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THE AISI DIRECT STEELMAKING PROGRAM

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AISI Direct Steelmaking

SUMMARY

After six months of operation of the pilot plant, the viability of in-bath smelting combined with a high level of post combustion has been demonstrated, and the opportunity exists for an early commercialization of the direct ironmaking part of the process while we continue to research direct steelmaking. The program should be of equal interest to integrated and electric furnace producers. Smelting of ore provides virgin iron units. Additionally, the process has the flexibility of melting scrap and varying the ore-to-scrap ratio over wide ranges. This process does not require coke, thus eliminating the cokemaking operation, a major source of environmental concern.

To go beyond ironmaking and to produce steel directly requires a new and different approach from those pursued in Europe and Japan. We believe we have a viable solution with a novel smelter design involving a two-zone countercurrent smelter. Proof of concept of this direct steelmaking operation will be sought by operating the present converter process in the steelmaking mode prior to installation of the two-zone smelter during the third quarter of 1991. The process engineering of the two-zone smelter is complete, and subcontracts for engineering and fabrication of major equipment have been let. The two-zone countercurrent smelter is projected to produce hot metal with 0.5 to 1.0% carbon and 0.1 to 0.3% sulfur that will be refined to steel for continuous casting in a modified ladle station.

The program is expected to cost approximately $46 million and take four years to complete. DOE will provide approximately 77% of the total funding, or about $35 million, and AISI the balance.

INTRODUCTION

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The AISI-DOE Direct Steelmaking process, the technical program, and its organization and structure have been described in detail elsewhere (see references 1, 2, and 3). The process consists of four major components as shown in the process schematic (Figure 1):

1. In-bath smelting is the heart of the process. Oxygen, prereduced iron ore, coal, and flux are introduced into a molten iron/slag bath. The FeO is reduced to a high-carbon iron, and part of the reduction product gases are post-combusted in the upper part of the vessel. The smelting vessel is multiported, thus permitting additions from the top, sides, and bottom of the vessel.

2. Prereduction is used to preheat and prereduce the iron ore feed to the smelter, using the offgases from the smelter. Although almost any degree of reduction is possible under the proper operating conditions, reduction to wustite of O/Fe of about 1.1 is the preferred choice for this process.

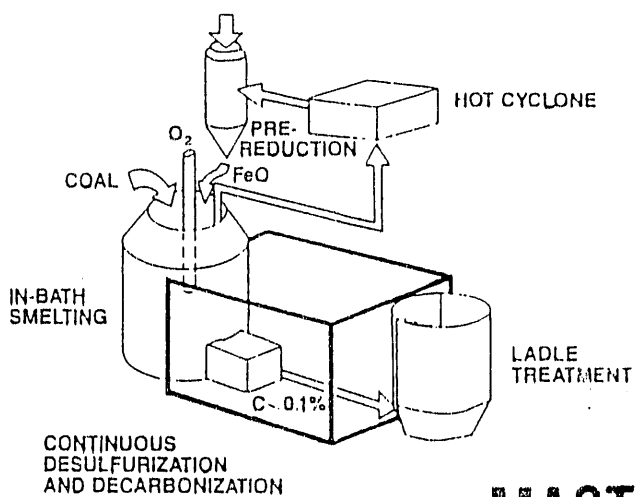

Figure 1

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3. <u>Offgas cleaning and handling</u> must condition the hot dusty offgas from the smelter to provide clean gas at a controlled temperature to the prereducer. The dust is recycled.

4. <u>Refining</u> (desulfurization and decarburization) will provide liquid steel suitable for ladle metallurgy treatment.

The first two years of this four-year program are now complete.

CURRENT STATUS

The second year of the Direct Steelmaking Program was a year of significant accomplishment. The various research programs proceeded essentially on schedule and the pilot plant, the centerpiece of the program, was completed and began operation in almost a picture-perfect manner. Stable, continuous operation has been achieved, much operational data has been generated, and much more is required. Studies for a two-zone, countercurrent smelter show promise of greater productivity than the one-zone, vertical smelter now in operation. Engineering of the two-zone, countercurrent smelter is nearing completion.

