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ARC/EPRI Consortium

Coal Processing Development Program

Development of Clean Coal and Clean Soil Technologies Using Advanced Agglomeration Technologies

Volume 2 – Upgrading of Bituminous Coals: The Aglofloat Process

DE-FG22-87PC79865

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April 1990

Notice

Foreword

These reports form the final output of the Phase I Coal Processing Development Consortium that jointly pursued the funding and development of advanced coal/oil agglomeration technologies from June 1987 to December 1989. For many of the participants, it was a challenging new experience and one that led to some important lessons and technical opportunities. Technology resulting from the treatment of tarry wastes is being seriously pursued as a commercial venture in Canada and the USA. The pyrite rejection technology is being scaled up in the USA, and the low rank coal/heavy oil technologies are being investigated in Canada. The financial and technical support of the consortium members in Phase I is acknowledged and recognized. Without their support, the program would not have been as successful as it was.

Phase II of the Coal Processing Development Program will be continued until December 1990 to provide more in-depth engineering data and scale up support for the key program elements. Results of Phase II and the overall conclusions will be reported in 1991. The continuing support of the Phase II participants is also acknowledged, and they are thanked for their on-going interest and contributions.

The Alberta Research Council thanks the Electric Power Research Institute, their program staff and representatives on the management and technical committees, for their support and guidance in our mutual work. Our special thanks go to Howard Lebowitz, Linda Atherton, Conrad Kulik, Bill Rovesti, Bill Weber and Norm Stewart.

Finally, we wish to thank the technical and support teams of the Alberta Research Council who have made the projects as successful as they are and who have worked under ever increasing demanding scopes of work as the program developed and improved.

Dr. Arvid H. Hardin, Department Head
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July 1990

Abstract

This report documents work completed by the Alberta Research Council for the ARC/EPRI Consortium, under the program entitled "Coal Processing Development Program: Development of Clean Coal and Clean Soil Technologies Using Advanced Agglomeration Techniques". The report is divided into three volumes:

Volume 1. Upgrading of Low Rank Coals: The Agflotherm Process

Test data, procedures, equipment, etc., are described for co-upgrading of subbituminous coals and heavy oil. The test results showed upgraded coals to have heating value above 11,000 BTU/lb, and syncrude (upgraded heavy oil) to have 21# API gravity or better. The coal products were acceptable for combustion and had handling properties superior to those of subbituminous coals. The syncrude was suitable for pipelining and refining. The techno-economic feasibility study of the Agflotherm process suggests that upgraded coal could be produced at $Cdn 37.90 per metric tonne at 15 percent DCF ROR (fob plant, after tax).

Volume 2. Upgrading of Bituminous Coals: The Aglofloat Process

Experimental procedures and data, bench and pilot scale equipments, etc., for beneficiating bituminous coals are described. The test results showed the beneficiated coal to have heating value of 13,000 BTU/lb or better, ash content of less than 10 percent and pyritic sulphur removal of up to 90 percent. The completed techno-economic feasibility study of the Aglofloat process suggests that beneficiated coal could be produced at $U.S. 52.85 per short ton, at ROM coal prices of $U.S. 27/t. For coal wash plant wastes, the product price would be $U.S. 25.26 per ton.

Volume 3. Soil Clean-up and Hydrocarbon Waste Treatment Process

Batch and pilot plant tests are described for soil contaminated by tar refuse from manufactured gas plant sites. The test results show the treated soil to be suitable for disposal in landfills and the by-product agglomerates containing tar and hydrocarbon contaminants to be suitable for combustion in industrial boilers. The techno-economic feasibility study of a mobile plant for the Clean Soil process shows the cost of cleaning to range from $Cdn 31.39 to $Cdn 46.97 per tonne of oily wastes, and to be about $Cdn 45 per tonne of tar refuse contaminated soil.

Acknowledgements

The multidisciplinary nature of the program undertaken required a group of experts from several fields of coal development technology. As a result, the achievements described in this report are, in part, due to the contributions of several subcontracted companies and individuals. Specifically, we would like to acknowledge the contributions of Sam Wong of ARC Technical and Economic Evaluation Group, for the economic analysis and costing of the conceptual Aglofloat plant; Lobbe Technologies Ltd., Regina, Saskatchewan, for the development of the Aglofloat plant design and for the preparation of this Final Report; and the Alberta Research Council Corporate Communications department for the production of this Final Report.

Executive Summary

I. Introduction

In 1987, the Alberta Research Council and EPRI formed a research consortium to develop new clean coal and clean soil technologies based on ARC's advanced spherical agglomeration research. The Consortium included 19 companies, government agencies and non-profit research organizations (see Appendix 1). The Consortium identified three technology development areas as being of immediate interest to its members:

1. Co-upgrading of low-rank coals and heavy oils.
2. Beneficiation of high sulphur bituminous coals.
3. Cleaning of tar refuse and hydrocarbon contaminated soils.

The Consortium authorized ARC to undertake research and development programs addressing technology needs in each of the identified areas. The programs were to include laboratory research and testing, fundamental engineering studies, development and operation of integrated agglomeration pilot plant facilities, and conceptual design and economic studies for the processes developed. The following is a summary of the projects undertaken and work completed to December 1989. It should be emphasized that since December, 1989, major progress has been made in further development of the three technologies and particularly in contaminated soil clean-up.

II. Co-Upgrading of Low Rank coals and Heavy oils

The objective of the project was to apply advanced agglomeration technology for co-upgrading of low-rank coals and heavy oil, namely:

- to increase the heating value of low-rank coals above 25.5 GJ/t (11,000 Btu/lb) by dewatering and deashing (upgrading) low-rank coals to capacity moisture and ash content of less than 10 percent each; and
- to upgrade heavy oil and/or bitumen used in agglomeration of coal to synthetic crude which would be suitable for pipelining and acceptable to refineries.

The outcome of the study was the development of the Agflotherm process (agglomeration, floatation and thermal treatment) which upgrades low-rank coal to high heating value solid fuel and heavy oil or bitumen to synthetic crude oil. Specific process research achievements related to the Agflotherm process are summarized below.

Batch Test Studies

Batch test procedures were developed for characterization of various coal and oil feedstock combinations for treatment in the Agflotherm process. The tests defined agglomeration and de-oiling parameters important in process optimization and operation. Selected results and products obtained in the process are shown in Table I. The product agglomerates from subbituminous coals had properties similar to those of western Canadian bituminous coals, and product upgraded oils were similar to synthetic crudes produced from bitumen in other heavy oil thermal upgrading processes.

Table I. Upgrading of low rank coal in Agflotherm process: Heatburg Coal, Batch Tests.

	Moisture, %	Ash, %	Volatile matter, %	Fixed carbon, %	Heating value Btu/lb
Feed Coal	16.3	24.6	30.3	28.8	7,840
Green Agglomerates	8.2	9.7	46.0	36.1	11,370
De-oiled Agglomerates (de-oiling temperature)					
350°C	4.1	10.8	35.8	49.3	11,580
390°C	3.5	12.5	31.5	52.5	11,530
420°C	3.5	13.9	24.6	58.0	11,320

Oil Recovery Studies

The bench scale tests showed that it is technically feasible to recover upgraded oil from coal agglomerates, and that oil yield and properties are attractive enough to consider potential commercialization of the process. The upgraded oil had API gravity above 21, and significantly reduced sulphur and nitrogen content. Different cuts from the upgraded oil blends were found to have acceptable properties for refining, namely:

- Naphtha cut (C_5/175°C) was rich in aromatics and had a higher octane number than petroleum-derived naphtha cuts. It would have to be hydrotreated before reforming (like all naphtha cuts from heavy oil syncrudes) and after treatment the blend could be used as a reformer feedstock for gasoline production.

- Jet fuel cut (145/260°C) had a low smoke point and would also require some hydrotreatment.
- Diesel fuel blend (177/343°C)would require hydrotreatment to reduce the contents of aromatics, sulphur and nitrogen.
- Vacuum gas oil cut (+343°C) had low content of Ni and V, but high sulphur and nitrogen.

Integrated Agglomeration Test Facility (IATF)

Engineering and operational data were obtained for the Agflotherm process using the IATF specially reconfigured for the process (flowsheet #ARC09). The plant produced well-formed, large agglomerates; however, in processing some feeds, difficulties were experienced with obtaining satisfactory performance of the pilot plant. These difficulties were primarily due to insufficient experience and process information in areas such as:

- Kinetics of agglomeration for coals characterized by long inversion times.
- Optimization of the floatation conditions for microagglomerates obtained from low-rank coals which contained a high clay concentration.
- Measurement of slurry flow, slurry solid concentration, density, etc.
- Process control system.

The pilot plant products were de-oiled and sent for laboratory combustion tests. The products were found to have good handling, storage and combustion characteristics including less susceptibility to spontaneous combustion than the "parent" coals.

Feasibility of the Agflotherm Process

A conceptual design for the Agflotherm process was developed to upgrade 2.8 million metric tonnes of ROM subbituminous coal and 448 thousand tonnes of heavy oil in Alberta, Canada. The plant production was estimated at 2.06 million tonnes per year of de-oiled agglomerates with a heating value of 26.7 GJ/t (11,300 Btu/lb) and 370 thousand tonnes of syncrude with API gravity of 21. The plant cost was estimated at $Cdn 113.6 million, operating cost at $Cdn 91 million per year and working capital at $Cdn 17.2 million. Based on 1989 feedstock and product prices ($Cdn 12/t of coal, $Cdn 93.4/t bitumen, $Cdn 33/t product agglomerates and $Cdn 124.2/t syncrude), the economic analyses of the plant showed DCF ROR after tax equal to 11.1 percent.

The key cost factors in the Agflotherm were the cost of heavy oil and coal, the yield and price of co-product oil, and the price of de-oiled agglomerates. The projected DCF ROR of 11.1 percent was contingent on the technical feasibility of a novel de-oiling process based on high temperature extrusion of coal-oil paste (described in Volume 1).

III. Beneficiation of High Sulphur Bituminous Coals

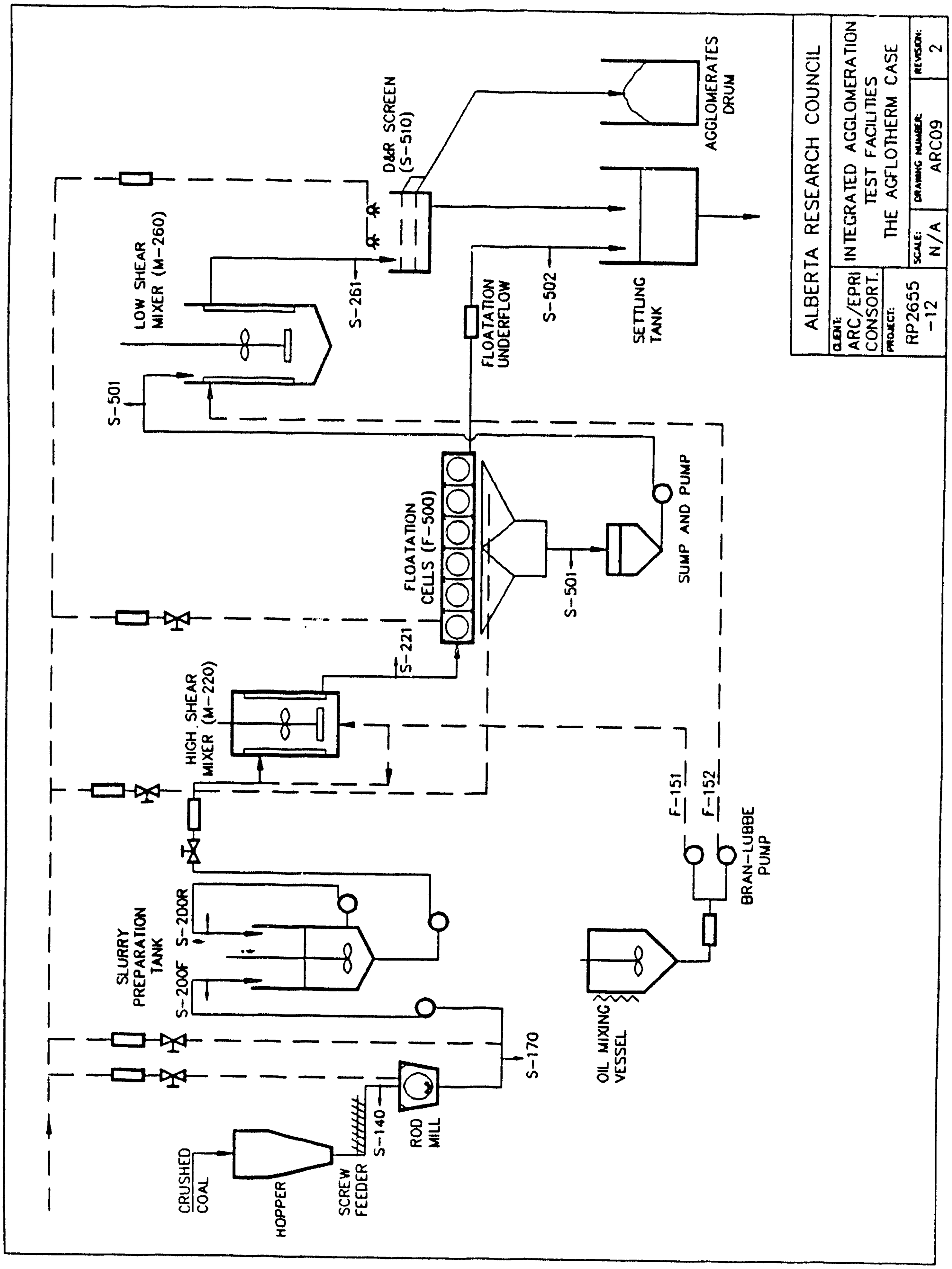
The objective of the bituminous coal project was the development of technology which would:

- Remove pyritic sulphur from high sulphur bituminous coals.
- Reduce mineral matter content in bituminous coals to 10 percent or less.
- Increase heating value of the processed coals above 13,000 Btu/lb.

The result of the process research was the development of a process, the Aglofloat process (agglomeration and floatation), capable of meeting all of the above listed project objectives. Specific process issues related to the performance and economics of the Aglofloat are discussed below.

Batch Test Studies

Laboratory tests were carried out to evaluate key factors influencing the Aglofloat process performance. Nine coals (ROM and coal preparation by-products) from the eastern U.S. and western Canada were studied. Typical results obtained with U.S. coals are shown in Figure I. The results were obtained using single-stage and two-stage (with regrinding and reprocessing of the product) batch processing. The tests show good combustibles recovery and pyrite rejection at bridging oil concentrations as low as 0.5 percent. For western Canadian coals, however, the Aglofloat procedures had to be modified and the amount of bridging oil had to be increased to 3 percent or more.



ALBERTA RESEARCH COUNCIL
CLIENT:
ARC/EPRI CONSORT.
INTEGRATED AGGLOMERATION TEST FACILITIES
THE AGFLOTHERM CASE
PROJECT:
RP2655 -12
SCALE:
N/A
DRAWING NUMBER:
ARC09
REVISION:
2
CRUSHED COAL
HOPPER
SCREW FEEDER
S-140
ROD MILL
S-170
SLURRY PREPARATION TANK
S-200F
S-200R
HIGH SHEAR MIXER (M-220)
S-221
FLOATATION CELLS (F-500)
S-501
SUMP AND PUMP
FLOATATION UNDERFLOW
S-502
SETTLING TANK
LOW SHEAR MIXER (M-260)
S-261
D&R SCREEN (S-510)
AGGLOMERATES DRUM
OIL MIXING VESSEL
BRAN-LUBBE PUMP
F-151
F-152

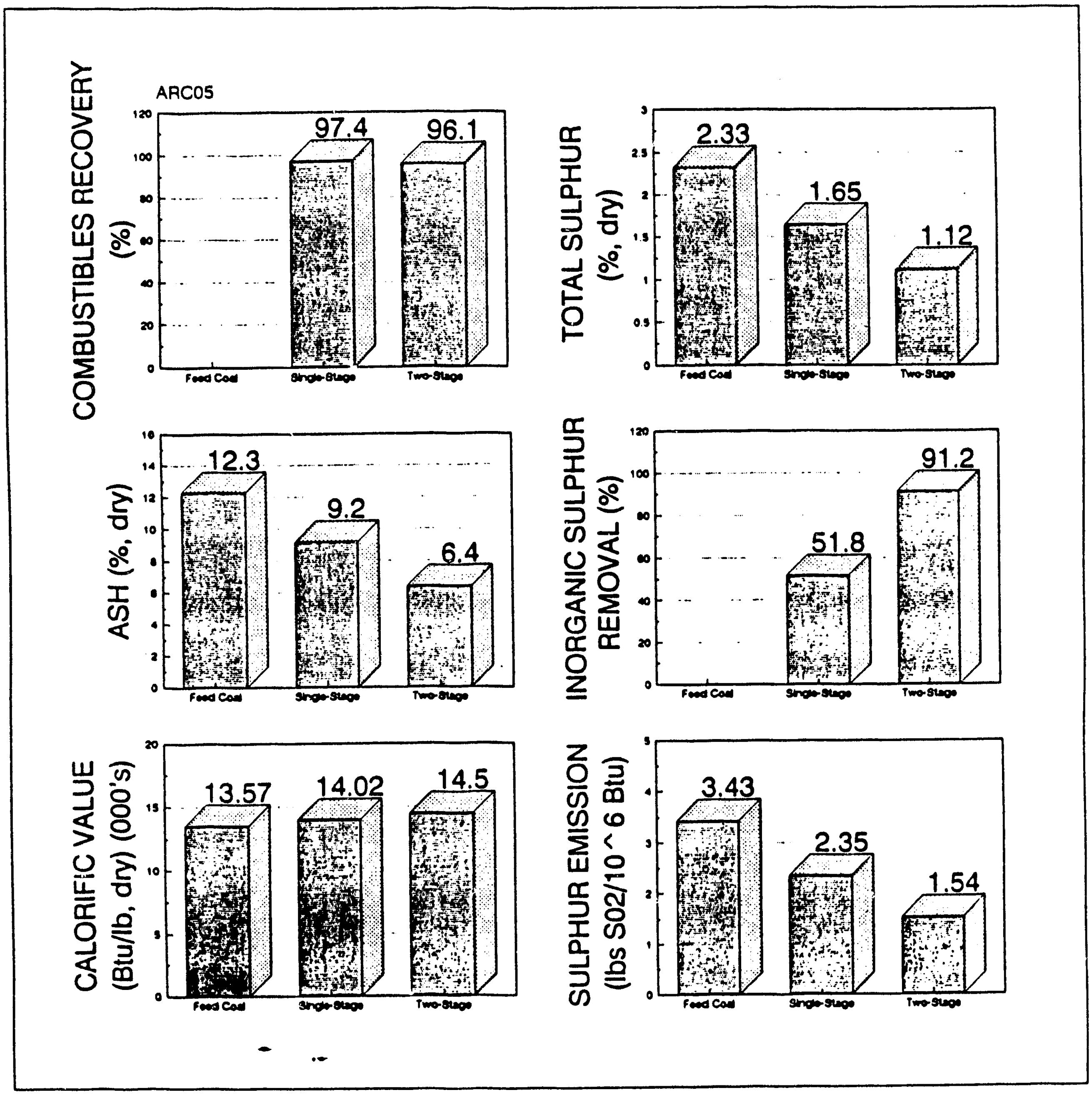
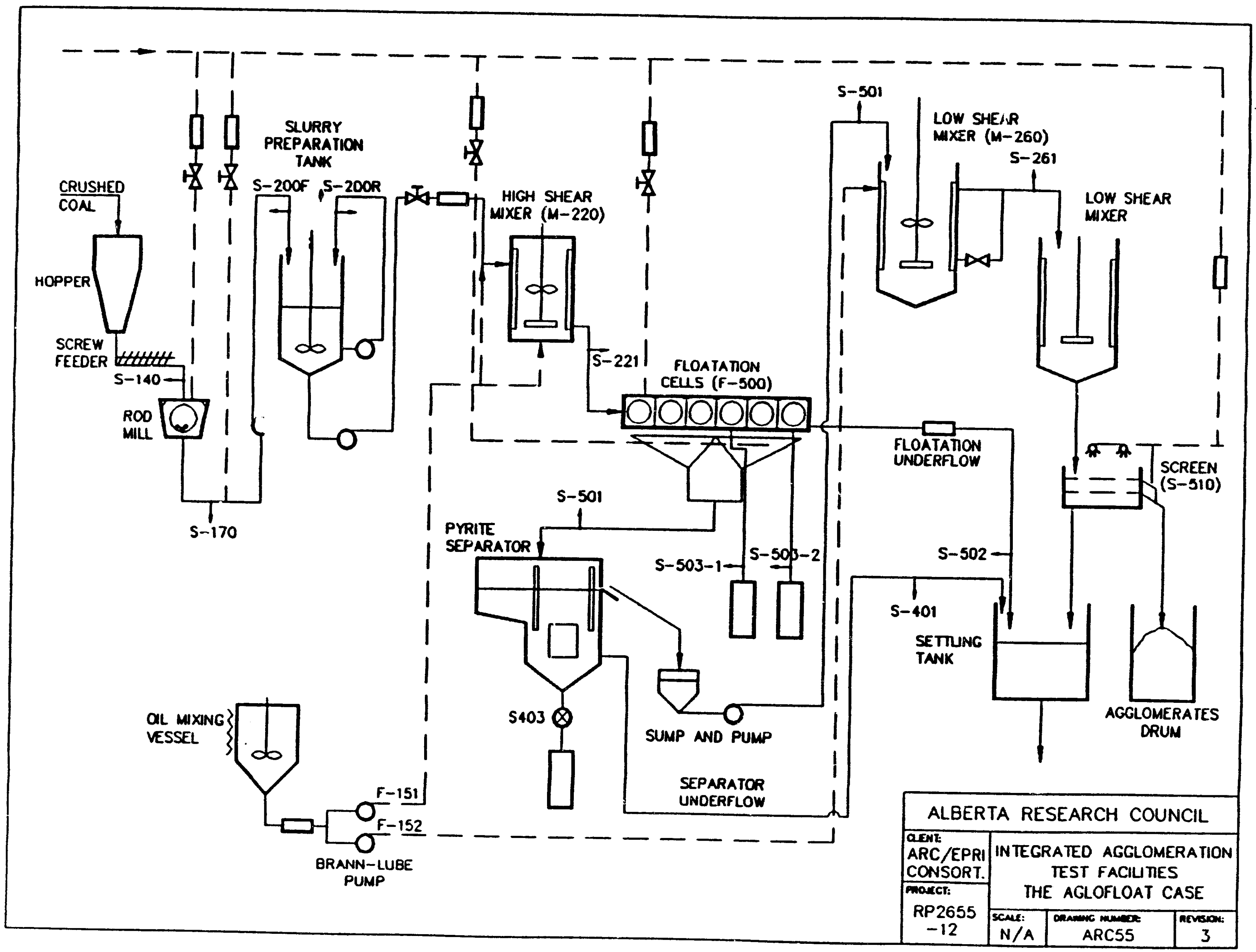


Figure I. Cleaning of upper Freeport Coal by Aglofloat process.

Continuous Pyrite Removal Unit (CPRU)

The feasibility of using hydraulic and flume separators for removal of pyrite from bituminous coals agglomerates was evaluated using a 5 kg/h bench scale CPRU. Both units showed reduction of pyrite in coal product; however, because of better operability, a system with a hydraulic separator only was chosen for the Aglofloat process. Tests using the CPRU with U.S. coals indicated that at the best conditions tested, the total sulphur reduction ranged from 50 to 55 percent, and the pyritic sulphur reduction ranged from 72 to 77 percent, while the ash reduction ranged from 82 to 86 percent. The information obtained in the CPRU was successfully used in the scale-up of the hydraulic pyrite separator in the pilot plant (IATF).



CRUSHED COAL
HOPPER
SCREW FEEDER
S-140
ROD MILL
S-170
SLURRY PREPARATION TANK
S-200F
S-200R
HIGH SHEAR MIXER (M-220)
S-221
FLOATATION CELLS (F-500)
S-501
PYRITE SEPARATOR
S403
S-503-1
S-503-2
SUMP AND PUMP
SEPARATOR UNDERFLOW
OIL MIXING VESSEL
F-151
F-152
BRANN-LUBE PUMP
LOW SHEAR MIXER (M-260)
S-261
LOW SHEAR MIXER
FLOATATION UNDERFLOW
SCREEN (S-510)
S-502
S-401
SETTLING TANK
AGGLOMERATES DRUM
ALBERTA RESEARCH COUNCIL
CLIENT: ARC/EPRI CONSORT.
INTEGRATED AGGLOMERATION TEST FACILITIES THE AGLOFLOAT CASE
PROJECT: RP2655 -12
SCALE: N/A
DRAWING NUMBER: ARC55
REVISION: 3

Large Pilot Plant Tests (IATF)

The hydraulic pyrite separator developed was incorporated into the Integrated Agglomeration Test Facility pilot plant in the Aglofloat process configuration (flowsheet #ARC55). The IATF results confirmed that well-formed agglomerates reduced in sulphur and mineral matter can be obtained in the process. Large, 0.8 to 3.0 mm agglomerates could be obtained at bridging oil concentrations as low as 12 percent (d.a.f. feed coal). The agglomerates had a heating value above 13,000 Btu/lb, ash content of less than 10 percent and pyritic sulphur content reduced up to 90 percent.

Considerable effort went into improving the process. Equipment efficiency and performance was evaluated for unit operations such as floatation of coal flocs, hydraulic pyrite separation and size enlargement of microagglomerates. One of the key issues studied was the effect of process operating parameters on process stability and performance. The key Aglofloat process parameters were identified; however, more experimentation will be necessary to understand the process and to further reduce the amount of bridging oil required.

Feasibility of the Aglofloat Process

The pilot plant work for the Aglofloat process was used as a basis for the conceptual design of an aglofloat plant capable of processing 2.8 million short tons of eastern U.S. bituminous coal to 2.74 million tons of agglomerates. The economic analysis of the process estimated the plant capital cost at $U.S. 61.5 million, operating cost at $U.S. 121.0 million per year and working capital at $U.S. 22.2 million. The product cost was calculated at $U.S. 52.85 per ton at DCF ROR equal 15 percent (after tax) and coal price of $U.S. 27/t fob plant. The key cost elements determining the product price were the coal price, the amount and price of oil, and to a lesser extent the operating and capital costs.

Variance analysis performed on the coal price suggested that using the Aglofloat to process coal refuse (coal price = $U.S. 0/t) could produce a clean coal product at $U.S. 25.26 per ton. Such a product would be competitive with the current cost of low- and medium-sulphur coals in the eastern U.S. (priced at $U.S. 20 to $U.S. 28 per ton).

IV. Cleaning of Tar refuse and Hydrocarbon Contaminated Soils

The objective of the Clean Soil study was to develop technology which would:

- Clean up contaminated soils at manufactured gas plant sites, coking plant sites, benzol plant sites, etc.
- Clean up contaminated soils from oil spills, oily wastes pits, and other hydrocarbon contaminated spills.
- Treat heavy oil wastes and emulsions from heavy oil recovery and upgrading plants.

The project led to the development of the Clean Soil process which cleans contaminated soils to a level of 1000 ppm (0.1 percent) or less, and yields by-product agglomerates which contain the hydrocarbon contaminants and are suitable for combustion in industrial boilers. Specific achievements related to the process performance and evaluation are summarized below.

Batch Test Studies

A rapid laboratory screening method for characterization of various contaminated soils for treatment in the Clean Soil process was developed. The tests performed suggest that a wide range of contaminant types and concentrations in the soil can be treated by the process. The concentration of residual contaminants in the clean soil was reduced to 0.1 percent or less (Table II). The key properties of the contaminated soil influencing the process performance were identified as:

- The amount and composition of the hydrocarbon contaminants.
- The particle size and particle size distribution of the soil.
- The presence of other materials in the contaminated soil capable of adsorbing the contaminants, e.g., coke.

Depending on the soil characteristics, the Clean Soil process procedures can be readily modified to achieve the best process performance.

Table II. Clean-up of contaminated soil using Clean Soil process: Overall Material Balance for Site #1-1, Batch Tests.

Type of contaminant	Contaminant concentration, % Feed	Processed soil*
Tar #1(1)	8.6	0.07
Tar #1(2)	1.2	0.00
Tar #2(2)	66.9	0.10
Tar #2(8)	0.7	0.10
Tar #1-1	5.6	0.07
Tar #2-2	10.6	0.17
Heavy Oil	8.7	0.04
Oil (light) Spills	2.0	0.17
Gasoline Spills	3.1	0.06
Oil (heavy) Spills I	43.0	0.08
Oil (heavy) Spills II	0.2	0.00

* Guidelines accepted by many regulatory agencies in North America require that the residual concentration of petroleum derived contaminants does not exceed 1000 ppm (0.1 percent) in the clean soil.

Large Pilot Plant (IATF)

The Integrated Agglomeration Test Facility was reconfigured for the Clean Soil process operation (flowsheet #ARC20). The pilot plant runs provided information on process control and performance of each unit operation at steady-state conditions. For some feeds, however, less than desired performance of the IATF was obtained because limited process information was available on the kinetics of agglomeration and the separation of contaminants from the cleaned soil.

A large sample of product agglomerates produced in the IATF was tested for its handling, grinding and combustion characteristics by Combustion Engineering, Inc. The tests showed that combustion performance and emissions for agglomerates from tar refuse were similar to combustion performance of HVB coal used in agglomeration.

Feasibility of the Clean Soil Process

The commercial feasibility of using the Clean Soil process for treatment of oily waste from bitumen upgrading was evaluated. The plant was assumed to be a mobile plant located in Alberta and capable of processing 30,500 tonnes of oily wastes per year. Depending on whether pulverized coal was purchased or prepared at the plant site, the plant capital cost was estimated at $Cdn 1.8 and $Cdn 2.06 millions, respectively. The cost of cleaning oily waste was estimated at $Cdn 31.39/t, for a case where the market for agglomerates exists near the plant, and at $Cdn 46.97/t for a case where agglomerates would have to be shipped for sale. The costs indicated are within the range of current costs of waste disposal ($Cdn 25 to $Cdn 35 per ton, for hauling and spreading). However, since spreading is likely to be unacceptable as a disposal method in the future, the Clean Soil process offers a viable new technology for oily waste disposal.

V. Conclusions

Three new processes were developed in the first two and one-half years of the Consortium Coal Processing Development Program based on ARC's advanced spherical agglomeration research. The preliminary evaluation of these processes suggest that the most promising opportunities and their constraints for further development, are:

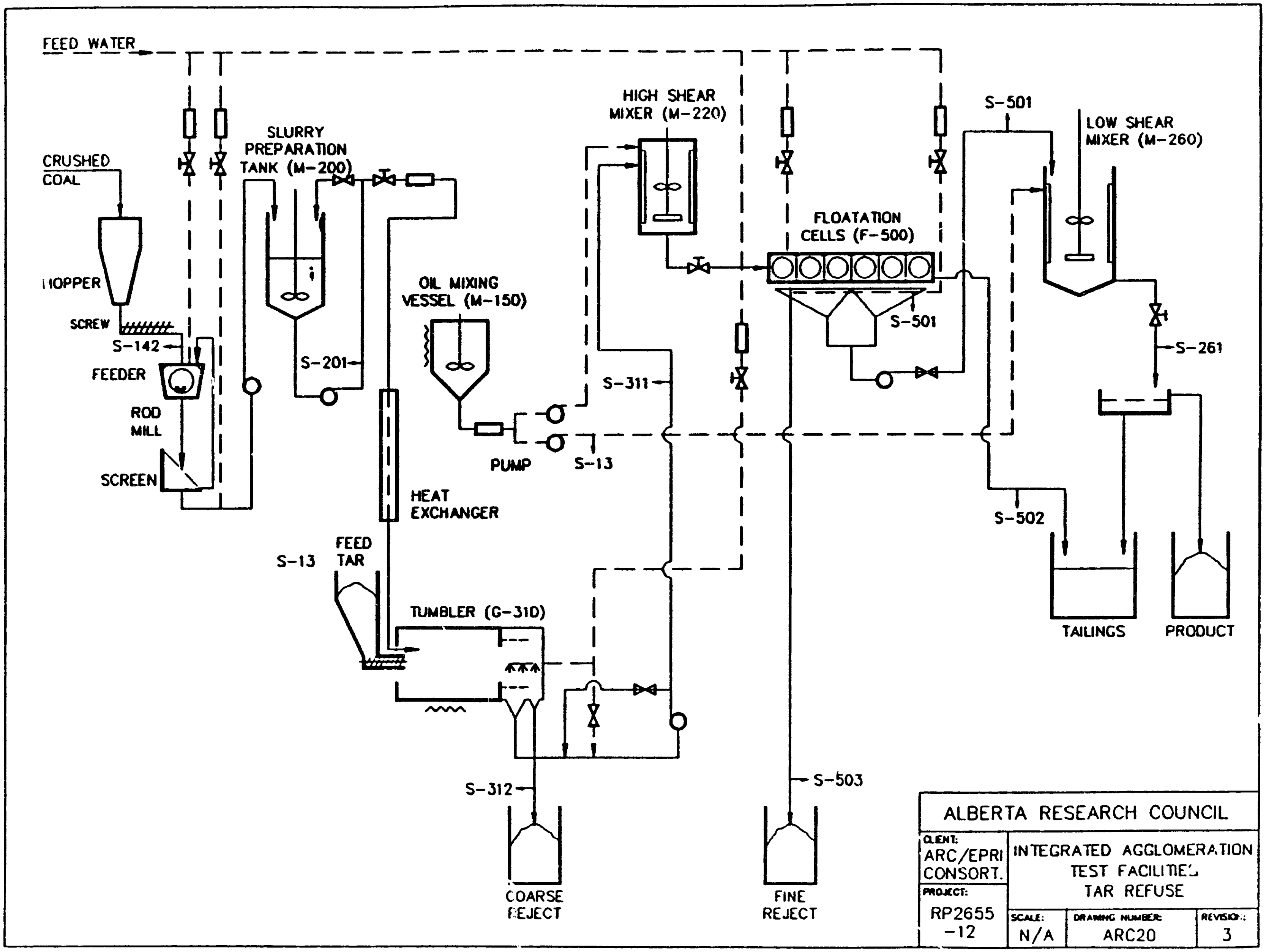
- co-upgrading of low rank coal and heavy oil;
- beneficiation of bituminous coal refuse and ROM coal; and
- clean-up of contaminated soil.

The major technical and economic constraints which must be solved for each process are:

- the technical feasibility of coal-oil paste extrusion in co-upgrading of coal and heavy oil;
- the reduction of the amount of bridging oil required for production of large size agglomerates in beneficiation of bituminous coals; and
- the optimization of the reprocessing steps in cleaning of some contaminated soils.

The results described in Volumes I, II, and III of this report summarized achievements completed prior to December 31, 1989. Since that time, however, further improvements in process performance were attained and presented to the Consortium members. These results will be described in detail in the updated reports for each process.

Each of these technology opportunities has advanced in this year (1990) of the consortium program, to a stage where it can be pursued by smaller R&D consortia comprised of members with an interest in one or two of the technology areas only. It is recommended that future work in this program be pursued by such consortia addressing each technology area separately.


FEED WATER
CRUSHED
COAL
HOPPER
SCREW
S-142
FEEDER
ROD
MILL
SCREEN
SLURRY
PREPARATION
TANK (M-200)
S-201
OIL MIXING
VESSEL (M-150)
PUMP
S-13
HEAT
EXCHANGER
FEED
TAR
S-13
TUMBLER (G-310)
S-312
COARSE
REJECT
HIGH SHEAR
MIXER (M-220)
S-311
FLOATATION
CELLS (F-500)
S-501
S-503
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REJECT
S-501
LOW SHEAR
MIXER (M-260)
S-261
S-502
TAILINGS
PRODUCT
ALBERTA RESEARCH COUNCIL
CLIENT:
ARC/EPRI
CONSORT.
INTEGRATED AGGLOMERATION
TEST FACILITIES
TAR REFUSE
PROJECT:
RP2655
-12
SCALE:
N/A
DRAWING NUMBER:
ARC20
REVISION:
3

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1. Introduction

1.1. The Aglofloat Process

The Aglofloat process is an advanced spherical agglomeration process capable of beneficiating high ash and sulphur, bituminous coals to clean fuel with a heating value above 13,000 Btu/lb, ash content of less than 10 percent, and significantly reduced (up to 95 percent) pyritic sulphur content.

The process and product streams are illustrated in Figure 1.1. First, run-of-mine coal is crushed, pulverized to -0.6 mm (-28 mesh) and slurried with recycle water. At the same time, crude oil is mixed with diesel fuel to form a bridging oil. The coal slurry and bridging oil are combined in a high shear mixer where coal and oil form microagglomerates about 0.2 mm in size. The microagglomerates are separated from coal mineral matter and refuse in a floatation cell, and washed and separated from pyrite particles in a hydroseparator. Then microagglomerates are transferred to a low shear mixer where more bridging oil is added and macroagglomerates are enlarged to 0.8 mm to 3.0 mm in size. The coal refuse in the floatation and hydroseparator underflow is removed and disposed of.

For coals which are difficult to clean, the microagglomeration process is run in two stages. First stage, as described above, is followed by wet grinding of microagglomerates to reduce the top particle size from -0.6mm (-28 mesh) to -0.15 mm (-100 mesh). The ground coal is resuspended in water and microagglomerated with an additional amount of bridging oil. The microagglomerates are separated by flotation and then agglomerated in low shear mixer for size enlargement.

The Aglofloat process offers several advantages for the processing of bituminous coals, namely:

1. It removes mineral matter and pyrite, and therefore increases ROM coal quality and heating value. Some medium sulphur coals can be brought into SO_2 emission compliance.
2. The process can be used to recover combustible matter from coal preparation plant rejects. When used in this way, it produces a saleable product and reduces the coal preparation plant's waste disposal costs.

The Aglofloat process has several advantages over other coal cleaning and upgrading technologies. Because it is based on differences between the surface properties of coal and mineral matter, it is very efficient for cleaning fine coals. Another advantage of the process is its potential to achieve high pyrite removal, at high combustible recoveries, without the need for expensive solvents and solvent recovery equipment. Also, when compared to multistage floatation, the Aglofloat process offers much higher combustible recoveries (Table 1.1). The Aglofloat is less expensive and generates more environmentally acceptable refuse than chemical cleaning processes.

Not proven yet.

The main disadvantage of the process is the large amount of oil which must be used in the size enlargement step. Work will continue to find ways to reduce the oil required in the size enlargement step. Process applications that do not require enlargement steps will also be sought.

Table 1.1. Comparison of Aglofloat to other coal desulphurization process.

	Coal	Feed		Product		Pyritic sulphur removal	Combustibles recovery
		Ash %	Total sulphur %	Ash %	Total sulphur %	%	%
	Illinois No. 6	39.5	4.19	6.8	3.70	77	89
Aglofloat	Upper Freeport	12.3	2.33	6.2	1.10	93	96
	Pittsburgh	17.7	4.98	5.5	3.24	85	95
Multistage Floatation	Prince Mine	13.2	3.70	5.0	-	8.2	72
Reverse	Pittsburgh	30.6	1.72	8.7	1.17	76	92
	Lower Freeport	31.4	2.65	6.8	0.92	92	89
Otsica	Upper Freeport	17.7	2.66	5.0	1.02	80	79
	Pittsburgh No. 8	30.2	4.51	6.4	3.41	57	94

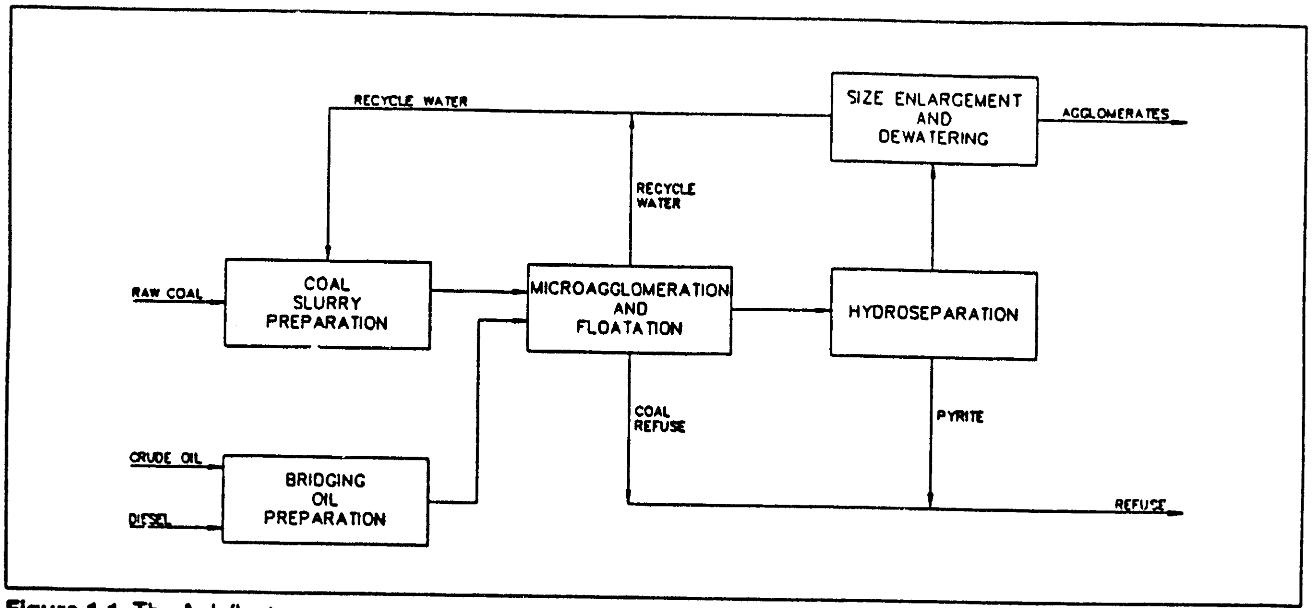


Figure 1.1. The Aglofloat process.

1.2. Objectives and Scope of the Program

The overall objective of the Coal Development program was to solve coal utilization problems caused by poor quality coals, which typically have high moisture, ash and sulphur content, through the development of clean coal technologies using coal-oil agglomeration. The general objectives with respect to high-sulphur bituminous coals were the development of technologies which would:

- Remove ash and pyrite from high-sulphur and -mineral matter bituminous coal, thus making these coals more marketable and more acceptable when burned. Their greater acceptability results from the fact that they produce a lower level of sulphur dioxide emissions.
- Recover coal from fines generated in coal preparation plants, thus improving utilization of ROM coals.
- Improve boiler operation and efficiency by supplying a coal product of more uniform quality, and improve the operation of coal handling and pulverization equipment by supplying a fuel that is lower in ash and pyrite.

The specific objectives of the bituminous coal program were to explore and evaluate the application of advanced agglomeration technology for:

- Desulphurization of bituminous coals to sulphur content acceptable within the current EPA SO_2 emission guidelines;
- deashing of bituminous coals to ash content of less than 10 percent; and
- increasing the calorific value of bituminous coals to above 13,000 Btu/lb.

Research during the project focused on establishing the technical and commercial viability of the Aglofloat process. There was a need to solve engineering problems and improve the economics of the process. As well, there was a need to demonstrate that the clean coal product is suitable for use in utility industry.

Testing the commercial potential of the Aglofloat process took two and a half years. Key technical and process economic issues addressed during this time included:

- **Process Research Studies:** to determine the expected process performance in batch characterization methods for selected feeds, and to obtain process information useful for the design and operation of the Integrated Agglomeration Test Facility (IATF) and Pyrite Removal Unit at ARC.
- **Engineering Studies:** to determine the key design concerns for the pilot plant and commercial plants, to develop process control strategy, to obtain engineering and operating data required for process evaluation, and to develop design criteria for conceptual design and cost analysis of the Aglofloat process.

- **Economic Studies:** to determine the economic feasibility of the process including variance analysis with respect to key economic and process assumptions.

Examples of activities undertaken during the bituminous coal project include: batch and continuous scale agglomeration and separation tests, construction and operation of a 6 tonnes per day pilot plant, and techno-economic assessment of the feasibility of the process. The results of these process development activites are discussed in Sections 2 through 7.

1.3. Project Organization

The project organization chart is presented in Figure 1.2.

Two committees provided direction for the project. These committees were:

1. A Management Committee with overall responsibility for program management, funding and implementation of the Coal Development program.
2. A Technical Committee with overall responsibility for the operation and conduct of the program.

The specific responsibilities of the Management Committee were: to approve the annual budgets and any changes in the scope of the program; to approve the Technical Committee's reports; to establish milestones, schedules, etc.; to approve major expenditures not included in the Annual Budget.

The specific responsibilities of the Technical Committee were: to oversee program development and achievement of milestones; to approve and evaluate manuals prepared by the engineering staff; to oversee development of designs and specifications; to prepare the Annual Budget and periodic reports for submission to the Management Committee.

1.4. Report Organization

The results of the ARC/EPRI Coal Processing Development Program are presented in three volumes, each addressing specific applications of advanced agglomeration technology:

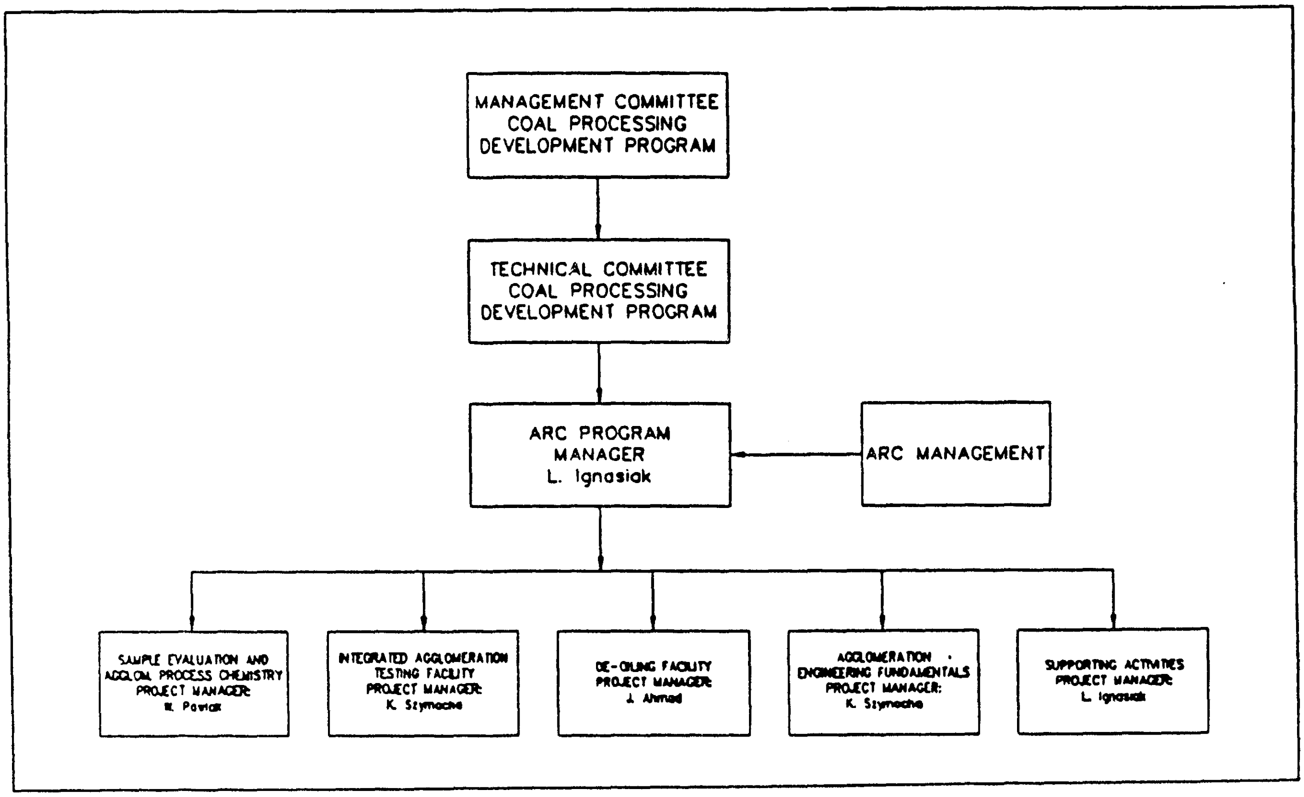


Figure 1.2. Project Organization Chart.

Volume 1. Upgrading of Low Rank Coals: the Agflotherm Process
Volume 2. Removal of Ash and Pyritic Sulphur from Bituminous Coals: the Aglofloat Process
Volume 3. Soil Clean-up and Hydrocarbon Waste Treatment Process: the Clean Soil Process

Each volume of the report is supplemented by an Appendix containing relevant background data and additional information and descriptions of process designs.

This volume of the report presents the results of ARC's laboratory and pilot plant work on the development of improved agglomeration technology for upgrading of bituminous coals. Chapter 2 begins with a description of the coals and oils selected for testing with the Aglofloat process. The chapter includes descriptions of the bench experimental procedures used and the results of process research and optimization work.

In Chapter 3, Volume 2, design studies completed on the agglomeration mechanism are reviewed. These studies focus on fundamentals of the Aglofloat process, application of agglomeration models in process design, and evaluation of critical design issues. The chapter also discusses batch and continuous operations and studies of agglomeration kinetics.

Chapter 4 includes a description of the design and operation of the Pyrite Removal Unit. It details major equipment included in the unit, the commissioning of the unit and results obtained during operation of the unit.

Chapter 5 describes the experimental results from the Integrated Agglomeration Test Facilities. The chapter starts with a review of major equipment and instrumentation. This is followed by a description of plant commissioning, details of the operating experience and unit improvements.

Chapter 6 briefly reviews the major emissions and waste streams for the Aglofloat process and the environmental control technology required to operate the process within the EPA emissions guidelines.

The conceptual design and cost analysis of an Aglofloat plant are presented in Chapter 7. The chapter includes process and economic data and assumptions, process area cost estimates, and financial analysis of the plant.

Chapter 8 presents the major conclusions and recommendations relating to the Aglofloat process. The key issues addressed are further improvements of the process economics and efficiency, and reduction of oil use for agglomerates size enlargement. The references quoted in Volume 1 of the report are presented in Chapter 9.

2. Bench Scale Characterization of Coals and Oils for the Aglofloat Process

2.1. Experimental Procedures

2.1.1. Approach

The batch tests which were performed for the Aglofloat process had three major process research and development objectives:

1. To determine process performance of the Aglofloat process for treatment of the selected coal/oil feedstock combinations.
2. To obtain process research information useful to the design and operation of the Integrated Agglomeration Test Facilities (IATF).
3. To conduct investigations in support of the Aglofloat process including research into the agglomeration and separation mechanisms for processing bituminous coals.

