 14:1 Coal Injection
120
100
80
60
40
20
0
%
09:55
10:00
10:05
10:10
10:15
10:20
10:25
Time
%CO
%O2
%CO2
%H2
%N2
%Ar
Tot


HyMelt 13:6 O2 Blowing
400
350
300
250
200
150
100
50
0
Conc.
14:45
14:50
14:55
15:00
15:05
15:10
15:15
Time
%CH4*100
%H2S*1000
ppm COS
ppm C2S*10
ppm HCN*10
ppm C2H2

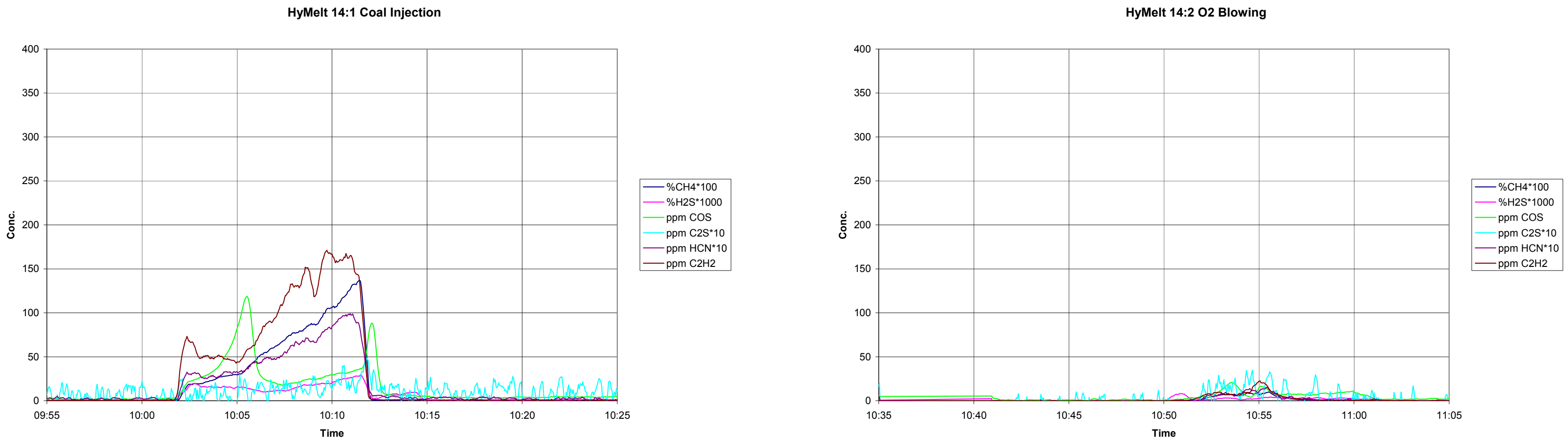


Figure 17 – Process gas HyMelt 14

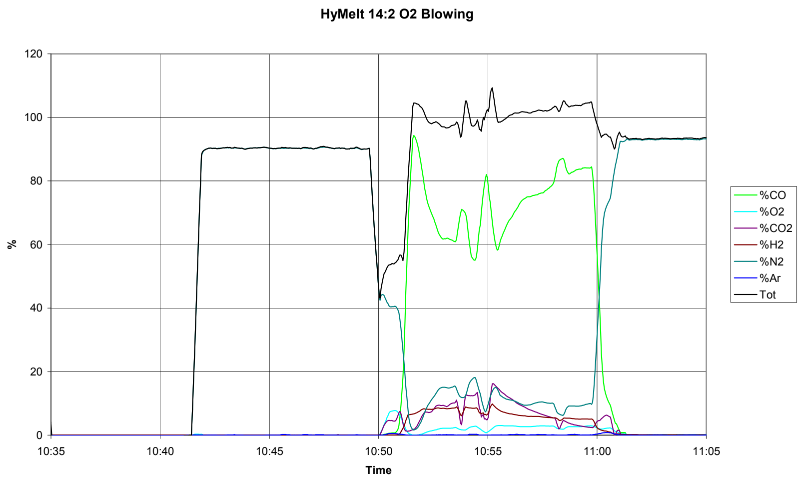
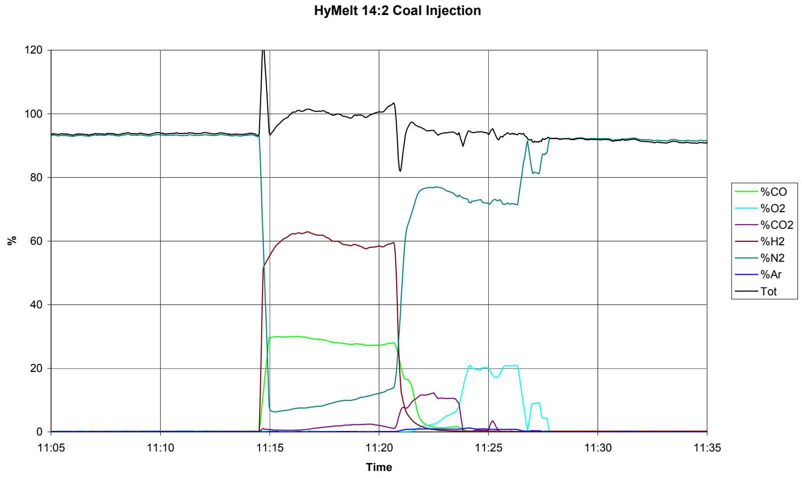
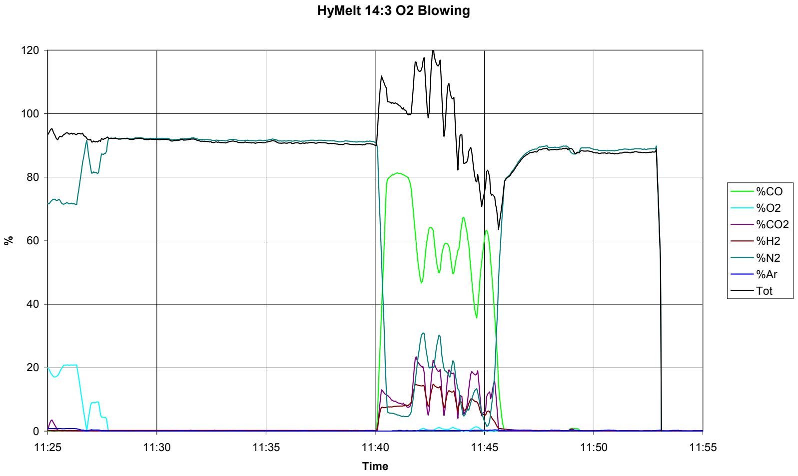
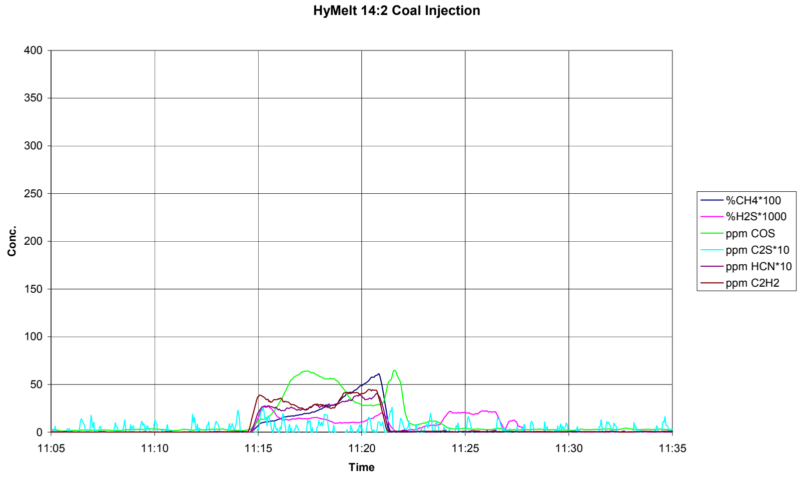
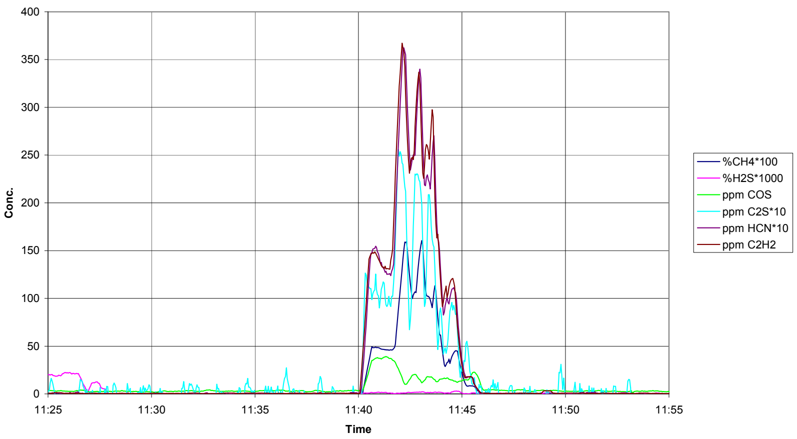