The laboratory research programs at MIT and CMU have provided valuable insight into the reactions that can take place among the melt, the foamy slag and its melt droplets, the coal or char, the reduced-ore pellets, and the post-combustion gases. An important result confirmed at the pilot plant is that the temperature of the pellets and their degree of reduction do not affect the kinetics of the smelting process, provided that necessary thermal energy is available.

The mathematical and physical modeling and heat transfer studies at McMaster, McGill, and Union Carbide Industrial Gases are proceeding well. Future work will be aimed at providing guidance for the pilot plant program.

The continuous refining modeling by USS and CMU has provided insight into future refining research showing that the refining vessel can be treated as a well-stirred reactor. Preliminary continuous refining experiments were conducted concurrently at the pilot plant.

Twenty-six pilot smelter trials have been completed with continuous production of hot metal as high as 4.2 tons per hour and indications that the design rate of 5 tons per hour was achievable. Computer control systems were gradually brought on line, and all are performing well. The same applies to the sampling lance and the gas sampling and analysis system. An experimental program carrying through June, 1991, is planned, at which time construction and installation of the two-zone, countercurrent vessel will begin.

Large-scale heat transfer studies have been carried out at Dofasco with the following results:

1. Control of the foaming slag is very sensitive to the CaO/SiO_2 ratio (stable only in the range of CaO/SiO_2 from 1.2 to 1.5).

2. Additions of ore pellets to a foaming slag (equal to 20% slag FeO) did not change either the post combustion ratio or heat transfer efficiency. Pellets dissolved and were reduced at a rate of 500 to 700 kg/min, which was less than the addition rate of 1000 kg/min.

3. Foaming slags in the 300 ton vessel were observed with higher superficial gas velocity than can be attained at the pilot plant. Carbon content of the metal during the foaming tests was in the same range as the steadystate projected for the two-zone, countercurrent smelter. This makes the results applicable to the next phase of the program.

4. As a spinoff from this work, Dofasco has increased scrap melting approximately 3/4% by controlled use of the "free" post combustion energy.

PREHEATING AND PREREDUCTION OF IRON ORE PELLETS INTO WUSTITE

HYLSA of Monterrey, Mexico, was contracted in October, 1989, to undertake a development program in support of the Direct Steelmaking Program. This contract included the following activities: 1) conduct a research and development program to provide the information required to design a pilot-scale shaft furnace for producing wustite pellets, 2) prepare a conceptual design for such a shaft furnace to be installed at the Direct Steelmaking pilot plant, and 3) provide a supply of wustite pellets for use at the aforementioned pilot plant.

Investigations by HYLSA on the pellet reduction part of the commercial Direct Steelmaking flowsheet are nearly complete. The technical viability of a moving-bed shaft to produce wustite using a gas of a composition similar to that expected to be produced in the smelter has also been studied. This work entailed laboratory and moving-bed pilot plant reduction tests using simulated smelter gas, determining the swelling and sticking characteristics of pellets, mathematical modeling of the moving-bed process, and developing the functional engineering specifications for a moving-bed shaft that could be installed at the Direct Steelmaking pilot plant.

HYLSA has successfully produced over 500 tonnes of wustite pellets (about 90% conversion) in their moving-bed pilot shaft at a rate of about 20 tonnes of iron per day. These pellets have been shipped to the Direct Steelmaking pilot plant at Universal and have been used as the iron-bearing feed in the smelting trials conducted there.

IN-BATH SMELTING

The pilot plant for in-bath smelting is shown schematically in Figure 2. The equipment and facilities include a refractory-lined 15 ton smelter converter vessel and the necessary support equipment to produce five tons of hot metal per hour. The support facilities include an ore storage and screening facility where the raw materials are stored and screened before they are put into the day bins. The bulk materials are then carefully weighed, taken to the top of the vessel by conveyor belt, and charged into the vessel via a water-cooled chute. Raw materials also may be introduced into the process by the pneumatic injection system. There are two separate coal injection systems, an ore system, and a flux injection system.