A standard floatation machine equipped with a 2 liter floatation cell was used during the tests. It was felt that experiments of this size would be adequate for all necessary analyses of agglomerates and oils. The tests and equipment selected were also capable of providing process research type information in support of the design and operation of the Integrated Agglomeration Test Facilities.

Figure 2.1 illustrates the experimental procedures used in batch-scale characterization of coals and oils. The experiments were performed in several steps. In a typical single-stage Aglofloat process, a known amount of coal was mixed with water to make up the required solids concentration. The resulting suspension was agitated for one minute to ensure complete wetting and then a specified amount of bridging liquid (usually 0.5 percent to 5 percent on dry coal) was added. The slurry was agitated up to the moment when phase separation occurred. Thirty to 60 seconds of agitation were usually required. The volume of slurry was then adjusted by adding water to achieve 10 percent solids concentration and coal flocs were separated by simple floatation. The collected coal was resuspended in fresh water, mixed for one minute to release the entrapped mineral matter (pyrite) particles, and separated again. The microagglomerates were dried, weighed and analyzed for moisture, ash, sulphur and calorific value. The two-stage Aglofloat experiments were a combination of two single-stage processes with interstage wet grinding. Table 2.1. depicts typical test conditions for the Aglofloat batch experiments.

2.1.2. Equipment

Equipment used during batch tests included an agglomeration tank, a laboratory floatation machine, and a sieve. Additional equipment and instrumentation was used for sample analyses, product analyses, product handling, etc. A detailed description of the batch agglomeration equipment is provided in Section 2.1. Volume 1 of this report.

Table 2.1. Aglofloat process: Test conditions.

Size of coal particles	Dry grinding:	top size 600µm, d_{50}~200µm
	Wet grinding:	top size 150µm, d_{50}~25µm
Solids concentration (in slurry)	Agglomeration:	10% - 25%
	Froth floatation:	5% - 12.5%
Bridging liquids	Blends of bitumen and/or heavy oils with diesel oil or kerosene	
Bridging liquid conc.	From 0.5% to 1.0%	
Impeller speed	Agglomeration:	2,100 rpm
	Froth floatation:	1,100 rpm
Temperature	Ambient	
pH of slurry	Natural	

2.1.3. Sample Preparation

A variety of coal and oil sample combinations were tested to determine their performance in the Aglofloat process. Each of these samples was subjected to the following preparation procedures:

1. The coal samples were air dried, crushed and ground to -600 µm top coal particle size (-0.6 mm or -28 mesh) and to a weight average mass median, particle diameter, d_{50}, about 200 µm.
2. The oil samples were mixed, divided into representative subsamples, and used as crude samples without any emulsification or dispersion in water.

2.1.4. Test Methods and Procedures

Table 2.2 lists the test methods and procedures used to characterize the feedstocks and agglomerate products. In addition to the tests in this table, other specialized tests such as gel permeation chromatography for oil characterization, or surface area measurement for coal, were used when necessary. These tests are described and discussed in the following sections.

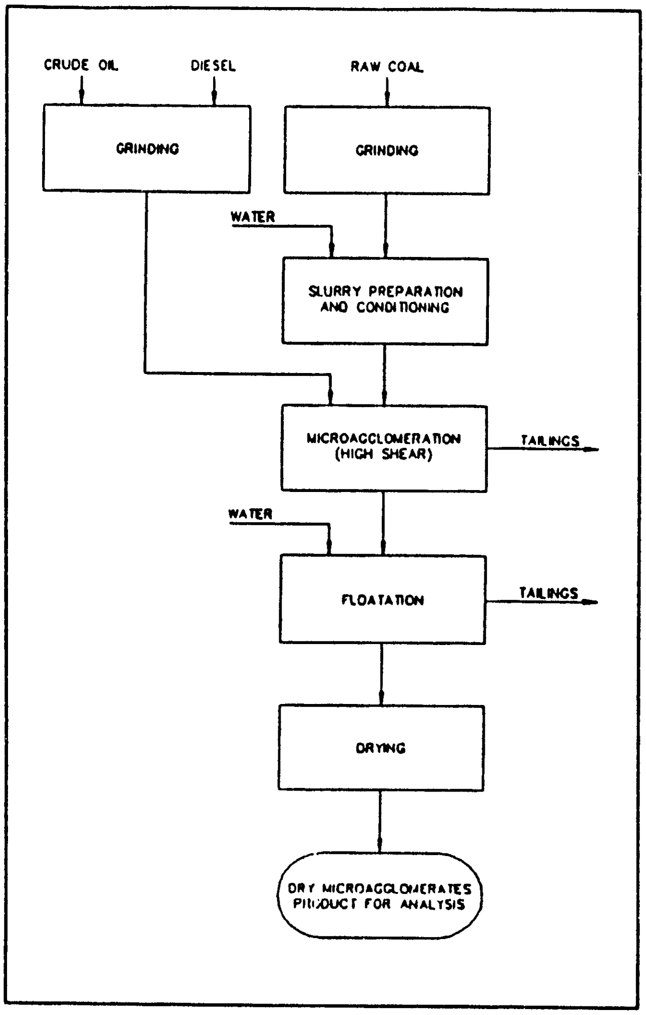


Figure 2.1. Schematic representation of Aglofloat batch procedures.

2.2. Process Research and Optimization

2.2.1. Coal Samples Data Base

Ten bituminous coal samples, six high sulphur bituminous coals from the U.S. and four coal preparation products from Alberta, were submitted for testing under this program. Participating organizations and their selected coals are listed in Table 2.3. The sample size varied from 5 kilograms to 20 tonnes, with the large samples being designated for the pilot plant tests. The samples were run-of-mine or washed grab samples including fines and precipitator dust from coal preparation plants.

Table 2.2. Test methods and procedures.

Sample	Test method	Procedure/standard
Coal/ agglomerate	Proximate	Fisher Coal Analyzer ASTM draft stage
	Ultimate	Leco CHN-600
	Total Sulphur	Leco SC-32 ASTM D 4239-85
	Heating Value	ASTM D 2015
	Particle Size	Granulometer 723 Laser Light Diffraction
	Capacity Moisture	ASTM D 1412-85
Oils	Density (API gravity)	PAAR Density Meter Model DMA 55
	Viscosity	Brookfield Digital Viscometer
	Simulated Distillation	ASTM D2887
	Molecular Weight	Vapor Pressure Osmometry Corona Wescan Molecular Weight Apparatus

Table 2.3. "Participating" coals: The Aglofloat process.

Organization	Sample name and description
U.S. Dept. of Energy	Upper Freeport - bituminous coal Illinois No. 6 - bituminous coal Pittsburgh Seam - bituminous coal
Ohio Ontario Clean Fuels	Ohio Sample - bituminous coal
Illinois State Geological Survey	Illinois No. 6 - bituminous coal (ROM) Indiana V - bituminous coal (washed)
Obed Mountain Coal Company	Obed - bituminous coal (precipitator dust) Obed - bituminous coal (washed)
Ontario Hydro	Byron Creek - bituminous coal (fines - filtercake) Byron Creek - bituminous coal reject

The range of properties for the samples submitted was as follows:

Moisture, % as received	8.5 - 24.5
Ash, %	9.2 - 34.8
Sulphur, % total	0.30 - 4.98
Sulphur, % pyritic	<1.3 - 3.4
Heating Value, GJ/t	19.4 - 31.5
Heating Value, Btu/lb	8,350 - 13,560

A detailed analysis of the samples submitted is given in Appendix 2.

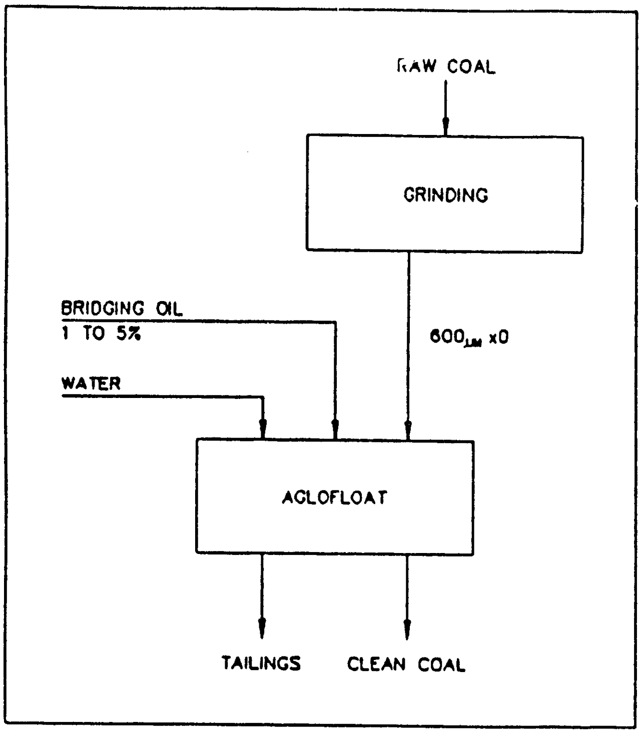


Figure 2.2. Single-stage Aglofloat process.

The following sections describe examples of the effects of different process variables and feed properties on cleaning of the "participating" coals. These examples are illustrative only and are not intended to provide proof for the trends discussed. Such proof and more detailed support for the conclusions drawn were reported previously in ARC's technical papers documenting several years of research by ARC on agglomeration of bituminous and subbituminous coals.

2.2.2. Single- and Two-Stage Processing

Two procedures were followed during characterization of the coal samples in the Aglofloat process:

1. A single-stage process where grinding coal to top size of -600 μm was sufficient for liberation of pyrite and mineral matter from the coal organic material (Figure 2.2).
2. A two-stage process with a regrinding of the product coal from the single-stage to top coal size of 150 μm and d_{50} ~ 25 μm and reagglomeration of the coal in order to achieve high pyrite and mineral matter liberation in the process (Figure 2.3).

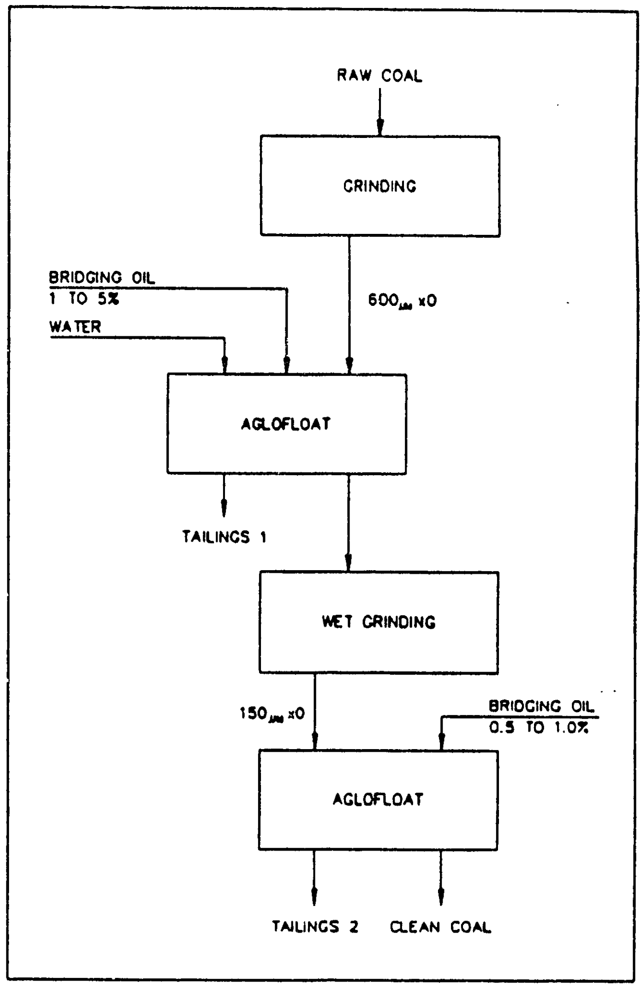


Figure 2.3. Two-stage Aglofloat process with interstage wet grinding.

The results of tests which compared single- and two-stage processes for the selected U.S. coals are depicted in Figures 2.4 to 2.7. The key conclusions which may be drawn from these tests are:

- Ash reduction increased by 2 to 4 percent (coal basis) by going from single- to two-stage processing.
- Total sulphur reduction increased by 0.5 to 1 percent (coal basis) when using the two-stage process instead of the single-stage process.
- The removal of inorganic sulphur increased from 50-55 percent to 60-80 percent by using the two-stage process.
- The recovery of combustibles decreased from 93-98 percent to 89-96 percent through the use of the two-stage process.

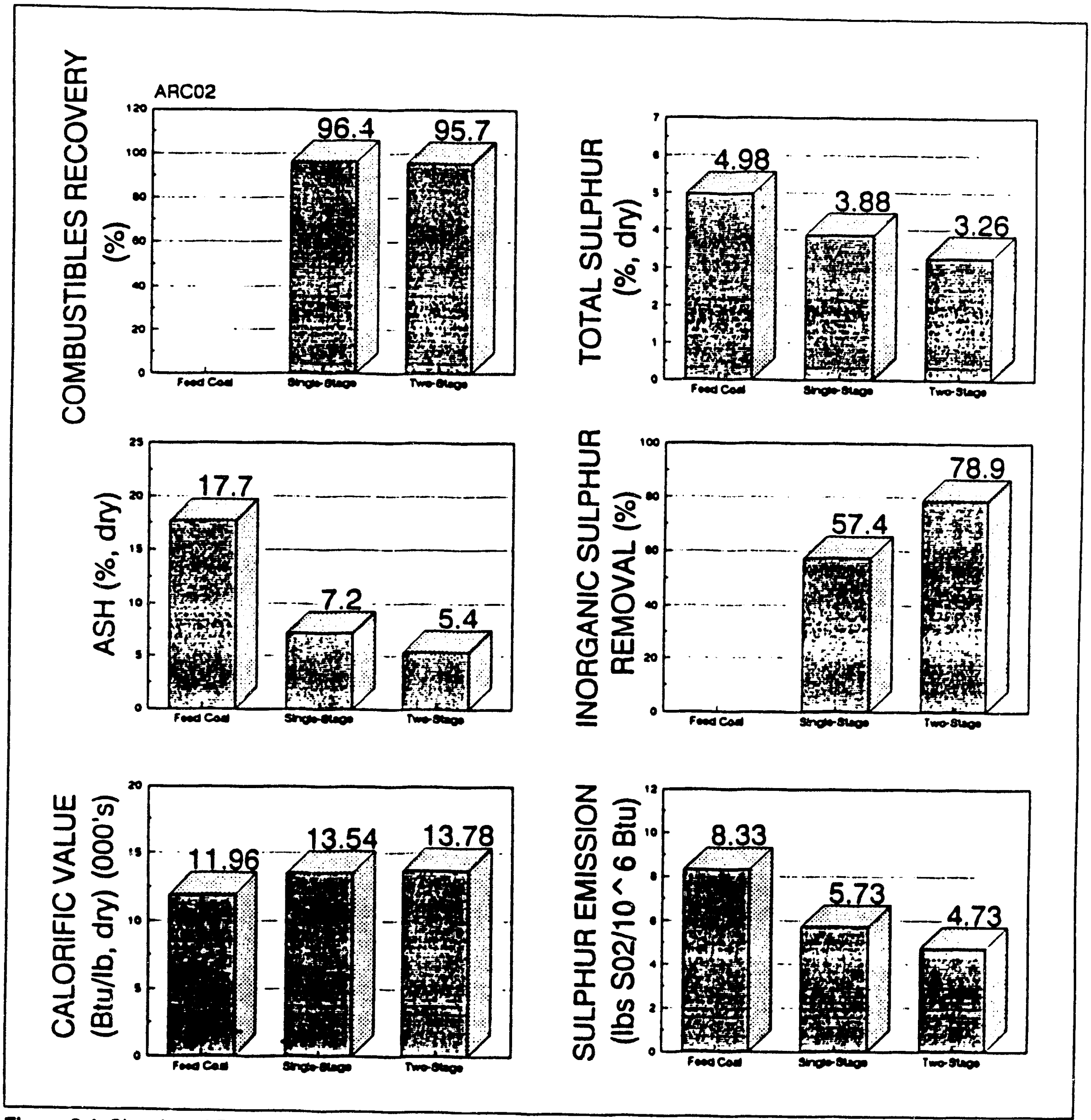


Figure 2.4. Cleaning of Pittsburgh seam coal by Aglofloat process.

The choice of a single- or two-stage process for processing of a selected coal sample would, therefore, depend on the level of ash and pyrite in the sample and the cleaning level desired. High ash, high pyrite samples containing particles of inorganic materials with a wide size distribution would require a two-stage process, whereas coals with large size mineral matter particles or low ash and pyrite content could be cleaned in a single-stage process.

2.2.3. Effect of Sample Preparation on Ash and Pyrite Rejection

A series of tests was performed to further evaluate the single- and two-stage processes. Specifically,

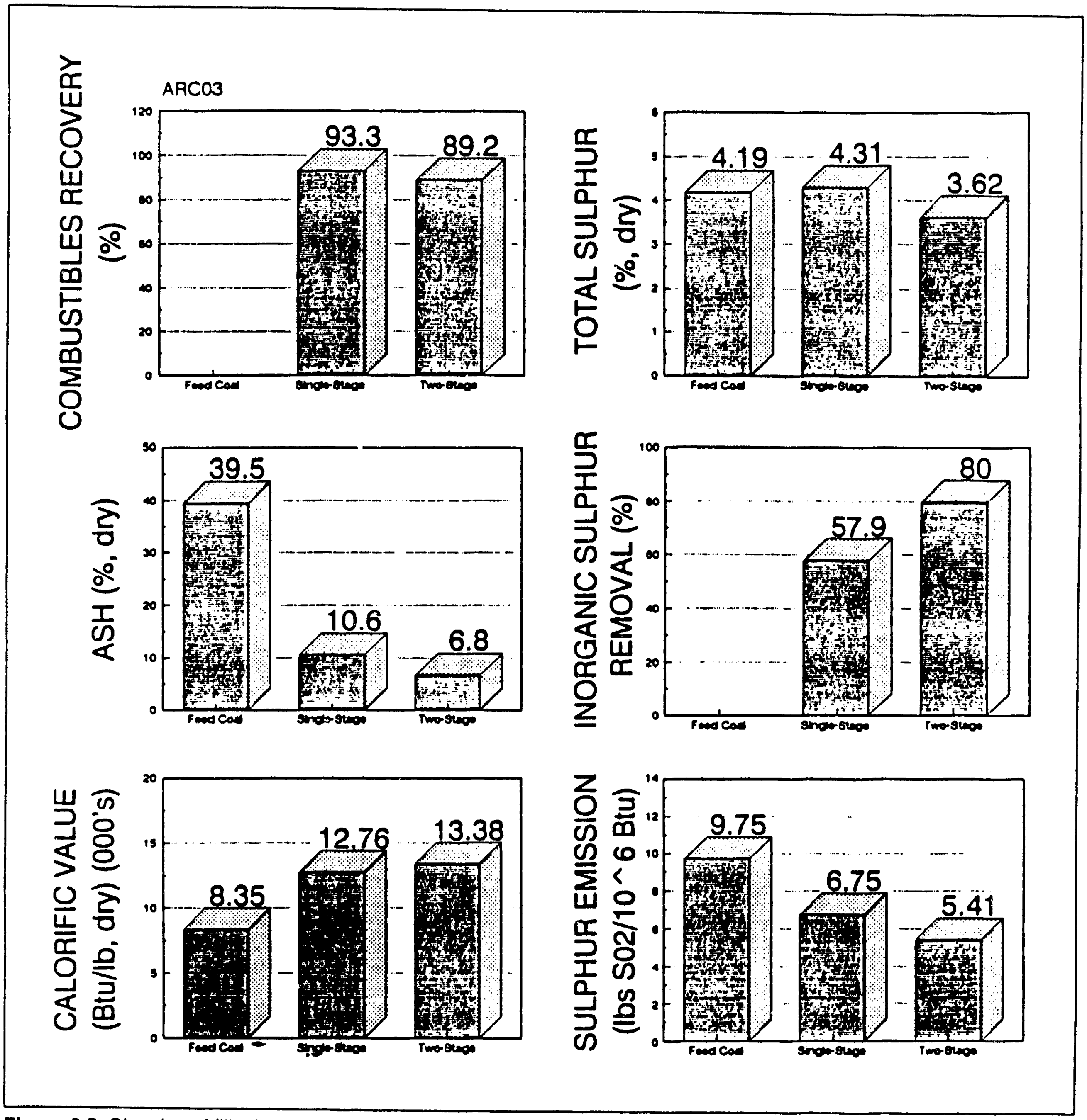


Figure 2.5. Cleaning of Illinois no. 6 coal by Aglofloat process.

tests to assess the effects of different degrees and types of grinding, to compare single-stage wet grinding to the two-stage Aglofloat process, and to compare single- and two-stage processing to washability tests were performed. The washability test is commonly considered a measure of the ease with which mineral matter can be separated from coal.

Comparison of single-stage wet grinding to two-stage processing using the same amount of bridging oil (1 percent) is depicted in Table 2.4. It is shown, again, that a second agglomeration and grinding step reduced the ash content in the product and increased the removal of inorganic sulphur.

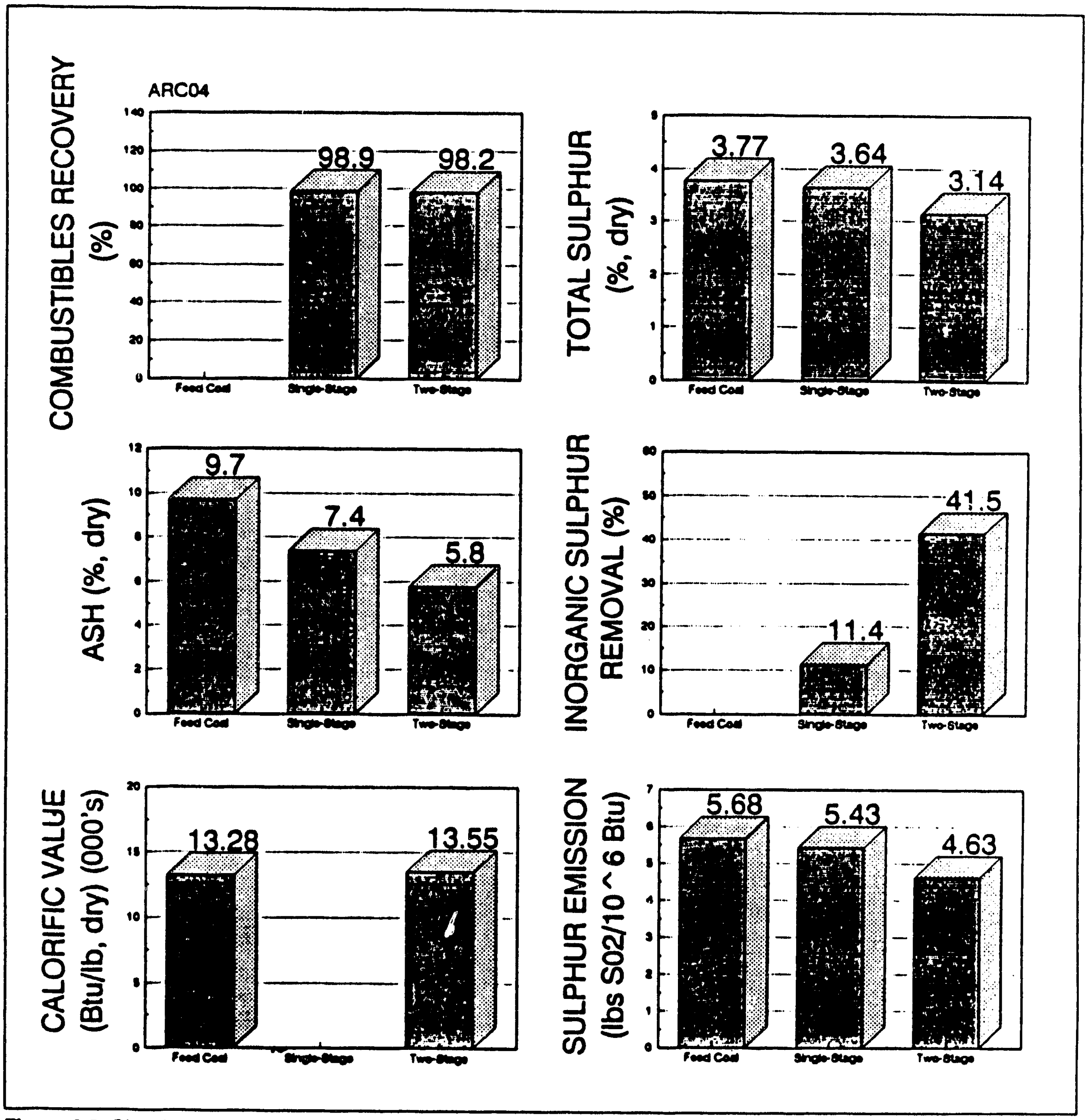


Figure 2.6. Cleaning of Indiana V coal by Aglofloat process.

A comparison of single-stage agglomeration to the float and sink test is presented in Table 2.5. The washability tests were performed using a modified float-sink procedure described by Franzidis and Harris (1986). The results suggest that both float-sink tests and single-stage agglomeration can be used as an indicator of the ease with which mineral matter can be separated from a sample of coal. Float-sink at a density of 1.6 g/cm^3 seems to yield coal recovery and ash content similar to the single-stage Aglofloat tests.

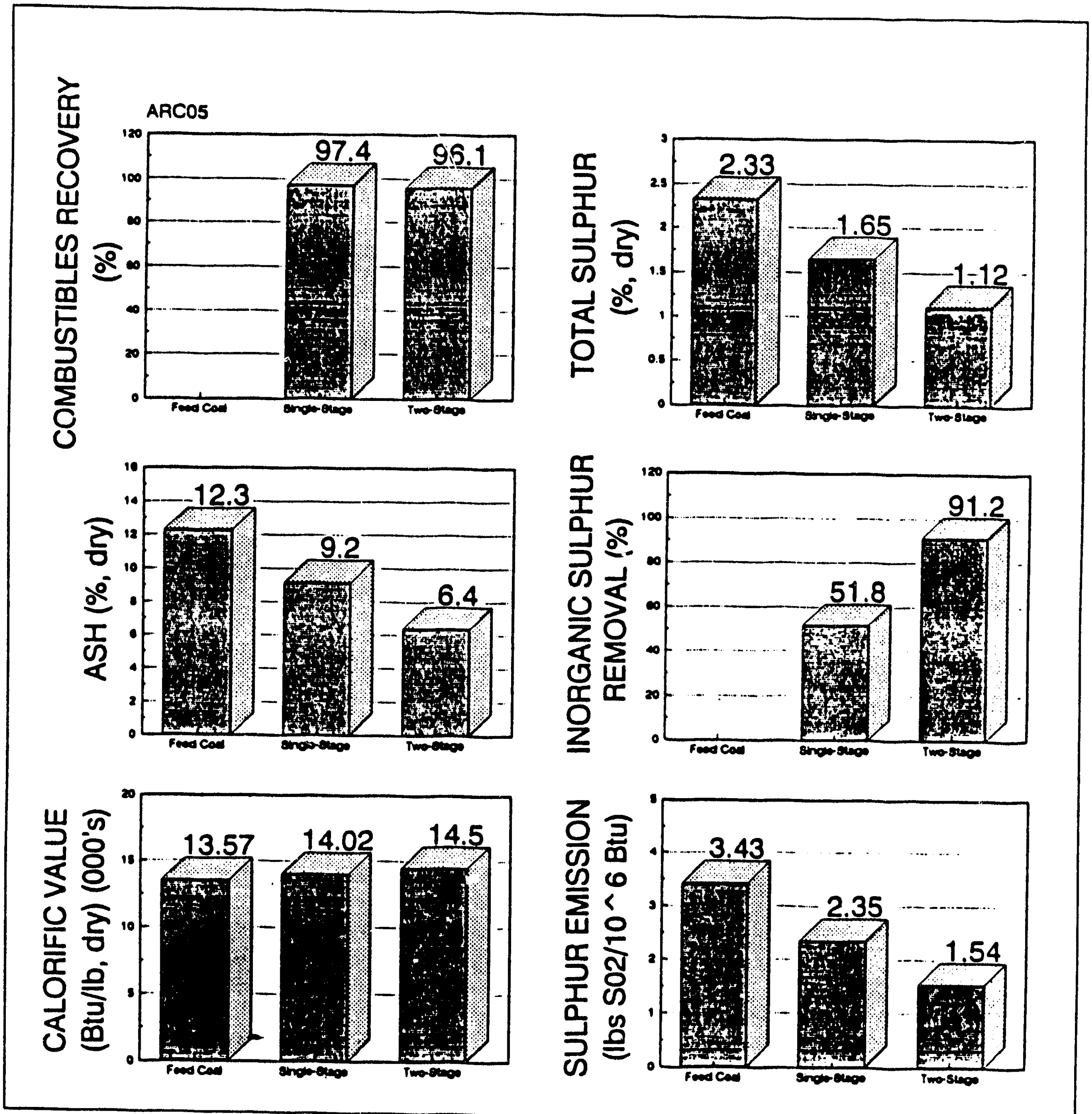


Figure 2.7. Cleaning of Upper Freeport coal by Aglofloat process.

2.2.4. Effect of Coal and Oil Concentration

Tables 2.6 to 2.8 depict the effect of coal and oil concentration on the ash and sulphur content of the agglomerate products and on combustibles recovery. The key effects presented are:

- An easy, good separation was obtained for a wide range of coal concentrations – 10 to 25 percent – with a slight increase in ash content observed for high solid loading due to an entrapment of mineral matter in agglomerates (Table 2.6).
- A consistent low ash and sulphur content in the product was obtained over a range of bridging oil addition (0.6 to 12 percent) with slightly higher pyrite and ash content observed at high oil

Table 2.4. Effect of grinding on Aglofloat process performance.

Experi-mental proce-dure	Bridging liquid addition[a] (%)	Combust. recovery (%)	Ash (%)	Total sulphur (%)	Inorganic sulphur removal (%)
Parent Coal[b]	–	–	14.3	4.27	–
Wet grinding followed by single-stage	1.0	99.8	7.7	3.04	70.7
Two-Stage	0.5+0.5	98.5	6.4	2.84	76.3

a: Mixture of heavy oil and diesel oil in ratio 2:3.
b: Illinois No. 6; Forms of sulphur: 1.98% pyritic, 0.15% sulfatic and 2.13% organic.

Table 2.5. Comparison of float-sink and Aglofloat tests[a].

	Yield	Ash
Float-Sink		
1.4 g/cm^3	38.6%	~ 6.7%
1.6 g/cm^3	58.8%	~ 12.5%
Single-Stage Aglofloat	63.0%	10-11%

a: Performed with Illinois No. 6, 39.5% ash. Top size 600 μm, d50 ~240 μm.

Table 2.6. Effect of solids concentration on Aglofloat process[a] performance.

Solids Concentration (%) Micro-agglom-eration	Separation	Combust. recovery (%)	Ash (%)	Total sulphur (%)	Total sulphur removal (%)
Parent Coal[b]		–	14.3	4.27	–
10	5.0	98.4	9.1	3.03	33.5
15	7.5	99.4	9.4	3.07	32.1
20	10.0	99.7	9.7	3.14	30.1
25	12.5	99.3	9.7	3.14	30.3

Note: All values on dry basis.
a: Single-stage process; 0.6% bridging liquid addition.
b: Illinois No. 5, Forms of sulphur: 1.98% pyritic, 0.15% sulfatic and 2.13% organic.

addition, again because of entrapment of the ash in agglomerates (Table 2.7).

- Consistent, high combustibles recovery was obtained at a bridging oil concentration above 0.5 percent. However, for concentrations less than 0.5 percent, the percentage of combustibles recovered decreased slightly while the content of ash and sulphur in the product remained the same, within the analytical error (Table 2.8).

Table 2.7. Effect of bridging liquid addition on Aglofloat process[a] performance.

Bridging liquid[b] addition (%)	Combustibles recovery (%)	Ash (%)	Total sulphur (%)	Total sulphur removal (%)
Parent Coal[c]	–	14.3	4.27	–
0.6	98.9	8.7	3.04	33.2
4.0	99.4	8.7	3.04	33.2
6.0	99.6	8.7	3.05	32.5
8.5	99.9	8.7	3.11	30.6
12.0	99.9	8.9	3.20	28.3

Note: All values on dry basis.
a: Single-stage process; b: Bitumen + diesel in ratio 2:3; c: Illinois No. 6, Forms of sulphur: 1.98% pyritic, 0.15% sulfatic and 2.13% organic.

Table 2.8. Effect of bridging liquid addition on Aglofloat process[a] performance.

Bridging liquid addition[b] (%)	Combustibles recovery (%)	Ash (%)	Total sulphur (%)	Inorganic sulphur removal (%)
Parent Coal[c]	–	14.3	4.27	–
1.0 (0.5+0.5)[d]	98.5	6.4	2.84	76.3
0.6 (0.5+0.1)[d]	98.1	6.6	2.91	73.3
0.3 (0.2+0.1)[d]	97.5	6.7	2.86	75.6

a: Two-stage; b: Mixture of heavy oil and diesel oil in ration 2:3; c: Illinois No. 6; forms of sulphur: 1.98% pyritic, 0.15 sulfatic and 2.13% organic; d: Oil addition in each stage

It should be noted, that the minimum oil addition required varied depending on coal properties. For example, with Byron Creek fines, the Aglofloat process required 5 percent of bridging oil for a 95 percent combustibles recovery; for high sulphur U.S. coals, 1 percent of bridging oil was sufficient to achieve high recovery. Typically, combustibles recovery of about 95 percent was achieved with 0.5 percent of bridging oil.

2.2.5. Effect of Oil Properties and Additives

Table 2.9 depicts results of single- and two-stage processing for different bridging oil compositions (heavy oil or bitumen/diesel 1:1 to 2:3). The results suggest that good combustibles recovery and significant reduction of ash and sulphur can be obtained with a wide range of bridging oil properties. However, as the content of the light oil in the bridg-

Table 2.9. Effect of bridging liquid composition on Aglofloat process performance.

Experimental Procedure	Bridging liquid[a]	Combustibles recovery (%)	Ash (%)	Total sulphur (%)
Parent Coal[b]		–	10.6	4.72
Single-Stage	Heavy Oil + Diesel (2:3)	93.1	6.4	4.08
	Bitumen + Diesel (2:3)	94.2	6.8	4.22
	Cold Lake + Diesel (1:1)	95.0	6.9	4.24
Two-Stage	Heavy Oil + Diesel (2:3)	90.4	5.1	3.56
	Bitumen + Diesel (2:3)	90.7	5.0	3.16
	Cold Lake + Diesel (1:1)	89.2	5.8	3.68

a: Oil addition: 0.6% single-stage and 1.1% two-stage.
b: Ohio coal; Forms of sulphur: 2.92% pyritic, 0.26% sulfatic and 1.51% organic.

Table 2.10. Effect of bridging liquid composition on Aglofloat process performance[a].

Bridging liquid[b] composition	Cleaned coal Combustibles recovery (%)	Ash (%)	Total sulphur (%)	Tailings ash (%)
Parent Coal[c]		9.2	4.72	–
50%-50%	94.5	7.2	4.52	53.1
55%-45%	95.7	7.0	4.56	50.6
60%-40%	77.2	5.8	3.83	20.0
65%-35%	63.7	5.4	3.72	16.0
70%-30%	33.8	4.5	3.39	11.7

a: Single-stage; 0.6% of bridging liquid addition.
b: Mixture of Cold Lake bottom and diesel oil.
c: Ohio coal.

ing oil was decreased, the performance of the Aglofloat also decreased (Table 2.9 to 2.11).

The poor Aglofloat performance, at low diesel oil concentrations in bridging oil, was significantly improved by the addition of selected surfactants (i.e., polydimethyl siloxan) suggesting that poor coal recovery at diesel concentrations of 50 percent or less is due to the bridging oil's lesser affinity to coal. The role of the surfactants would be, therefore, to change the charges on the coal surface or to improve emulsification of the bridging oil by changing charges on oil droplets. Both hypothesis are plausible and should be further studied.

Table 2.11. Effect of bridging liquid composition on Aglofloat process performance[a].

Bridging liquid[b] composition	Surfactant	Cleaned Coal Combustibles recovery (%)	Ash (%)	Total sulphur (%)
Parent Coal[c]		–	9.2	4.72
50%-50%	–	94.5	7.2	4.52
70%-30%	–	33.8	4.5	3.39
50%-50%	+	91.3	5.7	3.85
70%-30%	+	90.1	5.4	3.88

a: Single-stage; 0.6% of bridging liquid addition; b: Mixture of Cold Lake bottom and diesel oil; c: Ohio coal.

Table 2.12. Beneficiation of Byron Creek fines by Aglofloat process.

Process Conditions: Solids concentration (%)	Oil addition[a] (%)	Additives	Combustibles Yield (%)	Recovery (%)	Ash (%)
Initial Feed			–	–	21.9
10	0.6	–	77.0	86.2	12.5
10	0.6	+	84.8	94.0	13.4
25	0.6	+	85.4	93.9	14.0
25	5.0	+	90.0	95.8	15.8

Note: All values on dry basis.
a: Brooks oil.

2.2.6. Treatment of Western Canadian Coals

A series of separate tests were conducted for beneficiation of western Canadian coals, including coal fines reject and precipitator dust from coal preparation plants. In general, use of the Aglofloat procedures and bridging oil formulation developed for the U.S. coals gave poor combustibles recovery and ash reduction (Tables 2.12 and 2.13). Only after the formulation of special bridging oils and the addition of surfactants, were the results with western Canadian coals comparable to those with U.S. coals.

Byron Creek Fines and Reject

Tables 2.12 and 2.13 show that for coal concentration of 25 percent, high performance of the Agflotherm process (combustibles recovery >90 percent, etc.) can be obtained only with high bridging oil concentrations and the addition of surfactants.
Both Brooks oil and Cold Lake bitumen gave high combustibles recovery and large ash reduction for a bridging oil concentration of 5 percent, dry coal basis.

Table 2.13. Beneficiation of Byron Creek fines by Aglofloat process.

Process Conditions: Solids Concen-tration (%)	Oil addition[a] (%)	Additives	Combustibles: Yield (%)	Combustibles: Recovery (%)	Ash (%)
Initial Feed			–	–	21.9
10	0.6	–	71.2	79.5	12.7
10	0.6	+	83.1	92.5	13.1
25	0.6	+	80.4	89.5	13.0
25	2.0	+	84.4	93.0	13.5
25	5.0	+	86.7	94.2	14.1

Note: All values on dry basis.
a: Cold Lake bitumen blend.

Table 2.14. Recovery of combustible material from Byron Creek fines by Aglofloat process[a].

Oil addition[b] (%)	Yield (%)	Combustibles Recovery (%)	Ash (%)
Initial Feed	–	–	21.9
0.25	62.6	70.3	12.3
0.30	72.7	80.6	13.3
0.60	80.4	89.5	13.0
2.00	84.4	93.0	13.5
5.00	86.7	94.2	14.1

Note: All values on dry basis.
a: Single-stage with surfactant addition;
b: Cold Lake bitumen blend.

Table 2.14 depicts the effect of the addition of bridging oil on recovery of combustible materials using the single-stage Aglofloat process with surfactant addition. As the bridging oil concentration approached 2 percent or more, high combustibles recoveries were observed. However, the final product also had increased mineral matter content. As shown in Table 2.15, the type of bridging oil did not make a significant difference to the process performance or product yield.

Table 2.16 compares the results of the two-stage Aglofloat process to procedures which use a combination of wet grinding, Aglofloat and agglomeration with high oil concentration (20 percent). The latter procedures were intended to test whether further grinding of fines would improve the ash rejection. The results show that no significant improvement was obtained. The lower results for the Aglofloat plus agglomeration process configuration were primarily due to the dilution effect of oil.

Table 2.15. Beneficiation of Byron Creek fines by Aglofloat process.

Bridging Oil[a] (%)	Solids concentration (%)	Combustibles Recovery (%)	Ash (%)
Initial Feed	–	–	21.9
Cold Lake bitumen blend	10	92.5	13.1
	25	89.5	13.0
Brooks oil	10	94.0	13.4
	25	93.9	14.0

Note: All values on dry basis.
a: Oil addition 0.6% on dry feed.

Table 2.16. Beneficiation of Byron Creek fines - effect of additional grinding on deashing.

Experimental Procedure	Oil Addition[a] (%)	Yield (%)	Combustibles Recovery (%)	Ash (%)
Initial Feed		–	-	21.9
Two-Stage Aglofloat	2 + 2[b]	86.4	94.7	13.5
Wet grinding followed by Aglofloat	2	87.6	94.6	13.6
Wet grinding followed by Aglofloat and Agglomeration	2 + 20[b]	82.7	91.0	10.1

Note: All values on dry basis.
a: Brooks oil; b: Oil addition in each stage.

Table 2.17 depicts the effect of the type and amount of bridging oil, with and without additives, on the recovery and ash content of combustible materials from Byron Reject, using the single-stage Aglofloat process. Observations were similar to those for Byron fines (Table 2.14); as the bridging oil concentration increased, combustibles recovery and product ash increased. The type of oil seemed to have some effect on both product yield and combustibles recovery, as Brooks oil resulted in higher recoveries than did Esso Oil-bitumen blend.

Table 2.18 shows the effect of product yield and combustibles recovery on product ash content. As expected, higher product yield resulted in higher combustibles recovery and somewhat higher ash content of agglomerates.

Table 2.17. Beneficiation of Byron Creek reject by single-stage Aglofloat process.

Bridging Liquid Type	Addition (%)	Additives	Combustibles Yield (%)	Recovery (%)	Ash (%)
Initial Sample			–	–	47.1
	0.6	–	45.2	62.8	26.9
	0.6	+	55.5	76.3	27.8
Brooks	1.0	+	57.5	82.6	28.6
	5.0	+	74.3	96.7	34.5
	0.6	–	17.0	25.7	20.5
Esso	0.6	+	41.4	59.0	25.0
Bitumen	1.0	+	51.8	71.2	28.0
Blend	5.0	+	65.1	87.7	32.2

Note: All values on dry basis.

Table 2.18. Effect of process performance on product quality.

Experimental procedure	Yield (%)	Combustibles Recovery (%)	Ash (%)
Byron Creek Reject	–	–	47.1
Single-stage	57.5	82.6	28.6
Wet grinding followed by by single-stage	64.5	86.3	30.3
Two-stage	49.4	73.3	22.6

Note: All values on dry basis.

Table 2.19. Recovery of combustible material from precipitator dust.

Experimental procedure	Process Conditions Oil addition (%)	Modifiers Surfact	Depress.	Yield (%)	Combustible Recovery (%)	Ash (%)
Initial Sample	–	–	–	–	–	27.5
	3.75	–	–	69.4	85.1	10.2
Aglofloat	3.00	+	–	65.3	82.1	9.6
	3.00	–	+	68.3	86.2	9.3
Agglomeration	16.75	–	–	70.0	84.2	7.9

Obed Precipitator Dust

A sample of precipitator dust from a coal washing plant was tested for beneficiation using the Aglofloat process procedures. The results of several bench tests using a combination of bridging oil at different concentrations plus surface modifiers are shown in Table 2.19. The results show consistently low yields and combustibles recovery (80 to 90 percent) as compared to the Aglofloat results for U.S. coals (in the high 90's). What is interesting, is that with the Aglofloat process the recovery of Obed washed coal was much better than the recovery of Obed precipitator dust (Table 2.20). High yield and high combustibles recovery (95 percent) were achieved for all runs with Obed washed coal including those with oil concentrations of 1 percent and those in which surfactants were used. This suggests that specially suited surfactants might improve recovery of Obed precipitator dust.

In an attempt to obtain better ash reduction in Obed washed coal, two coal samples of different sizes were processed using the Aglofloat procedure. The results suggest (Table 2.21) that ash in the coal is uniformly and finely distributed and that further pulverization would provide little improvement in ash removal.

A summary of the test results with Obed precipitator dust, using different additives is depicted in Table 2.22. It is shown that by using a combination of additives and bridging oil concentrations, good ash reduction and reasonable combustibles recovery can be obtained. The procedures call for high oil concentration (3 percent) as compared to the bridging oil concentration for U.S. bituminous coals (0.5 percent).

2.2.7. Green Agglomerates Handling

A two-step procedure was tested for drying of green agglomerates: 1) pressure filtration of the agglomerates; and 2) subsequent low temperature drying of pellets made from pressure filter cake (Figure 2.8, Table 2.23). The results suggested that dry, solid agglomerates can be obtained by pelletizing the clean coal filter cake.

Table 2.20. Beneficiation of Obed washed coal by Aglofloat process[a].

Additives	Yield (%)	Combustibles Recovery (%)	Ash (%) Actual	Ash (%) Rejection
Initial feed			14.2	–
+	95.8	99.2	11.0	~26
+	92.2	96.1	10.5	~31
-	93.3	97.3	10.6	~30

Note: All values on dry basis.
a: Conditions: Solids concentration – 20% on dry basis; Bridging liquid – bitumen & diesel (2:3); Oil addition – 1% on dry solids.

Table 2.21. Beneficiation of Obed washed coal by Aglofloat process[a].

Particle Size (mm)	Yield (%)	Combustibles Recovery (%)	Ash (%) Actual	Ash (%) Rejection
Initial feed			14.2	–
100% minus 300	92.2	96.1	10.5	~31
100% minus 150	94.9	98.1	10.9	~25

Note: All values on dry basis.
a: Conditions: Solids concentration - 20% on dry basis.Bridging liquid - mixture of bitumen and diesel; Oil addition - 1% on dry basis.

Table 2.22. Beneficiation of Obed precipitator dust.

Experi-mental procedure	Oil addition (%)	Additives	Combustibles Yield (%)	Combustibles Recovery (%)	Ash (%)
Initial Feed			-	-	27.7
Single-Stage Aglofloat	3.0	Surfactant	65.3	82.1	9.6
	3.0	Depressant	68.3	86.2	9.3
	3.0	Surf.+Depr.	67.8	85.5	9.4
	3.75	Surfactant	69.4	85.1	10.2
Aglofloat followed by Agglomeration	16.75 (3.75+ 13.4)a	Surfactant	70.0	84.2	7.9

a: Oil addition in each step

Table 2.23. Dewatering of Aglofloat product[a] by pressure filtration[b].

Product	Cake-forming time(s)	Drying time(s)	Cake moisture (%)
Single-Stage	8	–	28.4
	8	120	17.6
Two-Stage	12	–	59.3
	12	120	31.4

a: Upper Freeport coal; Bitumen and diesel (2:3) – bridging liquid; Oil addition – 0.6% for single-stage procedure; 1.0% for two-stage procedure.
b: Conditions: Pressure – 40 psi; Cake Thickness – 16 mm.

2.3. Conclusions

Cleaning of bituminous coal was demonstrated using the Aglofloat process in the batch laboratory experiments. Addition of a combination of bridging oil and surfactant, in single- and two-stage Aglofloat procedures tests, resulted in product agglomerates with a heating value of 13,000 Btu/lb or less, ash content of 10 percent or more, and reduced total sulphur content of 30 percent or better. Total pyritic sulphur in coal was reduced up to 95 percent.

Two types of tests were used in the laboratory experiments: single-stage and two-stage tests. The two-stage Aglofloat procedure was a combination of two single-stage tests with inter-stage grinding.

Six high sulphur bituminous coals from the U.S. and four coal products and by-products from preparation plants in Alberta were evaluated. In general, the Aglofloat procedures and bridging oil formulation developed for U.S. coal did not perform well with the Alberta coals, and special bridging oil formulations which included the addition of surfactants were required for the Alberta coals.

Tests comparing the performance of single- and two-stage Aglofloat with the U.S. coals showed that although the two-stage process resulted in the removal of more ash and inorganic sulphur, it also resulted in a higher loss of combustible materials. The choice of single- or two-stage process would therefore depend on the level of cleaning and coal recovery required for each specific coal.

Comparison of the single-stage process to the float and sink test suggested that both can be used as a measure of the ease with which mineral matter can be separated. The washability curves were similar for both methods.

Good separation of mineral matter and pyrite was obtained for a wide range of coal and oil concentrations. However, with oil concentrations less than 0.5 percent, combustibles recovery decreased rapidly. The minimum oil concentration required depended on the coal properties, e.g., Byron Creek fines required 5 percent of oil for a 95 percent combustibles recovery while Illinois No. 6 required only 1 percent.

Bridging oil properties did not significantly affect the Aglofloat performance, provided that the content of diesel in the bridging oil was kept above 40 percent. At lower diesel oil concentrations, with Cold Lake bottom, the Aglofloat performance deteriorated. The performance could, however, be restored with the addition of surfactants, suggesting that poor coal recovery might have been due to a lesser affinity of the major bridging oil component (Cold Lake bottom) for coal.

A series of separate tests were conducted with western Canadian coals to modify the Aglofloat procedures for these coals. With these coals the Aglofloat performance was more affected by the bridging oil concentration and properties, by the surfactants added, and by the coal properties than was the case with U.S. coals. As a result, a special bridging oil formulation was developed for western Canadian coals. The Aglofloat procedure as modified for use with western Canadian coals also required the addition of 3 percent of oil versus 0.5 percent for the U.S. bituminous coals.

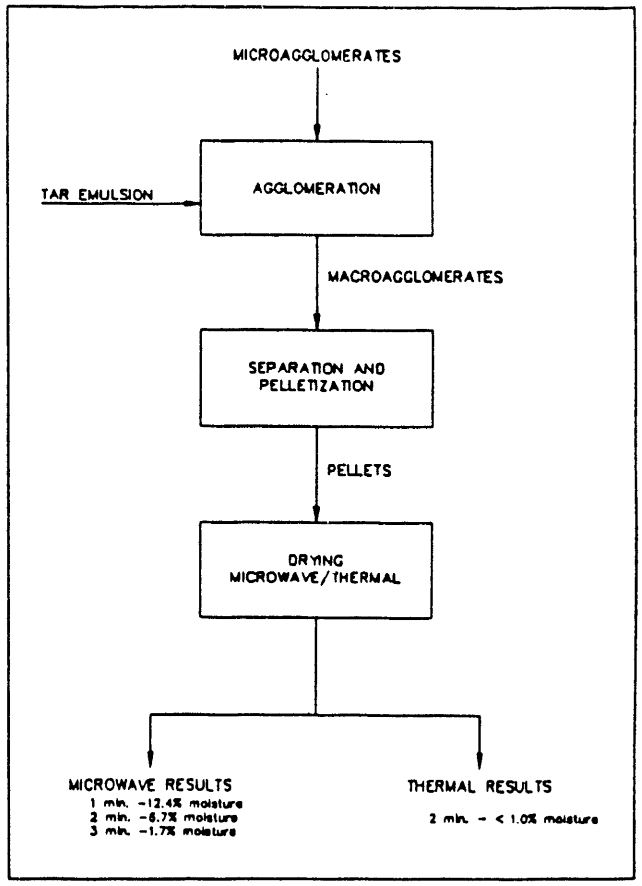


Figure 2.8. Green agglomerates drying tests.