Figure 18 – Process gas HyMelt 14

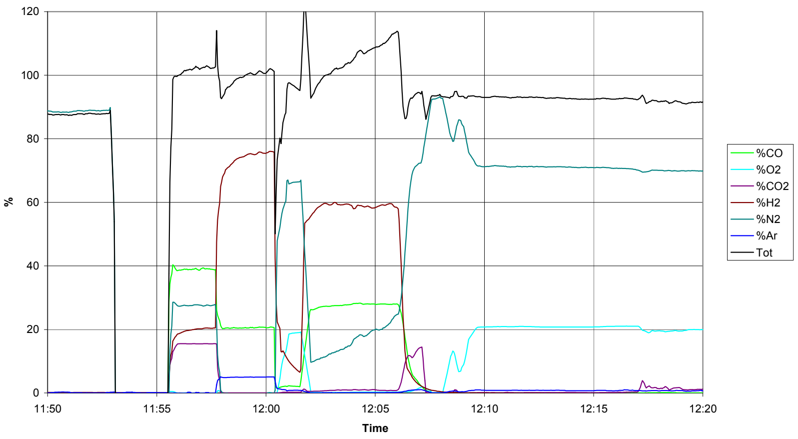




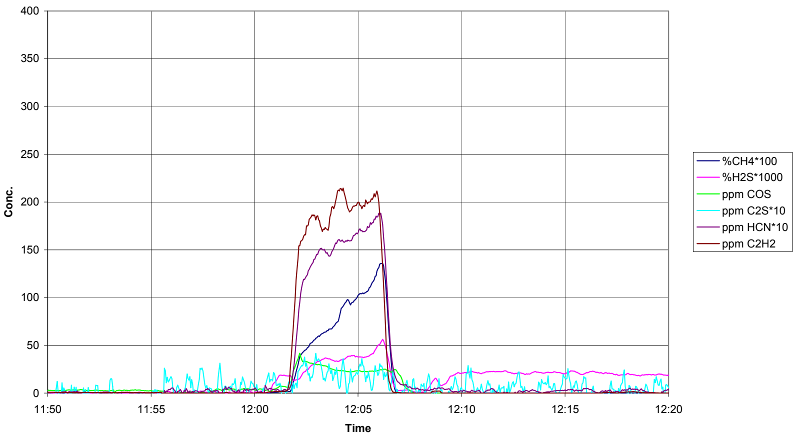




HyMelt 14:3 O2 Blowing

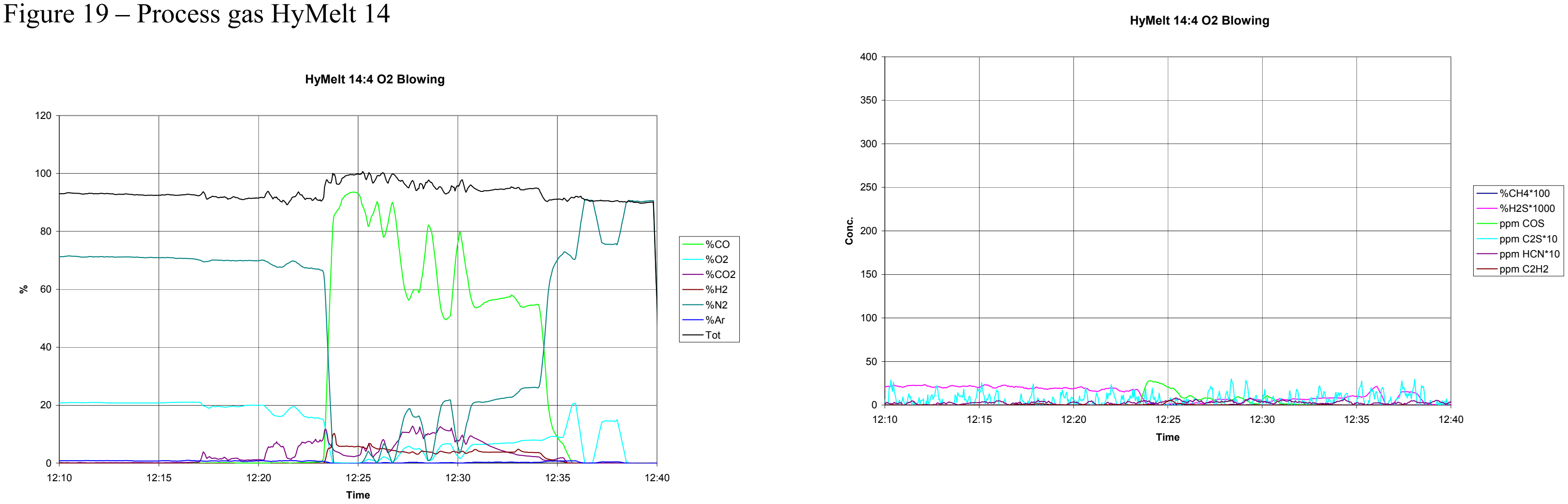


HyMelt 14:3 Coal Injection



HyMelt 14:3 Coal Injection

Figure 19 – Process gas HyMelt 14



5.5 Dust

The dedicated dust sampling probe for larger amounts of material for analysis was clogged and destroyed during period 13:1. The following samples were collected from the gas probe filter, as in previous campaigns.

Sample ID	HyMelt period	Process step	%C	Method	Note
1	11,1	Coke	82,6	Dust probe	
2	11,2	Coke	88,6	Dust probe	
3	12,1	Coke	91,5	Dust probe	
4	13,1	Coal	97,2	Dust probe	Clogging of probe during sampling
5	13,3	O2		Gas probe	Small amount of sample
6	13,3	Coal	97,1	Gas probe	
7	13,4	O2		Gas probe	Small amount of sample
8	13,4	Coal	99,3	Gas probe	
9	13,5	O2		Gas probe	Small amount of sample
10	13,5	Coke	78,1	Gas probe	Small amount of sample
11	13,6	O2	2,3	Gas probe	Small amount of sample
12	14,1	Coal	95,5	Gas probe	
13	14,2	O2		Gas probe	Small amount of sample
14	14,2	Coal	96,9	Gas probe	
15	14,3	O2		Gas probe	Small amount of sample
16	14,4	Coal	98,3	Gas probe	Small amount of sample
17	14,4	O2	2,5	Gas probe	Small amount of sample

Figure 20 – Dust samples

It is significant that the carbon content is higher in the dust than in the feed.

5.6 Carbon balances

The new set up for injection gives significantly better function at higher feeding rates for both coke and coal feeding. This is demonstrated below by calculation of the carbon transferred from powder to metal. The results are compared with the results obtained in previous campaigns.

