DOE/ID/12847--T1

# AISI DIRECT STEELMAKING PROGRAM

## ANNUAL TECHNICAL REPORT

FOR YEAR ENDING NOVEMBER 29, 1989

DEPARTMENT OF ENERGY

COOPERATIVE AGREEMENT NO.

DE-FC07-89ID12847

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DECEMBER 20, 1989

DOE/ID/12847--T1

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# ANNUAL TECHNICAL REPORT

## AISI - DOE Direct Steelmaking Program

## SUMMARY

The direct steelmaking program is proceeding essentially on schedule. The physical chemistry research programs at Carnegie Mellon University and the Massachusetts Institute of Technology, concerned with ore-slag, ore-melt, and melt-slag reactions, are proceeding on schedule and are generating information on reaction rates, gas evolution rates, and mass-transfer and heat-transfer rates that will help in understanding and modeling the smelting process.

Laboratory modeling of the refining process assisted in the design of a pilot-scale continuous refiner. Several runs of the continuous refiner from late October to early December yielded data that are currently being analyzed.

A preliminary environmental analysis was completed and a construction permit for the pilot plant was obtained from the Allegheny County Bureau of Air Pollution Control. Efforts are now concentrated on pilot smelter construction; the March 15, 1990, milestone for completion is still targeted. A process model for the smelter has been completed, and Level I process level controllers are being linked to the Level II computer. The system includes a data acquisition system that will provide a realtime data base and will accumulate a historical data base. System integration and checkout should be complete before March 15, 1990. Design of a shaft preheater and prereducer for the feed to the pilot smelter is underway; construction of the prereducer is scheduled for completion in late 1990. In the interim between pilot plant startup and shaft preheater completion, the plant will operate with material prereduced at HYLSA.

The post-combustion and heat-transfer workshop was successful in that 17 proposals were received and two were selected for funding. Union Carbide will study post combustion in AOD-type vessels and simulate heat-transfer conditions in a fluidized bed. McGill and McMaster Universities will physically and mathematically model metal circulation and slag-metal interactions and will adapt the models to the large-scale tests at Dofasco and to the pilot smelter. Baseline data are being collected at Dofasco in preparation for the slag foam, post-combustion, heat-transfer trials.

The fine ore processing study has been completed, a report has been issued, and plans for both fine ore and pellet processing are being established for the pilot plant operation.

An updated management plan has been prepared, a patent and intellectual property plan is being submitted, and a critical review of patents and open literature is in the final review stage.

# INTRODUCTION

In 1987 the American Iron and Steel Institute (AISI) formed a task force to assess the technology of direct steelmaking on a worldwide basis, to select a process that would be most appropriate to domestic materials, energy and environmental considerations, and future needs, and to develop a program for the rapid implementation of the process selected. The assessment was completed early in 1988, the findings and a preliminary program were assembled in March, 1988, and a proposal for a direct steelmaking research program was submitted to the Department of Energy (DOE) by AISI in July, 1988, under the congressionally-sponsored Steel Initiative.

In October, 1988, the DOE accepted the program for negotiation of a Cooperative Agreement and in November agreed to cofund allowable costs (at about 77%) subject to successful negotiation of an agreement. To maintain the momentum established by the task force and to assure the most rapid implementation of the program, the AISI funded the organizational and early project expenses until cofunding was granted and continued to advance all funds required until the cooperative agreement was executed in May, 1989, at which time the DOE cofunding was made retroactive to November, 1988.

A management plan was issued June 30, 1989, that described project organization and management philosophy, provided the statement of work, described safety, quality control, and environmental protection procedures, provided the spending plan, the master milestone plan, and milestone logs, and provided the first quarterly management summary report. This annual technical report will be concerned primarily with performance against the statement of work, the spending plan, and the milestones, and with changes that have been made to these objectives and the reasons therefor.

The objective of this project is to develop a coal-based continuous inbath smelting process for the direct production of liquid steel. The process development goals are: 1) reduced energy consumption compared to the conventional coke oven/blast furnace/basic oxygen furnace route, 2) at least 10% reduction in product cost, 3) flexibility in raw materials input, and 4) ease of startup and shutdown. The project will consist of laboratory studies, pilot-scale research and development, and full-scale plant trials. The project will also include studies on continuous decarbonization and desulfurization and on mixed-phase heat transfer and fluid flow.

The initial proposal involved design, construction, and operation of a pilot inbath smelting program, university-based physical chemistry research programs, a large-scale test program, a laboratory-scale continuous refining program, circulating fluid bed studies for fine-ore processing, and a workshop on and solicitation for proposals for heat-transfer and fluid-flow programs. The pilot smelting programs and the physical chemistry research programs are proceeding as proposed and are essentially on schedule. The large-scale test program has been enhanced over that initially proposed by the opportunity to conduct it at a commercial shop with bottom-blown converters that already are achieving significant levels of post combustion. The laboratory-scale continuous refining program has also been expanded to include pilot-scale refining trials. The circulating fluid bed studies have been tabled, but fine ores with various degrees of preheat and prereduction will be studied as smelter feed along with pellets. The workshop led to many fine proposals from which two were selected that will add significant contributions in process modeling and post combustion/heat transfer capabilities. In addition, a program was added to study the preheating and prereduction of pellets and to design and construct a pilot shaft preheater and prereducer for the pilot facility.

These programs are discussed further as to scope, schedule, and budget in the following Research Program section.

## RESEARCH PROGRAM

### TASK 1.0 - PHYSICAL CHEMISTRY

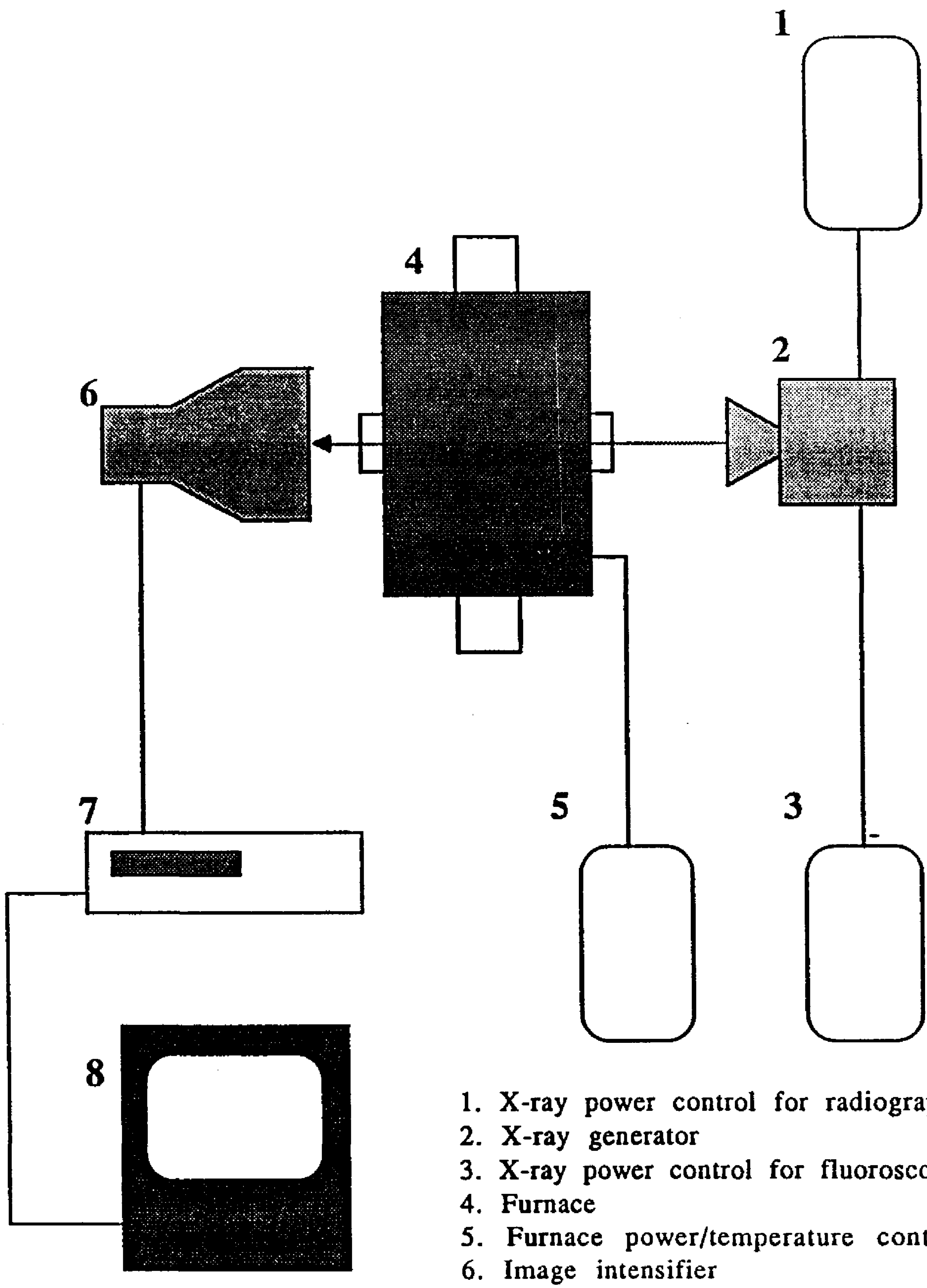
#### CMU

The laboratory-scale physical chemistry research programs at Carnegie Mellon University (CMU) and the Massachusetts Institute of Technology (MIT) are proceeding well and on schedule. These programs constitute tasks 1.1 through 1.5 of the statement of work with CMU concentrating on ore-slag reactions and MIT on ore-metal reactions.

CMU has installed a 20 KW induction furnace that can operate continuously at temperatures up to 1550°C and is designed to permit transverse x-ray fluoroscopy and radiography. They have acquired a 100 KV to 125 KV x-ray fluoroscopic system that can be used with an image intensifier, TV monitor, and video cassette recorder for motion recording or with x-ray film for radiography. This system, which has just become operational, will be used to study slag foaming and slag-droplet and droplet-gas interactions. Figure 1 presents the overall system; Figure 2 provides detail on the furnace.

#### SLAG FOAMING

In task 1.1, the slag foaming index, Sigma, defined as the foaming height divided by the superficial gas velocity, has been measured at small scale (150 g) and larger scale (1000 g) as a function of percent FeO in slag and basicity of the slag,




1. X-ray power control for radiography
2. X-ray generator
3. X-ray power control for fluoroscopy
4. Furnace
5. Furnace power/temperature control
6. Image intensifier
7. Video cassette recorder
8. TV monitor

**Figure 1:** A diagram for X-ray/furnace system

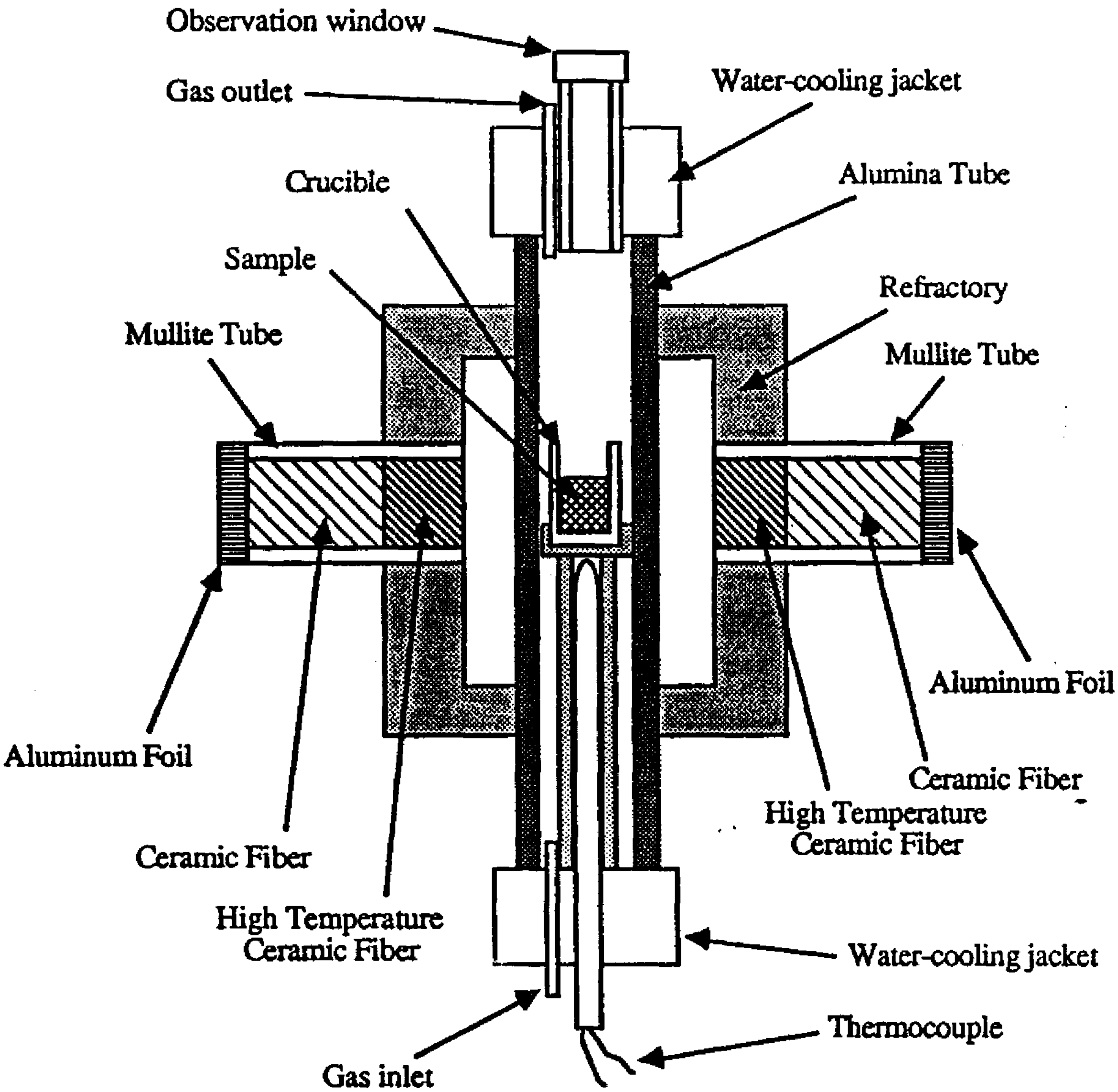



**Figure 2:** A schematic diagram for furnace

Figure 3, percent $CaF_2$, Figures 4 and 5, and percent CaS, Figure 6. In general, the larger scale results agree with the small scale results, the index decreases with increasing FeO up to around 10 or 15 percent, reaches a maximum at about 8% $CaF_2$, Figure 5, and decreases very slowly with CaS ranging from about 0 to 2.5%, Figure 6.