3. Design Studies of Agglomeration Mechanisms

3.1. Fundamentals of the Aglofloat Process

In Volume 1, "Upgrading of Low Rank Coals: the Agflotherm Process", a model of spherical agglomeration for prediction of the growth pattern of the agglomerates was presented. However, this description was limited to agglomeration conditions characterized by over-critical bridging oil concentration. This section, describes the model's principles and application in conditions characterized by under-critical bridging oil concentration, conditions which are more relevant when explaining agglomeration mechanisms in the Aglofloat process.

Like agglomeration in the Agflotherm process, agglomeration in the Aglofloat process begins with the formation of pellets from finely pulverized coal particles suspended in water. Agglomeration results from inter-particle collisions and adhesion of particles in a high shear agitation vessel in the presence of bridging liquid. The integrity of the agglomerate depends very much on the capillary forces caused by the presence of bridging oil between the particles. The strength of the capillary forces, which determines the tensile strength of the agglomerate, depends on the amount of bridging oil in the pore structure of the agglomerate.

The states of liquid saturation have been identified as pendular, funicular and capillary (Figure 3.1). In the pendular state, a small quantity of oil results in formation of liquid bridges between individual par-

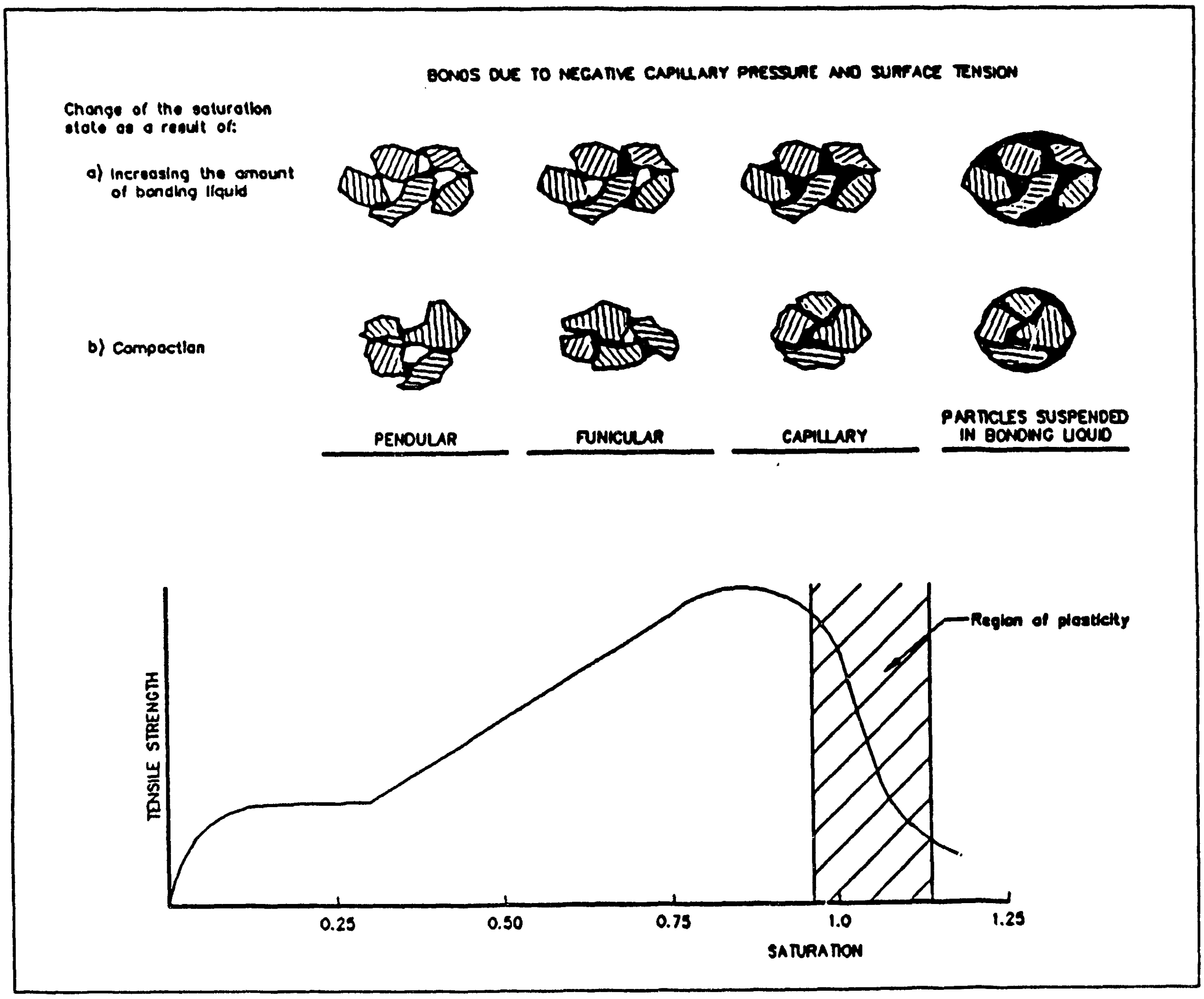


Figure 3.1. Schematic representation of agglomerates formation.

ticles. In the funicular state, oil bridges coexist along with some pores which are filled totally with bridging oil, while in the capillary state the pore space between particles is completely filled with oil.

Figure 3.1 depicts the relationship between the strength of the agglomerates and bridging oil saturation. The agglomerates' strength approaches its maximum when saturation exceeds 0.8, i.e., at its capillary state.

Growth Pattern for Under-Critical Oil Addition

Szymocha et al. (1989) have recently presented a model of a spherical agglomeration process based on the ARC and University of Alberta work on coal agglomeration in pipeline loops and stirred vessels and on published models of agglomeration. The model presents a number of technical implications for the Aglofloat process, as well as conceptualizations of the process. Some of the key features of the mechanism of this model are presented below.

The model postulates that the growth of agglomerates proceeds in a step-wise manner with three growth steps distinguished, i.e., primary, secondary and tertiary agglomerates formation steps (Figure 3.2). Each growth step is characterized by a different growth rate, growth factor and duration. Depending on the complexity of the system and the agglomeration condition we can see a succession of the agglomerates saturation states (pendular, funicular and capillary) for each growth period (Figure 3.3). A description of each growth period presented in Figure 3.3 is given below.

Wetting Period: No growth of agglomerates is observed in this period. The intensive mixing of the coal-water and bridging oil slurry results in dispersion of the bridging oil into fine droplets which are absorbed into the coal particles. The wetting period ends with phase inversion, i.e., the slurry suspension changes color and small flocs made of coal and bridging oil are formed. The inversion is considered complete when the slurry starts to show separation between coal and mineral matter.

Growth Period: This period starts with the thickening of the flocs and their coalescence, and with formation of primary agglomerates. The state of the primary agglomerates changes from pendular to funicular which results in an increase in the strength of the agglomerates. The number of particles per aggregate may range from two to five, depending on the bridging oil concentrations, with the agglomeration and redispersion of the aggregate acting as size averaging factors.

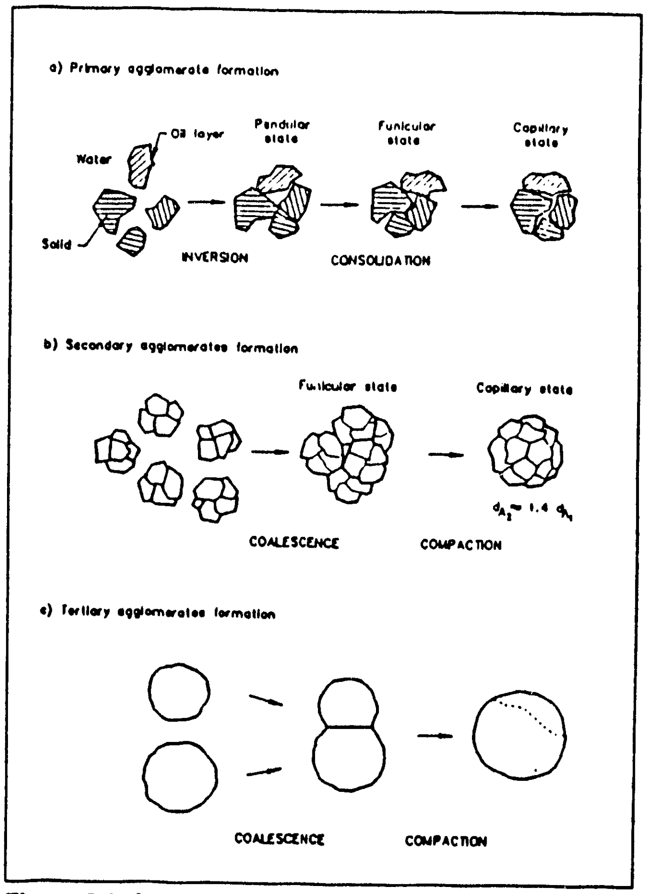


Figure 3.2. Agglomerate formation stages.

Consolidation Period: The agglomerates are further densified (compacted) during the consolidation period and porosity of the agglomerates is gradually reduced with available bridging oil filling up the pore space. The result is a shift of agglomerates from a funicular to a capillary state and a further increase of agglomerates' strength. In this state, referred to as the dry surface state, the amount of bridging oil at the agglomerate surface (outside) is not sufficient to coalesce the impacting agglomerates. However, as agglomeration proceeds, further densification of the agglomerates results in the "squeezing out" of the bridging oil, and formation of a wet surface state which is reflected in lower strength and increased plasticity of the agglomerates. The increased plasticity of the agglomerates sets a favorable condition for deformation and coalescence of the surface wet

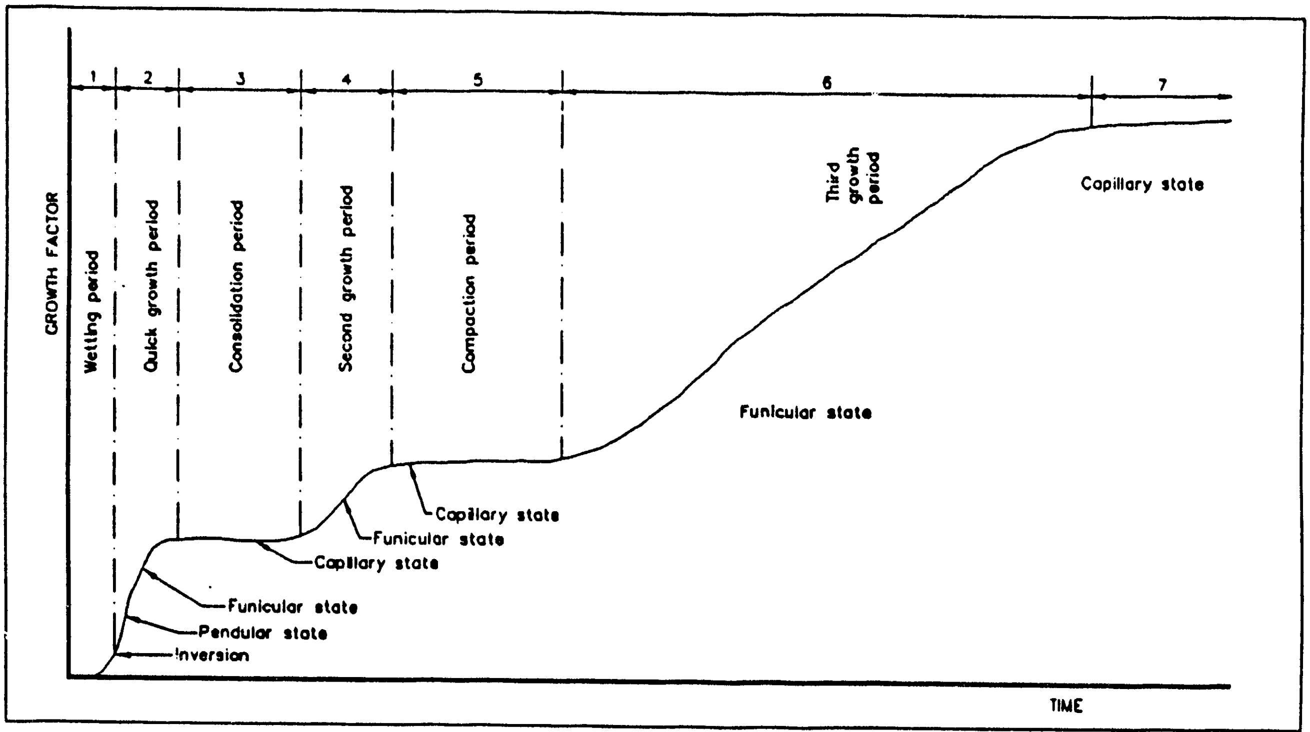


Figure 3.3. Relationship between growth factor, growth periods and oil saturation states.

agglomerates, and for initiation of the second growth period.

Second Growth Period: In the second stage of agglomerate growth, primary agglomerates aggregate into larger secondary agglomerates which have a "raspberry" type structure, and, initially, are in a funicular state (Figure 3.2b). The growth rate is determined by the fusion of the primary agglomerates, which depends on the plasticity of the aggregate.

Compaction Period: The assemblages created during the second agglomerate growth period are in the funicular state. Subject to compaction, the secondary agglomerates undergo plastic deformation and porosity reduction and gradually acquire a spherical shape and a smooth surface. They can be in a dry or wet surface state depending on the bridging oil concentration. If they are in a wet surface state, the agglomerates will undergo a third growth period.

Third Growth Period: Typically at this stage, the assemblages are already large and further growth involves collision of these assemblages, usually in pairs, to create bigger ones. After compaction, newly created assemblages can participate once more in the growth process (collision, bonding, deformation, compaction) until a final dry surface state is achieved. The final size of the agglomerates is, therefore, a function of the amount of bridging oil.

Equilibrium Period: After reaching the final dry state, the agglomerates are very strong and rigid. They do not possesss sufficient plasticity to deform and form bonds on collision. The "equilibrium" state agglomerates can keep a constraint size for a prolonged time. In one experiment reported, it took over 300 hours of hydrotransportation before any breakage occurred (Pawlak et al., 1985).

Effect of Bridging Oil Addition on Final Agglomerate Size

Four different growth patterns can be distinguished depending upon the amount of bonding liquid – regions A, B, C, and D in Figure 3.4. Each region is characterized by a different number of growth periods and different growth factors. For example, in region A, for relative oil concentration below 0.42, only one growth period is observed. The primary agglomerates achieve a final size which does not undergo any further changes under prolonged agitation. Growth factor d^* for region A varies from 1 (at C^*=0.04) to 1.6 (at C^*=0.42). Where

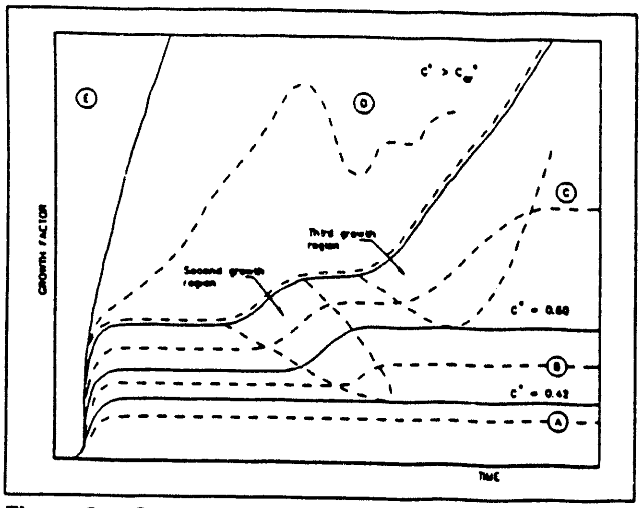


Figure 3.4. Growth regimes for the agglomeration process.

$$C = \frac{C_o}{C_{ocr}}$$

and

C_o = oil concentration, % d.a.f. basis
C_{ocr} = critical oil concentration, % d.a.f. basis

In region B (i.e., relative oil concentrations C^* in the range from 0.42 to 0.60), growth takes place in two steps. In the first step, the growth factor increases from 1.6 (at $C^* = 0.42$) to 1.9 (at $C^* = 0.60$), and for the second step, from 1 to 1.4. As a result of this two-step growth, the particle size increases from 1.6 (at $C^* = 0.42$) to 2.6 (at $C^* = 0.60$). In region B, as compared with region A, a longer agglomeration time is needed to complete the growth of agglomerates.

In region C, three growth steps are distinguished. In the first step, the size of agglomerates increases from 1.9 (at $C^* = 0.60$) to 2.60 (at $C^* = 1.0$). In the second step, the size increases by a factor of 1.4. Figure 3.4 shows the increase in size during the third growth step. In region C, the time required to reach the final size is significantly longer than for region B.

If oil concentration exceeds the critical value (C^* 1), growth accelerates; growth periods start overlapping and eventually become indistinguishable. In region D, the agglomerates grow very quickly, but their growth rate varies remarkably and finally the system enters the size instability region. As the relative oil concentration increases, the maximum size of agglomerates diminishes. In region E (see Figure 3.4), because of a significant excess of oil, agglomeration does not proceed and the product is recovered in the form of a paste.

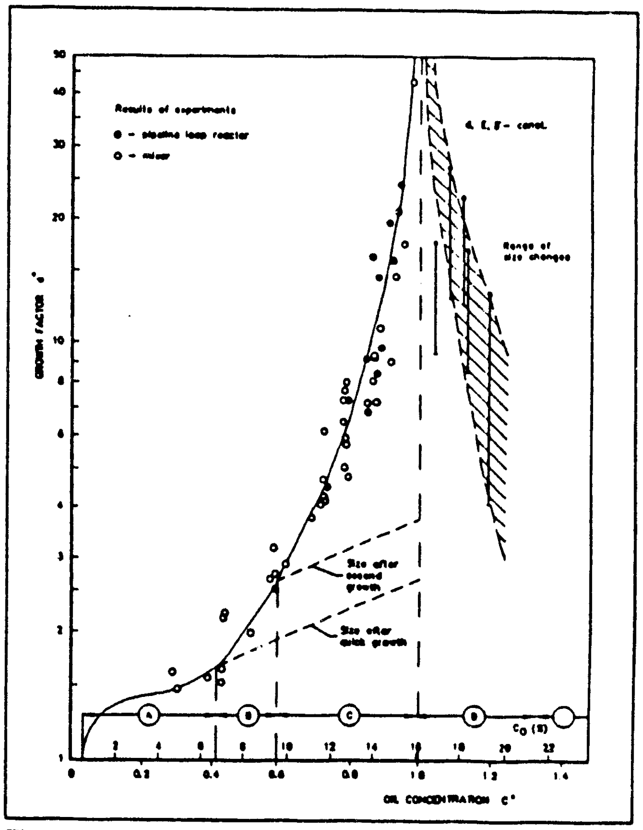


Figure 3.5. Relationship between growth factor and oil concentration.

Experimental results for a range of oil-coal concentrations are presented in Figure 3.5. These results support the Sherrington model (Sherrington, 1968) and confirm that the median diameter of the agglomerates increases exponentially with the amount of bridging liquid.

The relationship between the growth factor d* and the oil concentration C_o can be obtained from the following equation:

$$d^* = \frac{t}{1 - \left[\frac{1-\varepsilon}{\varepsilon} \; \frac{q_s}{q_L} \; \frac{C_o}{100}\right]^{1/3}}$$

Where:
d^* = growth factor (d_A/d)
t = withdrawal factor

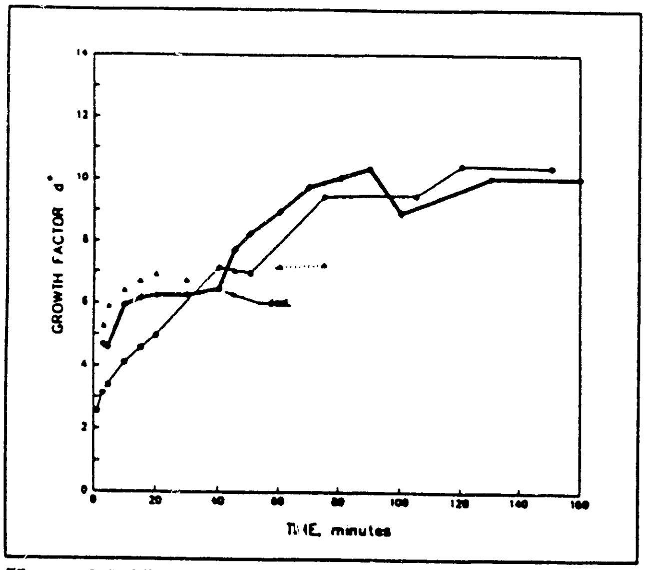


Figure 3.6. Kinetics of Agglomeration process of Illinois #6 coal. ● d_{50}=225 μm, 1800 rpm; ◆ d_{50}=40 μm, 1800 rpm; ▲ d_{50}=40 μm, 1800 rpm.

ε = porosity of agglomerate (dimensionless)
q_S = solid density (kg/m^3)
q_L = liquid density (kg/m^3)
C_o = oil concentration, % d.a.f. basis

3.2. Batch Tests and Results

3.2.1. Kinetics of Bituminous Coal Agglomeration

Szymocha, et al. (1989) report that several factors influence the kinetics of coal agglomeration and the size of coal-oil agglomerates. A list of these factors appears in Section 3.2.1., Volume 1 of this report. The selected key factors studied in the agglomeration of bituminous coals were:

- coal particle size
- intensity of mixing
- oil concentration
- solids concentration
- coal desliming
- design of the mixer.

The results of the completed tests are depicted in Figures 3.6 to 3.10. The key conclusions which can be drawn from these tests are:

- The mean coal particle size, d_{50}, had an effect on the growth factor at the beginning of the process

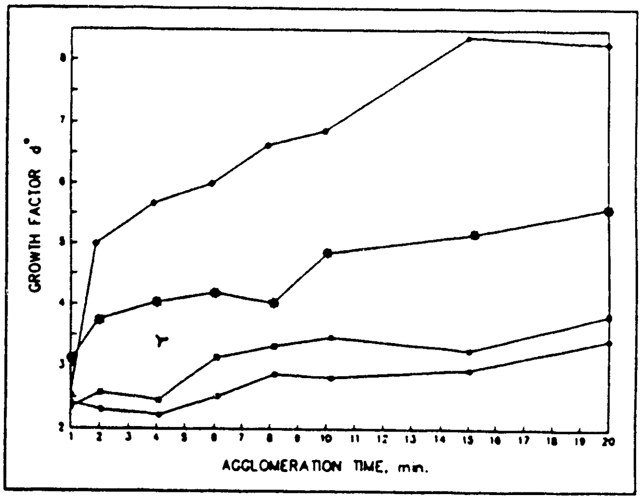


Figure 3.7. Kinetics of Agglomeration process for Dodds coal. ● C_0=14%; ■ C_0=18%; • C_0=22%; ◆ CO=26%.

(up to 40 minutes). When the agglomeration time was extended (40 min), the difference in growth factors for the particle size studied appeared to be negligible.
- Higher bridging oil concentration leads to larger growth factors at all agglomeration times (Figure 3.7). The effect of bridging oil concentration appears to be much stronger than the effect of factors such as intensity of mixing.
- The growth factor can sometimes vary quite significantly with only a small difference in bridging oil concentration, provided that sufficient agglomeration times are allowed (Figure 3.8).

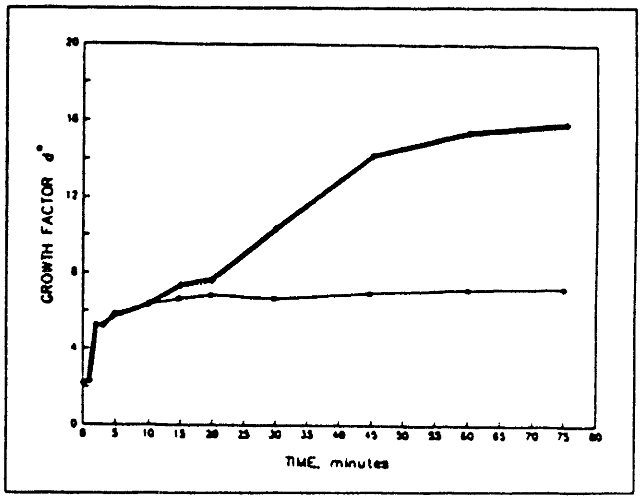


Figure 3.8. Influence of oil addition on growth agglomerates from Illinois coal (Mixer M-260). ● C_0=11%; ◆C_0=12.5%.

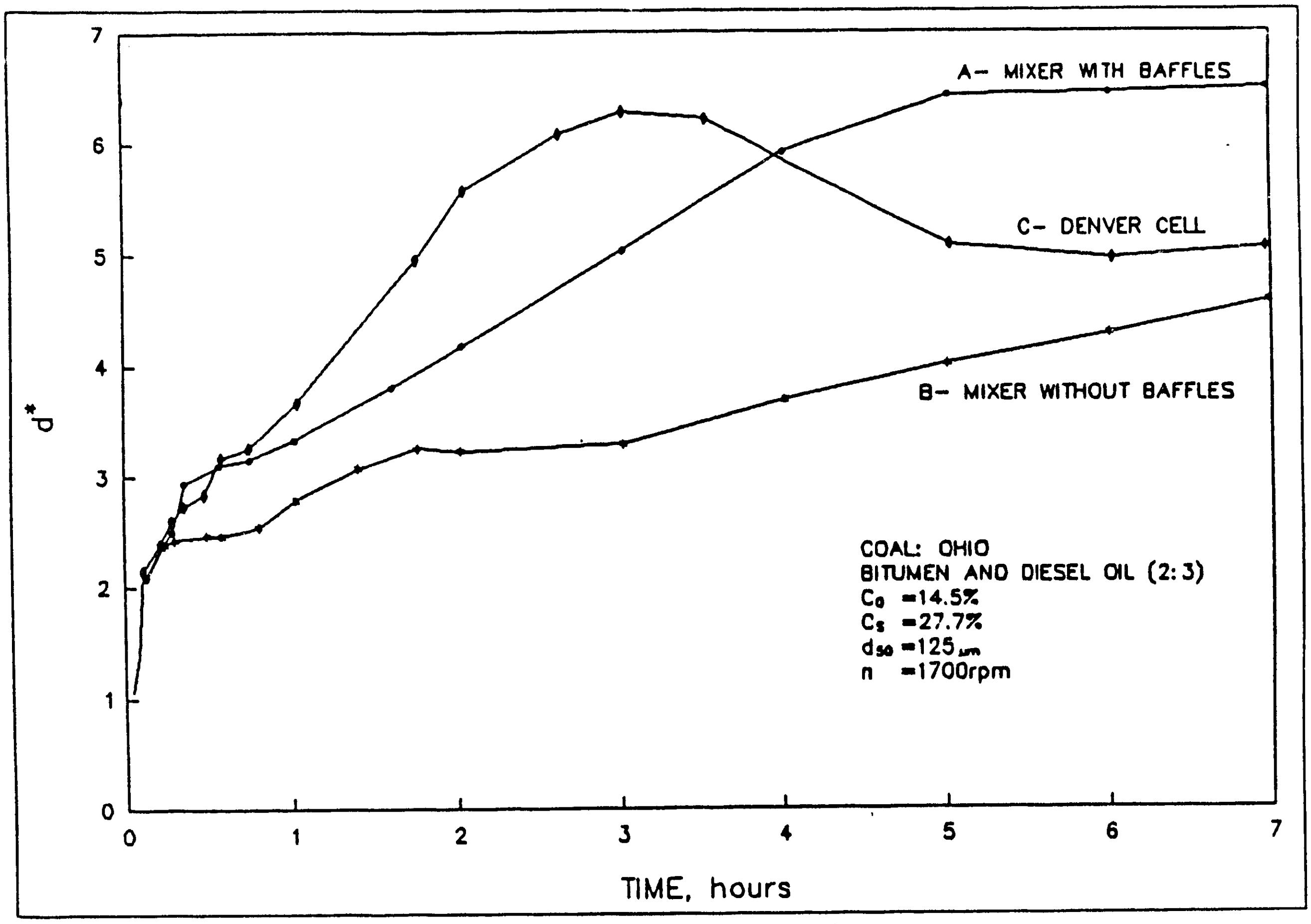


Figure 3.9. Batch tests on kinetics of the agglomeration process for Ohio coal.

- Design of the mixer can have a strong effect on the rate of growth and on the size of the product (Figure 3.9). Presence of baffles in the mixer often improves the agglomeration kinetics and product size.
- Desliming of coals containing a high percentage of mineral matter was found to have a significant effect on the agglomeration kinetics and the size of the agglomerates. Reduction of mineral matter content increased the agglomerate size by a factor of 2 (Figure 3.10).

3.3. Conclusions

A model describing the growth pattern of agglomerates during application of the Aglofloat process was developed. The model suggested that for under-critical bridging oil concentrations the size of the agglomerates depends on the amount of bridging oil. The model also postulated that the growth of agglomerates proceeds in a step-wise manner with three growth steps, each characterized by a different growth rate, growth factor and duration.

The effect of bridging oil addition on final agglomerate size was described by an empirical equation correlating the growth factor d^* and the oil concentration in the agglomerates. The experimental results showed good correlation between the predicted and actual agglomerates growth, at different oil concentrations. The strength of the agglomerates depends on the amount of oil, compaction and pore structure of agglomerates (Schubert, 1977, Tanaka et al, 1985).

The batch kinetic tests showed that the key factors influencing the agglomeration of bitumen coals were:

- coal particle size,

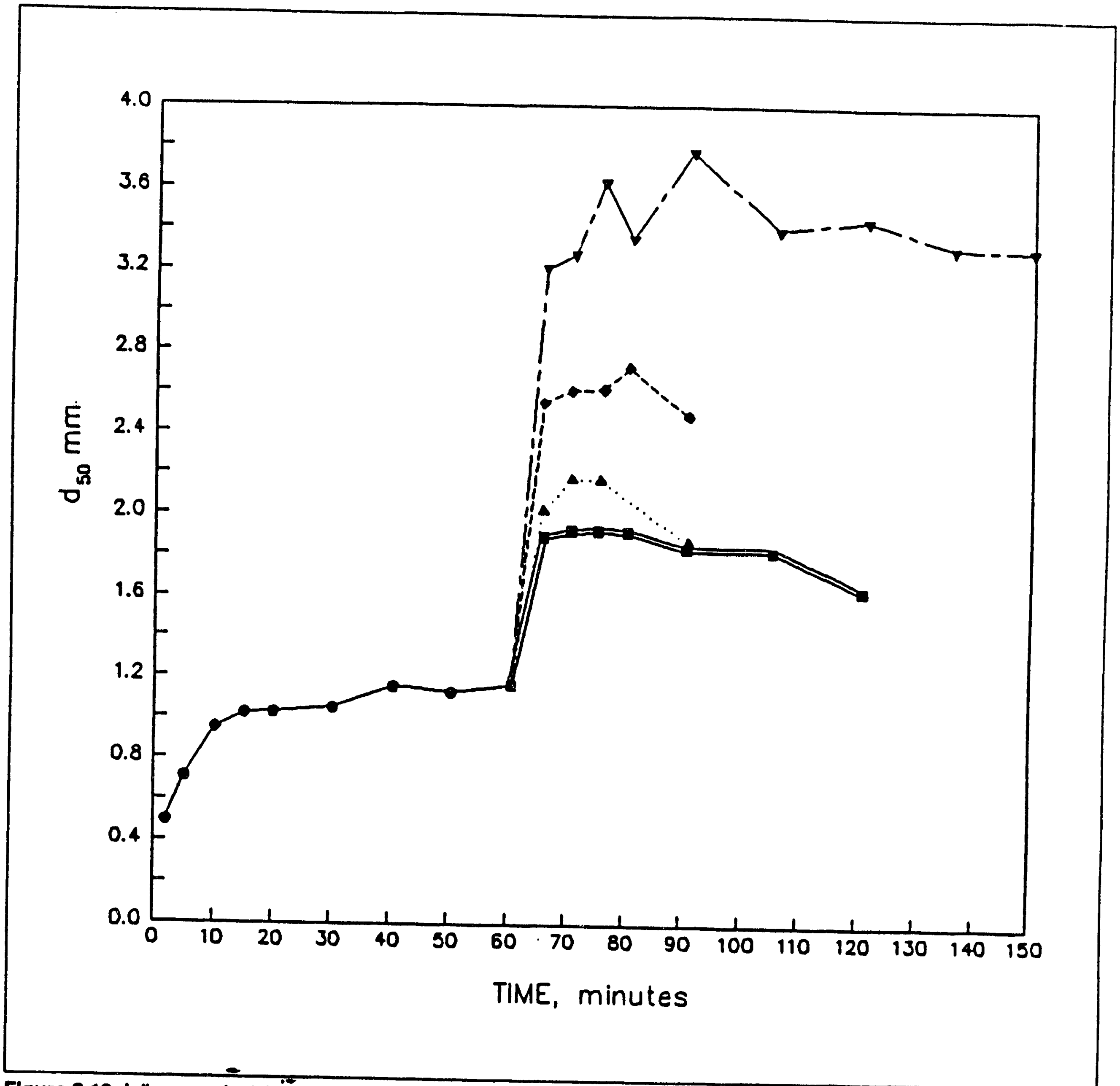


Figure 3.10. Influence of mixing rate and desliming on kinetics of agglomeration for Highvale coal. ● M-260, d_{50}=260 µm; ■ M-2, 1800 rpm; ▲ M-2, 1800 rpm desl.; ◆ M-2, 1300 rpm, desl.; ▼ M-2, 1300 rpm desl. no baffles.

- intensity of mixing,
- oil concentration,
- coal desliming, and
- design of the mixer.

The full effect of these factors on the agglomerate kinetics was considered in the development of the bench-scale continuous pyrite removal unit (CPRU) and pilot plant facilities (IATF) for the Aglofloat process. Details of the designs and experimental results obtained in the CPRU and IATF are presented in Chapter 4 and 5 of this report.

4. Continuous 5 kg/hr Pyrite Removal Unit (CPRU)

4.1. CPRU Design for the Aglofloat Process

The overall objectives of the Continuous Pyrite Removal Unit (CPRU) was to study the removal of small pyrite particles from the floatation flocs (see Appendix 3) and to investigate the process performance for different equipment configurations, particularly the flume (stationary bed) separator. A graphic representation of the flume separator appears in Appendix 3. The specific objectives were to evaluate the technical feasibility of using the flume and hydraulic separators for pyrite removal, to develop design criteria for scale-up of the hydraulic separator, and to assess the separator performance in terms of combustibles recovery and sulphur reduction.

4.1.1. CPRU Design Specifications

The bench-scale, continuous unit included equipment for conditioning of coal-water slurry, for agglomeration of the slurry, for floatation of the microagglomerates, and for pyrite separation from the coal flocs (microagglomerates).

The nominal design specifications for the CPRU were:

Solid Throughput: 2.5 to 7.5 kg/hr of coal (as received).

Equipment Configuration: a slurry conditioning tank followed by a high shear mixer, floatation cell and pyrite separator (hydraulic or flume separator).

Hydraulic Classifier: a 4.75 liter vessel consisting of floatation, washing and settling zones. A DENVER D12 floatation machine is used in the floatation.

Flume Pyrite Separator: a 110 mm wide and 700 mm long vessel with spiral feeder (transfer) for the frother, and total holding capacity of 1.8 liters.

Slurry Tank: 1.5 liter capacity, acrylic tank, with 1/8 hp agitator.

Agglomeration Tank: 1.4 liter capacity, acrylic tank, with 1/8 hp agitator, and turbine impeller.

Utilities: water, 2 liters per minute; electricity, 50 amp 110 V.

Space: 10 square meters, with a floor track drainage system.

The following sections describe the equipment used, the work performed and the design methods developed in the CPRU.

4.1.2. CPRU Process Flowsheet

Figures 4.1 and 4.2 present two CPRU process configurations. The unit includes the following major equipment.

- slurry conditioning tank
- high shear agglomeration tank
- floatation cell (or flume pyrite separator)
- hydraulic classifier

4.1.3. Major Equipment and Instrumentation

Slurry Conditioning Tank

The coal slurry conditioning tank is made of acrylic pipe with a conically shaped bottom and has a capacity of 1.49 liters at 1200 rpm. It has a 139 mm internal diameter and is 210 mm high. The tank is equipped with a mixer set. The mixer set has a 1/8 hp motor and one mixing impeller.

High Shear Agglomeration Tank

The high shear tank has a capacity of 1.43 liters at 1750 rpm, an inside diameter of 126 mm, an inside depth of 206 mm, and a centerline depth of 230 mm. It is equipped with a 1/8 hp mixer with a turbine impeller.

Floatation Cell

The floatation cell has a working volume of about 2.75 liters at 100 rpm. The cell is equipped with a overflow weir device which controls the pulp level and extended froth retrieval paddles.

Hydraulic Separator

The hydraulic separator has a working volume of 4.75 liters at 1100 rpm (Figure 4.3). The separator is cylindrical in shape and has three zones:

- **Washing zone:** The washing zone is rectangular in shape with a length of 104 mm, a width of 85 mm, and a depth of 103 mm. The dimensional volume of the wash zone is about 1.1 liters, however, the zone is equipped with high penetration water wash nozzles and the working

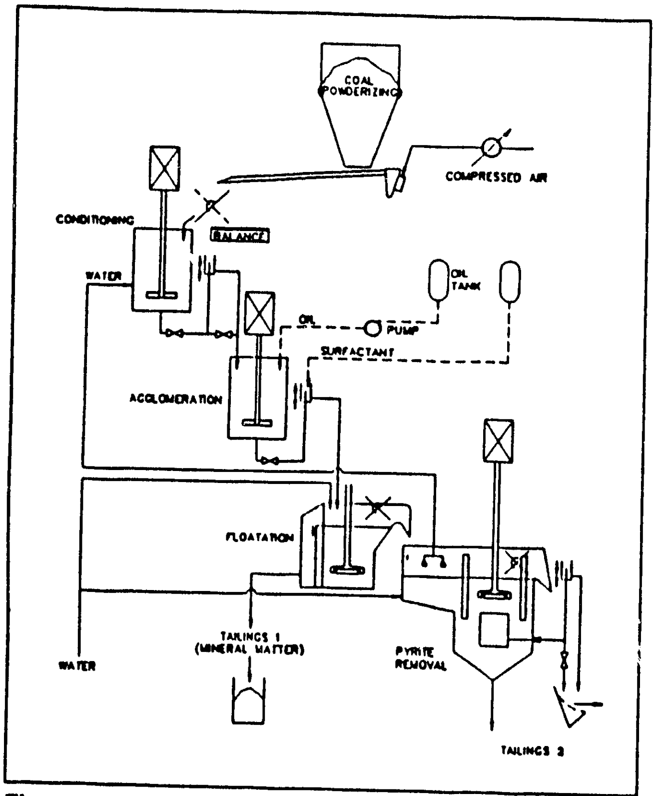


Figure 4.1. Continuous pyrite removal bench unit (system 1).

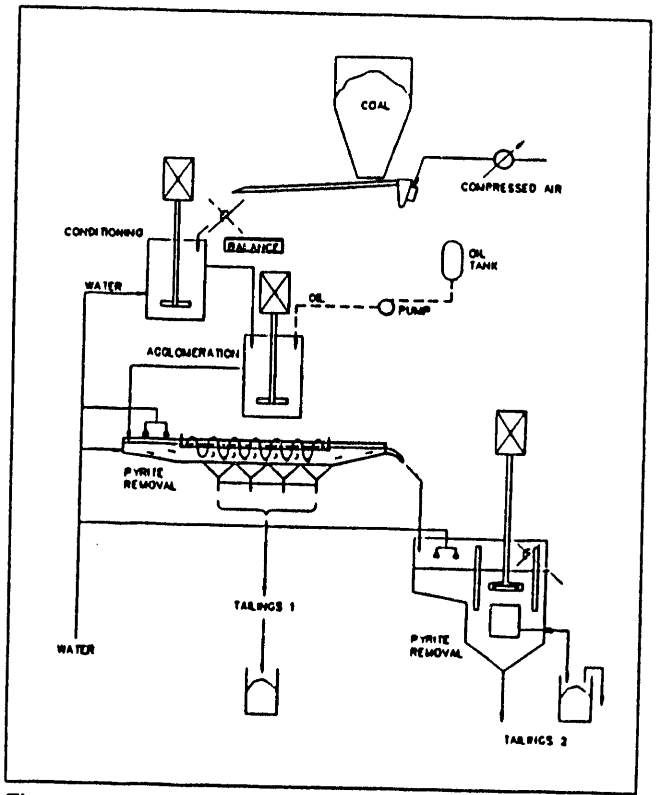


Figure 4.2. Continuous pyrite removal unit (system 2).

volume is expected to be lower. The water wash nozzles can operate in the 6 to 30 kg/h range and they penetrate the froth about 50 mm.

- **Floatation zone:** The floatation zone is 140 mm in diameter, has a 149 mm depth and is equipped with long stationary baffles to dampen the axial motion of the floatation impeller within the settling zone. The baffles are 89 mm long and 12 mm wide. A DENVER Floatation Machine, Model D12, is used in the hydraulic separator and was equipped with a variable speed control, a rpm tachometer, and a self aeration impeller system. The approximate air input to the floatation cell is 1.4 liters/minute at 100 rpm.
- **Settling zone:** The settling zone is 131 mm in depth. The flow stabilizer is cylindrical in shape with a diameter of 60 mm, and an overall height of 88 mm. The bottom of the settling zone is conical in shape at an angle of 30 degrees.

Details of the hydraulic separator are given in Figure 4.3.

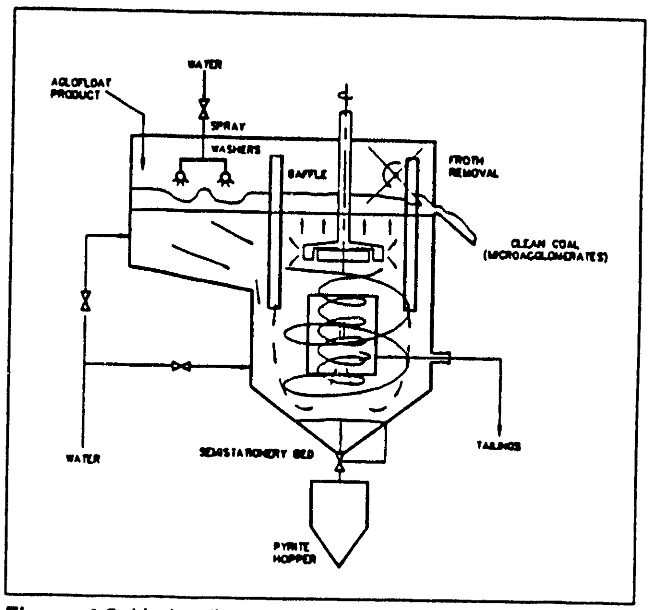


Figure 4.3. Hydraulic separator.

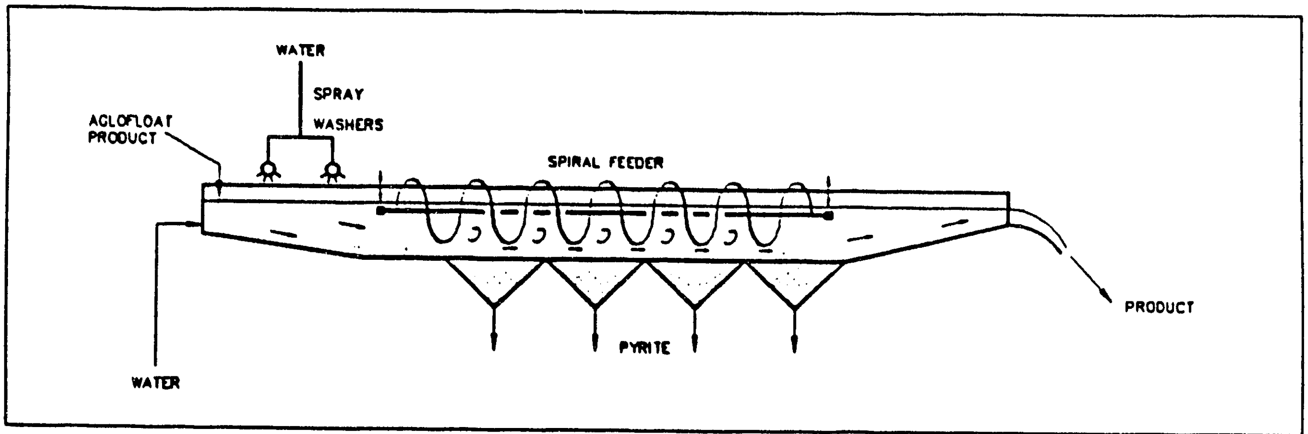


Figure 4.4. Flume separator.

Flume Pyrite Separator

The separator acts as a replacement for the floatation cell (Figure 4.2). The separator is 110 mm wide and 700 mm long. It has a total holding capacity of 1.8 liters. The separator is equipped with a spiral feeder (transporter) powered by a 1/8 hp motor-gear assembly (Figure 4.4).

The equipment operates by means of water flow which carries the washed microagglomerates to the bend sieve. Pyrite particles are collected in four stationary bed cones from where they are removed with the tailings.

4.2. CPRU Operating Experience and Optimization

4.2.1. Unit Commissioning and Results

The pyrite removal from coal microagglomerates or floatation flocs was investigated in two process configurations, namely:

1. System 1 consisting of a floatation cell followed by a hydraulic classifier (Figure 4.1).
2. System 2 including a flume pyrite separator and a hydraulic classifier (Figure 4.2).

In the initial tests, both systems were evaluated for their performance, then the results of these tests were compared to standard washability tests performed by DOE and ARC using Upper Freeport bituminous coal with pyrite content of 2.17 percent. The results of the evaluation tests are presented in Figure 4.5. Performance of both systems is closely correlated with the washability curve which suggests that:

- The primary mechanism (selection) in operation is that of separation of pyrite from coal material due to the gravity difference between these materials.
- The effectiveness of the separation for both systems, approached the separation limit for the Upper Freeport coal as defined by the washability test.
- For the conditions studied, System 1 yielded higher coal recovery and higher sulphur content in the product than System 2; however, operations at lower coal recovery would reduce the coal recovery and sulphur level in the clean coal product to levels shown for System 2.

The commissioning of the unit was conducted over a period of several months. The major equipment modifications implemented were:

- A second high shear mixer was installed in series to enhance the oil the combustible solids contact, to reduce the oil dosage requirement, and to improve the overall combustibles recoveries.
- A second floatation cell was designed, fabricated and installed in series with the floatation tailings to improve combustibles recoveries.
- Accumulation vessels were installed on both the floatation cells and the bench scale hydraulic separator to enhance the removal of sulphur and ash rich particles and to improve the repeatability of experimentation.
- A temperature controlled feed water source was installed to maintain higher system temperature,

to improve oil dispersion and coal/oil wetting within the high shear mixer.

Following the commissioning, the unit operated at its nominal capacity of 5 kg/hr of feed coal. Typical results for System 1 for Upper Freeport and Ohio coals are presented in Table 4.1.

4.2.2. Parametric Studies for Systems 1 and 2

Figures 4.1 and 4.2 present the two alternate pyrite removal process configurations studied (Systems 1 and 2). The major factors which varied in these studies were the coal feed rate and the bridging oil concentration. A summary of the completed test results follows.

System 1

Table 4.2 and Figure 4.6 depict the performance of System 1 for Upper Freeport bituminous coal using bitumen and diesel oil at a 2 to 3 weight ratio as bridging oil. The key conclusions and trends presented in Table 4.2 are:

- High combustible recoveries were obtained for the conditions studied, i.e., coal feed 2.16 to 5.14 kg/hr and oil concentration 2.4 to 6.2 percent.
- Over the range of coal feed rates and oil concentrations above, the total sulphur removal ranged from 28 to 36 percent, pyrite sulphur removal ranged from 46 to 59 percent and inorganic sulphur removal (pyrite + sulphites, etc.) ranged from 50 to 62 percent.
- The majority of the pyrite was removed in the floatation and separation steps (Figure 4.6).

System 2

Performance of System 2 with the Upper Freeport coal is summarized in Table 4.2 and Figure 4.7. The major conclusions from the data presented are:

- The percentage of sulphur reduction for Upper Freeport coal ranged from 39 to 49 percent for total sulphur, 50 to 72 percent for pyritic sulphur and 64 to 70 percent for total inorganic sulphur.
- The larger percentage of sulphur removal in System 2 as contrasted with System 1 may be due to higher sulphur contents in the coal feed samples. This conjecture is supported by the fact that the sulphur content is higher (total and pyritic) in the product of System 2, than in the product of System 1.

Table 4.2 also presents, for comparison, deashing and desulphurization data for Upper Freeport coal

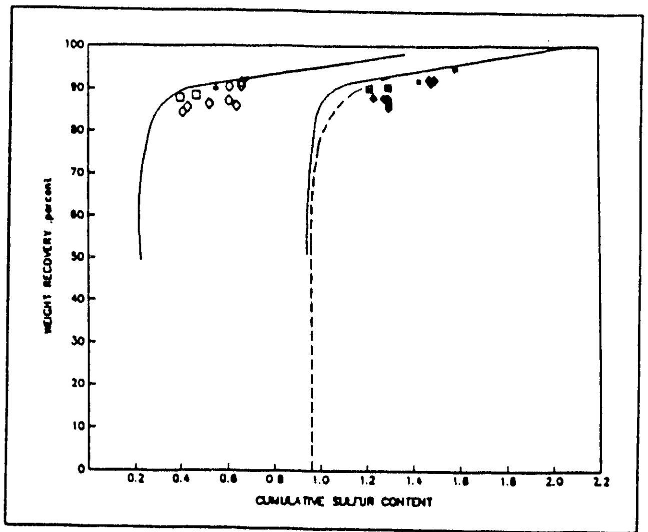


Figure 4.5. Cleaning of Upper Freeport coal by Aglofloat process in continuous pyrite separation unit (5 kg/hr).
□ syst 2, pyritic S; ◇ syst 1, pyritic S; ◆ syst 1, total S; ■ syst 2, total S; * batch test (single stage) — DOE wash. curves (d_{50}=114 μm); -- ARC Wash. curves (d_{50}=220 μm).