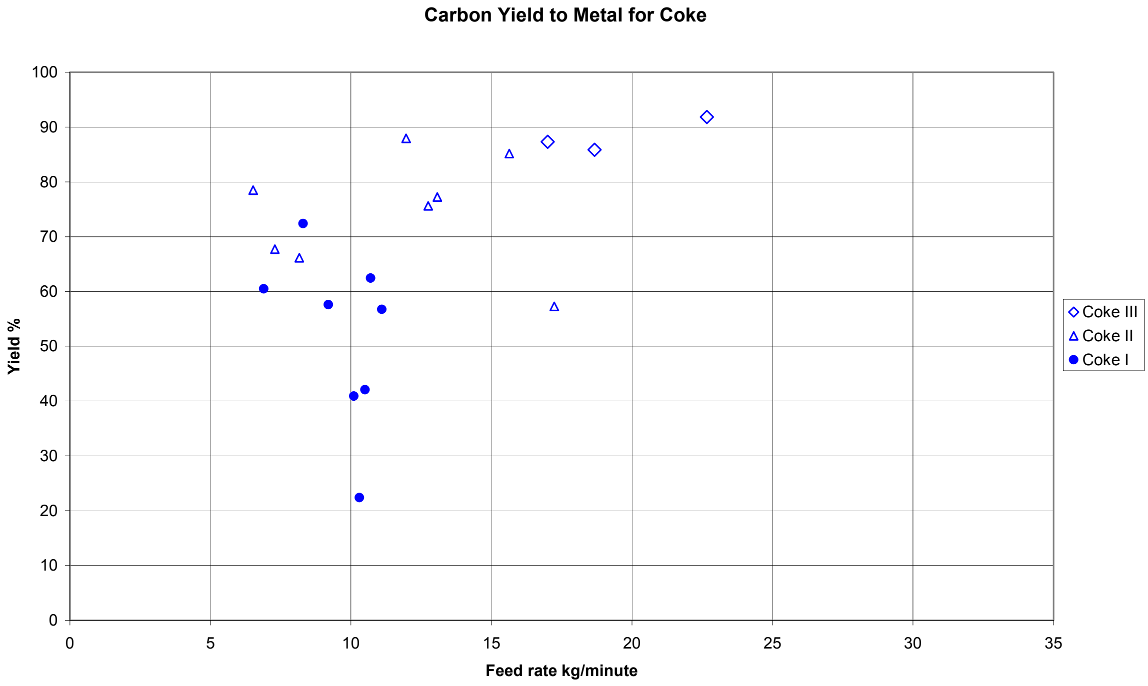


Figure 21 – Carbon yield to metal coke feed Campaign I to III

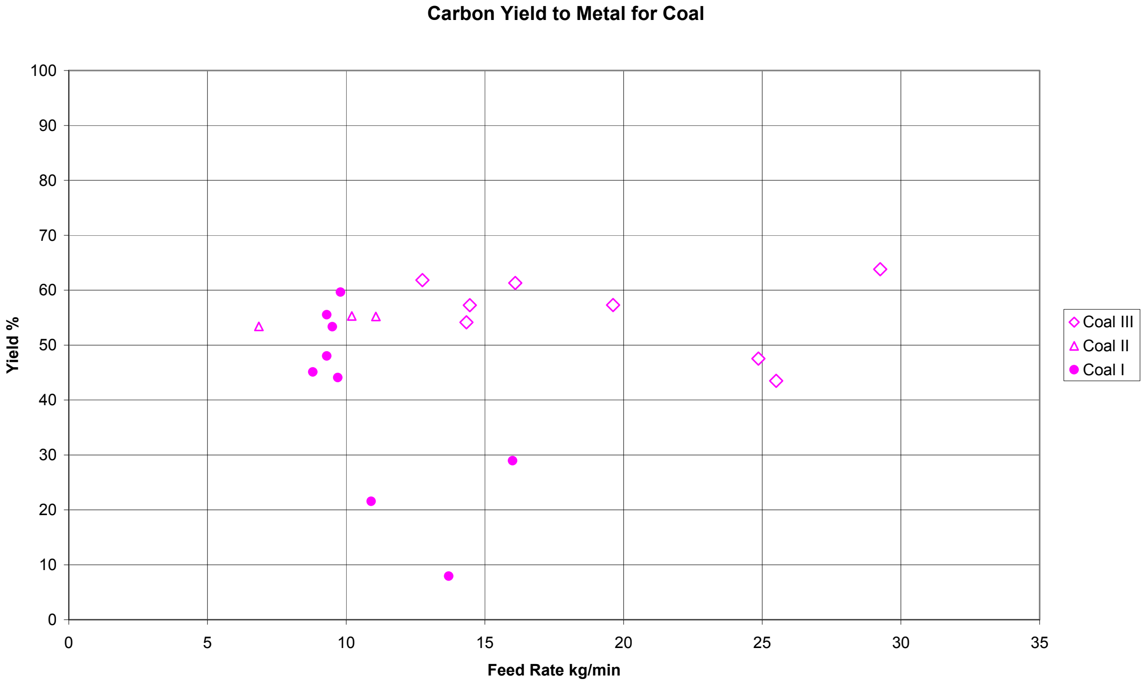


Figure 22 – Carbon yield to metal coal feed Campaign I to III

6 Discussion

6.1 Coal and coke injection

The expected gas composition and carbon yield can be estimated by a simple mass balance for coke and coal injection

To process

Coal	20 kg/min		
C	71,14 w%	14,23 kg/min	1,186 kmol/min
H	4,91 w%	0,98 kg/min	0,982 kmol/min
O	8,26 w%	1,65 kg/min	0,103 kmol/min
N	1,48 w%	0,30 kg/min	0,021 kmol/min
Air	0,5 m3n/min		
O2	21 v%	0,11 m3n/min	0,005 kmol/min
N2	79 v%	0,40 m3n/min	0,018 kmol/min
Nitrogen	0,2 m3n/min		
N2	100 v%	0,20 m3n/min	0,009 kmol/min

To process

C			1,186 kmol/min
H			0,982 kmol/min
O			0,113 kmol/min
N			0,074 kmol/min

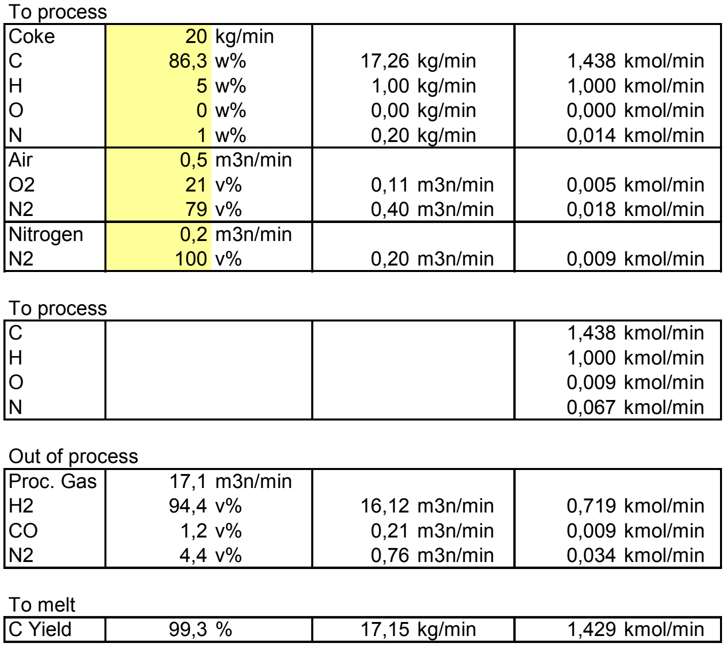
Out of process

Proc. Gas	16,6 m3n/min		
H2	79,8 v%	13,29 m3n/min	0,593 kmol/min
CO	15,2 v%	2,52 m3n/min	0,113 kmol/min
N2	5,0 v%	0,83 m3n/min	0,037 kmol/min

To melt

C Yield	90,5 %	12,88 kg/min	1,073 kmol/min

Figure 23 – Estimation of ideal coal feed mass balance