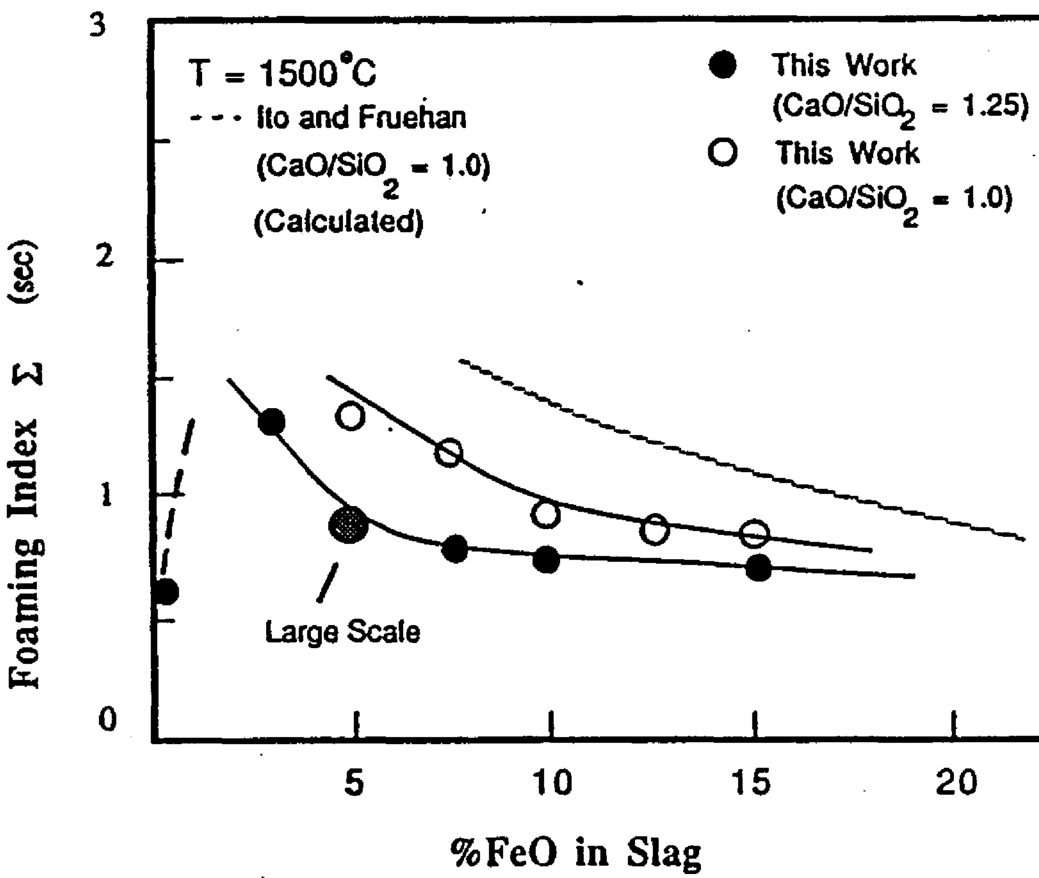
SLAG-CARBON

For task 1.3, the reduction of FeO in slag by carbon, experiments were conducted with a rotating graphite cylinder in molten slag, Figure 7, as a function of slag weight, FeO concentration, rod rotation speed, rod immersion depth, rod diameter, and slag temperature, Figure 8. Reduction was monitored by the rate of CO evolution. In subsequent experiments, coke discs and coal char will be substituted for the graphite. Computer programs were written to solve equations for rate of CO evolution as a function of FeO concentration, and for mass transfer coefficients as a function of CO evolution, rod rotation, and rod area.

As part of this same task, 1.3, experiments were conducted on coal volatilization, Figure 9. Such volatilization is important because a significant amount of the energy of the coal is contained in the volatiles and their rate of release may determine how effectively they can be utilized and because the site and rate of release may have a significant effect on the slag foam. A suite of 7 coals obtained for the AISI project by USX Coal and Coke Laboratories from Professor J. C. Ferm at the University of Kentucky was studied. The coals are characterized in Table 1. The influence of particle size on rate of devolatilization is shown in Figure 10 and the times for 50% and 5% devolatilization are shown in Figure 11 for six of the seven coals. Conclusions to date are that neither coal type nor coal rank significantly affect devolatilization of large coal particles, probably due to heat transfer and mass transfer limitations. Heating rates have a significant influence on devolatilization. Future work will study devolatilization in smelting slags and will attempt to determine kinetic rate constants.

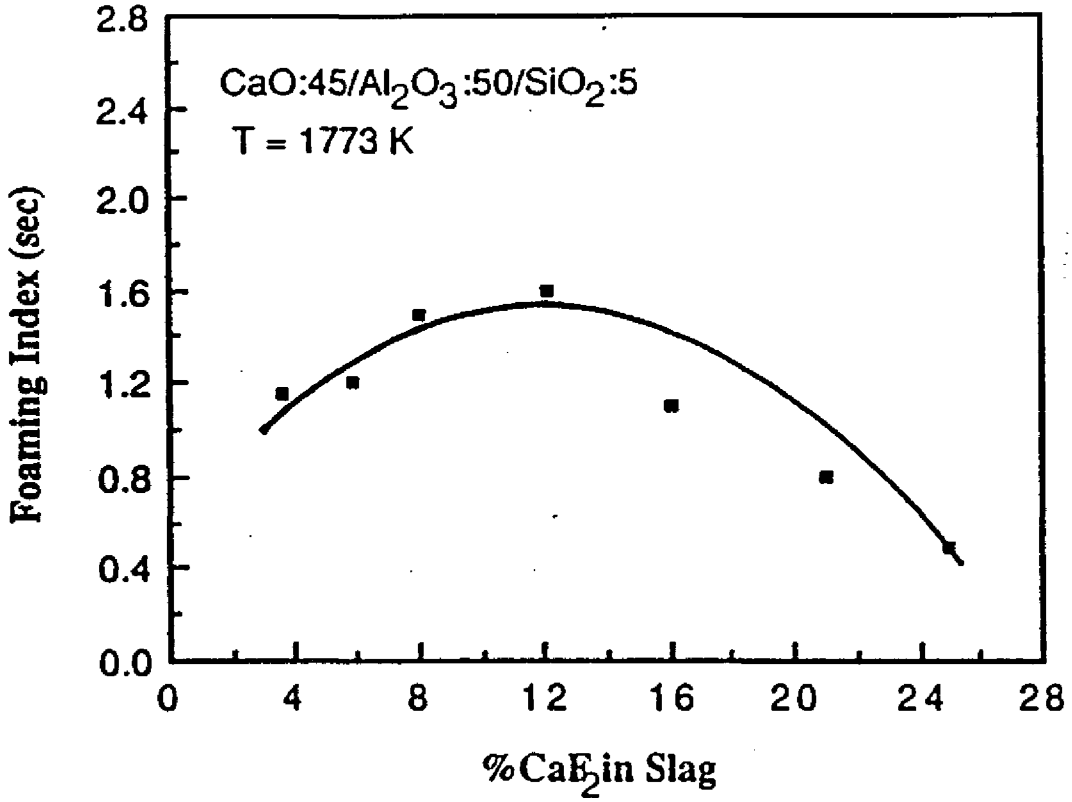
IRON DROPLETS

With respect to Task 1.5 and the interaction of iron droplets with slag, D. J. Min and R. J. Fruehan have constructed an apparatus, Figure 12, consisting of a furnace and a reaction vessel. The furnace provides a uniform 240 mm hot zone, controlled to about 2 K and operating at about 1673 K. The uniform zone is required to prevent the molten slag from freezing on the crucible wall. The furnace operates at atmospheric pressure, under an argon purge, until time for the molten droplet to drop into and react with the slag. The purge is halted, the drop is released, and the flow rate of CO from