Table 4.1. Pyrite removal in CPRU (System 1)[a].

Coal	Feed		Product		Sulphur removal, %		
	Ash	Total sulphur	Ash	Total sulphur	Total	Pyr.	Inor.
Upper Freeport	12.2	2.3	8.4	1.6	36	51	54
Ohio	9.7	4.6	5.5	3.5	27	36	43

a: Feed rate ~ 5 kg/hr, oil addition ~ 2%.

using the single-stage Aglofloat procedure in a batch mode. This comparison suggests that the deashing and desulphurization performance of Systems 1 and 2 is equal or better than that which could be expected from the single-stage Aglofloat process. Table 4.2 also compares the performance of the CPRU to single- and two-stage batch processes. As indicated by the product properties, CPRU performance falls between the single- and two-stage processes.

Table 4.3 presents additional Aglofloat data for an equipment configuration which bypasses the floatation step and, therefore, indirectly indicates the importance and impact of the floatation step on the overall circuit performance in System 1. Comparison of the results in Table 4.3 for tests C-6 and C-7 with the results of the reference test C-5, suggests that

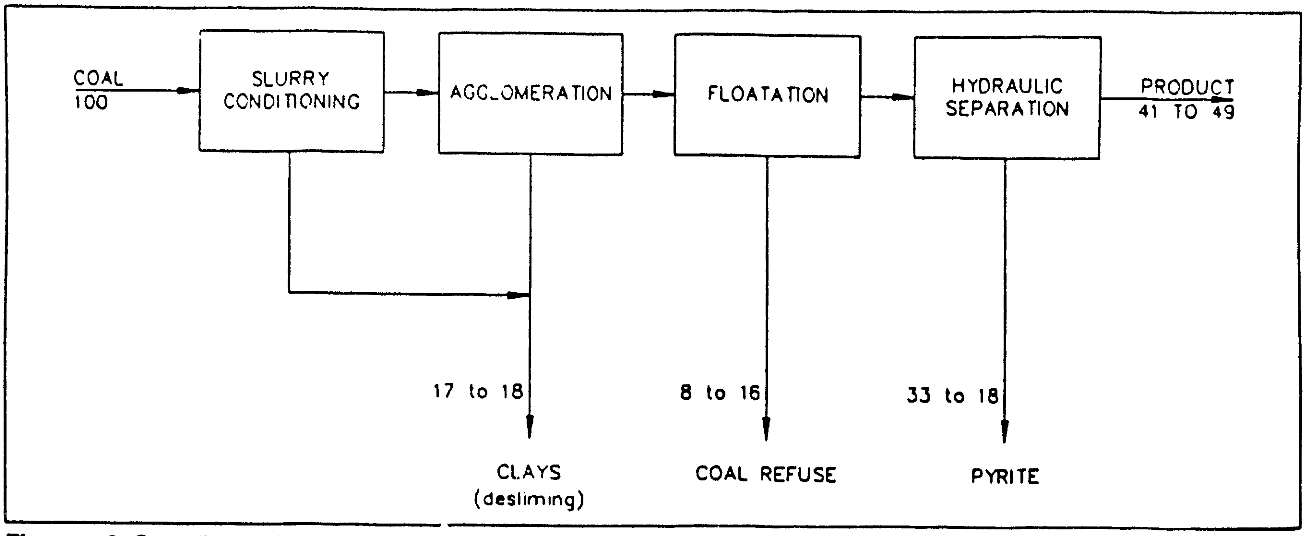


Figure 4.6. Overall material balance for pyrite removal for system 1 (Runs C-3 and C-5).

removal of 1/2 to 1/3 of the pyritic sulphur is possible during floatation and that this step is an important unit operation in the overall system (System 1). Bypassing the floatation cell not only decreases the overall pyrite removal but also reduces the performance of the hydraulic separator (Figure 4.8).

4.2.3. Steady-State Studies with Illinois #6 Coal

A series of tests was performed, using Illinois #6 coal, to establish the repeatability of the CPRU results and to evaluate steady-state operation of System 1. It was also felt that the combustibles recovery and the amount of bridging oil required could be improved by further refinement of the CPRU.

Figures 4.9 to 4.11 show the effect of variation in bridging oil addition in the range of 2.0 to 3.0 percent (dry coal basis) on combustible recovery, and total sulphur and pyrite sulphur in the products collected from the hydraulic separator. The key conclusions from these experiments were:

- For the oil concentration range studied, oil concentration did not influence the amount of combustibles recovered (Figure 4.9).

Table 4.2. Cleaning of Upper Freeport coal in continuous pyrite separation unit.

Test	Coal cap. (kg/hr)	Oil add. (%)	Initial Coal Ash (%)	Initial Coal Total S (%)	Product Ash (%)	Product Total S (%)	Product Pyr. (%)	Sulphur reduction Total (%)	Sulphur reduction Pyr. (%)	Sulphur reduction Inorg. (%)	Recov. (%)
System 1											
C-2	3.8	2.2	13.0	2.17	8.2	1.57	0.67	32	52	58	
C-3	4.6	1.9	13.0	2.17	8.5	1.54	0.61	33	59	62	
C-4	2.16	6.2	12.2	2.30	9.5	1.70	0.72	28	46	50	94
C-5	5.14	2.4	12.2	2.30	8.4	1.55	0.67	36	51	54	95
System 2											
C-21	5.37	2.20	16.5	2.27	9.6	1.36	0.47	44	62	64	92
C-22	5.85	2.38	16.5	2.27	9.5	·1.26	0.39	49	69	70	92
Batch System											
Aglofloat	–	2.0	12.3	2.33	8.4	1.49	–	40.9	60	64	94
Single-Stage	–	0.6	12.3	2.33	9.2	1.65	–	34	–	52	97.4

Note: All values on dry basis. Bitumen and diesel oil in 2:3 ratio. Feed particle size the same for batch and continuous tests (d_{50} approx. 220μm).

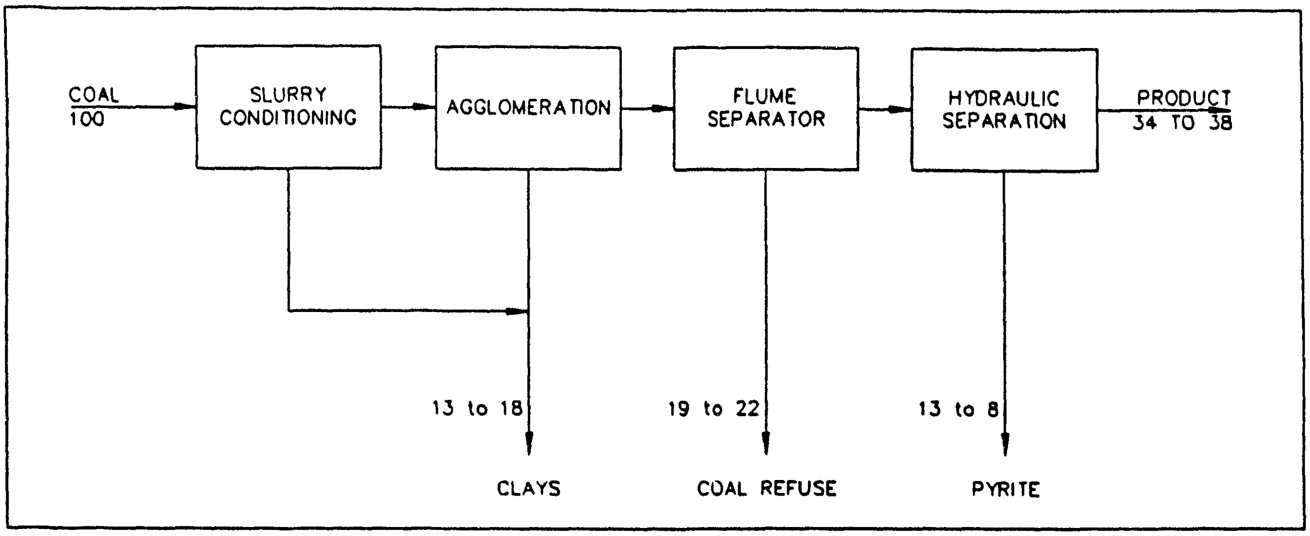


Figure 4.7. Overall material balance for pyrite removal system with flume separator.

- Total sulphur in agglomerates also was not influenced by an increase in bridging oil concentration (Figure 4.10).
- The pyritic sulphur content in agglomerates was influenced more by a non-controlled operating parameter than by the change in oil concentration, as indicated by the wide scatter of the data.

A second series of tests was carried out on System 1 with Illinois No. 6 ROM coal to study the effect of hydroseparator operating parameters on agglomerate product properties. Detailed data for these tests are presented in Appendix 2, Tables A2.1 to A2.5. These data are summarized in Figures 4.12 to 4.14. The key conclusions depicted are:

- CPRU was capable of recovering over 75 percent of combustibles with sulphur reduction of about 35% (Figure 4.12).
- CPRU product had a reduced pyritic sulphur content (~ 1.3 percent, w/w dry basis) at combustibles recovery of over 75 percent (Figure 4.13).
- CPRU ash washability curve (Figure 4.14) showed somewhat lower combustibles recovery than for standard washability curves, with the same ash content in the product.

Table 4.3. Cleaning of Upper Freeport coal in continuous pyrite separation unit.

Test	Coal cap. (kg/hr)	Oil add. (%)	Initial coal Ash (%)	Initial coal Total S (%)	Product Ash (%)	Product Total S (%)	Product Pyr. (%)	Sulphur reduction Total (%)	Sulphur reduction Pyr. (%)	Sulphur reduction Inorg. (%)	Recovery (%)
C-5 (Ref)	5.14	2.4	12.2	2.30	8.4	1.55	0.67	36	51	54	95
C-6	5.34	2.28	12.3	2.06	9.0	1.58	0.77	26	37	43	Floatation step bypassed
C-7	5.34	2.28	12.3	2.06	9.6	1.75	0.91	18	26	33	Floatation step bypassed & sprinkling discontinued.

Note: All values on dry basis. Bitumen and diesel oil in 2:3 ratio. Feed particle size the same for batch and continuous tests (d_{50} approx. 220 μm).

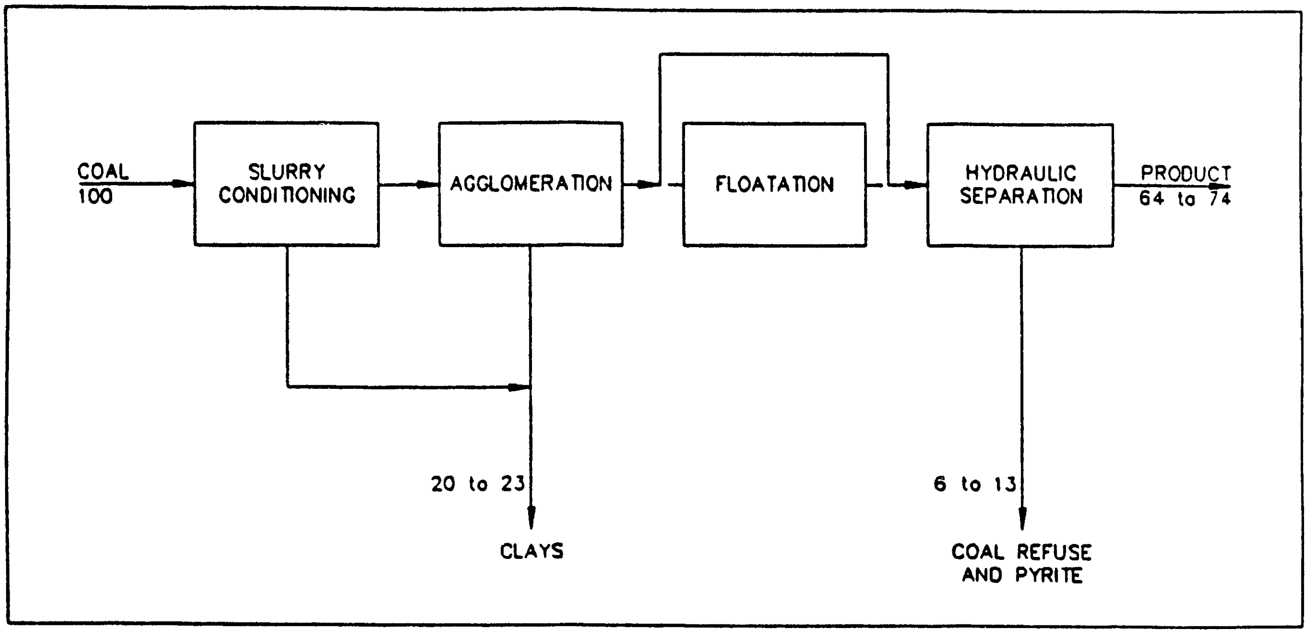


Figure 4.8. Overall material balance for pyrite removal in systems with bypassed floatation step (Runs C-6 and C-7).

The tests completed provided a basis for scale-up of the hydraulic separator for the large pilot plants (IATF).

4.2.4. Scale-up of the Hydraulic Separator

The design used for the scale-up of the hydraulic separator subdivided the separator vessel into three zones: the floatation zone, the settling zone and the washing zone (Figure 4.15). The procedures used in the design of each zone are described below:

Floatation Zone

The scale-up procedure for the design of the floatation zone used kinetic test data for floatation of microagglomerates and empirical correlations derived from manufacturers' designs for floatation

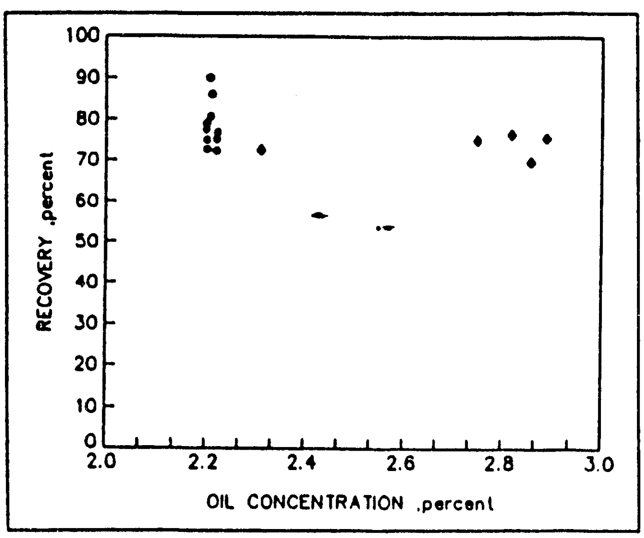


Figure 4.9. Effect of oil concentration on combustible matter recovery. ● Runs 6, 7, and 8; ◆ Runs 3 and 4.

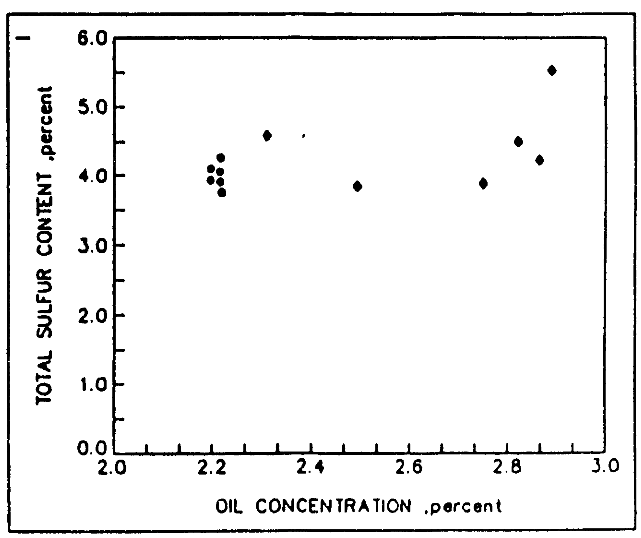


Figure 4.10. Effect of oil concentration on total sulphur content. ● Runs 6, 7, and 8; ◆ Runs 3 and 4.

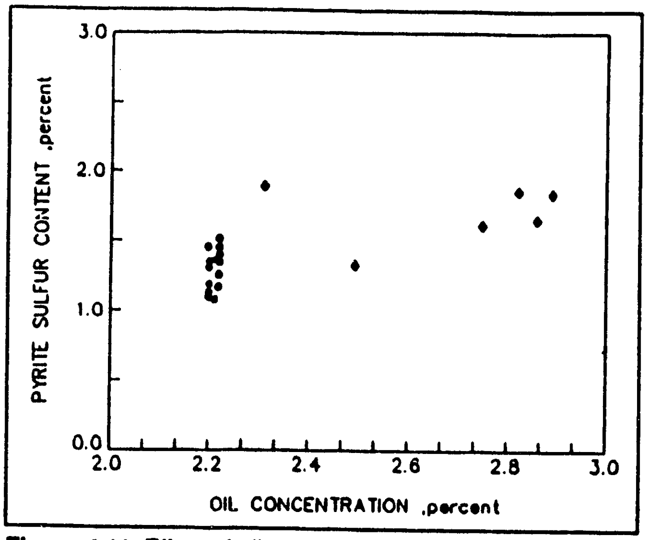


Figure 4.11. Effect of oil concentration on sulphur content. ● Runs 6, 7, and 8; ◆ Runs 3 and 4.

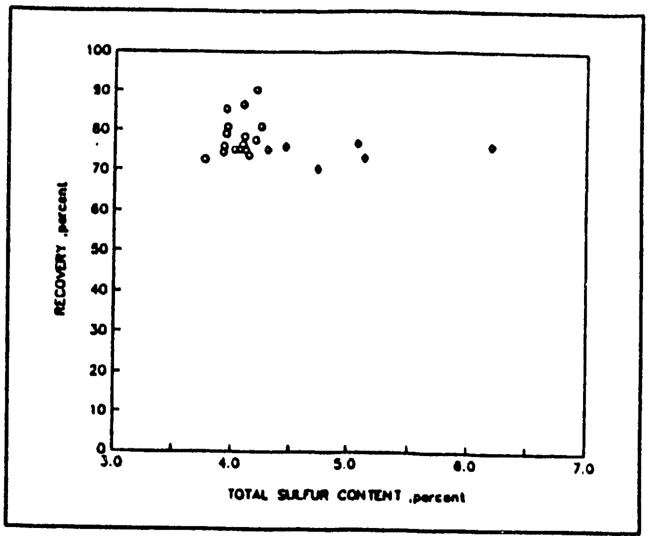


Figure 4.12. Total sulphur washability curve for Illinois 6 coal. ○ Runs 6, 7, and 8; ◇ Runs 3 and 4.

cell geometry and impeller dimensions. Specific design parameters used were:

- **Floatation time required:** derived from the floatation kinetics tests data for Illinois #6 coal (Figure A3.1 in Appendix 3).
- **Floatation zone volume requirement:** calculated from slurry feed rate, solid loading and density.
- **Volumetric safety factor:** estimated at 25 percent of the floatation volume.
- **Geometric cell configuration:** calculated from an empirical relationship between cell volume and cell depth based on manufacturers' data (Figure A3.2 in Appendix 3).

Based on the design calculations, the floatation zone for the IATF hydraulic separator is cylindrical in shape with a depth of 432 mm and a diameter of 508 mm. The discharge paddle assembly has a steep angle of 60 degrees to allow unobstructed

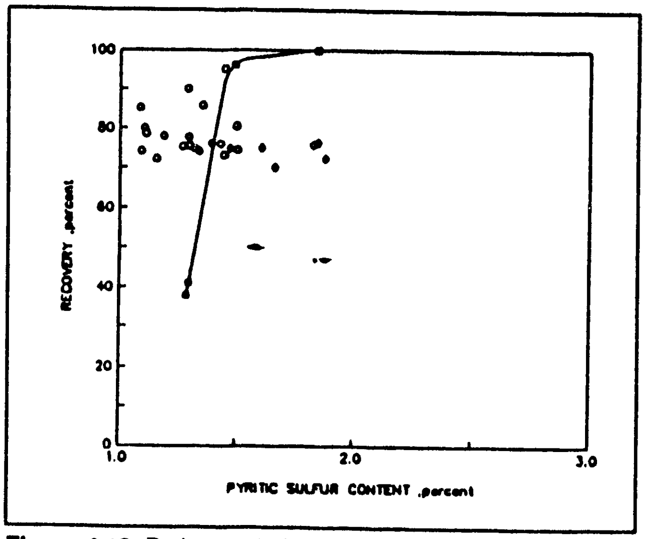


Figure 4.13. Pyrite washability curve for Illinois 6 coal. ○ Runs 6, 7, and 8; ◇ Runs 3 and 4; □ wash pyrite d_{23}=150 μm.

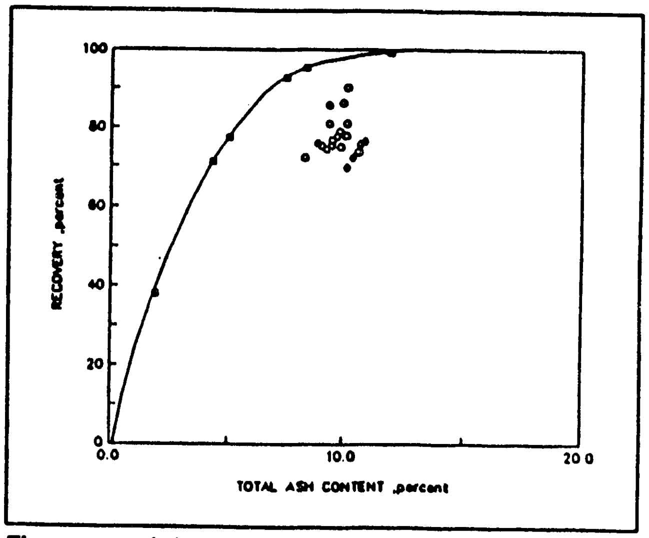


Figure 4.14. Ash washability curve for Illinois 6 coal. ○ Runs 6, 7, and 8; ◇ Runs 3 and 4; □ wash pyrite d_{23}=150 μm.

drainage of water and sulphur/ash rich particles. The width of the discharge trough is 356 mm. The impeller is 254 mm in diameter and can be positioned over a range of depths.

Settling Zone

The settling zone was defined by three regions: the spiral settling region, the bed washing region, and the vortex region (Figure 4.15). The critical parameters defined in the design were:

- **Geometric constraints:** zone diameter, depth and angle of the conical shaped bottom.
- **Velocity assumptions:** critical velocities for each region plus velocity at the interface of the settling and floatation zone.
- **Flow baffles:** designed to achieve the required velocities within each region.

Based on the design calculations, the settling zone for the IATF is 508 mm in diameter and 432 mm in depth. It is equipped with a conical shaped bottom with a 30 degree angle to allow continuous removal of solids and to stabilize a semi-stationary solids bed. The flow stabilizer is 321 mm in diameter, 271 mm in height and is positioned 120 mm from the bottom of the floatation zone. The baffles are 100 mm in width, tapered at the center of the settling zone, and cut short of the flow stabilizer so as not to protrude into the vortex region.

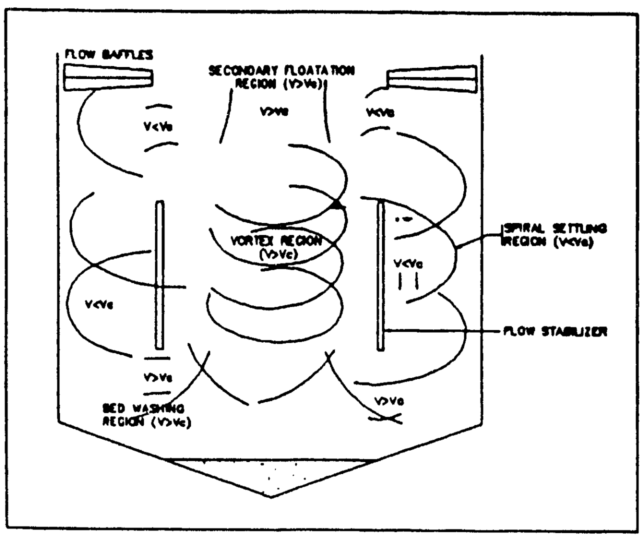


Figure 4.15. Settling zone velocity configuration.

Washing Zone

The design of the washing zone was based on the following constraints:

- **Maximum zone depth:** defined by the floatation zone depth and location of the communication region between the three zones.
- **Incline of the washing zone:** a 30 degree angle to the horizontal was selected.
- **Surface area ratio:** between the floatation and the washing zone, based on the CPRU.
- **Froth communication ratio:** the CPRU froth communication ratio between the floatation and washing zone was maintained.

4.3. Conclusions

Studies of coal cleaning performed with Systems 1 and 2 indicated promising results for both systems. Both unit processes showed reduction of pyrite in the agglomerates; however, the flume separator was found to be more operationally complex than the floatation cell. As a result, System 1, including the floatation cell and hydraulic separator was selected for the Aglofloat process configuration.

The experiments conducted with high sulphur Illinois No. 6 coal indicated that at best conditions obtained, the combustibles recovery ranged from 75 to 80 percent, the total sulphur reduction ranged from 50 to 55 percent, the pyritic sulphur reduction ranged from 72 to 77 percent, and the ash reduction ranged from 82 to 86 percent.

The operating parameters identified as important for optimization of the process were:

- oil concentration.
- frother concentration.
- high shear mixing speed.
- high shear mixing time.
- size of the coal.
- solid loading in floatation cell.

The floatation cell removed about 65% of pyritic sulphur while the hydraulic separator was responsible for removing the remaining 35% of pyritic sulphur.

Specific operational issues found with the CPRU were:

- Sufficient wash water volume and froth penetration with the wash zone of the hydraulic separator were required for the separator to function properly.

- Tests conducted indicate that approximately 15 percent and 8 percent of the total combustible matter is lost in the floatation cell and hydraulic separator, respectively.
- Although the CPRU demonstrated good repeatability of the product quality, accumulation within the system appeared to influence the product quality as the time of the run was extended. Hence, it is recommended that units constructed in the future include some means of removing the accumulated solids.

The CPRU was successfully used for the scale-up of the hydraulic separator for the large pilot plant (IATF). Design procedures developed will be further used to improve the hydroseparator in the IATF.

5. Integrated Agglomeration Test Facilities (IATF)

5.1. IATF Design for the Aglofloat Process

The overall objective of the IATF was to conduct process research & engineering studies on:

- beneficiation of low rank coal by deashing and moisture reduction (the Aglotherm process);
- desulphurization of bituminous coal through pyrite removal (the Aglofloat process); and
- the cleaning of hydrocarbons from contaminated soils (the HC Clean Soil process).

For each of these processes, the IATF was used to:

- verify the developed agglomeration processes in the smallest possible continuous unit;
- identify the factors which would be used in scaling-up the process for commercialization;
- obtain engineering and operation data required for process evaluation and large plant development; and
- develop process control philosophy.

5.1.1. IATF Design Specifications

The IATF included all major equipment in flowsheet configurations studied in the Aglofloat process. The exceptions were equipment needed for the primary and secondary crushing of coal.

The nominal IATF design specifications were as follows:

Maximum Plant Capacity: 250 kg/h of coal treated.

Process Configuration: various flowsheet configura-tions as required in process optimization research.

Coal Grinding System: 250 kg/h; feed coal top size - 10 mm; pulverized size variable.

Agglomeration Section: high shear mixer, 58 liters capacity, with 4 minutes mean residence time; low shear mixer, 500 liters capacity, with 26 minutes mean residence time; total slurry flow – 750 to 950 kg/h.

Floatation Cells: 410 kg/h of froth.

Hydroseparator: 400 kg/h of froth.

Floor Space: three levels, 63 square meters each.

Utilities: water, 2.5 tonnes per hour electricity, 120 amp, 575 V.

Plant Operation: 8 to 10 hour test periods extended up to 72 hours.

Equipment: waterproof, electrical enclosures meeting NEMA 12 standard or equivalent.

The following sections describe the equipment used, the work performed and the design methods developed in the IATF.

5.1.2. IATF Flowsheet

Reference flowsheet #ARC55 presents the IATF configuration for the Aglofloat process. The facilities make possible the following unit operations:

- coal grinding and slurry preparation,
- oil preparation,
- microagglomeration,
- floatation,
- pyrite removal,
- macroagglomeration,
- separation,
- waste treatment, and
- process control.

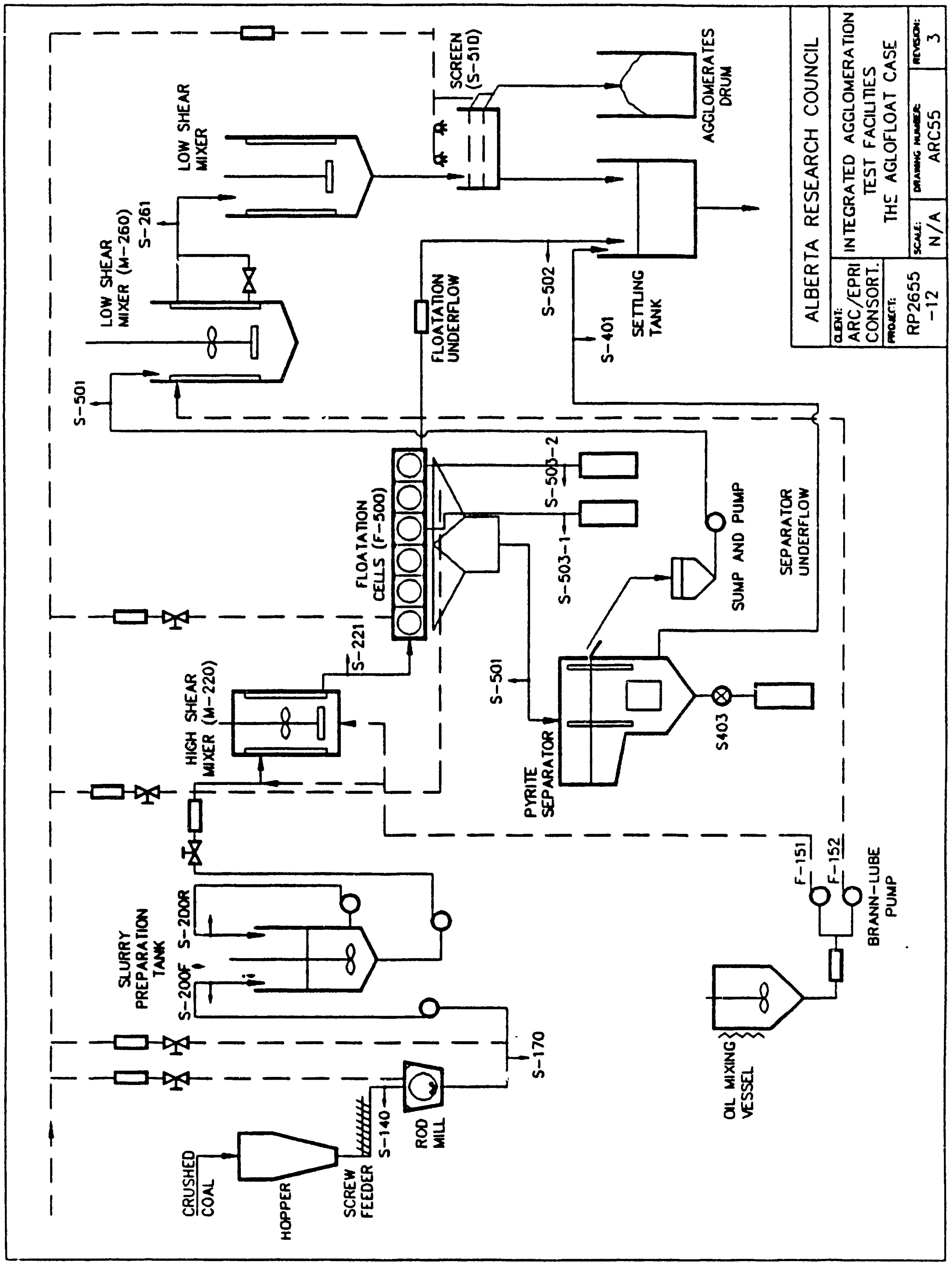
5.1.3. Major Equipment and Instrumentation

A detailed description of the remaining equipment of the IATF is included in Section 4, Volume 1 of this report. The following summarizes only the key equipment used in different IATF sections.

Coal Grinding and Slurry Preparation: This section contains a coal hopper and feeder system, a rod-mill, a vibrating Derrick coal screen, a coal slurry preparation tank, a drum tipper, a sump pump and two water storage tanks.

Oil Preparation: The system includes an electrically heated and agitated oil-mixing vessel, a hoist and crane for receipt of heavy oil and solvent drums, and an oil pump.

Microagglomeration: Equipment in the microagglomeration section consists of two 58 liter, 4 minute residence time high shear mixers, and a sump pump.


ALBERTA RESEARCH COUNCIL
CLIENT: ARC/EPRI CONSORT.
INTEGRATED AGGLOMERATION TEST FACILITIES THE AGLOFLOAT CASE
PROJECT: RP2655 -12
SCALE: N/A
DRAWING NUMBER: ARC55
REVISION: 3
CRUSHED COAL
HOPPER
SCREW FEEDER
S-140
ROD MILL
S-170
SLURRY PREPARATION TANK
S-200F
S-200R
HIGH SHEAR MIXER (M-220)
S-221
FLOATATION CELLS (F-500)
S-503-1
S-503-2
S-501
LOW SHEAR MIXER (M-260)
S-261
LOW SHEAR MIXER
SCREEN (S-510)
AGGLOMERATES DRUM
FLOATATION UNDERFLOW
S-502
S-401
SETTLING TANK
SUMP AND PUMP
SEPARATOR UNDERFLOW
PYRITE SEPARATOR
S403
OIL MIXING VESSEL
F-151
F-152
BRANN-LUBE PUMP

Floatation: A DENVER Sub-A floatation cell is used in the floatation section.

Pyrite Separation: Pyrite separation equipment developed by ARC, with sump pump.

Macroagglomeration: This section has two low shear mixers with 25 to 50 minutes residence time.

Separation: A double-decker drain and rinse screen, a tailings tank and a microagglomerates receiving drum, are used in the separation section.

Waste Treatment Section: Equipment in the waste treatment section consists of a settling tank, a skimmer for removal of solids, and a bag filter in the recycle water line.

Instrumentation

The IATF has the following instrumentation and sampling points in support of the Aglofloat process studies:

- twelve slurry water sampling points, as indicated on reference flowsheet #ARC55.
- temperature measurement sensors: two K-thermocouples per each mixer, one thermocouple in the oil tank.
- flow measurement sensors, to monitor the flow of rod-mill water to monitor slurry flow.

Descriptions of the sampling points, their locations, the sizes of the samples taken and the types of analyses performed are given in Table 5.1. The rationale for and objectives of the sampling and measurement instrumentation are discussed in detail in Volume 1, Section 4 of this report.

The key steps to process control and optimization of the Aglofloat process were:

- measurement and control of the feed rate and size distribution in the slurry preparation tank;
- flow rate measurement of the bridging oil feed to the high and low shear mixers;
- measurement and control of the bridging oil to coal ratio and measurement of the solid concentration in the high shear mixer;
- measurement and control of the slurry flow rate; and
- measurement of slurry solid concentration and the bridging oil in the low shear mixer.

The process control requirements described above were difficult to implement because the rheology of the agglomerate slurry in the mixers is quite different from the rheology of coal-water slurries. At higher solids concentration, the agglomerate slurries are non-Newtonian, and it was difficult to ensure the target solid concentration in the mixers just by adjustment of the coal slurry input. For a more accurate measurement and adjustment of the solids concentration ratio in the high and low shear vessels, nuclear density meters were installed on the feed lines; however, in-situ measurement of the solids concentration in the vessels would still be desirable.

Process Control

The IATF's process control and data acquisition hardware includes:

1. SAFE 8000 PC 8253 Process Control Computer.
2. Two IBM PS/2 Computers.
3. VAX 6800 for data base management and reporting.

The IATF's process control hardware is run by a distributed control system DMACS (Distributed Manufacturing and Automatic Control Software) using an IBM ETHERNET network. The architecture of the control system provides for all the required data acquisition and process control including facilities for building interactive process schematics. Other system functions and capabilities include:

- Visual indication of equipment status, process operating parameters, etc., using the process draw facility in DMACS.
- PID control blocks and on-line process calculations using PID calculation blocks.
- Data analysis program including analysis of trends, statistical analysis of collected data, flagging of the alarms, etc.

5.1.4. Plant Safety and Environmental Issues

A risk assessment was conducted for the IATF to identify potential safety hazards in the plant. In general, the plant operation was classed as relatively low risk since it involves low temperatures and pressures and hydrocarbons with low volatility. Exceptions to this general classification were:

- the generation of coal dust in the coal grinding area, and
- potential equipment hazards such as sparking in the fan handling dust, high noise levels, staff being caught in drives or burnt by hot equipment, etc.

Table 5.1. Sampling and analyses.

	Samplings Sample	Place and amount of sampling	Analysis to be done
S-140	Initial Feed Coal (Sample A)	Drums	Proximate (ash & moisture) Total Sulphur Forms of Sulphur Calorific Value
S171	Rod Mill Discharge	Mill outlet before oversize screen 1 l x 2 hrs	PSD (wet)
S200	Coal-Water Slurry (discharge)	Slurry tank feed 1 l x 1/2 hr Slurry tank recycle 1l x 1/2 hr	PSD (wet) Solids Concentration
S221	Floatation Feed (Sample B)	After high shear mixer Before floatation 1 l x 1/2 hr	Proximate Total Sulphur Forms of Sulphur
S501	Floatation Product/Pyrite Separator Feed (Sample C)	Inlet to pyrite separator 1 l x 1/2 hr 1 l x 1/2 hr	Proximate Total Sulphur Forms of Sulphur
S502	Floatation Tailings	Floatation cell discharge	Mass Rate Solids Concentration Proximate (Ash)
S503-1 S503-3	Floatation Bottoms	Bottom of floatation cells #1 & #3 1l x 1/2 hr (each cell)	Proximate (Ash) Total Sulphur
S401	Pyrite Separator Product (Sample D)	Inlet to low shear mixer (V-260) 1l x 1/2 hr	Solids Concentration Proximate (Ash) Total Sulphur Forms of Sulphur
S402	Pyrite Separator Tailings	Discharge of separator tailings line 1l x 1/2 hr	Mass Rate Solids Concentration Proximate (Ash) Total Sulphur
S403	Pyrite Separator Bottoms	Bottom of pyrite separator	Proximate (Ash) Total Sulphur Forms of Sulphur
S261	Low Shear Product (Sample E)	Discharge of first low shear mixer 2lx 1/2 hr	PSD (wet) Proximate (ash) Total Sulphur Forms of Sulphur
S281	Low Shear No. 2 Product	Discharge of Second Low shear mixer (V280) 1l x 1/2 hr	PSD (wet)

* Samples taken every hour at steady-stage conditions

Table 5.2. Cleaning of Illinois coal in IATF unit (system without pyrite separator).

Test	Coal through. (kg/h)	Oil Add. (%)	Initial Coal Ash (%)	Initial Coal Total sulph. (%)	Froth Ash (%)	Froth Total sulph. (%)	Sulphur Reduction Total (%)	Sulphur Reduction Inorg. (%)	Product (Agglom.) Ash (%)	Product (Agglom.) Total sulph. (%)	Sulphur Reduction Total (%)	Sulphur Reduction Inorg. (%)
Run 1	258	2.3 + 11.0	25	2.8	11.6 11.8	1.97 2.32	34	46	7.8 8.0	2.15 1.98	40	59
Run 2	228	2.5 + 14.5	35.4 33.6 32.5	4.34 4.59 4.70	16.3 14.3 18.4	4.61 4.24 4.63	20	37	9.3	4.62	22	49
Run 5	270	3.2 + 7.15	30.8	5.10	17.5	4.50	26	33	10.6	4.51	31	48
C-16 Sys. 1	1.83	3	34.8	4.82	–	–	–	–	8.8	3.9	42	71
1 Stage Batch	–	0.6	34.8	4.82	11.7	4.29	–	–	–	–	39	52

* All values of ash and sulfur on dry basis.

These potential hazards were reduced by installation of a non-sparking fan for handling dust, installation of guards for all rotating equipment, and insulation of hot pipes and equipment. Special enclosures were installed around rod-mills to reduce noise. The protective measures taken, the equipment installed and the environmental review conducted are described in detail in Section 4 of Volume 1.

5.2. Plant Operating Experience and Optimization

5.2.1. Plant Commissioning and Results

Commissioning of the IATF for the Aglofloat Process started on May 9, 1989, with the processing of Illinois No. 6 coal. The commissioning tests included three runs (#1, 2 and 5). These runs are depicted in Table 5.2 together with the results from the bench-scale pyrite removal unit and batch-tests for comparison. The variations in key process parameters for these tests are presented in Figures A4.1 and A4.2 in Appendix 4. In general, the total and the inorganic sulphur removed in the IATF compared well with single-stage batch tests but was below the results obtained in the CPRU (Table 5.2).

Following the test runs #1, 2, and 5, commissioning tests were conducted to obtain 6 to 7 tonnes of agglomerates using Ohio coal. The tests were successfully conducted for 96 hours producing 54 drums of low ash (6 percent) agglomerates. The tests also permitted identification and correction of operating problems in areas of coal feed, product screen performance, waste treatment, etc.

5.2.2. Equipment Studies and Modification

Sections 4.2.2. in Volume 1 and Volume 3 discuss equipment modifications made to the IATF in the course of the program. Equipment modifications conducted specifically for the Aglofloat process (the design of the hydraulic separator) was described in Section 4 of this report.

5.2.3. Pilot Plant Tests

Following the incorporation of the hydraulic separator into the Integrated Agglomeration Test Facilities (Process Flowsheet #ARC55), a series of continuous runs was performed with Illinois No. 6 ROM coal. The objective of these runs was to optimize the high shear step operation with respect to bridging oil concentration and the relative performance of the floatation cell and hydroseparator. Figures 5.1 to 5.6 depict the effect of bridging oil concentration on the pyritic sulphur and ash contents in the floatation and hydrocarbon classifier product for runs #18, 19 and 20. A summary of the optimization runs is presented in Figures 5.7 and 5.9. More detailed process data for each run are presented in

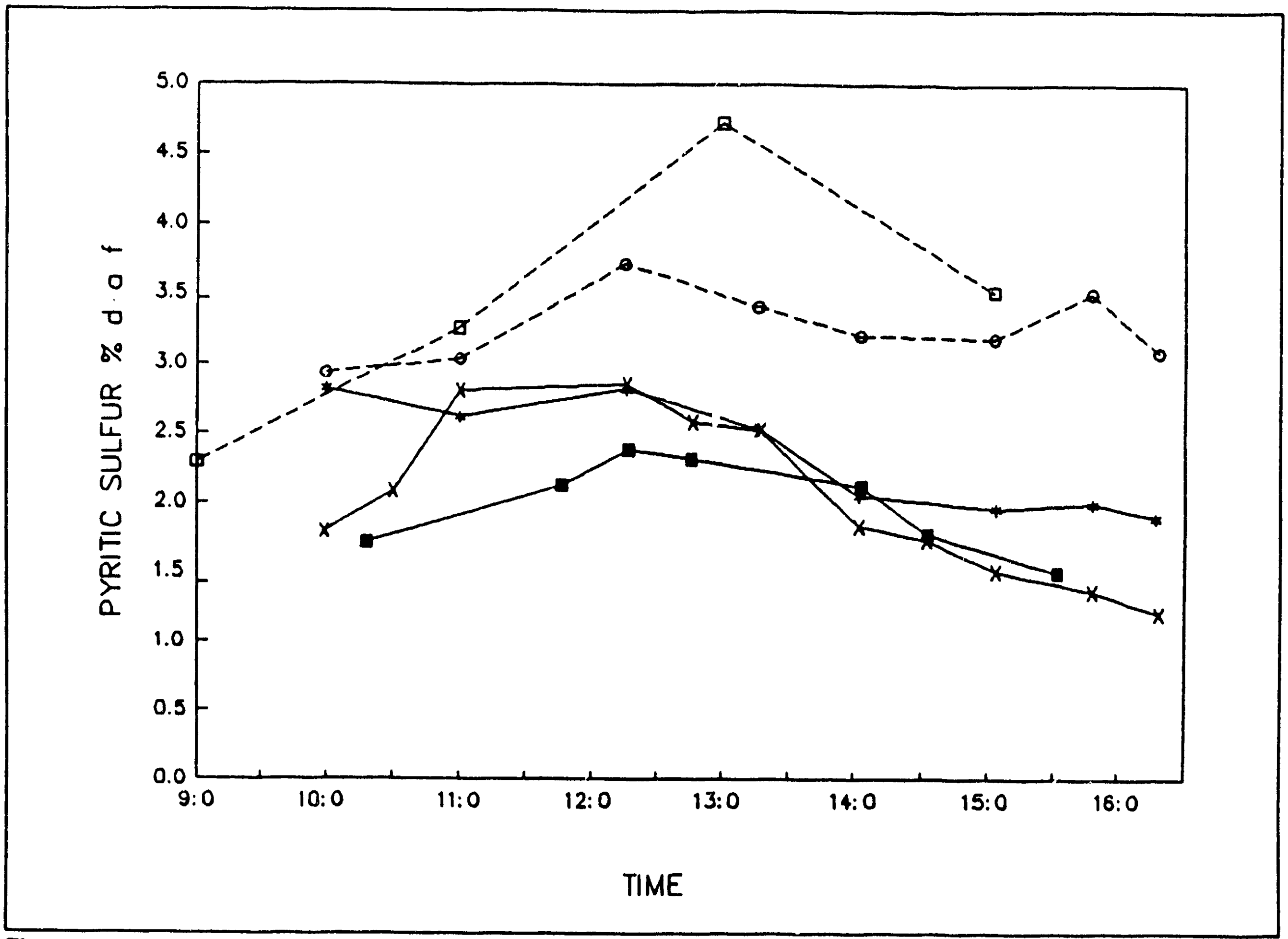


Figure 5.1. Pyritic sulphur removal in IATF Run 18. feed; product; floatation feed; * floatation product; X hydroseparation product.

Appendix 4. The key process design and development conclusions were:

- Pyritic sulphur content after floatation ranged from 2.5 to 3.0 percent for oil concentration 1.0 to 3.0 percent. At 0.5 percent of bridging oil concentration, the products pyrite content was less than 1.5 percent. This was because of poor coal recovery.
- For the same oil addition of 1.0 to 3.0 percent, the coal recovery after pyrite separation was about 90 percent. At lower oil concentration, coal recovery ranged from 60 to 86 percent.
- The plots of coal recovery versus pyrite content in the clean coal products generated curves similar to washability curves. The results suggest that product with about 2 percent of pyrite may be obtained for coal recovery of 90 percent in the IATF.

5.3. Conclusions

The Integrated Agglomeration Test Facilities were modified by incorporating a hydraulic classifier in order to obtain process and engineering information on the Aglofloat process. Specifically, the plant was to provide information on scale-up of the Aglofloat process, on technical feasibility of the Aglofloat process and on the process control required. The plant included all Aglofloat unit operations except for equipment required for primary crushing of ROM coal.

The major process areas and unit operation of the pilot plant included coal grinding and slurry preparation, oil preparation, microagglomeration, floatation, pyrite separation, macroagglomeration, macroagglomerates' separation, and waste treatment. The IATF instrumentation included process control and data acquisition hardware and software.

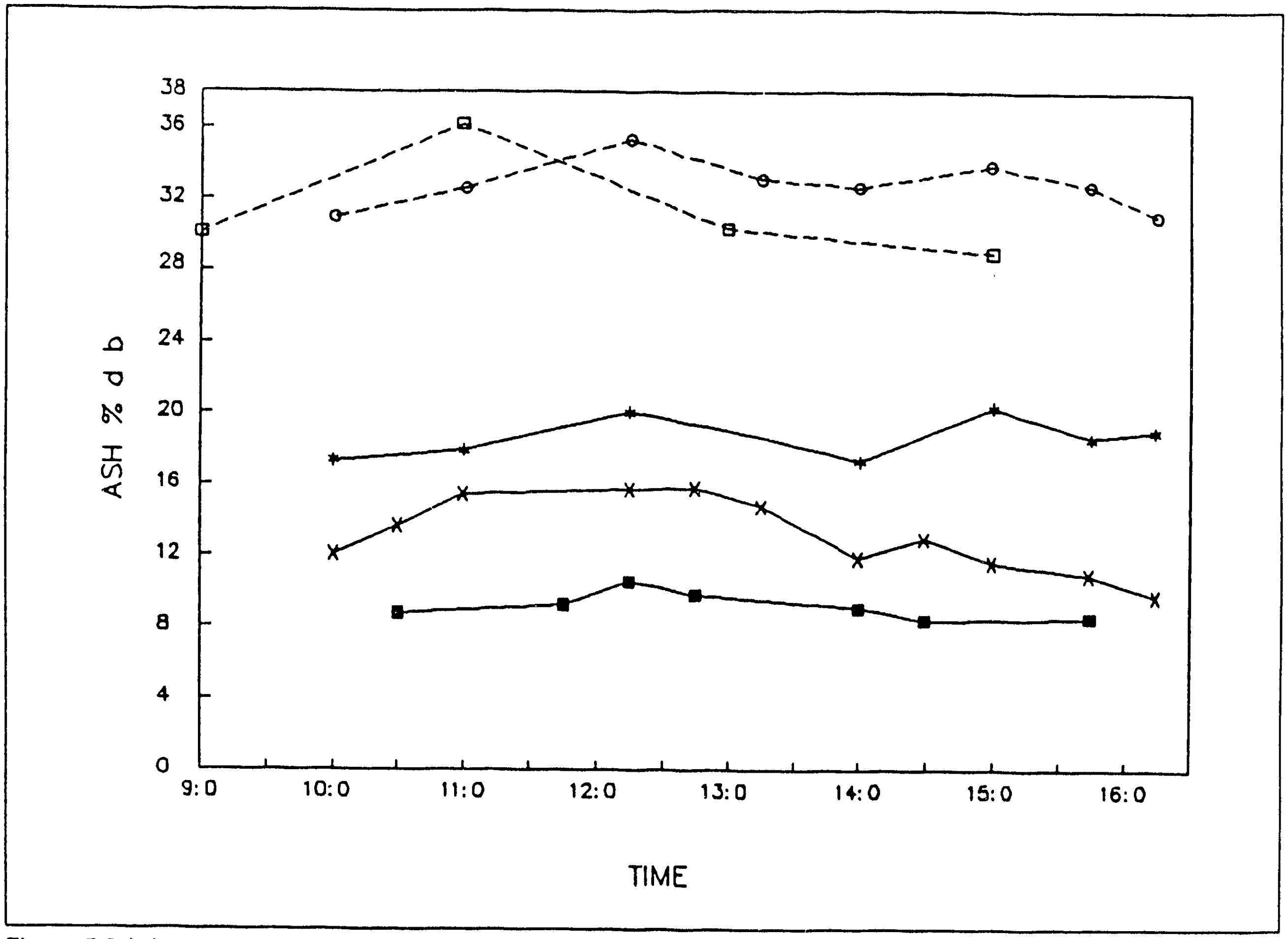


Figure 5.2. Ash removal in IATF Run 18. □ feed; ■ product; O floatation feed; * floatation product; X hydroseparation product.