A double-venturi, wet-gas cleaning system cleans the gases coming from the process. This system is able to operate in the total combustion and suppressed combustion modes. To clean the water from the gas system, a water treatment system, complete with clarifier and belt thickener, was installed. To cool the offgas hood, a totally closed, boiler-quality water system was installed. This system was designed to handle offgas temperatures of up to 1750°C. Oxygen, nitrogen, and argon are supplied are supplied to the plant in liquid form and stored in tanks. The liquid then is vaporized and fed into the system on a demand basis.

To take metal and slag samples and temperatures during the trial, the plant is equipped with a sensor lance. There is also a gas-sample lance that samples the gas continuously from inside the vessel during operation and transfers and filters it through a heat-traced line to a mass spectrometer for analysis. To analyze the metal and slag samples in a timely fashion during a trial, an X-ray spectrometer, carbon/sulfur analyzer, and sample preparation equipment were installed at the pilot plant, and the crew was trained in their use.

The flows, temperatures, and pressures are measured and controlled by a PLC-based control system that is linked to the IBM RPMIS system. Most of the equipment can be started and controlled by the computer system. Set points and controllers also may be set at the back panels of the control room as a safety backup.

There is a staff of 12 trained technicians that prepares the facility for the trials and operates the plant on trial days. Most members of the staff have experience in operating steel plants, and a solid team has been formed. The safety of the team is paramount. If anything is not ready, the trial will not begin. The product of the trials is information, not metal and slag. If good data cannot be gained from a trial, there is not much purpose in running it.

As of March 1, 1991, twenty-six experimental trials have been run. The trials have ranged from two to twelve hours in length. Wustite has been smelted successfully to hot metal. Production rates up to 4.2 tons per hour have been achieved and continuously cast. Procedures to control metal temperature and foaming slags have been developed and are being refined.

It is the aim in the near future to achieve the design production rate of 5 tons per hour. Knowledge of the process is built in a step-by-step controlled manner.

Initial tests of the pilot plant dust collector sludge show the sludge to be non-hazardous by EPA standards. This agrees with the previous calculations. In the full flowsheet, the components of the sludge would be injected back into the process to improve yield.

To date, the refractory wear has been excellent. AISI Direct Steelmaking is working with the North American Refractories Company to develop the optimum refractories for the process. NARCO's research and day-to-day technical support, all donated to the project, have been very beneficial.