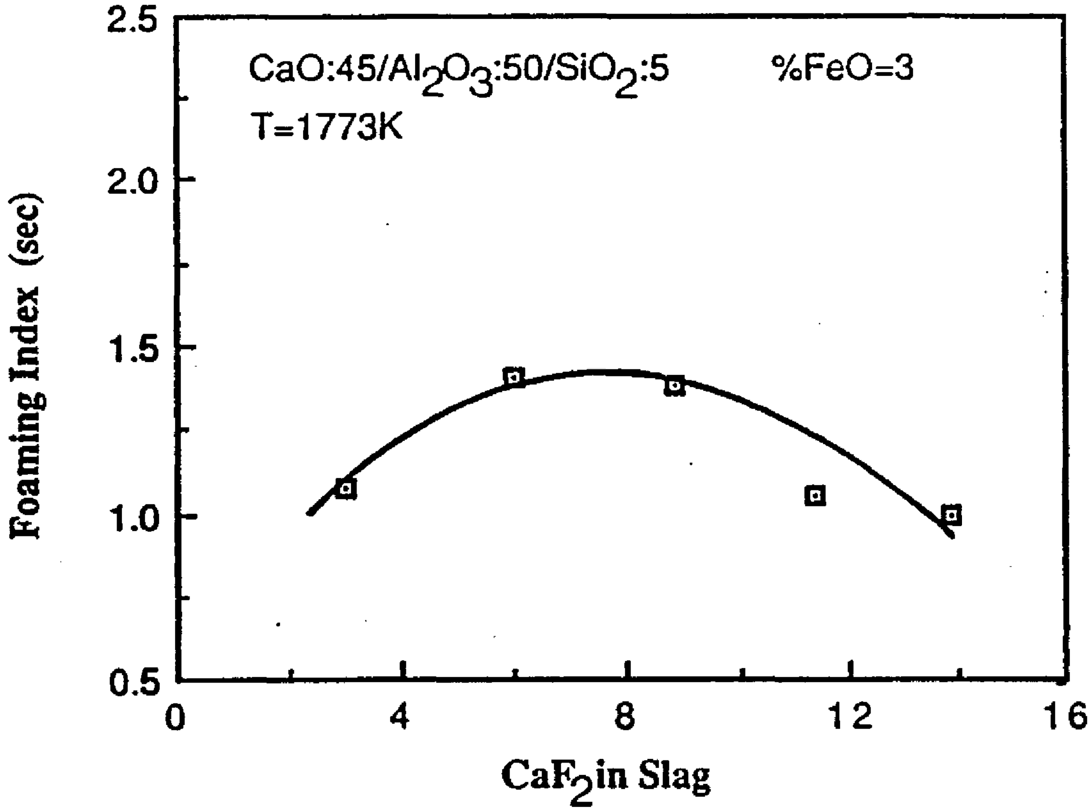

# Large Scale Verification of Foaming Index

FIGURE 3



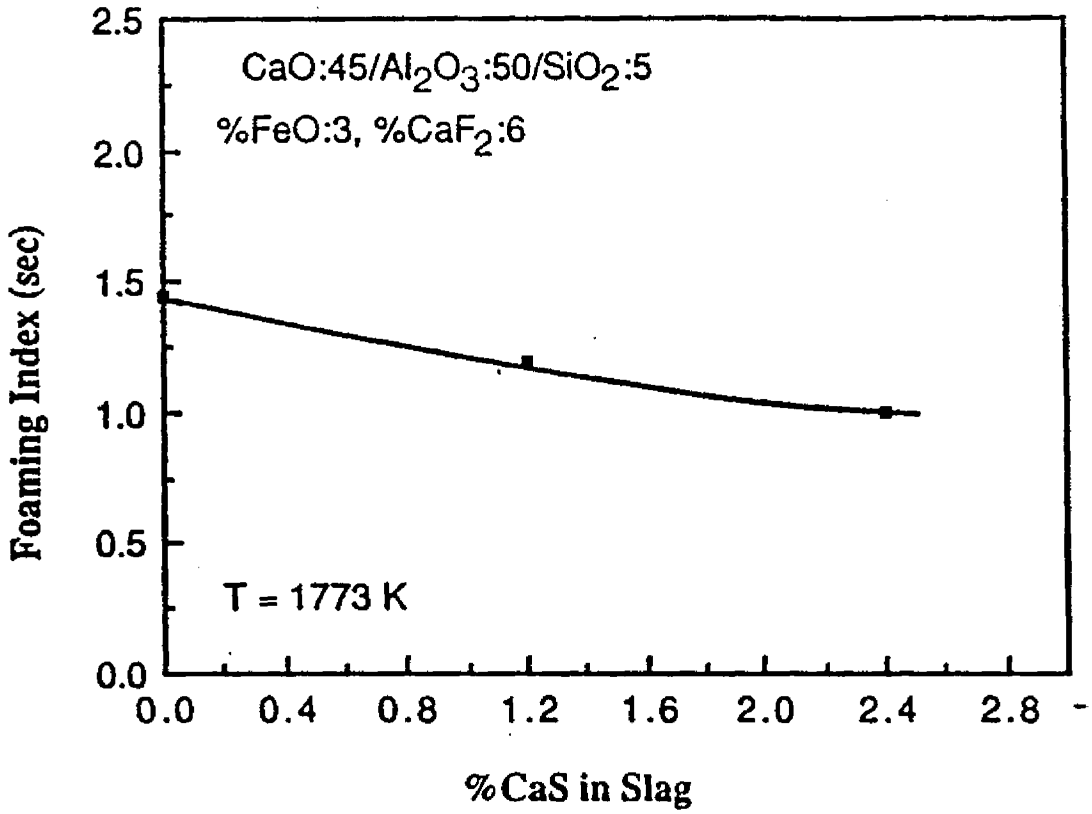

**Effect of $CaF_2$ on Ladle Slag Foaming**

FIGURE 4



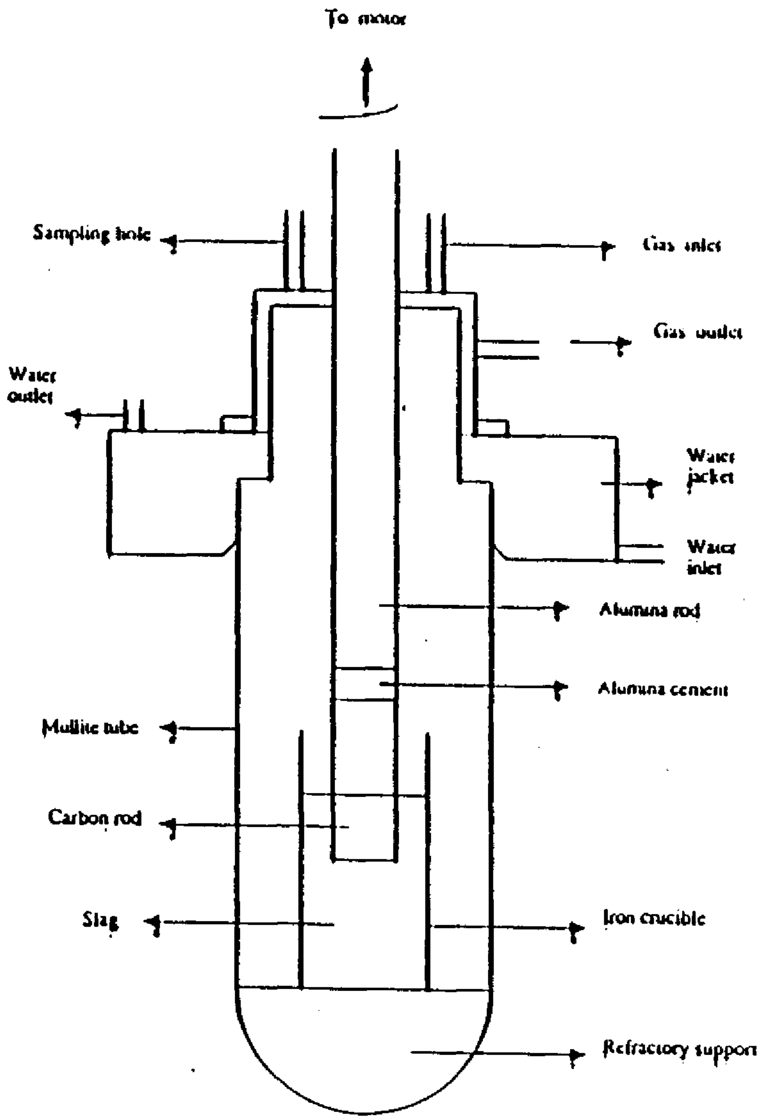

**$CaF_2$ Effect on Foaming (with FeO Added)**

FIGURE 5




# Effect of CaS on Ladle Slag Foaming

FIGURE 6




Experimental Setup

FIGURE 7

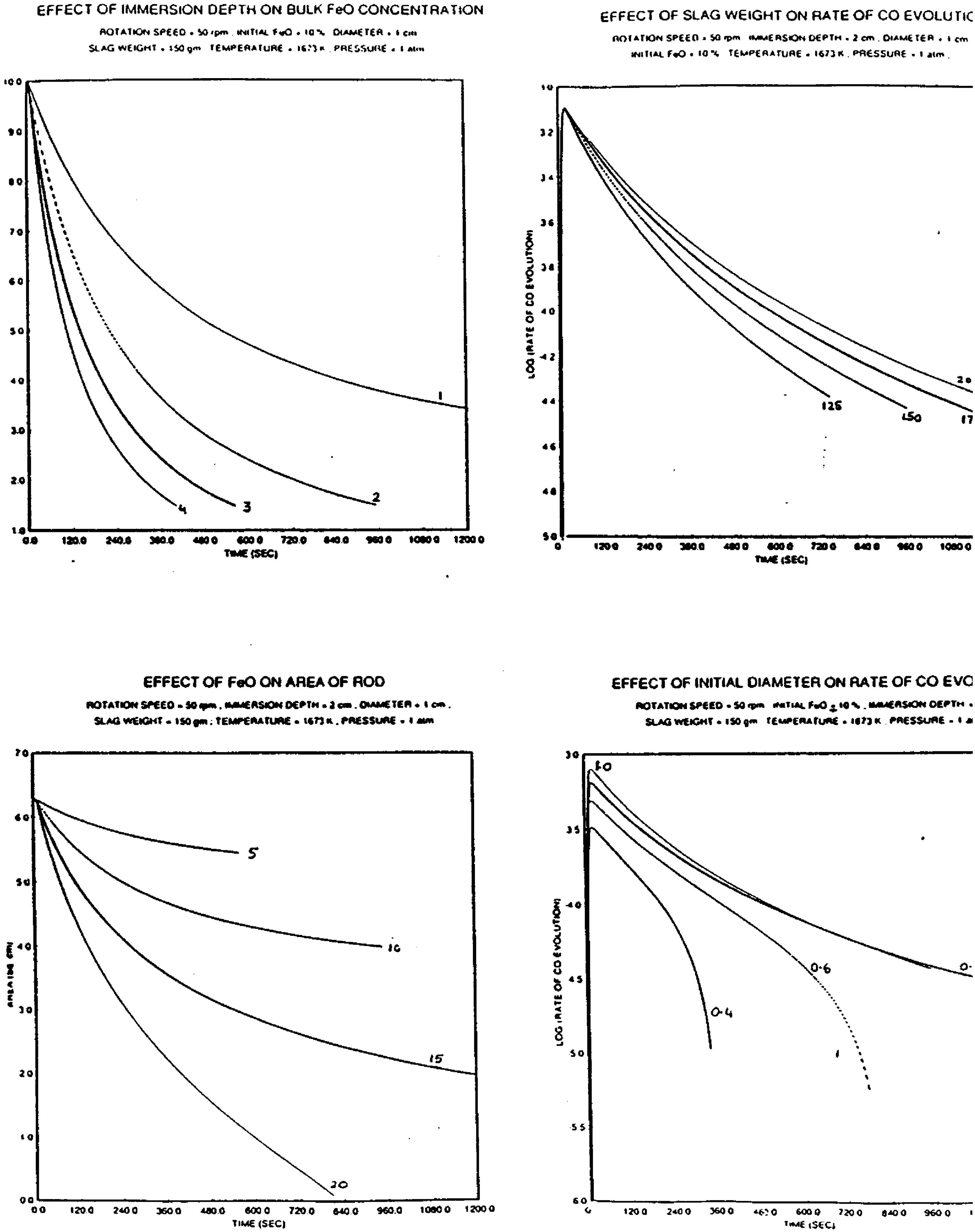
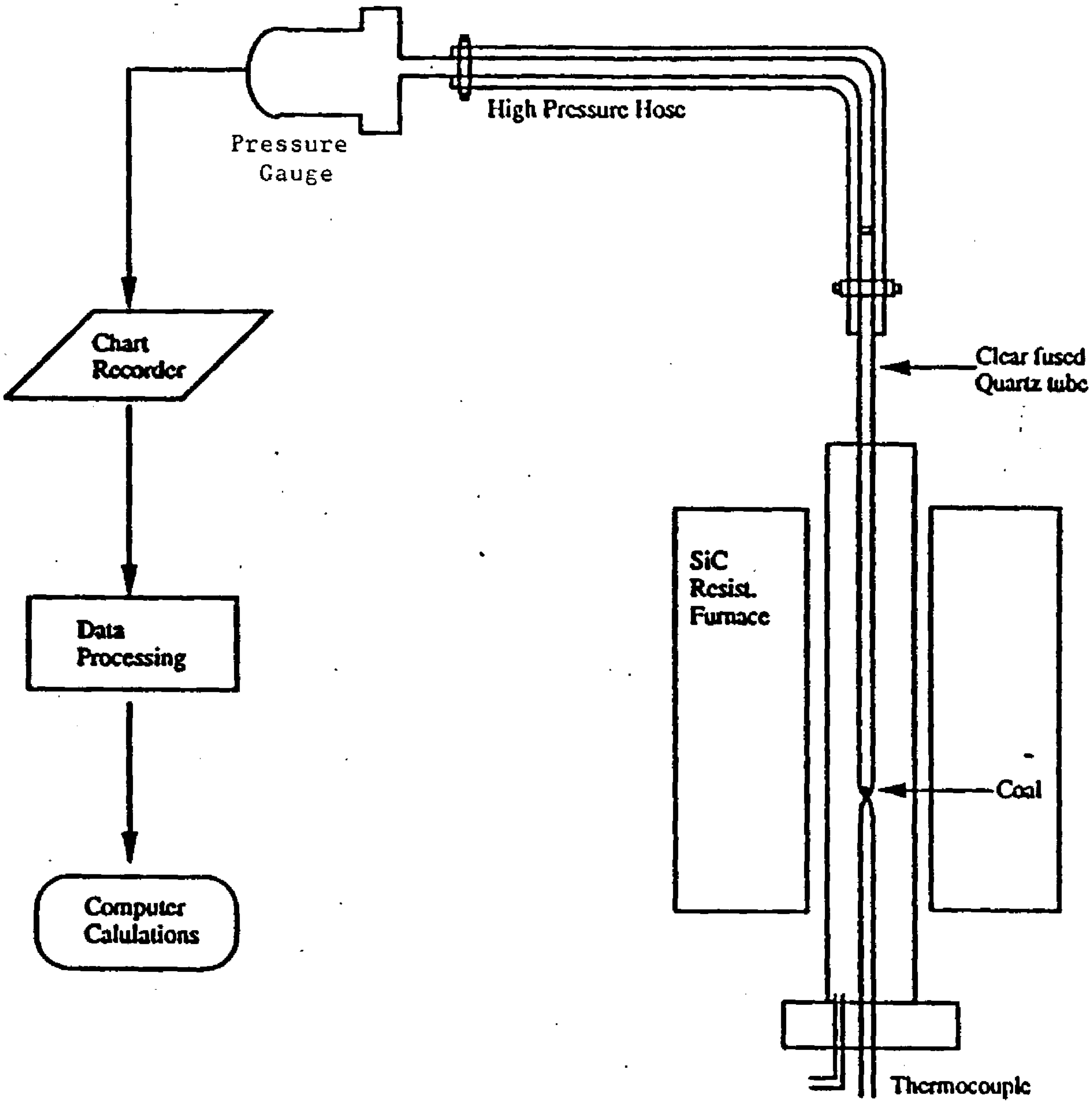
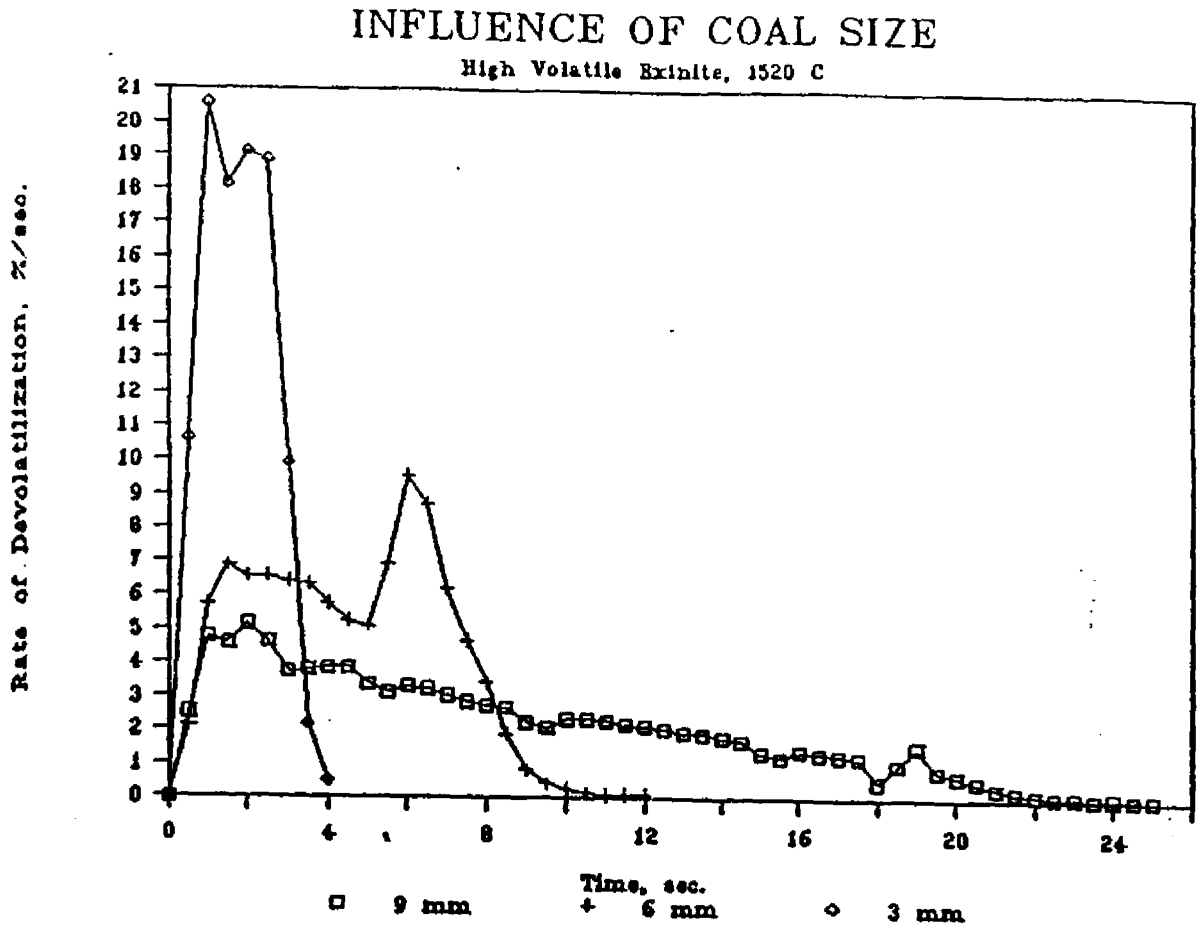