To process

Coke	20 kg/min		
C	86,3 w%	17,26 kg/min	1,438 kmol/min
H	5 w%	1,00 kg/min	1,000 kmol/min
O	0 w%	0,00 kg/min	0,000 kmol/min
N	1 w%	0,20 kg/min	0,014 kmol/min
Air	0,5 m3n/min		
O2	21 v%	0,11 m3n/min	0,005 kmol/min
N2	79 v%	0,40 m3n/min	0,018 kmol/min
Nitrogen	0,2 m3n/min		
N2	100 v%	0,20 m3n/min	0,009 kmol/min

To process

C			1,438 kmol/min
H			1,000 kmol/min
O			0,009 kmol/min
N			0,067 kmol/min

Out of process

Proc. Gas	17,1 m3n/min		
H2	94,4 v%	16,12 m3n/min	0,719 kmol/min
CO	1,2 v%	0,21 m3n/min	0,009 kmol/min
N2	4,4 v%	0,76 m3n/min	0,034 kmol/min

To melt

C Yield	99,3 %	17,15 kg/min	1,429 kmol/min

Figure 24 – Estimation of ideal coke feed mass balance

In both cases, it is obvious from the process gas analysis that the air flow rate has to be increased considering not only pressurised air but also leakage air. The leakage air can be due to leakage directly into the converter or into the gas sampling system.

In the figures below the total amount of air is set to 5 m^3n/min and the results are somewhat closer to achieved results.

