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COAL-OIL MIXTURE COMBUSTION PROGRAM INJECTION INTO A
BLAST FURNACE

By
S. G. Jansto
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Interlake, Inc.
Oak Brook, Illinois

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INJECTION INTO A BLAST FURNACE

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ABSTRACT

A chemically stabilized coal-oil mixture (COM) was made and used as an auxiliary fuel in a blast furnace for 44 days. Approximately 485,000 gallons of COM were produced at an on-site COM plant. Composition was 47.9% coal, 47.6% No. 6 oil, 4.0% water, and 0.5% emulsifier. Average injection rates were 3.8 to 13.0 gpm during different periods of the trial. Coal handling equipment, mixing and processing equipment, pumps, piping, fuel lances, and instrumentation are discussed. The blast furnace performance during the trial is compared to a Base Period of injecting No. 6 oil. Blast furnace performance was satisfactory, with one pound of COM replacing one pound of coke or 0.8 pound of No. 6 oil. The production of COM and its usage in a blast furnace is economical and feasible.

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EXECUTIVE SUMMARY

Due to the impending need for oil conservation, Interlake initiated, in 1973, development of a process for producing and utilizing a stable coal-oil mixture. Preliminary laboratory work resulted in a process to produce a coal-oil mixture (COM) in a single comminuting and mixing operation. Grinding the coal in the oil eliminated the environmental problems inherent in previous COM processes. In addition, the use of a small amount of water and emulsifier stabilized the COM and greatly retarded settling of the coal particles. Bench scale tests resulted in an optimum COM composition of 50% coal, 45% No. 6 fuel oil, 4.5% water, and 0.5% emulsifier. This COM was reasonably low in both water and emulsifier content, was stable for periods of six weeks or longer at a temperature of 150°F, and was readily pumpable.

Fifty gallons of COM were made in the laboratory and injected into one tuyere of Interlake's Chicago 'B' Blast Furnace at a rate of 2 gallons per minute (gpm). Combustion appeared satisfactory. A second, larger-scale injection trial was made in May, 1975. At that time, approximately 4,000 gallons of COM were made and delivered to the furnace via tank truck. Three thousand gallons of COM were injected through six 3/8-inch lances over two 4-hour periods at an average injection rate of 7 gpm. Combustion was excellent and the trial was viewed as a success.

This early experimental work demonstrated that a stabilized COM could be injected into a blast furnace without coking in the lances. Yet, many questions remained unanswered concerning the production of COM at an on-site furnace location, the stability of COM, the replacement ratio of COM for No. 6 fuel oil and the overall economics of COM. These questions could be answered only through continuous injection for extended periods.

In 1976, Interlake submitted a proposal to the Energy Research and Development Administration, now the Department of Energy (DOE), for construction and operation of a demonstration plant to produce COM and inject it into 'B' Blast Furnace for an extended period of time. The goals of the program were threefold:

- 1) Demonstrate that a stable coal-oil mixture could be produced on a commercial scale.
- 2) Verify that COM is stable over an extended period of time.
- 3) Confirm the expected economic benefits of the COM as compared to the fuel oil or coke it replaces in the blast furnace.

In 1977, DOE and Interlake's Board of Directors approved the plan, and design engineering for the facility got under way. Construction of the COM plant was started in December, 1978.

A 44-day trial was conducted in which COM comprised of 47.9% coal, 47.6% No. 6 fuel oil, 4.0% water, and 0.5% emulsifier was injected into 'B' Furnace. Approximately 485,000 gallons of COM were produced on site and used during this trial. The COM was pumped a distance of 650 feet to the furnace and injected at daily average flow rates of 3.8 to 13.0 gallons per minute for various periods of time. The trial generated useful operating data not only on the behavior of the blast furnace, but also on the operation of the COM plant. By the last week of the program, it was possible to produce 20,000 gallons of COM in two 8-hour shifts (based on a 30-minute batch time). Decreasing the batch time to 15 minutes, which would be feasible if crushed coal were utilized, would increase the production capacity of the COM to approximately 55,000 gallons per day.

The COM plant consists of coal handling, oil delivery, and emulsifier-water mixture systems, a COM production and storage system, and a COM injection circuit for the blast furnace. Three methods of filling the coal hopper were tried -- a crane with a reclaiming bucket, a pneumatic truck, and an inclined belt conveyor. The inclined belt conveyor was the preferred equipment for filling the coal hopper; it produced less dust than either the pneumatic method or the crane-operated reclaiming bucket.

Two dispersers, each of 800 gallons working capacity, operated well throughout the trial, and significant improvement were made in disperser blade life. Earlier experimental work utilizing hardfaced grade 1020 steel blades resulted in severe wear after only 10 batches. However, the use of tungsten carbide inserts allowed as many as 317 batches to be made with no visible wear.

The Gorator grinding pump, which grinds any +1/8 inch coal particles escaping the disperser, was the most critical piece of equipment prone to wear. On two occasions, plugging of the duplex steam pump, which delivers the COM to the furnace, was attributed to the worn Gorator pump. A finer sized coal feed to the disperser might increase Gorator service life. It was also concluded that at least two Gorator pumps should be placed in the COM system.

Initially, the injection of COM at the furnace was accompanied by many lance and hose plugging problems. However, by the end of the trial, considerable progress had been made, and reliable, uniform COM injection had been achieved. Following a determination that the existing circle pipe system (designed for No. 6 oil) was unsuitable for COM, several modifications were made. Lances were fabricated in 3/8-inch Schedule 40 pipe, most of the 90° elbows preceding the lances were eliminated, and steam-purged return lines were installed between the circle pipe and the main return line to the COM plant. These changes improved the consistency of injection rates.

The metallurgical objectives of the COM trial were to determine the effect of COM injection on blast furnace operation, and to determine the value of COM as a source of energy to replace coke or fuel oil in the blast furnace. Metallurgical operating data for a 28-day Base Period, using No. 6 oil, was compared with the data for the 44-day COM Test Period. During the Test Period, COM average injection rates varied from 3.8 to 13.0 gallons per minute. Various subperiods were extracted from the Test Period for metallurgical analysis and comparison with the Base Period. The effect of COM on blast furnace operation was determined by analyzing furnace productivity, actual versus theoretical coke rate (through the application of the Flint Carbon Rate Formula), coke quality, fuel oil and COM characteristics, furnace burden, and miscellaneous operating parameters.

The 28-day Base Period was a record tonnage production month for 'B' Furnace -- 1,397 net tons of hot metal (NTHM) per day, corresponding to 5.17 NTHM per day per 100 cubic feet of working volume. This productivity level is relatively high for a blast furnace of this size and age. Therefore, the Test Period data is compared with a very high standard.

As a result of business conditions and hot metal chemistry requirement, some of the subperiods during the 44-day COM trial necessitated somewhat different raw materials than the Base Period.

One 7-day period (IV-C), September 18-24, had a raw materials practice similar to the Base Period. Results were very encouraging. Productivity was only 20 tons below the record of 1,397 NTHM per day, and the actual equivalent coke rate was 1,063 lbs. of coke per net ton of hot metal for Period IV-C versus 1,072 lbs. per NTHM for the Base Period. For the other Test Periods, it was necessary to utilize the Flint Carbon Rate Formula to take into account the effect of different raw materials on the coke rate. The change in furnace practice due to less scrap, more flux, change in humidity, and some other operating factors accounted for an additional 84.5 lbs. of coke per NTHM during the COM trial. The adjusted results show similar total equivalent coke rates using COM as compared with the No. 6 oil Base Period.

Based on the injection of approximately 485,000 gallons of COM during the 44-day Test Period, 182,640 gallons of No. 6 oil were conserved. Such performance converts to an annual savings of 3.9 million gallons of No. 6 oil at a production level of 1.1 million tons of hot metal. The operating and material cost of the COM plant was approximately \$0.73 per gallon of COM as compared to \$0.62 per gallon for No. 6 oil. It is believed that the use of lower quality coal, a less expensive emulsifier, and pursuing the recommended COM plant modifications would easily reduce the COM cost to approximately 15 percent below the present No. 6 fuel oil cost.

The following conclusions can be made regarding COM and its effect on the blast furnace:

A consistent quality of COM product can be produced economically at an on-site COM facility, and can be injected into a blast furnace without major problems.

- COM injection through three tuyeres at 3.8 gpm and through six tuyeres at 13.0 gpm did not hinder productivity.
- Hot metal quality specifications, i.e., chemistry and temperature for Interlake's customers, were satisfactorily achieved.
- One pound of COM successfully replaced approximately one pound of coke or 0.8 pound of No. 6 oil.
- Test Period data as well as theoretical considerations suggest that COM injection should be about 2.0 gpm per tuyere, or 0.37 gallon (3.3 lbs.) of COM per 1,000 standard cubic feet (scf) of dry air.
- COM injection conserved 40.5% of the No. 6 oil that would have been injected into the furnace to replace an equivalent amount of coke.

This 44-day trial showed that COM injection into a blast furnace would make it possible to reduce No. 6 oil consumption by 40.5%, replacing it with coal, a more abundant resource in the United States. Somewhat higher oil replacement ratios should be possible using COM containing higher percentages of coal. It is believed that a coal content as high as about 60% would be practicable.

SECTION I

INTRODUCTION

I.1 History Of Blast Furnace Fuel Injection

Blast furnaces have long been the principal equipment used to extract metallic iron from iron ore. Until 1960, 100% of the fuel for a blast furnace was charged into the top of the furnace, usually in the form of metallurgical coke. In passing down through the blast furnace stack with other raw materials, most of the coke survives, in solid form, until reaching the hearth area where it is burned in streams of high velocity heated air entering the hearth through the tuyeres. About 20 years ago, it was discovered that a certain proportion of the fuel requirements of a blast furnace could be provided by injecting gaseous or liquid fuels at the tuyeres. The advantages of injecting fuel are the added flexibility of an alternate supplementary fuel, the reduction in requirements for expensive and sometimes inadequate coke supplies, and the ability to operate the blast furnace at higher production rates.

Originally, natural gas was widely used as an injectant. However, as the availability of cheap, reliable gas supply decreased, fuel oil came into more prominent usage. Coke oven gas and coal tar have been used as auxiliary fuels, but their use has been limited for technical reasons and because of other needs or markets for these by-products. Pulverized coal injection systems have been developed and used successfully, but such systems are very expensive to construct and have not been widely accepted. For these reasons, fuel oil has become the most widely used injectant.

In the early 1960's, one of the major oil companies did considerable development work on a coal-oil mixture injection process. Several installations were made at blast furnace plants, but certain problems, such as the settling out of the coal, could not be solved, and no such systems remain in operation in this country.

I.2

Preliminary Investigation Of Stabilized Coal-Oil Mixture

Because of the impending need for oil conservation, Interlake initiated, in 1973, development of a process for producing and utilizing coal-oil mixture which would not have the limitations of earlier processes. The objective was to reduce oil consumption by replacing approximately one-half of the fuel oil injected into the blast furnaces with more plentiful and less costly coal.

A process was developed in which a coal-oil mixture (COM) is produced in a single comminuting and mixing operation, performed in a high-speed disperser. Grinding the coal in oil has the advantage of eliminating environmental problems inherent in previous methods. In addition, the use of a small amount of water and emulsifier was found to stabilize the COM and greatly retard settling of the coal particles.

I.2.1

Bench Scale COM Tests

Bench-scale batches of COM were produced using a conventional 2-speed household blender. No. 6 fuel oil was heated to 200°F in the bowl of the blender, then an emulsifier-water mixture was added while mixing. After one minute, minus 2-inch coal was added, and mixing and comminution of the coal proceeded for an additional 10 minutes. Either blender speed was capable of producing stable COM. Final batch temperature was about 160°F.

These preliminary laboratory tests established both the method for producing stabilized COM and the best coal-oil mixture compositions for subsequent study. Economic considerations dictated maximizing the amount of coal and minimizing the amount of emulsifier used in preparing COM. However, very high coal concentrations increased the viscosity of the COM, which would make pumping more difficult even at elevated temperatures. Too little water reduced COM stability, but too much would be detrimental to the blast furnace.

Examples of the coal-oil mixtures prepared in these early tests are listed in Table 1.

TABLE 1. EXPERIMENTAL COAL-OIL MIXTURES

	Percent By Weight			
	<u>Coal</u>	<u>No. 6 Oil</u>	<u>Added Water</u>	<u>Emulsifier</u>
COM A	30	65	4.5	0.5
COM B	45	45	9.5	0.5
COM C	50	45	4.5	0.5
COM D	65	30	4.0	1.0
COM E	70	20	8.5	1.5
COM F	50	40	9.0	1.0
COM G	50	45	4.8	0.2
COM H	50	50	0	0

It appeared from these tests that the optimum composition of COM was 50% coal, 45% No. 6 fuel oil, 4.5% water and 0.5% emulsifier. This COM was reasonable low in both water and emulsifier concentrations, was stable for periods of six weeks or longer at a temperature of 150°F, and appeared to be easily pumpable.

I.2.2 Pilot Scale Trials

Bench scale tests were followed by pilot trials in which the COM was produced in a bottom-drive, high-speed disperser that had a capacity of 20 gallons. Working volume was approximately 15 gallons. The disperser was jacketed to permit temperature control using either hot or cold water. Coal-oil mixtures containing 25% to 65% coal were produced in this unit at temperatures between 140° and 180°F.

The screen analysis of the coal from one of the pilot trials is shown in Table 2.

TABLE 2. TYPICAL COAL PARTICLE SIZE DISTRIBUTION IN COM

<u>Screen Size</u>	<u>% Larger Than Identified Screen</u>
12 mesh	3.3%
25 mesh	31.5%
35 mesh	45.5%
70 mesh	80.0%
100 mesh	89.9%
200 mesh	99.9%

The mixture consisting of 50% coal, 45% No. 6 fuel oil, 4.5% added water and 0.5% emulsifier again appeared best, considering all factors. Pumping tests in the laboratory using a rotary pump verified the stability of this COM during handling and simulated injection through 3/8-inch lances. A test followed in which 50 gallons of this COM were injected into one tuyere of Interlake's Chicago 'B' Furnace at a rate of 2 gpm using the rotary pump and a 3/8-inch lance. The pump overheated and had to be cooled with water; otherwise the test went very well. Combustion, as viewed through the peep sight, looked very good.

A second, larger-scale injection trial was made in May, 1975. Approximately 4,000 gallons of COM were produced in a 300-gallon -capacity, bottom-drive, high-speed disperser owned by a paint manufacturer in East Chicago, Indiana. This material was brought to Interlake's Chicago Plant in a heated tank truck which also served as the storage tank for the COM during the test. This COM consisted of 50% Illinois No. 6 coal, 45% No. 6 fuel oil, 4.5% added water and 0.5% emulsifier.

A screen test showed the coal in this COM to be somewhat coarser than the size distribution achieved in earlier tests; 50.6% of the coal was larger than 18 mesh. This was attributed at least in part to the relatively low processing temperature in the disperser. The disperser was not equipped with a heat jacket, and oil temperature ranged from a high of 110°F at the start of COM

production to a low of 90°F at the end. The low temperature and high viscosity of the mixture in the disperser impeded the rapid and complete grinding of the coal. COM temperature was raised to 180°F in the tank truck after it was brought to the Chicago Plant. The truck was equipped with a hairpin heating coil and was heated with steam.

A screw pump was used to inject the COM into the blast furnace. Approximately 3,000 gallons of COM were injected through six 3/8-inch lances over two 4-hour periods spanning two consecutive days. Injection temperature was 170° to 180°F; injection pressure was 40 to 42 psi. The injection rate averaged 7 gpm. The COM appeared to burn well, as viewed through the peep sights. No soot was observed in the top gas scrubber water. Overall, the trial was viewed as a success.

I.3 Need For A Demonstration Plant

The injection of a tank-truck load of COM into Interlake's Chicago 'B' Furnace was the practical limit of test work that could be done without an on-site COM preparation facility. This early work demonstrated that a stabilized COM, suitable for blast furnace use, could be produced and injected into a blast furnace without coking in the lances. Visual inspection through the peep sights indicated good combustion, and the economics of COM appeared favorable as compared to No. 6 fuel oil. This cost advantage was expected to widen with time in the light of continually rising oil prices during the 1970's. Yet many questions remained unanswered in the area of COM production and furnace performance over extended periods. Typical questions were:

- . How reliable would a COM plant and its components be?
- . What would be the operating and maintenance costs of the COM plant?
- . How stable would the COM have to be to avoid plugging in the piping and lances? Would scale-up to a commercial size production facility provide the necessary stability?

- . What were the limits of COM injection if proper combustion was to be maintained?
- . Would the blast furnace accept the COM over extended periods without hindering productivity or changing the quality of the product?
- . What is the replacement ratio of COM for No. 6 fuel oil? The ratio can be estimated using the Flint Carbon Rate Formula, but it can be determined accurately only with extensive testing.
- . Considering all production and raw materials costs and fuel replacement ratios, how would COM and No. 6 fuel oil compare in an overall economic evaluation?

The answers to these and other questions could be provided only with continuous testing for extended periods. A test of sufficient duration was impossible with existing equipment.

I.4 Joint Venture With The U.S. Department Of Energy

The test work had enabled Interlake to establish mixing proportions for the COM, determine the types of equipment required for a production facility, and estimate the cost of such a facility. In 1976, Interlake submitted a proposal to the Energy Research and Development Administration, now the Department of Energy, for construction and operation of a demonstration plant to produce COM and inject it into 'B' Blast Furnace for an extended period of time. The goals of the program were three-fold: first, to demonstrate that a stable coal-oil mixture could be produced on a commercial scale; second, to verify that the COM is stable over an extended period of time; third, to confirm the expected economic benefits of the COM as compared to the fuel oil or coke it replaces. In 1977, the Department of Energy and Interlake's Board of Directors approved the plan, and design engineering for the facility got under way.

SECTION II

SITE FOR THE COM DEMONSTRATION PLANT

Interlake's Chicago Plant includes three separate parcels of land totaling about 285 acres. The plant is located on the Calumet River, with ironmaking facilities on the east side of the river and coke-making facilities on the west side. A high level suspension bridge carrying a coke conveyor and gas and steam mains connects the two plant areas.

II.1 Coke Plant

The Coke Plant consists of coal unloading and storage facilities, two batteries of 50 Wilputte underjet ovens each and a by-products plant. A simple block diagram of Coke Plant material and by-products flow is shown in Figure 1.

Coal is delivered to the Coke Plant by rail. It is unloaded by car dumper and delivered by conveyors to the storage area. Here the stocking system is served by three Euclid Twin-Scraper units which handle coal into or out of stock as received or required. The normal coal storage capacity of 150,000 tons can be expanded readily if necessary.

Coal going to the ovens is reclaimed from the storage area and is conveyor-fed to a pulverizer and then to the mixer building bins. Next, it is blended in the desired proportions and conveyed to the oven storage bins. From these bins it is drawn, as required, into the coke-oven larry car or charging car. The larry car, which is designed to hold the amount of coal needed for charging one oven, runs on tracks supported on top of the batteries of ovens. Coal is charged into each oven through three holes which are sealed immediately after the charging operation is completed.

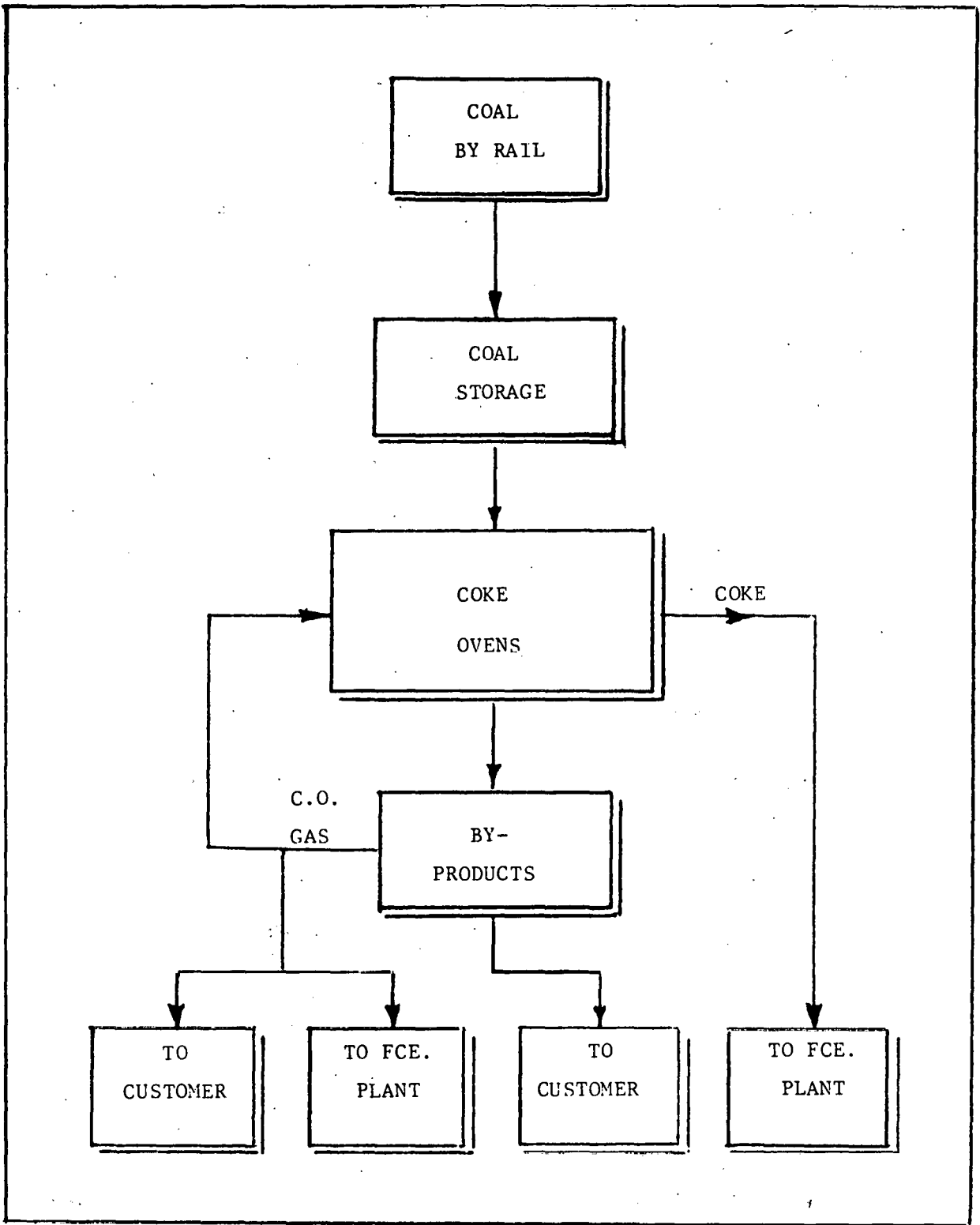


FIGURE 1. CHICAGO COKE-OVEN PLANT - FLOW DIAGRAM

II.1.1 Coke Ovens

The two batteries of ovens, built in 1956-1957, are of relatively modern design. They are usually operated on a continuous 17-hour cycle basis. Each oven is designed to receive a charge of 18.0 tons of coal. In 17 hours, 11.5 tons of coke are produced per oven. This results in a yearly coal consumption of 870,000 tons, and a yearly coke production of 555,000 tons, including 510,000 tons of coke suitable for blast furnace use.

A typical coal mix for coke-making includes three main coals proportioned as follows: 30% low-volatile coal, 35% high-volatile coal, and 35% high-volatile fluid coal. As the coal is heated in the oven, it becomes plastic at 660° to 890°F, forming a fused mass irrespective of its form when charged. Through this range of temperature, volatile matter is given off, rapidly at first, then more slowly up to about 1740°F. These volatile constituents are transported to the by-products plant.

A good metallurgical coke will retain very little volatile matter -- not over 2% -- and will contain 85 to 90% fixed carbon. The remainder is ash, sulfur, and phosphorus. A typical analysis of metallurgical coke (dry basis) is shown in Table 3.

TABLE 3. CHEMISTRY OF METALLURGICAL COKE

Fixed carbon	-	90.0	%
Volatile matter	-	1.3	%
Phosphorus	-	.005	%
Sulfur	-	.75	%
Other ash materials	-	7.945	%

Coke is discharged from the ovens and is quenched at a water-spray type quench tower. It is then conveyed over a series of belt conveyors to a screening station at the southwest corner of the Blast Furnace Plant.

II.1.2 By-Products Operation

The volatile materials evolved during the coking process are a combination of gases and vapors. Gases include hydrogen, methane, ethane, carbon monoxide, carbon dioxide, and unsaturated hydrocarbons such as ethylene, propylene, butylene and acetylene. Other gaseous compounds present are hydrogen sulfide, ammonia, oxygen and nitrogen. The vaporized liquids in the gases exiting from the ovens include a variety of hydrocarbons generally grouped into three categories: ammonia liquor, tar, and light oil. Chemicals volatilized during the coking process are piped to the by-products plant where ammonium sulfate, tar, pitch, and light oil are removed from the coke-oven gas.

II.2 Blast Furnace Plant

In the ironmaking area, east of the Calumet River, there are two blast furnaces, ore unloading and storage facilities, a coke screening station, a sinter plant, a boiler house, two 2-strand pig machines, a pig storage yard, and miscellaneous supporting facilities.

II.2.1 Raw Materials Handling And Storage

In an average year, the Chicago Plant consumes the quantities of raw materials shown in Table 4.

TABLE 4. BLAST FURNACE PLANT RAW MATERIALS

Coke *	670,000 tons
Limestone	110,000 tons
Dolomite	160,000 tons
Iron Ore (55% Fe)	60,000 tons
Pellets (62% Fe)	1,600,000 tons
Scrap	70,000 tons
Miscellaneous Iron-Bearing Materials	50,000 tons

* Includes Purchased Coke

Figure 2 is a block diagram showing the pattern of material and by-product flow in the Blast Furnace Plant. Inasmuch as the quantities of raw materials handled are so large and deliveries to the plant may be seasonal, control of raw material movement is of utmost importance. The raw material storage capacities are limited, and the optimum quantities of some materials are somewhat unpredictable due to changes in iron analysis and in raw material prices and availability.

Ore, sinter, pellet, and flux (limestone and dolomite) storage is provided in three storage yards: the north dock storage, 780 feet long by 210 feet wide; the south dock storage, 650 feet long by 350 feet wide; and the south storage yard, 497 feet long by 390 feet wide. The north and south docks will each accommodate a lake carrier of the longest type. Materials are unloaded from a carrier by means of an ore unloading tower and unloading bridges with lifting aprons.

Two 5-ton bridges serve the north dock, while the south dock is served by one 10-ton bridge and a 20-ton unloading tower. A conveyor system serving the entire length of the south dock will accept material from either unloader along this dock and deliver it to a trough under the bridge serving the south storage yard. The south storage yard is served by a 20-ton bridge.

Two 50-ton transfer cars operate on a continuous highline track which runs the entire length of all storage yards. A second highline track at the Blast Furnace stockhouse is used to supply some coke and miscellaneous materials to the furnaces.

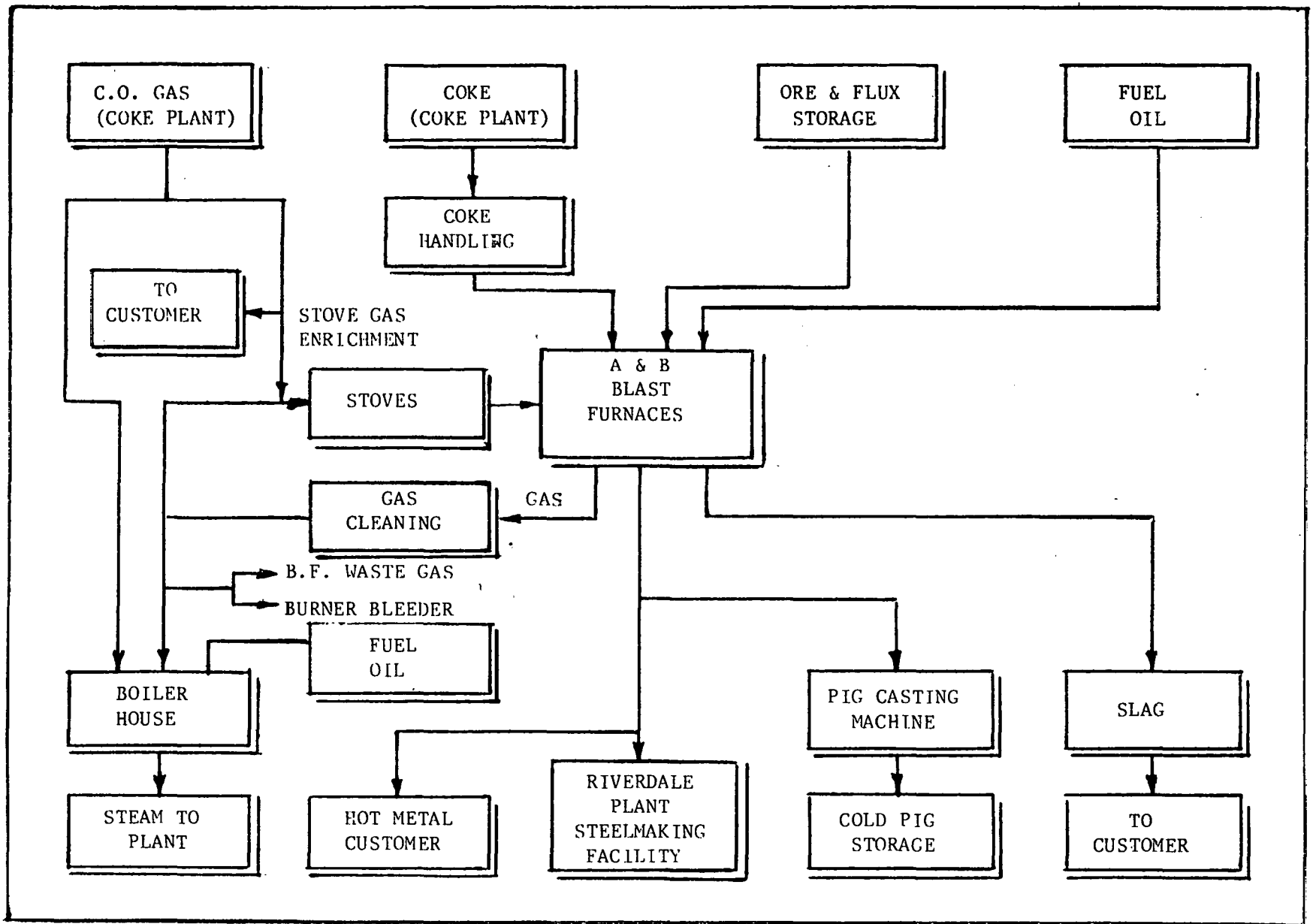


FIGURE 2. CHICAGO BLAST FURNACE PLANT-FLOW DIAGRAM

II.2.2 Blast Furnaces

The two blast furnaces at the Chicago Plant produce the molten iron required by the basic oxygen steelmaking shop at Interlake's Riverdale Plant, and by a customer's ingot mould facility located adjacent to the Blast Furnace Plant. The furnaces also produce some iron which is pigged and sold as merchant grades of pig iron. Total iron production of the two furnaces is 1,100,000 tons per year.

Figure 3 is a diagrammatic cross-section of a typical blast furnace, identifying the principal elements of construction and indicating the flow of gases through the material burden within the furnace. The working dimensions of the Interlake's "B" Furnace are shown on this cross-section.

Essentially the blast furnace process consists of charging iron-bearing materials (ore and pellets), fuel (coke) and flux (limestone and dolomite) into the top of the furnace, and blowing heated air into the bottom of the furnace. The furnace is a huge steel shell lined with carbon and ceramic refractories. Once started, the furnace generally runs continuously until all or part of the lining needs repair, or until demand for the iron decreases.

Iron-bearing materials, coke, and fluxes in alternate layers work their way down from the top of the furnace, becoming hotter as they descend. In the upper portions of the furnace, reducing gases produced from the reaction of the coke and auxiliary fuels injected with the air blast at the tuyeres start to reduce the heated ore and other iron oxide materials. Midway down the furnace stack, fluxes begin to react with impurities in the burden to form slag. Next, the iron becomes a porous mass as the burden moves down the stack, progressively yielding molten metal which drips down through the burden and collects in the hearth of the furnace.