EFFECT OF IMMERSION DEPTH ON BULK FeO CONCENTRATION
ROTATION SPEED = 50 rpm , INITIAL FeO = 10 % , DIAMETER = 1 cm
SLAG WEIGHT = 150 gm , TEMPERATURE = 1673 K , PRESSURE = 1 atm
TIME (SEC)
EFFECT OF SLAG WEIGHT ON RATE OF CO EVOLUTIC
ROTATION SPEED = 50 rpm , IMMERSION DEPTH = 2 cm , DIAMETER = 1 cm
INITIAL FeO = 10 % , TEMPERATURE = 1673 K , PRESSURE = 1 atm .
LOG (RATE OF CO EVOLUTION)
TIME (SEC)
EFFECT OF FeO ON AREA OF ROD
ROTATION SPEED = 50 rpm , IMMERSION DEPTH = 2 cm , DIAMETER = 1 cm ,
SLAG WEIGHT = 150 gm ; TEMPERATURE = 1673 K , PRESSURE = 1 atm
TIME (SEC)
EFFECT OF INITIAL DIAMETER ON RATE OF CO EVO
LOG (RATE OF CO EVOLUTION)
TIME (SEC)

FIGURE 8




The Pressure Measurement Apparatus - CVPI

FIGURE 9



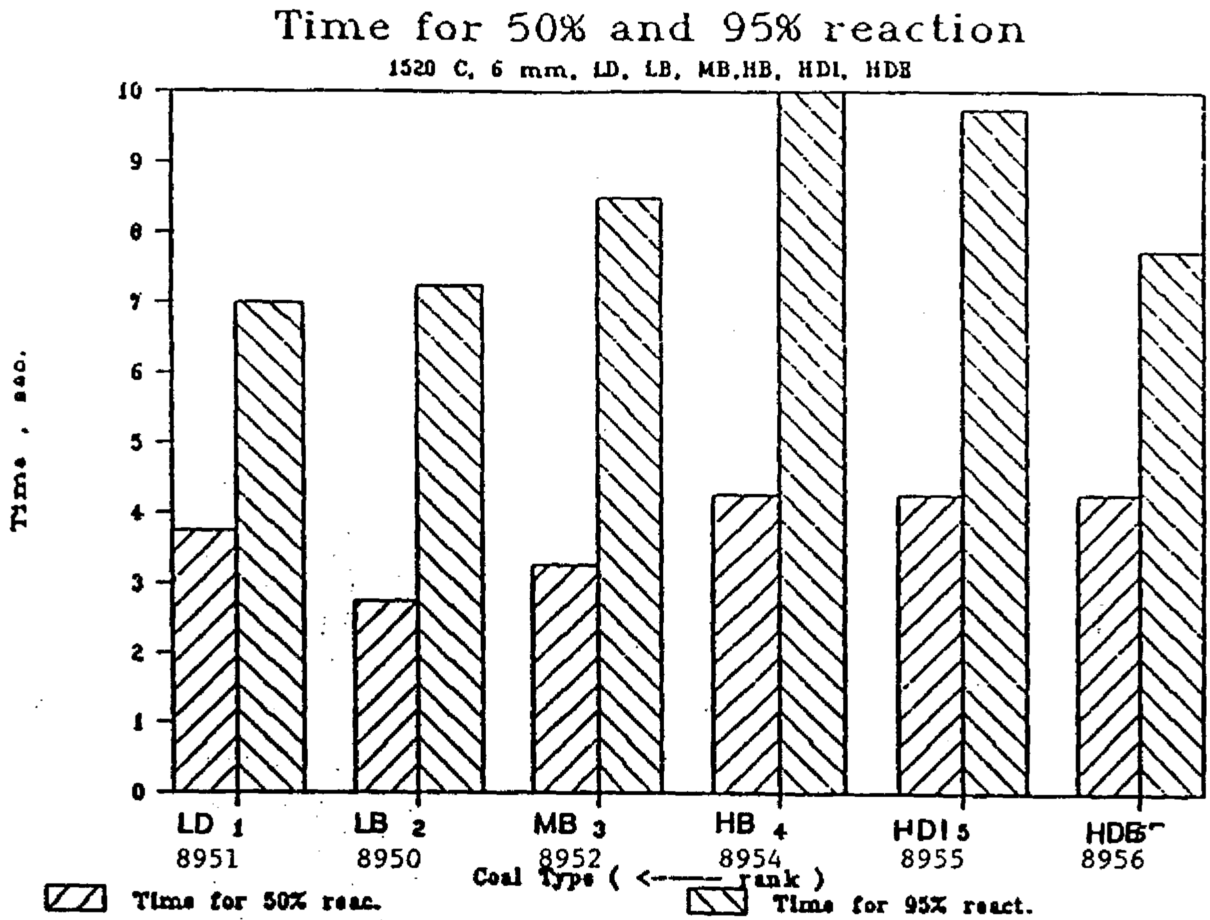

Rate of devolatilization as a function of coal size at 1520 °C for a high volatile exinite rich coal sample.

FIGURE 10

TABLE I

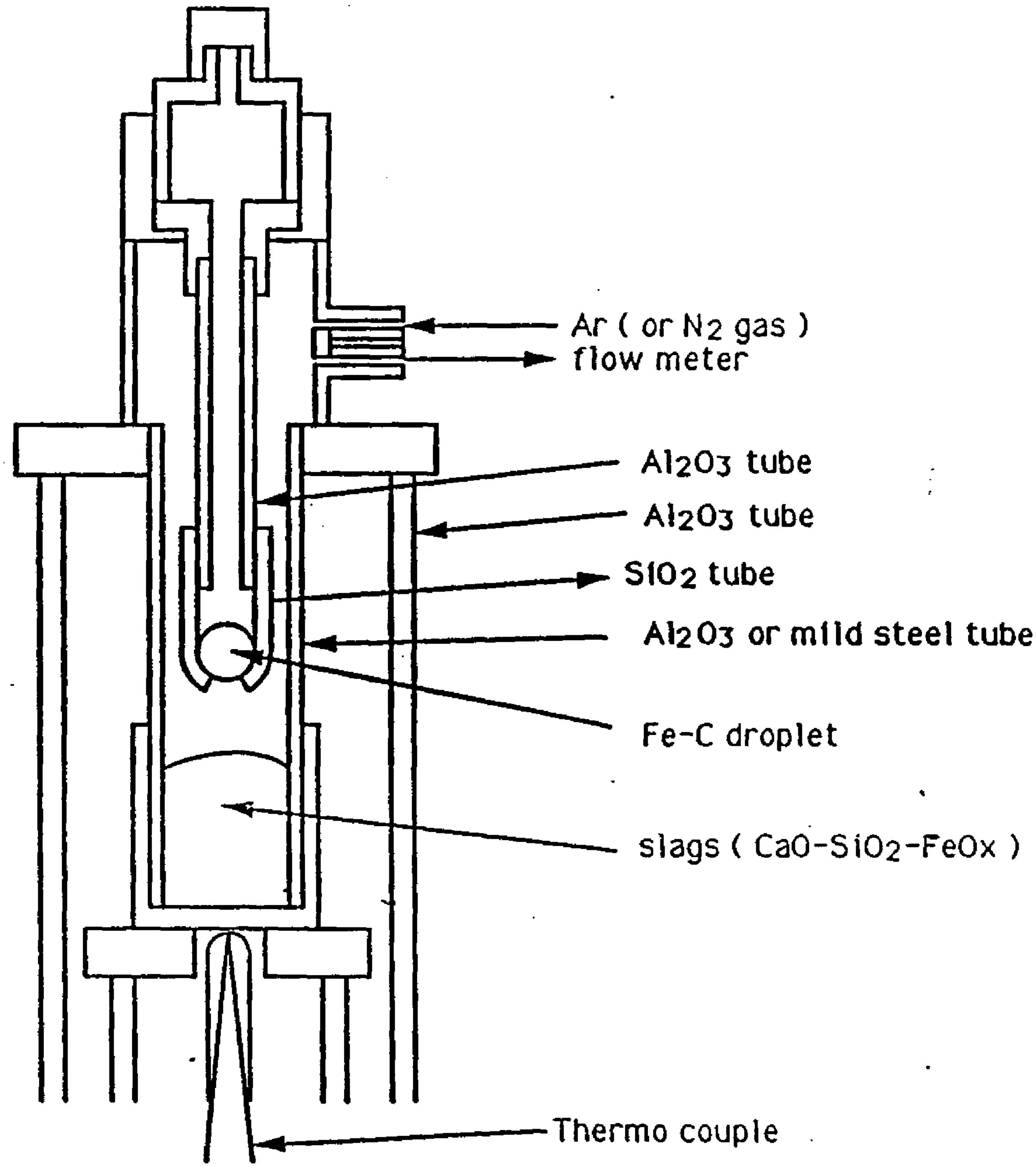
## Sample Description for Special AISI Coal Samples

| UEC. No. | Sample Description |
|---|---|
| 8950 | Low. Vol. - Bright Fraction. No. 96 Mine, Underground, Smoky River Coal from Grande Cach, Alberta, Canada. July, 1989. (958 grams) |
| 8951 | Low. Vol. - Dull Fraction. No. 96 Mine, Underground, Smoky River Coal from Grande Cach, Alberta, Canada. July, 1989. (1440 grams) |
| 8952 | Med. Vol. - Bright Fraction. Sewell Seam, Davis Ridge Mine, from Nickolas Co. West Virginia. July, 1989. (929 grams) |
| 8953 | Med. Vol. - Dull Fraction, High Inert. Jewell Seam, Cardinal River Mine, from Luscar, Alberta, Canada. July, 1989. (850 grams) |
| 8954 | High Vol.- Bright Fraction. Fireclay Rider Seam, from Leslie Co., Kentucky. July, 1989. (901 grams) |
| 8955 | High Vol. - Dull Fraction, High Inert. Fireclay Rider Seam, from Leslie Co., Kentucky. July, 1989. (1003 grams) |
| 8956 | High-Vol. - Dull Fraction, High Exinite. Top Portion of Lower Kittaning, cannel coal from Mahonning County, Ohio, East Fairfield Coal Company. July, 1989. (1280 grams) |




Time for 50% and 95% reaction for six 6mm coals of differing types at 1520 °C.

FIGURE 11




Schematic diagram of experimental apparatus.

FIGURE 12

the reaction FeO + C = Fe + CO is measured. Figure 13 presents the flow rate of CO vs. time. The CO flow rate can be converted into an FeO reduction rate with 1 ml CO corresponding to the reduction of 0.0032 g FeO and the consumption of 0.000536 g C.

The apparatus has only recently been completed, and few experiments have been conducted. Further work will cover the FeO content of the slag ranging from 3 to 15%, the droplet weight ranging from 1 to 5 g, variations in C and S content of the droplets, and x-ray fluoroscopy to observe the interaction of the droplet.

SMELTING MODEL

As part of Task 1.5, R. J. Fruehan has developed a simplified model for the smelting reduction that includes the slag-metal, slag-coal char, and ore-metal reactions. When the model is applied to Nippon Steel's published results for their 1 ton and 5 ton vessel experiments, indications are that about 50% of the reduction of FeO to Fe is accomplished by the coal char in the slag. Because energy is required to melt the pellets in the slag and to heat and crack the coal (assuming top feeding of pellets and coal) as well as for about 50% of the reduction, the implication is that much of the post-combustion energy need only be transferred to the slag and smaller amounts to the melt.