The IATF test runs confirmed that well-formed agglomerates with reduced sulphur and ash can be obtained from bituminous coals. The agglomerate product properties were similar to those obtained in the batch and continuous bench-scale experiments, with agglomerates heating value above 13,000 Btu/lb, ash less than 10 percent, and sulphur significantly reduced below that of raw coal.

Design specifications selected for the conceptual Aglofloat process, based on IATF tools performed with Illinois No. 6 ROM coal are as follows:

- **oil addition – high shear:** 0.8 percent, d.b. feed coal.
- **oil addition:** 12 percent, d.a.f. coal feed basis.
- **residence time:** 4 min. high shear mixer (HSM). 25 min. low shear mixer (LSM).
- **slurry concentration:** 30 percent in HSM. 18 percent in floatation cells and hydraulic separator. 30 percent in LSM.
- **product agglomerate size:** 0.8 to 3.0 mm.
- **moisture in agglomerate:** 40 percent in froth. 20 percent in agglomerate product.
- **combustibles recovery:** 95 percent, w/w coal Btu basis.
- **ash rejection:** 69 percent, w/w coal ash basis.
- **pyritic sulphur rejection:** 59 percent, w/w coal sulphur basis.

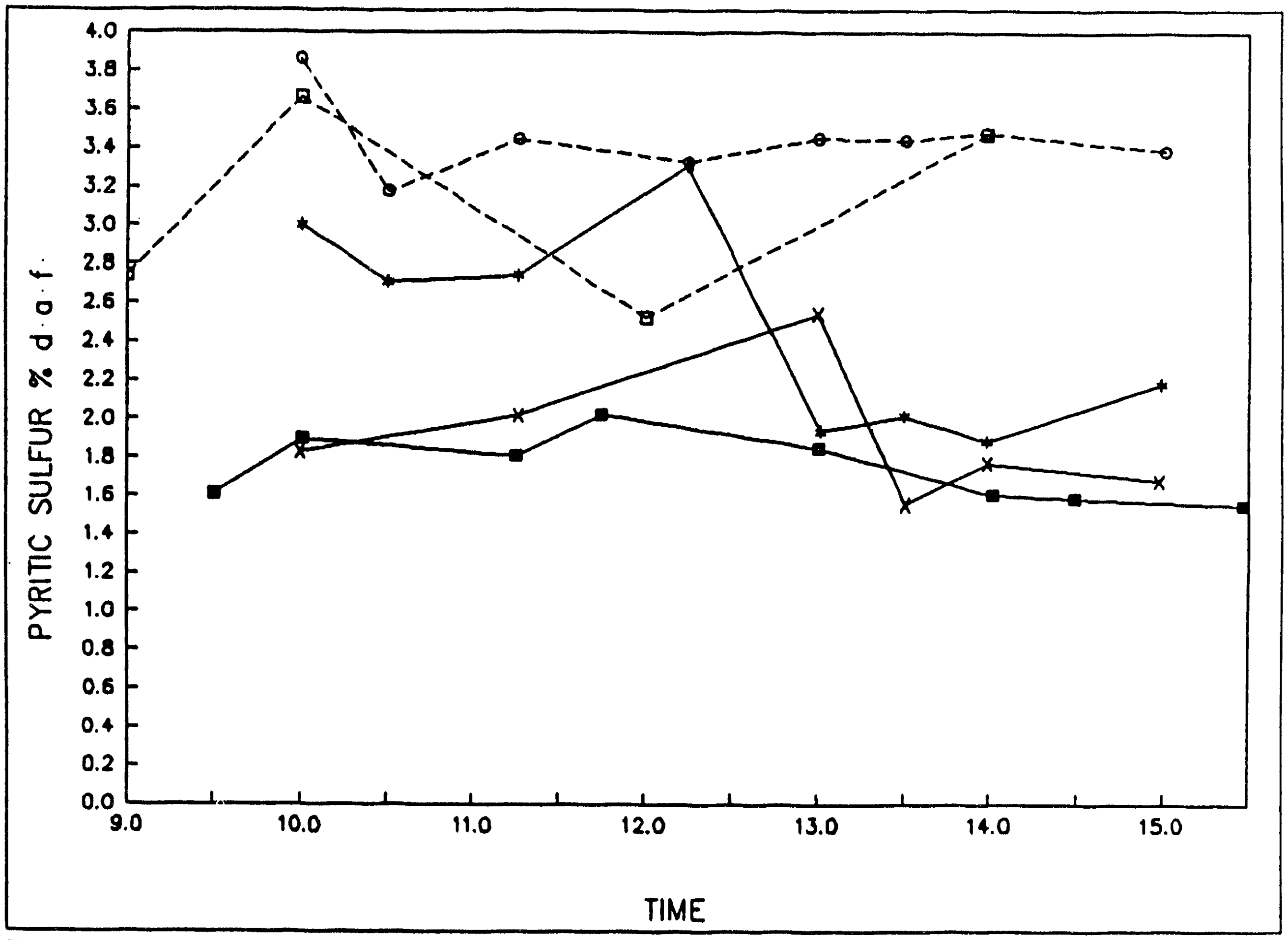


Figure 5.3. Pyritic sulphur removal in IATF Run 19. □ feed; ■ product; ○ floatation feed; * floatation product; X hydroseparation product.

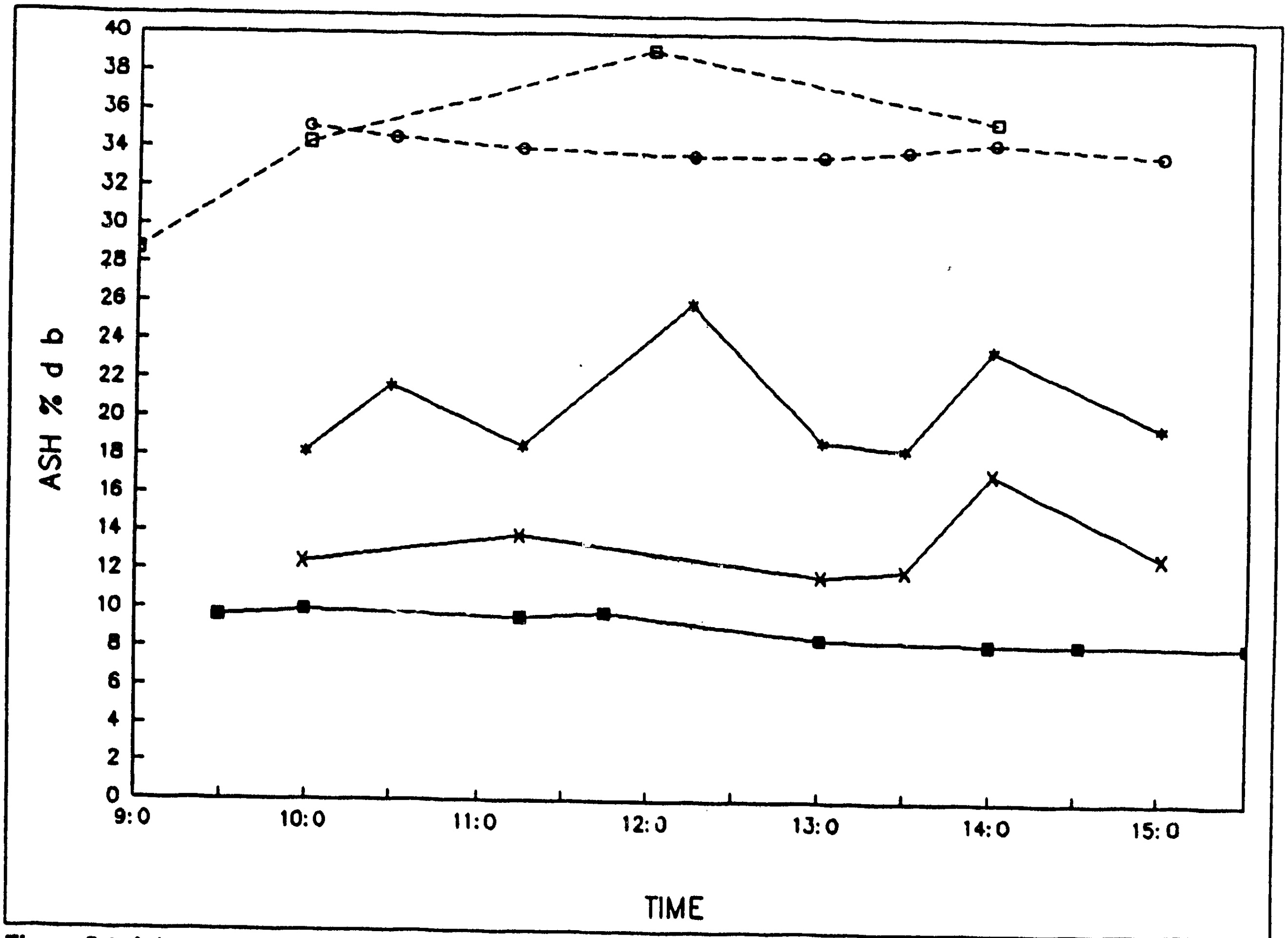


Figure 5.4. Ash removal in IATF Run 19. □ feed; ■ product; ○ floatation feed; * floatation produc., X hydroseparation product.

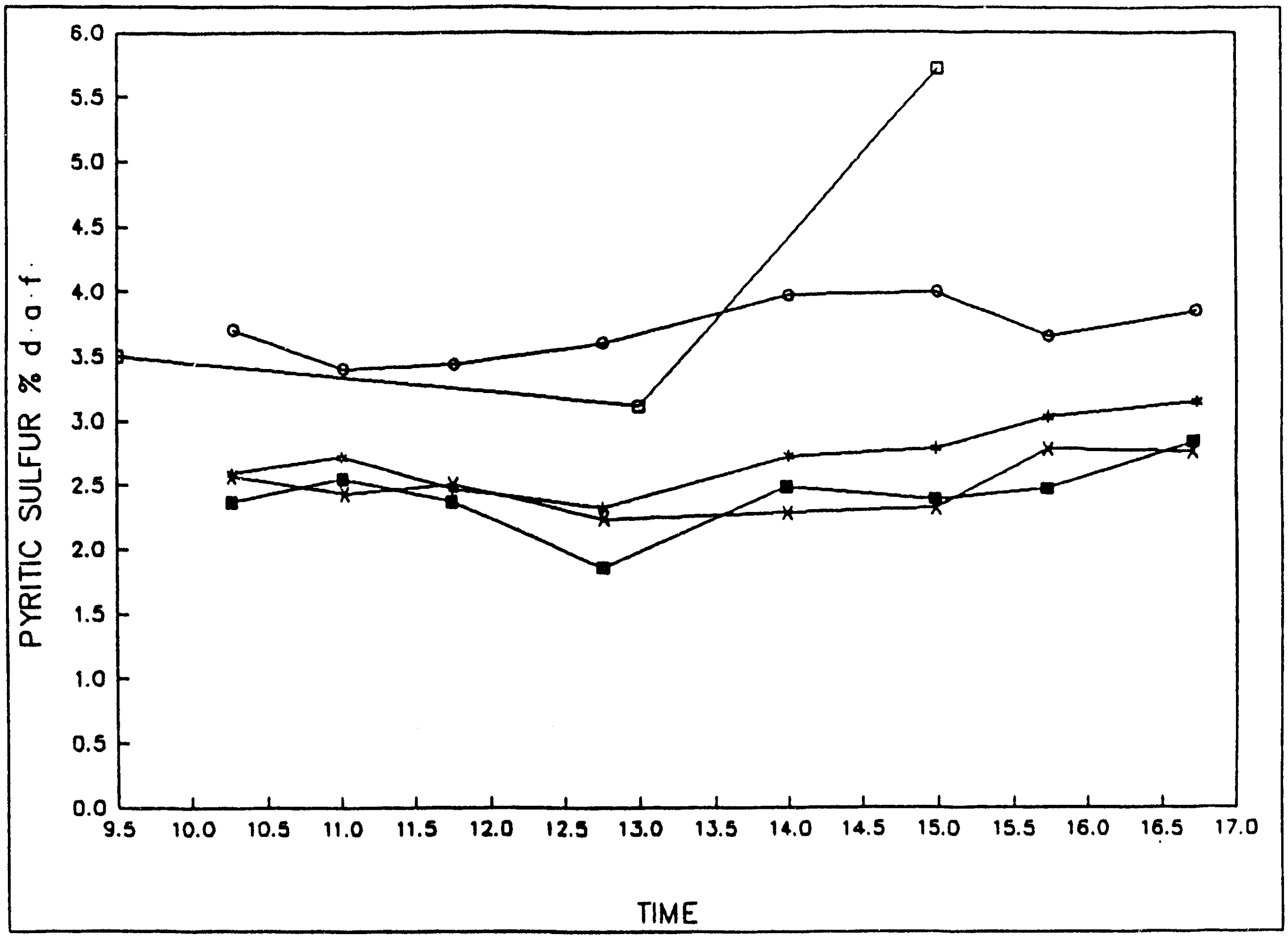


Figure 5.5. Pyritic sulphur removal in IATF Run 20. ◻ feed; ■ product; O floatation feed; * floatation product; X hydroseparation product.

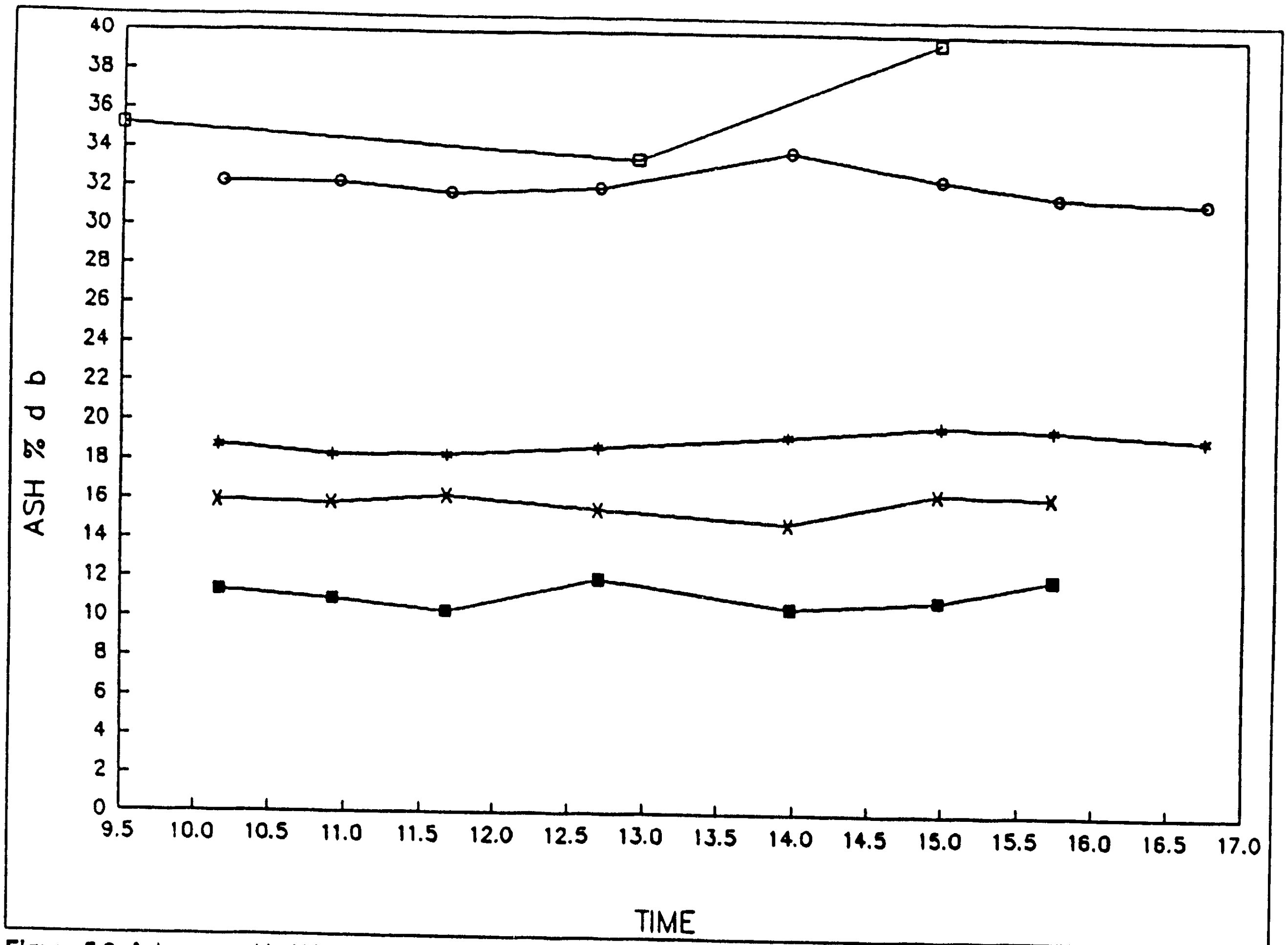


Figure 5.6. Ash removal in IATF Run 20. □ feed; ■ product; O floatation feed; * floatation product; X hydroseparation product.

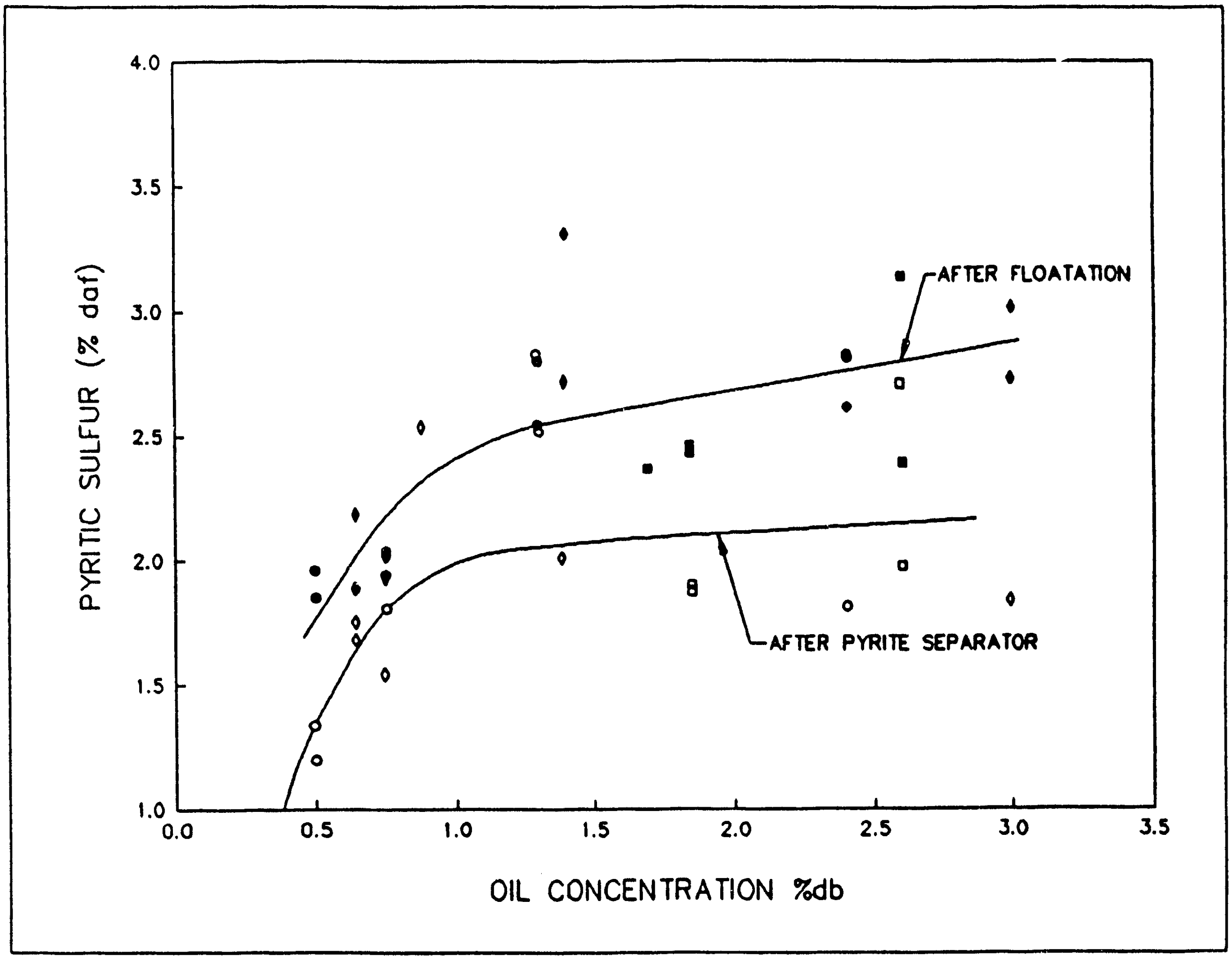


Figure 5.7. IATF Runs: Effect of oil concentration on pyritic sulphur removal. □, ■ Run 17; ○, ● Run 18; ◇, ◆ Run 19; open symbols = product after hydraulic separation, solid symbols = product after floatation cells.

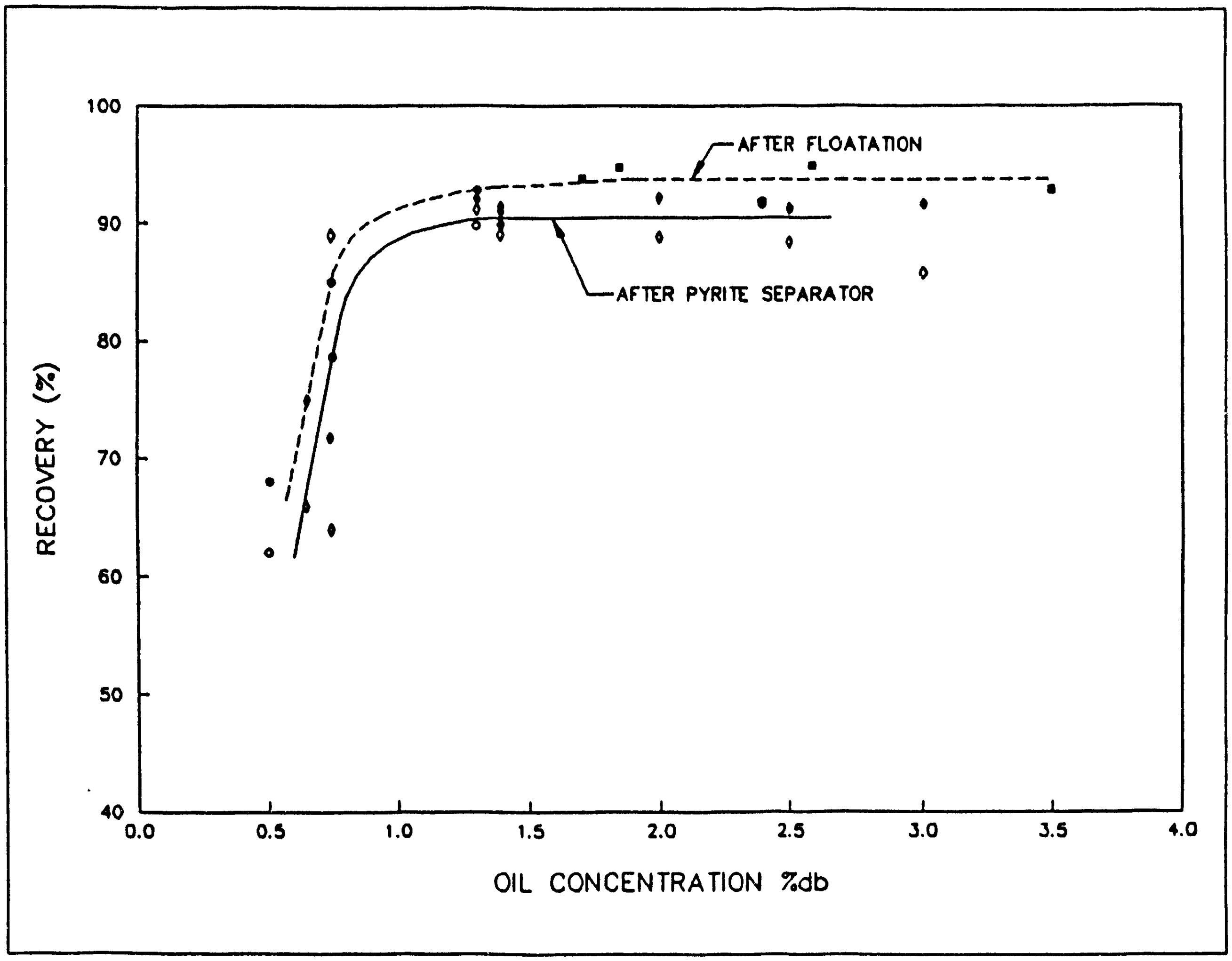


Figure 5.8. IATF Runs: Effect of oil concentration on coal recovery. □ , ■ Run 17; ○ , ● Run 18; ◇ , ◆ Run 19; open symbols = product after hydraulic separation, solid symbols = product after floatation cells.

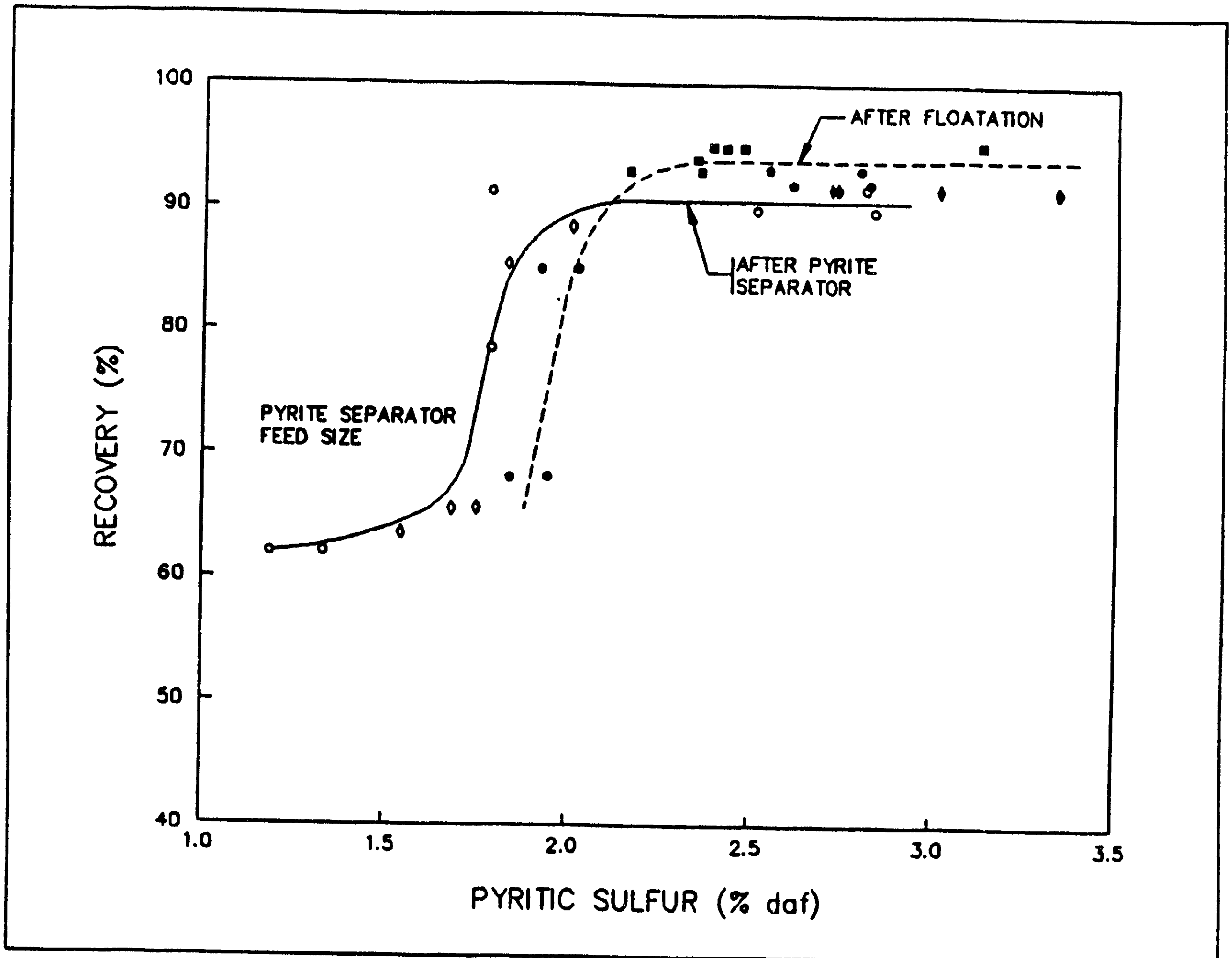


Figure 5.9. IATF Runs: Recovery curves for floatation and pyrite separation units. □ , ■ Run 17; ○ , ● Run 18; ◇ , ◆ Run 19; open symbols = product after hydraulic separation, solid symbols = product after floatation cells.

6. Environmental Analysis

The design assumptions for the Aglofloat process in Section 7 require that the plant meets EPA 1989 standards for air, water and refuse discharge from the plant. The key control requirements with respect to plant emissions are:

- air contaminants such as coal and mineral matter dust, hydrocarbon vapors, etc.;
- water contaminants including runoff water from coal stockpiles, recycle water ponds, etc.; and
- refuse contaminants in the refuse coal.

The following section briefly describes the design approach proposed for the major effluent streams.

Air Emissions

The major sources of air emissions are the coal and oil handling areas. Potential dust and hydrocarbon emissions in those areas were eliminated by the incorporation of dust and hydrocarbon collection systems in the plant design. The performance required for dust and hydrocarbon collection systems will be determined by the National Ambient Quality Standards.

Water Contaminants

The Aglofloat plant requires a net makeup of process water from wells or surface water sources. The majority of plant water contaminants will come from runoff waters from coal and agglomerates storage and emergency refuse stockpiles. The plant design calls for collection of runoff water and use of this water as a makeup water.

The recycle water streams are clarified in two static thickeners in the Agglomeration and Floatation Area

Refuse Disposal

It is expected that the refuse will be disposed of either in the mined pits (in case of the strip mines) or at a disposal site near the coal upgrading plant. The construction and operation of the disposal site will be governed by the Mine Safety and Health Administration (MSHA) regulations. Key considerations in selection, preparation and maintenance of a refuse site are:

1. Base (foundation) at the site should be stable and have low permeability.
2. Erosion due to surface water drainage should be prevented.
3. Refuse should be weathered before it is placed in the refuse site.
4. Refuse should be spread in layers and compacted. Fresh and older refuse should not be mixed.
5. Regular inspection and maintenance should be conducted at the site.

A disposal cost of $ 7/ton of coal refuse is assigned to the plant operating cost.

7. Conceptual Design and Cost Analysis of an Integrated Commercial Plant for the Aglofloat Process

7.1. Process and Economic Data

7.1.1. Design Basis and Assumptions

Plant Size

A conceptual plant size of 2.8 million tons nominal capacity of input ROM coal was used. This size of plant permits relative economies of scale in mining, in transportation and in the operation of the plant itself. As well, it is suitable for the initial target markets.

Plant Load Factor

It is assumed that the Aglofloat plant will be operating about 7000 hours per annum. It is recognized that this load factor will determine the degree of redundancy of plant equipment, and will influence other design components such as the storage of products, etc.

Plant Location

The conceptual design was not intended for a specific plant site. It is assumed that the plant will be a mine-mouth plant located in the Appalachia region of the U.S. and that it will not have any unusual topographical problems.

Plant Equipment

The plant equipment selected is commercially available. Also, where possible, support areas such as water treatment have been costed as turn-key, package plants.

Plant Boundary

The plant boundary, for costing purposes, includes all facilities required to operate the plant, to unload fuel, to load the upgraded products and to treat waste streams.

Environment Guide

All plant process units are designed to meet 1989 emission standards in the U.S.

Feedstock and Product Variability

All calculations of material and heat balances and sizing of equipment were performed using the ROM coal in Table A5.9 in Appendix 5. Table A5.9 also depicts properties of the refuse coal.

Financial Analysis

All site financial analyses were performed in constant 1989 U.S. dollars.

7.1.2. Sources and Methods of Process Cost Estimates

Tables A5.1 to A5.3, Appendix 5 depict the cost factors used for estimating capital and annual operating costs for the conceptual plant. Table A4.4 lists prices and rates for chemicals, fuels, utilities, etc. used in the Aglofloat cost estimates. The major sources of cost estimates were:

- vendors' estimates for equipment, and
- in-house data for equipment and support areas.

All equipment costs were updated to 1989 dollars using the Chemical Plant Cost Index or the M&S Equipment Index.

7.2. Process Description

Plant Description

The beneficiation facility will upgrade 2.8 million tonnes of ROM coal per year based on 7000 hours per year. The production of saleable products on an annual basis from the facility will be 2.74 million tonnes of agglomerates with a heating value of 13,300 Btu/lb.

The plant facility has six operating areas as outlined below. The basic plant concept is shown in Figure 7.1. A more detailed description and a flowsheet for each area can be found in Appendix 5 of this study.

7.2.1. Major Process Areas

Coal Delivery, Storage and Crushing

Coal is delivered to the plant in trucks owned by the coal company on a 12 h/day x 5 days/week basis. The ROM coal is fed from a dump hopper via an apron feeder to a coal breaker where it is reduced to -150mm x 0. Belt conveyors transfer the crushed coal either forward to the Aglofloat plant for upgrading or to the outside storage area where 3-day live storage and 10-day compacted storage piles are located. Rocks are removed from the coal breaker and stockpiled at the rate of 10 tph. Belt scales have

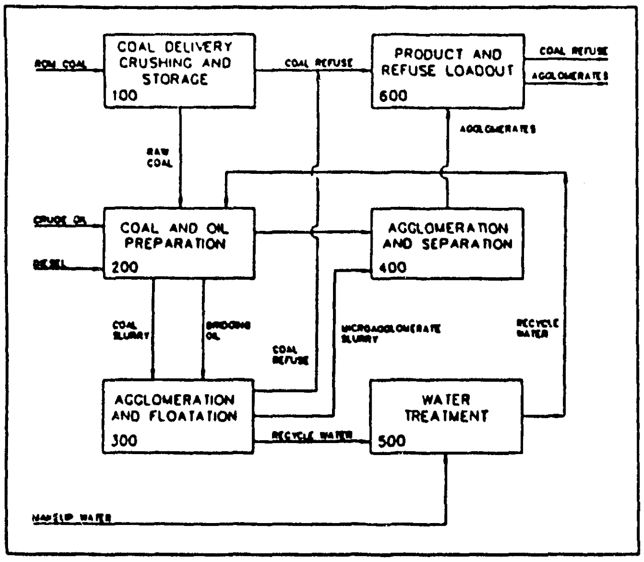


Figure 7.1. The Aglofloat Process.

been included to monitor the quantity of the coal deliveries.

The -150mm x 0 material that is directed to the plant is screened and crushed at the rate of 390 tph to -50mm x 0 on a 24 h/day x 7 days/week basis.

Coal and Heavy Oil Preparation

Sized -50mm x 0mm coal is transferred by belt conveyor to four primary grind circuit mills operating in parallel. The mills pulverize the coal to 45 percent minus 100 mesh at the rate of 390 tph. The pulverized coal is slurried with 910 tph of water, and pumped to the Agglomeration and Floatation Area. The concentration of the coal slurried is about 29.4 percent dry coal, w/w basis.

Crude oil and diesel are delivered to the preparation area by a pipeline. The heavy oil is stored in a 50,000 bbl crude oil tank, ensuring a 5-day supply. The tank is insulated and a steam system is used to preheat the oil in water before it is pumped to the bridging oil tank.

Diesel is stored in a 300 ton capacity tank. 0.4 tph of diesel is mixed in a bridging oil tank with preheated crude oil at the ratio of 1 to 4 (w/w). The purpose of the bridging oil tank is to prepare an oil mix with optimal physical and chemical properties for agglomeration of coal.

Agglomeration and Floatation

The Agglomeration and Floatation area processes pulverized coal slurry at the rate of 1300 tph. The slurry is mixed with 2.0 tph bridging oil in eight high shear mixers operating in parallel. The coal is wetted by oil and forms microagglomerates ~0.2 mm in size, while coal mineral matter is deslimed in water. The output of high shear vessels is mixed with 823 tph recycle water to a slurry, dry coal concentration of 18 percent, and transferred to four floatation cells to separate coal from mineral matter. Each cell processes about 150 tph of clean coal froth. The microagglomerates are transferred to four hydroseparators where they are diluted with 1291.7 tph recycle water, washed, separated from pyrite particles and transferred to a sump. The clean coal froth (533.2 tph) is then again diluted with recycle water and pumped to the Agglomeration and Separation Area.

The floatation cell underflow is transferred to a static clarifier where refuse coal and mineral matter are separated from the recycle water, filtered in a vacuum filter, and after being combined with hydroseparator refuse, transferred to the refuse loading bin in the Product Loadout Area. The hydroseparator underflow is discharged into the second static thickener where refuse pyrite and coal are removed and filtered and water is recycled to the hydroseparator.

Approximately 70.5 tph of refuse coal will be removed from the underflow circuits of the floatation and hydroseparation units.

Agglomeration and Separation

The Agglomeration and Separation Area processes 1062 tph of microagglomerates slurry. The microagglomerates slurry is mixed with 38 tph of crude oil in eight low shear mixers operating in parallel. The microagglomerates are enlarged to 0.8 mm to 3.0 mm macroagglomerates. The green macroagglomerates are discharged on four drain and rinse vibrating screens where they are dewatered to 25 percent moisture. The agglomerates are then transferred to eight centrifugal extractors operated in parallel, where they are further dewatered to 10 percent moisture. The final dry agglomerate product is transferred to the Product Loadout Area at the rate of 392 tph.

All process water from the D&R screens and the centrifugal extractor is recycled to the Coal and Oil Preparation Area.

Water Treatment

Most of the process water from the plant is recycled back to the process areas. Each process area maintains its water chemistry by reusing the same water in each major process step. The process make-up water is well or surface water which is treated and stored in the water pond along with the treated recycle water.

Product Loadout

The agglomerates are transferred from the Agglomeration and Separation Area at the rate of 392 tph into a 10,000 tonne live capacity stockpile. The agglomerates are withdrawn from the pile with vibrating feeders and transferred to a loadout bin for loading into conveyors via shuttle conveyor. The cars are weighed and the surface of the product is sprayed with a latex solution prior to shipment.

The coal refuse is loaded at the rate of 70.5 tph from a 500 t capacity refuse bin. The refuse is loaded on trucks and hauled to the refuse disposal area. An allowance is made for an emergency 10-day refuse storage pile at the plant site.

Offsites and Buildings

The costs of offsites and buildings in this study have been factored from the total direct costs for each plant area.

7.3. Cost Estimates and Financial Analysis

7.3.1. Capital and Operating Cost Estimates

The evaluation of the direct plant cost for the Aglofloat process was based on individual costing of the six major process areas, using one of the following methods:

- Factored cost estimate based on vendor or in-house data for major pieces of equipment.
- Factored cost estimates based on equipment capacity and published cost estimates for the process area.

The accuracy of the individual process area cost estimates is expected to be %30 percent.

A summary of Total Capital Cost for the Agflotherm process is presented in Table 7.1. The table also depicts Working Capital and Total Plant Cost. Total Plant Cost consists of the Total Direct Cost, EPCM, and contingency for each plant area.

The EPCM costs were estimated at 20 percent of the total direct cost for each plant area. This cost covers the cost of process and project engineering, design drafting, engineering procurement and construction management.

The Contingency Cost estimates were based on the direct cost and the uncertainty associated with each plant area. Forexample, the contingency is 35 percent for the Agglomeration and Separation Area, 20 percent for Water Treatment, and 10 percent for the Coal Delivery, Storage and Crushing Area. This cost covers possible additional costs that would result from a more detailed design of the plant at an actual site. A description of the contingency factors is given in Table A5.5, Appendix 5.

A summary of working capital is provided in Table 7.2. The cost data and assumptions used for calculation of the working capital cost elements are presented in Appendix 4. A summary of the annual operating costs is presented in Table 7.3. The direct operating costs were estimated as follows:

- ROM coal was assumed at $27/t (f.o.b. plant),
- fuel cost (natural gas) at $2.90/MMBtu,
- raw water cost at $0.60/1000 gallons,
- electricity at $0.0.65/kWh,

Table 7.1. Total capital cost: Aglofloat.

Area	Description	Total direct cost, 000's	EPCM @20%, 000's	Contingency 000's	Total 000's
100	Coal delivery, storage and crushing	5,267	1,053	527	6,847
200	Coal and oil preparation	12,742	2,548	1,274	16,565
300	Agglomeration and floatation	9,018	1,804	3,156	13,978
400	Agglomeration and separation	5,392	1,078	1,887	8,358
500	Water treatment	1,150	230	230	1,610
600	Product loadout	7,810	1,562	781	10,153
700	Offsites	3,724	745	-	4,469
Total Plant Costs					**$ 61,979**
Working Capital					22,155
Total Capital Cost					**$ 84,134**

Table 7.2. Working capital summary: Aglofloat.

Description	000'S
One Month of Operating Cost	10,088
One Month of Accounts Receivable	12,067
Total Working Capital	**22,155**

- chemicals and operating labour as summarized in Table A5.7, Appendix 5; and
- maintenance labour and materials as summarized in Table A5.8, Appendix 5.

The indirect operating costs were estimated as follows:
- the administrative and support labour at 15% of direct operating and maintenance labour,
- the general administrative expense at 60% of direct operating and maintenance labour, and
- property taxes and insurance at 1.5% per year of Total Plant Cost.

7.3.2. Financial Analysis

The criteria for the financial analysis of the Agflotherm process and costing of the product (f.o.b. plant) included:

- equity financing: 100 percent
- taxable rate: 38% annually
- construction allocation: over 3 years
- plant life: 25 years
- depreciation: straight line over 10 yrs
- plant load: 80%

It is assumed that the plant will be in full production in the fourth year after the start of construction. It is also assumed that an inventory consisting of a ROM coal stockpile of 100,000 tons, 10,000 tons of agglomerates and 10,000 tons of crude oil inventory is established in the first year. These inventory costs are included in the first year's operating cost but not in the revenue calculation.

Base Case

A summary of the Base Case financial analysis is presented in Table 7.4. The analysis is based on the following financial assumptions:

- Total Plant Production: 2.74 x 10^6 t/y agglomerates
- Total Plant Cost: $ 61,979,000
- Total Operating Cost: $ 121,100,000
- Coal Price: $27/t

Table 7.3. Operating cost summary: Aglofloat.

Direct Cost	000'S
ROM Coal	75,600
Crude Oil and Diesel	28,441
Diesel	500
Fuel	131
Electricity	6,132
Chemicals	765
Operating Labour	1,578
Maintenance Labour	720
Maintenance Materials	1,081
Refuse Disposal	3,455
Total Direct Cost	**118,402**
Indirect Cost	
Administrative and Support Labour	345
General and Administrative Expense	1,379
Property Taxes and Insurance	930
Total Indirect Cost	**2,654**
Total Operating Cost	**121,056**

Table 7.4. Summary of plant revenue and costs over the plant life: Aglofloat.

Total Cash Flow	
+ Revenue	3,620,000,000
- Total Operating Cost	3,027,500,000
- Working Capital	22,155,000
- Income Tax	202,000,000
- Equity Capital Cost	61,979,000
= Net Cash Flow	306,366,000
DCF Rate of Return, %	15

- Crude Oil Price: $ 102.60/t
- Diesel Price: $ 178.40/t
- DCF ROR (after taxes): 15%

Variance Analysis

The impact of major economic and process assumptions was studied by performing sensitivity analyses with respect to those assumptions. All variance cases are presented in relation to the Base Case analysis (Figures 7.2 to 7.5).

Amount of Oil for Agglomeration

The agglomerate prices were based on the addition of 12 percent of oil (coal basis) for size enlargement of the agglomerates. ARC's process development work is currently directed towards reduction of the

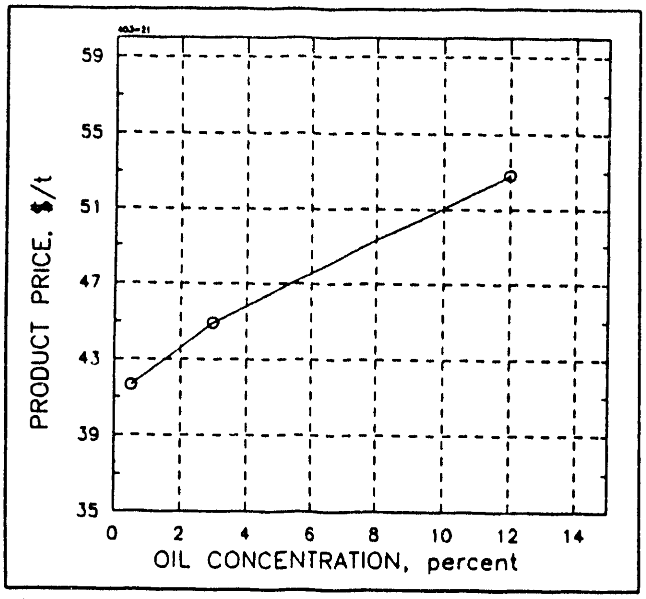


Figure 7.2. The effect of oil concentration on product price (Aglofloat).

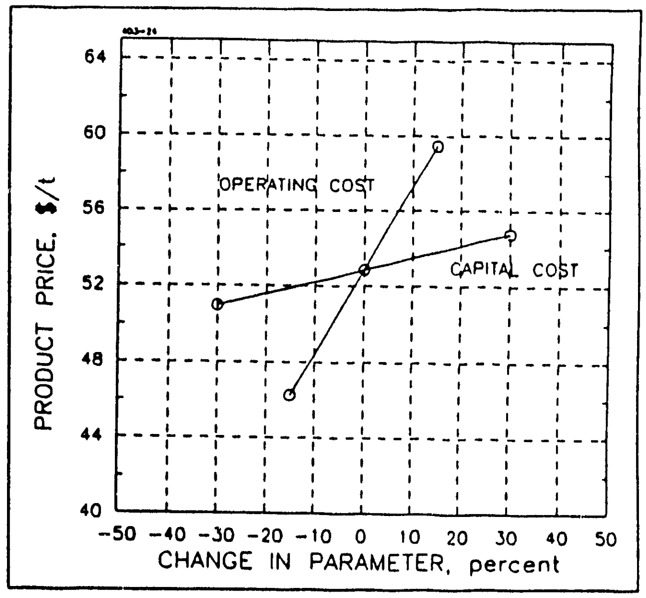


Figure 7.3. The effect of capital and operating cost on product price (Aglofloat).

amount of oil, and, hence, reduction of agglomerate price. Two more cases were, therefore, evaluated in the variance analysis. These cases were a 3 percent oil addition for agglomerates size enlargement based on the anticipated process improvements and a 0.5 percent oil addition in agglomeration based on elimination of the size enlargement step.

Base Case:	12 percent (dry, ash coal feed basis).
Decrease I:	3 percent (dry, ash coal feed basis).
Decrease II:	0.5 percent (dry, ash coal feed basis) less capital and O&M for Area 400.

Total Plant Cost

The plant Total Capital Cost is based on the expected cost, estimating accuracy of %30 percent. The performed variance analysis included:

Base Case:	$ 61,979,000.
Decrease:	$ 43,385,000 (Base Case - 30 percent).
Increase:	$ 80,573,000 (Base Case + 30 percent).

Operating Cost

Allowances for the variance in Total Operating Cost included the following factors:

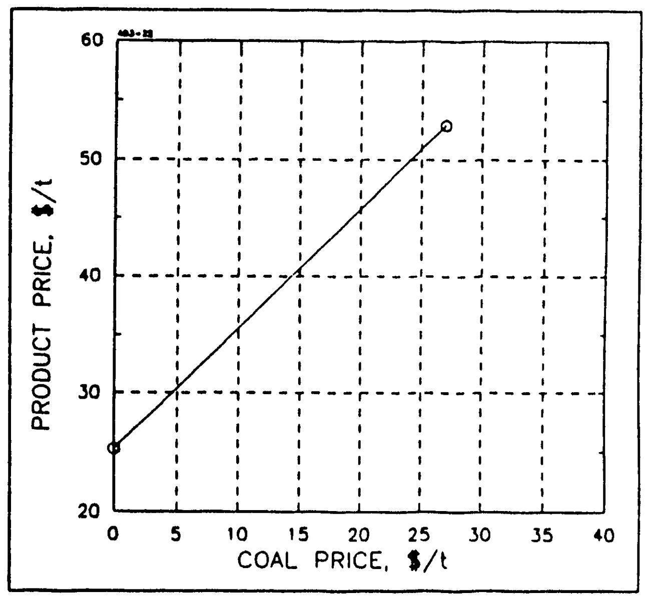


Figure 7.4. The effect of coal price on product price (Aglofloat).

Base Case:	$ 121,100,000.
Decrease:	$ 102,935,000 (Base Case - 15 percent).
Increase:	$ 139,265,000 (Base case + 15 percent).

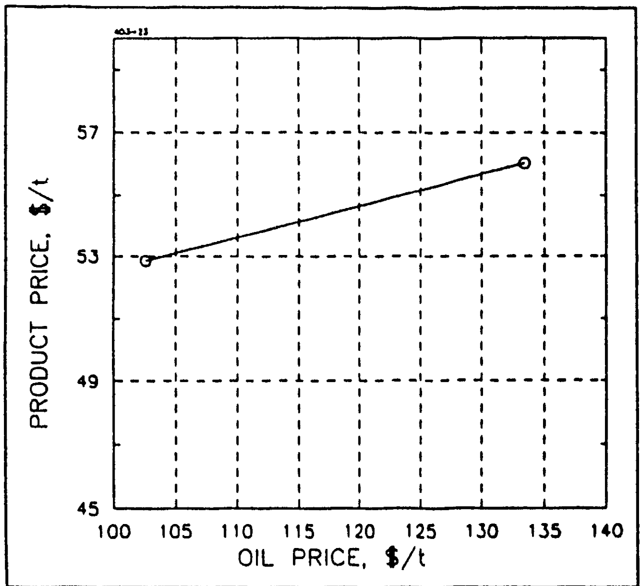


Figure 7.5. The effect of oil price on product price (Aglofloat).