Ash from the coke is absorbed by the slag which drips down to form a pool of molten slag on top of the iron pool. The fluxing constituents can be adjusted to effect the absorption of varying sulfur input.

Coke reaches the region of the tuyeres in a white hot condition and reacts vigorously with the oxygen in the hot air blast to produce the heat and the reducing gases needed for the blast furnace process. Periodically (from 5 to 9 times a day) the furnace is tapped, and iron and slag are withdrawn. Iron is transferred in hot metal torpedo cars to the Riverdale BOF Shop, the ingot mould facility, or to the pig machine located within the Chicago Plant.

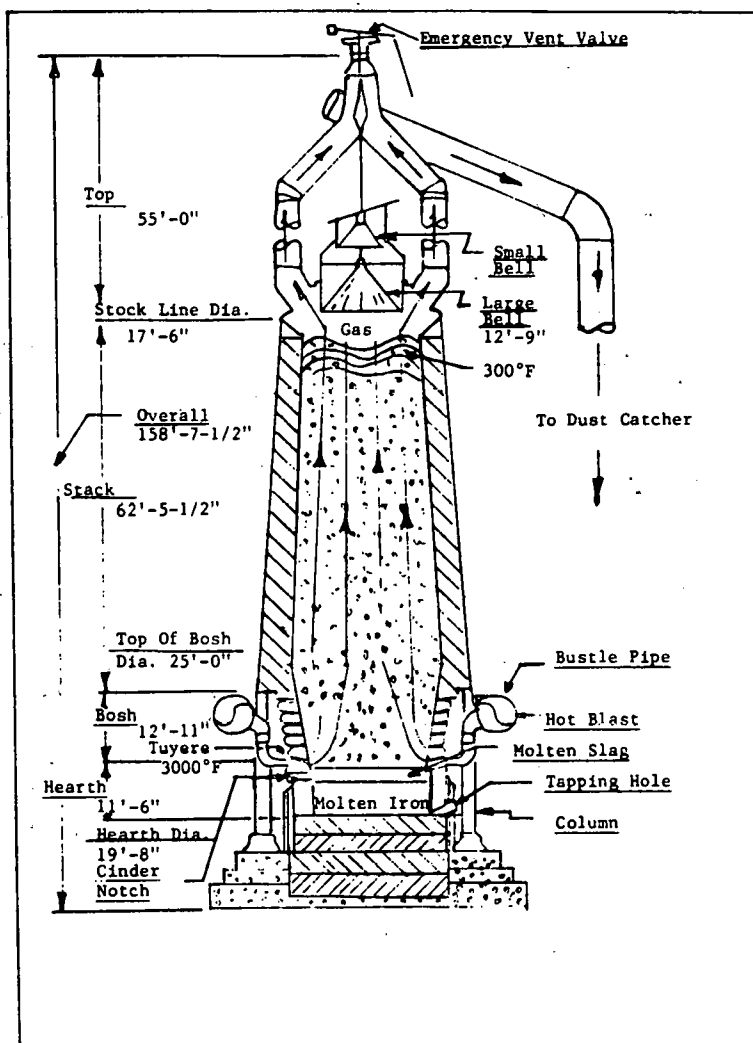


FIGURE 3. BLAST FURNACE 'B' WORKING DIMENSIONS

SECTION III

DESIGN OF THE COM FACILITY

Preliminary design work for the COM demonstration plant began in 1974. Final design and detail engineering commenced following approval of the joint program with the Department of Energy in 1977. Construction started in December 1978.

The plant was sized so that an entire day's COM requirement could be produced in a single shift. The design called for producing COM in a batch process, each batch having a volume of 800 gallons, the largest working volume available at the time with a high-speed disperser. Target overall cycle time was 15 minutes, which included 10 minutes for grinding and mixing after all materials had been charged to the disperser. This production schedule would permit a COM injection rate of up to 17 gallons per minute. The COM would consist of 50% coal, 45% No. 6 fuel oil, 4.5% added water and 0.5% emulsifier. A flow diagram of the COM system is shown in Figure 4. Figure 5 shows an exterior view of the plant.

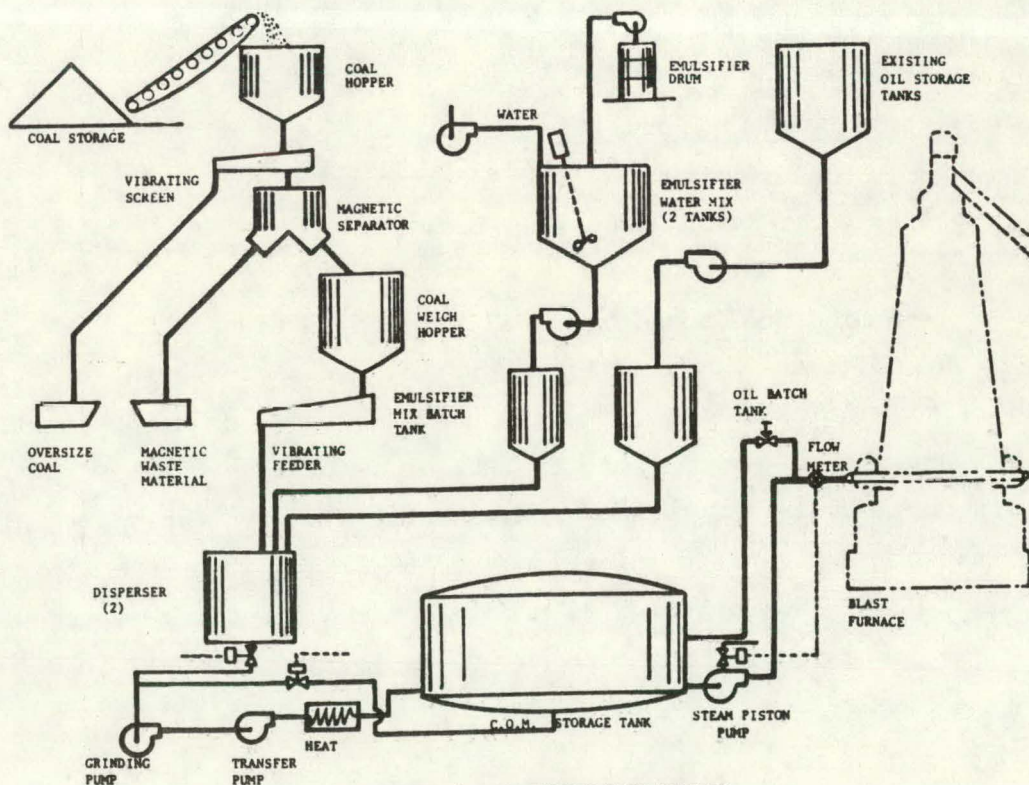


FIGURE 4. COM SYSTEM FLOW DIAGRAM

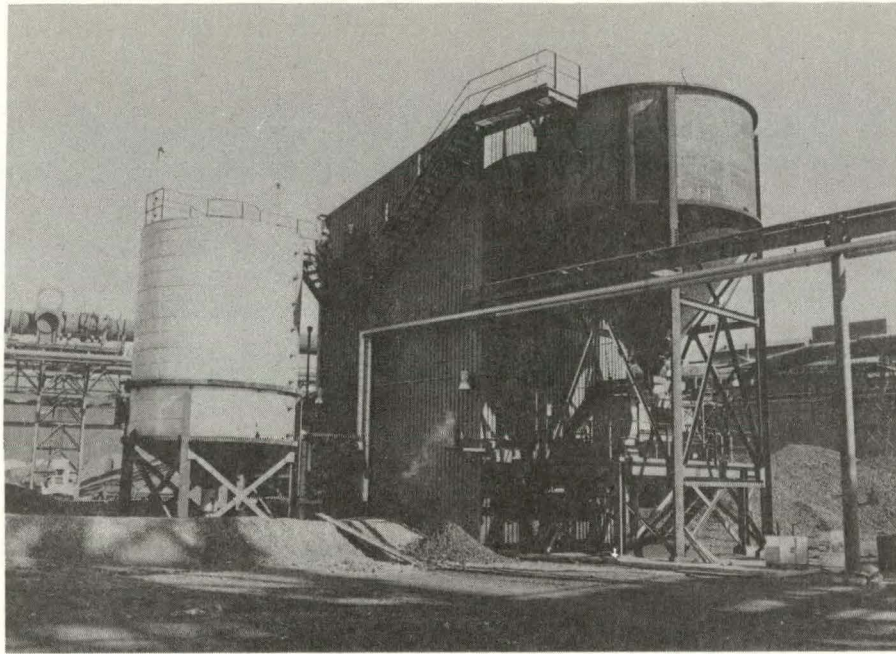


FIGURE 5. EXTERIOR VIEW OF COM PLANT

III.1 Material Handling Facilities

III.1.1 Coal Feed System

Run-of-mine coal with a nominal size of 0-2 inches is charged to the coal storage hopper by means of a crane or conveyor belt. The coal storage hopper has a capacity of 4,850 cu.ft. and a working volume of 4,012 cu.ft. It is capable of storing approximately 100 tons of coal, nearly a 2-day supply for the maximum anticipated injection rate of 17 gpm using COM containing 50% coal. Construction of a complete coal handling system was postponed pending the outcome of feasibility trials.

Situated beneath the coal storage hopper is a vibrating grizzly bar screen for removing oversize coal and large tramp material. The grizzly bar screen has a rated capacity of 30 tons per hour, but its feed rate is fully adjustable. On the highest setting it is capable of feeding the 3,700 lbs. of coal needed per batch of COM in less than 4 minutes. Oversize material discharges to a 20 -- inch conveyor and is deposited off to the side of the COM preparation building.

Coal passing through the grizzly bar screen falls onto a rotating-drum magnetic separator to remove any tramp ferromagnetic material. The magnetic separator is rated at 50 tons per hour. It is shown, with the vibrating grizzly bar screen, in Figure 6. The coal then discharges to the bottom of a bucket elevator, which is at ground level, and is conveyed to the top floor of the 4-story COM preparation plant where it discharges into the coal weigh hopper.

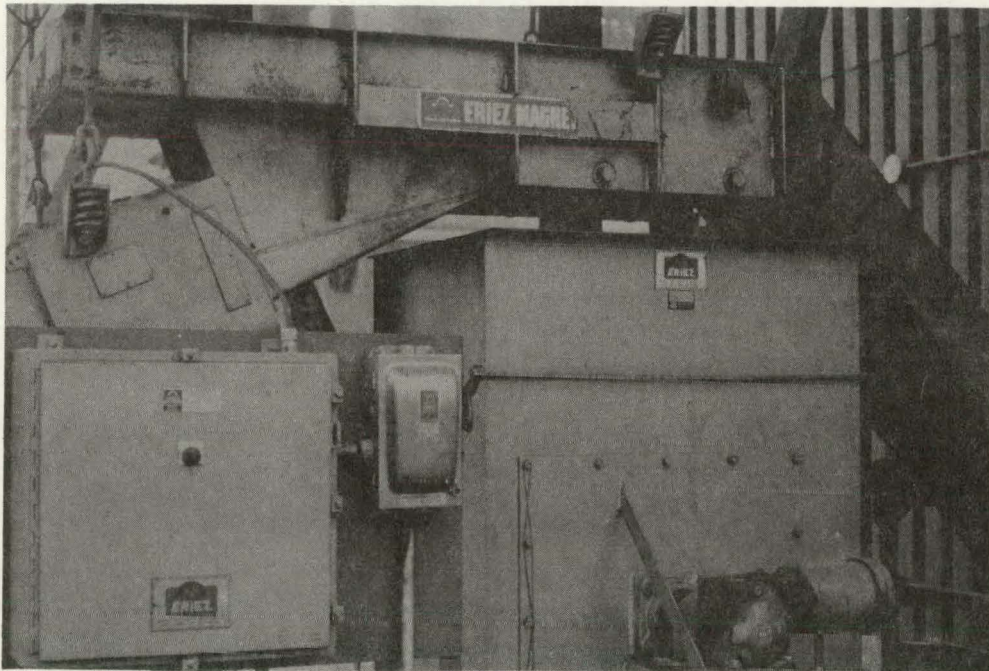


FIGURE 6. MAGNETIC SEPARATOR AND VIBRATING GRIZZLY BAR SCREEN

The bucket elevator has a capacity of 30 tons per hour. The coal weigh hopper has a working volume of 80 cubic feet. The control panel for the coal weigh hopper is located on the first floor near the main process control panel. The tops of the bucket elevator and coal weigh hopper are shown in Figure 7.

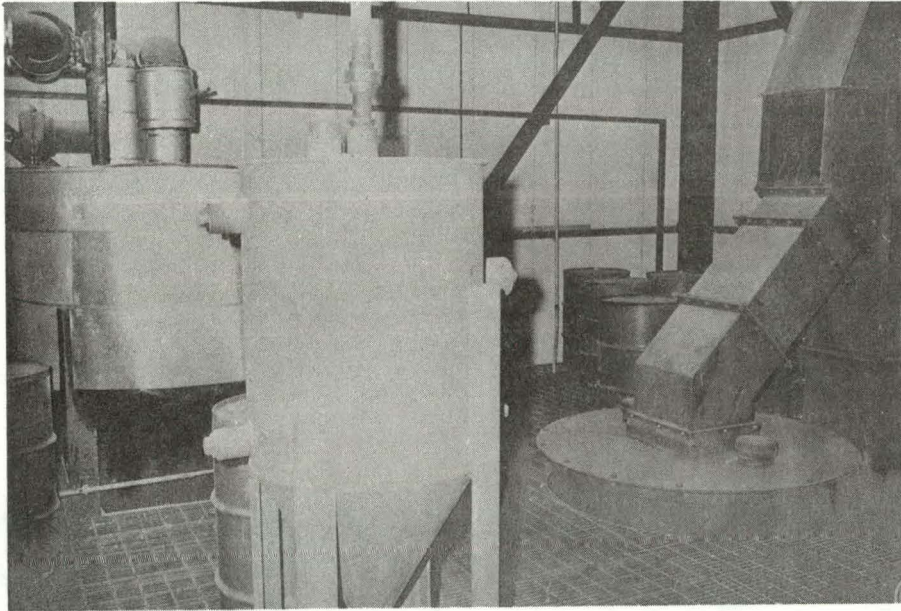


FIGURE 7. BATCH TANKS AND TOP OF COAL FEED SYSTEM

Coal is transferred from the weigh hopper to the disperser by means of a vibrating feeder, shown in Figure 8. The vibrating feeder has a rated capacity of 60 tons per hour, but its feed rate is fully adjustable. A manually operated diverter sits below the vibrating feeder to direct the coal into whichever of the two dispersers is being operated. The coal feed system is complete with a 1,200 CFM bag house to remove any dust.

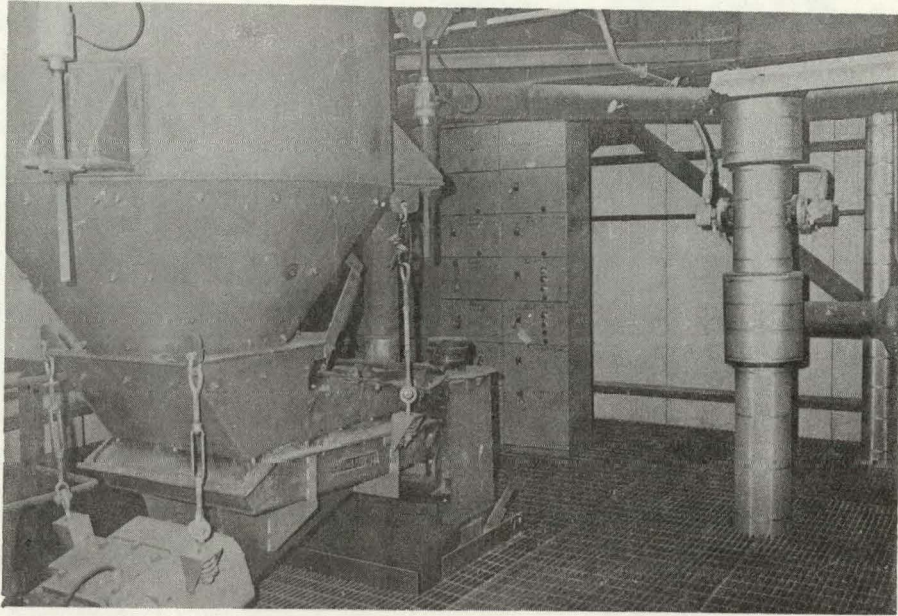


FIGURE 8. COAL WEIGH HOPPER AND VIBRATING FEEDER
Motor Control Center In Background

III.1.2 Oil Delivery System

No. 6 fuel oil is pumped to the COM preparation plant from the Chicago Blast Furnace Plant's central fuel oil storage system. The oil circulates between the central oil storage system and the COM plant through insulated 3-inch pipes. The oil is delivered, at a flow rate of 35 gpm and a temperature of approximately 175°F, to the oil batch tank situated on the fourth floor of the COM preparation plant (Figure 7). On and off flow of oil to the batch tank is controlled by two air-operated ball valves which are activated by the main process control system. When filling the tank, one valve opens the flow of oil to the batch tank while the other stops return flow to storage. Oil batch size is controlled by a high-level pressure switch located immediately below the

batch tank in the insulated 6-inch drain pipe. A low-level pressure switch located in the same area closes the drain valve and initiates refilling of the oil batch tank after it drains. Two manual valves in the oil discharge piping divert the flow to the disperser in use. The oil batch tank drains in less than one minute.

III.1.3 Emulsifier-Water Mixture System

The emulsifier is received in 55 gallon drums. The material is pumped from the drum into either of two emulsifier-water mix tanks located on the first floor of the COM plant. Each mix tank has a capacity of 600 gallons and is equipped with a small mixer. After the emulsifier has been pumped into the mix tank, water is added to bring the mixture to final volume. A high-level pressure switch signals an air-operated ball valve in the water supply line to close when the predetermined level is reached. When the level in the mix tanks gets low, a low-level pressure switch sounds an alarm to manually switch to the second mix tank and make a new batch. The mix tanks are shown in Figure 9.

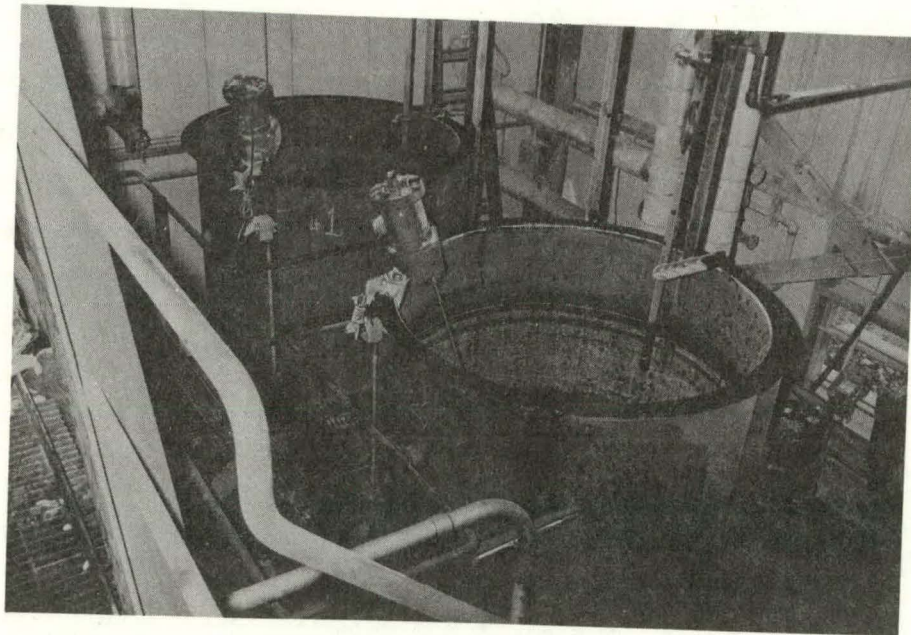


FIGURE 9. EMULSIFIER-WATER MIXING TANKS

The emulsifier-water mixture is pumped at the rate of 20 gpm from the mix tank to the batch tank on the fourth floor of the COM plant (Figure 7). The emulsifier-water batch tank has a capacity of 48 gallons. A high-level pressure switch turns off the flow from the mix tank when the desired level is reached. A low-level pressure switch closes an air-operated ball valve in the 2-inch drain line and initiates refilling of the batch tank after draining. The emulsifier-water mixture discharges from the batch tank to the disperser in about one minute. Manual gate valves direct the flow to the disperser in use.

Figure 10 illustrates the raw material handling systems for the COM demonstration plant.

III.2 COM Production And Storage System

Original plans called for the use of bottom-drive, high-speed dispersers of the same design used in the preliminary test program. However, this equipment was not available from the manufacturer at the time of construction. Top-drive dispersers from a different supplier were selected in their place. Each of these two dispersers has a working volume of 800 gallons and is powered by a 200 horsepower motor. A system of pulleys and ten matched belts transmits the power from the motor to the shaft of the disperser. The two dispersers cannot be operated simultaneously. One operates while the other in stand-by. The dispersers have heat jackets through which steam is passed to bring the batch to proper temperature, and they are fully insulated. The two dispersers are mounted on the first floor and extend upwards to just below the third floor. Figure 11 is a view of the dispersers at the second floor level.

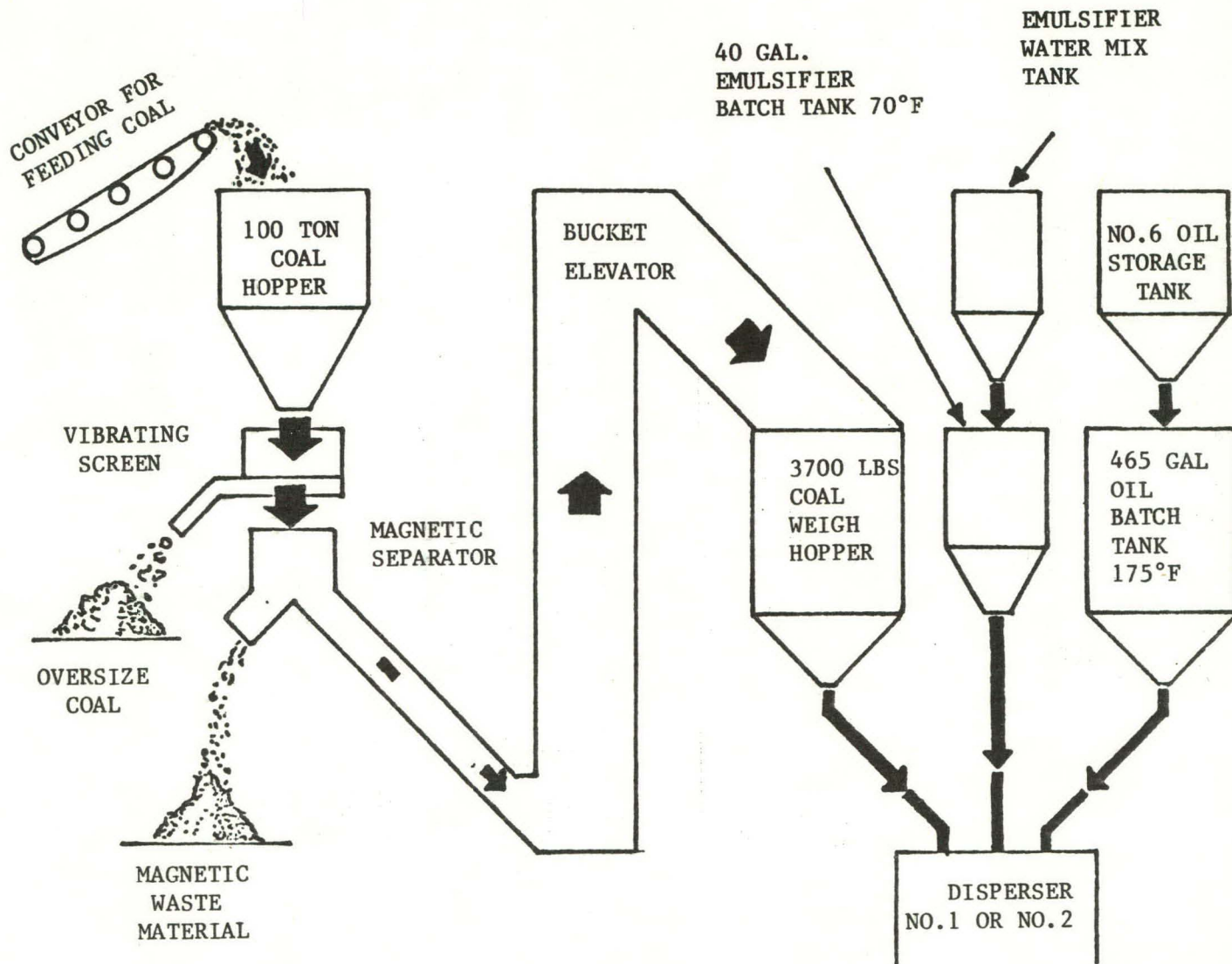


FIGURE 10. RAW MATERIAL HANDLING SYSTEM FOR THE COM PLANT

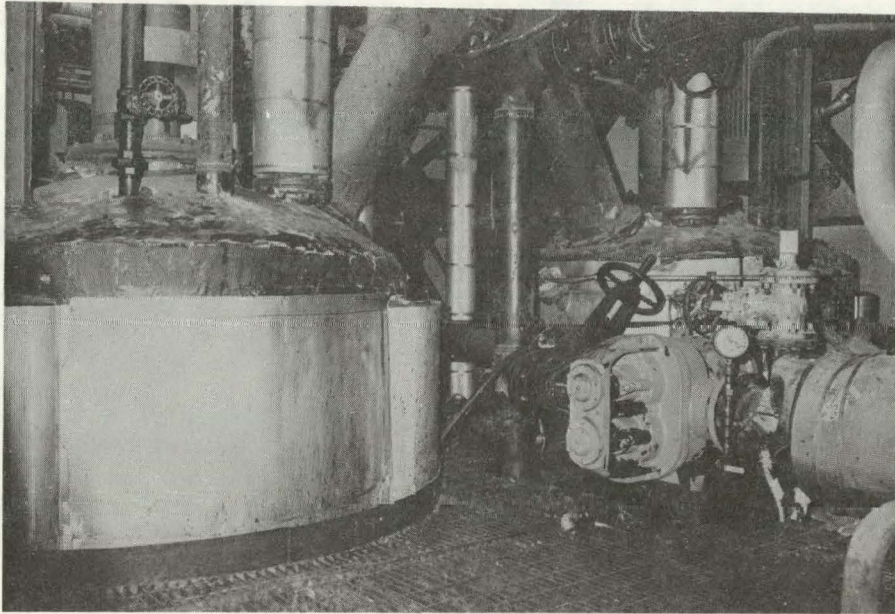


FIGURE 11. DISPERSERS AND COM TRANSFER PUMP

COM batch cycle time is controlled from the main process control panel shown in Figure 12. In automatic mode, cycle time is adjustable up to a maximum of 30 minutes. When a cycle is initiated, the disperser starts and the oil and the emulsifier-water mixture discharge by gravity flow from the batch tanks to the disperser. One minute later, coal begins feeding in from the weigh hopper. The batch tanks and coal weigh hopper begin to refill automatically after their contents have been discharged.

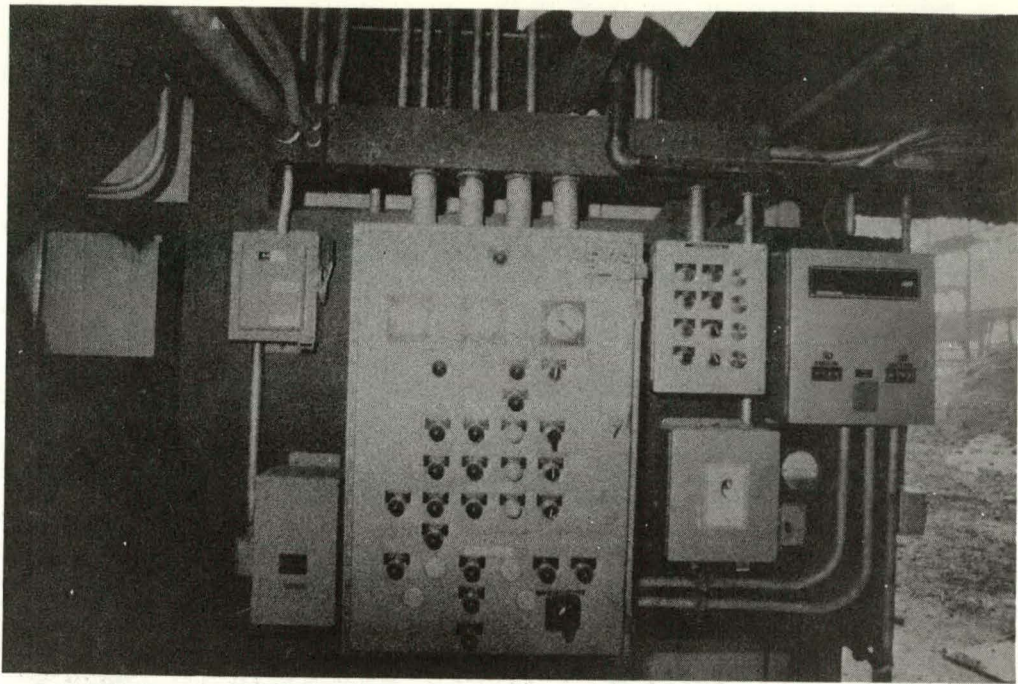


FIGURE 12. MAIN PROCESS CONTROL PANEL

The introduction of the coal and emulsifier-water mixture lowers the temperature of the mixture in the disperser to a point significantly below the temperature of the oil. The temperature drop is 40° to 50°F in warm weather and would be even greater in cold weather. A thermocouple senses this loss of temperature and activates the steam control system for the disperser's heat jacket to bring the mixture temperature back to the desired level. This temperature recovery is aided by the action of the disperser, with some of the input energy being converted to heat.

When the preset batch cycle time expires, the disperser stops and the COM is drawn through an in-line Gorator grinding pump, a Tuthill positive displacement transfer pump, and a shell and tube heat exchanger, on its way to the COM storage tank. The COM storage tank is positioned just outside the main COM preparation building. The in-line grinding pump is designed to reduce any oversize coal that may have escaped proper size reduction in the

dispenser to 1/8-inch to minimize plugging of the lances in the blast furnace. The transfer pump is rated at 200 gallons per minute and a pressure of 45 psi. The heat exchanger contains 48 1-1/2 inch diameter tubes for a total heat exchange surface area of 120 square feet. The grinding pump is shown in Figure 13; the transfer pump is visible in Figure 11.