PELLET REDUCTION

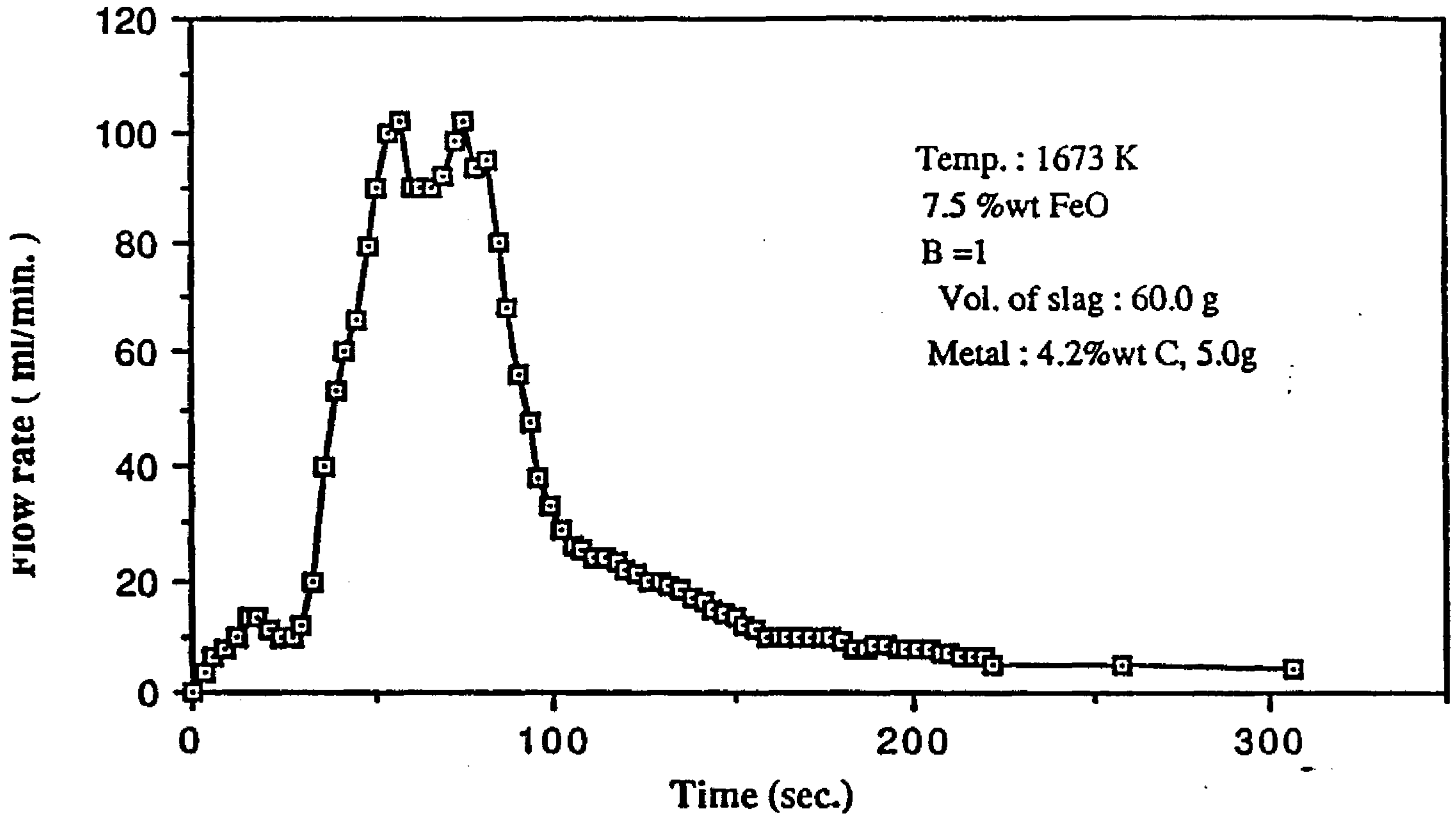
Apparatus has also been completed and preliminary data have been collected on the rate of reduction of acid, low-basicity, and high-basicity pellets in offgases from coal at various post-combustion ratios. The USX Technical Center is testing the reduced pellets for compression strength. The work will be coordinated with the prereduction trials underway at HYLSA.

MIT

Work at MIT has included modeling of the heating and melting of various types of pellets in liquid slag (Task 1.2) and experiments on the rates of solution and reduction of FeO particles and higher oxides of iron when injected into the metal phase (Task 1.4) and on the rate of reduction of FeO in the slag by carbon dissolved in the metal (Task 1.5).

PELLET-SLAG INTERACTION

The model of heating and melting of particles (pellets) in liquid slag that was developed by Dr. R. J. O'Malley in his doctoral thesis has been partially updated for use in this program (Task 1.2.1). The model is written in Fortran 77 and runs on VAX machines with the VMS operating system. The program is readily adapted to other operating systems and computers, but the recent work has been directed to updating the algorithms for specific use of the present research program. Experimental




Flow rate of CO vs. time at 1673 K, 7.5wt%FeO

FIGURE 13

results and the use of the model show that the rate of heating of a neutrally-buoyant particle in a liquid slag is strongly dependent on certain properties of the slag: temperature, liquidus temperature, viscosity, thermal conductivity, and apparent density; and on the nature of the pellet being heated: initial temperature, melting temperature, thermal conductivity, communicating porosity, size, and presence of carbon in partially-reduced pellets. Stirring and turbulence of the slag system are also important to the rate of heating. The effects of solidification and remelting of a solid shell of slag on the surface of the pellet on the heating and melting of the pellet are also included in the model.

FURNACE

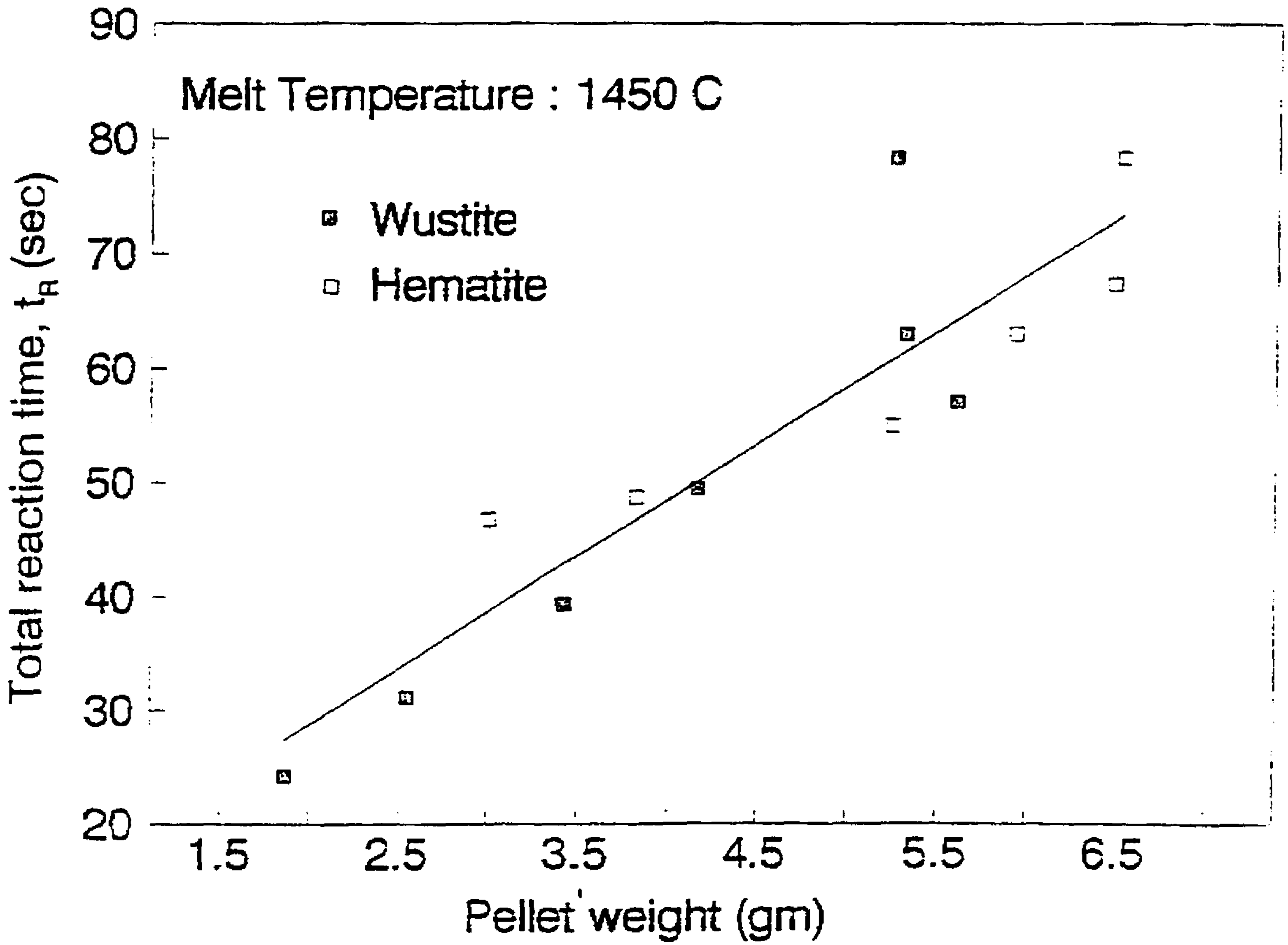
The furnace system required for Tasks 1.4 and 1.5 was placed in operation in early June. The flash x-ray apparatus and the necessary techniques for recording images of the reacting system in the furnace were brought up to a satisfactory operating level in late May.

PELLET-METAL BATH REACTION

Experiments have been conducted to measure the rate at which an oxide pellet reacts with carbon in a carbon-saturated bath. The measurements include determination of the rate of evolution of gas, the composition of the gas, and the time interval over which gas evolution takes place. A melt of approximately 300 gm. is contained in a graphite crucible which, in turn, is contained in a closed, induction-heated furnace. The temperature range of the experiments is from 1450 to 1650°C, and a sweep gas (Ar) flows through the reaction chamber at a rate of 1.5 liters per minute. The pressure in the furnace is 1 atm. Single pellets are dropped onto the surface of the melt, and the volumetric rate of evolution of gas and internal pressure of the furnace are measured continuously. The composition of the gas evolved is also measured continuously with a mass spectrometric gas analyzer, and it has been found to be pure CO (g) at all of the experimental temperatures. It appears that quantitatively all of the oxygen in the pellet is evolved as CO. The functional form of the curve of gas evolution is an almost square-topped pulse that has a duration of between 10 and approximately 100 seconds, depending on temperature, pellet weight, and type of oxide.

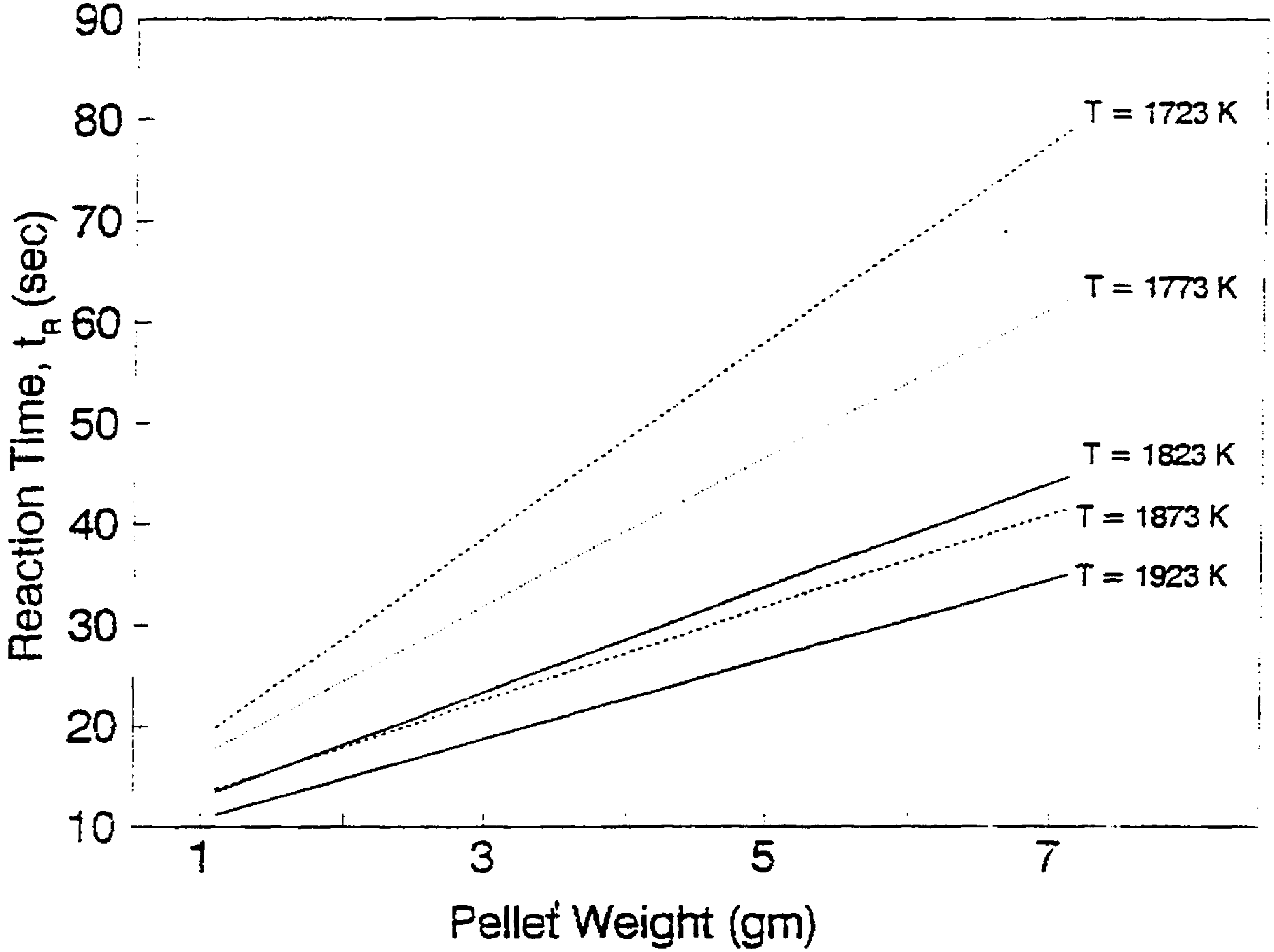
Spherical pellets of chemically pure hematite and wustite with weights ranging from 1 to 7 g have been employed. Figure 14 shows the correlation of pellet weight and time of gas evolution that was obtained at 1450°C. Figure 15 is a summary of the results for five temperatures: 1450°C (1732 K), 1500°C (1773 K), 1550°C (1823 K), 1600°C (1873 K), and 1650°C (1932 K). The time of evolution of gas is proportional to pellet weight, and at a given weight, the interval decreases with increasing temperature of the melt; but there is little

FIGURE 14




THE REACTION TIMES OF WUSTITE AND HEMATITE PELLETS WITH CARBON SATURATED Fe-C MELTS AT 1450 C.