Coal Cost

The price of $27/t was recommended for 2 to 3 million tonnes of ROM coal. The sensitivity analysis included the following ROM coal prices:

Base Case: $27/t.
Decrease: $0/t (coal refuse from a coal preparation plant).

Oil Cost

The Mexican Maya crude (22# API) was priced out of U.S. Gulf Coast less the WTI/Maya crude differential of - $4.00/bbl, plus a transportation tariff of $1.00/bbl to Northern Appalachia.

Base Case: $ 102.60/ton.
Increase: $ 133.40/ton (Base Case + 30 percent).

7.4. Process and Market Economic Implications

7.4.1. Breakdown of Product Cost

Table 7.5 presents a breakdown of the prices of agglomerates according to various process cost factors. The key cost factors are discussed below.

The cost of coal and oil are the largest cost factors involved. They are, respectively, $27.59 and $10.56 per ton of agglomerates, or 52.2 and 20.0 percent of the product price.

The charge is $8.67 per ton or 16.4 percent of the product price. The operating component of the product price is $6.03 per ton or 11.4 percent.

Table 7.5. Breakdown of the estimated cost for agglomerates[1].

	Product Cost[1]		
Cost Factors	**$/t**	**$/MMBtu**	**%**
ROM Coal	27.59	1.04	52.2
Bitumen and Light Oil	10.56	0.40	20.0
Operating Cost	6.03	0.23	11.4
Capital Charge	8.67	0.33	16.4
	52.85	1.99	100.0

1: DCF ROR equals 15 percent, 13,300 Btu/lb product.

7.5. Conclusions

A conceptual design and a cost analysis were developed for the Aglofloat process. The process description, process data and design were based on tests performed in batch laboratory experiments, the CPRU and the IATF. The plant was to upgrade 2.8 million short tons of ROM coal per year to 2.74 million tons of agglomerates with 13,300 Btu/lb heating value, 6.2 percent of ash, and 2.5 percent of total sulphur. The plant was assumed to be a mine-mouth plant located in the Appalachia region of the U.S.

The majority of the plant areas and equipment selected were commercially proven and available, the exception was the Agglomeration and Floatation Area where a new design was proposed for the hydraulic separator. Because of the similarity of the hydraulic separator to the floatation cell, the cost of the hydroseparator was factored from the floatation cells' cost estimates.

The financial and variance analyses performed indicated the Base Case product cost, at 15 percent DCF ROR, equaled $52.85/t. The Base Case Total Plant Cost was $61,979,000, Operation Cost was $121,056,000 and Working Capital was $22,155,000. The costs of coal and bridging oil were the largest cost factors involved (52.2 and 20.0 percent, respectively) while the capital charges and operating cost combined contributed the remaining 20 percent.

8. Summary and Recommendations

The study's objective was to apply advanced agglomeration technology for upgrading of high sulphur bituminous coals. The results achieved included development of the Aglofloat process for upgrading of bituminous coals to a solid fuel with a heating value of above 13,000 Btu/lb, ash content less than 10 percent, and reduced pyritic sulphur content (up to 95 percent). The work completed also suggested further process research and development needs which are summarized below.

Batch-Test Studies

Two types of laboratory tests were developed for characterization of bituminous coal clean-up in the Aglofloat: single-stage and two-stage tests. The tests indicated that two-stage processing with interstage regrinding resulted in more ash and sulphur removal but also higher loss of combustible materials. The choice of the Aglofloat procedure would depend, therefore, on the amount of sulphur removal and coal recovery required for each specific coal.

The process variables studied (bridging oil concentration and preparation, coal concentration, addition of surfactants, etc.) provided information on the key factors influencing the Aglofloat performance with bituminous coals. It was found, for example, that for western Canadian bituminous coals, the Aglofloat procedure had to be modified in order to achieve high combustibles recovery (90 percent or higher). The modified procedures called for addition of surfactants and bridging oil at 3 percent concentration (w/w dry coal basis) versus 0.5 percent for the U.S. bituminous coals. It is recommended, therefore, that further detailed batch tests be conducted to study process issues such as:

- The effect of coal properties and preparation on agglomeration kinetics, and the required bridging oil addition.
- The use of surfactants and other pretreatment methods for agglomeration of "difficult" coals.
- Development of predictive methods for characterization of the Aglofloat performance with different bituminous coals.

Continuous Pyrite Removal Unit

The completed tests provided information on the feasibility of using hydraulic and flume separators for the removal of pyrite from bituminous coal flocs. Both unit processes showed reduction of pyrite in the coal product; however, a system including a floatation cell and hydraulic separator was chosen over a more operationally complex system which included a flume separator.

The experiments conducted with high sulphur Illinois No. 6 coal indicated that at best conditions, the combustibles recovery ranged from 75 to 80 percent, the total sulphur reduction ranged from 50 to 55 percent, the pyritic sulphur reduction ranged from 72 to 77 percent, and the ash reduction ranged from 82 to 86 percent. The important operation parameters identified were oil, frother and coal concentration, size of coal, high shear mixer operating condition (speed and residence time).

The CPRU was successfully used for the scale-up of the hydraulic separator for the large pilot plant (IATF). The design procedures developed were also helpful for further optimization of the hydraulic separator in the IATF.

In general, the CPRU required more bridging oil than the IATF or batch tests. Further recommended studies and equipment modification for the CPRU included:

- Installation of a second high shear mixer to increase HSM mean residence time for slurries requiring higher inversion times.
- Installation of a second floatation cell in series with the floatation tailings to recover coal from the tailings.
- Installation of accumulation vessels for the floatation cell and hydraulic separator to facilitate periodic removal of the accumulated solids.
- Further studies of the main factors and interaction effects in agglomeration of different bituminous coals.
- Further development of correlation and scale-up equations for the CPRU and IATF.

Integrated Agglomeration Test Facilities

A hydraulic separator was incorporated in the IATF to operate the pilot plant in the Aglofloat process configuration. The IATF runs confirmed that well-formed, reduced in sulphur and ash agglomerates can be obtained in the Aglofloat process. The agglomerates had a heating value above 13,000 Btu/lb, ash content of less 10 percent and pyritic sulphur removal of up to 95 percent.

Based on the tests performed, design specifications were defined for the conceptual design of a 2.8 million ton Aglofloat plant. The specifications included a relatively high amount of bridging oil (12 percent d.a.f. feed coal basis) in order to obtain 0.8 to 3.0 mm agglomerates. More research on the IATF is, therefore, recommended in order to reduce the amount of oil used in the process. Recommended research includes:

- Investigation of the relationship between feed size, feed properties, and product quality, at different oil additions.
- Improvement of floatation and pyrite separation efficiency, at high solid slurry loading.
- Development of better control strategies for different feeds.
- Evaluation of the Aglofloat process configurations where size enlargement by agglomeration is eliminated and other options to size enlargement are considered.

Feasibility of the Aglofloat Process

A conceptual design for the Aglofloat plant was developed for beneficiating 2.8 million tons of ROM bituminous coal per year to 2.74 million tons of agglomerates with a heating value of 13,300 Btu/lb, ash content of 6.2 percent and sulphur content of 2.5 percent. The economic analyses of the plant cost estimated the Capital Cost at $61,978,000, Operating Cost at $121,056,000 and Working Capital at $22,155,000. The Product Cost was estimated at $52.85 per ton at DCF ROR equal to 15 percent (after tax).

The Product Cost was sensitive to the cost of coal, to the cost and quantity of bridging oil, and to a lesser extent, to Capital and Operating Cost (excluding coal).

For variance case, where Aglofloat is applied to cleaning coal refuse, the Product Cost was estimated at $25.26/t. This cost is competitive with the average cost for low and medium sulphur coal in the eastern U.S. of $20 to $28 per ton.

Recommended future work on the conceptual design of the Aglofloat process includes:

- Updating of the design and costing of the process areas based on additional experimental work performed at the Integrated Agglomeration Test Facility.
- Evaluation of the process design and area costing for alternative size enlargement process options in the Aglofloat process.
- Review of the economic feasibility and market potential of the Aglofloat process for the updated process designs.

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Appendix 2.

Table A2.1. Properties of bituminous coals tested.

	DOE Supplies Ill. No. 6	Ill. No. 6	Ohio	Pitts.	Indiana V	Upper Freeport	Byron Creek	Obed Washed	Obed Precip. Dust
Moisture							24.5	8.5	10.5
Ash	14.3	34.8	9.2	17.7	9.7	12.3	21.9	14.2	27.7
Volatile Matter	-	28.8	-	-	-	-	22.1	36.2	32.6
Fixed Carbon	-	36.4	-	-	-	-	56.1	49.5	39.7
Total Sulphur	4.27	4.19	4.72	4.98	3.77	2.33	0.30	0.51	-
Pyritic Sulphur	1.98	2.33	2.94	2.70	1.83	1.37	-	-	-
Heating Value	11,980	8,350	12,390	11,960	13,270	13,560	11,530	10,510	8,140

* on moist basis.

Appendix 3.

Table A3.1. Pyrite removal process performance – Test Data, Run No. D3.

Run/ Per.	Oil conc. db %	Sample A (S-140) Parent coal (db) A %	TS %	PS %	SS %	Sample B (S-201) Coal slurry A %	TS %	PS %	SS %	Sample C (S-S01) (S-221) Product C A %	TS %	PS %	SS %	Sulphur Removal ΔTS %	ΔPS %	Coal Recov %
A	3.0	34.1	4.65	2.53	0.37	30.5	4.37	1.70	0.09	11.8	4.25	1.70	0.09	29.0	82.9	87.6
B	2.9	34.5	4.84	2.53	0.37	30.9	4.33	1.75	0.21	14.1	4.33	1.75	0.21	23.2	61.4	88.5
C	2.8	33.8	5.24	2.53	0.37	30.9	4.50	2.17	0.22	14.7	4.50	2.17	0.22	20.6	58.6	89.0
D	2.3	33.3	4.95	2.53	0.37	31.8	5.02	2.33	0.12	14.8	5.02	2.33	0.12	21.7	78.2	87.0

Table A3.1. Pyrite removal process performance – Test Data, Run No. D3 (cont'd).

Run/ Per.	Oil conc. db %	Sample D (S401) Product D A %	TS %	PS %	SS %	Ash & Sulphur Removal ΔA %	ΔTS %	ΔPS %	ΔSS %	Coal Recovery %
A	3.0	9.47	4.04	1.48	0.04	82.3	44.3	66.3	69.8	75.3
B	2.9	10.72	5.53	1.83	0.07	84.1	45.0	61.0	65.2	75.8
C	2.8	10.96	4.51	1.85	0.04	83.4	49.7	59.4	63.3	76.4
D	2.3	10.41	4.60	1.88	0.04	85.6	51.2	62.1	66.2	72.4

Table A3.2. Pyrite removal process performance – Test Data, Run No. D4.

Run/ Per.	Oil conc. db %	Sample A (S-140) Parent Coal (db) A %	TS %	PS %	SS %	Sample B (S-201) Coal Slurry A %	TS %	PS %	SS %	Sample C (S-S01) (S-221) Product C A %	TS %	PS %	SS %	Sulphur removal ΔTS %	ΔPS %	Coal recov %
A	2.4	34.3	4.88	2.89	0.20	32.3	16.6	2.55	0.15	16.6	4.97	2.81	0.06	-	-	-
B	2.7	34.0	5.14	2.89	0.20	32.8	13.4	2.60	0.13	13.4	4.46	2.38	0.06	-	-	-
C	2.6	33.8	5.09	2.89	0.20	32.8	14.3	2.71	0.13	14.3	4.55	2.01	0.06	-	-	-

Table A3.2. Pyrite removal process performance - Test Data, Run No. D4 (cont'd).

Run/ Per.	Oil conc. db %	Sample D (S401) Product D A %	TS %	PS %	SS %	Ash and sulphur removal ΔA %	ΔTS %	ΔPS %	ΔSS %	Coal recovery %
A	2.4	9.30	3.85	1.33	0.05	89.7	70.0	82.5	81.9	52.5
B	2.7	10.20	4.25	1.66	0.05	85.5	60.1	72.3	72.4	65.6
C	2.6	9.60	3.90	1.61	0.05	85.3	60.6	71.3	71.5	70.5

Table A3.3. Pyrite removal process performance – Test Data, Run No. D6.

Run/ Per.	Oil conc. db %	Sample A (S-140) Parent Coal (db) A %	TS %	PS %	SS %	Sample B (S-201) Coal Slurry A %	TS %	PS %	SS %	Sample C (S-S01) (S-221) Product C A %	TS %	PS %	SS %	Sulphur Removal ΔTS %	ΔPS %	Coal Recov %
A	-	32.7	51.8	2.72	0.35	-	-	-	-	-	-	-	-	51.1	-	82.4
B	-	32.7	51.8	2.72	0.35	34.6	4.47	2.19	0.45	15.2	4.93	1.93	0.17	34.2	51.8	85.9
C	-	32.7	51.8	2.72	0.35	35.6	4.65	2.40	0.46	15.4	4.81	2.03	0.16	34.5	51.6	84.0
D	-	32.7	51.8	2.72	0.35	34.9	4.53	2.36	0.40	15.6	4.84	2.57	0.16	32.9	37.4	85.1
E	-	32.7	51.8	2.72	0.35	35.8	4.82	2.39	0.44	15.4	4.27	1.75	0.15	33.4	52.4	85.0
F	-	32.7	51.8	2.72	0.35	-	-	-	-	-	-	-	-	39.8	-	82.9

Table A3.3. Pyrite removal process performance – Test Data, Run No. D6 (cont'd).

Run/ Per.	Oil conc. db %	Sample D (S401) Product D A %	TS %	PS %	SS %	Ash and sulphur removal ΔA %	ΔTS %	ΔPS %	ΔSS %	Coal recovery %
A	–	9.30	3.91	1.10	0.12	84.3	60.0	77.7	78.1	74.4
B	–	9.90	3.94	1.12	0.17	82.5	46.5	75.9	75.4	78.9
C	–	9.95	4.11	1.34	0.15	85.0	48.3	73.7	74.1	74.5
D	–	9.80	4.10	1.19	0.18	83.4	48.2	75.0	74.4	78.1
E	–	10.07	4.21	1.29	0.15	83.6	49.0	21.6	73.6	77.5
F	–	10.59	4.12	1.45	0.09	82.6	61.6	77.0	78.2	73.0

Table A3.4. Pyrite removal process performance – Test Data, Run No. D7.

Run/ Per.	Oil conc. db %	Sample A (S-140) Parent Coal (db) A %	TS %	PS %	SS %	Sample B (S-201) Coal Slurry A %	TS %	PS %	SS %	Sample C (S-S01) (S-221) Product C A %	TS %	PS %	SS %	Sulphur Removal ΔTS %	ΔPS %	Coal Recov %
A	–	32.7	5.18	2.72	0.35	–	–	–	–	–	–	–	–	45.1	–	81.0
B	–	32.7	5.18	2.72	0.35	32.2	4.78	2.56	0.35	15.6	4.79	2.24	0.14	32.2	46.7	83.9
C	–	32.7	5.18	2.72	0.35	31.8	4.70	2.65	0.32	14.3	4.60	2.04	0.17	33.1	51.8	83.8
D	–	32.7	5.18	2.72	0.35	32.6	4.74	2.62	0.35	15.6	4.77	2.31	0.17	32.7	45.6	84.1
E	–	32.7	5.18	2.72	0.35	31.6	4.81	2.48	0.38	16.1	4.73	2.48	0.18	32.7	40.6	84.6
F	–	32.7	5.18	2.72	0.35	–	–	–	–	–	–	–	–	32.8	–	84.8
G	–	32.7	5.18	2.72	0.35	–	–	–	–	–	–	–	–	34.5	–	83.5
H	–	32.7	5.18	2.72	0.35	–	–	–	–	–	–	–	–	28.6	–	87.5

Table A3.4. Pyrite removal process performance – Test Data, Run No. D7 (cont'd).

Run/ Per.	Oil conc. db %	Sample D (S401) Product D A %	TS %	PS %	SS %	Ash and sulphur removal ΔA %	ΔTS %	ΔPS %	ΔSS %	Coal recovery %
A	–	8.34	3.77	1.16	0.09	84.8	50.1	79.4	80.2	72.4
B	–	8.91	3.91	1.27	0.11	83.6	51.9	76.7	77.4	75.5
C	–	9.08	4.03	1.33	0.11	83.7	50.7	74.8	75.7	74.9
D	–	9.39	4.08	1.30	0.13	83.6	51.3	73.6	74.4	75.5
E	–	9.54	4.07	1.40	0.13	82.8	53.2	76.2	76.6	76.3
F	–	9.58	4.09	1.43	0.13	83.0	54.5	74.6	75.2	76.1
G	–	9.56	4.05	1.51	0.12	83.4	55.4	74.5	75.3	74.9
H	–	10.07	4.25	–	0.14	81.6	50.5	70.8	71.5	80.5

Table A3.5. Pyrite removal process performance – Test Data, Run No. D9.

Run/ Per.	Oil conc. db %	Sample A (S-140) Parent Coal (db) A %	TS %	PS %	SS %	Sample B (S-201) Coal Slurry A %	TS %	PS %	SS %	Sample C (S-S01) (S-221) Product C A %	TS %	PS %	SS %	Sulphur Removal ΔTS %	ΔPS %	Coal Recov %
A	2.2	32.3	5.18	2.72	0.35	30.3	4.98	2.27	-	14.3	4.54	1.79	0.08	38.6	46.9	76
B	2.2	32.3	5.18	2.72	0.35	31.4	5.06	2.57	-	13.0	4.47	1.61	0.07	37.7	55.7	82
C	2.2	32.3	5.18	2.72	0.35	31.5	4.88	2.55	-	14.7	4.92	1.85	0.08	26.5	47.1	82
D	2.2	32.3	5.18	2.72	0.35	30.4	4.80	2.58	-	13.9	4.61	2.16	0.08	25.2	34.8	86

Table A3.5. Pyrite removal process performance – Test Data, Run No. D9 (cont'd).

Run/ Per.	Oil conc. db %	Sample D (S401) Product D A %	TS %	PS %	SS %	Ash and sulphur removal ΔA %	ΔTS %	ΔPS %	ΔSS %	Coal recovery %
A	2.2	9.4	3.95	1.11	0.06	84.7	52.9	78.6	80.0	67.2
B	2.2	9.4	3.94	1.09	0.05	83.9	53.9	77.8	79.5	67.8
C	2.2	10.6	4.10	1.36	0.06	81.3	48.6	71.5	73.6	74.5
D	2.2	10.2	4.20	1.29	0.06	81.4	48.8	72.0	74.1	74.2

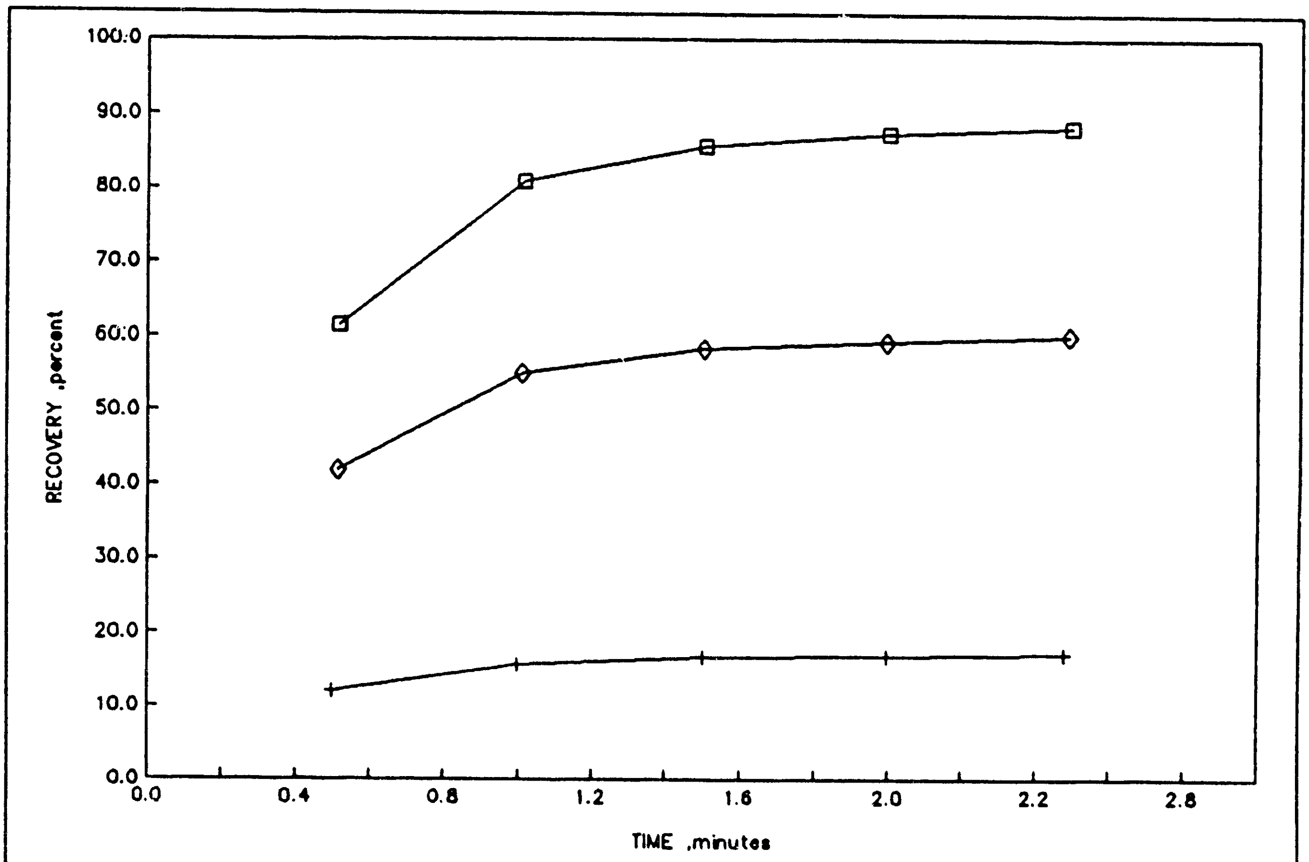


Figure A3.1. Floatation kinetic test results – Influence of floatation time on recovery. Comb.; + Ash; Sulphur.

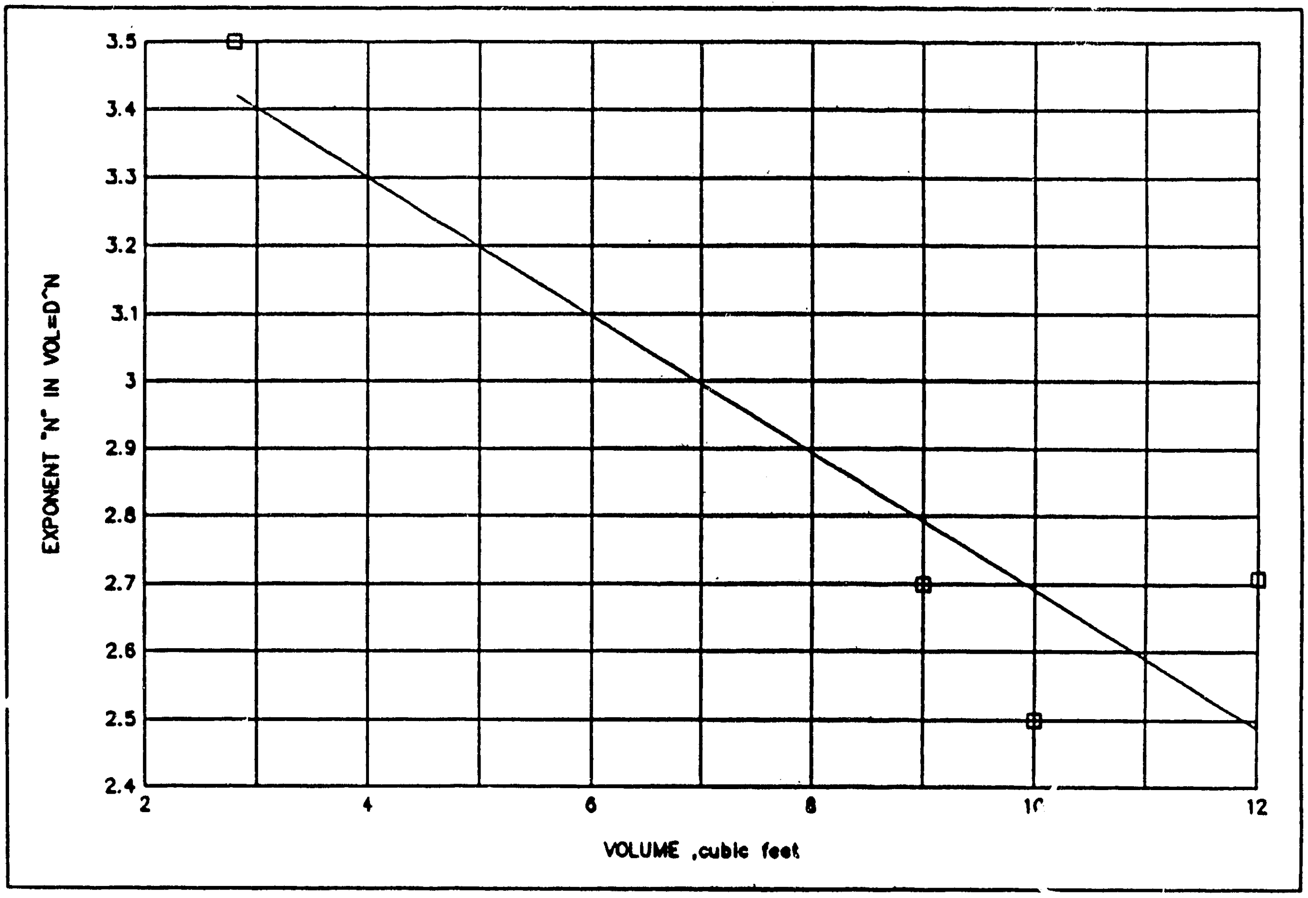
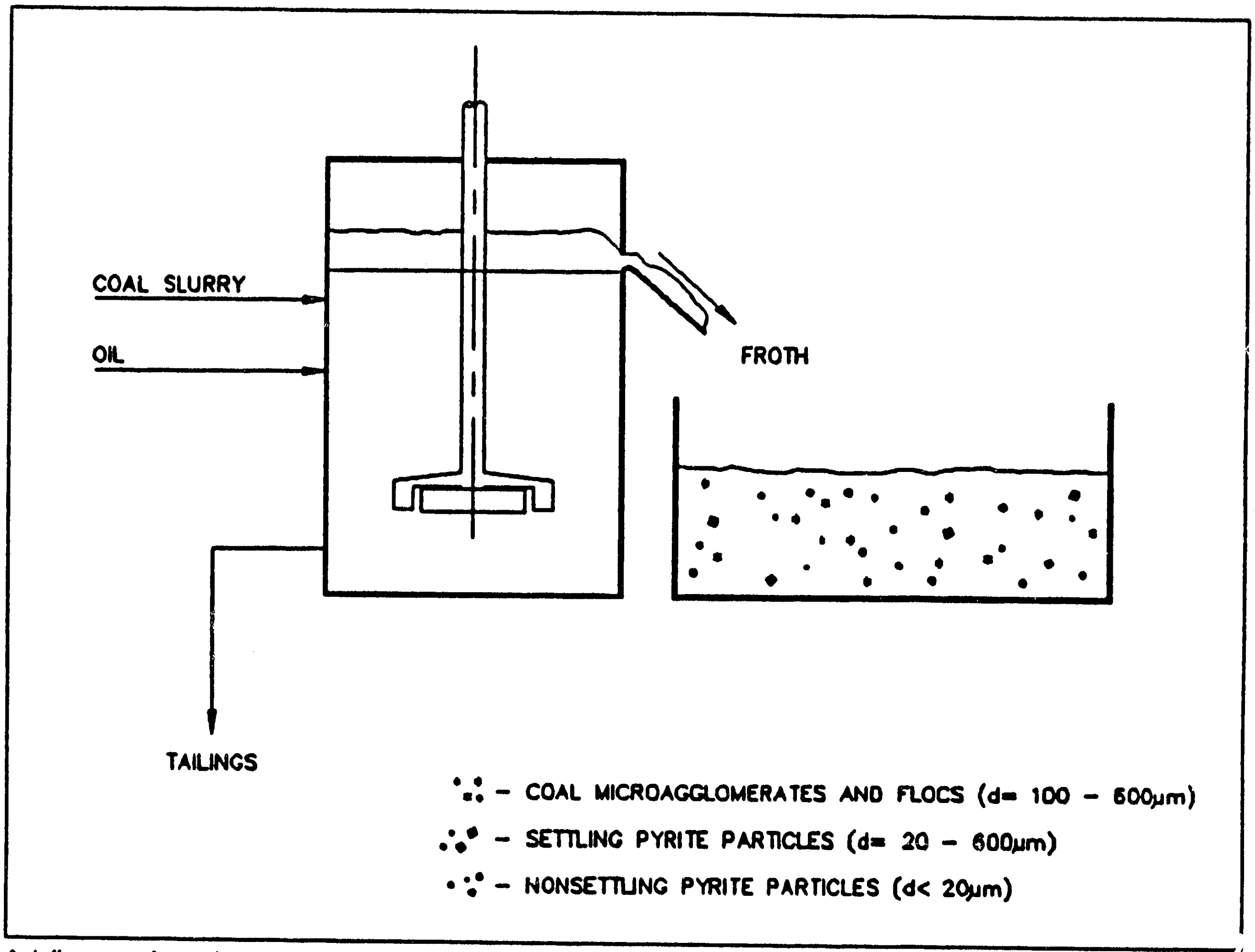
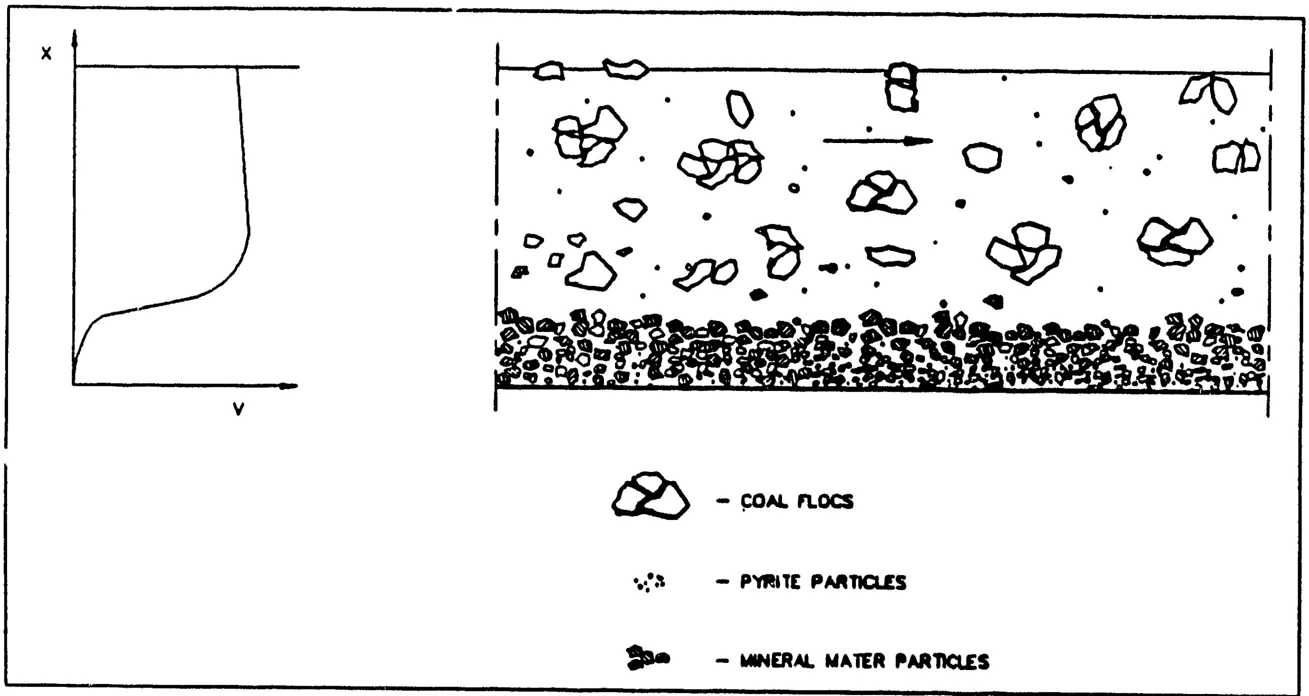


Figure A3.2. Floatation cells geometric configuration.



Aglofloat step for pyrite washing.



Settling, semistationary bed formaton and interstitial trickling effect.

Appendix 4.

IATF Data for Runs 17 to 20

Sample point designation:

A = S-140 (feed coal)
B = S-221 (HSM output)
C = S-501 (floatation cell froth)
D = S-401 (pyrite separator)

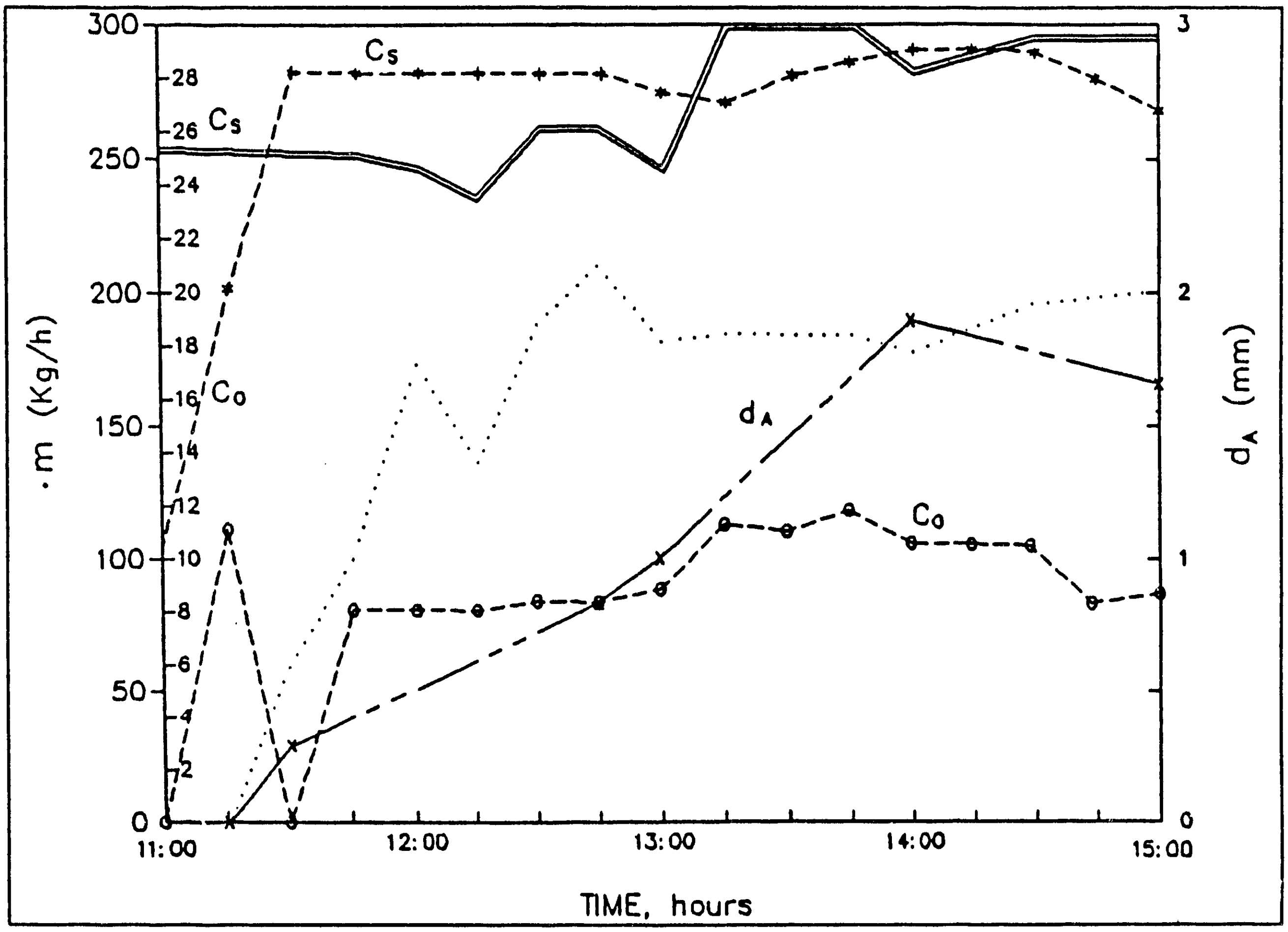


Figure A4.1. Variation of the main process parameters during Run 1.

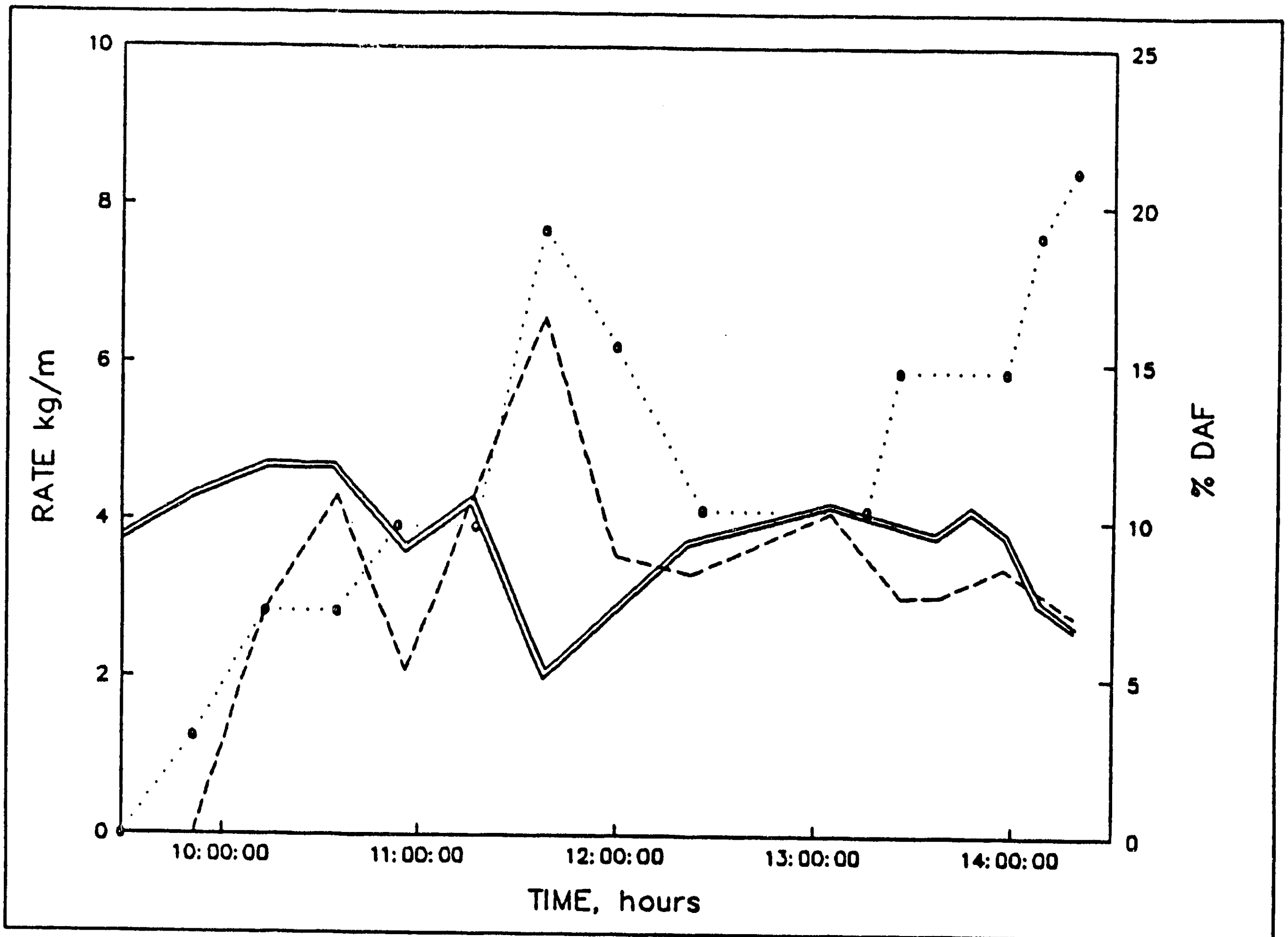
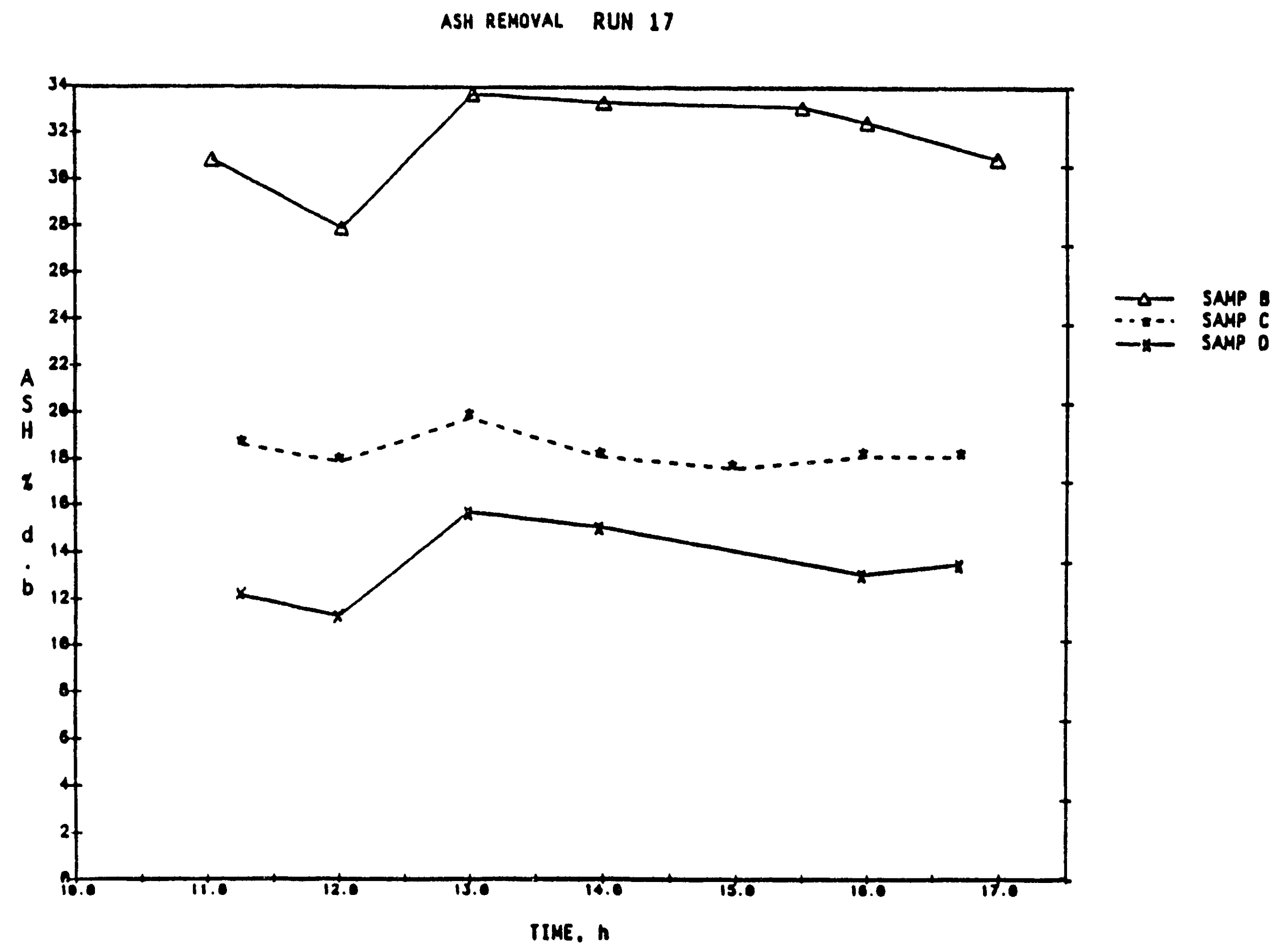
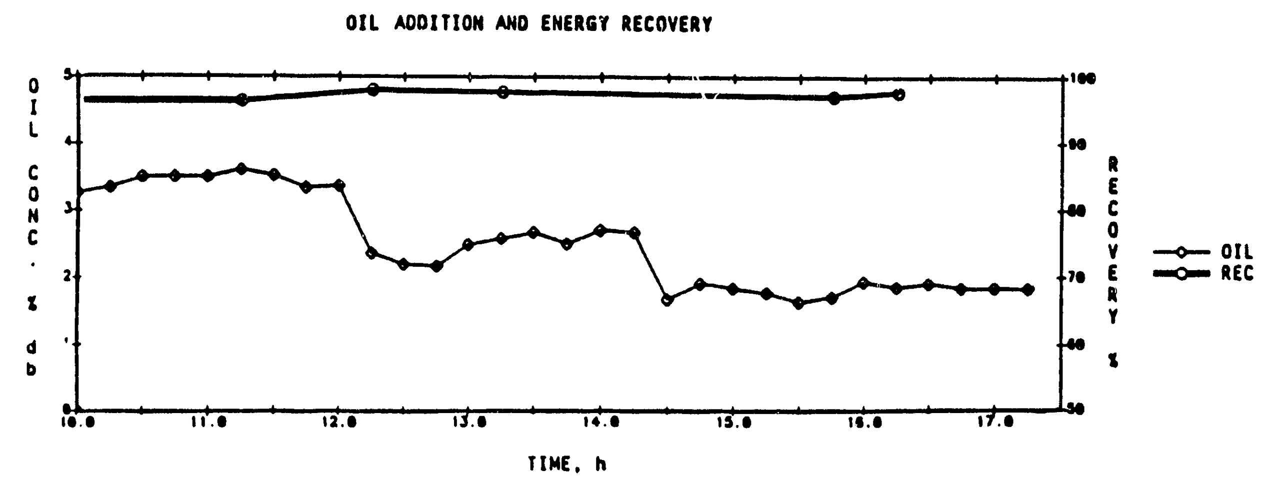


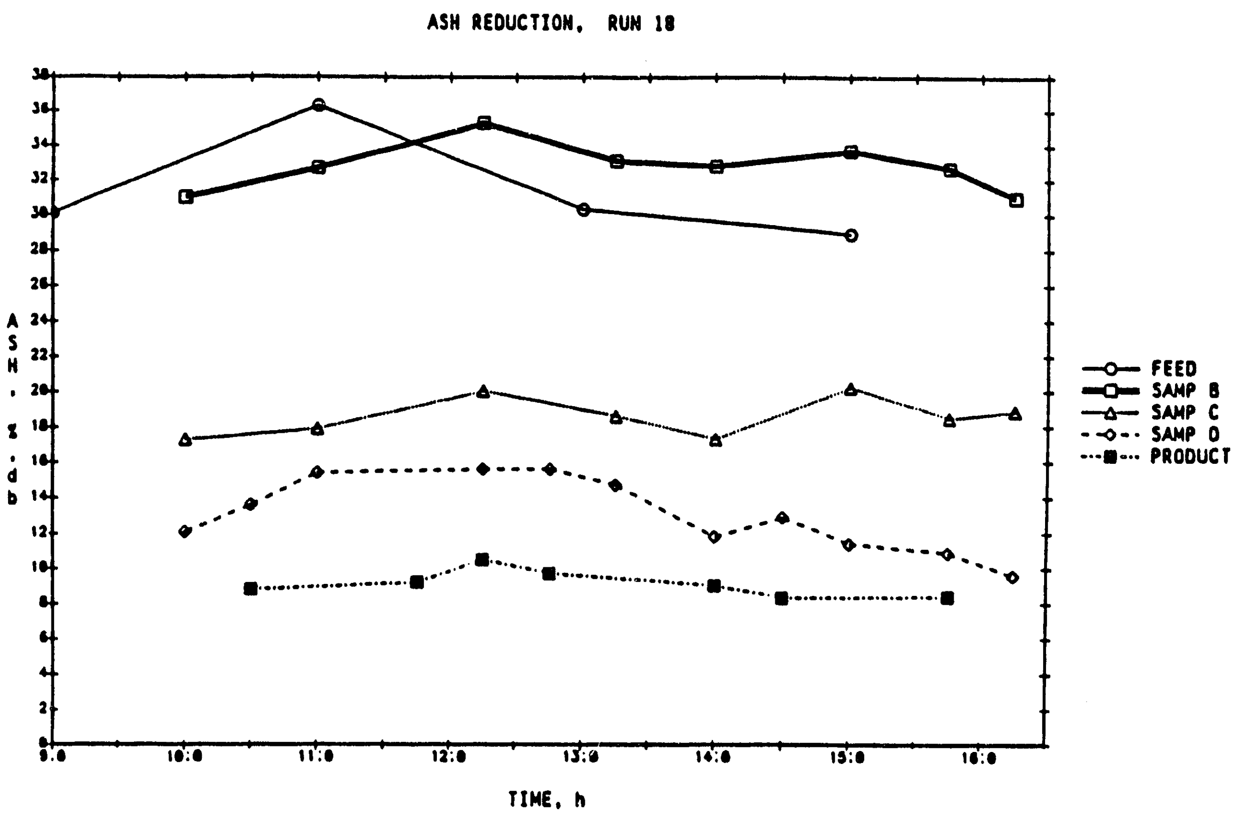
Figure A4.2. Variation of the main process parameters during Run 5.