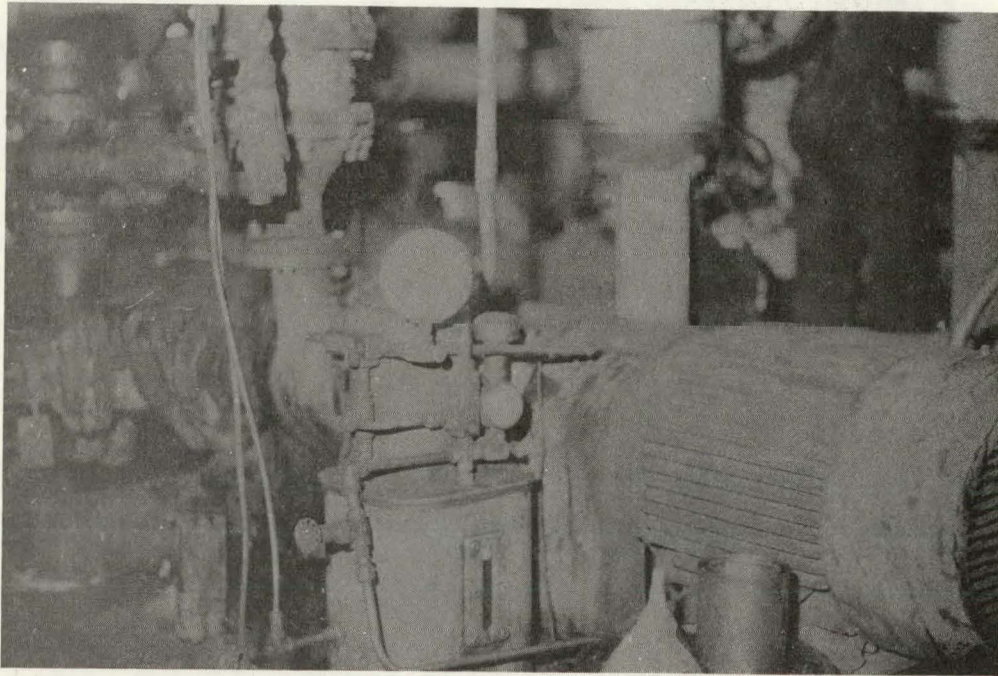


FIGURE 13. IN-LINE GRINDING PUMP

When COM is not being drained from the dispenser, COM from the storage tank recirculates through the in-line grinding pump, the transfer pump, and the heat exchanger to maintain agitation of the COM and temperature control. A system of air-operated ball valves controls the draining and recirculating modes of operation. A low-level pressure switch at the bottom of the dispenser initiates the change from drain to recirculation mode. The 6-inch diameter COM piping network is insulated and has electrical heat tracing. It is equipped with an in-line viscometer and an in-line densitometer for continuous monitoring

of the quality of the COM. Figure 14 illustrates the mixing and recirculating system within the COM preparation building.

The COM storage tank has a height of 25 feet, a diameter of 15 feet, and a working capacity of 26,000 gallons, one day's supply of COM at an injection rate of 17 gpm. For recirculation, the COM is drawn off the conical bottom of the tank and is returned tangentially 3 feet above the top of the cone. The storage tank is fully insulated but has no built-in heating system. All heat is supplied to the COM by the shell and tube heat exchanger described earlier. There is no mechanical mixing system in the storage tank. Agitation is furnished by the recirculation loop and by bubbling air into the bottom of the storage tank.

A multipoint recorder provides a continuous record of oil batch temperature, disperser temperature, heat exchanger outlet temperature, viscosity, density and COM storage tank temperature. Pressure and temperature gauges are located at various points in the COM system.

III.3 COM Injection Circuit

A separate recirculation loop is used to deliver COM to the blast furnace. COM is drawn from the storage tank and is pumped to the blast furnace by means of a Worthington steam-driven duplex piston pump located on the first floor of the COM preparation plant. The pump is rated at 30 gpm and 140 psi. COM can be drawn off from either the bottom of the cone or a level one foot above the top of the cone. The level one foot above the top of the cone is preferred to minimize the chance of fouling the steam pump in the event any coal settles in the storage tank. The steam-driven piston pump is shown in Figure 15. Figure 16 illustrates the COM injection circuit before modifications.

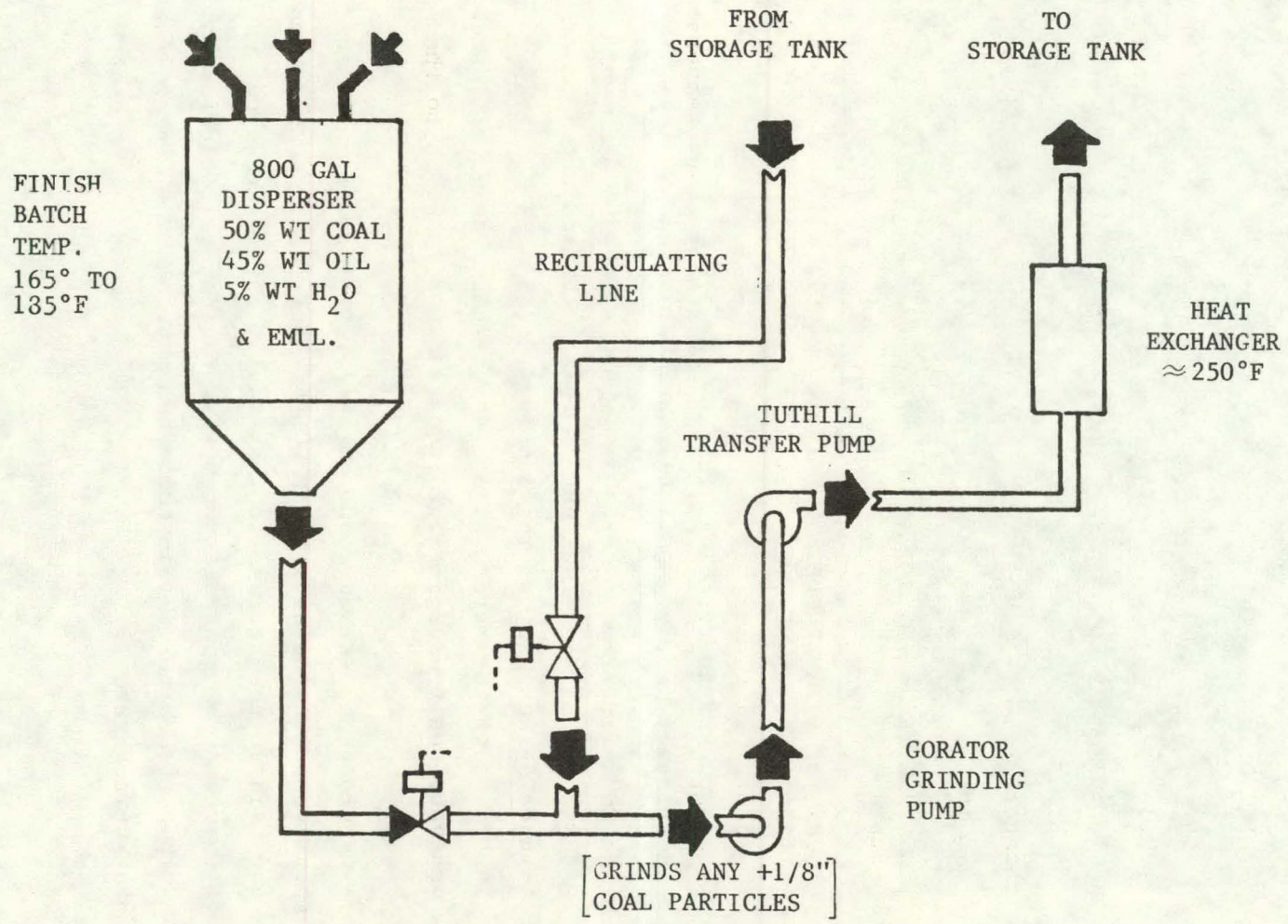


FIGURE 14. DISPERSER DRAIN AND COM RECIRCULATION PIPING SYSTEM

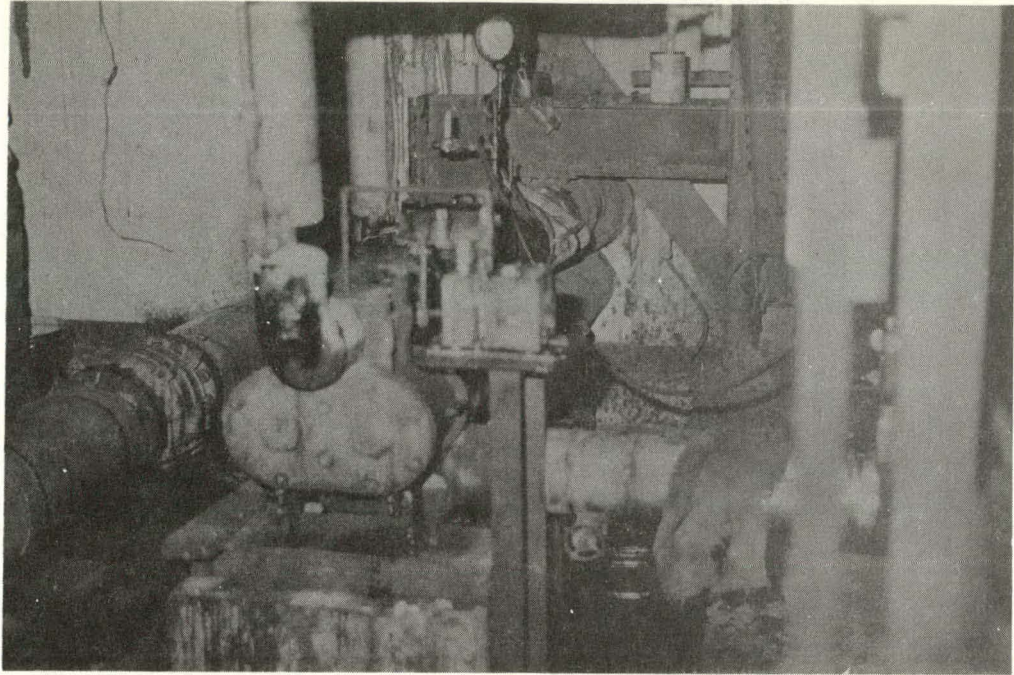


FIGURE 15. STEAM DRIVEN DUPLEX PISTON PUMP

COM is pumped to the blast furnace through an insulated, electrically-heat-traced line and is distributed around the furnace using a 2-inch circle pipe. The piping loop between the storage tank and the blast furnace consists of 650 feet of 4-inch pipe on the supply side, and 687 feet of 3-inch line on the return side. The circle pipe is the same one previously used for oil injection and it is fully insulated.

A manifold pipe arrangement in the blast furnace cast house permits manual adjustment of COM pressure going to the blast furnace and back to the storage tank by way of the return line. A mass flowmeter/flow control system was provided to control the volume of COM to be injected. The manifold and flowmeter are shown in Figure 17.

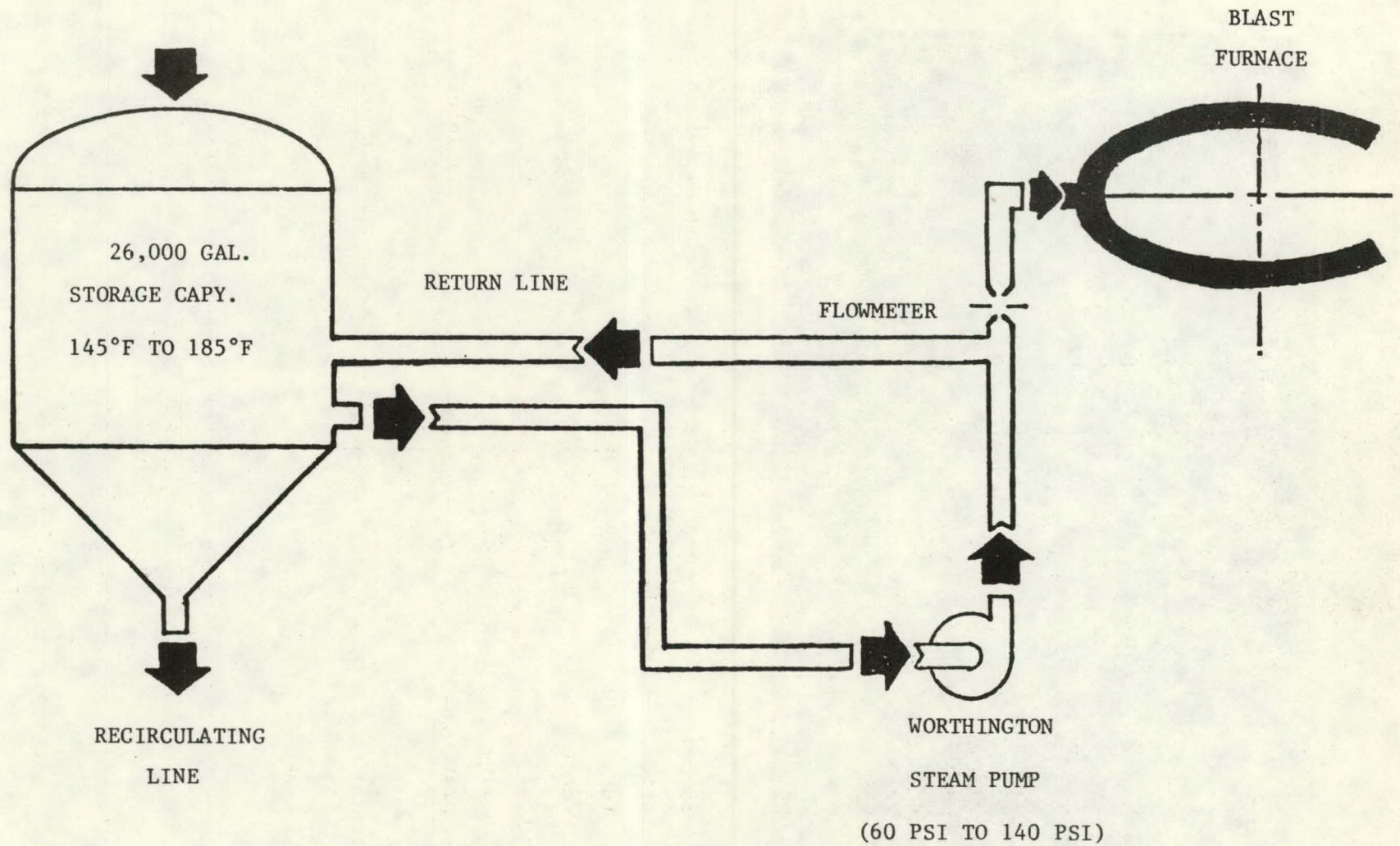


FIGURE 16. ORIGINAL COM INJECTION CIRCUIT

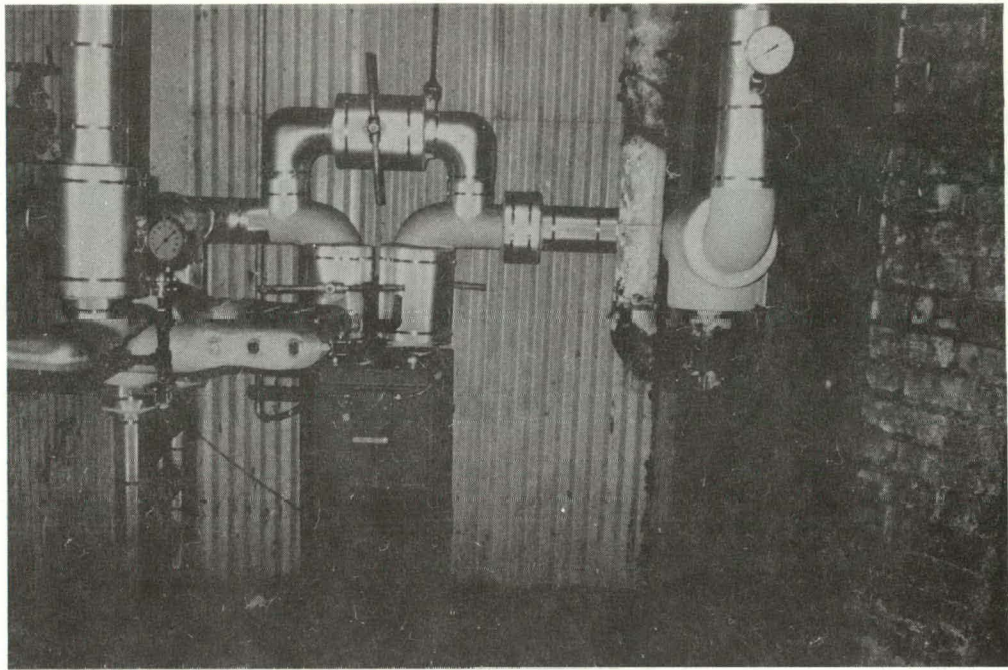


FIGURE 17. BY-PASS MANIFOLD AND MASS FLOWMETER

An air-operated three port, two-way valve in the COM line permits rapid shut-off of COM flow to the blast furnace and steam purging of the COM lines in the cast house if needed. Individual COM lines from the circle pipe can also be steam-purged manually. A top-gas analyzer was provided for a continuous record of the composition of the furnace gas.

SECTION IV

OPERATION OF THE COM PLANT

This section discusses the various operating and equipment problems encountered within the COM plant during the preparation and recirculation of the coal-oil mixture. Approximately 485,000 gallons of COM were produced during the 44-day trial. Composition averaged 47.9% coal, 47.6% oil, 4.0% water, and 0.5% emulsifier.

IV.1 Coal Handling And Coal Handling Problems

Obtaining problem-free movement of coal through a plant requires care in design, and even then modifications to the plant are frequently required after the coal handling system has been operated. Such was the case with the COM plant coal handling system.

The original plan called for coal to be trucked from the nearby Coke Plant and to be loaded into the coal hopper with a crane and reclaiming bucket. A crane was used during preliminary tests made in early 1980, as shown in Figure 18. The crane and operators were provided by a local crane rental service.

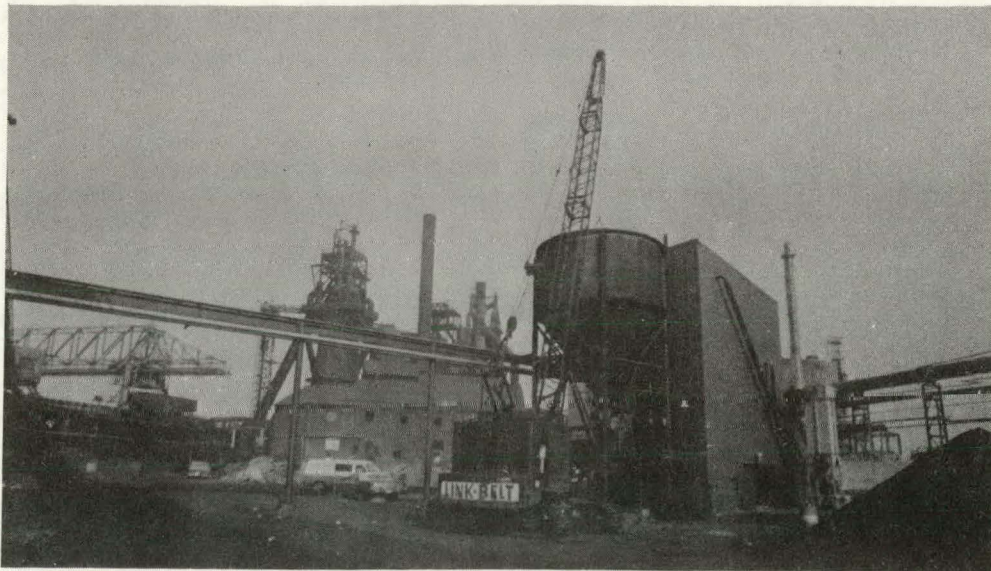


FIGURE 18. CRANE FOR FILLING COAL HOPPER

The crane was capable of filling the coal storage hopper in 2 to 3 hours. However, union work rules required a minimum of 8-hours pay for each of the two operators. This, combined with the crane rental fee of \$4,000 per month, made coal loading costly. Another drawback was the tendency of the reclaiming bucket to pick up foreign material from the ground with the coal. Pieces of hard materials such as slag and coke that passed to the dispersers caused disperser blade damage and premature wear of the pumps. These were major problems during the tests made in early 1980.

IV.1.1 Pneumatic Truck

Prior to the start of the COM demonstration trial in August, 1981, it was decided that all efforts would be made to eliminate contaminants from the coal that could damage COM processing equipment. The best way to accomplish this was to take crushed coal from one of the Coke Plant's mixer bins and transfer it directly to the coal storage hopper without putting it back on the ground. The crushed coal from the mixer bins is 80% minus 1/8-inch in size.

A pneumatic truck was rented to transport the coal from the mixer bin to the coal storage hopper. The truck had a capacity of 6-7 tons of coal. However, coal delivery to the COM plant proved to be too slow even for the early stage of the COM demonstration trial when the target COM injection rate was 7 gpm. It would have been impossible to maintain an injection rate of 14 gpm. Since a heavy equipment operator's strike prevented using a crane for loading the coal, arrangements were made to rent a wheeled, inclined belt conveyor for this purpose.

While awaiting the conveyor, the procedure of drawing coal from the mixer bin was abandoned in an effort to minimize coal shortages at the COM plant. Beginning August 27, run-of-mine coal was

brought to the COM plant by dump truck, and the pneumatic truck was used to transfer the coal from the pile to the storage hopper. Some improvement in coal delivery was achieved, but it was still too slow for production needs and necessitated reductions in the amount of coal used per batch for several days. Coal concentration reached a low of 2,900 lbs. per batch on August 28. Rainy weather was particularly detrimental to the pneumatic conveyance of coal. The pneumatic truck was used until the belt conveyor became available on September 1.

The pneumatic conveyance of coal had a serious problem in addition to slow delivery rates. It pulverized (98% minus 1/8 inch), dried and fluffed the coal to such an extent that fluid-like flow was sometimes experienced beyond the storage hopper. On a number of occasions the bucket elevator used to convey coal from below the storage hopper to the top of the processing plant was buried when fluidized coal continued to flow into the bottom of the elevator after the buckets had been stopped. Excessive amounts of the dried and fluffed coal were also carried from drop points within the plant to the bag house. Overall dust losses are estimated as high as 20% when the pneumatic truck was in use.

IV.1.2 Inclined Belt Conveyor

The belt conveyor is shown in Figure 19. The inclined belt conveyor was a rented unit that was operated by Interlake personnel. The coal storage hopper was loaded in 2 hours with a crew of three people—a front-end loader operator, one person at the bottom and one person at the top of the conveyor.

The cost for conveyor rental was \$7,500 per month. The operating cost to fill the coal storage hopper was approximately \$200 for the front-end loader and three people. When picking up coal, the operator of the front-end loader kept the bucket one-foot above ground level to minimize contamination.

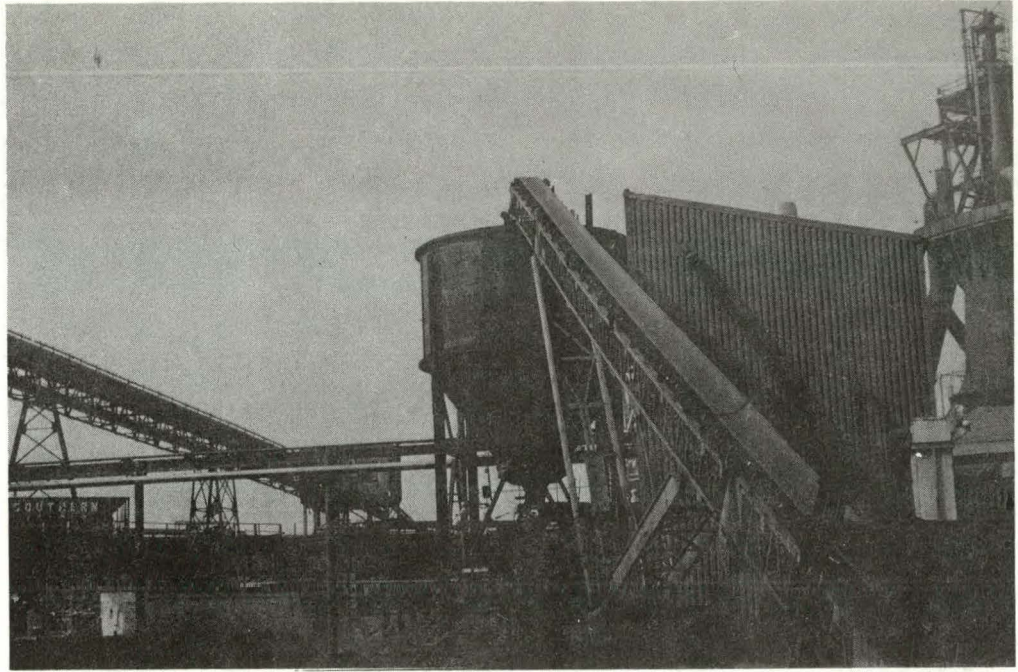


FIGURE 19. INCLINE BELT CONVEYOR

Coal loaded into the hopper by the conveyor was far less dusty than coal loaded by the pneumatic truck, and it was easier to handle within the plant. The higher coal moisture level did cause one problem. The coal tended to stick to the drum of the magnetic separator, and excessive amounts were diverted along with magnetic materials. Air jets directed at the drum eliminated this problem while allowing proper operation of the magnetic separator. Thus, the belt conveyor resolved the hopper filling problem and proved to be far more feasible than either the crane or pneumatic truck methods.

IV.2 Coal Storage Hopper And Associated Equipment

The coal storage hopper is cylindrical with a conical bottom; it is elevated to allow positioning of other equipment below it. The top of the hopper is 41 feet above ground level. The cover at the top of the hopper is removable for loading by crane; a 2 foot by 2 foot door in the cover was used for loading coal using the inclined belt conveyor.

The discharge opening at the bottom of the hopper was originally 18 inches in diameter. However, after severe "rat holing" was experienced, the bottom of the cone was cut off to provide a 6-foot diameter opening for attachment of a vibrating bin bottom. The live bin bottom provided reliable coal feed from the hopper to the vibrating feeder. Working capacity of the coal storage tank is 100 tons, or about two days coal supply at the maximum injection rate obtained during the Test Period.

IV.3 Vibrating Bottom Feeder And Screen

Upon demand, the live bottom of the bin feeds coal to the vibrating screen, which is actually a combination vibratory tray feeder and bar screen. The amplitude of vibration is adjustable to allow regulation of the feed rate. The bar screen allows diversion of large pieces of coke, stone, lumber and other contaminants found in the coal. A negligible amount of coarse coal was diverted by the screen. Original bar spacing was 2 inches. Bar spacing was later reduced to 1-1/4 inches to provide greater protection from any contamination.

IV.4 Magnetic Separator

Coal falls from the bar screen onto the magnetic separator roll. The magnetic separator protects the processing equipment from tramp ferromagnetic materials being conveyed into the disperser.

As was mentioned previously, damp coal tended to stick to the magnetic roll and was diverted to the magnetic reject pile. Four 1/4-inch diameter tubes were fitted to the magnetic separator and were supplied with compressed air to blow adhering coal off the rotating magnetic roll. This arrangement is shown in Figure 20. This measure reduced improper diversion of coal to a negligible amount.

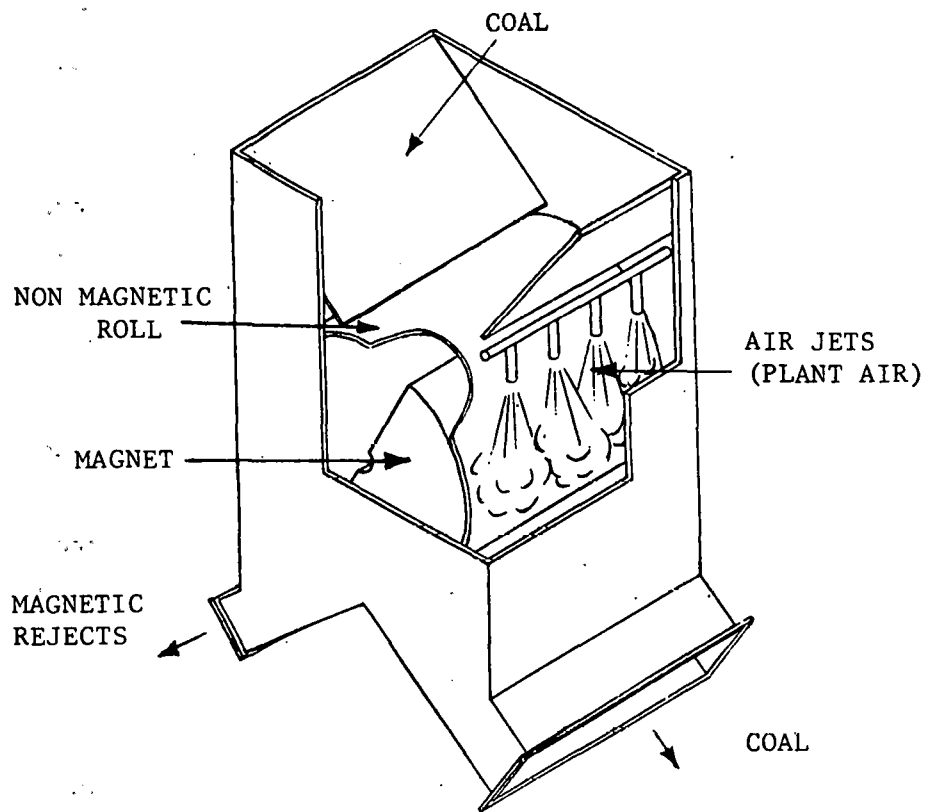


FIGURE 20. AIR WIPES ON MAGNETIC SEPARATOR ROLL

IV.5

Bucket Elevator

From the magnetic separator, the coal slides down an inclined chute to the foot of the bucket elevator. The bucket elevator is 38 feet tall and consists of a rubber belt fitted with steel buckets along with an enclosure, pulleys, and normal drive components. The enclosure is vented to the bag house to control dust. The base of the elevator is in a pit 18 inches below ground floor level. This location proved to be troublesome on occasions when the elevator was jammed by excessive amounts of coal settling out in the bottom of the elevator housing. It was necessary to shovel this excess coal out of the elevator, a job that would have been simpler had the elevator been mounted on or above the floor. When the bucket elevator jammed, some of the buckets were actually buried by the coal so that the motor of the elevator could not overcome the load. Figure 21 illustrates the bucket elevator jammed with coal.

IV.6

Weigh Hopper

The bucket elevator feeds coal into a batch weigh hopper. This weigh hopper is cylindrical with a conical bottom. The top is enclosed and is vented to the bag house through the bucket elevator. Nominal capacity of the coal batch weigh hopper is 2 tons. Both the weigh hopper and the vibratory feeder beneath it are suspended on three force cells.

The associated electronic system allows filling and emptying to predetermined and readily selectable weights. During the trial, 2,900 to 3,700 pounds of coal were used per batch. The vibratory tray feeder regulates the flow of coal from the weigh hopper to the processing vessel so that coal is not fed to the disperser faster than it can be incorporated into the oil-water portion of the mixture. Feed times of 2 to 4 minutes proved to be suitable and are obtainable through adjustment of the amplitude of vibration. Different amplitudes of vibration were utilized to accommodate the different size coals from the pneumatic truck or belt conveyor.

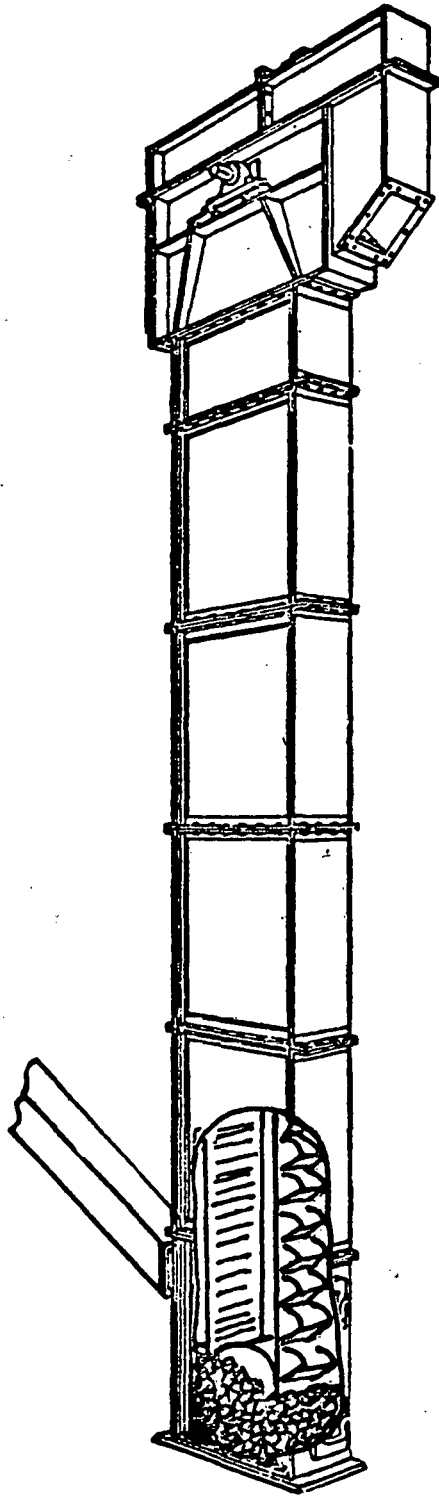


FIGURE 21. BUCKET ELEVATOR WITH BOTTOM OF HOUSING
FILLED WITH COAL BURYING THE LOWER BUCKETS

After the modifications discussed and adjustments of various operating variables, the coal handling system provided reliable, economical, and nearly dust free operation.