To process

Coal	20 kg/min		
C	71,14 w%	14,23 kg/min	1,186 kmol/min
H	4,91 w%	0,98 kg/min	0,982 kmol/min
O	8,26 w%	1,65 kg/min	0,103 kmol/min
N	1,48 w%	0,30 kg/min	0,021 kmol/min
Air	5 m3n/min		
O2	21 v%	1,05 m3n/min	0,047 kmol/min
N2	79 v%	3,95 m3n/min	0,176 kmol/min
Nitrogen	0,2 m3n/min		
N2	100 v%	0,20 m3n/min	0,009 kmol/min

To process

C			1,186 kmol/min
H			0,982 kmol/min
O			0,197 kmol/min
N			0,391 kmol/min

Out of process

Proc. Gas	22,1 m3n/min		
H2	60,2 v%	13,29 m3n/min	0,593 kmol/min
CO	20,0 v%	4,41 m3n/min	0,197 kmol/min
N2	19,9 v%	4,39 m3n/min	0,196 kmol/min

To dust

C	7,0 %	1,00 kg/min	

To melt

C Yield	61,9 %	8,81 kg/min	

Figure 25 – Estimation of coal feed mass balance compensated for leakage air

To process

Coke	20 kg/min		
C	86,3 w%	17,26 kg/min	1,438 kmol/min
H	5 w%	1,00 kg/min	1,000 kmol/min
O	0 w%	0,00 kg/min	0,000 kmol/min
N	1 w%	0,20 kg/min	0,014 kmol/min
Air	5 m3n/min		
O2	21 v%	1,05 m3n/min	0,047 kmol/min
N2	79 v%	3,95 m3n/min	0,176 kmol/min
Nitrogen	0,2 m3n/min		
N2	100 v%	0,20 m3n/min	0,009 kmol/min

To process

C			1,438 kmol/min
H			1,000 kmol/min
O			0,094 kmol/min
N			0,385 kmol/min

Out of process

Proc. Gas	22,5 m3n/min		
H2	71,5 v%	16,12 m3n/min	0,719 kmol/min
CO	9,3 v%	2,10 m3n/min	0,094 kmol/min
N2	19,1 v%	4,31 m3n/min	0,192 kmol/min

To dust

C	0,0 %	0,00 kg/min	

To melt

C Yield	87,8 %	15,16 kg/min	

Figure 26 – Estimation of coke feed mass balance compensated for leakage air

6.2 Oxygen blowing

Similar calculations can be made for O_2 blowing periods and also in this case better agreement can be achieved if leakage air is considered.

To process

Propane	0,4	m3n/min			0,018	kmol/min
C	3	kmol/kmol			0,054	kmol/min
H	8	kmol/kmol			0,143	kmol/min
Air	0	m3n/min				
O2	21	v%	0,00	m3n/min	0,000	kmol/min
N2	79	v%	0,00	m3n/min	0,000	kmol/min
Oxygen	6,5	m3n/min				
O2	100	%	6,50	m3n/min	0,290	kmol/min

To process

C					0,054	kmol/min
H					0,143	kmol/min
O					0,580	kmol/min
N					0,000	kmol/min

Out of process

Proc. Gas	13,6	m3n/min				
H2	4,4	v%	0,60	m3n/min	0,027	kmol/min
CO2	0,0	v%	0,00	m3n/min	0,000	kmol/min
CO	95,6	v%	13,00	m3n/min	0,580	kmol/min
N2	0,0	v%	0,00	m3n/min	0,000	kmol/min

Figure 27 – Estimation of ideal gas composition at oxygen blowing

To process

Propane	0,4	m3n/min			0,018	kmol/min
C	3	kmol/kmol			0,054	kmol/min
H	8	kmol/kmol			0,143	kmol/min
Air	5	m3n/min				
O2	21	v%	1,05	m3n/min	0,047	kmol/min
N2	79	v%	3,95	m3n/min	0,176	kmol/min
Oxygen	6,5	m3n/min				
O2	100	%	6,50	m3n/min	0,290	kmol/min

To process

C					0,054	kmol/min
H					0,143	kmol/min
O					0,674	kmol/min
N					0,176	kmol/min

Out of process

Proc. Gas	16,6	m3n/min				
H2	3,6	v%	0,60	m3n/min	0,027	kmol/min
CO2	6,3	v%	1,05	m3n/min	0,047	kmol/min
CO	78,2	v%	13,00	m3n/min	0,580	kmol/min
N2	11,9	v%	1,98	m3n/min	0,088	kmol/min

Figure 28 – Estimation of gas composition at oxygen blowing compensated for leakage air

6.3 Slag % Fe_{tot} in relation to metal % C

The bottom blown converter has as expected a stable and lower content of Fe_{tot} in the slag. The divergent values are more likely as a result of poor samples than a realistic description of the slag. If the carbon content in the metal can be kept higher than 1 % the % Fe_{tot} can be expected to be lower than 5 %.

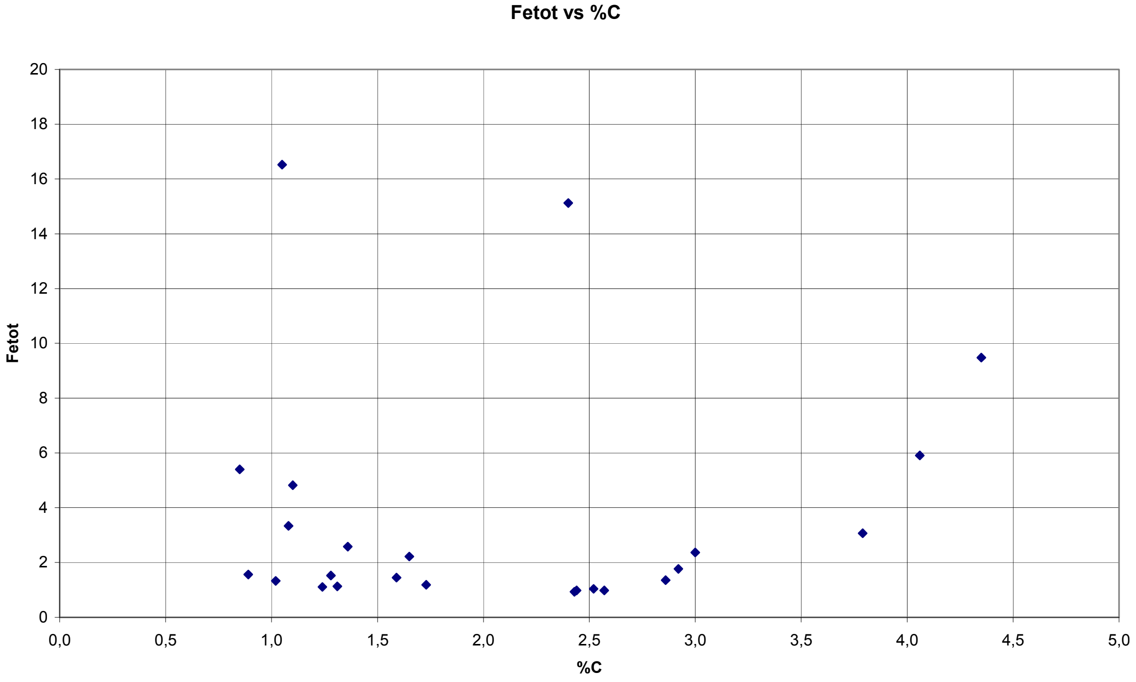


Figure 29 – Fe_{tot} as function of % C

6.4 Process control

Bottom material injection and bottom oxygen blowing simplify the operation and improves process performances. Some of the most obvious observations are:

- No lance sculling and no oxygen lance maintenance
- More stabile operation with less slag foaming and slopping
- Reduced oxygen level in the slag at the end of oxygen blowing improves the gas quality in the beginning of coal/coke injection.
- Improved material conversion gives higher possible gas production

The operation can probably be further improved by a more sophisticated process strategy. The result shows less hydrocarbons in the beginning of the injection period indicating a dependency between transformation capacity and metal temperature or/and carbon level. It is likely that the feeding rate can be optimised for each minute during injection, starting at a higher input successively reduced. Possible input parameter can be CH_4 of the process gas.

Compared to experiences from simultaneous coal/oxygen injection the possible feed rate in HyMelt is surprisingly high. The amount of gas in the process can be of greater importance than what earlier have been understood. It is of great interest to investigate how much a lower carrier gas to material ratio effects the transformation capacity.

Appendix IX

HYMELT – “Pressurised converter”

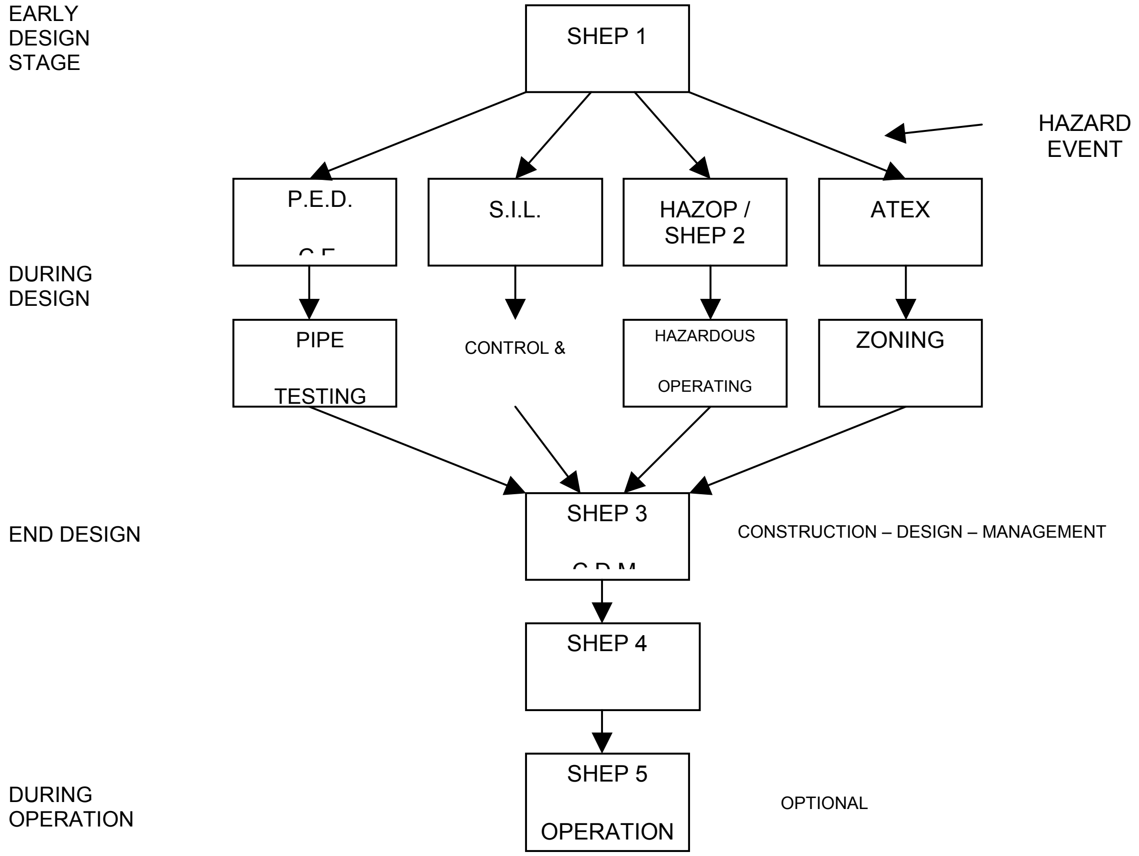
HYMELT – “Pressurised converter”

Hazardous Event / Situation

Time and Place:	26 June 2006 13:00 – 16:00 and 29 June 13.00 – 15:30 MEFOS
Attending:	Nils Edberg, Chairman Christer Larsson Stig-Anders Granbom Anders Strålberg Lars-Åke Ekervhen Thomas Olsson Nils-Olov Lindfors Janne Tikka Per Hellberg, secretary