FIGURE 15




SUMMARY OF MEASUREMENTS OF REACTION TIMES OF OXIDE PELLETS WITH CARBON SATURATED Fe-C MELTS.

difference in the behavior of the two types of oxides. It is observed that for a given weight of pellet, there is 40% more oxygen and 5% less iron (by weight) in a hematite pellet than in the wustite pellet. The analysis of these data to explain the rate determining process(es) has not been completed.

A number of commercial pellets also have been reacted in the furnace, but interpretation of their behavior is complicated because the gangue and fluxing agents in the pellets leave a residue of slag in the crucible. Modeling of the behavior of pellets in this experiment is in progress.

Flash x-ray images and observation of the crucible after an experiment show that the reaction between pellet and carbon in the melt results in considerable spatter of the metal bath into the freeboard of the crucible. Extensive effort was required to develop a satisfactory arrangement of the x-ray source and furnace, and work with various types of x-ray films and intensifying screens is continuing to obtain suitable images of the reacting system.

## SLAG-METAL BATH REACTION

The same furnace is being employed for the study of reactions between high-carbon iron and liquid slag (Task 1.5.1) The internal parts of the system can be changed as needed to include an alumina crucible to contain the slag phase and apparatus for adding small quantities of an Fe-C melt to the slag. The apparatus for this subtask was completed in late June, and a number of experiments have been carried out recently. The weight of slag is 300 g, and that of the metal droplet is 1 to 7 g.

Measurements that have been made include determination of the volumetric rate of evolution of gas from the reactions that take place, continuous monitoring of the gas composition, and imaging of the reacting system with the flash x-ray system. The reaction between the droplet of metal and the slag in the crucible results in the immediate formation of a slag foam. The physical condition of the reacting system at precise times after the droplet enters the slag have been recorded on x-ray film.

## CONTINUOUS REFINING MODELS

The Direct Steelmaking program includes continuous refining. Current research is concerned with physically and mathematically modeling this process (Task 1.6). The major portion of the experimental work is being carried out at the USS Technical Center with the primary researcher being a CMU graduate student. Additional research and modeling is being carried out at CMU.

To date, a physical chemical mathematical model of the process has been developed, slag minimization during tapping has been studied, and residence time distribution measurements have been made. The experimental work has been done using an existing CMU model and a model obtained from General Motors Research and is progressing according to schedule.

A kinetic model for the refining of steel in the continuous refiner was developed. The model is based on the known physical chemistry of bottom blown processes, theory of continuous reactors, and operating data from actual U.S.S. Q-BOP steelmaking vessels.

Briefly, from the model, the following information was obtained:

1. An equation was developed to predict the steady state or tap carbon content as a function of the initial carbon content, the production rate, and the decarburization constant.

2. The decarburization constant was obtained by extrapolating the decarburization constant for 220, 190, and 30 ton Q-BOP vessels.

3. The model was used to calculate the amount of iron oxidized and the flux requirement for dephosphorization.

This model indicated that the proposed process is feasible and was used to establish the operating conditions for the pilot plant converter.

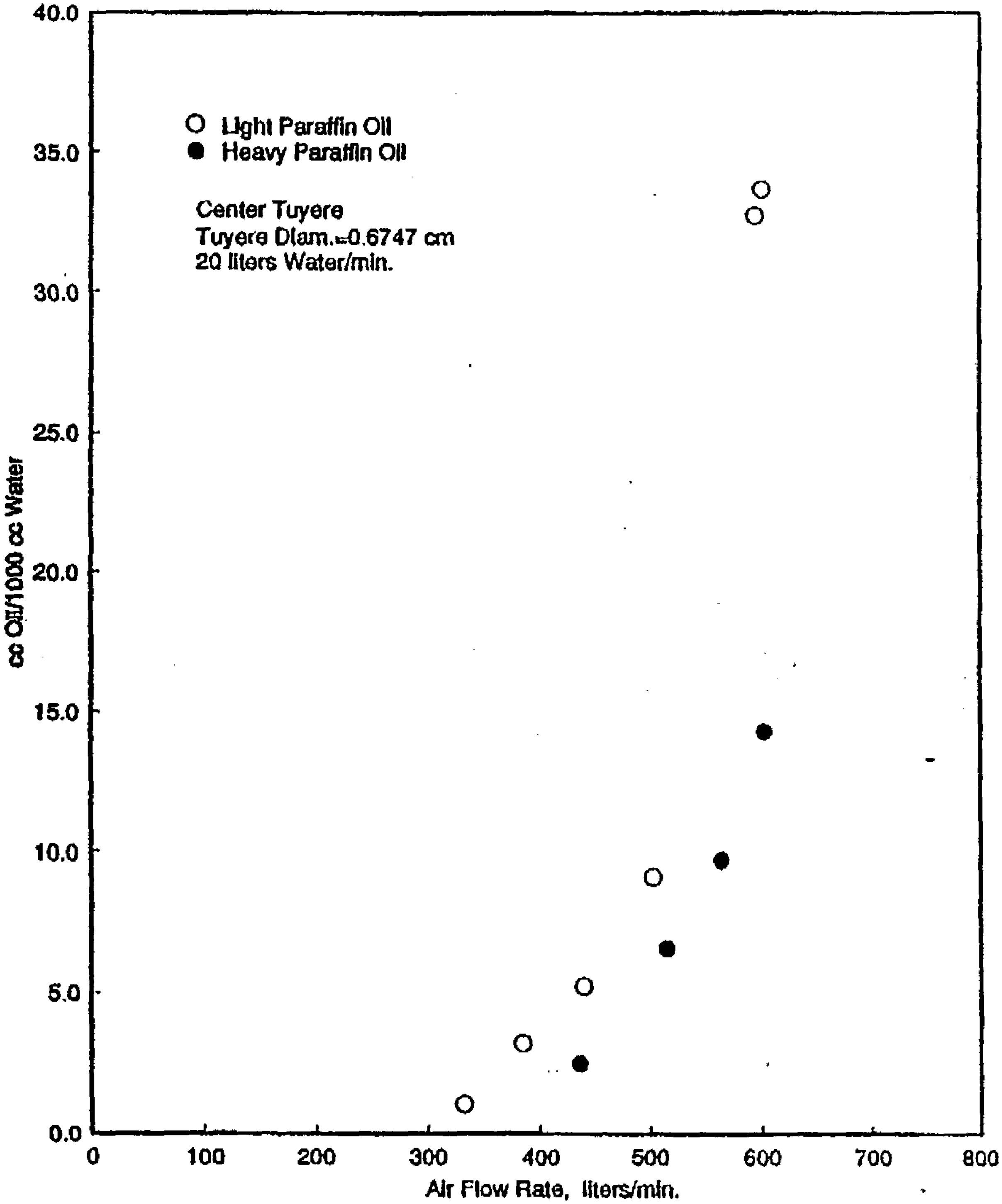
Due to the extreme turbulence in the reactor, there was some concern about tapping slag out of the vessel with the metal. Therefore, experiments were conducted at CMU using an existing model of the reactor. The model was approximately one-half scale of the pilot converter and used water-oil to simulate the steel-slag. Briefly, the conclusions were as follow:

1. The bottom tuyere should be at about one-half radius in line and in the direction of the tapping spout. In this configuration the flow pattern reduced the amount of slag reaching the spout. The next best position for the tuyere was the center of the converter bottom.

2. The amount of slag tapped for a given tuyere position increases with stirring energy or gas flow rate (Figure 16).

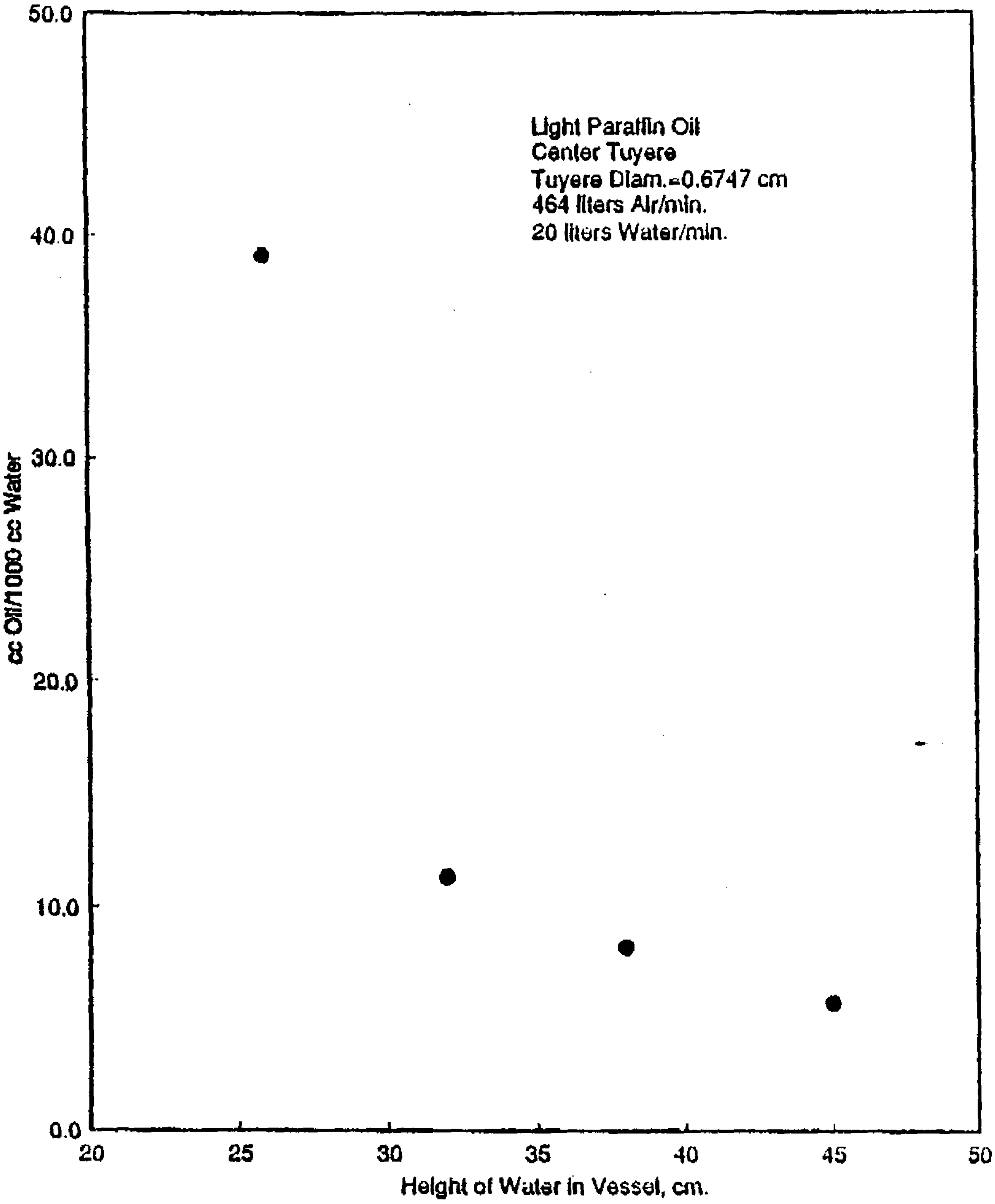
3. The amount of slag tapped will be inversely proportional to the bath depth (Figure 17).

4. The amount of slag tapped will increase with decreasing slag viscosity and interfacial energy between the slag and metal.




**Amount of oil tapped with water as a function of gas flow rate or stirring energy.**

FIGURE 16




The amount of oil tapped as a function of bath depth.