IV.7 Pumps And Pump Related Problems

The COM plant has two separate circulation loops. The first draws COM, including any large settled solids, from the conical bottom of the storage tank, directs it through the Gorator grinding pump, the Tuthill transfer pump, and an in-line heater, and finally returns the material to the storage tank. This loop is also provided with valves to allow transferring newly made COM from the disperser vessels through the pumps and in-line heater to the storage tank.

The second loop is the injection circuit. COM is withdrawn from a point 6.5 feet above the bottom of the storage tank and is pumped to the blast furnace cast house where a portion of the flow enters the furnace and the balance is returned to the storage tank. This loop has one pump, a steam-driven duplex piston pump, referred to as the Worthington steam pump.

IV.7.1 Gorator Grinding Pump

The grinding pump is a Dorr-Oliver "Gorator." This pump was incorporated into the system to provide size reduction of any large particles that escaped reduction in the disperser. The Gorator was required to perform under severe abrasion conditions, thus wear was also severe. Maintenance during the Test Period consisted of periodic replacement of the rotor plate and wear liner bars. Just prior to the Test Period, more time-consuming replacement of the mechanical seal assembly was required due to previous use, but the new seal lasted the entire demonstration period.

The Gorator pump is direct-driven by a 40 horsepower, 1,750 RPM motor. The rotor plate is a flat oval casting centered on the shaft. The plate is set at about a 30° angle to the axis of the pump. Rotation of this plate provides a centrifugal pumping action while the close passage of notched teeth on the edge of the plate past fixed teeth on the case liner bars provides a grinding action. Outlet slots also provide a sizing action. The Gorator is shown in Figure 22.

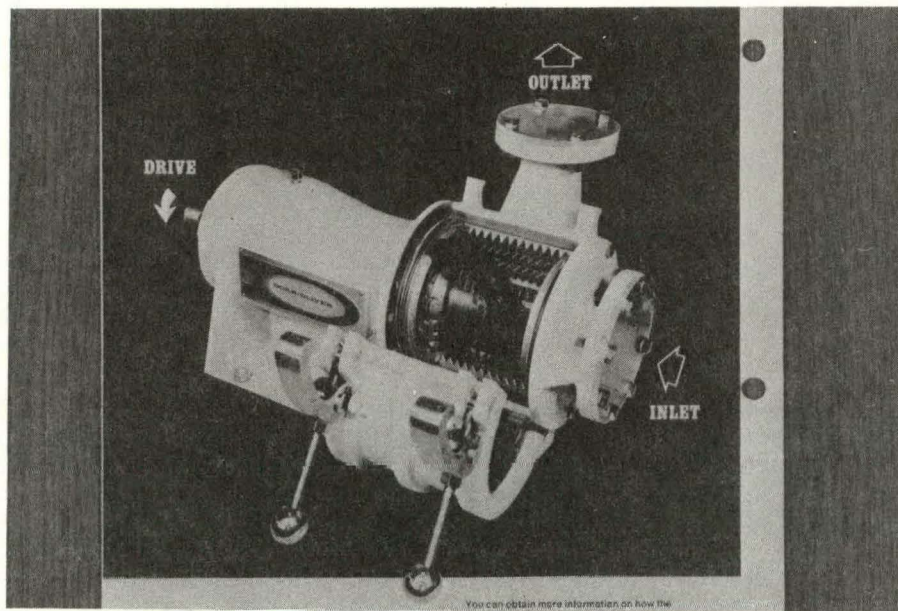


FIGURE 22. GORATOR LINER BAR AND ROTOR ARRANGEMENT

IV.7.1.1 Gorator Wear

The rotor plate is made of AISI 4340 steel and is heat-treated to Rockwell C50 hardness. The liner bars and seal cap are cast from ASTM A597 Grade CD-2 tool steel and are heat-treated to Rockwell C60 hardness. In spite of these impressive hardnesses, rotor plates were in service as little as 5 days due to excessive erosion; liner bars lasted about twice as long. The rotor plate

was replaced four times during the test. The liner bars were replaced three of these times and were reversed the fourth time. Liner bars and rotor plates would have been replaced even more frequently if parts had been available.

Figure 23 illustrates the service time experienced with the Gorator liner bars and rotor plates

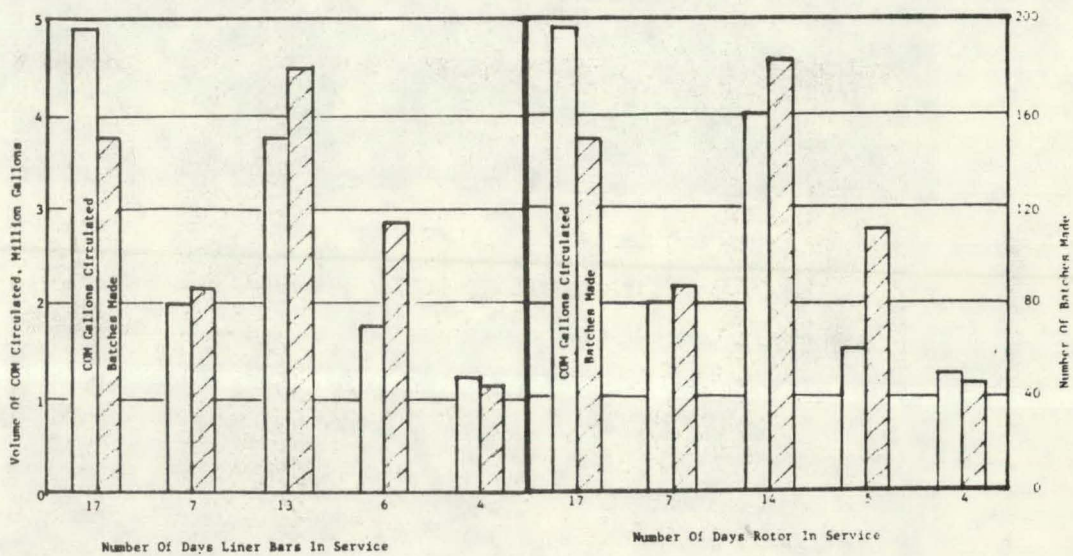


FIGURE 23. SERVICE LIFE OF LINER BARS

SERVICE LIFE OF ROTOR PLATES

Typical worn conditions of the rotor plate and liner bars are shown in Figure 24. New parts are shown in Figure 25.

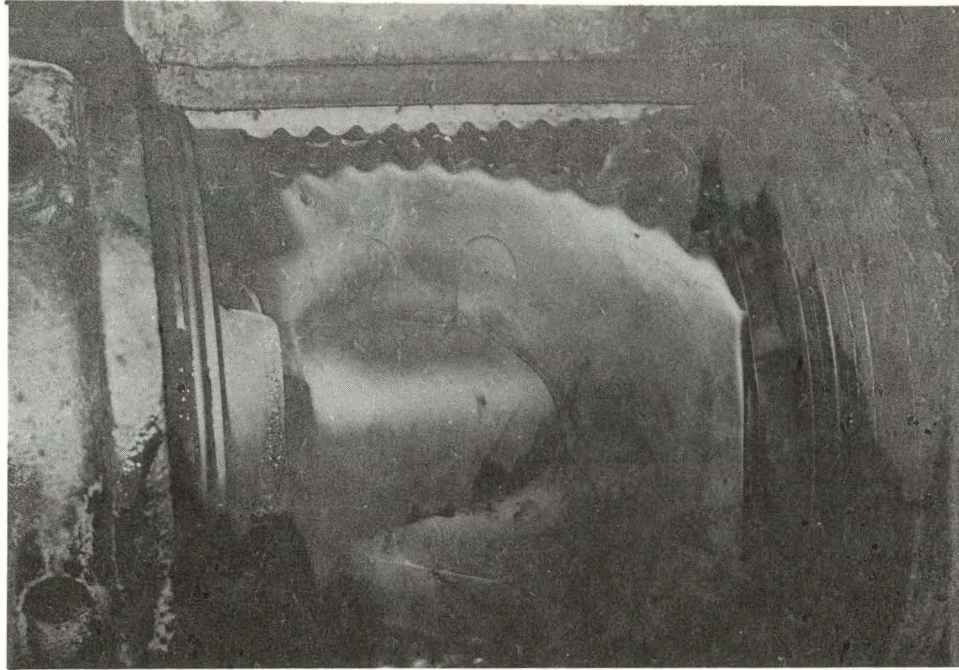


FIGURE 24. WORN CONDITION OF ROTOR PLATE AND LINER BARS

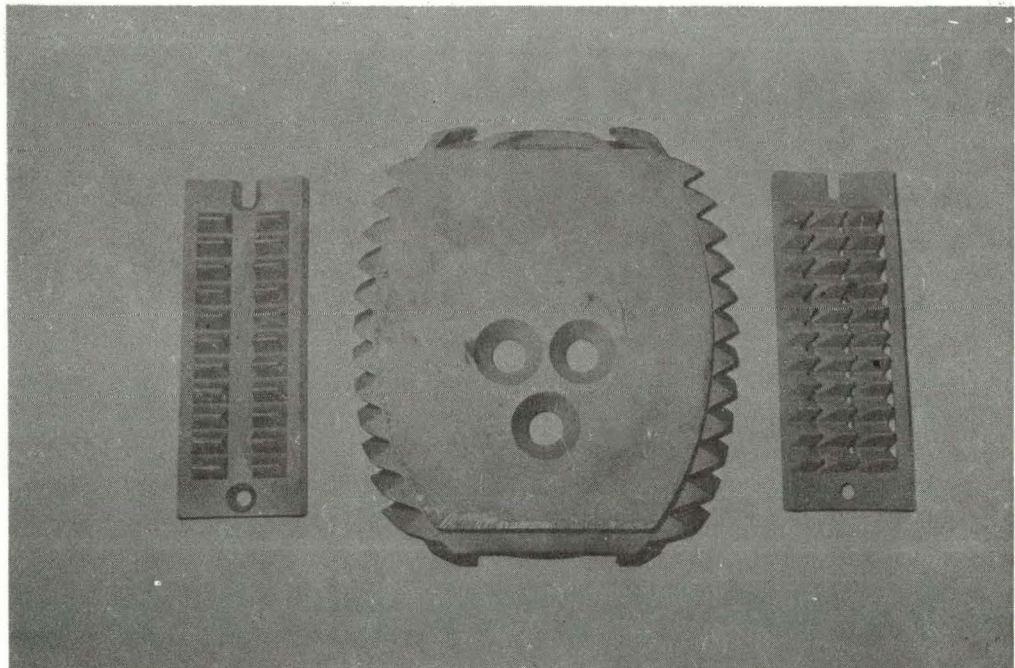


FIGURE 25. NEW GORATOR ROTOR PLATE AND TWO OF TEN LINER BARS

Following the various service times between Gorator repairs, gaps of 0.12 inch to 0.44 inch were measured between the rotor plate and liner bars. Design clearance is 0.050 to 0.070 inch.

IV.7.1.2 Miscellaneous Gorator Wear Parts

The drive shaft was fitted with one tungsten carbide-tungsten carbide and one carbon-nihard mechanical face seals. The seals were cooled and pressurized by lubricating oil that was circulated between the two seals from an external pump and heat exchanger.

The mechanical seal assembly was replaced prior to the start of the demonstration trial. A gasket on the seal cap leaked and was replaced during the test. Also, the seal cap hold-down screws, the heads of which are exposed to the abrading action of the COM, were replaced three times during the test. Following the 44-day test, the tungsten carbide seal showed fine radial cracks on the sealing face, but no visible wear. The carbon-nihard seal showed some wear but never passed any oil.

IV.7.1.3 Operation Of Gorator Pump

The Gorator pump operated 24 hours per day for the majority of the Test Period. It was shut down only for repair. When the Gorator pump was shut down, a by-pass line was opened and circulation was maintained by the Tuthill pump. COM was not made during Gorator outages because of the likelihood of coarse particles passing into the storage tank and subsequently plugging the injection pump or injection lances. The Gorator inlet was subject to a positive head pressure when COM was circulating properly. Gorator outlet pressure held quite steady at about 9 psi.

IV.7.1.4 Lubricating Oil For Gorator Pump

Excessive amounts of seal lubricating oil (as much as 50 gallons) were lost during the first 2 to 3 weeks of the test. Oil consumption dropped to near zero during the latter weeks of the test. Better performance coincided with a change to heavier oil and replacement of the seal cap screws. It is believed the fit of the seal cap was improved when the cap screws were replaced.

IV.7.2 Tuthill Pump

The Tuthill Bump-Ulrich Model 600 pump was selected to provide positive pumping action, particularly for pumping freshly made COM against the high head of the nearly filled storage tank. The Tuthill pump has several design features that tend to reduce abrasive wear. The pump runs at a relatively low speed, 155 RPM, and the use of large pump lobes minimizes the surface contacting the abrasive COM. The operation of the Tuthill pump is shown in Figure 26.

This pump continued to work well throughout the Test Period in spite of considerable wear. At the end of the Test Period, wire gauges were used to determine clearance between the rotating lobes and the case. Clearance was 0.125 inch. Manufacturer's clearance at the time of new installation was 0.010 inch. The high solids loading and appreciable viscosity of the pumped product no doubt aided in maintaining pumping action in spite of the large clearance in the pump.

The pump shafts were sealed with packing glands. Packing was added once early in the Test Period, but after packing was properly seated no leakage occurred. No adjustment was required for the last month of the test.

Inlet pressure was nearly constant at 9 psi. Outlet pressure varied from 12 to 22 psi, depending largely on the storage tank head

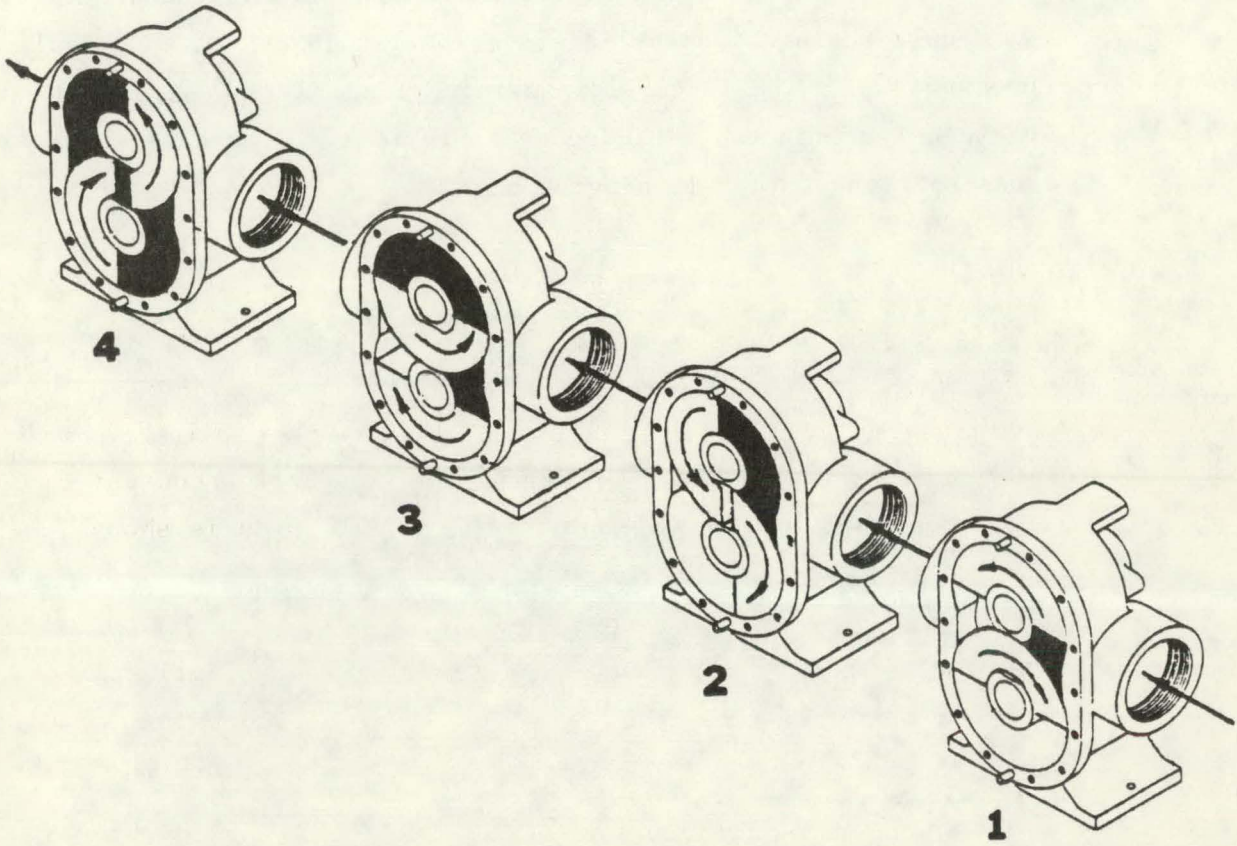


FIGURE 26. TUTHILL PUMP SHOWING PROGRESS OF MATERIAL THROUGH PUMP
(Dark areas are pumped COM)

opposing the pump.

IV.7.3 Worthington Steam Pump

A Worthington duplex steam pump was used to deliver COM to the blast furnace at high pressure for injection through the tuyeres. This pump has two double acting liquid cylinders directly connected to two double acting steam cylinders. The liquid is valved by ball check valves. The large slow-moving cylinders (approximately 20 cycles per minute) minimize wear problems. Figure 27 shows a cross-section of the Worthington pump.

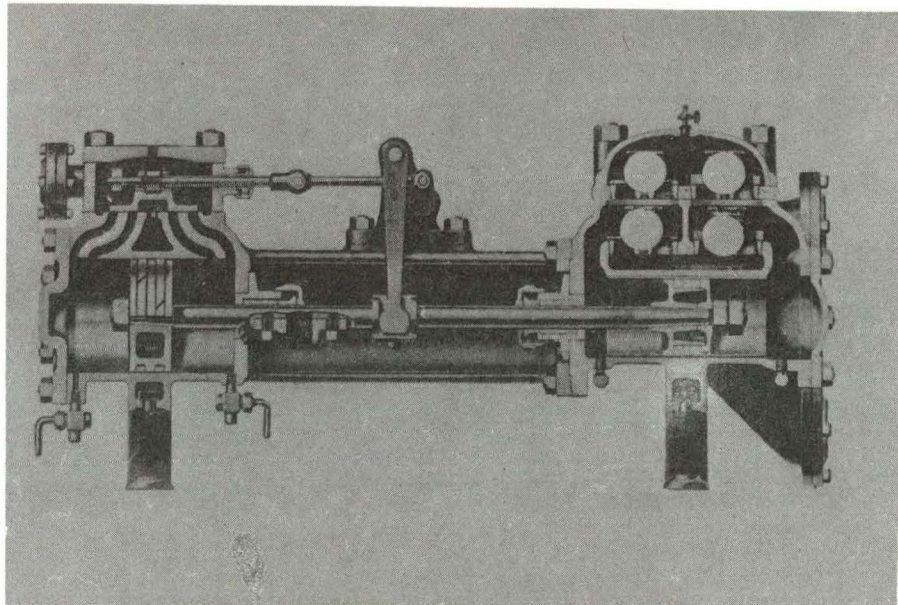


FIGURE 27. WORTHINGTON STEAM PUMP

The reciprocating shafts connecting steam and liquid cylinders are provided with packing glands. These glands were packed at the start of the test and once during the course of the test. On several occasions coarse particles prevented the ball check valves from seating, which in turn caused the pistons to get out of synchronization and jam. The pump was torn down for cleaning and

examination on two occasions when the pump jammed. Both times the ball check valve chamber was found to be loaded with coarse particles of coal and some metallic debris. As experience was gained, it was found that improved adjustment of the pump smoothed pump operation. It was also found that coarse debris could generally be flushed from the valve chamber with No. 6 fuel oil supplied under pressure to the pump inlet.

In earlier trials, the injection pump was successfully regulated through closed loop control from a flowmeter/flow control unit located at the cast house. Since problems were encountered with the flowmeter during the Test Period, flow was regulated by manually throttling the steam supply line to the Worthington pump and regulating COM by-pass valves at the cast house. Shortly after the test started, a steam pressure regulator was installed in the steam line to the pump. This reduced variation in steam supply pressure and aided in maintaining uniform COM injection rates.

The Worthington pump showed no signs of slippage at 150 psi dead head pressure at the end of this test, at which time the pump had operated a total of about 7 months in COM service.

IV.7.4 Disperser And Disperser Blade Wear

Interlake's process for coal-oil mixture preparation combines the grinding of coal and liquid-solid mixing in a single step. Grinding is accomplished principally by high-speed impact between a revolving disperser blade and coal particles that are suspended in a moving oil-water mixture. In 1980 the disperser manufacturer informed Interlake that they would be unable to supply abrasion resistant blades. The development of an effective and durable disperser blade became an important part of the program.

IV.7.4.1 Disperser Operation

Two 800-gallon working capacity dispersers were purchased and installed to allow uninterrupted operations. One disperser serves as a stand-by unit and is available immediately when the other requires service. The dispersers are upright cylinders with dished heads top and bottom. Raw materials enter from the top, and finished product drains from the bottom. The impeller shafts enter from the top and are belt-driven by 200 horsepower motors.

Four vertical baffles were installed in each vessel to reduce vortexing of the liquid and to increase the power input to the system.

Current draw at 1,111 RPM was 45 amperes with an empty tank, 77 amperes with oil and water, and 160 amperes after all of the coal had been added to the disperser. A current draw of 160 amperes corresponds to 162 horsepower.

A 4-inch high collar was welded around the drain of each disperser to retain coarse and rapid-settling particles for further processing during the following cycle. The disperser vessels are steam-jacketed.

Each vessel is fitted with two pressure switches. One indicates when the vessel has drained and allows a new cycle to start. The other pressure switch indicates when the vessel is overfilled and is in danger of overflowing.

IV.7.4.2 Disperser Draining Problems

Typically, batch cycle time during the trial was 27 minutes, with some variation due to irregular batch draining times. If a batch failed to drain or drained slowly, and cycle time extended beyond 30 minutes, an annunciator panel alerted personnel to the abnormal condition.

Generally the drain line from the disperser in use was found to be plugged at the start of each day's COM-making operation. It is believed that solids accumulated in the stagnant arms of the tees where the disperser drain lines join the recirculation line. It was necessary to open these drain lines by reverse blowing with steam each morning.

IV.7.4.3 Disperser Batch-Making Procedure And Control

The COM plant is designed to bring batch quantities of coal, oil and water-emulsifier mixture to the top floor of the plant from where they may be fed rapidly to the disperser by gravity. With this approach, it is possible to obtain maximum production time in the disperser without using unnecessarily large pumps or elevators to feed the materials to the disperser.

Batch quantities of coal were weighed directly. The oil and water-emulsifier batches were calibrated and reported as volume measurements, although the pressure switches used to measure these liquids actually respond to weight rather than volume.

It was necessary to fill the three batch tanks before processing could begin. Generally the coal and the water-emulsifier batch tanks were allowed to fill while the last batch of the day was being processed. Hot oil was charged to the oil batch tank before the first batch was made on the following day. Once the last of the batch tanks was loaded, it was necessary only to turn on eight electrical switches to initiate automatic cycling of the COM process. The system could then continue to make COM without intervention the remainder of the day. In actual practice, the batch-making process was closely watched, and frequent intervention was required to correct a variety of conditions including failure to drain, buried bucket elevator, electrical breaker open and emulsifier-water tank empty. The frequency of process upsets requiring intervention dropped dramatically as the test progressed. At the

start of the test low production rates were maintained only through the constant and diligent effort of three to five men. By the end of the test, operations had improved to such a degree that high production rates could be maintained by a single operator. Additional help was needed for equipment maintenance and for coal loading.

The automatic process was under the control of three timers and a number of interlocking switches that allowed the process to proceed if batch tanks, valves and pumps were in their correct status. After all batch tanks had been filled and all required pumps, conveyors, feeders and the like had been activated, the process was started by turning the main control switch to the "Automatic" position. This caused the oil and emulsifier-water mixture to drain into the disperser, the disperser motor to start, and the first timer clock to start. The oil and water-emulsifier mixture were agitated by the disperser for one minute to form an emulsion. The oil batch tank started to refill immediately while the water-emulsifier batch tank was not allowed to refill until 2 minutes had elapsed.

At the end of one minute the first timer clock stopped, the second and third clocks started and coal feed began. The rate of coal feed was regulated by dial adjustment of vibrating feeder amplitude. Feed rate was regulated to empty the batch tank in 2 to 4 minutes. A change in dial setting was required when the pneumatic truck was replaced by the inclined belt conveyor. Coal batch full and empty weights were each adjustable by four digit thumb wheels. Refilling of the coal hopper started as soon as empty weight was reached.

The second timer regulated the duration of processing from the time coal feed started until the disperser motor stopped and the valves switched to drain the finished COM from the disperser to the COM storage tank. A pressure switch mounted in the bottom of the disperser indicated when the disperser was empty and reversed the

valves to the recirculation position. A limit switch indicated when the valves had actually completed the return to the recirculation position and restarted the disperser motor. If all batch tanks were full and all pumps and conveyors were running, the process started again after a 15 second delay. If all batch tanks were not full, or if all pumps and conveyors were not running, the disperser would start, but raw materials would not drop into the disperser until all conditions were met.

The third timer sounded an alarm and lit an explanatory panel on an annunciator if the process cycle had not been completed and the next cycle started within 30 minutes. Temperature regulation, by means of a thermostat-regulator on the steam jackets of the dispersers, was the only other control on the batch-making process.

The temperature profile for a typical batch of COM is shown in Figure 28, COM Plant Recorder Chart. The temperature of the oil-water mixture at the start of each cycle was relatively steady at about 140°F. This was a result of the combined heat contents of the vessel walls, the incoming oil and the incoming water-emulsifier mixture. The vessel wall temperature was about 185°F due to heat from the previous batch or due to deliberate application of heat by way of the steam jacket at the start of the day. Oil was piped to the oil batch tank at a controlled temperature of about 165°F. The water-emulsifier mixture was at ambient temperature, about 70°F during the Test Period. The coal also was at ambient temperature. Temperature generally fell to about 130°F after all of the coal had entered the disperser. The complete COM was then heated to a finishing temperature of about 185°F by the combined energy inputs of the steam jacket and the disperser motor.

Higher finishing temperatures were attainable by adjustment of the steam regulator for the disperser steam jacket, However, higher temperatures were believed to be detrimental to COM stability and

were found to aggravate disperser draining problems -- excessive temperature caused cavitation at the Gorator pump.

The elevated temperature of the finished COM was of particular value at the start of the Test Period. The storage tank was partially filled with COM that had cooled to about 145°F. The addition of fresh hot material to the storage tank was more effective for raising storage tank temperature than was the in-line heater.

Other traces on the COM plant recorder chart exemplified in Figure 28 include COM storage tank temperature, oil batch tank temperature, heat exchanger outlet temperature and COM viscosity. The heat exchanger outlet temperature trace shows a slight peak when freshly made COM was being pumped through the heat exchanger. The remainder of the period shows the temperature of recirculated COM. The COM viscosity line does show that the instrument responded to differences between freshly made COM and recirculated COM, but the instrument was not calibrated; therefore, no numerical values can be read from the charts.

IV.7.4.4 Disperser Blades

IV.7.4.4.1 Work Prior To Demonstration Trial

The disperser manufacturer supplied several 22-inch diameter disperser blades made of 1/4 inch 1020 steel. Interlake had one of these blades weld hardfaced and sprayed with tungsten carbide. Even the hardfaced blade did not provide acceptable life. The hardfaced teeth were severely worn after processing 10 batches of coal-oil mixture.

The disperser manufacturer also supplied blades of 26 and 30 inches diameter. These blades were not designed for abrasion resistance and were intended principally for evaluation of blade size and configuration. The 30-inch diameter blade produced a fine

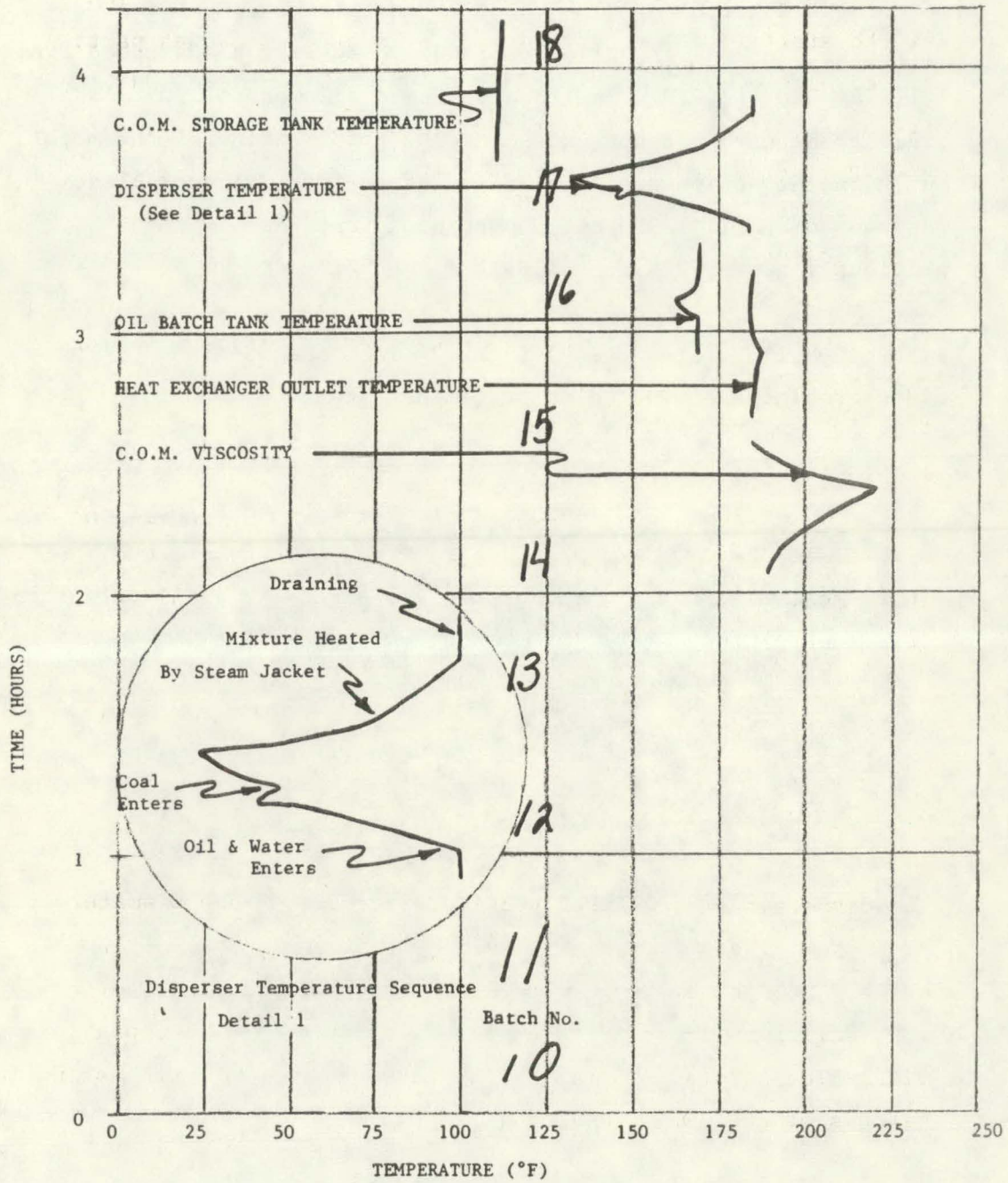


FIGURE 28. COM PLANT RECORDER CHART

coal-oil mixture with less tendency to settle than COM made with the smaller diameter blades. Power draw with the 30-inch blade sometimes exceeded the motor rating and frequently the motor breaker tripped. The motor on one of the dispersers was fitted with a smaller pulley to reduce disperser blade speed from 1,111 RPM to 817 RPM. The reduced speed allowed the 30-inch blade to be used without exceeding the power rating of the motor, but grinding action was reduced. The 26-inch diameter blade was tested at 1,111 RPM but showed no advantage over the previously tested 22-inch blade.