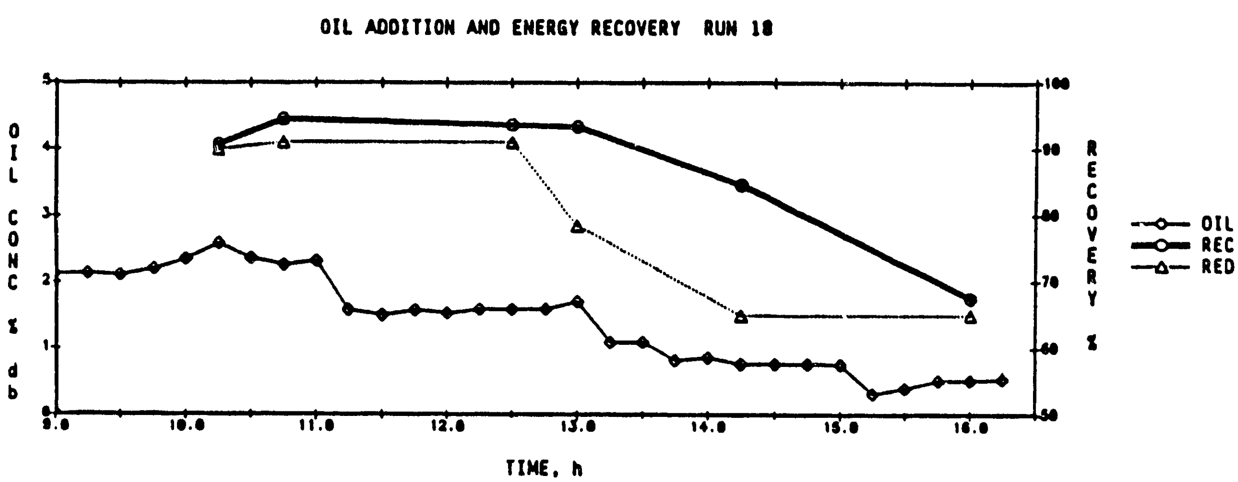


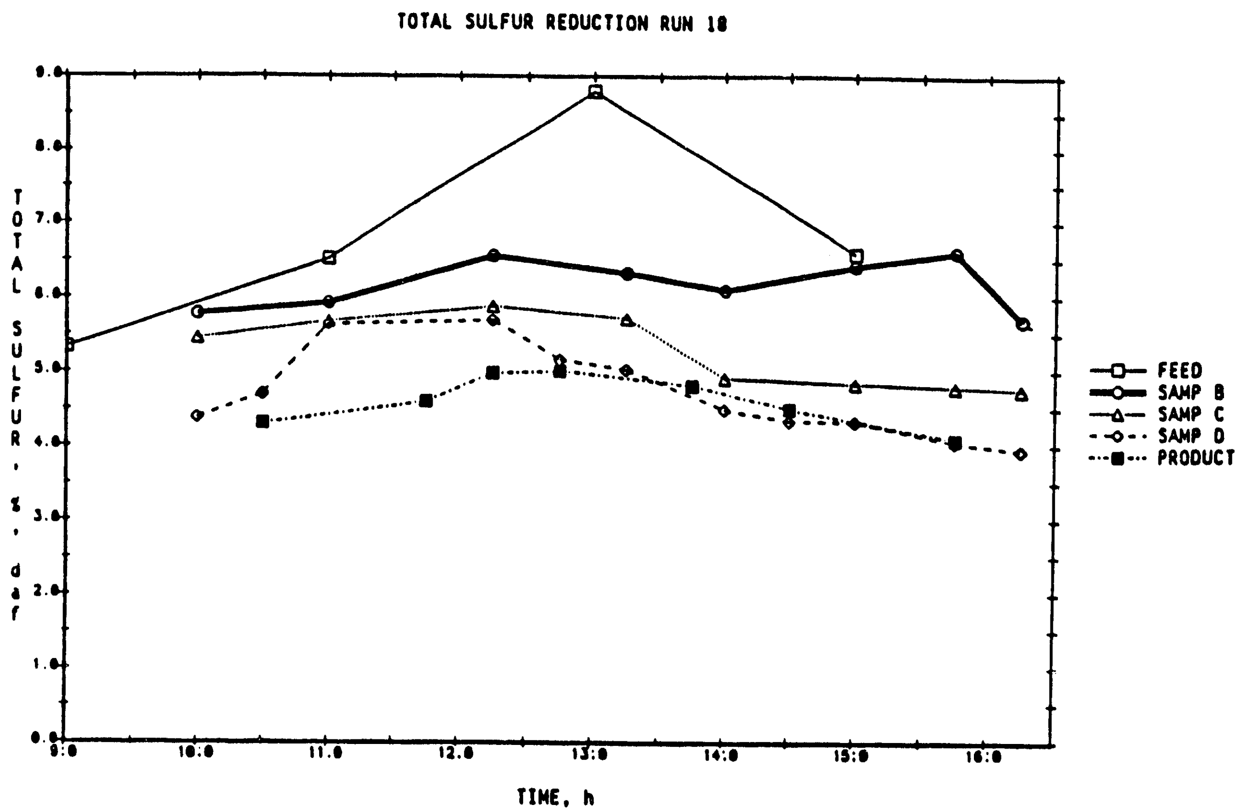
ASH REMOVAL RUN 17
ASH % d.b
TIME, h
SAMP B
SAMP C
SAMP D

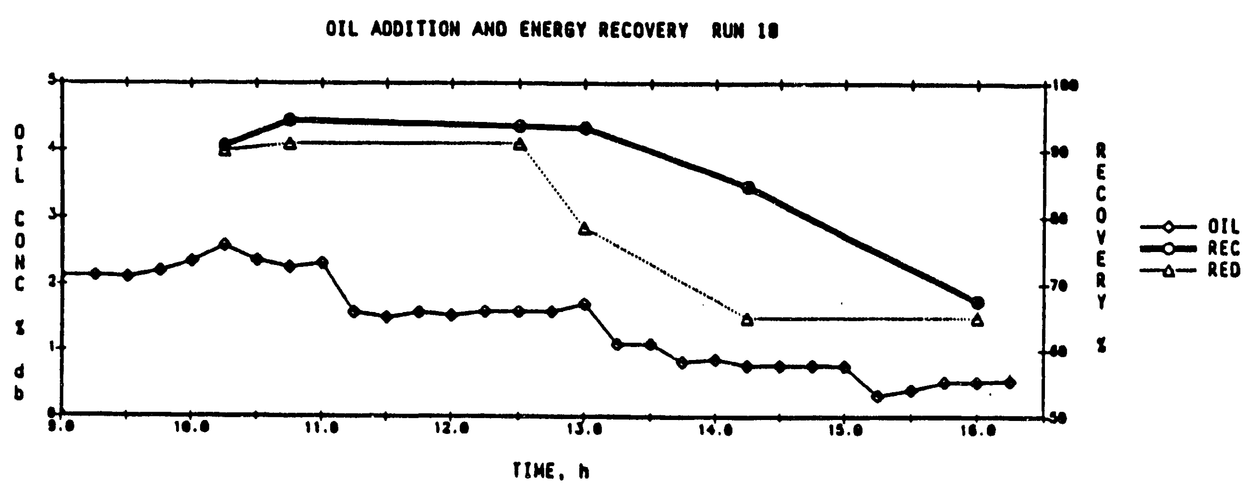


OIL ADDITION AND ENERGY RECOVERY
OIL CONC. % db
RECOVERY %
TIME, h
OIL
REC

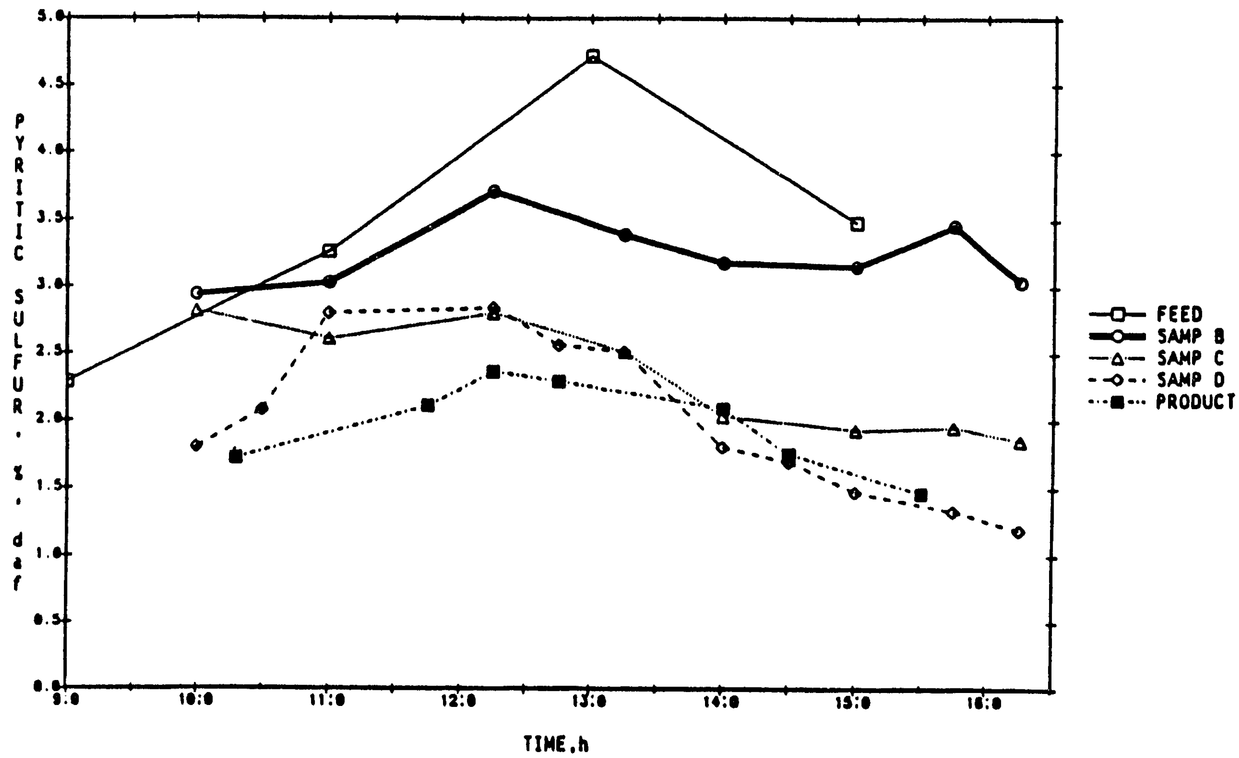

ASH REDUCTION, RUN 18
ASH, % db
TIME, h
FEED
SAMP B
SAMP C
SAMP D
PRODUCT


OIL ADDITION AND ENERGY RECOVERY RUN 18
OIL CONC % db
RECOVERY %
TIME, h
OIL
REC
RED

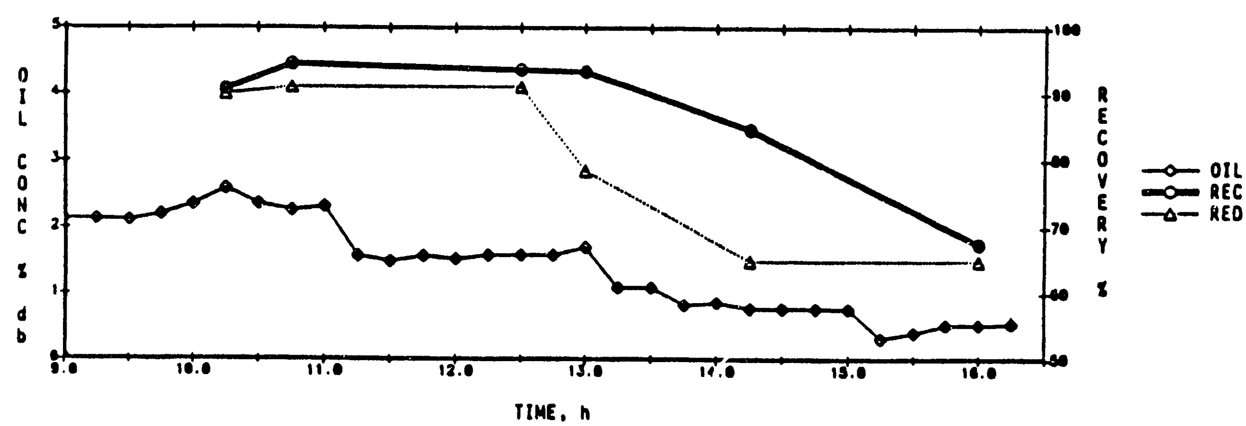

TOTAL SULFUR REDUCTION RUN 18
TOTAL SULFUR, %, daf
TIME, h
FEED
SAMP B
SAMP C
SAMP D
PRODUCT


OIL ADDITION AND ENERGY RECOVERY RUN 18
OIL CONC % db
RECOVERY %
TIME, h
OIL
REC
RED

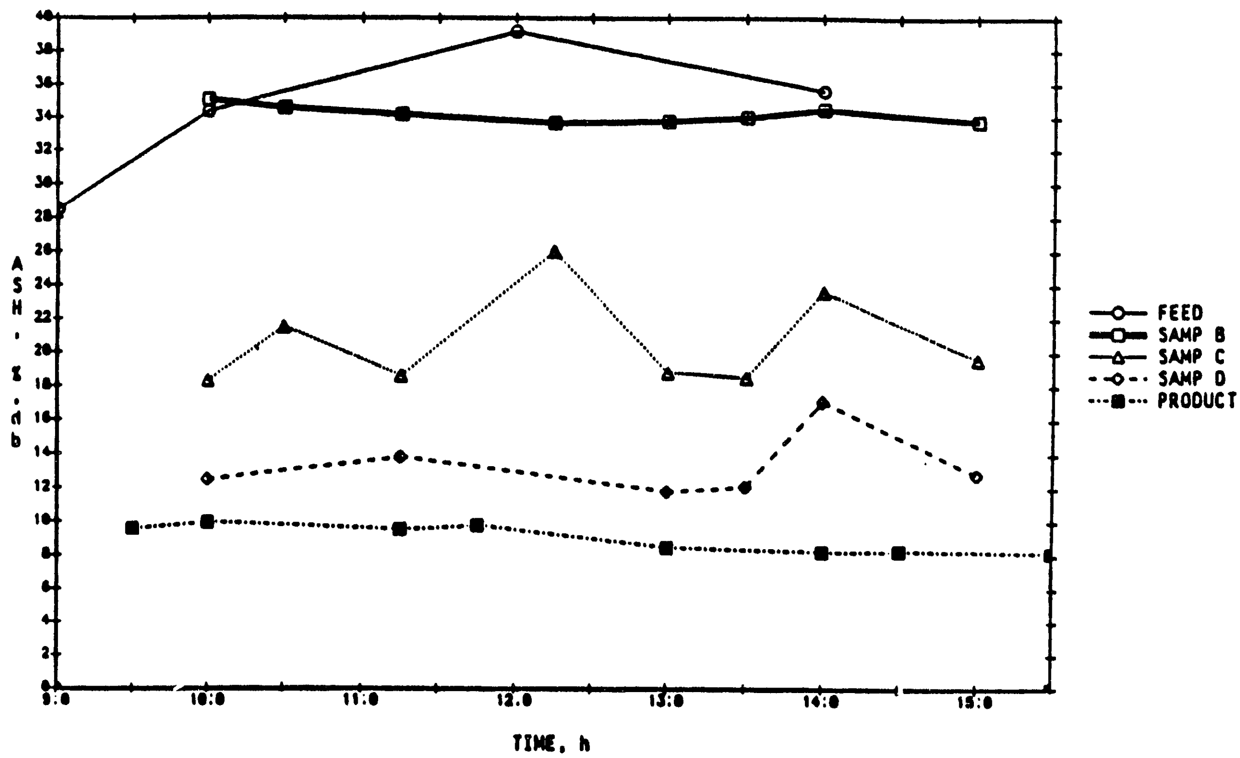
PYRITE REDUCTION, RUN 18



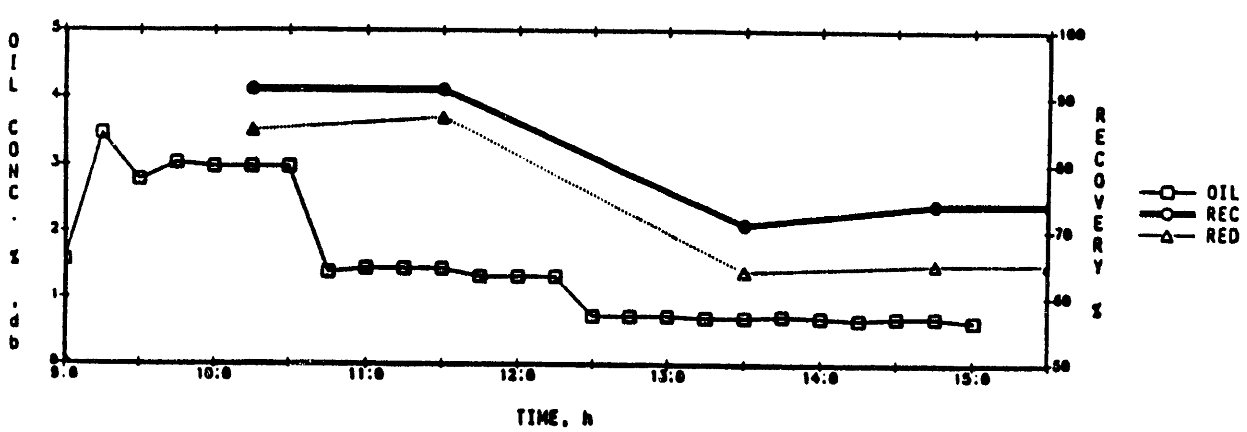
OIL ADDITION AND ENERGY RECOVERY

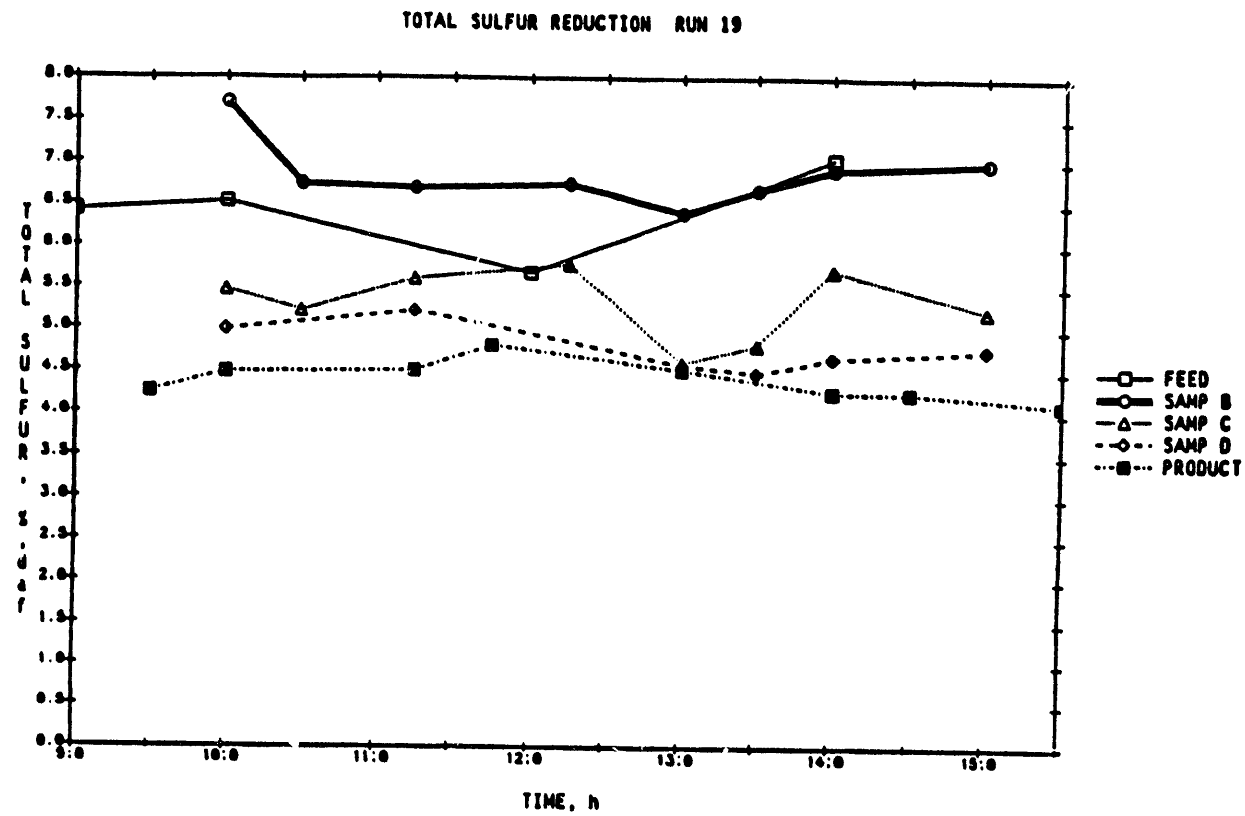


ASH REDUCTION, RUN 19

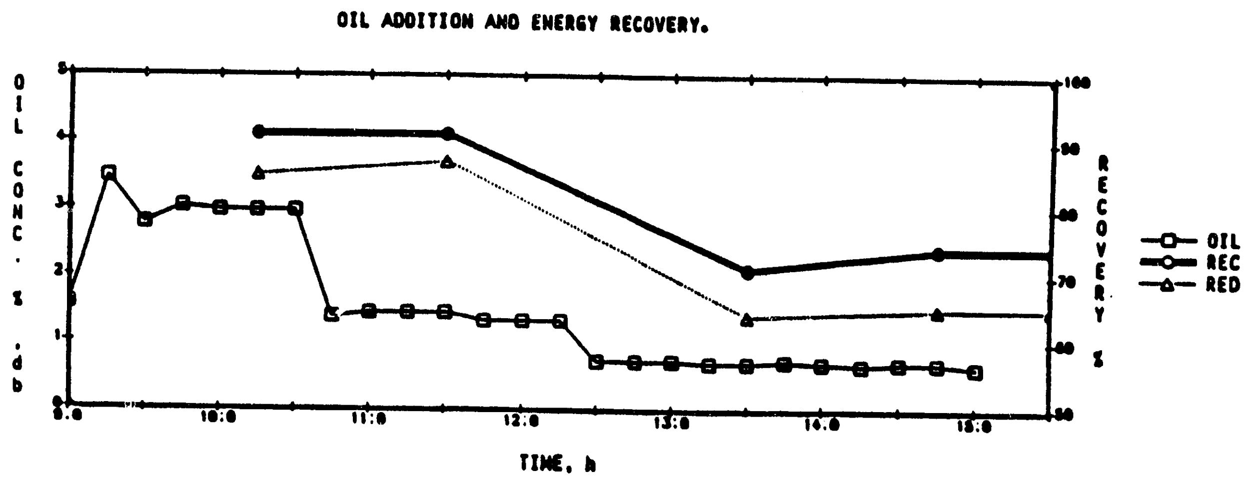


OIL ADDITION AND ENERGY RECOVERY

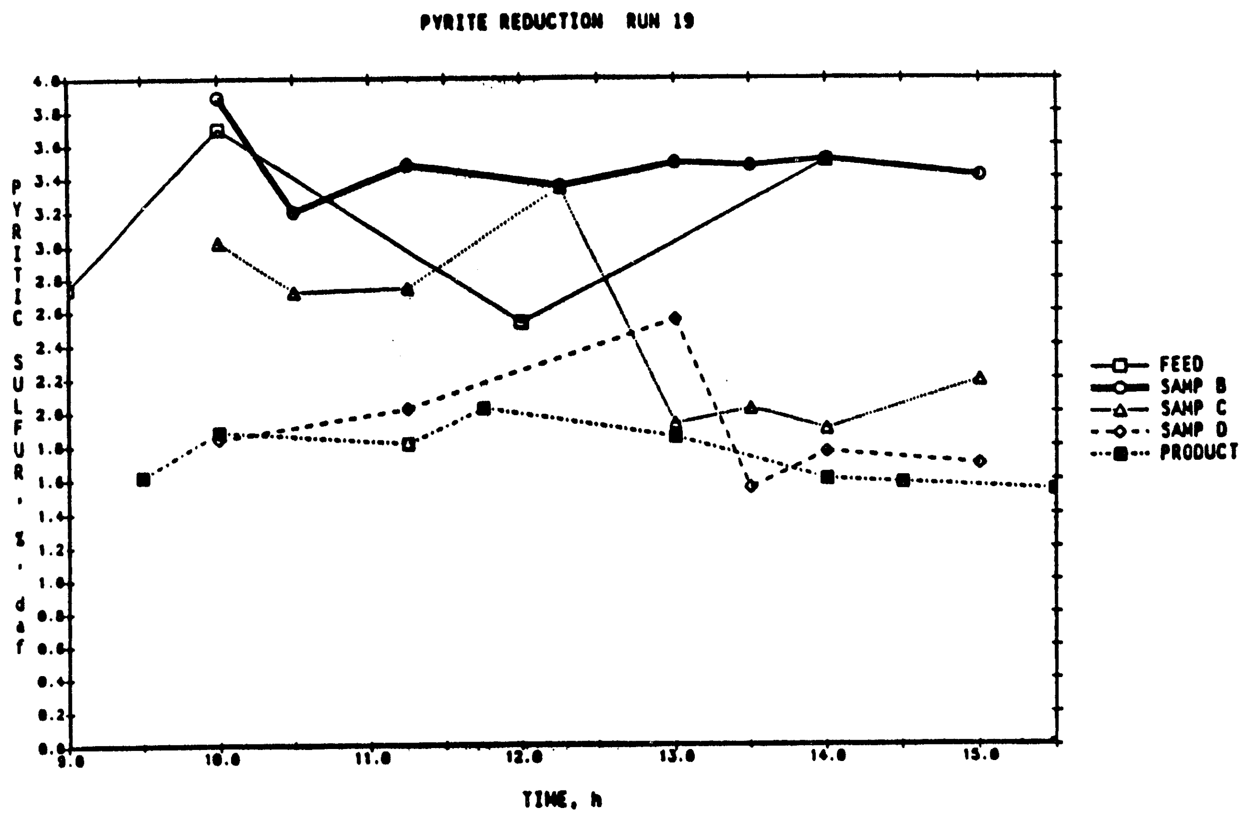


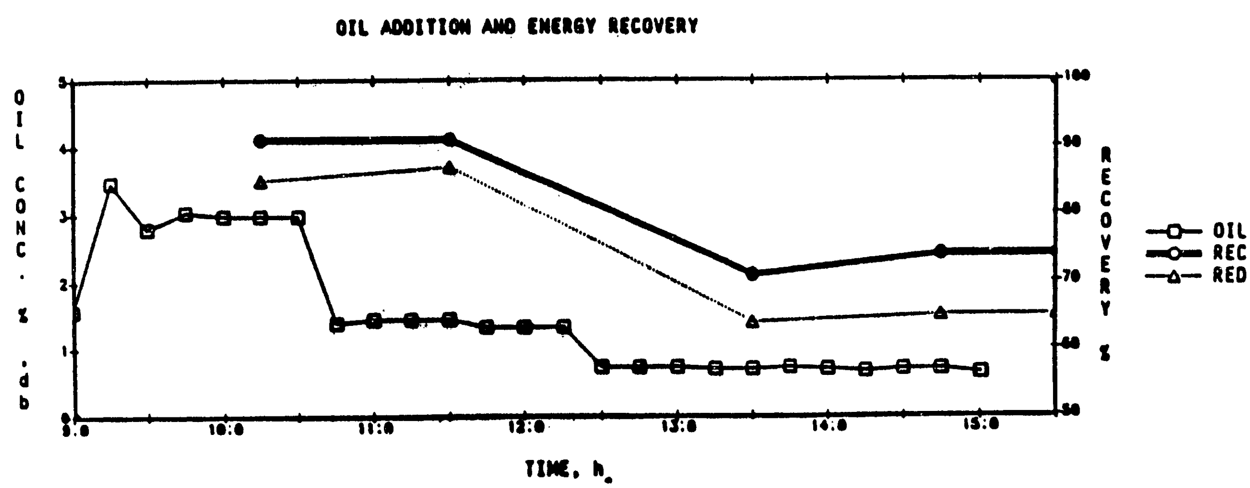


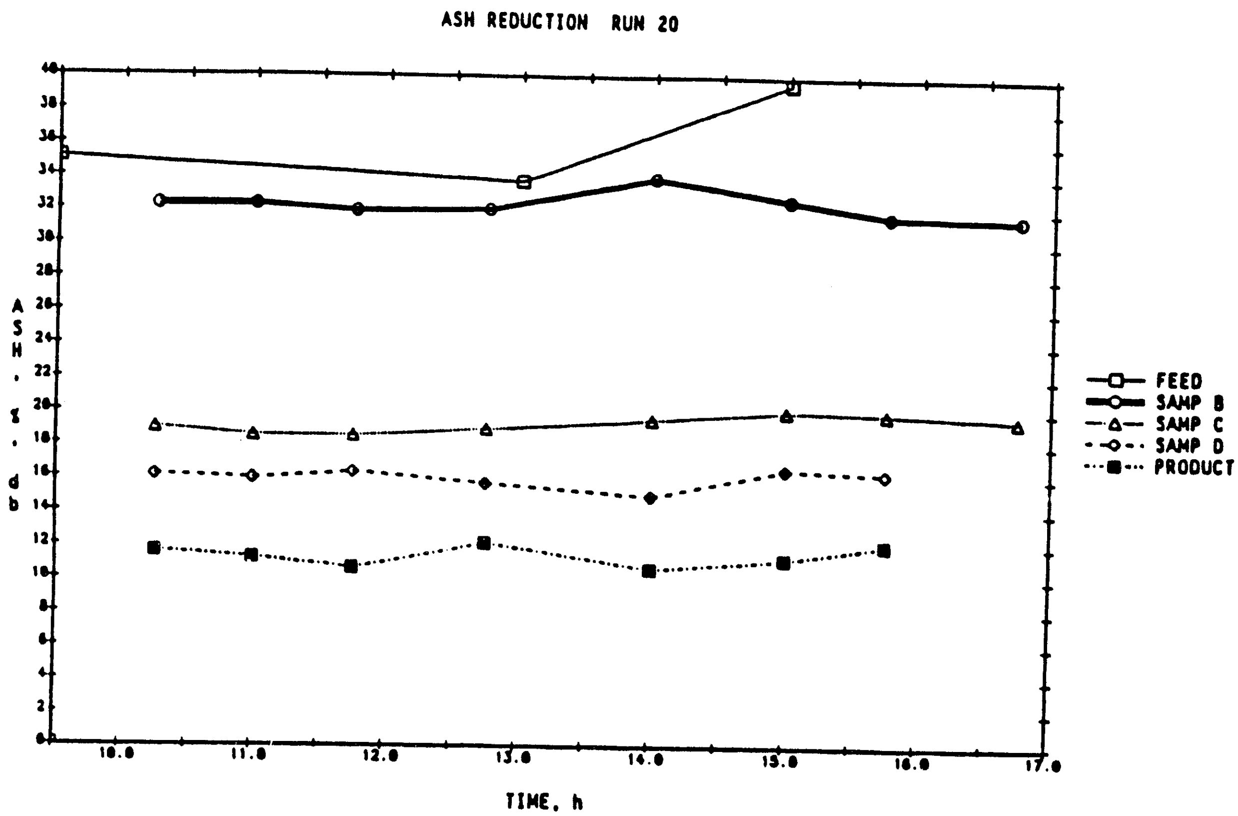
TOTAL SULFUR REDUCTION RUN 19
TOTAL SULFUR, %, d.a.f
TIME, h
FEED
SAMP B
SAMP C
SAMP D
PRODUCT

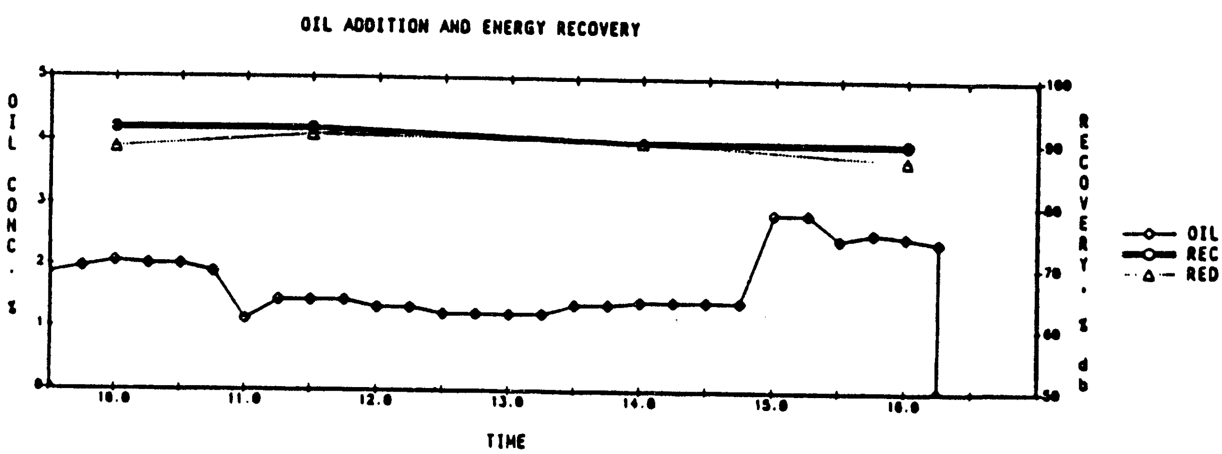


OIL ADDITION AND ENERGY RECOVERY.
OIL CONC. %, db
RECOVERY %
TIME, h
OIL
REC
RED

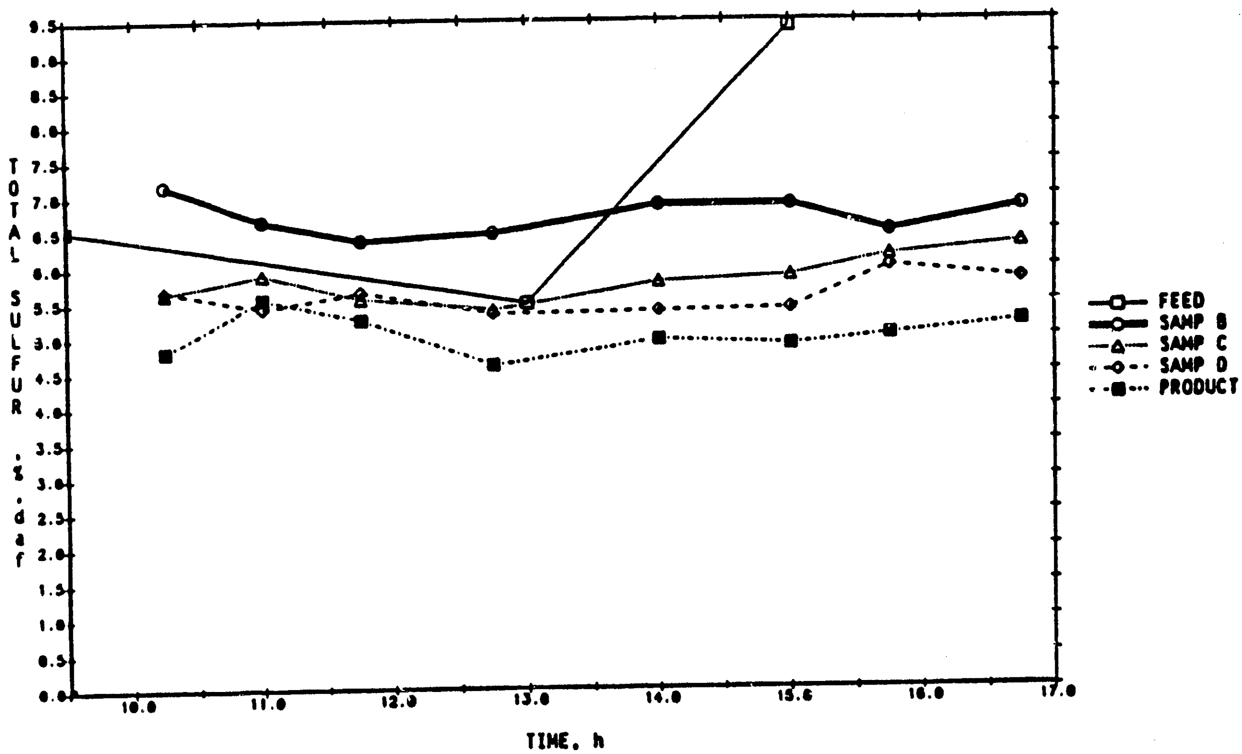

PYRITE REDUCTION RUN 19
PYRITIC SULFUR, %, daf
TIME, h
FEED
SAMP B
SAMP C
SAMP D
PRODUCT


OIL ADDITION AND ENERGY RECOVERY
OIL CONC. % .db
RECOVERY %
TIME, h
OIL
REC
RED

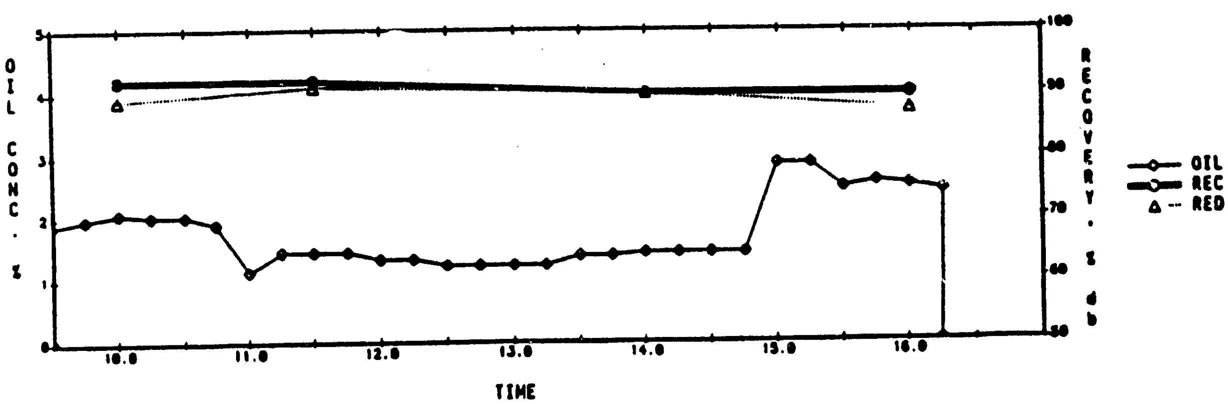

ASH REDUCTION RUN 20
ASH, %, db
TIME, h
FEED
SAMP B
SAMP C
SAMP D
PRODUCT

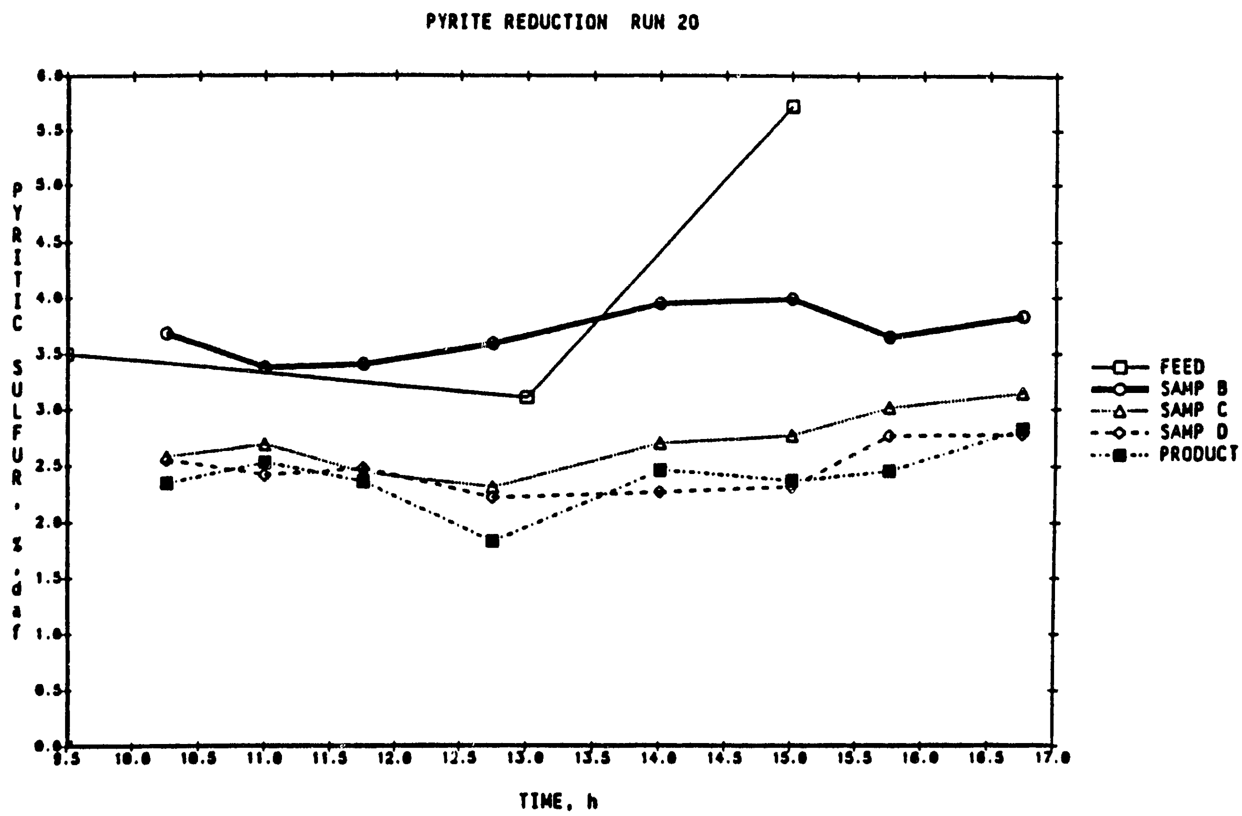

OIL ADDITION AND ENERGY RECOVERY
OIL CONC., %
RECOVERY, % db
TIME
OIL
REC
RED

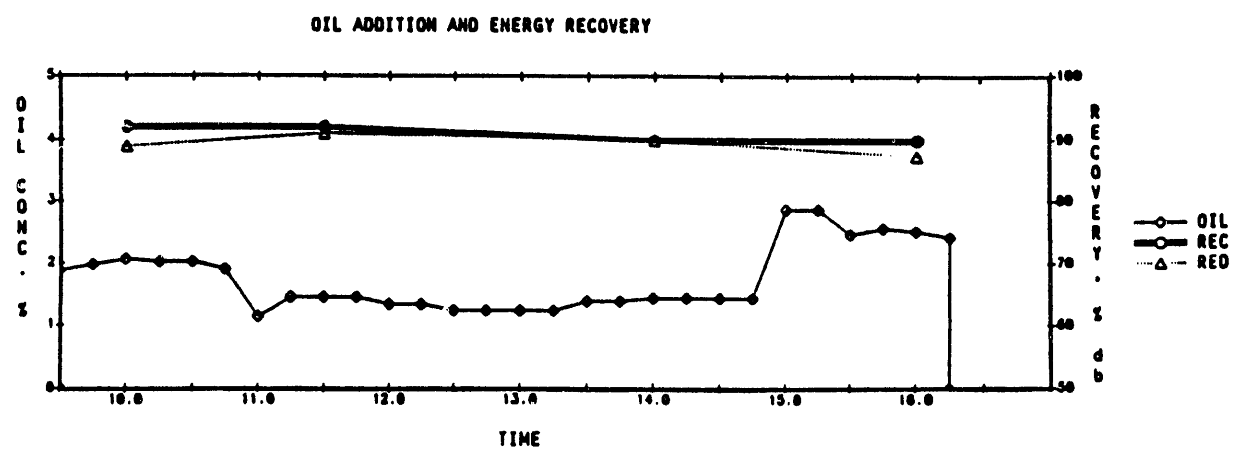
TOTAL SULFUR REDUCTION RUN 20



OIL ADDITION AND ENERGY RECOVERY




PYRITE REDUCTION RUN 20
PYRITIC SULFUR, %, daf
TIME, h
FEED
SAMP B
SAMP C
SAMP D
PRODUCT


OIL ADDITION AND ENERGY RECOVERY
OIL CONC., %
RECOVERY, % db
TIME
OIL
REC
RED

Appendix 5.

Organization of Appendix 5: Volume 2

5.1. Economic Data and Factors

Table A5.1. Annual operating cost factors.

Cost Element	Factors
Chemicals, Fuel, Water	Quantities from design, unit prices from Table A4, power use assumed at a rate equal to connected horsepower.
Operating Supplies	
Salaries and Wages	From manpower estimates.
Payroll Burden	25 percent of salaries and wages.
Plant Operating Labour	
Maintenance Labour	40 percent of 1 to 6 percent per year of Total Direct Cost.
Maintenance Materials	60 percent of 1 to 6 percent per year of Total Direct Cost.
Plant Maintenance Cost	
Plant Operating Direct Cost	
Administration and Support Labour	15 percent of direct plant operating and maintenance labour.
General Administration Expenses	60 percent of direct plant operating and maintenance labour.
Property, Taxes and Insurance	1.5 percent per year of Total Plant Cost.
Plant Operating Indirect Cost	

Table A5.2. Factors used for estimating capital cost of different areas.

Cost Element	Factors
Major Equipment Cost	Vendors' quotes or previous study.
Installation of Equipment	Varied (10 to 45 percent of major equipment cost).
Total Process Equipment Installed Cost (PEIC)	
plus:	
Piping	Varied (7 to 60 percent of PEIC).
Instrumentation	Varied (2 to 15 percent of PEIC).
Electrical	Varied (4 to 30 percent of PEIC).
Buildings and Structures	Varied (10 to 65 percent of PEIC).
Total Direct Cost (TDC)	
plus:	
Engineering, Procurement, Construction Management (EPCM)	20 percent of TDC.
Contingencies	Varied (5 to 80 percent of TDC).
Total Plant Cost	
plus:	
Prepaid Royalties	As required.
Working Capital	one month of operating cost and one month of supplies at nominal capacity.
Total Capital Cost (TCC)	

Table A5.3. Financial factors.

Cost Indices and Cost Data:	1989 U.S. Dollars
Financial Criteria	– 100 percent equity for ROR calculation – prices f.o.b. plant site – taxation – full capacity and operation in Year 1 – depreciation straight line over 10 years – plant life 25 years
Total Plant Cost Allocation	Year 1 - 20 percent Year 2 - 50 percent Year 3 - 30 percent

Table A5.4. Prices and rates for chemicals, fuels, utilities, etc.

Feed Coal	\$ 27.00 / ton
Feed Oil (Maya)	\$ 102.60 / ton
Feed Diesel	\$ 178.40 / ton
Electricity	\$ 0.065 / kwh
Fuel	\$ 2.90 / 10^6 Btu coal
Water	\$ 0.60 / 1000 U.S. gallons
Chemical	
Floculants	\$ 1.60 / lb
Refuse Disposal	\$ 7.00 / ton

Table A5.5. Contingency factors.

New concepts with limited data	80%
Concept with bench-scale data available	60%
Small pilot-plant data	35%
Full-size demonstration plant	20%
Commercial process	10%

Area	Description	Factor Used
100	Coal Delivery, Storage and Crushing	10
200	Coal and Oil Preparation	10
300	Agglomeration and Floatation	35
400	Agglomeration and Separation	35
500	Water Treatment	20
600	Product Loadout	10
700	Offsites	-

5.2. Plant Areas

Area No.	Area Designation
100	Coal Delivery, Storage and Crushing
200	Coal and Oil Preparation
300	Agglomeration and Floatation
400	Agglomeration and Separation
500	Water Treatment
600	Product Loadout
700	Offsites

5.2.1. Coal Delivery, Storage and Crushing: Area 100 – Reference Flowsheet # ARC47

Design Considerations

ROM coal would be delivered from the mine to the plant in trucks owned by the coal company. No provision was made for spare or duplicate equipment for back-up in case of equipment failures.

The selection and sizing of equipment for the area was based on the following design considerations:

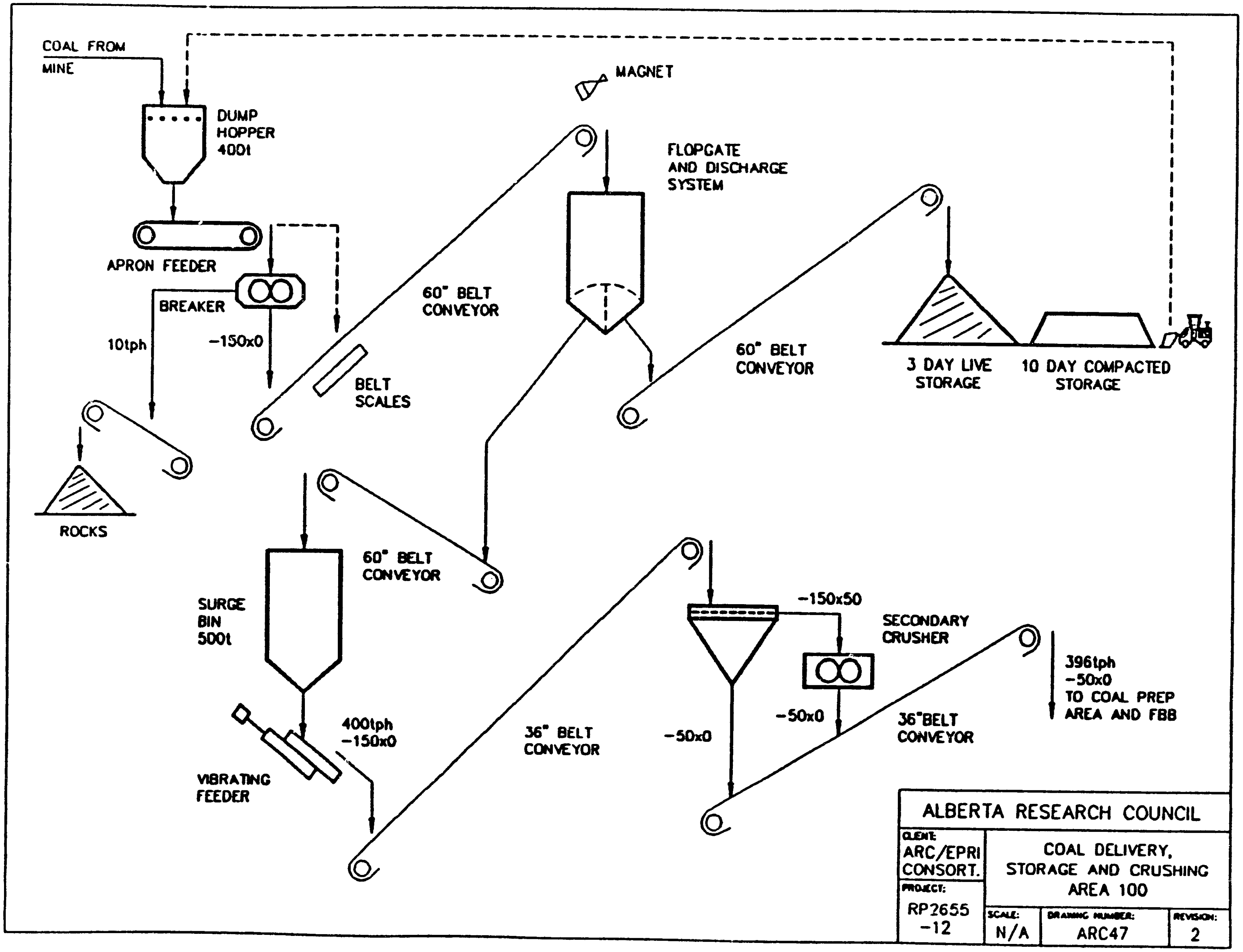
- Trucks will deliver coal to the plant on a 12 h/day x 5 days/week basis.
- The crushing circuit is to provide 390 tph of -50mm x 0 raw coal for the Coal and Oil Preparation Area on a 24 h/day x 7 days/week basis.
- The production of fines through the crushing circuit is to be minimized.