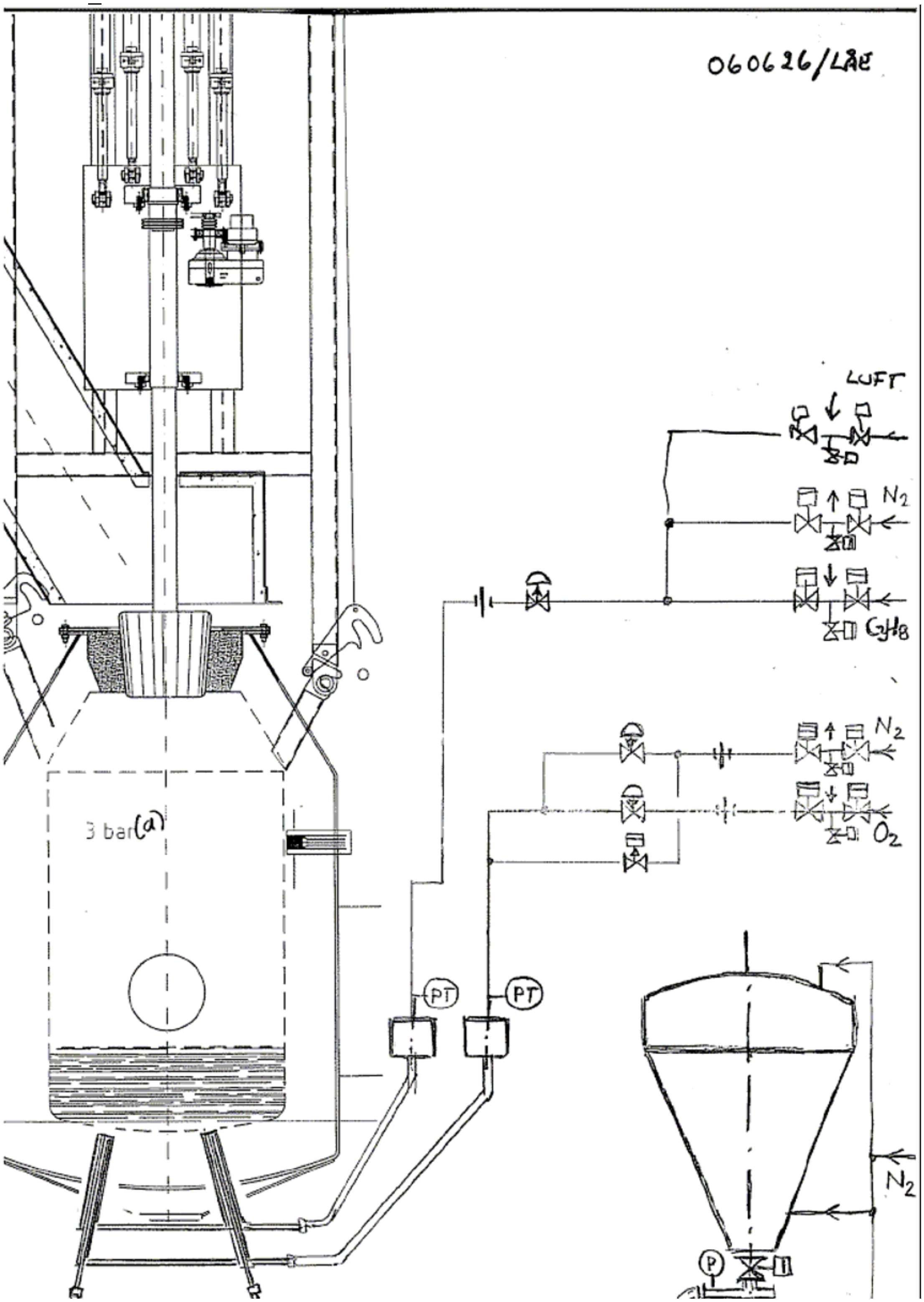
Introduction

A Hazardous event study has been performed within the project “HYMELT”. The study was done according to the following process steps.



Plant description

An overview of the plant is shown below.


060626/LÅE
LUFT
N2
C3H8
N2
O2
3 bar(a)
PT
PT
N2
P

The universal converter is used and the converter is pressurised during a certain process step. The pressure in the furnace is controlled by a “plug”.

The process steps are roughly as follow:

- Preheating with propane, using the nozzles in the bottom of the converter
- The hot metal is melted in the EAF
- The melted metal is put in to the converter. The hot metal has a high carbon content
- Blowing of the hot metal, reduce the carbon content of the metal.
- Carbonisation step with pressurized converter

The following remarks on the plant and process steps have been done during the meeting:

- The gas analyse inside the converter in very important. The gas analyse inside the converter can also be compared with the gas analyse in the off gas system.
- The insulation bricks are made of carbon magnesite.
- The plug is rotating, to ensure that the plug is not getting stuck.
- The vessel and the plug unit is linked together to prevent oscillations during blowing.
- Water cooling has to be installed in the plug lance, off gas hood and flange on top of the vessel.
- The assumed coal rate during carbonisation is about 10 - 12 kg /min. This gives the smallest gap between the plug and vessel, which is about 1 mm.
- The media to the converter is divided into tree cases (se plant overview)
  Inert: Nitrogen, Nitrogen
  Carbonisation: Coal, Air (Nitrogen)
  Blowing: Propane, Oxygen
- The propane pressure is limited to max 4.5 bar.
- No temperature measurement or metal sampling during trails only when the vessel is tilted.
- Pressure measurement is done in two cases, in the mantle and by measuring the pressure on the plug.

Hazardous Event / Situation

The Hazard study 1 is enclosed below. The following remarks have been done on the Hazard study during the meeting:

- Frozen slag in the top part of the converter.
- A cut through of the vessel. The vessel is constructed for a maximum temperature of 400 C, the normal temperature is assumed to be about 300 C.
- The vessel is painted with paint that changes colour depending of the surface temperature.
- If the pressure quickly rises in the vessel the plug is removed and nitrogen is injected in the converter, this should be done using automatic process.
- If the plug can not be removed from the vessel, an additional gas evacuation from the vessel must be constructed. Only use the nozzles to evacuate the pressure in the vessel is not enough.
- To increase the temperature in the top of the converter an air nozzle can be installed and used it when the vessel is not pressurised.
- Problems during filling and tapping are discussed, no decision are made.
- The support for the plug lance has to be heat protected.
- Due to the support for the plug lance the converter can not be tilted in both directions.
- Preheating of the converter is done by using the nozzles in the bottom.
- The major insurance financial is to low.
- We have two coal powder vessels is designed from 12 bar and 7 bar.
- When exchange sealing in the converter a working platform has to be designed and when exchanging the plug or reparation work at the off gas hood the whole support has to be removed and placed on the floor. A separate support for the hood has to be constructed.
- A new design of fixing the converter and plug lance support were discussed.
- A safety switch was discussed when working high up near the carne.
- When the power is cut-off nitrogen is injected with a pressure of 10 bar, a reduction of the pressure has to be installed.
- If electivity fails (dip) the plug automatic go up, this has to be done by using mechanics.