Figure 29 illustrates the 22-inch, 26-inch and 30-inch diameter blades evaluated in preliminary testing.

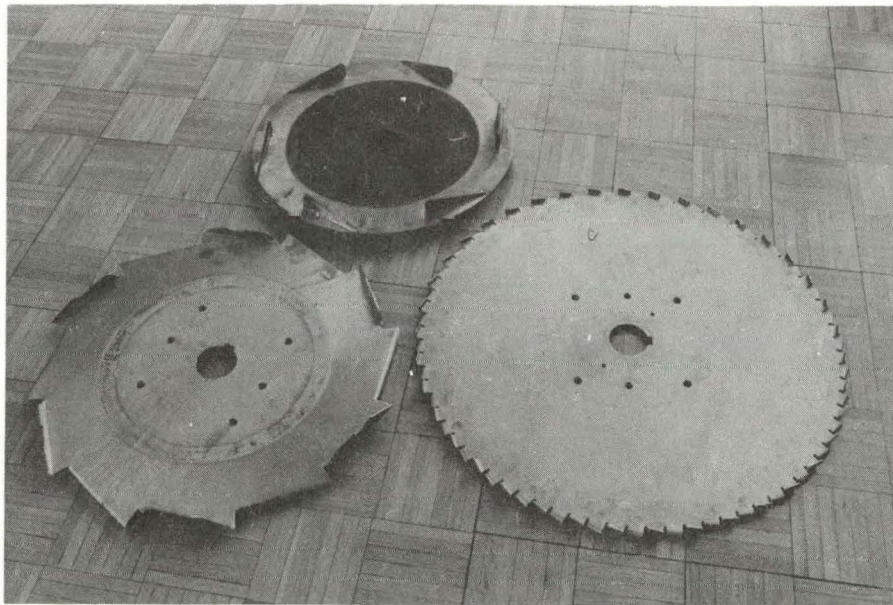


FIGURE 29. THREE DISPERSER BLADES

Top--22 inch diameter blade
Left--26 inch diameter blade
Right--30 inch diameter blade

Plastic disperser blades have been found to be effective and long lasting in some pigment dispersing operations. The disperser manufacturer submitted a 30-inch diameter polypropylene blade for testing. Blade wear was very rapid. No further consideration was given to plastic blades.

At this point Interlake looked for wear-resistant, disk-shaped blades from sources other than the disperser manufacturer. Two manufacturers and resharpeners of tungsten-carbide-tipped circular saw blades were located; modified saw blades were purchased for use as disperser blades. The first saw blade tested was one of the manufacturer's standard 24-inch diameter, carbide-tipped, 60-tooth, 0.196 inch kerf saw blades. It was modified to provide a shaft hole and keyway to fit the disperser, and eight additional holes 2-3/8 inches in diameter were placed near the outer edge to improve vertical mixing. When tested at 817 RPM, this blade drew only 90 amperes. Examination after the run showed little dulling or wear of the carbide inserts, but the relatively thin steel disk had cracked between a tooth root and a nearby circulation hole.

The other saw-type blade was designed by Interlake and was of much heavier construction. This blade was also 24 inches in diameter and had eight 3-inch diameter holes for vertical circulation, but the disk was 1/4 inch thick and had only 24 large carbide-tipped teeth. The tungsten carbide inserts were 1/4 inch thick and presented a 3/8 by one inch impact face.

Since the inserts were offset to the left or right on alternate teeth, the blade had a kerf of 1/2 inch. This blade proved to be very durable when operated at 817 RPM, and also appeared to offer satisfactory wear resistance at 1,111 RPM. The blade produced a rather coarse but usable COM at 817 RPM. COM produced at 1,111 RPM seemed much finer, judging by feel and appearance and the reduced grinding noises from the Gorator pump. Figure 30 shows one of these blades mounted in the disperser.

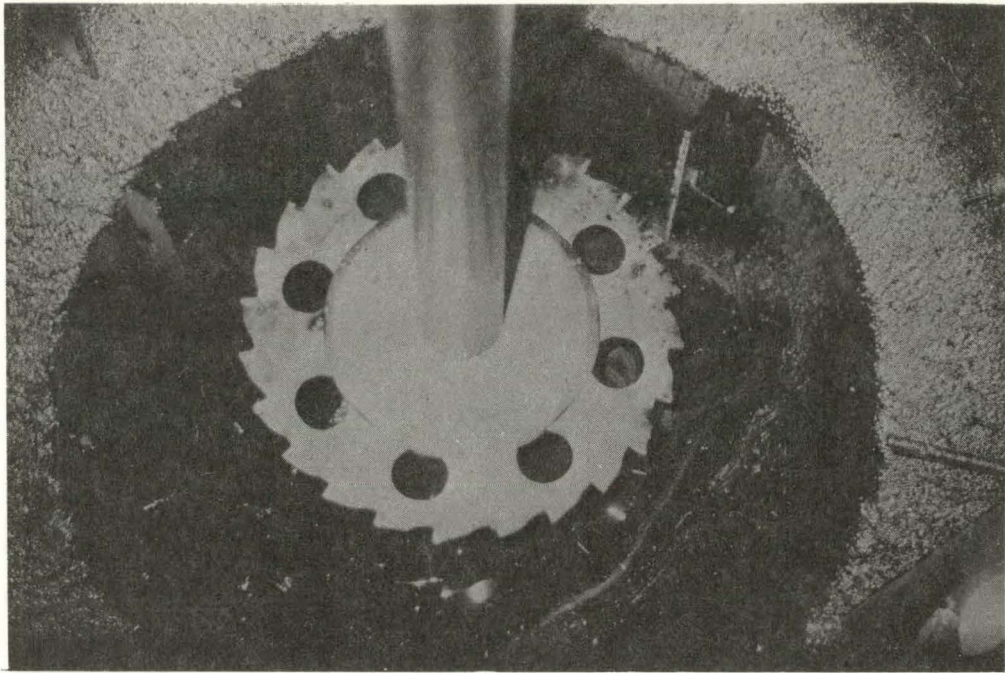


FIGURE 30. TUNGSTEN CARBIDE TIPPED BLADE MOUNTED IN DISPERSER

One of the heavy saw-type blades was modified to provide 16 additional vertical teeth similar to those on the original 22-inch blade, but fitted with one inch by 3/4 inch carbide inserts. Power draw increased as compared to the 24-tooth blade without added teeth -- 135 amperes vs 100 amperes at 817 RPM -- and stirring action was noticeably increased. Although the extra teeth offered some advantage, they were dropped from immediate consideration because of their increased cost and the difficulty of replacing the carbide tips on the vertical teeth. It was also felt that the flat blade could be run at high speed with increased power draw and improved grinding action.

In summary, only the heavy 24-inch carbide-tipped blade demonstrated good prospects for economical life. After running fifteen batches at 817 RPM and three batches at 1,111 RPM, the

carbide inserts showed almost no wear. Blades of this type were used exclusively during the Test Period.

IV.7.4.4.2 Demonstration Trial

During the Test Period, the carbide-tipped blades proved to be extremely abrasion resistant. The carbide inserts showed no wear that was visible to the naked eye after 317 batches had been made with one blade. The steel disk did show significant wear on the trailing edges of the holes that had been provided for improved circulation, and trailing along the centermost face of the carbide inserts. Figure 31 is a sketch of the blade showing its wear pattern.

The carbide tips failed by sudden and unpredictable massive fracture of most or all inserts. It is almost a certainty that these fractures were caused by impact with large, dense and hard bodies that entered the disperser as contaminants in the coal. The random nature of these blade failures is illustrated in Table 5.

TABLE 5. DISPERSER BLADE FAILURES

<u>Date Of Failure</u>	<u>Days To Failure</u>	<u>Number Of COM Batches To Failure</u>
August 30, 1981	13	121
September 3, 1981	4	37
September 10, 1981	7	97
September 30, 1981	20	317

The blades used in this test were fitted with tungsten carbide inserts of intermediate hardness and toughness. Blades fitted with softer and tougher tungsten carbide inserts were ordered when it appeared that we might run out of blades; however, they did not arrive in time to be placed under test.

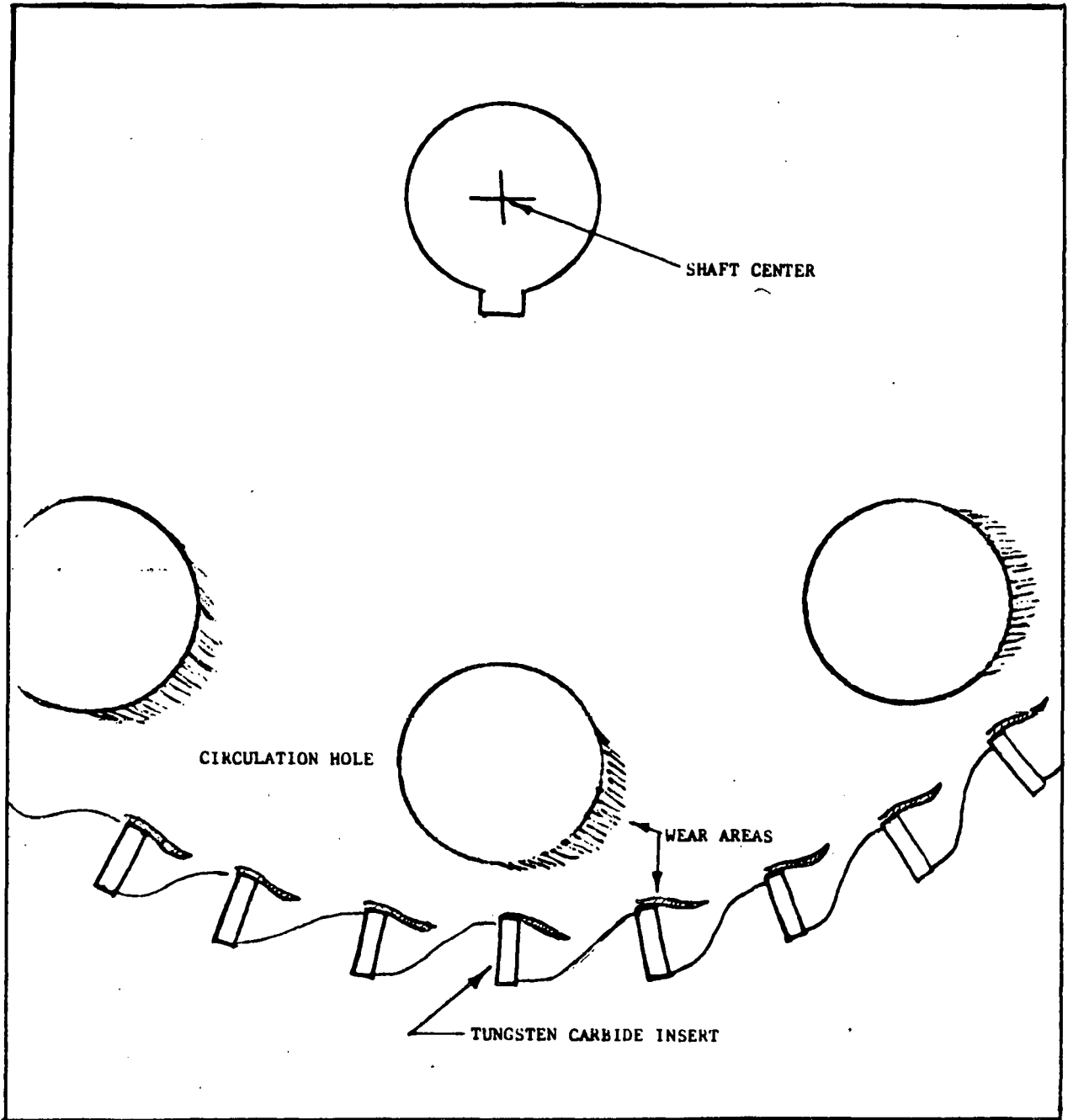


FIGURE 31. A SECTION OF A 24 INCH DIAMETER DISPERSER BLADE SHOWING TUNGSTEN CARBIDE INSERTS, CIRCULATION HOLES AND ASSOCIATED WEAR AREAS

The COM system was provided with sensors, and in some cases remote indicators or recorders, to allow monitoring of temperatures and pressures throughout the system, and tank levels as well as coal batch weight within the COM processing plant. Most of these sensors, indicators, and recorders worked well and were used throughout the test.

The instrumentation utilized within the COM plant to monitor production and recirculation of COM were the disperser temperature, heat exchanger outlet temperature, storage tank temperature, viscometer, densitometer, and storage tank level. A multipoint recorder located in the COM plant recorded this data. The multipoint recorder is depicted in Figure 32.

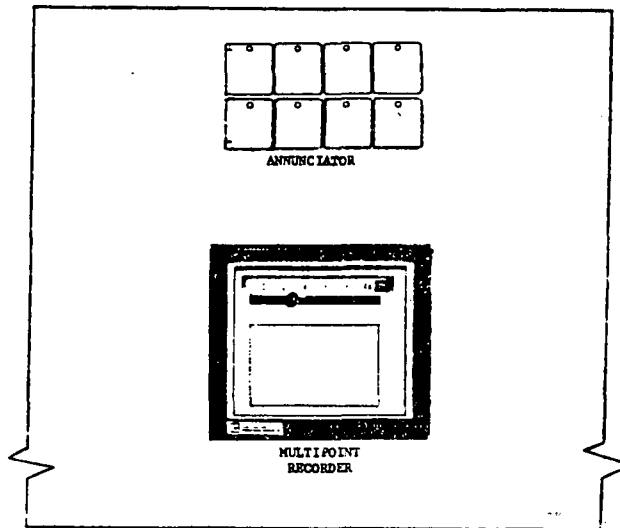


FIGURE 32. MULTIPOINT RECORDER

IV.7.5.1 Viscometer And Densitometer

A viscometer and a densitometer were installed in the recirculation-disperser drain circuit. The viscometer is a vibrating-rod type instrument. The viscometer did respond when freshly made COM passed through the system, but steady state readings were not obtained for recirculating COM between batches. Steady state was reached over night.

The densitometer is of the vibrating "U" tube type. It was not possible to maintain circulation through the densitometer during the test, but relocation of this instrument should allow uninterrupted density indication. Because reliable and continuous readings were not available from these instruments, density and viscosity were determined on composite samples at a commercial laboratory. Density was also determined daily in Interlake's own laboratory.

IV.7.5.2 Temperatures

Oil batch temperature, heat exchanger outlet temperature, and storage tank temperature were recorded. Recorded storage tank temperature response was very slow and did not seem to bear any relationship to actual storage tank temperature. The storage tank thermocouple should be relocated. Dial thermometers within the piping at various locations were provided to allow routine observation of temperature.

The temperature of the COM coming from storage was measured by dial thermometers installed at the injection pump and at the blast furnace cast house. Average storage tank temperature was 172°F. Figure 33 illustrates the daily average COM storage temperatures during the Test Period.

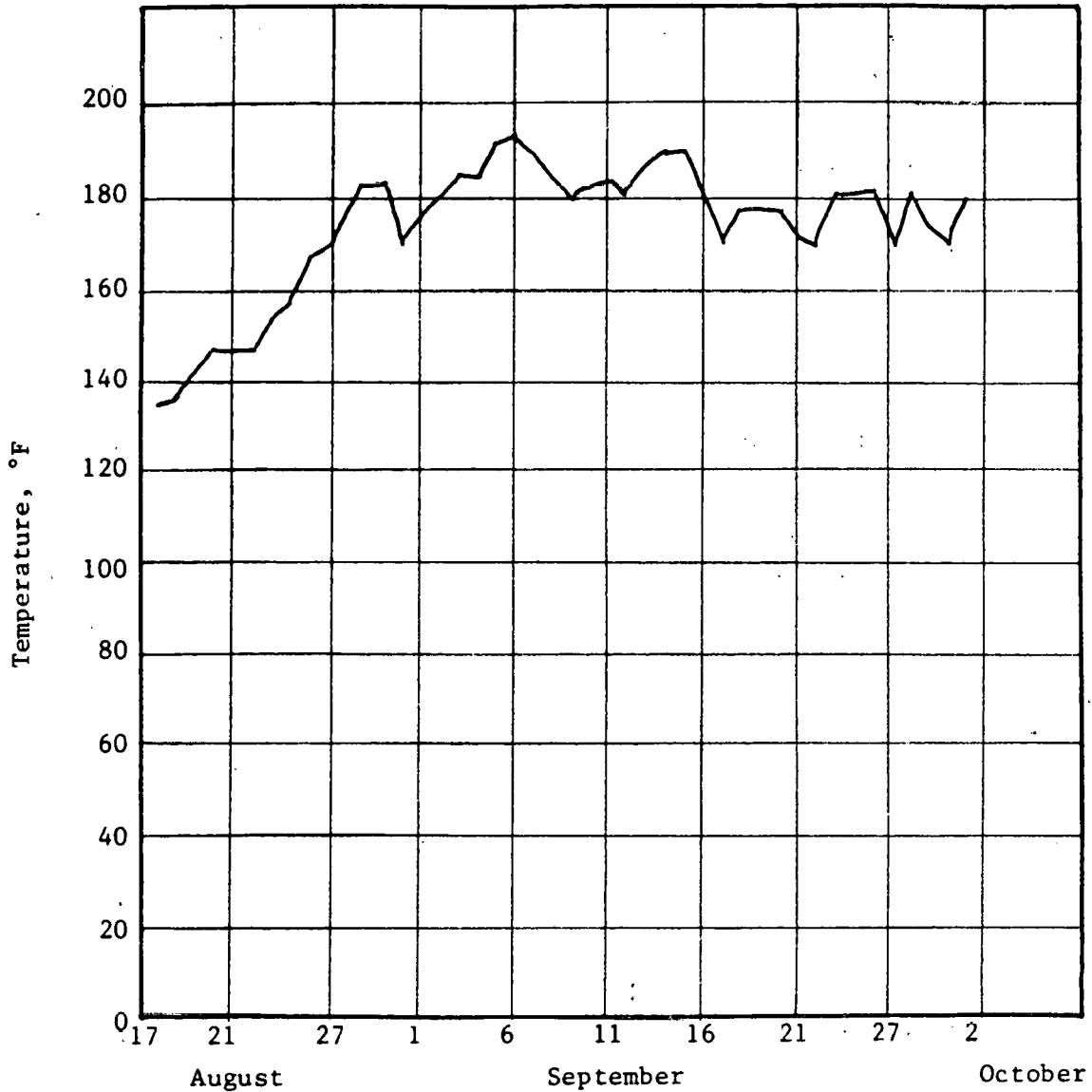


FIGURE 33. DAILY AVERAGE STORAGE TANK TEMPERATURE

Temperatures measured at the cast house were generally higher than those measured at the pump. Even if one allows for possible error in the dial thermometers, it appears that the heat tracing and insulation at least maintained the temperature of the COM as it was pumped from the storage tank to the furnace. COM temperature at the cast house varied from 160°F to 196°F and averaged 180°F for the entire period.

IV.7.5.3 Pressures

Pressure was measured at a number of points in the recirculation and injection loops. Pressure gauges were fitted with diaphragm isolators at several of these locations. Some of the non-isolated gauges plugged from time to time and had to be replaced. The piston pump used in this test gave a pulsating pressure. Isolators and snubbers would aid control by giving a single pressure reading rather than a range of readings indicated by a pulsating pressure gauge needle. Pressures in the injection circuit are shown in Figure 34.

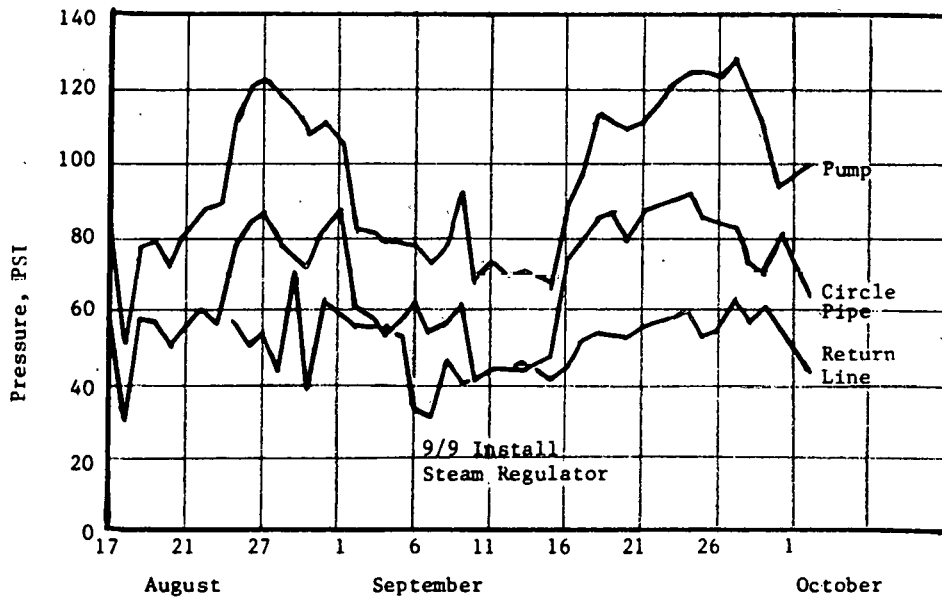


FIGURE 34. INJECTION CIRCUIT PRESSURES

IV.7.5.4 Storage Tank Level Detector

An electronic level detector, based on the damping of an immersed high frequency radio antenna, was installed in the COM storage tank to provide continuous indication of tank level and alarms for high and low level.

This level indicator performed well for its intended purpose. It became necessary, however, to provide tank level readings to the nearest inch to confirm COM usage rates. For this purpose a float and cable system was installed during the course of the test.

An alarm panel in the COM processing building indicated, by flashing lights and a horn, abnormal or dangerous operating conditions. This alarm panel signaled low COM storage tank level, high disperser tank level, water-emulsifier mixer tank low level, and automatic processing stop.

IV.7.5.5 Control Panel

The control panel is fitted with lights to indicate that batch tanks are filled, motors are running, and valves are opened or closed. The weight of coal in the batch weigh hopper is indicated to the nearest pound on a digital readout. With this array of annunciator lights, the weight readout, and three process timer clocks, it is possible to evaluate the status of the processing system from a brief scan of the control panel. A second annunciator panel in the Furnace Office signals high COM pressure, low COM pressure and low COM temperature.

IV.7.6 Summary Of COM Plant Operation

During the 44-day trial, approximately 485,000 gallons of COM were produced (approximately 600 batches). Valuable experience

was gained in the operations within the COM plant and in the use of the following equipment:

1. Coal Handling -- crane versus pneumatic versus belt conveyor
2. Magnetic Separator
3. Bucket Elevator
4. Disperser And Disperser Blades
5. Gorator, Tuthill, and Worthington Pumps

Filling of the coal hopper with the inclined belt conveyor was a far less dusty and more feasible method than either the crane or pneumatic truck. Problems with the crane technique involved the tendency of the reclaiming bucket to pick up foreign material from the ground. The use of the pneumatic truck was too slow for COM production requirements and, on some days, necessitated reductions in the amount of coal used per batch. The pneumatic truck also pulverized the coal (98% minus 1/8 inch), dried, and fluffed the coal to such an extent that fluid-like flow was sometimes experienced beyond the storage hopper.

Damp, fine coal tended to stick to the magnetic roll and was diverted to the magnetic reject pile. Therefore, compressed air was used to blow adhering coal off the magnetic roll. Some problems were encountered early in the program with fine coal burying the bucket elevator.

The two 800-gallon working capacity dispersers operated well throughout the trial. Some draining problems were encountered at the start of each day's COM-making operations. As many as 17 batches could be made during an 8-hour shift using a 30-minute batch time. Finish temperature could be controlled well by utilizing the disperser steam jacket.

Significant improvements were made with disperser blade life. Early work, using 1020 steel, resulted in severe wear after only

ten batches. Using tungsten carbide inserts resulted in 317 batches being made with no visible wear of the tips.

Three pumps are operated within the COM plant: 1) the Gorator grinding pump which grinds any coal exceeding 1/8 inch size as it drains from the disperser, 2) the Tuthill transfer pump for pumping freshly made COM into the storage tank and for recirculating COM, and 3) the Worthington duplex steam pump which delivers COM to the blast furnace at high pressure for injection into the tuyeres.

The Gorator pump rotor plate and liner bars are the critical parts providing the grinding action. Four rotor plate and liner bar changes required during the trial showed the Gorator to be the most critical piece of equipment prone to wear. The Tuthill pump worked well throughout the Test Period in spite of considerable wear.

On several occasions, coarse coal particles in the COM prevented the ball check valves of the Worthington pump from sealing properly, resulting in jamming of the steam pump. It was found that coarse debris and coarse coal particles could generally be flushed from the valve chamber with No. 6 fuel oil supplied under pressure to the pump inlet.

Finally, the system was provided with instrumentation -- sensors, indicators or recorders -- to allow monitoring of COM temperature and pressure at various locations throughout the plant.

SECTION V

INJECTION OF COM INTO 'B' FURNACE

V.1 Piping Arrangement

The pipeline from the COM plant to 'B' Furnace is 4 inches in diameter; the return line from the furnace back to the COM plant is 3 inches in diameter. The circle pipe around 'B' Furnace is 2 inches in diameter, with 3/4 inch pipe branches feeding from the top of the circle pipe to the individual lances. The 3/4 inch lines enter three-way regulating valves and proceed through 3/4 inch piping to the lance hoses. Both 1/2 inch and 3/4 inch hoses were tested during this program. Lances were made of 3/8 inch Schedule 80 pipe at the start of the trial. Figure 35 shows the circle pipe and the hose and lance arrangement at one of the tuyeres.

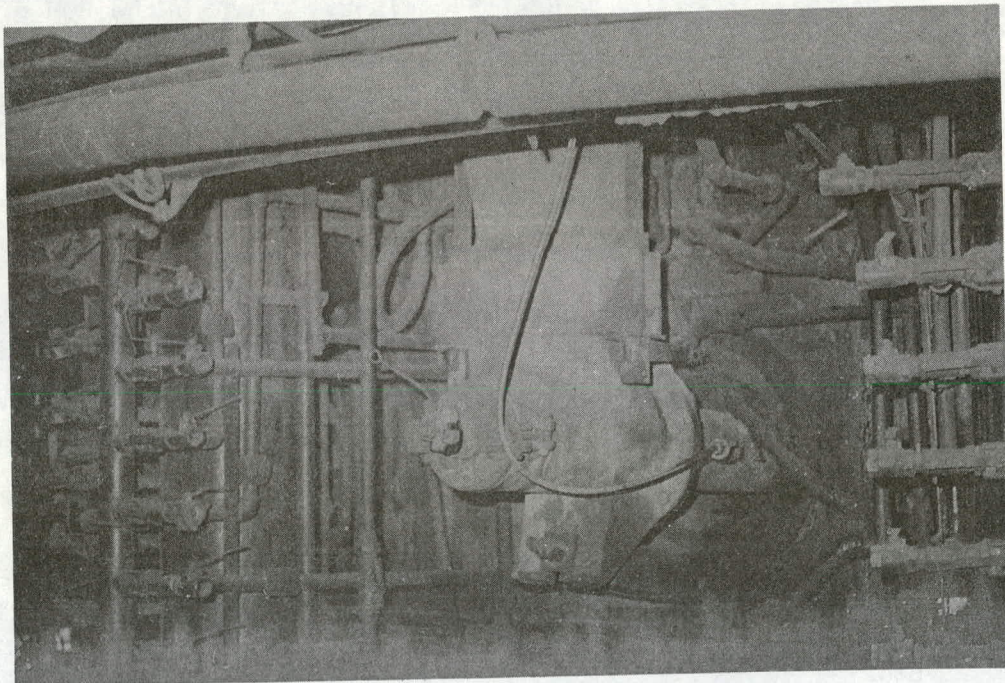


FIGURE 35. CIRCLE PIPE AT TOP AND TUYERE WITH HOSE AND LANCE AT CENTER OF PHOTOGRAPH

The coal-oil mixture was pumped 650 feet from the storage tank to the blast furnace. Figure 36 shows a schematic of the pipelines, as well as the manifold bypass and circle pipe arrangement, at the start of the test.

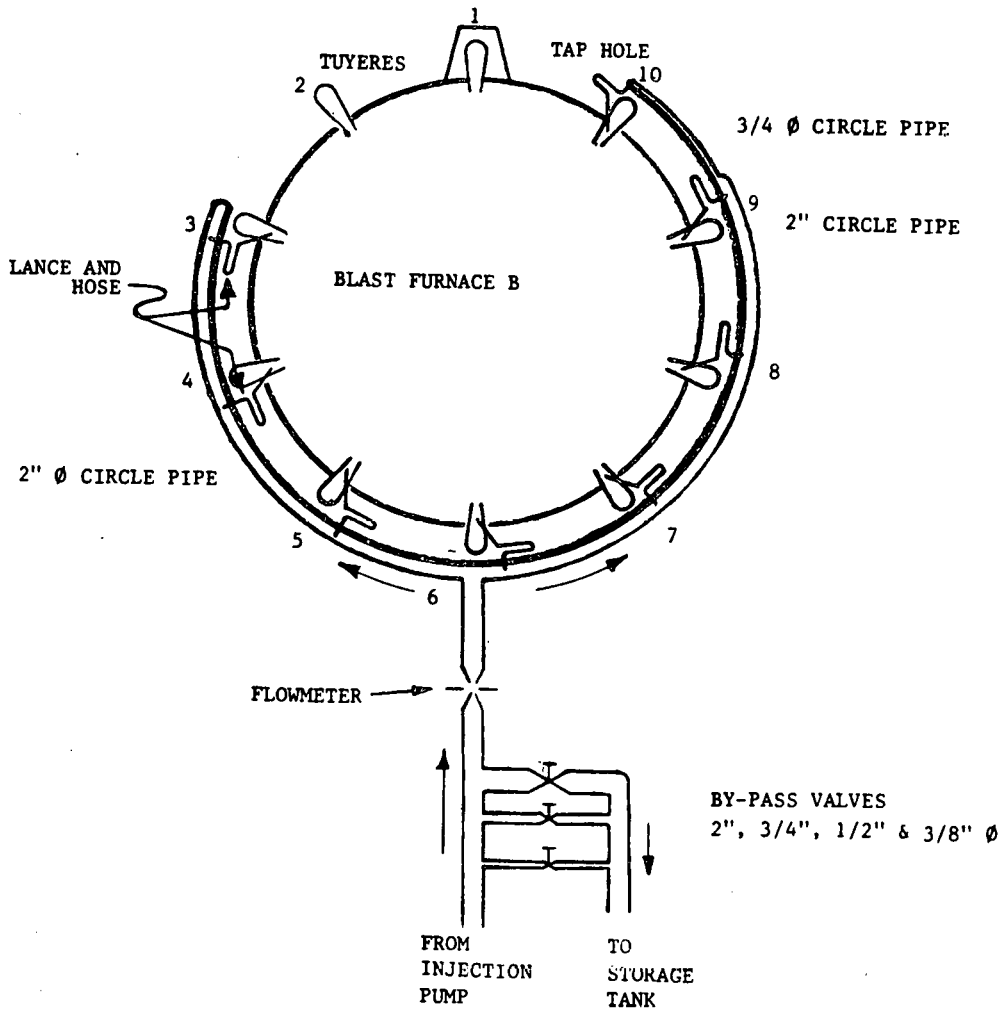


FIGURE 36. COM SUPPLY LINE AND CIRCLE PIPE AT START OF TEST

An unexpected problem was the unreliable operation of the mass flowmeter. The mass flowmeter was designed to tie into the controller in the Furnace Office, so that COM flow rate could be set and automatically regulated at the desired rate with the controller. As a result of electrical problems, the mass flowmeter

could not be made to operate properly. Therefore, flow rate was controlled by manual settings of the Worthington steam pump and valves in the bypass manifold. During the sixth week of the project, a Brown electric flowmeter system was installed to measure the flow rate.