FIGURE 17

Based on a very simple model, it is predicted that the amount of slag which will be tapped in the pilot process will be no more than in conventional steelmaking. Whereas, the stirring energy is much greater in the pilot smelter than in the model, the density difference between the slag and metal is also much greater than the oil and water. The buoyancy energy required to take the slag to the bottom of the converter is proportional to the difference in density of the two phases. Consequently, the model predicts relatively small amounts of slag will be tapped with the metal.

TASK 2 - CONTINUOUS REFINING

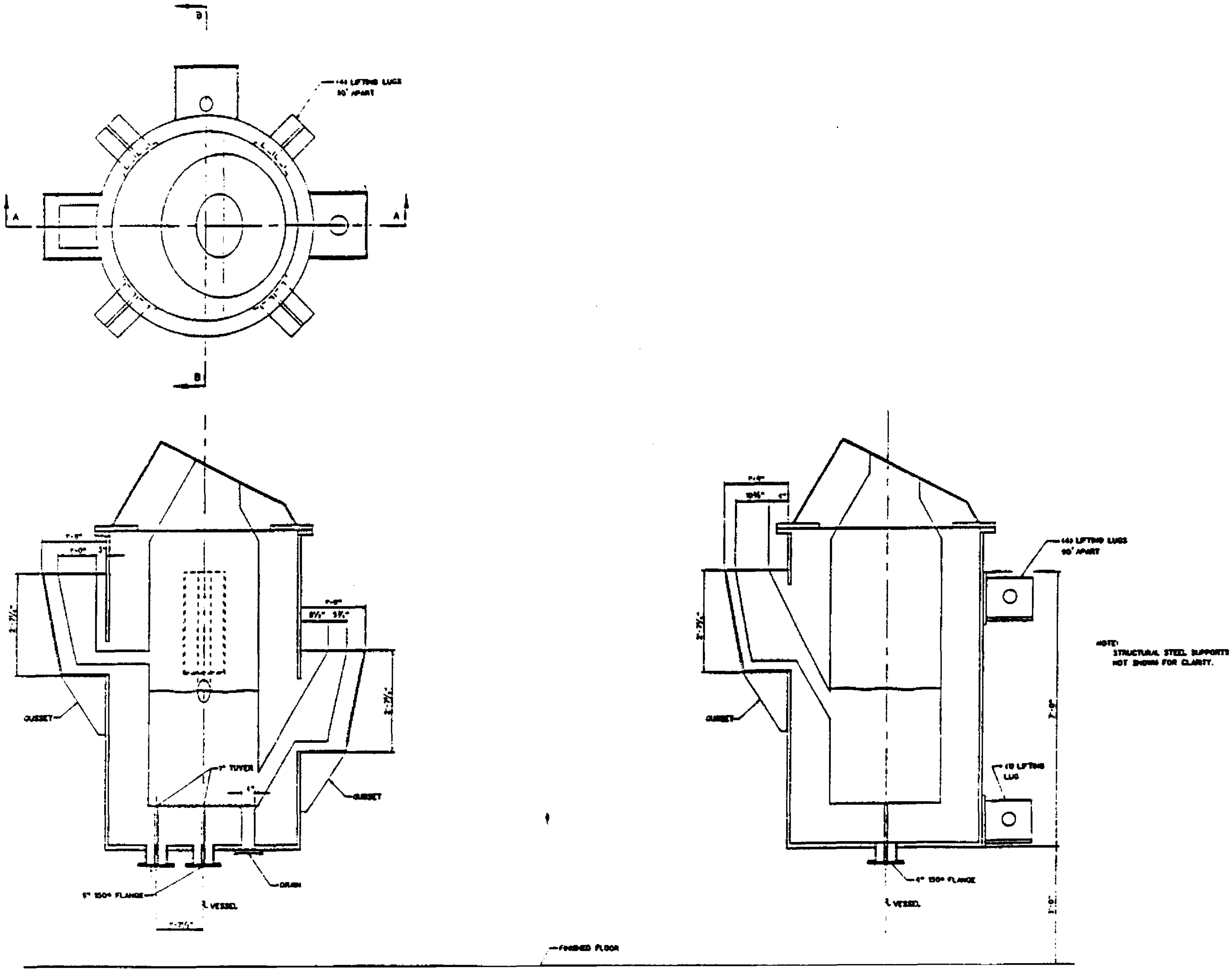
The direct steelmaking process includes continuous refining of the hot metal from the smelter to steel. Such continuous refining, besides offering the natural advantage of coupling continuous processes, namely continuous smelting to continuous refining, also offers the advantage of providing a continuous supply of CO from which the energy can be recovered to improve the overall efficiency of the process. Although, in principle, the energy from the CO produced in the BOF batch refining process could be recovered, in practice it is not because the cost of adapting to an intermittent and varying concentration of CO cannot be justified.

The direct steelmaking program has the major refining experimentation as Task 3.6 after several smelter trials have been completed and the range of carbon and sulfur levels in the hot metal has been established. However, there was opportunity to conduct some preliminary trials at the pilot plant facility prior to the time when it had to be fully committed to smelter construction, provided that the refining vessel and its operating system could be designed, constructed, and installed promptly. Operation of the pilot-scale refining vessel would also provide valuable training for the operating crew and might identify operating problems and safety concerns that should be addressed for subsequent operations.

Results from early experiments with the refining models in Task 1.6 were embodied in the design of the refining vessel. Construction and operating permits for the refiner were secured by July, 1989; and construction and installation took place into October. Figure 18 provides three cross-sections of the vessel.

The first trial took place October 27, 1989, and three more trials were conducted in the period through December 8, which was the latest date for which operation could be permitted without interfering with the pilot smelter construction schedule. The first two runs were primarily "shake-down" runs to establish operating conditions, sampling procedures, and data acquisition procedures. Operation was hampered by sculling problems, baghouse temperature problems, bath-temperature

FIGURE 18



(4) LIFTING LUGS
90° APART
A
A
B
B
GUSSET
1" TUYER
GUSSET
DRAIN
VESSEL
(4) LIFTING LUGS
90° APART
NOTE:
STRUCTURAL STEEL SUPPORTS
NOT SHOWN FOR CLARITY.
GUSSET
(1) LIFTING
LUG
4" 150# FLANGE
VESSEL
FINISHED FLOOR

measurement problems, and sample probe operation. The third and fourth trials ran more smoothly and continuously and yielded relatively good samples and temperature measurements; and, in the fourth trial, copper was added to give information on mixing rates. The data for the third and fourth runs are currently being analyzed.

A report is scheduled for February 1, 1990.

## TASK 3 - PILOT SCALE SMELTER

### PERMITTING

A preliminary engineering study for the pilot plant was completed by Hatch Associates in October, 1988, and was used as the basis for the preliminary cost estimates and for establishing an engineering and construction schedule to identify critical path items. The study was also used as the basis for a review of environmental concerns, for the preparation of a Preliminary Environmental Analysis, Task 3.1.2, filed April 4, 1989, and to secure a construction permit from the Allegheny County Health Department, Bureau of Air Pollution Control, received May 31, 1989, Task 3.1.1.

### PILOT SMELTER - VERTICAL VESSEL

The smelter and its auxiliary equipment are shown schematically in Figure 19. Hatch has virtually completed all engineering, contracts for the major equipment items have been let, and the last of the installation contracts should be issued by mid-January.

As of December 11, 1989, hot metal melting and refining has ceased. All efforts at the pilot plant facility are now directed at construction of the vertical-vessel, inbath smelter. No impediments to its construction are foreseen.

AISI and Hatch Associates are monitoring all contractors closely and seeking ways to assure that the March 15, 1990, milestone for completion of construction of the pilot plant will be met.

### HORIZONTAL VESSEL

The layout of the pilot plant facility has been designed to accommodate a horizontal vessel, i.e. a vessel with a larger horizontal surface area to volume ratio than the vertical vessel. Such a vessel is currently being designed, and costs and schedules for its construction will be developed.

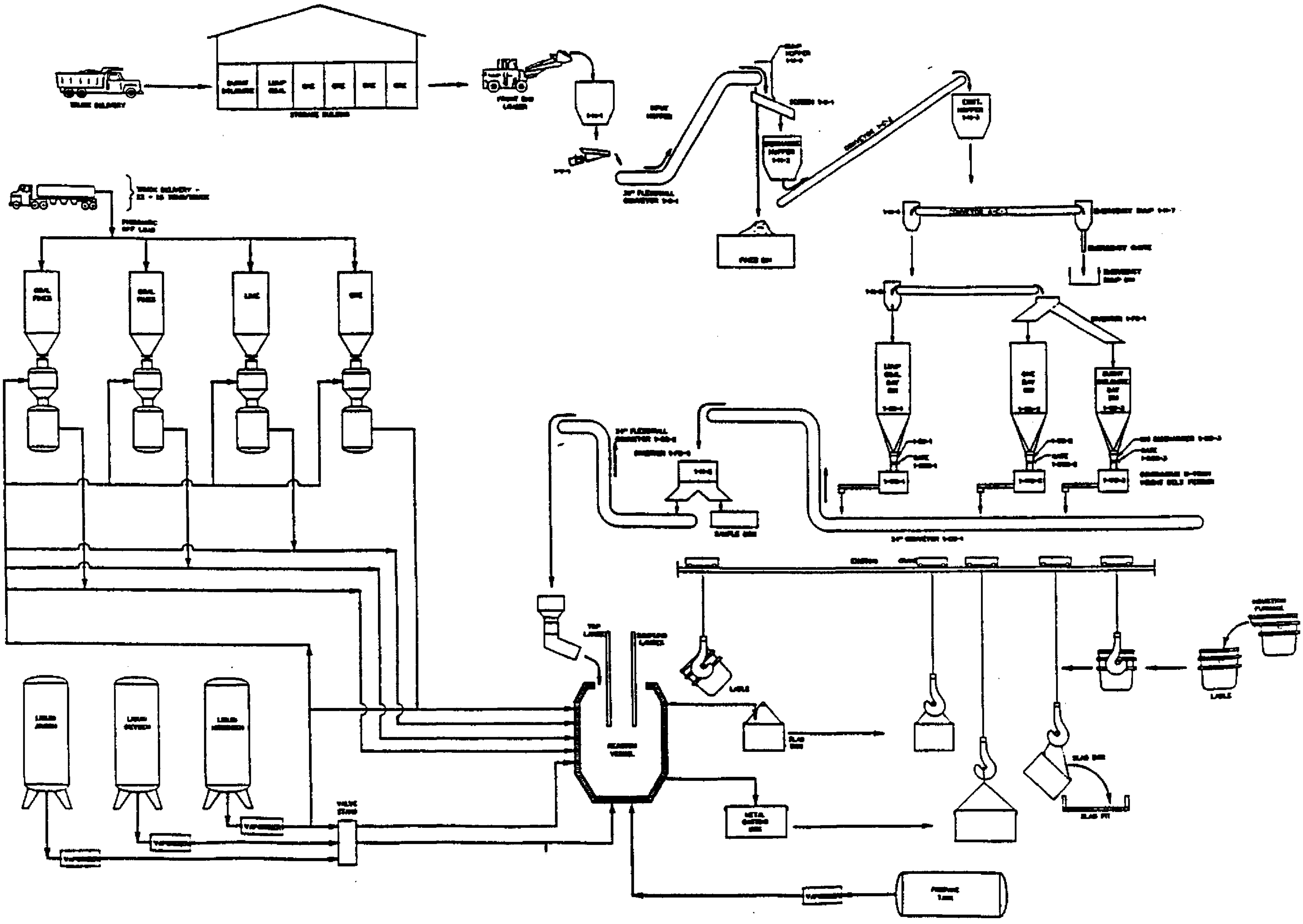


FIGURE 19

PROCESS MODEL AND CONTROL SYSTEM

A process model, Task 3.3, has been developed. This required, first of all, specification of the primary process measurements (inputs) and the frequency of their measurement and an understanding of how the hardware and software system worked to provide a foundation for the calculations. A preliminary functional specification was written in April, 1989, which included a preliminary list of measured variables.

Hatch Associates then developed a more detailed functional specification to evaluate the various systems.

The control system was specified as a two-level system. The first level will consist of five process level controllers (PLCs): PLC1 for gas cleaning, PLC2 for bulk material handling, PLC3 for material injection, PLC4 for gas systems, and PLC5 for supervisory and safety functions. These controllers will be connected to a Level II control system by a data highway.

The Level II computer is a mid-range computer with 16 megabytes core memory and over three gigabytes data storage capability. An intermediate input/output (I/O) processor will be used to manage the data transfer to and from the data highway. Full operator, engineer, and system interfaces will be provided by a system of consoles and personal computers.

Data from the process measurements go into a realtime database and are accumulated in an historical database. An additional software package will give extended archiving and historical review capabilities. Data can be offloaded for analysis at a remote location, if desired. The system also allows easy transfer of historical data into a spreadsheet.

Implementation of the system is being performed by Hatch Associates, who are also handling all the Level I PLC's and instrumentation.

The process model was written in Fortran by AISI staff and consists of mass and heat balance calculations, using process data as the input variables. The model will be run on a one-minute basis and will calculate the production rate, chemical composition, and temperatures of hot metal and slag produced. Additional process parameters, such as post-combustion ratio and heat transfer efficiency, will also be calculated. Accumulated values will be used to calculate the amounts, temperature, and compositions of the hot metal and slag in the vessel throughout the run.

Some data (tapped weights and chemical compositions, for example) are not available on an ongoing basis, so mass and heat balances will also be recalculated based on delayed entry of some variables.