HAZARD STUDY 1

	Author: Per Hellberg	Title:	Meeting Date: 2006-06-26	
	Drawing Title:	Drawing No.	Revision	Meeting No:

Team Members (name and role)			
Christer Larsson	Lars-Åke Ekervhen	Janne Tikka	
Nils Edberg	Thomas Olsson		
Stig-Anders Granbom	Nils-Olov Lindfors		
Anders Strålberg	Per Hellberg		

Hazardous Event or Situation	Caused by	Consequences Immediate / Ultimate	Prevented or Corrected by	Emergency Measures / Mitigation	Action Required	Action By	Action No
External Fire	Hydraulic Oil	Loss of equipment Risk for life	Equipment construction	Fire Hose	Investigation		1
External Fire	Propane leakage	Loss of equipment Risk for life	Propane detection system in the slag pit	Fire Hose			2

External Fire	Coal powder leakage	Loss of equipment Risk for life	Protection shield (Splitter)	Fire Hose	Investigate remote control of the injection system		3
External Fire	Handling liquid metal	Loss of equipment Risk for life		Fire Hose			4
External Fire	Hot combustible gases	Loss of equipment Risk for life		Fire Hose			5
External Fire	Unexpected gas release of combustible gases	Loss of equipment Risk for life		Fire Hose			6

SAFETY HEALTH AND ENVIRONMENTAL PROTECTION REVIEWS

	HAZARD STUDY 1			
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	Drawing Title:	Drawing No.	Revision	Meeting No:

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Nils Edberg	Thomas Olsson		
Stig-Anders Granbom	Nils-Olov Lindfors		
Anders Strålberg	Per Hellberg		

Hazardous Event or Situation	Caused by	Consequences Immediate / Ultimate	Prevented or Corrected by	Emergency Measures / Mitigation	Action Required	Action By	Action No
Internal Fire/explosion	Unexpected gas release of combustible gases into the off gas system	Loss of equipment Risk for life		Fire Hose	Investigation		7
Internal Explosion	Water cooling leakages in the “Plug lance”	Loss of equipment Risk for life	– Measurement of cooling water flow (in/out) – Measurement of cooling water Temperature				8

Internal Explosion	Water cooling leakages in the flange on the top of the converter	Loss of equipment Risk for life	– Measurement of cooling water flow (in/out) – Measurement of cooling water Temperature				9
Internal Explosion	Water cooling leakages in the off gas hood	Loss of equipment Risk for life	– Measurement of cooling water flow (in/out) – Measurement of cooling water Temperature				10
Internal Explosion	Unable to remove the plug in the converter	Loss of equipment Risk for life			Investigation		11

SAFETY HEALTH AND ENVIRONMENTAL PROTECTION REVIEWS

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Anders Strålberg	Per Hellberg		

Hazardous Event or Situation	Caused by	Consequences Immediate / Ultimate	Prevented or Corrected by	Emergency Measures / Mitigation	Action Required	Action By	Action No
Internal Explosion	High pressure in the converter due to frozen slag in converter top	Loss of equipment Risk for life	– Plug removal (fast) – Nozzles in the converter bottom		– Splitter protection – Pressure measurements in the converter		12
Confined Explosion	Coal powder or propane	Loss of equipment Risk for life	– Propane detection system in the slag pit		Investigation		13
Unconfined Explosion							
Acute harmful/ Noxious exposure	CO gas leakage	Risk for life	– CO detection system in the building – Personal CO detectors				14
Chronic harmful/ Noxious exposure	Coal powder	Toxic					15

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Anders Strålberg	Per Hellberg		

Hazardous Event or Situation	Caused by	Consequences Immediate / Ultimate	Prevented or Corrected by	Emergency Measures / Mitigation	Action Required	Action By	Action No
Chronic harmful/ Noxious exposure	CO in the off gas system cleaning water	Toxic			Investigation		16
Environmental pollution							
Violent release of	Leakage in the hydraulic oil system				Investigation		17

energy							
Noise	Hot gases from the pressure control system	– Working environment – Personal damage	Personal safety equipment		– No working near the furnace during pressurised converter – Camera		18
Visual impact							

SAFETY HEALTH AND ENVIRONMENTAL PROTECTION REVIEWS

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Stig-Anders Granbom	Nils-Olov Lindfors		
Anders Strålberg	Per Hellberg		

Hazardous Event or Situation	Caused by	Consequences Immediate / Ultimate	Prevented or Corrected by	Emergency Measures / Mitigation	Action Required	Action By	Action No
Major Financial effects							
Moving objects	Tilting of the converter	Injuries			Investigation		19
Moving objects	Fixation of the support of the plug lance	Injuries			Investigation		20
Moving objects	Plug lance, up-down , twist	Injuries			Investigation		21
Moving objects	Transport of material in and out of the converter, Tractor, Truck, Crane	Injuries			Investigation		22
Moving objects	Transport of material in and out of the converter, Tractor, Truck, Crane	Injuries			Investigation		23
Trapping Hazards							
Ergonomics	Change of nozzles in the bottom converter	Injuries			Construction of a working platform		24

SAFETY HEALTH AND ENVIRONMENTAL PROTECTION REVIEWS

	HAZARD STUDY 1		
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Anders Strålberg	Per Hellberg		

Hazardous Event or Situation	**Caused by**	**Consequences Immediate / Ultimate**	**Prevented or Corrected by**	**Emergency Measures / Mitigation**	**Action Required**	**Action By**	**Action No**
Cutting hazards							
Hot surfaces	The Converter mantle	Injuries			Investigation		25
Hot surfaces	Change of plug and flange on top of converter	Injuries			Heat protection, radiation shield		26
Electrical hazards	Static electricity, Coal powder, propane	Risk of lift			Investigation		27
Loss of operator interface	Plug always removed	Loss of equipment Risk for life			Investigation		28
Loss of operator interface	The converter is inert using nitrogen	Loss of equipment Risk for life			Investigation, Rebuild the nitrogen supply system		29
Loss of critical functions	Pressure measurements in the converter	Loss of equipment			Investigation		30

		Risk for life					
Loss of critical functions	Low pressure in the media system, nitrogen is injected	Loss of equipment			Investigation		31

SAFETY HEALTH AND ENVIRONMENTAL PROTECTION REVIEWS

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Anders Strålberg	Per Hellberg		

Hazardous Event or Situation	**Caused by**	**Consequences Immediate / Ultimate**	**Prevented or Corrected by**	**Emergency Measures / Mitigation**	**Action Required**	**Action By**	**Action No**

Loss of critical functions	Loss of pressure measurement in the off gas system	Loss of equipment			Investigation		32
Loss of non critical functions	Data logging	Loss of test data			Investigation		33
Loss of non critical functions	Researcher interface	Loss of test data			Investigation		34