V.2 Injection Lance And Circle Pipe Modifications

The plugging of injection lances was a serious problem at the beginning of the demonstration program. A number of factors contributed to these problems. These factors included injection lance diameter, circle pipe design and piping, and steam purge systems. After several piping modifications were made, instances of injection lance plugging were reduced considerably.

When injection began on August 17th, 3/8-inch Schedule 40 lances were installed in tuyeres Nos. 3, 6, and 8. Other tuyeres were fitted with lances as the test progressed. During the first week of testing, generally No. 6 and No. 8 lances stayed open; however, Nos. 3, 4, and 10 were difficult to keep open. Figure 37 illustrates the lance observation report for the August 21 - 24 period. Additional lance observation reports are in Appendix A.

On August 26th, one-inch return lines were installed from the ends of the circle pipe at No. 3 and No. 10 tuyeres and were piped back to the circle pipe near No. 6 tuyere. This is shown in Figure 38. It was theorized that the "dead end" of the 2-inch circle pipe at tuyere No. 3 was the cause of the continual plugging at No. 3 lance.

The new return lines as well as any exposed steel on the circle pipe were insulated. Following this modification, the plugging problems moved to No. 6 tuyere. Although No. 3 lance appeared to stay open for longer periods of time, No. 6 lance, which rarely plugged before the return line modification, now plugged more frequently.

10	O O O O O P P P P P P O P O O O P P O O P P P P P P P Pulled																															
9	Not In Use → → → → →																															
8	O P O O O O O O O O O O O P O O O O O O O O O O O P O O O O																															
7	Not In Use → → → → →																															
6	O O O O O O O O O O O O O P O O P P O O O O P O O O O O O O O O																															
5	Not In Use → → → → →																															
4	Pulled Pulled → O O O P P P O O P O P P O Pulled → O P																															
3	P P C O O P P P P O O O O O Pulled → P P P P O P P P P																															
Total # Of Lances Open	3	2	4	4	4	2	2	2	2	4	4	5	3	2	3	4	2	1	4	3	2	3	1	2	2	2	2	2	2	3	3	
Injection Rate, CPM	1.6				4.5								3.3				4.2															
Time	August 21				August 22								August 23				August 24															
	3:30 P.M.	5:30 P.M.	8:00 P.M.	10:15 P.M.	11:00 P.M.	12:00 A.M.	3:00 A.M.	6:00 A.M.	8:00 A.M.	10:30 A.M.	12:00 P.M.	3:30 P.M.	7:50 P.M.	12:00 P.M.	11:00 A.M.	3:30 P.M.	5:00 P.M.	6:15 P.M.	8:00 P.M.	9:45 P.M.	12:00 A.M.	3:30 A.M.	5:45 A.M.	8:00 A.M.	10:00 A.M.	2:00 P.M.	4:40 P.M.	6:15 P.M.	6:40 P.M.	8:00 P.M.	9:35 P.M.	11:00 P.M.

FIGURE 37. TYPICAL LANCE OBSERVATION REPORT

(P = plugged and O = open at time of observation)

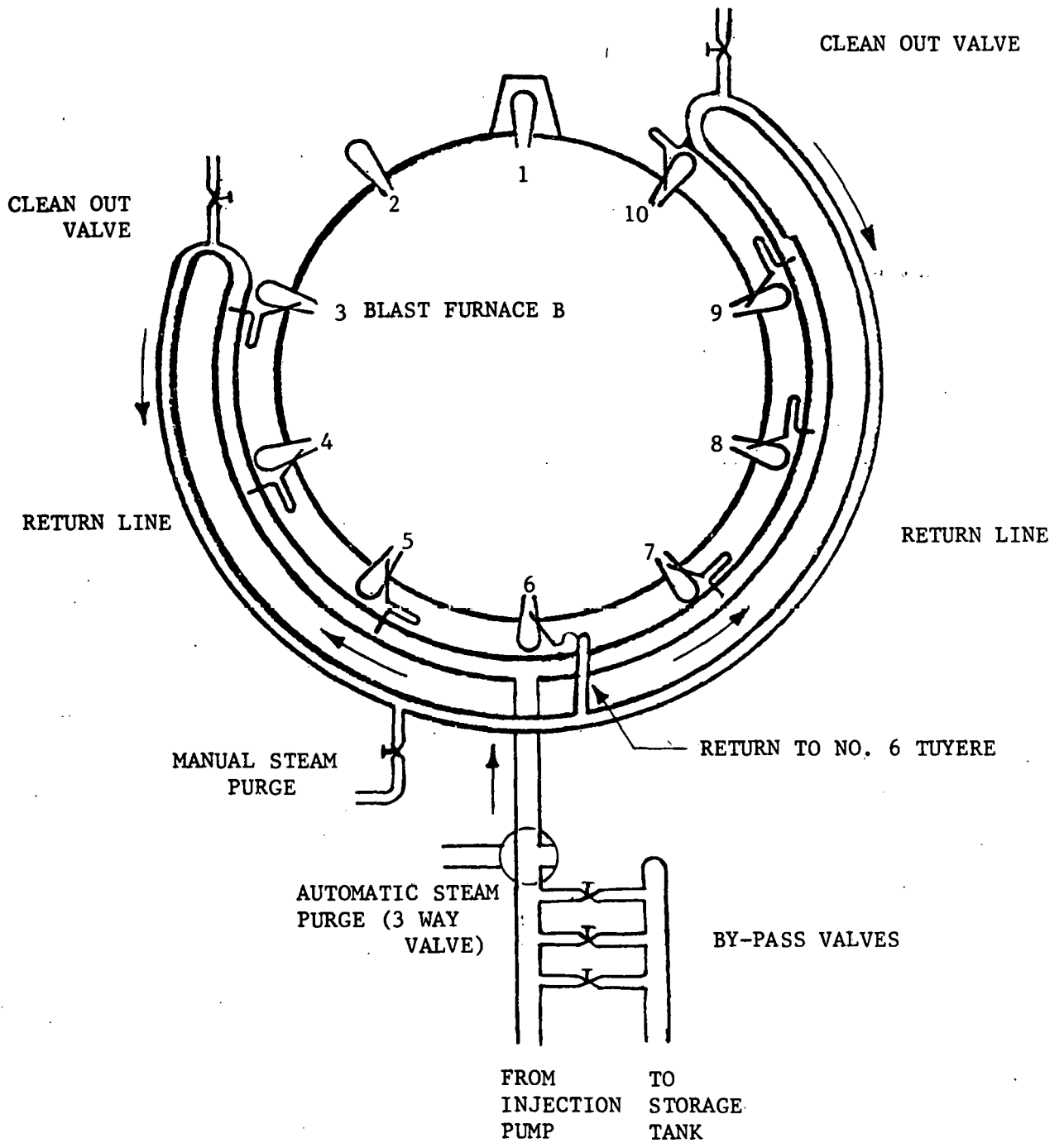


FIGURE 38. FIRST STAGE MODIFICATION OF BLAST FURNACE B CIRCLE PIPE

Following disperser blade and Gorator rotor plate and liner bar replacement, difficulties were experienced in maintaining a target flow rate of 7 gpm thru four lances. Flow rate tended to run higher than 7 gpm. An attempt to regulate the flow with the three-way valve at each lance was unsuccessful. Consequently, smaller lances were tried. Lances No. 4 and No. 8 were switched to 1/4 inch Schedule 40, and No. 3 and No. 6 were maintained with 3/8 inch Schedule 80. When the lances stayed open, the flow was successfully reduced to the target of approximately 7 gpm on September 8th. However, plugging problems developed at Nos. 3, 4, and 6 with this lance arrangement. It was concluded that 1/4 inch Schedule 40 pipe is too small for a lance.

It was believed that part of the plugging problem was due to coal settling out because of the large number of 90° bends between the circle pipe and lances. A survey of the furnace piping revealed the following count of 90° elbows between the furnace and circle pipe:

TABLE 6. NUMBER OF 90° ELBOWS AT THE FURNACE

<u>Lance No.</u>	<u>No. Of 90° Elbows</u>
3	4
4	6
5	5
6	6
8	7

A meeting was held with operating personnel to discuss the plugging problems experienced in the lances and hoses, and to work up a field design change in the circle pipe. The following changes were agreed upon September 9th:

- 1) Use 3/4 inch diameter hoses in place of the 1/2 inch I.D. hoses leading to the lances.
- 2) Minimize the number of 90° elbows between the circle pipe and the lances by using flexible hoses all the way from the lances to the three-way valves.

- 3) Pipe one-inch return lines from the circle pipe into the 3-inch return line to the COM storage tank.
- 4) Pipe No. 6 lance directly into the furnace from the circle pipe.

By September 16, only one 90° bend was present between the circle pipe and each lance. The piping, shown in Figure 39, was now suitable for handling the target 14 gpm injection rate. At this higher injection rate, six lances were used -- Nos. 3, 4, 5, 6, 8 and 10.

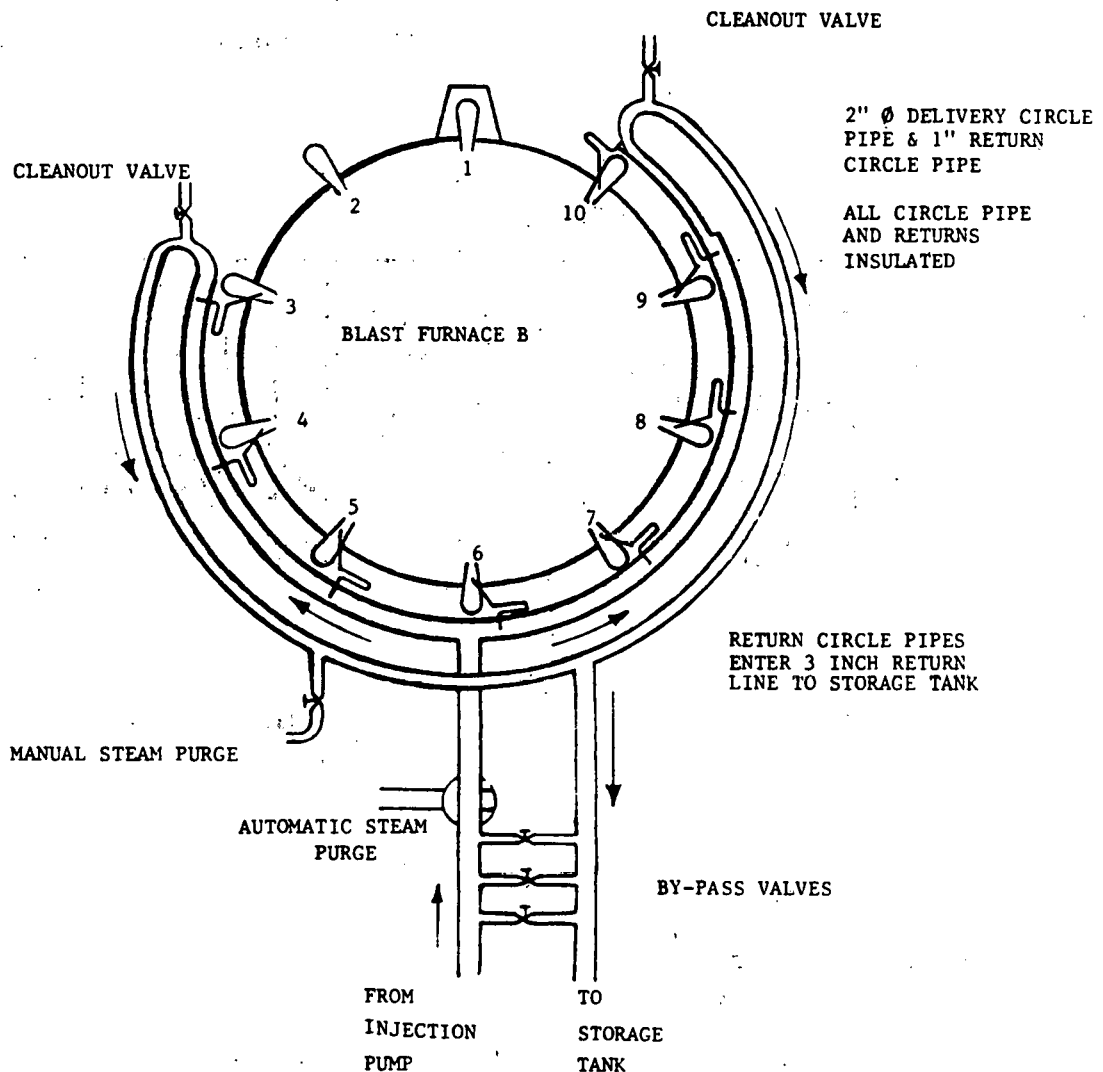


FIGURE 39. CIRCLE PIPE AND RETURN LINES AT END OF TEST

A definite improvement in COM flow at the lances was observed following the circle pipe modifications. As long as the one-inch return lines remained open, return flow from the circle pipe aided in moving the COM.

Figure 40 illustrates the reduction in plugged lances as the program progressed and circle pipe and lance modifications were made. The percent of plugging refers to the percentage of time the lances were found plugged during the routine daily checks. Note the significant decrease in plugged lances the day following a grinding pump rotor and liner bar replacement, indicated by arrows. These replacements resulted in a finer grind of coal-oil mixture.

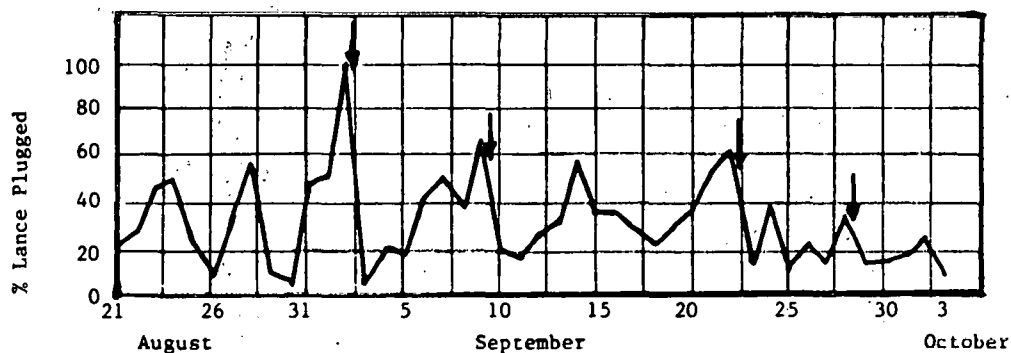


FIGURE 40. PERCENT LANCES PLUGGED - Arrows Indicate Grinding Pump Rotor And Liner Bar Replacement

V.3

Steam Purge System

The circle pipe was designed to accommodate manual as well as automatic steam purging. With the circle pipe return line modifications, manual steam purge lines were connected to the

return lines as well. (See Figure 39 in Section V.2). The manual steam purge system, illustrated in Figure 39, also includes clean-out valves at No. 3 and No. 10 tuyeres that could be opened to allow for a reverse flush of the one-inch return line.

The automatic steam purge system was designed so that the injection of COM into the furnace could be shut off automatically, and all coal-oil mixture would be recirculated through the bypass manifold and back to the COM storage tank. Simultaneously, the circle pipe and injection lances would be purged with steam. A push button control for the automatic purge was located in the cast house control room. Frequently, insufficient dry steam was available to completely purge the 50 feet of circle pipe plus the associated branch pipes, hoses and lances. Thus it was often necessary to use the manual purge system.

V.4

Flowmeters

The COM system was provided with a Micro Motion flowmeter, a Honeywell controller, and a steam throttling valve, to allow closed loop control of the COM flow into the blast furnace. In preliminary tests, closed loop control was obtained. Sensitivity and response times proved to be suitable for this application, and the flow indicator at the controller was calibrated against a known output from the positive displacement injection pump. Figure 17, in Section III of this report; shows the Micro Motion meter and associated piping.

The Micro Motion flowmeter uses gyroscopic principles to measure mass flow as the measured fluid passes through a vibrating "U" tube. This meter was selected for COM service because its flow readings are independent of the density, temperature and viscosity of the measured fluid, and no parts move except the vibrating "U" tube. Shortly into the present test program, problems developed in the electronic portion of the flowmeter, and Interlake and Micro Motion engineers decided the meter was

inoperable in its present condition. The manufacturer recommended factory updating modification of the electronic unit.

It was not possible to delay the tests while these modifications were made. Therefore, the test was continued with frequent "dip-stick" measurement of the COM storage tank level to allow calculation of flow rates. An adjustment of steam flow to the injection pump was used to regulate flow. At this time it was planned that the variable area flowmeter, that had been routinely used to measure oil flow to the blast furnace, would be relocated to measure COM flow.

The variable area flowmeter and its circular chart recorder - controller were Brown Instruments (Honeywell Inc.) units. Figure 41 illustrates a cross section of the flowmeter.

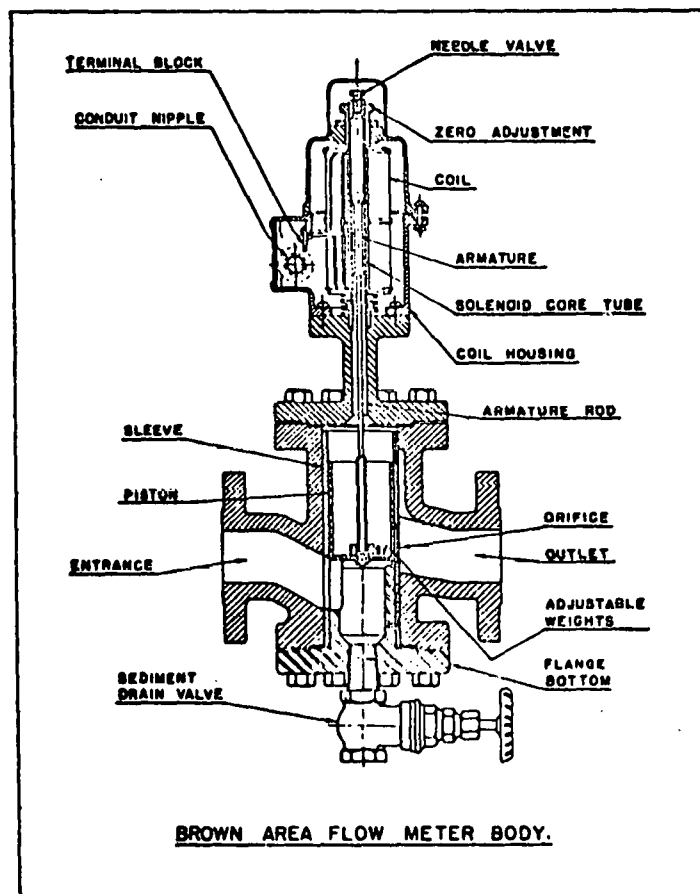


FIGURE 41. CROSS SECTION THROUGH BROWN FLOWMETER

The new location of the variable area flowmeter is shown in Figure 42. The controller was not connected to any throttle valve, therefore, the control loop was not closed. The flowmeter was placed at the COM storage tank, and was piped so that it measured COM as it was withdrawn from the storage tank. The measured COM was mixed with recirculated COM downstream from the flowmeter, and was subsequently pumped to the blast furnace. This piping arrangement, shown in Figure 42, caused some problems since the COM lost temperature in the return line, and the cool COM returning from the furnace was not exchanged for hot COM from the storage tank. Occasionally it was necessary to enrout the recirculated COM into the storage tank in order to increase the flow of hot COM into the injection system.

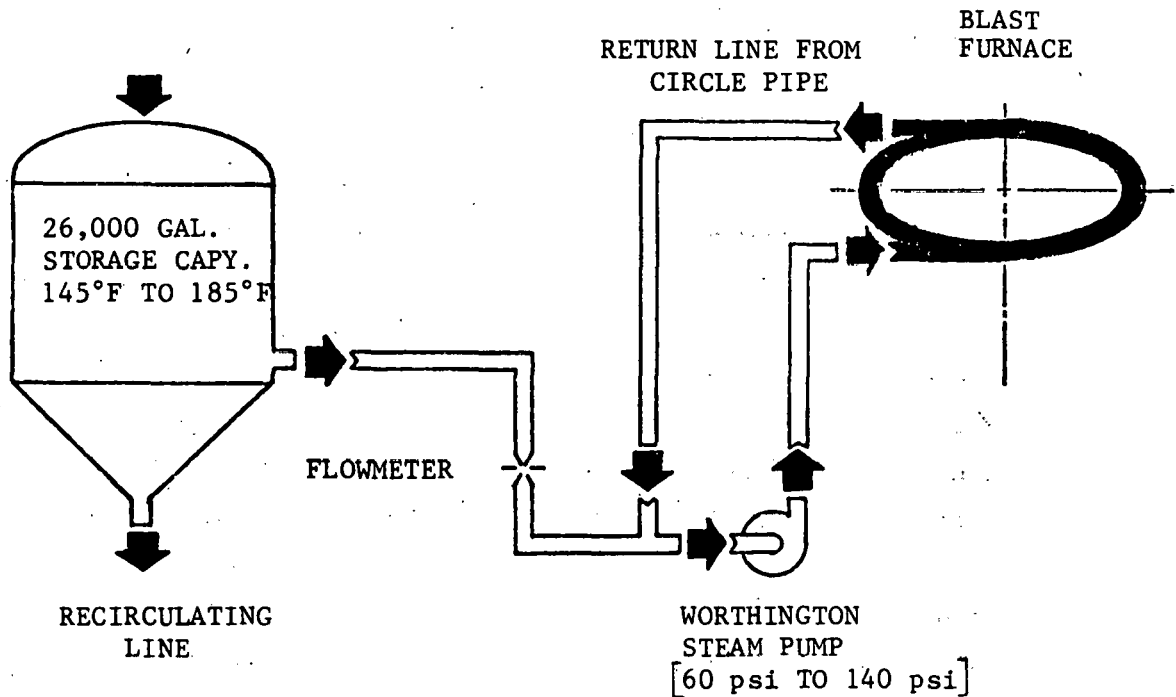


FIGURE 42. BROWN FLOWMETER LOCATED ADJACENT TO STORAGE TANK

Figure 43 is a copy of the flowmeter chart from September 24. The chart runs from 5:00 P.M. September 24 to 4:30 P.M. September 25, and the flow range for No. 6 fuel oil is 0 to 25 gallons per minute. The flowmeter was found to read higher than actual flow when used with COM. Although the meter was not recalibrated to the actual COM flow rate, the relative values indicated on the flow recorder were useful for monitoring and controlling the injection operation. The chart clearly shows when 4, 5 or 6 lances were in operation, and shows that flow rates were relatively uniform over extended periods when no lances plugged. The sector of the chart between 8:45 P.M. and 11:30 P.M., for example, shows a 2.75 hour period with 6 lances in operation and a very uniform rate of injection.

Figure 44 is a plot of indicated flow vs the number of lances actually injecting COM. The indicated flow rates were read from recorded flows on September 24 and 29.

The number of lances operating had been noted on the charts at the time of the recording. Correlation between flow rate and number of lances was excellent, 0.99, on both days. The slopes of the two lines were somewhat different, as would be expected since pressure and viscosity were not the same on both days. The two curves intercept the Y axis at about 4.5 gpm, indicating that the meter was not properly zeroed. If 4.5 gallons per minute are subtracted from the indicated readings, the differences would then be in reasonable agreement with known COM usage rates.

It is therefore possible to interpret the slopes of the two lines as representing flow rates of 2.78 and 2.30 gallons per minute per lance.

This flowmeter was subject to plugging and had to be opened up with steam on several occasions. The sawtooth trace between 10:00 A.M. and 12:00 P.M., in Figure 43, may indicate that the

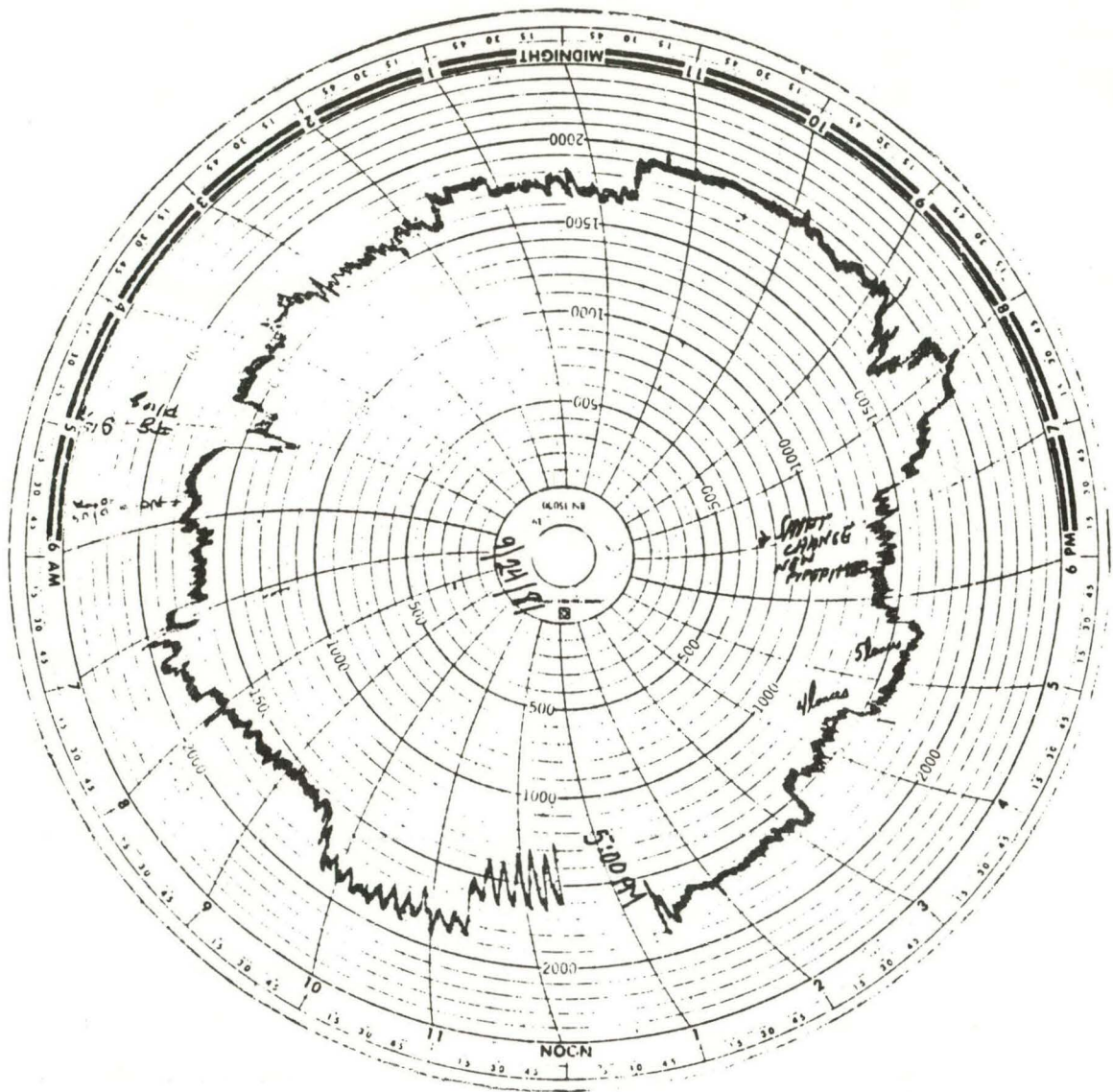


FIGURE 43. FLOWMETER CHART SEPTEMBER 24, 1981

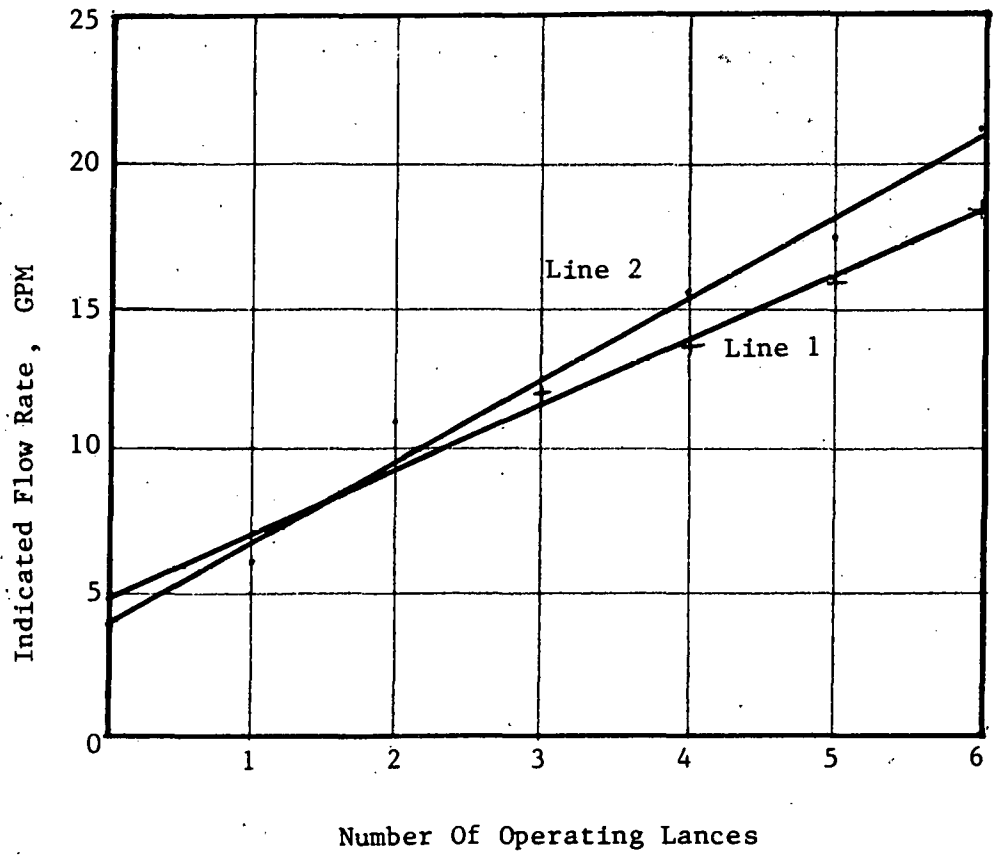


FIGURE 44. INDICATED FLOW RATE vs NUMBER OF OPERATING LANCES PER BROWN VARIABLE AREA FLOWMETER

Line 1 - 9/24/81, $Y = 2.30 X + 4.9$, Correlation 0.994

Line 2 - 9/29/81, $Y = 2.78 X + 4.2$, Correlation 0.994

meter was tending to plug and clear itself at about 10 minute intervals.

Neither flowmeter provided entirely satisfactory measurement, but the variable area flowmeter, or an updated Micro Motion flowmeter, might prove satisfactory if recirculated COM flow rate were increased sufficiently to minimize COM cooling problems.

V.5

Summary Of Injection Of COM Into 'B' Furnace

During the 44 days of the blast furnace trial, considerable progress was made towards the reliable and uniform injection of COM into 'B' Furnace. Lance, hose and even circle pipe plugging had been severe problems at the start of the test. Increased COM temperature provided rapid improvement in operations, but lance plugging incidents were still too frequent.

Stepwise modification of the circle pipe, to provide continuous COM flow past all lance branch lines, and a systematic campaign to eliminate 90° elbows from branch lines, provided further improvement in lance operating time. Selection of 3/8 Schedule 40 pipe for lances was the final step made during the test.

SECTION VI

COM COMPOSITION AND ANALYSIS

As stated earlier, the target COM composition for the demonstration trial was 50% coal, 45% No. 6 fuel oil, 4.5% added water and 0.5% emulsifier. Actual composition for the 44-day trial came very close to this goal -- 47.95% coal, 47.59% No. 6 fuel oil, 4.02% added water and 0.44% emulsifier.

The 44-day trial was divided into four periods for the purpose of evaluating the effect of COM on blast furnace operations at different injection rates. These periods and their corresponding average injection rates are shown in Table 7. Period V, the entire 44-day trial, is included in this table.