Process Description:

ROM Coal is dumped by trucks through a grizzly into a 400 t capacity dump hopper. An apron feeder is then used to deliver the coal from the dump hopper to the coal breaker at a rate of 1500 tph. The coal breaker reduces the coal to 150 mm x 0 and the coal is then taken by belt conveyor to a transfer house. Belt scales have been included to monitor the quantity of the coal deliveries. Rocks are removed from the breaker and stockpiled at the rate of 10 tph. From the transfer house the coal can be directed either to the outside storage area or to the 500 tonnes raw coal storage bin in the plant crushing area. The conveyor system which goes from the dump pit area to the transfer house and to the plant crushing area will be enclosed in insulated and heated galleries.

Coal that is transferred to the outside storage area becomes part of a 3-day live storage pile or 10-day compacted storage pile. Reclamation from the piles is done with a front-end loader and the coal is introduced back into the system through the 400 t dump hopper.

Inside the crushing plant, coal will be fed from the 500 t raw coal bin via a vibrating feeder at a rate of 390 tph to the secondary crusher circuit. The 150mm x 0 material will be screened at -50mm, the oversize crushed in a double roll crusher to -50mm, and the product added back to the screen underflow. The -50mm product will then be transferred via belt conveyor to the Coal and Oil Preparation Area. Allowance has been made for dust collection at various points in the system.


COAL FROM
MINE
DUMP
HOPPER
400t
APRON FEEDER
BREAKER
10tph
-150x0
BELT
SCALES
60" BELT
CONVEYOR
ROCKS
MAGNET
FLOPGATE
AND DISCHARGE
SYSTEM
60" BELT
CONVEYOR
3 DAY LIVE
STORAGE
10 DAY COMPACTED
STORAGE
60" BELT
CONVEYOR
SURGE
BIN
500t
400tph
-150x0
VIBRATING
FEEDER
36" BELT
CONVEYOR
-150x50
SECONDARY
CRUSHER
-50x0
-50x0
36"BELT
CONVEYOR
396tph
-50x0
TO COAL PREP
AREA AND FBB
ALBERTA RESEARCH COUNCIL
CLIENT:
ARC/EPRI
CONSORT.
PROJECT:
RP2655
-12
COAL DELIVERY,
STORAGE AND CRUSHING
AREA 100
SCALE:
N/A
DRAWING NUMBER:
ARC47
REVISION:
2

ESTIMATE SUMMARY

CLIENT: ARC/EPRI CONSORTIUM **TYPE OF ESTIMATE:** ±30%

PROJECT NO.: RP2655-12 **DATE OF ISSUE:** ____

AREA DESIGNATION: Coal Delivery, Storage and Crushing: Area 100

EQUIPMENT	INSTALLED COST
____	$____
____	____
____	____
____	____
____	____
____	____
____	____
____	____
____	____
____	____
____	____
TOTAL PROCESS EQUIPMENT INSTALLED COST (PEIC)	$ 3,628,000
ALLOWANCE FOR:	
Piping	$
Instrumentation	
Electrical	
Bldg./Structural	
	1,640,000
TOTAL DIRECT COST	$ 5,267,000

EQUIPMENT LIST

CLIENT: ARC/EPRI CONSORTIUM **SHEET NO.:** 1 OF 2

PROJECT NO.: RP2655-12 **ISSUE DATE:**

AREA DESIGNATION: Coal Delivery, Storage and Crushing: Area 100

ITEM NO.	QUANTITY	DESCRIPTION	PRICE
1	1	400 t Capacity Dump Hopper c/w grizzly	$ 773,000
2	1	Apron Feeder, 1500 tph capacity, 20 hp motor, dribble chute	83,000
3	1	Rotary Breaker , 1500 tph capacity, +4" feed, 3" x 0 product, 100 hp, 100 hp motor, discharge chute	196,000
4	1	Belt Scales	41,000
5	1	Magnet (cost included in #4)	---
6	1	Flop-Gate and Discharge Chutes	76,000
7	1	500 t Capacity Surge Bin	69,000
8	1	Vibrating Feeder, 450 tph, 25 hp motor, discharge chute	43,000
9	1	Front End Loader	534,000
10	1	Vibrating Screen, 450 tph, 50 mm aperture, 6' x 16', single deck, 10 hp motor, discharge chute	29,000
11	1	Raw Coal Roll Crusher, 450 tph capacity, double roll 34" x 36", 2 x 75 hp motors, discharge chute	155,000
12	1	Flop-Gate and Discharge Chutes (cost included in #15)	---

EQUIPMENT LIST

CLIENT: ARC/EPRI CONSORTIUM **SHEET NO.:** 2 OF 2

PROJECT NO.: RP2655-12 **ISSUE DATE:**

AREA DESIGNATION: Coal Delivery, Storage and Crushing: Area 100

ITEM NO.	QUANTITY	DESCRIPTION	PRICE
13	-	Dust Collection System, total motor hp = 140	$ 88,000
14	-	Dump Pit Sump Pump and Storage Area Sump Pump, total motor hp = 10	193,000
15	-	Belt Conveyors: Allowance for 700 ft of 60" belts, 300 ft of 36" belts, total motor hp = 350	603,000
		TOTAL EQUIPMENT COST	$ 2,883,000
		INSTALLATION AT 26% OF EQUIPMENT COST	$ 745,000
		TOTAL INSTALLED EQUIPMENT COST FOR AREA	$ 3,628,000

5.2.2. Coal and Oil Preparation: Area 200 – Reference Flowsheet # ARC48

Design Considerations

The purpose of the Coal and Oil Preparation Area is to prepare and condition coal water slurry including addition of additives, and to receive and mix bridging oil components (crude oil and diesel) to be used in the Agglomeration and Floatation Area.

The following design guidelines were developed:

- The area is to process 300 tph of -50mm x 0 raw coal on a 24 h/day x 7 days/week basis.
- Raw -50mm x 0 coal is to be pulverized to 50 percent minus 100 mask or d_{50}=150 Mm.
- A residence time of 5 minutes is to be allowed for coal conditioning (wetting) in the slurry mixing tanks.
- The crude oil and diesel delivery tanks are to provide five and thirty days delivery storage, respectively.
- The crude oil tank is to be insulated and equipped with steam heating coils to keep the oil temperature (viscosity) at above 20°C (14.5°API).
- All piping for crude oil and bridging oil is to be insulated and steam heated so that it is possible to pump the oil in cold weather.
- Oil tanks are located in a bermed area to contain any spills.

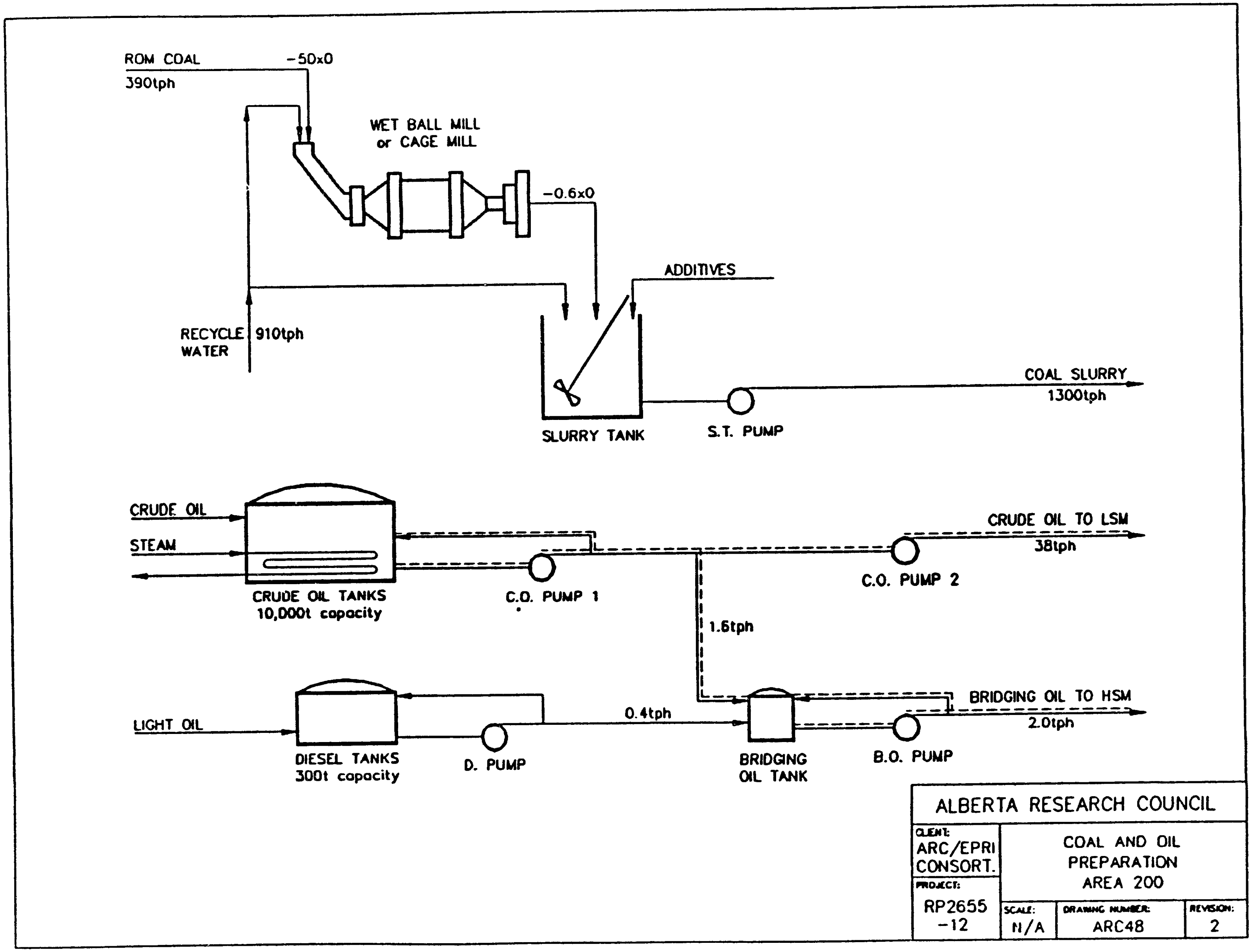
Process Description

390 tph of -50mm x 0 coal from the Coal Delivery, Storage and Crushing Area is transferred by conveyor to four ball mills, operating in parallel, where it is pulverized to -0.6mm x 0. The coal is then discharged to two slurry mixing tanks where 910 tph recycle water is added to prepare a 29.4 percent coal slurry, dry w/w basis. The coal slurry is conditioned in the mixing tanks by adding appropriate additives and mixing for 5 minutes (mean residence time). Each tank is equipped with an agitator and a slurry pump to move the slurry to the Agglomeration and Floatation Area.

The Coal and Oil Preparation Area also serves to receive crude oil and diesel, and to blend the oil into bridging oil formulation. The crude oil is delivered to a 50,000 bbl, 5-day storage tank. The tank is steam heated and mixed using a recirculation loop on the crude oil pump. The diesel is delivered to a 300 ton, 30-day storage tank from where it is pumped to the bridging oil tank.

1.6 tph of crude oil and 0.4 tph of light oil are mixed in the bridging oil tank by recirculation of the blended oil. The bridging oil tank, like the crude oil tank, is insulated and steam heated to keep the oil viscosity °API 15. The crude and bridging oil pipes are steam traced to keep the oil pumpable in cold weather.

The blended bridging oil is transferred to the Agglomeration and Floatation Area via the B.O. pump at the rate of 2.0 tph.


ROM COAL
390tph
-50x0
WET BALL MILL
or CAGE MILL
-0.6x0
ADDITIVES
RECYCLE WATER
910tph
SLURRY TANK
S.T. PUMP
COAL SLURRY
1300tph
CRUDE OIL
STEAM
CRUDE OIL TANKS
10,000t capacity
C.O. PUMP 1
C.O. PUMP 2
CRUDE OIL TO LSM
38tph
1.6tph
LIGHT OIL
DIESEL TANKS
300t capacity
D. PUMP
0.4tph
BRIDGING OIL TANK
B.O. PUMP
BRIDGING OIL TO HSM
2.0tph
ALBERTA RESEARCH COUNCIL
CLIENT:
ARC/EPRI CONSORT.
PROJECT:
RP2655 -12
COAL AND OIL
PREPARATION
AREA 200
SCALE:
N/A
DRAWING NUMBER:
ARC48
REVISION:
2

PROCESS EQUIPMENT

ESTIMATE SUMMARY

CLIENT: ARC/EPRI CONSORTIUM **TYPE OF ESTIMATE:** ±30%

PROJECT NO.: RP2655-12 **DATE OF ISSUE:** ____________

AREA DESIGNATION: Coal and Oil Preparation: Area 200

EQUIPMENT	INSTALLED COST
____________	$____________
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________
____________	____________
TOTAL PROCESS EQUIPMENT INSTALLED COST (PEIC)	$ 8,527,000
ALLOWANCE FOR:	
Piping	$
Instrumentation	
Electrical	
Bldg./Structural	
	4,215,000
TOTAL DIRECT COST	$ 12,742,000

EQUIPMENT LIST

CLIENT: ARC/EPRI CONSORTIUM **SHEET NO.:** 1 OF 1

PROJECT NO.: RP2655-12 **ISSUE DATE:** ______

AREA DESIGNATION: Coal and Oil Preparation: Area 200

ITEM NO.	QUANTITY	DESCRIPTION	PRICE
1	4	Wet Ball Mills, 100 tph capacity each, 4 x 2500 hp	5,467,000
2	2	Slurry Mix Tanks, 15'ϕ x 10' SS	58,000
3	2	Agitators, 2 x 100 hp motor	230,000
4	4	Slurry Pumps, 2500 USGPM, 2 x 50 hp, one spare	61,000
5	1	Crude Oil Tank, 50,000 bbl, insulated, with steam heating coils	573,000
6	2	Crude Oil Pump, 1 & 2, 400 USGPM, 20 hp	12,000
7	1	Diesel Tank, 3,000 bbl	45,000
8	1	Diesel Pump, 20 USGPM, 5 hp	2,000
9	1	Bridging Oil Tank, 10,000 US gallons, insulated	16,000
10	1	Bridging Oil Pump, 20 USGPM, 5 hp	4,000
11	-	Oil Sampling System and Allowance for steam tracing of crude oil and bridging oil pipes	48,000
		TOTAL EQUIPMENT COST	$ 6,516,000
		INSTALLATION AT 31% OF EQUIPMENT COST	$ 2,011,000
		TOTAL INSTALLED EQUIPMENT COST FOR AREA	$ 8,527,000

5.2.3. Agglomeration and Floatation: Area 300 – Reference Flowsheet # ARC72

Design Considerations

The purpose of the Agglomeration and Floatation Area is to remove mineral matter and pyrite, and agglomerate the -0.6mm x 0 raw coal into ~0.2mm (40 percent moisture) microagglomerates that can be further enlarged in the Agglomeration and Separation Area.

Selection and sizing of the equipment for this area has been done using the following design considerations:

- Mean residence time required for growth of 0.2 mm to 0.5 mm flocs in high shear vessels is 4 minutes.
- Optimal solid slurry concentration is 30 percent in high shear mixers, 18 percent in floatation cell and hydroseparator.
- Total ash rejected is 69 percent of ROM coal feed ash with 48 percent rejected in the floatation cell underflow and 15 percent rejected in the hydroseparator underflow.
- Moisture content in floatation froth is estimated at 40 percent.
- Total pyritic sulphur rejected is 59 percent of ROM coal feed pyritic sulphur with 41 percent rejected in the floatation cell underflow and 18 percent rejected in the hydroseparator underflow.

Process Description

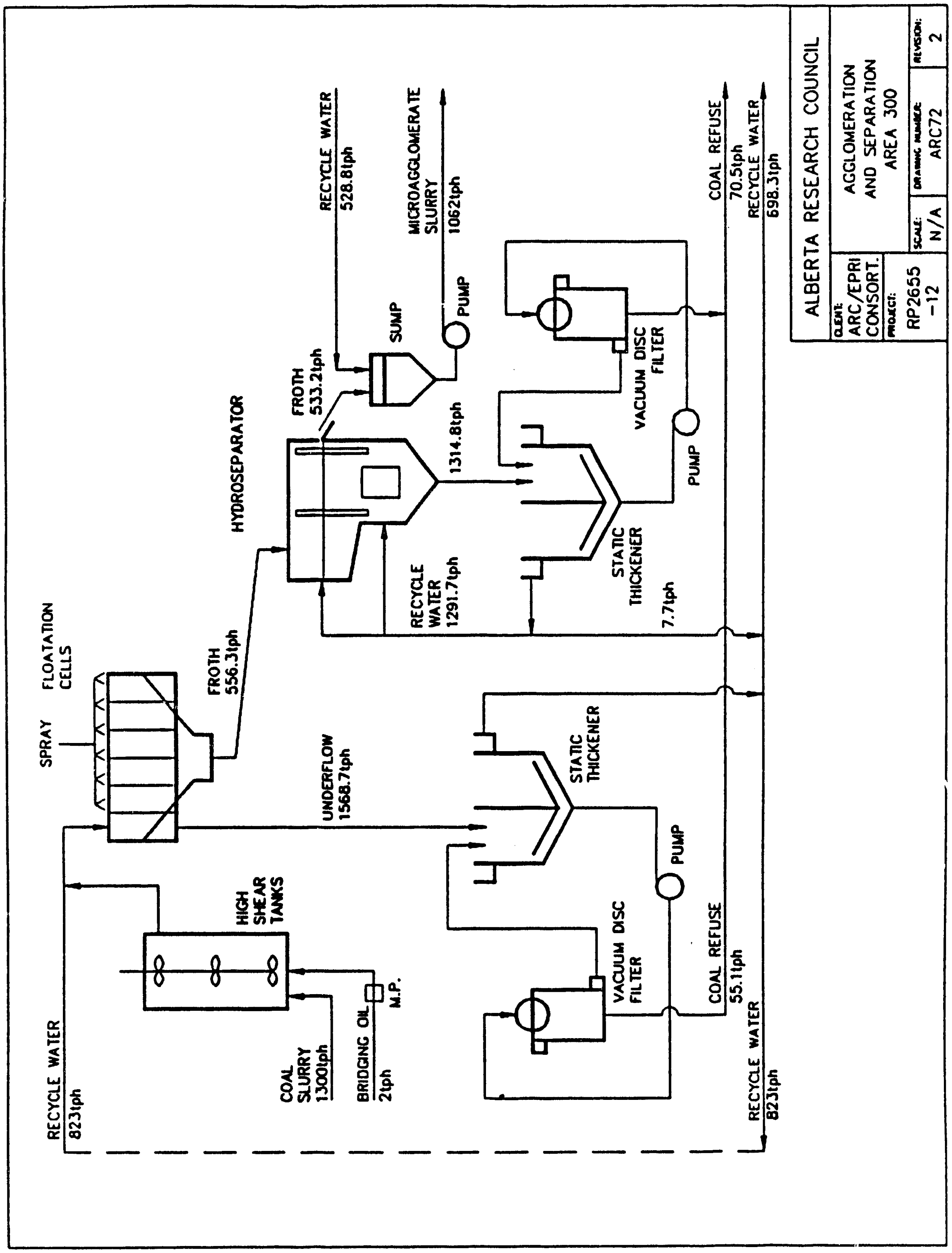
1300 tph of 29.4 percent coal slurry is received from the Coal and Oil Preparation Area and mixed with the bridging oil in eight parallel high shear mixers. The coal is wetted by bridging oil and formed into microagglomerates 0.2mm in size. The product of the high shear mixing is diluted with 823 tph recycle water to 18 percent solids, (dry w/w slurry basis) and is fed into four floatation cells, operating in parallel, each 150 tph capacity, wet froth basis. The clean coal floated from the circuit will be approximately 556.3 tph and 40 percent moisture.

The froth is transferred to four hydroseparators operating in parallel where it is again diluted with recycle water to 18 percent solids, w/w slurry basis. The froth is washed, separated from the pyrite particles and then the clean froth is transferred to a sump where it is mixed with recycle water before it is pumped to the Agglomeration and Separation Area.

The floatation underflow, containing about 3.2 percent solids is discharged into a static thickener. A large-volume, conventional settling tank design was selected for the thickener to accommodate process upsets more easily. The concentrated coal refuse is removed in the vacuum disc filter. The coal refuse from the floatation cells circuit will be approximately 55.1 tph, 10 percent moisture.

The hydroseparator underflow with about 1.1 percent of solids is discharged into the second static thickener. The refuse pyrite and coal are removed in the vacuum filter and transferred together with the floatation underflow refuse to the refuse bin. The total refuse will be approximately 70.5 tph and will be trucked away by coal hauling trucks.

A significant amount of process water, 823 tph, is required to dilute the product of the high shear mixers. All the required water is recovered from the floatation circuit and is recycled back after removal of the suspended solids.


RECYCLE WATER
823tph
HIGH
SHEAR
TANKS
COAL
SLURRY
1300tph
BRIDGING OIL
2tph
M.P.
SPRAY
FLOATATION
CELLS
FROTH
556.3tph
UNDERFLOW
1568.7tph
STATIC
THICKENER
PUMP
VACUUM DISC
FILTER
COAL REFUSE
55.1tph
RECYCLE WATER
823tph
HYDROSEPARATOR
FROTH
533.2tph
SUMP
PUMP
RECYCLE WATER
528.8tph
MICROAGGLOMERATE
SLURRY
1062tph
1314.8tph
RECYCLE
WATER
1291.7tph
STATIC
THICKENER
7.7tph
PUMP
VACUUM DISC
FILTER
COAL REFUSE
70.5tph
RECYCLE WATER
698.3tph
ALBERTA RESEARCH COUNCIL
AGGLOMERATION
AND SEPARATION
AREA 300
CLIENT:
ARC/EPRI
CONSORT.
PROJECT:
RP2655
-12
SCALE:
N/A
DRAWING NUMBER:
ARC72
REVISION:
2

PROCESS EQUIPMENT

ESTIMATE SUMMARY

CLIENT: ARC/EPRI CONSORTIUM **TYPE OF ESTIMATE:** ± 30%

PROJECT NO.: RP2655-12 **DATE OF ISSUE:** ______

AREA DESIGNATION: Agglomeration and Floatation: Area 300

EQUIPMENT	INSTALLED COST
______	$______
______	______
______	______
______	______
______	______
______	______
______	______
______	______
______	______
______	______

TOTAL PROCESS EQUIPMENT INSTALLED COST (PEIC)	$ 4,099,000	
ALLOWANCE FOR:		
Piping	$	
Instrumentation		
Electrical		
Bldg./Structural	4,913,000	
TOTAL DIRECT COST		$ 9,018,000

EQUIPMENT LIST

CLIENT: ARC/EPRI CONSORTIUM SHEET NO.: 1 OF 2

PROJECT NO.: RP2655-12 ISSUE DATE: ________

AREA DESIGNATION: Agglomeration and Separation: Area 300

ITEM NO.	QUANTITY	DESCRIPTION	PRICE
1	10	High Shear Mixers, 2 spare, 5.5'ϕ x 15', including agitators, 8 x 360 hp @ 1,600 rpm	$ 2,121,000
2	10	Oil Metering Pumps, 2 spare, 2 USGPM, 8 x 1 hp	20,000
3	4	Flotation Cells, 150 tph froth each, 4 x 150 hp each	197,000
4	4	Hydroseparators, 150 tph froth each, 4 x 180 hp each	244,000
5	1	Static Thickner, 6900 USGPM, 3% solids loading, 73' dia., 10' deep 20 hp motor	132,000
6	1	Vacuum Disc Filter, 730 USGPM, 25% solids loading, incl vacuum pump, total motor hp = 80	48,000
7	2	Cleanup Sump and Pump, 5 hp motor	11,000
8	1	Refuse Coal Belt Conveyers, 32" wide, 50' long, total motor hp = 75	48,000
9	1	Static Thickener, 5800 USGPM, 1% solids loading, 67' dia. 10' deep, 10 hp motor	121,000
10	1	Vacuum Disc Filter, 220 USGPM, 25% solids loading, incl vacuum pump, total motor hp = 25	13,000

EQUIPMENT LIST

CLIENT: ARC/EPRI CONSORTIUM **SHEET NO.:** 2 OF 2

PROJECT NO.: RP2655-12 **ISSUE DATE:**

AREA DESIGNATION: Agglomeration and Separation: Area 300

ITEM NO.	QUANTITY	DESCRIPTION	PRICE
11	5	Froth Sump Pumps, 1300 USGPM, one spare, 4 x 30 hp	$ 60,000
		TOTAL EQUIPMENT COST	$ 3,015,000
		INSTALLATION AT 36% OF EQUIPMENT COST	$ 1,084,000
		TOTAL INSTALLED EQUIPMENT COST FOR AREA	$ 4,099,000

5.2.4. Agglomeration and Separation: Area 400 – Reference Flowsheet # ARC73

Design Considerations

The purpose of the Agglomeration and Separation Area is to enlarge the microagglomerates from ~0.2mm to 0.8mm to 3.0mm in size, and to dewater the macroagglomerates to 10 percent moisture, w/w basis.

The following design assumptions were made in selection and sizing of the equipment:

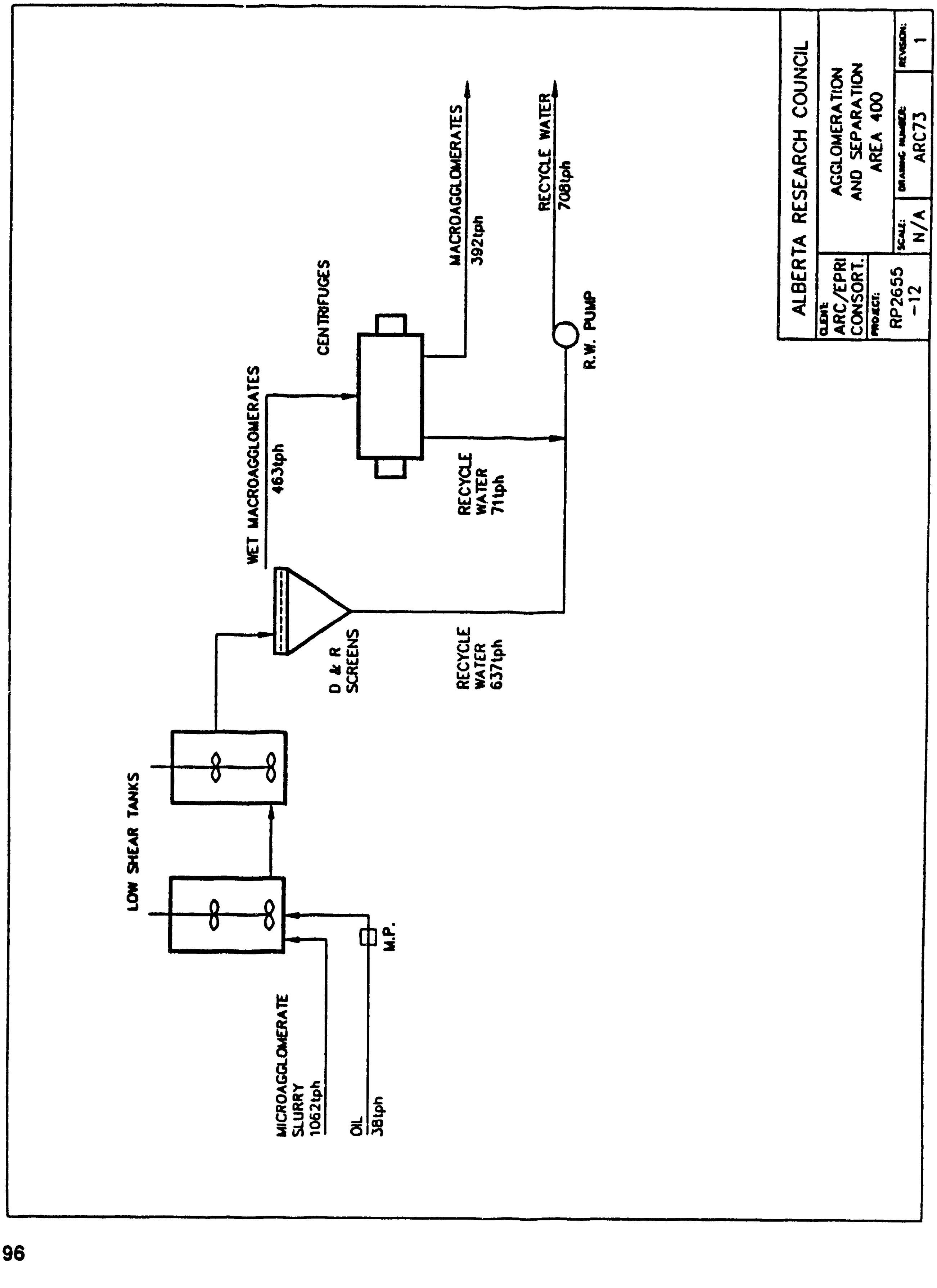
- To achieve a narrower residence time distribution in the low shear mixers, and a more uniform product, two mixing vessels, in series, with a combined residence time of 26 minutes are used. The second vessel also serves as a surge capacity tank before green agglomerates are dewatered.
- The growth process for the agglomerates require addition of light crude oil to a level of 12 percent (dry w/w coal basis).
- Low rpm centrifugal extractors are to be used for drying green macroagglomerates.

Process Description

The hydroseparator product (froth) diluted to 30 percent microagglomerates slurry is pumped from the Agglomeration and Floatation Area into the low shear mixers. 38 tph of bridging oil is also added in the low shear mixers to promote growth of the floc particles into green agglomerates 0.8 to 3.0mm in size. The product slurry of macroagglomerates is discharged on four drain and rinse, double deck vibrating screens, where it is drained, rinsed and dewatered. The green agglomerates from the D&R screens will be approximately 463 tph and 25 percent moisture.

The wet agglomerates are transferred to eight centrifugal extractors operated in parallel where the product is further dewatered to 10 percent moisture. The extractors are oscillating, conical-screen type and operated at low rpm.

All process water from the D&R screens' underflow and the centrifuges is recycled to the Coal and Oil Preparation Area.



ALBERTA RESEARCH COUNCIL
CLIENT: ARC/EPRI CONSORT.
PROJECT: RP2655 -12
AGGLOMERATION AND SEPARATION AREA 400
SCALE: N/A
DRAWING NUMBER: ARC73
REVISION: 1
LOW SHEAR TANKS
MICROAGGLOMERATE SLURRY 1062tph
OIL 38tph
M.P.
D & R SCREENS
WET MACROAGGLOMERATES 463tph
CENTRIFUGES
MACROAGGLOMERATES 392tph
RECYCLE WATER 71tph
RECYCLE WATER 637tph
R.W. PUMP
RECYCLE WATER 708tph

PROCESS EQUIPMENT

ESTIMATE SUMMARY

CLIENT: ARC/EPRI CONSORTIUM **TYPE OF ESTIMATE:** ± 30%

PROJECT NO.: RP2655-12 **DATE OF ISSUE:** ______

AREA DESIGNATION: Agglomeration and Separation: Area 400

EQUIPMENT	INSTALLED COST
	$
TOTAL PROCESS EQUIPMENT INSTALLED COST (PEIC)	$ 2,765,000
ALLOWANCE FOR:	
Piping	$
Instrumentation	
Electrical	
Bldg./Structural	
	2,627,000
TOTAL DIRECT COST	$ 5,392,000

EQUIPMENT LIST

CLIENT: ARC/EPRI CONSORTIUM — SHEET NO.: 1 OF 2

PROJECT NO.: RP2655-12 — ISSUE DATE:

AREA DESIGNATION: Agglomeration and Separation: Area 400

ITEM NO.	QUANTITY	DESCRIPTION	PRICE
1	8	Low Shear Mixers, 12' x 22', incl. agitators, 8 x 120 hp @ 600 rpm	$ 743,000
2	4	Bridging Oil Metering Pumps	$ 29,000
3	4	Drain and Rinse Screens, 12' x 17', 150 tph each, 0.8mm apertures double deck, discharge chutes	$ 257,000
4	10	Centrifugal Extractors, 60 tph solids each, two spare, 80 hp each	$ 975,000
5	2	Recycle Water Pumps, 1800 USGPM each, 2 x 40 hp	$ 31,000
		TOTAL EQUIPMENT COST	$ 2,035,000
		INSTALLATION AT 36% OF EQUIPMENT COST	$ 730,000
		TOTAL INSTALLED EQUIPMENT COST FOR AREA	$ 2,765,000

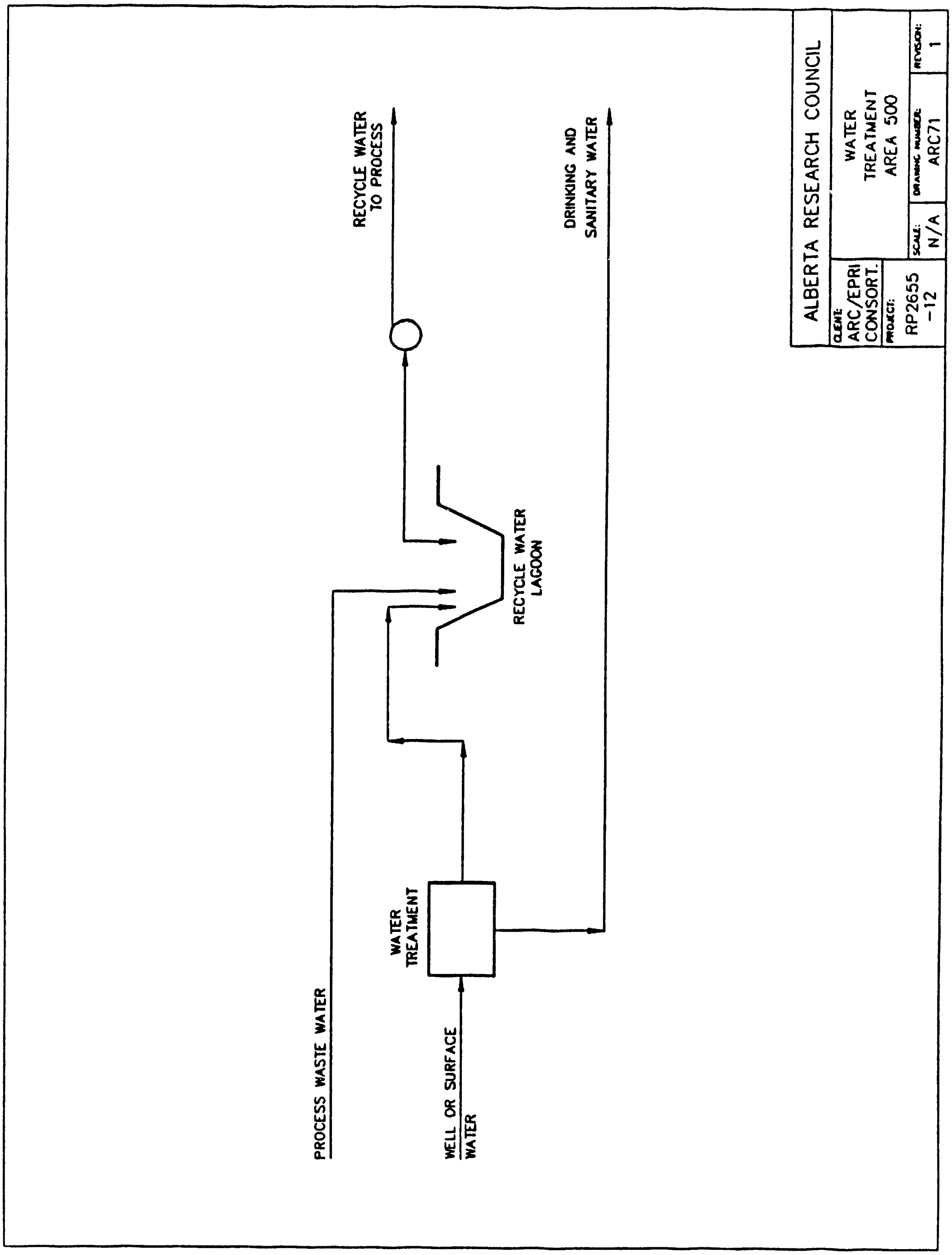
5.2.5. Water Treatment: Area 500 – Reference Flowsheet # ARC71

Design Considerations

The basic design and cost information for treating the make-up water for the Aglofloat process was based on water treatment package plants.

Process Description

For the plant water needs, well or surface water will be treated and stored in the recycle water pond. The well or surface water will be treated to process water quality standards. In addition, a small amount of water will be treated for drinking water and for sanitary purposes.



ALBERTA RESEARCH COUNCIL
CLIENT: ARC/EPRI CONSORT.
WATER TREATMENT AREA 500
PROJECT: RP2655 -12
SCALE: N/A
DRAWING NUMBER: ARC71
REVISION: 1
RECYCLE WATER TO PROCESS
DRINKING AND SANITARY WATER
RECYCLE WATER LAGOON
WATER TREATMENT
PROCESS WASTE WATER
WELL OR SURFACE WATER

PROCESS EQUIPMENT

ESTIMATE SUMMARY

CLIENT: ARC/EPRI CONSORTIUM

TYPE OF ESTIMATE: ± 30%

PROJECT NO.: RP2655-12

DATE OF ISSUE: ______

AREA DESIGNATION: Water Treatment: Area 500

EQUIPMENT	INSTALLED COST
______	$______
______	______
______	______
______	______
______	______
______	______
______	______
______	______
______	______
______	______
______	______
TOTAL PROCESS EQUIPMENT INSTALLED COST (PEIC)	$ ---

ALLOWANCE FOR:

Piping	$
Instrumentation	
Electrical	
Bldg./Structural	______
TOTAL DIRECT COST	$ 1,150,000

EQUIPMENT LIST

CLIENT: ARC/EPRI CONSORTIUM **SHEET NO.:** 1 **OF** 1

PROJECT NO.: RP2655-12 **ISSUE DATE:**

AREA DESIGNATION: Water Treatment - Area 500

ITEM NO.	QUANTITY	DESCRIPTION		PRICE
		Total Direct Cost from data for packaged plants, water quantity and quality:		
		Make-up Water Requirements	32.5 tph	
		Energy Requirements:	100 hp	
		TOTAL DIRECT COST FOR AREA 500		$ 1,150,000

5.2.8. Product Loadout: Area 600 – Reference Flowsheet # ARC70

Design Considerations

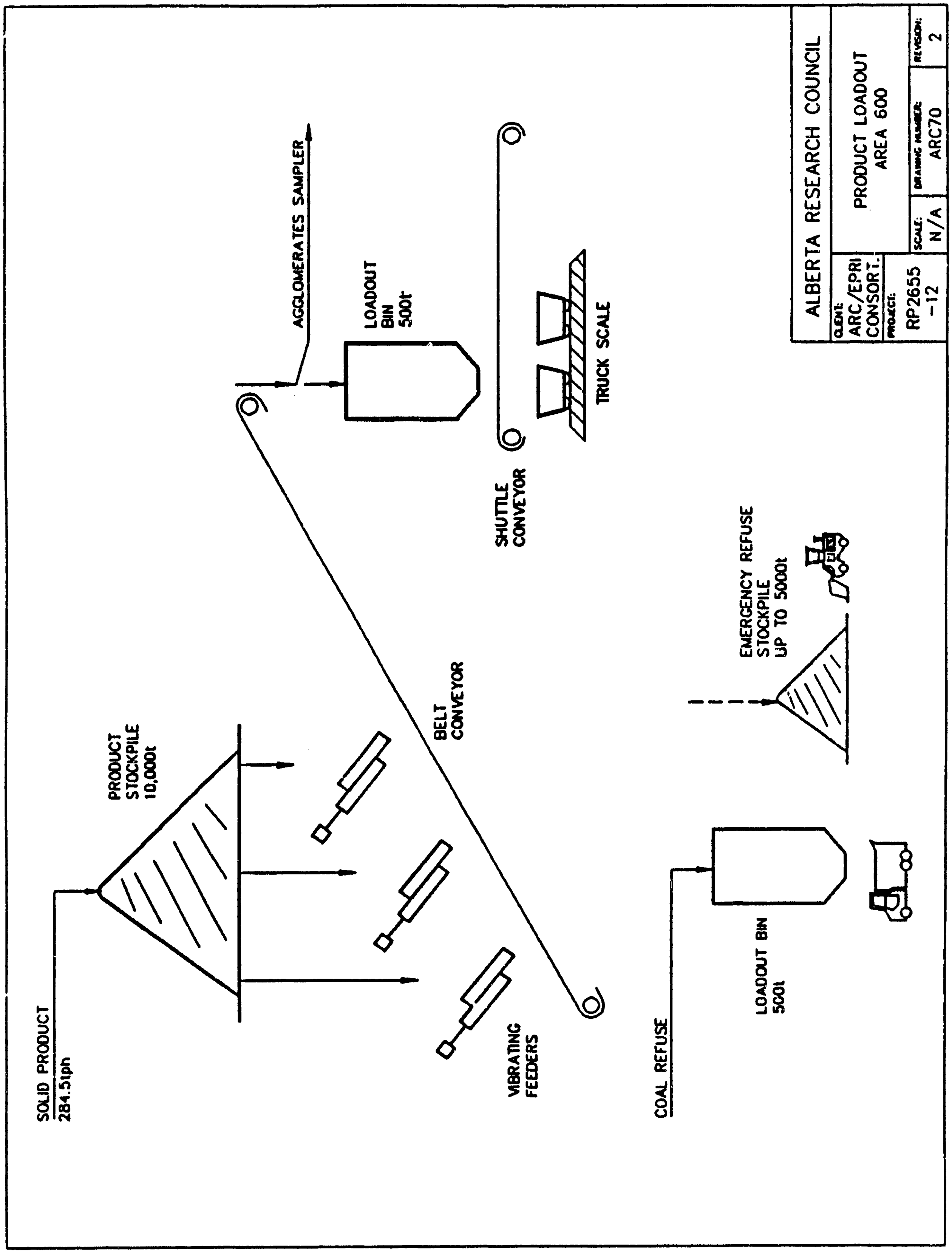
The design of the Product Loadout Area for agglomerates and coal refuse provides two days production storage for agglomerates and three days production storage for coal refuse. The loadout facility for rail cars has been included in the design.

Process Description

The dry agglomerates product will be transferred from the Agglomeration and Separation Area via belt conveyors. A single 10,000-ton live capacity ground stockpile will be maintained. The product will be withdrawn from the stockpile by vibrating feeders and transferred to a 500-ton loadout bin for loading into railcars via a shuttle conveyor.

The weighing system is a simple design using the tare weight of the railcar and track scales. A track mobile will be used to move the cars during loading. Prior to shipping, the surface of the product will be sprayed with a latex solution to prevent dust losses enroute and to conform to environmental industry standards.

The coal refuse is transferred from the Agglomeration and Floatation Area at the rate of 70.5 tph to 500 ton capacity refuse loadout bin. The refuse will be loaded on coal delivery trucks and hauled back to a display area. In case of emergency, coal refuse can be directed to an outside, 3-day emergency refuse storage pile. The refuse will be withdrawn from the pile with a front-end loader and conveyor system. The refuse pile area will be constructed using a proper ground lining and drainage trenches for run-off waters.



ALBERTA RESEARCH COUNCIL
CLIENT:
ARC/EPRI CONSORT.
PRODUCT LOADOUT
AREA 600
PROJECT:
RP2655 -12
SCALE:
N/A
DRAWING NUMBER:
ARC70
REVISION:
2
SOLID PRODUCT
284.5tph
PRODUCT STOCKPILE 10,000t
VIBRATING FEEDERS
BELT CONVEYOR
AGGLOMERATES SAMPLER
LOADOUT BIN 500t
SHUTTLE CONVEYOR
TRUCK SCALE
COAL REFUSE
LOADOUT BIN 500t
EMERGENCY REFUSE STOCKPILE UP TO 5000t

ESTIMATE SUMMARY

CLIENT: ARC/EPRI CONSORTIUM **TYPE OF ESTIMATE:** ±30%

PROJECT NO.: RP2655-12 **DATE OF ISSUE:** ________

AREA DESIGNATION: Product Loadout: Area 600

EQUIPMENT	INSTALLED COST
________	$ ________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
________	________
TOTAL PROCESS EQUIPMENT INSTALLED COST (PEIC)	$ 6,971,000
ALLOWANCE FOR:	
Piping	$
Instrumentation	
Electrical	
Bldg./Structural	________
	839,000
TOTAL DIRECT COST	$ 7,810,000

EQUIPMENT LIST

CLIENT: ARC/EPRI CONSORTIUM **SHEET NO.:** ___ **OF** ___

PROJECT NO.: RP2655-12 **ISSUE DATE:** ________

AREA DESIGNATION: Product Loadout: Area 600

ITEM NO.	QUANTITY	DESCRIPTION	PRICE
1	1	Product Stockpile Storage Area, Live Capacity 10,000 t, includes site preparation, reclaim tunnel and dust collection system.	$ 3,507,000
2	6	Reclaim Vibrating Feeders, 150 tph capacity each, total motor hp = 60, discharge chutes	90,000
3	2	500 t Capacity Agglomerates Loadout Bins	204,000
4	-	Allowance for Rail Car Loadout System	188,000
5	-	Belt Conveyors: Allowance for 750 ft of 30" belts, total hp = 200	172,000
6	-	Latex or Calcium Hydroxide Spray System	29,000
7	1	Coal Refuse Bin, 500 t capacity	102,000
8	1	Coal Refuse/Storage Area, Live Capacity, 5000 t, includes site preparation, reclaim hopper and conveyor belts, total motor hp=80	2,314,000
9	1	Front End Loader	267,000
		TOTAL EQUIPMENT COST	$ 6,873,000
		INSTALLATION AT 1% OF EQUIPMENT COST	$ 98,000
		TOTAL INSTALLED EQUIPMENT COST FOR AREA	$ 6,971,000

5.3. Design Basis

5.3.1. Design Basis: Summary of Process Electrical Requirements

Table A5.6. Summary of process electrical requirements.

Area	Description	Connected H.p.	Operating Kw
100	Coal Delivery, Storage and Crushing	905	681
200	Coal and Oil Preparation	10,330	7,768
300	Agglomeration and Floatation	4,548	3,420
400	Agglomeration and Separation	1,700	1,278
500	Water Treatment	100	75
600	Product Loadout	340	256
	Total	17,923	13,478

5.3.2. Design Basis: Operating Cost Estimates

Table A5.7. Agglofloat Process: Plant Operations.

Salaries and Wages Day Shift	Numbers	Salary/ wages	Total
Plant Superintendent	1	$ 50,000	$ 50,000
General Plant Foreman	1	45,000	45,000
Process Engineer	1	45,000	45,000
Process Technician/Analyst	2	37,000	74,000
Technical Clerk	1	25,000	25,000
Shipping Foreman	1	42,000	42,000
Loading Crew	4	25,000	100,000
	11		$ 381,000
Payroll Burden @ 35%			$ 133,000
Subtotal			$ 514,000
Shift Workers			
Coal Delivery and Reclaim Attendant	4	$ 31,000	$ 124,000
Coal and Oil Preparation	4	31,000	124,000
Agglomeration and Floatation	4	31,000	124,000
Agglomeration and Separation	4	31,000	124,000
Central Control Operator	4	31,000	124,000
Shift Foreman	4	42,000	168,000
	24		$ 788,000
Payroll Burden @ 35%			$ 276,000
Subtotal			$ 1,064,000
Total: Plant Operating Labour			$ 1,578,000

Operating Supplies

Chemicals	
Water Treatment	20,000
Floculant 50 kg/hr of methylisobutyl carbinol x 7,000 hrs x $ 1.60/kg	560,000
Latex Spray	185,000
Fuel	
4.5 x 10^3 MMBtu/y natural gas x $ 2.90/MMBtu	131,000
Electricity	
94.5 x 10^6 kWh x $ 0.065/kWh	6,132,000
Water	
60.2 x 10^6 gal x $0.6/1000 gal	36,000
ROM Coal	
400 tph x 7000 hrs x $ 27.00/t	75,600,000
Crude Oil	
39.6 tph x 7,000 hrs x $ 102.6/t	28,441,000
Diesel	
0.4 tph x 7,000 hrs x $ 178.4/t	500,000

Table A5.8. Maintenance cost estimate: Aglofloat.

Area	Description	Total area cost, 000's	Annual %	Annual labour	Cost, 000's Materials
100	Coal Delivery, Storage and Crushing	5,267	3	63	95
200	Coal and Oil Preparation	12,742	4	204	306
300	Agglomeration and Floatation	9,018	6	216	325
400	Agglomeration and Separation	5,392	6	129	194
500	Water Treatment	1,150	3	14	21
600	Product Loadout	7,810	3	94	141
Total Maintenance Cost				720	1,081

5.4. Design Data

Table A5.9. Analysis of design ROM coal, coal refuse and dried clean coal product.

	Feed Coal	Refuse Coal	Clean Product
Proximate, percent			
Moisture	2.0	10.3	2.2
Ash	17.0	66.9	6.2
Volatile	36.5	10.1	40.4
Fixed Carbon	44.5	12.7	50.6
Ultimate			
Moisture	2.0	10.3	2.2
Ash	17.0	66.9	6.2
Carbon	66.4	19.3	76.9
Hydrogen	4.3	1.2	4.9
Nitrogen	1.1	0.3	1.3
Sulphur, organic	1.2	0.6	1.3
Sulphur, pyrite	2.4	8.0	1.2
Oxygen (diff)	5.6		6.0
Heating Value, Btu/lb	11,900	3,350	13,300
GJ/t	27.4	7.7	30.7

END

DATE FILMED

2 / 26 / 92