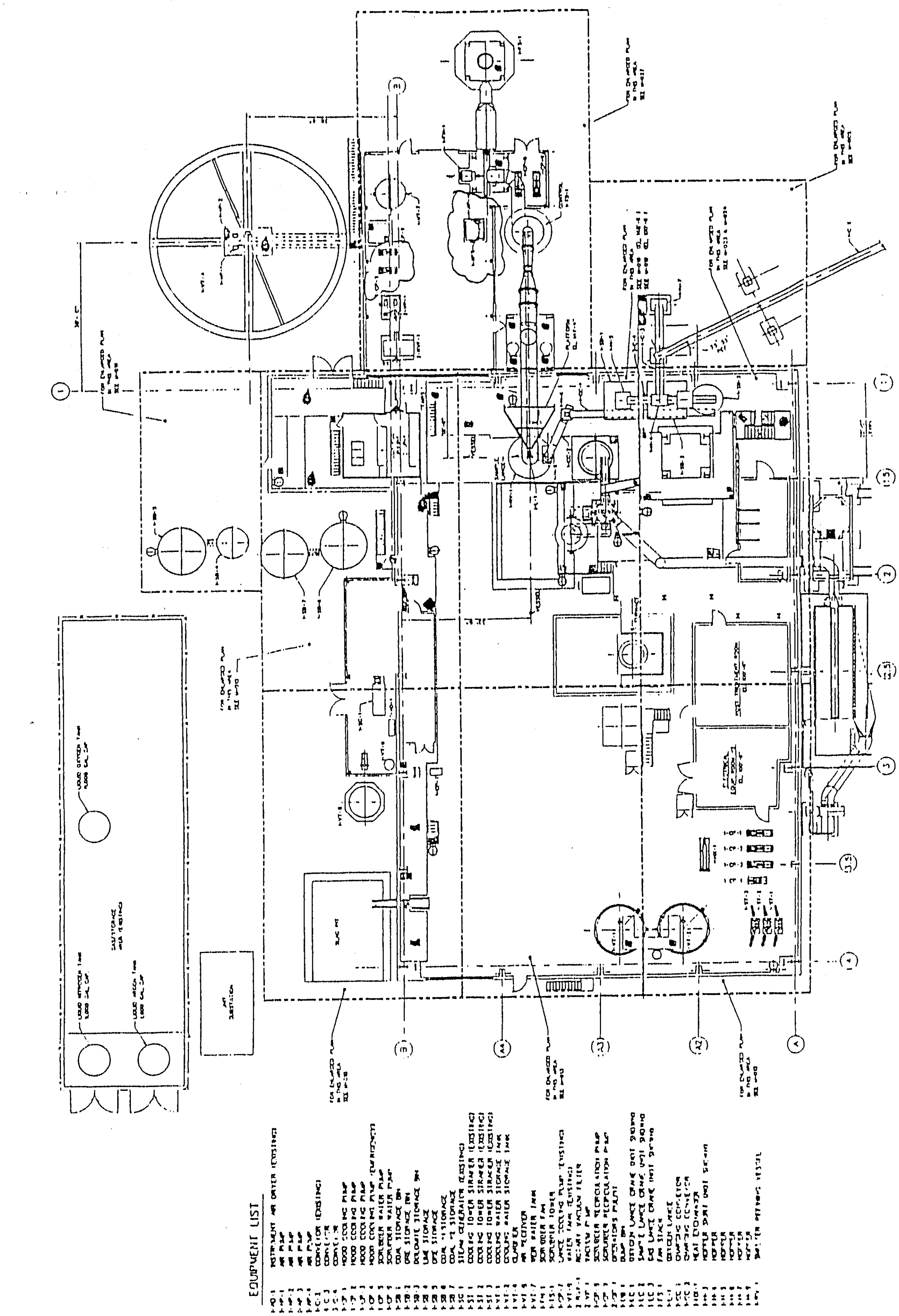

Figure 2

Work is proceeding on schedule, and the results achieved to date are encouraging.

The main process variables that have been investigated during the smelting trials are as follows:

(1) Type and size of coal
(2) Lance position, oxygen flow rate, and ratio of primary to secondary oxygen
(3) Slag composition, especially lime/silica ratio
(4) Carbon content of hot metal
(5) Feed rate of ore and coal
(6) Amount of char in the slag
(7) Effect of going to closed hood operation
(8) Effect of bottom stirring with nitrogen
(9) Effect of continuous tapping of metal and slag while smelting

A number of special experiments are conducted during each test. The results are used to improve the process control strategy, discover useful relationships between selected process variables and smelting results, and fine-tune the process model. A noteworthy accomplishment has been the development and effective use of sublance sampling equipment that can be inserted in the vessel during smelting. The temperature and composition of the slag, metal, and gas can be measured. As a result of good performance of the sublance system, it is now possible to carry out long experiments without the need for interruption to measure the bath temperature and composition. A thermal monitoring program has been underway since the beginning of the project; thermocouples are imbedded in the furnace lining at several points, and the results are used to calculate heat loss.

CONCLUSIONS

Direct Ironmaking - The ironmaking flowsheet as originally proposed by AISI has been demonstrated on a pilot scale and appears to be cost effective for North America.

AISI Ironmaking	
Coal (kg/t)	706
Oxygen (Nm^3/t)	477
Post combustion ratio %	40
Export gas	
BTU/SCF	155
Heat value MMBTU/NTHM	6.47

Direct Steelmaking - After completing the work with the single-zone smelter at the pilot plant, the two-zone smelter will be installed and tested later this year.

A one-half scale physical cold model of the vessel to study the feasibility of the proposed process is being modeled by R. J. Fruehan and A. Vassilicos at the flow lab at USS.

We are projecting:
1. The production rate to be increased by 100% or more over similar size single-zone smelter.

2. Production of metal lower in carbon (i.e., closer to steel) that is more conducive for the continuous refiner.

The program is scheduled for completion by March, 1993.

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