TABLE 7. COM INJECTION PERIODS AND RATES

<u>Period</u>	<u>Inclusive Dates</u>	<u>COM Injection Rate, gpm</u>
I	August 20-August 24, 1981	3.76
II	August 25-September 9, 1981	7.58
III	September 9-September 16, 1981	5.00
IV	September 17-October 2, 1981	10.80
V	August 20-October 2, 1981	7.91

For evaluating furnace performance, Periods II and IV were sub-divided to exclude days when little or no COM was injected, or to highlight an interval of exceptionally good operation. These sub-divisions have no bearing on the composition or analysis of COM and will not be considered further here.

The composition of the COM produced during each of the four Test Periods is shown in Table 8. These figures were calculated from the weights of the raw materials used to produce batches. The weights of raw materials and the data on batch production are also included in Table 8. With the exception of batch count, which is an actual count, the data for Period V represent weighted averages from Periods I through IV based on the number of batches made per period.

TABLE 8. COMPOSITION OF COAL-OIL MIXTURE

PARAMETER	INJECTION PERIOD				
	I	IIA & IIB	III	IVA, IVB, & IVC	V
Weight Per Batch, Lb					
Coal	3616	3473	3600	3642	3578
Oil	3575	3564	3550	3538	3551
Added Water	300	300	300	300	300
Emulsifier	33	33	33	33	33
Composition, % Wt.					
Coal	48.06	47.12	48.11	48.48	47.95
Oil	47.51	48.36	47.44	47.09	47.59
Added Water	3.99	4.07	4.01	3.99	4.02
Emulsifier	0.44	0.45	0.44	0.44	0.44
No. Of Batches	45	190	76	262	573
Calculated Batch Volume					
At 175°F, Gal	835	822	834	837	831
At 60°F, Gal	815	802	814	817	811
Calculated Gravity					
At 175°F, Lb/Gal	9.011	8.966	8.972	8.976	8.980
At 60°F, Lb/Gal	9.232	9.190	9.193	9.196	9.201

VI.1.1 Raw Materials For COM

VI.1.1.1 Coal

The coal used in this trial was a low-volatile coal, a 1:1 blend of Sewell and Pocahontas No. 4 coals from McDowell County, West Virginia. The weight of coal per batch varied from a low of 2,900 lbs. on August 28 to a high of 3,700 lbs. Most batches were made with 3,600 lbs. of coal, the average coal weight being 3,578 lbs. per batch for the 44-day trial. Lower weights were used when necessary to stretch the coal supply when it was running low.

The most serious problems in this regard occurred during the first half of Period II when the pneumatic truck was being used to deliver coal. The original target coal weight of 3,700 lbs. per batch was used sparingly because of concern about overfilling the coal weigh hopper. This happened several times during the preliminary tests in early 1980. The coal weigh hopper is slightly undersize for this plant. The analyses of coal by period are presented in Table 9.

VI.1.1.2 Fuel Oil

The variations in batch oil weight, shown in Table 8, for the different injection periods were due to small differences in the specific gravity of the oil. Oil volume was held constant at 465 gallons per batch at 175°F, which is equivalent to 445 gallons at 60°F, the temperature at which specific gravities are measured. The chemical analysis, gravity, kinematic viscosity and heating values of the oil used during each period are listed in Table 10. Viscosity data at 150°F, 170°F and 190°F are shown in Table 11. These measurements were made according to ASTM Method D2196, "Rheological Properties Of Non-Newtonian Material", for comparison with the viscosity of COM which was measured in this manner.

TABLE 9. COAL USED FOR COM

PARAMETER	INJECTION PERIOD				
	I	IIA & IIB	III	IVA, IVB, & IVC	V
Water, %	3.84	4.70	5.91	7.06	5.87
% Dry Basis					
Volatile Matter	16.40	17.49	17.80	16.98	17.21
Fixed Carbon	77.85	75.62	76.06	77.01	76.49
Ash	5.75	6.90	6.14	6.01	6.30
SiO ₂	2.71	2.86	2.66	2.91	2.84
Al ₂ O ₃	1.31	0.99	1.33	1.24	1.17
Fe ₂ O ₃	0.76	0.89	0.61	0.49	0.66
MgO	0.19	0.21	0.09	0.09	0.14
CaO	0.44	0.32	0.13	0.24	0.27
Na ₂ O	0.04	0.04	0.04	0.04	0.04
K ₂ O	0.06	0.05	0.04	0.05	0.05
Carbon (Ultimate)	86.02	85.00	85.51	85.85	85.54
Hydrogen	4.37	4.26	4.26	4.22	4.25
Nitrogen	1.27	1.22	1.33	1.26	1.26
Chlorine	0.12	0.12	0.12	0.12	0.12
Sulfur	0.72	0.75	0.73	0.71	0.73
Oxygen	1.75	1.75	1.91	1.83	1.80
BTU/LB (Dry Basis)	14845	14584	14629	14745	14684
Screen Size, %					
On 1 Inch	0	0	1.31	0.88	0.58
On 1/2 Inch	0.23	6.66	13.22	14.82	10.76
On 1/4 Inch	0.73	9.44	23.02	24.78	17.57
On 1/8 Inch	1.37	8.62	21.63	12.83	11.70
On 20 Mesh	9.04	17.68	21.63	22.84	19.88
On 35 Mesh	10.32	9.57	6.53	13.08	10.83
On 50 Mesh	17.49	9.23	4.16	4.19	6.90
On 100 Mesh	43.74	14.12	4.16	4.35	10.66
On 200 Mesh	16.35	21.19	4.08	2.05	9.79
Thru 200 Mesh	0.73	3.49	0.26	0.18	1.33

ADDITIONAL DATA

Source: McDowell County, West Virginia

Seam: 1:1 Blend Of Sewell And Pocahontas No. 4 Coals

Hardgrove Grindability Index : 92

Apparent Specific Gravity: 1.314

TABLE 10. OIL USED FOR COM

PARAMETER	INJECTION PERIOD				
	I	IIA & IIB	III	IVA, IVB, & IVC	V
Carbon, %	87.25	87.19	86.97	87.11	87.13
Hydrogen, %	11.33	11.35	11.43	11.40	11.38
Sulfur, %	0.85	0.87	1.10	0.86	0.89
Ash, %	0.14	0.03	0.04	0.04	0.04
Water, %	0.40	0.10	0.05	0.03	0.08
Sediment, %	0.89	0.04	0.09	0.03	0.11
Gravity					
Specific @ 60/60°F	0.9646	0.9617	0.9580	0.9546	0.9582
Lb/Gal @ 60/60°F	8.033	8.009	7.978	7.950	7.980
° API	15.2	15.6	16.2	16.7	16.2
Viscosity @ 122°F					
Kinematic (Centistokes)	271	279	280	297	-
Heating Value					
Cross BTU/Lb.	18406	18670	18762	18664	18659
Net BTU/Lb.	17372	17634	17719	17624	17620
Gross BTU/Gal.	147860	149525	149680	148380	148891
Net BTU/Gal.	139550	141237	141360	140117	140609

TABLE 11. VISCOSITY OF OIL USED FOR COM

RPM	Viscosity, cp				
	@ 150°F		@ 170°F		@ 190°F
	No. 4 Spindle	No. 2 Spindle	No. 4 Spindle	No. 2 Spindle	No. 4 Spindle
SUB-PERIOD II, 8/25/81 - 8/31/81					
6	*	70	*	55	*
12	100	65	*	47.5	*
30	120	60	140	46	40
60	120	60	110	46	100
30	120	58	120	42	60
12	100	55	*	37.5	*
6	*	55	*	40	*
6 After standing 2 min.	*	*	*	45	*
SUB-PERIOD IV, 9/17/81 - 9/23/81					
6	100	85	100	45	*
12	150	80	100	45	*
30	160	77	100	45	80
60	150	71	100	46.5	90
30	160	69	100	44	100
12	150	70	100	42.5	*
6	100	65	100	40	*
6 After standing 2 minutes	100	65	100	45	*

* No reading could be made -- off scale. No. 2 spindles were used where indicated in order to obtain a more precise determination.

Method: ASTM D2196, Rheological Properties Of Non-Newtonian Materials

VI.1.1.3 Water And Emulsifier

The quantities of water and emulsifier added per batch were held constant throughout the trial. Each batch contained 40 gallons of water-emulsifier mixture containing 10% emulsifier. The emulsifier used was EM-23D, a product of the Tretolite Division of the Petrolite Corporation.

VI.1.2 COM Analyses

VI.1.2.1 Analysis Of Batch COM

Most of the analytical work was reserved for COM going to the blast furnace, to characterize the material being injected. A number of batch samples were taken from the disperser, however, and four of them were analyzed. These samples were obtained by reaching into the disperser through the access opening at the top using a 600 ml stainless steel beaker fitted with a long handle.

The COM was transferred immediately to covered sample containers. Samples were obtained one minute before the disperser stopped at the end of the processing cycle. This was done to help assure a representative sample with the dispersers still operating, yet comminution of the coal was essentially complete.

The compositions, partial chemical analyses, coal screen analyses and final temperatures for the four batch samples are in Table 12. The August 28 batch contained only 2,900 lbs. of coal, the lowest coal concentration during the program. The September 8, 10 and 18 batches contained 3,600 lbs. of coal. The small differences in the composition of the three September samples were due to small differences in the specific gravity of the oil. Viscosity data at 150°F, 170°F, and 190°F for the August 28 and September 18 samples are listed in Table 13.

TABLE 12. ANALYSIS OF COM IN DISPERSER

PARAMETER	8/28/81	9/8/81	9/10/81	9/18/81
Composition, % Wt.				
Coal	42.67	48.02	48.11	48.19
Oil	52.43	47.54	47.44	47.35
Added Water	4.41	4.00	4.01	4.02
Emulsifier	0.49	0.44	0.44	0.44
COM Analysis, % Wt.				
Water	6.6	4.6	5.1	6.9
Ash	2.28	2.52	3.00	2.40
Sulfur	0.99	1.01	0.69	0.70
Screen Size, % Wt.				
On 20 Mesh	11.3	12.1	11.7	19.0
On 35 Mesh	10.9	14.1	10.4	17.6
On 50 Mesh	10.9	12.4	10.6	12.7
On 100 Mesh	15.7	14.3	14.3	14.1
On 200 Mesh	16.9	11.1	12.1	11.4
Thru 200 Mesh	34.3	36.0	40.9	25.2
Final Batch Temperature,				
°F	190	192	180	186

TABLE 13. VISCOSITY OF COM IN DISPERSER

RPM	Viscosity, cp		
	@ 150°F	@ 170°F	@ 190°F
Batch From 8/28/81			
6	1300	1000	600
12	1100	700	550
30	920	600	460
60	800	500	380
30	880	580	400
12	1000	750	450
6	1100	700	500
6 After standing 2 minutes	1200	700	500
Batch From 9/18/81			
6	2000	1000	700
12	1550	800	600
30	1140	640	460
60	980	580	400
30	1080	600	460
12	1300	750	550
6	1500	800	600
6 After standing 2 minutes	1600	900	600

Method: ASTM D2196, Rheological Properties Of Non-Newtonian Materials.

VI.1.2.2 Analysis Of COM At The Blast Furnace

Samples of COM were obtained at the casthouse each shift during the trial. The only exceptions were a few shifts when COM was not being injected; these interruptions will be discussed elsewhere. Individual samples were analyzed for water, ash and sulfur contents. Many of the samples were tested for coal particle size distribution. These data provide a day-to-day record of COM quality and are shown in Figure 45. In this figure the daily chemical analyses represent the average of the analyses of the three shift samples.

More complete analyses were run on composite COM samples for injection Periods I-IV. These samples were made by combining equal volumes of individual shift samples and mixing thoroughly. The chemical analyses, gravities, heating values and coal particle size distributions for these period samples are presented in Table 14. The data listed in Table 14 for Period V were calculated based on a weighted average of the number of batches made during each of the four individual injection periods.

The viscosity data for the period COM samples at 150°F, 170°F, and 190°F are listed in Table 15. Two samples were tested for Period II; they are identified as Sub Period II, 8/21/81-8/31/81, and Sub-Period II, 9/1/81-9/9/81. This separation was made to isolate COM produced using pulverized coal that had been delivered by the pneumatic truck from COM that was made using run-of-mine coal delivered by the conveyor belt. Two samples were tested for Period IV as well. They are identified as Sub-Period IV, 9/17/81-9/23/81, and Sub-Period IV, 9/24/81-10/2/81. This division was prompted by the high ash analyses for the September 24-October 2 shift samples.

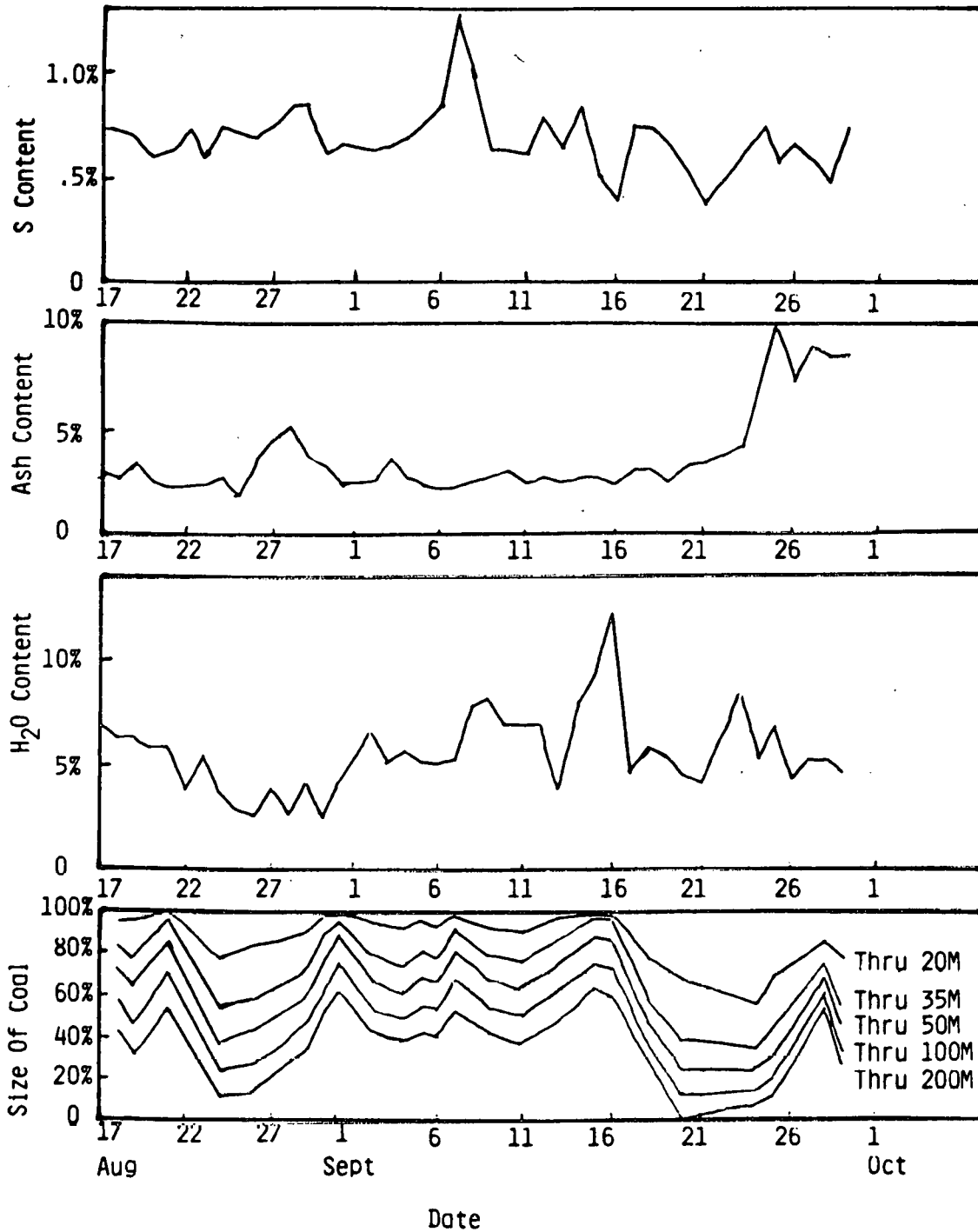


FIGURE 45. ANALYSES OF DAILY COM SAMPLES

TABLE 14. COM. SAMPLED AT THE BLAST FURNACE

PARAMETER	Injection Period				
	I	IIA & IIB	III	IVA, IVB, IVC	V
Analysis, % Wet Basis					
Water	5.60	6.06	7.03	6.03	6.14
Carbon	82.33	81.18	79.93	80.44	80.77
Hydrogen *	8.15	7.92	8.33	7.58	7.84
Sulfur	0.69	0.59	0.63	0.68	0.64
Ash	2.52	3.04	2.92	5.93	4.30
Gravity					
Specific @ 60/60°F	1.12	1.13	1.12	1.19	1.16
Lb/Gal @ 60°F	9.34	9.42	9.34	9.92	9.67
Heating Value					
Gross BTU/LB	15833	15885	15521	15262	15548
Net BTU/LB	15089	15162	14761	14570	14833
Gross BTU/GAL, 60°F	147880	149637	144966	151399	150349
Net BTU/GAL, 60°F	140931	142826	137867	144534	143425
Screen Size, %					
On 20 Mesh	6.7	19.2	10.1	24.3	19.3
On 35 Mesh	22.3	22.2	12.3	23.1	21.3
On 50 Mesh	16.1	13.7	9.0	13.2	13.0
On 100 Mesh	18.2	13.4	11.7	11.3	12.6
On 200 Mesh	13.3	9.6	9.3	6.6	8.5
Thru 200 Mesh	23.4	21.9	47.6	21.5	25.3

* Includes Hydrogen From Water

TABLE 15. VISCOSITY OF COM SAMPLES AT THE BLAST FURNACE

RPM	Viscosity, cp		
	@ 150°F	@ 170°F	@ 190°F
<u>PERIOD I, 8/20/81 - 8/24/81</u>			
6	1400	1200	500
12	1350	1000	500
30	1140	760	460
60	1030	720	420
30	1020	720	440
12	1153	850	500
6	1300	900	500
6 After standing 2 minutes	1400	1000	500
<u>SUB-PERIOD II, 8/25/81 - 8/31/81</u>			
6	2700	1300	1100
12	2150	1100	950
30	1760	1020	700
60	1550	920	600
30	1640	900	660
12	1900	1000	700
6	2200	1100	800
6 After standing 2 minutes	2200	1100	700
<u>SUB-PERIOD II, 9/1/81 - 9/9/81</u>			
6	2000	1300	800
12	1600	1000	700
30	1320	840	580
60	1200	730	500
30	1200	740	560
12	1300	850	600
6	1500	900	700
6 After standing 2 minutes	1500	1000	600
<u>PERIOD III, 9/10/81 - 9/16/81</u>			
6	2000	1300	900
12	1600	1015	800
30	1300	900	580
60	1140	800	540
30	1200	860	600
12	1400	1050	650
6	1500	1100	700
6 After standing 2 minutes	1600	1300	700
<u>SUB-PERIOD IV, 9/17/81 - 9/23/81</u>			
6	2500	1600	1500
12	2100	1250	1000
30	1700	1100	860
60	1420	940	730
30	1520	1000	740
12	1750	1150	900
6	2000	1200	1000
6 After standing 2 minutes	2300	1400	1000
<u>SUB-PERIOD IV, 9/24/81 - 10/2/81</u>			
6	3500	1800	1000
12	2550	1650	900
30	2040	1240	740
60	1840	1120	680
30	1840	1200	700
12	2050	1400	800
6	2300	1500	900
6 After standing 2 minutes	2500	1600	900

METHOD: ASTM D2196, RHEOLOGICAL PROPERTIES OF NON-NEWTONIAN MATERIALS

Discussion On COM Chemical Analyses

Table 16 compares the analyses of COM sampled at the blast furnace to theoretical analyses calculated from the amounts and analyses of the raw materials used to produce it. In general, these data compare very well. The main deviations from calculated values are the high ash content determined for the COM used in Period IV, somewhat higher specific gravities, particularly in Period IV, and somewhat lower moisture contents in the samples tested from Periods I, II, and IV.

TABLE 16. ANALYSIS OF COM-CALCULATED vs ANALYSIS OF COMPOSITE SAMPLES

COMPONENT	Injection Period				
	I	IIA & IIB	III	IVA, IVB, IVC	V
Calculated					
Water, %	6.03	6.33	6.87	7.42	6.87
Carbon, %	81.44	80.60	80.28	80.08	80.39
Hydrogen, %*	8.09	8.15	8.16	8.14	8.14
Sulfur, %	0.73	0.76	0.85	0.72	0.75
Ash, %	2.73	3.12	2.81	2.74	2.87
Gravity, Lb/Gal @ 60°F	9.23	9.19	9.19	9.20	9.20
Analyzed					
Water, %	5.60	6.06	7.03	6.03	6.14
Carbon, %	82.33	81.18	79.93	80.44	80.77
Hydrogen, %*	8.15	7.92	8.33	7.58	7.84
Sulfur, %	0.69	0.59	0.63	0.68	0.64
Ash, %	2.52	3.04	2.92	5.93	4.30
Gravity, Lb/Gal @ 60°F	9.34	9.42	9.34	9.92	9.67

* Includes Water

High ash values are also evident in the daily results reported in Figure 45 starting September 24. COM analyses for some of these days showed higher ash levels than the 6.01% ash contained in the coal, yet the COM contained only 48.48% coal. Oil ash content was only 0.04% in Period IV. Contamination was ruled out as the source of the high ash because the coal samples were obtained at the vibrating feeder immediately above the disperser. Beyond that point there is no place for foreign material to enter the system.

The high ash levels in the Period IV COM samples are attributed to ash, and possibly some coal, settling in the COM line near the sample taps, and the subsequent wash-out of this ash into the sample container during sampling. Two factors contributed to this phenomenon:

- 1) The sample taps were located in the COM return line at the piping manifold used to manually adjust pressure between the blast furnace and return to storage. This is a region of multiple 90° elbows and throttled manual valves, conditions that favor settling.
- 2) The velocity of COM in the return line fell too low due to a shortage of pumping capacity. The steam pump used to deliver COM to the furnace was rated at 30 gpm and was usually cut back to 25-27 gpm. This was necessary because the pump was being used as part of the manual flow control system following failure of the automatic flow control system at the onset of the trial. The velocity of COM in the delivery circuit was low at all times. Velocity in the 4-inch supply line was 0.66 feet per second (FPS) when the pump was delivering 26 gpm. Velocity in the return line was at a minimum during Period IV when the injection rate was highest. Table 17 lists typical COM velocities in the return pipe during the trial. Although the average injection rate for Period IV was 10.8 gpm, this figure includes downtime. The injection

rate was 14-17 gpm much of the time. At an injection rate of 16 gpm, velocity in the 3-inch return line was only 0.43 fps. This low velocity apparently allowed heavier particles to settle in the line, and they subsequently bled into the sample container with the sample. The settling of solids in the return line during Period IV was serious enough to cause a blockage between the COM plant and the blast furnace on September 30 forcing a one-day shutdown.

TABLE 17. COM VELOCITY IN DELIVERY CIRCUIT

<u>Line</u>	<u>Injection Period</u>	<u>COM Delivery Rate, GPM</u>	<u>COM Use Rate, GPM</u>	<u>COM Return Rate, GPM</u>	<u>COM Velocity, FPS</u>
4-inch Supply	All	26	-	-	0.66
3-inch Return	-	26	0	26	1.13
	I	26	3.76*	22.24	0.97
	II	26	7.58	18.42	0.80
	III	26	5.00	21.00	0.91
	IV	26	10.80	15.20	0.66
	V	26	7.91	18.09	0.79
	=	26	16.00	10.00	0.43

* Use Rates For Periods I-V Are Average Injection Rates

Interlake's overall experience with the COM plant from late 1979 through the end of this trial includes 7 months of recirculating COM to the casthouse. There were no line pluggings in the supply or return line prior to September 30, 1981. It appears that a velocity of 0.66 fps is adequate to maintain suspension of the COM, but a break point is reached somewhere between 0.66 and 0.43 fps and heavy particles begin to settle. A higher capacity pump would resolve this problem. Relocating the sample taps to a point on the supply side away from elbows would also

be beneficial.

Referring to Table 16 again, the specific gravities of the COM for Periods I-III were found to be slightly higher than calculated values. Though analytical error cannot be ruled out completely, the data most likely reflect small positive deviations in the specific gravity from values calculated by the addition of specific volumes of raw materials. The influence of slight moisture losses is not significant. The high gravity for the Period IV COM reflects the additional solids that were drawn into the samples as a result of settling in the return line.

The generally lower moisture contents of the analyzed samples, as compared to calculated moisture levels, is attributed to the loss of moisture in storage. These losses were aided by the practice of bubbling air into the bottom of the COM storage tank to help minimize any settling.

Due to the introduction of settled solids in the samples obtained for Period IV, the analyses shown in Tables 14 and 16 do not accurately represent the COM that was injected into the blast furnace during that period. This, in turn, leads to erroneous data for Period V since those analyses were calculated from the analyses of Period I-IV samples. To more accurately describe the analyses of COM used in Periods IV and V, an analysis for COM injected into the blast furnace during Period IV was synthesized as follows: the values that were calculated from the amounts and analyses of raw materials used during that period were adjusted to reflect the loss of moisture in storage.

Specifically, the calculated values listed for Period IV at the top of Table 16 were adjusted to dry basis, then were recalculated to a moisture level of 6.03%, the actual moisture content of the Period IV composite sample.

The analysis of COM for Period V was then calculated using the actual analyses for Periods I-III and the synthesized analysis for Period IV. The results, shown in Table 18, represent the COM that was injected into the blast furnace during each of the four injection periods, and the weighted average analysis of COM used over the entire 44-day trial.

VI.1.4 Discussion On COM Coal Particle Size

The particle size distribution of the coal in the COM can be viewed as a function of five variables: (1) the grindability of the coal, (2) disperser operation characteristics, (3) the size of the raw coal used, (4) the number of times the COM passes through the in-line grinding pump, and (5) the condition of the grinding pump with respect to wear. For all practical purposes, coal grindability and disperser operation characteristics were constant throughout the demonstration trial. Therefore, differences in COM coal particle size distribution must be due to changes in one or more of the other three variables listed above.

TABLE 18. ANALYSIS OF COM INJECTED INTO BLAST FURNACE

COMPONENT	Injection Period				
	I	IIA & IIB	III	IVA, IVB, IVC	V
Water, %	5.60	6.06	7.03	6.03	6.14
Carbon, %	82.33	81.18	79.93	81.28	81.15
Hydrogen, %*	8.15	7.92	8.33	8.10	8.07
Sulfur, %	0.69	0.59	0.63	0.73	0.67
Ash, %	2.52	3.04	2.92	2.78	2.86

* Includes Hydrogen From Water

The size of the coal used during injection Periods I-IV is compared with the size of the coal in corresponding COM samples in Figure 46. Table 19 lists the number of times the COM for each period passed through the Gorator grinding pump, and the average number of days wear on the grinding pump for each period. The number of passes through the grinder was estimated from the total volume of COM produced each period; a recirculation flow rate of 200 gpm, the rating of the transfer pump, was assumed.

The period of finest COM coal grind was Period III, followed by Period I, Period II and Period IV in the order of increasing size. Yet Period III had the largest size incoming coal, followed by Period IV, Period II and Period I in the order of decreasing size. Clearly, the particle size of the incoming coal did not directly control the particle size of the coal in the COM.

Period I COM had the highest number of passes through the in-line grinder, 38 times. However, Period I COM showed relatively minor size reduction as compared to the coal used, and it contained substantially less minus 100 mesh and minus 200 mesh coal than Period III COM which passed through the grinder 32 times.

Despite a relatively low number of passes through the grinder, 18 times, the coal in Period IV COM showed an effective size reduction second only to Period III. Size reduction for Period II, with 30 passes through the grinder, was only a modest improvement over Period I. It is evident that the number of passes through the grinding pump was not the primary factor in determining final COM coal particle size.

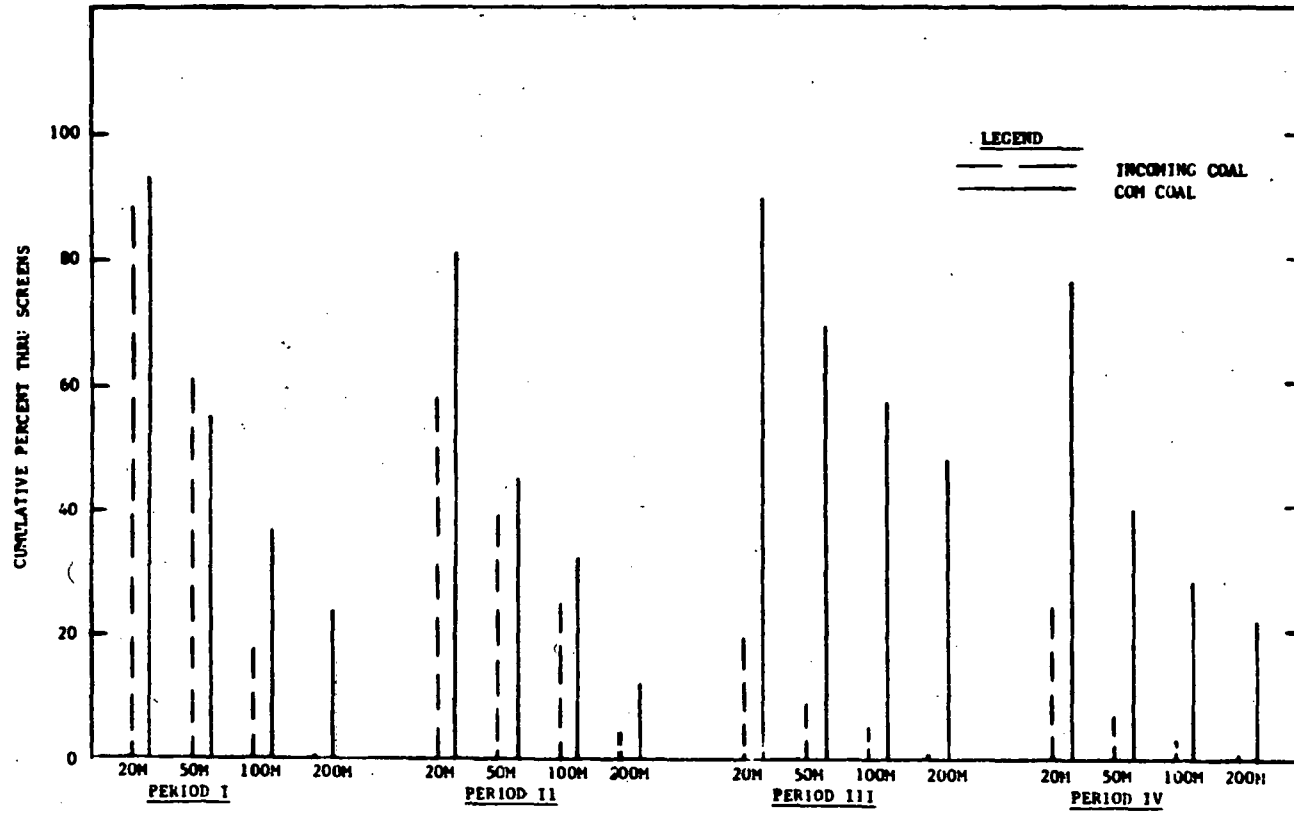


FIGURE 46. COMPARISON OF INCOMING AND COM COAL PARTICLE SIZE.

TABLE 19. USE AND CONDITION OF IN-LINE GRINDING PUMP

Period	Days In Period	Grinder Operating Days	COM Made, Gal. @ 175°F	Passes Thru Grinder	Average Days Wear On Grinder
I	5	5	37575	38	16 *
II	16	16	156180	30	13
III	7	7	63384	32	4
IV	16	14	219294	18	5
V	44	42	476433	25.4	9

* Pump started August 6 to recirculate several batches of COM in storage tank from preliminary trials.

The variable that had the greatest influence on final coal particle size was the amount of wear on the internal grinding pump parts. During Period III, when the largest size incoming coal was reduced to the smallest size COM coal, Gorator parts wear averaged only 4 days. Period IV ranked second to Period III in overall coal size reduction despite the relatively low number of passes through the grinding pump. Gorator parts had an average of 5 days wear in Period IV. Periods I and II showed relatively minor coal size reductions in spite of a high number of passes through the grinder in each case. The average wear on the Gorator parts for these periods was 16 days and 13 days, respectively.