The Level II management system allows several models to be running on the system at the same time. It is expected that improved and more complex models will be added as our knowledge base grows. Modification or addition of process models can be accomplished without interfering with the process control capability of the system.

In addition, an "inverted" version of the model is being written which will function as a charge model. Using current values for operating conditions, the charge model will calculate the setpoints for material and gas feed rates required to achieve a specified change in operation. This will be especially useful for startup and for changing production rates.

The fully integrated system will be completed and checked out by March 15, 1990.

## PREREDUCED IRON OXIDES

The direct steelmaking program calls for prereduced iron oxides to be introduced to the smelter either as pellets or fines. The degree of prereduction will depend on a combination of operating, energy, and economic considerations yet to be determined. In order to provide preheated, prereduced feed material for the smelter, HYLSA of Monterrey, Mexico, leaders in direct reduction technology, will engineer a shaft reducer for the pilot plant facility. In order to provide prereduced starting material for use prior to completion of the shaft reducer, HYLSA will prereduce pellets in one of their direct reduction pilot plants to specifications required for the experimental program. These will be ground to fines when prereduced fines are called for as starting material.

Experimental work and engineering are on schedule. Construction of the shaft reducer at the pilot facility is scheduled for completion in the fourth quarter of 1990.

# TASK 4 - POST COMBUSTION AND HEAT TRANSFER

## WORKSHOP

A workshop (Task 4.2) was held on February 20, 1989, at the Pittsburgh Airport to present to invited technical experts a description of the direct steelmaking smelting program and to identify areas of concern with respect to post combustion, heat transfer, and fluid flow for which additional research might be required. Forty-one experts were invited from academe, government laboratories, and industrial research laboratories, of whom 37 attended along with 12 members of the AISI-DOE technical staff.

The meeting provided an excellent forum for presentation and discussion of both the basic and the applied research that could contribute to the success of the inbath smelting program, considerable give-and-take took place, and participants indicated an intent to consider the problems in more detail and to prepare research proposals as appropriate. Participants were asked to submit short proposals, along with preliminary budgets and schedules, for information and screening purposes. Interdisciplinary proposals were encouraged. Participants were told that a few of the short proposals would be selected for further consideration and proposers would be asked to expand and focus those proposals.

## POST-COMBUSTION AND HEAT-TRANSFER PROPOSALS

Of 17 proposals received, five were selected for expansion. Criteria and guidelines were established and sent to each of the five round-two proposal groups along with suggestions specific to each group for changing the emphasis and improving the focus of the proposal, as appropriate. From these five, two were selected for implementation and support. One was the proposal from Union Carbide Industrial Gases (UCIG), Inc., with Drs. Ronald J. Selines, H. Kobayashi, and S. K. Sharma as key project personnel. The other was a joint proposal from McMaster and McGill Universities with Professors Gordon A. Irons, W.-K. Lu, and Roderick I. L. Guthrie as principal investigators. These programs will be retroactively funded to October 1, 1989, but time is required to build up to the planned effort. Task 4.3 is the task for these two programs.

## UNION CARBIDE

The UCIG program is composed of seven tasks. Task 1 is a detailed analysis of the post-combustion and heat-transfer conditions of the smelter. Task 2 is a test program to study the reaction of high-velocity oxygen jets in a hot CO atmosphere. Task 3 is the physical modeling of heat transfer from the post-combustion zone to slag and metal droplets under highly-stirred conditions and the use of a fluidized bed to simulate the conditions in the head space of the smelter containing emulsified slag, metal/slag splash, coal, and ore particles. Task 4 will apply existing data collected from small and large Argon Oxygen Decarbonization (AOD) vessels to validating the model work of Task 3 and the mass and thermal balances of Tasks 1 and 2. Task 5 is for the generation of new data from small and large AOD vessels under modified operating conditions that would help understand the post-combustion and heat-transfer processes in the smelting operation. Task 6 will develop and apply diagnostic equipment for converters to enhance data quality, and Task 7 will be to apply the analytical and experimental results of Tasks 1 - 6 to smelter design and operation.

With respect to UCIG Task 1, pertinent literature has been reviewed. An evaluation of information in key references and an overall assessment of post combustion and heat transfer technology and practices in current direct steelmaking programs will be prepared in December.

With respect to UCIG Task 2, a safety analysis for operating the test furnace with oxygen jets in a CO containing atmosphere was completed, and the required modifications to the furnace and safety interlock systems were defined.

With respect to UCIG Task 3, and in response to AISI requests to model foamed slags, preliminary foam visualization tests were conducted by injecting diffuse gas jets into a tank containing soap or POLYOX Water Soluble Polymer solutions with offgas velocities of 0.8 and 5.5 ft/sec. The foaming behavior of POLYOX solutions was judged to be a reasonable representation of the foamed slag region of the smelter and to offer an approach to modeling the effects of post-combustion jets, solid particle phases, and gas evolution patterns on fluid flow and mixing behavior. Further work is in progress to make sure that this system remains well behaved at higher gas velocities and to identify techniques for obtaining quantitative data.

Work on the remaining tasks was not scheduled and has not yet been initiated. UCIG expects to meet the established schedule.

MCGILL/MCMASTER

The McGill/McMaster program is composed of four tasks. Task 1 will extend a steel recirculation model and a post-combustion model to the normal operation of the Dofasco K-OBM vessel to help understand the data to be generated in the Dofasco full-scale trials (Task 4.6). Their Task 2 will be to expand the model further and to develop physical models that will include foaming slag conditions, droplet formation, and recirculation in slag and metal. Task 3 will generalize and link the models from the previous tasks to model the entire smelting reactor. Task 4 will apply pilot plant data to validation of the mathematical model. The model then could be used to simulate process improvements and scale up.

Work at McGill has been on computational modeling of submerged gas-driven flows (part of McGill Task 1) for use with the K-BOP vessel at Dofasco. The model exceeds departmental computer facilities so arrangements are being made with Supernet to use the CRAY XMP at the Dorval weather station. Computer accounts and computer communications links have been established for the investigation between McGill and McMaster Universities.

McMaster personnel have been working on the development of post combustion in the gas phase model. Both McGill and McMaster personnel will meet the schedules they have established.

DOFASCO FULL-SCALE TRIALS

The diagnostic equipment, Task 4.5, for the gas sampling, temperature monitoring, and data acquisition for the large-scale trials of Task 4.6 at Dofasco have been installed. System checkout and equipment calibration are nearly complete. All are expected to be complete and online in time for the collection of base-line data in December.

Task 4.6 has been delayed because Dofasco's last campaign has exceeded expectations and scheduled downturns were postponed. After the collection of base-line data in December, decisions will be made as to the initiation and extent of the post-combustion and heat-transfer trials under various modified slag and oxygen-blow conditions.

## TASK 5 - FINE ORE PROCESSING

The AISI project initially included a fine ore program focused on the development of a prereduction process. Discussions with a major equipment manufacturer for the joint development of a continuous fluidized bed prereducer revealed that a major problem was the interface between the smelter and the fluidized bed prereducer. The scoping study was initiated to resolve the issues on the use of fine ores in the direct steelmaking program. The major emphasis was placed on the use of fine ores in the smelter.

The study covers the use of fine ores for direct steelmaking with regard to:

1. feeding and handling systems

2. smelting reduction reactor performance

3. overall process design including the prereduction unit.

Recommendations were made for the injection of fines into the smelter, the installation of a fines feeding system for both melt and freeboard injection, and an experimental program to resolve the problem of the smelter/prereducer interface.

A report, "The Smelting Reduction of Iron Oxide Fines", prepared by D. R. Mac Rae of the Bethlehem Steel Corporation has been issued.

TASK 6 - TECHNOECONOMIC ANALYSIS

There is not yet sufficient information to perform a new technoeconomic analysis. The analyses presented in the proposal are still as valid as they were then.

TASK 7 - PROJECT MANAGEMENT

An updated management plan has been prepared that contains the current statement of work, including the new post-combustion and heat-transfer research programs, and the corresponding schedule, milestone log, and budget.

The patent and intellectual property plan and the critical review of patents and open literature are in the final stages of review and should be issued early in 1990.

SPONSORS

The Department of Energy, Office of Industrial Programs, is funding about 77% of the project with contract management provided by the Idaho Operations Office.

The American Iron and Steel Institute is providing the remaining 23 percent. Its member companies that have participant status are:

| AISI Member Company | Headquarter Location |
|---|---|
| Acme Steel Company | Riverdale, Illinois |
| Armco, Inc. | Parsippany, New Jersey |
| Atlantic Steel Company | Atlanta, Georgia |
| Avesta Stainless, Inc. | Fairfield, New Jersey |
| Berg Steel Pipe Corporation | Panama City, Florida |
| Bethlehem Steel Corporation | Bethlehem, Pennsylvania |
| California Steel Industries, Inc. | Fontana, California |
| Citisteel USA, Inc. | Claymont, Delaware |
| Cleveland-Cliffs Inc | Cleveland, Ohio |
| Copperweld Corporation | Warren, Ohio |
| A. Finkl and Sons Company | Chicago, Illinois |
| Geneva Steel Company | Provo, Utah |
| Georgetown Industries, Inc. | Charlotte, North Carolina |
| Gulf States Steel, Inc. | Gadsden, Alabama |
| M. A. Hanna Company | Cleveland, Ohio |
| Harsco Corporation | Camp Hill, Pennsylvania |
| Hi Specialty America | Irwin, Pennsylvania |
| Inland Steel Industries, Inc. | Chicago, Illinois |
| Earle M. Jorgensen Company | Los Angeles, California |
| Laclede Steel Company | St. Louis, Missouri |
| Lone Star Steel Group, Lone Star Technologies, Inc. | Dallas, Texas |
| LTV Steel, Inc. | Cleveland, Ohio |
| Lukens Inc. | Coatesville, Pennsylvania |

| AISI Member Company | Headquarter Location |
|---|---|
| McLouth Steel Products Corporation | Trenton, Michigan |
| National Steel Corporation | Pittsburgh, Pennsylvania |
| North Star Steel Company | Minneapolis, Minnesota |
| Ocean State Steel, Inc. | East Providence, Rhode Island |
| Oglebay Norton Company | Cleveland, Ohio |
| Raritan River Steel Company | Perth Amboy, New Jersey |
| Rouge Steel Company | Dearborn, Michigan |
| Sandvik, Inc. | Scranton, Pennsylvania |
| Sharon Tube Company | Sharon, Pennsylvania |
| Stony Creek Steel, Inc. | Hollsopple, Pennsylvania |
| The Timken Company | Canton, Ohio |
| USS, Division of USX Corporation | Pittsburgh, Pennsylvania |
| Valley-Vulcan Mold Company | Latrobe, Pennsylvania |
| Warren Consolidated Industries, Inc. | Warren, Ohio |
| Weirton Steel Corporation | Weirton, West Virginia |
| Wheatland Tube Company | Collingswood, New Jersey |
| Wheeling-Pittsburgh Steel Corporation | Pittsburgh, Pennsylvania |

**SUBCONTRACTORS**

The major subcontractors, their headquarter locations, and their responsibilities follow:

| Subcontractor | Location | Area(s) of Involvement |
|---|---|---|
| Armco, Inc. | Middletown, OH | Technical manpower |
| Baumco, Inc. | Pittsburgh, PA | Suppressed combustion and offgas handling system |
| Bethlehem Steel Corporation | Bethlehem, PA | Technical manpower |
| Bryan Mechanical | Pittsburgh, PA | Mechanical and piping - pilot plant |
| F. J. Busse Co. | Pittsburgh, PA | Civil/structural work - pilot plant |
| Carnegie-Mellon University | Pittsburgh, PA | Smelting research |
| Contract Employment Services, Inc. | Bridgeville, PA | Pilot plant manpower |
| Dofasco, Inc. | Hamilton, Ont. | Full-scale BOF test program |
| Hatch Associates Consultants, Inc. | Buffalo, NY | Pilot plant engineering and management of plant construction |

| Subcontractor | Location | Area(s) of Involvement |
| --- | --- | --- |
| Hylsa, S.A. de C.V. | Monterrey, Mex. | Technical development on prereduction or iron ore; supply of wustite pellets to pilot plant |
| IBM Corporation | Pittsburgh, PA | Provide computer hardware, software, and systems support |
| Inland Steel Co. | E. Chicago, IN | Technical manpower |
| Liquid Air Corp. | King of Prussia, PA | Supply of industrial gases to pilot plant |
| LTV Steel Company | Independence, OH | Technical manpower |
| Macawber Engineering, Inc. | Maryville, TN | Pneumatic injection system - pilot plant |
| McGill University | Montreal, Que. | Heat transfer and combustion research |
| McMaster University | Hamilton, Ont. | Heat transfer and combustion research |
| MIT | Cambridge, MA | Smelting research |
| North American Refractories Co. | Cleveland, OH | Refractory supply and services |
| Pa. Engineering Corporation | New Castle, PA | Engineering and construction of the smelter for the pilot plant |
| Tico Electric, Inc. | McKeesport, PA | Electrical installation - pilot plant |
| Timken Research | Canton, OH | Technical manpower |
| UEC, Subsidiary of USX | Pittsburgh, PA | Administrative services |
| Union Carbide | Tarrytown, NY | Heat transfer and combustion research |
| USS Division of USX | Pittsburgh, PA | Technical manpower and modeling |
| USX Corporation | Pittsburgh, PA | Lease of pilot plant facility |