SECTION VII

METALLURGICAL EFFECT OF COM ON BLAST FURNACE OPERATION

VII.1

Introduction

The metallurgical objectives of blast furnace COM injection trials were to demonstrate the feasibility of COM production at the plant site and its injection into a blast furnace, and to determine the effect of COM injection on blast furnace operation. The trials included a Base Period and a Test Period. The Base Period lasted 28 days, from March 30 through April 26, 1981, when No. 6 fuel oil was injected into 'B' Blast Furnace at 5.3 gallons per minute. The Test Period lasted 44 days, from August 20 through October 2, 1981, when the average COM injection rates for various sub-periods varied from 3.8 to 13.0 gpm.

The blast furnace operation, furnace productivity, iron quality and total fuel consumption were of particular interest during the injection trials. In addition, operating variables such as coke rate, fuel oil and COM injection rates, metallic burden, flux stone burden, hot metal temperature and analysis, wind rate, blast temperature and moisture were compared for these periods.

The coke replacement value of COM was determined by analyzing the Base and Test Periods according to the Flint Coke Rate Formula. Before the application of the Flint Coke Rate Formula, reliability of the data was ascertained on the basis of iron and carbon balances for the Base Period and for the sub-periods of the COM trial period.

Combustion of COM in the blast furnace was discussed on the basis of actual observations. The effect of COM injection on combustion zone gas characteristics was also reviewed on a theoretical basis and compared with the effect of fuel oil injection.

Finally, an appraisal was made of the economics of COM production and injection into the blast furnace and its implications for reducing the nation's dependency on imported fuel oil.

VII.2 Procedures Followed At The Blast Furnace

VII.2.1 Data Generation And Accumulation

Routine plant procedures were adhered to for data generation during the Base Period and Test Period. The exception to this routine was the collection of information on COM production, COM quality and COM injection, which has been meticulously documented in Sections IV, V and VI.

VII.2.2 Procedure For Sampling And Testing Raw Materials And Various Operating Parameters

The routine procedure for sampling and testing relevant input and output materials were as follows:

Coke -- Coke samples were collected once each 8-hour shift, or three times a day. Each shift sample was screen tested for size distribution. Each shift sample was also tested for ASTM stability and hardness. Daily composite samples were analyzed for proximate analysis.

Erie Pellets and Wabush Pellets -- Pellet samples were collected once each day from the furnace stockhouse and tested for screen size. Chemical compositions of pellets were determined only for the samples collected from the incoming pellet shipments.

Roger Ore -- Chemical composition was determined for samples collected from the incoming shipments.

Iron Scrap -- Several times a month, scrap samples were collected from the stockhouse and analyzed for chemical composition.

BOF Slag -- BOF slag samples were collected from the stockhouse once each day and analyzed on a daily basis.

Olivine, Dolomite Stone, and Calcite Stone -- Incoming shipments were sampled and analyzed.

Hot Metal and Slag -- Samples collected from each cast were analyzed.

Top Gas Analysis -- Samples were collected once each shift, or three times a day, and analyzed using Orsat apparatus.

Blast Furnace Flue Dust and Filter Cake -- These materials were sampled once a week, composited into a monthly sample, then analyzed for chemical composition.

Blast temperature, blast moisture, blast pressure, top gas pressure, top gas temperature, etc. were obtained from daily charts.

Weights -- In the determination of the amount of input and output materials to the furnace, furnace records were depended on.

Shipment distribution of 'B' Furnace hot metal production was procured from the Iron and Steel Accounting Department. Blast furnace flue dust and filter cake weights, which were estimated, were also obtained from the same source.

VII.3 Planning And Execution Of Blast Furnace COM Trials

VII.3.1 Selection Of A Base Period

Selection of a Base Period was very critical for comparing

productivity, coke rates, and other operating data with the COM injection data. Originally, the Base Period selected for No. 6 fuel oil injection on 'B' Furnace was November and December, 1979. However, as a result of a change in the burden practice, furnace practice, as well as some changes in the raw materials properties, it was decided to utilize a more current time period as a base. Thus, April, 1981 'B' Furnace operation was selected as a Base Period by the representatives of DOE and Interlake.

The reasons for selecting April, 1981 as the Base Period were as follows:

- (1) 'B' Furnace had been banked for over eight months, from June, 1980 to February, 1981, and the earliest month with fuel oil injection prior to June, 1980 was December, 1979. As mentioned, December, 1979 proved to be non-representative of the present Test Period with respect to ore burden, coke quality, and other furnace practices.
- (2) The burdening and operating practices during April, 1981 were consistent, and the fuel oil injection was maintained constant at a flow rate of about 5.3 gpm.

VII.3.2 Selection Of COM Test Period

VII.3.2.1 COM Test Period

Although the plan was to begin injection of COM into 'B' Furnace in June, 1981, a coal miners' strike resulted in a delay of the start of the test. During the 72-day long strike, the typical coals utilized in coke-making to produce 56 ASTM coke stability were difficult and in some cases impossible to receive. Consequently, coals of lower quality had to be purchased, resulting in below-standard coke quality. Hence, the COM test was postponed until mid-August by which time coke stability,

ash, and sulfur were restored to their standard level.

The injection of COM into 'B' Furnace started at 6:00 P.M. on August 17, 1981 and ended at 1:10 A.M. on October 3, 1981. During this Test Period, approximately 485,000 gallons of COM were successfully produced and injected into 'B' Furnace.

Since August 17, 18 and 19, 1981 were mostly debugging days, the analysis of the COM injection data was limited to 44 days, from August 20 to October 2, 1981.

Although an average injection rate of 7.9 gpm was calculated for the 44-day period, injection rates were considerably higher or lower than that rate for some time periods within the program.

VII.3.2.2 Selection Of Sub-Periods For COM Injection Test

The August 20 thru October 2 COM injection trial was subdivided into four major periods as shown in Table 20.

Table 20. FOUR MAJOR COM INJECTION TEST PERIODS

<u>Test Periods</u>	<u>Dates</u>	<u>No. Of Days</u>	<u>COM Injection Rate, gpm</u>
Period I	August 20-24, 1981	5	3.8
Period II	August 25-Sept. 9, 1981	16	7.6
Period III	Sept. 10-16, 1981	7	5.0
Period IV	Sept. 17-Oct. 2, 1981	16	10.8
<hr/>			
Period V	August 20-Oct. 2, 1981	44	7.9

Periods II and IV were further scrutinized by eliminating the days in which COM injection rates were very low or zero due to the Worthington steam pump or grinding pump wear problems experienced at the COM plant. (The Worthington pump problem is discussed in Section IV.7.3 and the Gorator wear problems in Section IV.7.1)

There were three bad days for both Periods II and IV. When these days were eliminated, the average COM injection rates increased from 7.6 to 8.7 gpm for Period II and from 10.8 to 13.0 gpm for Period IV. Furthermore, seven consecutive days within Period IV were extracted when molten iron demand was high and the furnace burdening practice was quite similar to the Base Period. Based on these considerations, the periods selected are shown in Table 21.

TABLE 21. COM INJECTION PERIODS

<u>Periods</u>	<u>Dates</u>	<u>No. Of Days</u>	<u>Oil Or COM Injection</u>
<u>Base Period</u>	March 30-April 26, 1981	28	5.2 gpm Oil
<u>Test Periods</u>			
Period I	Aug. 20-24, 1981	5	3.8 gpm COM
Period IIA	Aug. 25-Sept. 9, 1981	16	7.6
Period IIB	Aug. 25-Sept. 9, 1981 Excluding Aug. 31-Sept. 1 and 2	13	8.7
Period III	Sept. 10-16, 1981	7	5.0
Period IVA	Sept. 17-Oct. 2, 1981	16	10.8
Period IVB	Sept. 17-Oct. 2, 1981 Excluding Sept. 22, 23, and Oct. 1	13	13.0
Period IVC	Sept. 18-24, 1981	7	9.0
Period V	Aug. 20-Oct. 2, 1981	44	7.9

Each of these eight periods was analyzed, and all charging data, raw material chemistry, as well as operating data were utilized to determine the calculated coke rate (using the Flint Carbon Rate Formula). The calculated coke rate was then compared with the actual coke rate.

VII.4 Blast Furnace Practice During No. 6 Oil And COM Injection Periods

VII.4.1 Operating And Burdening Practice

Standard operational procedures followed at the Blast Furnace

Plant were not changed during the COM injection trials. Driving rates were held at a level to meet hot metal production requirements. Ore-to-coke ratios were adjusted to insure a desired product quality with respect to silicon and hot metal temperature. These specifications were to satisfy product mix specifications which consist of basic iron, foundry iron, and merchant pig iron (Bessemer). As in all blast furnace practices, blast moisture was changed from time to time to counteract abrupt changes in hot metal silicon content. Hot metal was tapped from the furnace normally eight times per day at approximately 3 hour intervals. Flux stone additions were adjusted to control slag basicity and hence hot metal sulfur content. Blast temperature was maintained almost constant at about 1800°F. Top gas pressure was maintained at 6 to 9 psi. Blast pressure was maintained between 23 and 25 psi to provide about 54,000 SCFM (standard cubic feet per minute) wind to the furnace.

Metallic burden consisted of Erie pellets, Wabush pellets, Roger ore (sized hematitic ore), iron scrap and basic oxygen furnace slag. Changes to the ore burden were made on the basis of availability of ores, and/or on the basis of hot metal manganese specifications, which is to a great extent controlled by the amount of manganese-rich Wabush pellets in the ore burden.

Metallic burden changes also involved an increase in iron scrap charges with a corresponding decrease in the ore burden charges whenever orders demanded increased hot metal production.

Since the amount of coke introduced to the furnace per charge was maintained constant, the ore-to-coke ratios were changed as the circumstances dictated. These changes were accomplished by adjusting the amount of the ore burden or by adding extra skips of coke to the furnace instead of adjusting the amount of ore charged. The extra coke was provided either by adding three extra coke skips to the furnace at every 15th, 12th, or

10th charges, which correspond to increasing the coke rate by 6.7%, 8.3%, and 10.0% respectively, or by adjusting the amount of the ore burden. However, extra coke skip charging practice was more prevalent than the adjustment of the ore burden.

During the COM injection tests, whenever COM injection rates were increased or decreased the ore-to-coke ratios were adjusted by one of the methods mentioned in order to compensate for COM injection.

VII.4.2 Filling Sequence

Charging sequence consisted of ore-coke-coke/ore-ore-coke. Stone, scrap and miscellaneous charges were made with the ore charges. Eight charges made one round. Total charges, for example, averaged about 103 per day during the Test Period.

VII.5 Results And Discussion Of COM Effect On Blast Furnace Operation

The pertinent information regarding the blast furnace COM injection trials is summarized in Table 22.

VII.5.1 Blast Furnace Productivity

Hot metal production during the Base Period was 1,397 NTPD (net tons per day) as compared to 1,171 NTPD average for the Test Period. The decrease in hot metal production during the Test Period was not due to COM injection but a result of the depressed business conditions reducing hot metal demand at the time. A review of Figure 47 illustrates hot metal production and fuel consumption rates for the 3 year period from January,

TABLE 22. SUMMARY OF BLAST FURNACE COM INJECTION TRIALS AT 'B' FURNACE, CHICAGO PLANT, INTERLAKE, INC.

Trial Periods Sub Periods	Base	Test								
		I	II	IIB	III	IVA	IVB	IVC	V	
Dates From	3-30	8-20	8-25	8-25 to 9-9	9-10	9-17	9-17 to 10-2	9-18	8-20	
To	4-26	8-24	9-9	excluding 8-31 & 9-1,2	9-16	10-2	excluding 9-22,23 & 10-1	9-24	10-2	
Item And Units										
No. Of Operating Days	28	5	16	13	7	16	13	7	44	
Hot Metal Production										
Total	NT	39109	5564	17919	14276	8034	20022	16148	9637	51539
Daily Actual	NT/Day	1397	1113	1120	1098	1148	1251	1242	1377	1171
Daily Adjusted For Delays	NT/Day	1421	1184	1156	1137	1234	1272	1256	1377	1213
Delays	%	1.70	6.00	3.08	3.45	6.94	1.63	1.14	0	3.43
Productivity, NT/Day/100 ft. ³ W.V.		5.17	4.12	4.14	4.06	4.25	4.63	4.60	5.09	4.33
Coke And Injectants										
Coke, Dry	LB/NTHM	1018.0	1073.4	1126.2	1134.9	1099.2	1020.6	1017.1	977.5	1074.7
Fuel-Oil	LB/NTHM	43.6								
Fuel-Oil At 7.989 LB/Gal	GPM	5.3								
Coal-Oil Mixture	LB/NTHM		43.6	87.2	101.8	56.1	112.6	136.2	84.6	87.5
Coal-Oil Mixture	GPM		3.8	7.6	8.7	5.0	10.8	13.0	9.0	7.9
Total Coke Equivalent	LB/NTHM	1072.5	1117.0	1213.4	1236.7	1155.3	1133.2	1153.3	1062.1	1162.2
Coke Analysis, Dry Ash										
% By Wt		8.51	8.41	8.01	8.01	8.00	8.11	8.11	8.14	8.14
Sulfur	% By Wt	0.774	0.864	0.954	0.954	0.93	0.792	0.792	0.795	0.795
Coke Stability	ASTM	55.3	53.8	54.5	54.5	55.3	53.5	53.5	54.2	54.2
Coke Size +2 in.	% By Wt	45.6	51.9	49.0	49.0	50.9	49.2	49.4	49.1	49.6
-1 in.	% By Wt	9.4	8.5	8.1	8.1	7.6	8.2	8.6	8.1	8.1
Metallic Burden										
Erie Pellets	LB/NTHM	2114	1813	2151	2229	2533	2226	2230	2121	2204
Wabush Pellets	LB/NTHM	478	483	486	485	364	561	556	544	496
Roger Ore	LB/NTHM	0	604	447	404	0	0	0	0	220
Total Ore	LB/NTHM	2592	2900	3084	3118	2897	2787	2786	2665	2920
Scrap	LB/NTHM	356	176	100.3	103.2	90	184.7	180.5	240	140
B.O.F. Slag	LB/NTHM	74	44	32	29	22	42	42	40	44
Flux Stone										
Dolomite	LB/NTHM	235	254	287	288	257	240	242	262	261
Calcite	LB/NTHM	100	171	190	191	175	162	163	176	175
Olivine	LB/NTHM	18	0	0	28	26	25	25	24	26
Flue Dust And Filter Cake, Dry	LB/NTHM	61	67	64	64	67	67	67	67	66
Hot Metal Analysis, Si										
% By Wt		1.78	1.61	1.71	1.70	1.71	1.61	1.59	1.51	1.66
S	% By Wt	0.025	0.030	0.028	0.028	0.028	0.033	0.029	0.032	0.028
Mn	% By Wt	0.86	0.83	0.79	0.78	0.61	0.84	0.84	0.84	0.79
P	% By Wt	0.047	0.047	0.039	0.038	0.026	0.028	0.034	0.034	0.036
Hot Metal Temp At Iron Runner	°F	2787	2761	2768	2764	2764	2760	2757	2757	2764
Slag Volume										
Slag Volume	LB/NTHM	430	485	520	540	491	488	495	523	516
Slag Analysis SiO ₂										
% By Wt		33.1	33.5	33.6	33.8	31.5	32.6	33.5	33.4	33.8
Al ₂ O ₃	% By Wt	7.5	7.0	6.3	6.2	6.2	6.3	6.3	6.3	6.3
CaO	% By Wt	36.6	38.0	38.2	36.9	36.5	36.7	36.7	37.0	36.9
MgO	% By Wt	17.3	14.3	14.9	16.3	16.4	16.0	15.9	15.8	16.0
S	% By Wt	2.54	1.99	2.25	2.20	2.19	1.87	1.74	2.37	1.83
Slag Bases To Acids Ratio		1.33	1.29	1.33	1.33	1.33	1.33	1.33	1.33	1.32
Other Operating Data										
Wind Rate	1000 SCFM	54.4	53.6	54.5	54.2	54.5	54.2	54.2	55.1	54.3
Total O ₂ In Blast	% By Vol	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9	20.9
Blast Temperature	°F	1806	1800	1800	1800	1800	1803	1804	1810	1801
Blast Humidity, Grains/CF		12.1	13.2	14.0	13.9	13.3	11.7	11.8	11.2	13.0
B.F. Gas Analysis, CO										
% By Vol		24.5	23.8	21.8	22.1	22.4	24.1	23.9	22.7	22.9
CO ₂	% By Vol	14.1	13.5	13.6	13.8	14.7	14.5	14.1	15.2	14.1
H ₂	% By Vol	2.5	2.5	3.8	3.8	2.8	3.4	3.6	3.6	3.4
N ₂	% By Vol	58.9	60.2	60.9	60.3	60.2	58.0	58.3	58.7	59.6
CO/CO ₂ Ratio		1.77	1.78	1.59	1.59	1.53	1.68	1.71	1.51	1.63
BF Gas Heating Value BTU/SCF		86.2	83.6	80.4	80.4	80.5	86.8	86.6	83.2	82.8
BF Gas Temperature	°F	328	366	398	396	378	387	401	333	387

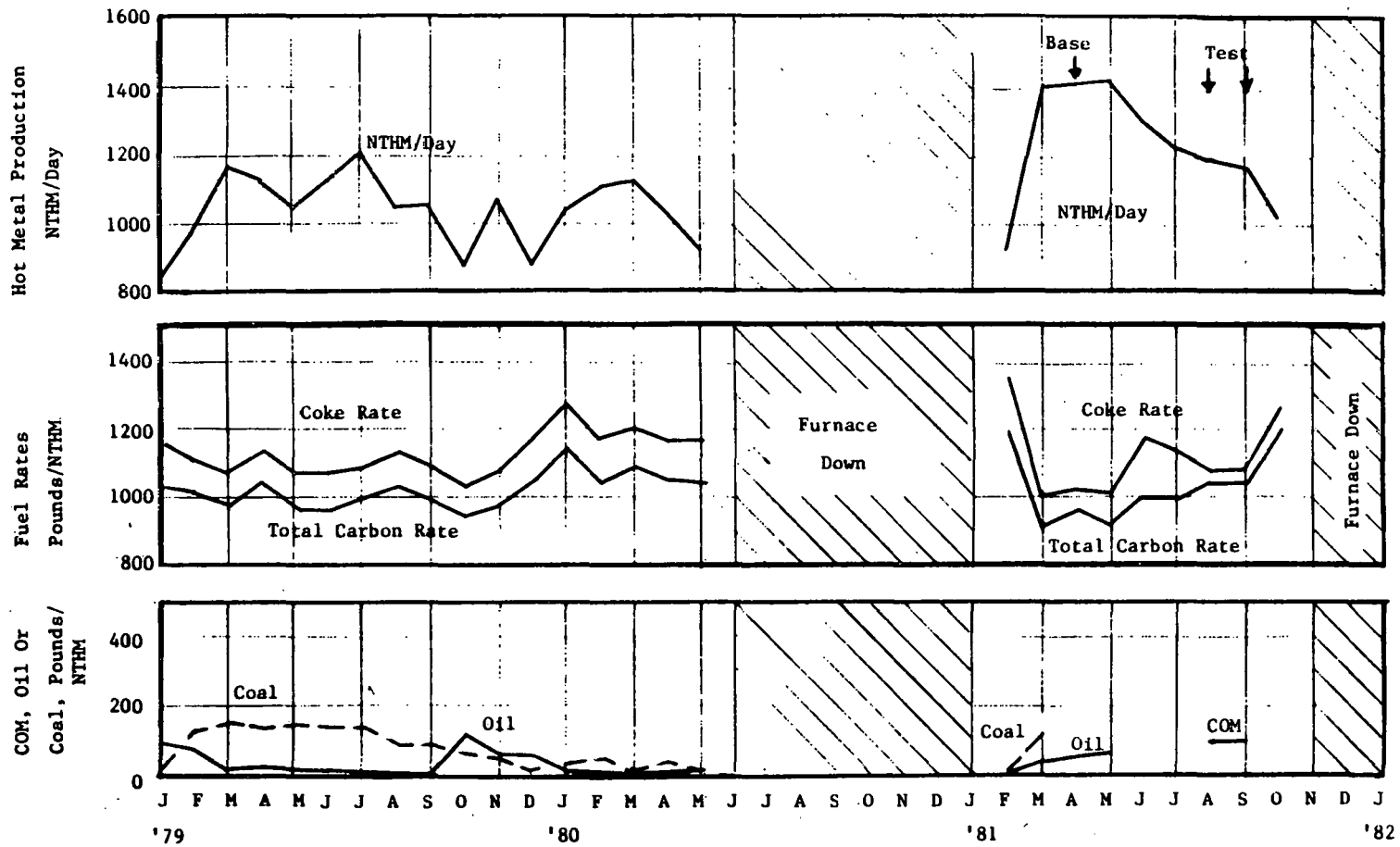


FIGURE 47. MONTHLY HOT METAL PRODUCTION AND FUEL RATE FOR 'B' FURNACE FROM JANUARY, 1979 THROUGH DECEMBER, 1981

1979 to December, 1981. While normal hot metal production rate fluctuated between 900 and 1,200 NTPD on a monthly basis in the past, the average production during the Base Period was 1,397 NTPD because of increased demand on hot metal production. A 1,397 net ton hot metal production per day at 'B' Furnace corresponds to a productivity of 5.17 NTHM per day per 100 cubic feet of working volume, a high level of productivity when compared to North American blast furnaces of similar size and age. In fact, the Base Period was a record tonnage month for 'B' Furnace.

This high furnace productivity during the Base Period was achieved by using very large amounts of scrap. Scrap usage during the Base Period averaged 356 pounds/NTHM while the scrap consumption during the COM Test Period was only 140 pounds/NTHM. Therefore, comparing the Base and Test Periods without taking into account the factors discussed would be truly misleading.

Fortunately, during the Test Period there were short intervals where the hot metal demand was high and high scrap usage was required. This situation resulted during Test Period IVC, which lasted 7 days, from September 18 to 24, 1981, with a scrap rate of 240 lb/NTHM. Although this high scrap usage was still lower than the 356 lb/NTHM scrap rate during the Base Period, a production level of 1,377 NTPD was accomplished.

The average hot metal silicon of 1.78% for the Base Period versus 1.51% for Test Period IVC illustrates the need for more basic iron during the Test Period. This 1,377 NTPD production level fares well in comparison to the 1,397 NTPD for the Base Period.

This point may be clarified well by comparing the past furnace production records with the Test Period in its expanded form, that is, with the Test Periods I, IIA, III, IVA, and IVC as shown in Figure 48.

When reviewing Figure 48, it can be seen that hot metal production during the Test Period IVC was almost the same as during the Base Period for the reasons explained above. It can also be seen that as the COM injection tests proceeded, hot metal production increased gradually from 1,113 NTPD for Test Period I to 1,120 NTPD for Test Period IIA, and then to 1,148 NTPD for Test Period III, and finally to 1,251 NTPD for Test Period IVA. This gradual increase in hot metal production was partly due to improvements made to the COM injection system during the course of the Test Period. Reduced plugging of lances and more consistent injection rates, achieved later in the program, are discussed and illustrated in Section V.

VII.5.2 Product Quality

During the Base and Test Periods, as in all other times, 'B' Furnace was producing three grades of iron, in broad categories, chemical specifications of which are given in Table 23. The ranges given below for merchant pig iron represent specifications on the majority of the merchant pig iron sales by Interlake. Silicon specifications on merchant pig iron sold actually vary from 1.75 to 3.00%.

TABLE 23. IRON GRADES PRODUCED

	<u>Basic Iron</u>	<u>Foundry Iron</u>	<u>Merchant Pig Iron</u>
Si%	0.900	1.750	2.00-2.25
S%	0.030	0.024	0.050 max.
Mn%	0.900	0.870	0.75-1.00
P%	0.040	0.084	0.080 max.

Hot metal specifications with respect to chemistry as well as temperature were met during the Base and Test Periods without any off-grade hot metal production losses.

Hot metal analyses and temperatures during the Base and Test Periods are shown in Table 24.

TABLE 24. HOT METAL ANALYSIS AND TEMPERATURE

	<u>Base Period</u>	<u>Test Period</u>
Si%	1.78	1.66
S%	0.025	0.028
Mn%	0.86	0.79
P%	0.047	0.036
Runner Temp., °F	2787	2764

A lower silicon content in hot metal during the Test Period, 1.66% as compared to 1.78% Si during the Base Period, might be misconstrued if the product mix requirements, which are shown in Table 25, are not taken into consideration.

TABLE 25. PRODUCT MIX

<u>Product Mix</u>	<u>Base Period</u>	<u>Test Period</u>
Basic Iron, %	14.2	34.4
Foundry Iron, %	66.3	59.4
Merchant Pig Iron, %	19.5	6.2
Total	100.0	100.0

Basic iron production during the Base Period, for example, constituted 14.2% of the total hot metal production as compared to 34.4% basic iron production during the Test Period. This explains the reason for the lower hot metal silicon content during the Test Period. It could be argued that hot metal silicon content during the Test Period was lower, and that is the reason for more hot metal diverted to basic iron grade. However, the facts were not so, since the production was based on the hot metal requirements in each grade rather than the distribution of the product according to the grades produced.

A 23°F drop in hot metal temperature during the Test Period may be attributable partly to the lower hot metal silicon, and partly to the effect of COM injection on the adiabatic flame temperature which is discussed in Section VII.8.1.

VII.5.3 Fuel Consumption Rate And Quality

Fuel consumption consisted of coke and No. 6 fuel oil during the Base Period and coke and COM during the Test Period.

VII.5.3.1 Fuel Quality

VII.5.3.1.1 Coke Quality

The quality of coke used during both periods with respect to proximate analysis and ASTM stability was almost identical. However, moisture content of coke during the Base Period was higher than that during the Test Period and also the Base Period had a smaller size coke than the Test Period. This is shown in Table 26.

TABLE 26. COKE ANALYSIS

	<u>Base Period</u>	<u>Test Period</u>
Coke Proximate Analysis:		
Volatile Matter,% dry wt.	1.32	0.88
Fixed Carbon,% dry wt.	90.14	90.80
Ash,% dry wt.	8.51	8.14
Sulfur,% dry wt.	0.774	0.795
H ₂ O,% wet wt.	10.11	8.40
ASTM stability index, %	55.3	54.2
Coke Size, % By Wt.		
+ 3 inch	6.7	8.9
- 3 inch + 2 inch	38.9	40.7
- 2 inch + 1-1/2 inch	27.5	26.1
- 1-1/2 inch + 1 inch	17.5	16.2
- 1 inch + 1/2 inch	8.0	6.8
- 1/2 inch	1.4	1.3

VII.5.3.1.2 No. 6 Fuel Oil Quality

No. 6 fuel oil injected to 'B' Furnace during the Base Period for all practical purposes could be considered identical to No. 6 fuel oil that we used in the preparation of COM during the Test Period. The chemical analysis and heating value of the fuel oil are given in Table 27.

TABLE 27. CHEMICAL ANALYSIS AND HEATING VALUE OF NO. 6 FUEL OIL

C, %	87.13
H (inclusive H ₂ O), %	11.38
S, %	0.90
Ash, %	0.05
H ₂ O, %	0.09
Sediment, %	0.14
Heating Value, BTU/Lb	18,652

VII.5.3.1.3 COM Quality

The COM was prepared using a low volatile metallurgical coking coal, No. 6 fuel oil and water-emulsifier mixture. The COM components during the individual Test Periods were as shown in Table 28.

TABLE 28. COM COMPONENTS

	I	Test Periods			
		II	III	IV	V
Coal, %	48.06	47.12	48.11	48.48	47.95
Fuel Oil, %	47.51	48.36	47.44	47.09	47.59
Water-Emulsifier, %	4.43	4.52	4.45	4.43	4.46
Total, %	100.0	100.0	100.0	100.0	100.0

The chemical composition of COM on a day-to-day basis was fairly consistent as can be seen in Figure 45 in Section VI.

VII.5.3.2 Fuel Consumption

The fuel consumption during the Base Period consisted of 1,018.0 lbs. of coke on a dry weight basis and 43.6 lbs. of fuel oil per net ton hot metal. In contrast, the fuel consumption during the Test Period was 1,074.7 lbs. of coke and 87.5 lbs. of COM. That is, the coke consumption during the Test Period was 56.7 lbs. more per net ton of hot metal than during the Base Period even though the COM injection exceeded the fuel oil injection by 43.9 lbs/NTHM (Table 29).

TABLE 29. FUEL CONSUMPTION - BASE VERSUS TEST PERIOD

	<u>Base Period</u>	<u>Test Period</u>	<u>Difference</u>
Coke, dry, lb/NTHM	1,018.0	1,074.7	+56.7
Fuel Oil, lb/NTHM	43.6	-	-43.6
COM, lb/NTHM	-	87.5	+87.5

Similarly, the total fuel consumption during the individual Test Periods, with the exception of Test Period IVC, was much higher than the Base Period. This is shown in Table 30.

TABLE 30. FUEL CONSUMPTION -- BASE VERSUS TEST SUB-PERIODS

	<u>Base Period</u>	<u>Test Periods</u>						
		<u>I</u>	<u>IIA</u>	<u>IIB</u>	<u>III</u>	<u>IVA</u>	<u>IVB</u>	<u>IVC</u>
Coke, lb/NTHM	1018	1073	1126	1135	1099	1021	1017	978
Fuel-oil, lb/NTHM	44	-	-	-	-	-	-	-
COM, lb/NTHM	-	44	87	102	56	113	136	85
Total Fuel								
lb/NTHM	1062	1117	1213	1237	1155	1134	1153	1063

The fuel consumptions during the Base Period and Test Period IVC were nearly identical because the furnace operating conditions during Test Period IVC were very similar to Base Period furnace operating conditions.

If the blast furnace operating conditions, that is, blast furnace burdening, hot metal chemistry, slag volume, slag chemistry, wind rate, etc. were held identical during the Base and Test Periods, the efficiency of COM as a blast furnace fuel could have been assessed simply by comparing the fuel consumption figures. For example, a rough comparison between the Base Period and Test Period IVC, assuming that all conditions were identical during these periods with the exception of the type of injectant, would have yielded 1.1 lb. coke replacement per pound of COM injection as shown in Table 31.

TABLE 31. BASE VERSUS TEST PERIOD IVC

	<u>Base Period</u>	<u>Test Period</u>	<u>IVC Difference</u>
Coke, lb/NTHM	1,018	978	- 40
Fuel Oil, lb/NTHM	44	-	- 44
COM, lb/NTHM	-	85	+ 85

That is, 85 lb COM replaced 40 lb of coke and 44 lbs of fuel oil per net ton of hot metal. Assuming a 1.25 lb. coke replacement per lb of fuel oil, a proven value which is accepted by the industry in general, the following equality can be developed:

$$\frac{85 \text{ lb COM}}{\text{NTHM}} = \frac{40 \text{ lb coke}}{\text{NTHM}} + \frac{44 \text{ lb oil}}{\text{NTHM}} \times \frac{1.25 \text{ lb coke}}{\text{lb oil}}$$

The solution of this equation would yield about 1.1 lb. coke per lb. of COM.

Since identical conditions between a Base and a Test Period could seldom be satisfied, the efficiency of COM injectant as blast furnace fuel must be calculated by making proper adjustments to the coke rate based on the differences observed between the Base and Test Periods. This will be undertaken under the heading of "Determination Of Coke Replacement Value Of COM" in Section VII.6. Reasons will also be presented for adjustment of coke useage for different operating conditions.

Metallic Burden Considerations

Metallic burden consisted of Erie pellets, Wabush pellets, Roger Ore, scrap and BOF slag. The specific metallic consumptions for the Base and Test Periods are summarized in Table 32.

TABLE 32. METALLIC BURDEN COMPARISON -- BASE VERSUS TEST PERIOD

<u>Item</u>	<u>Base Period</u>	<u>Test Period</u>
Erie pellets, lb/NTHM	2114	2204
Wabush pellets, lb/NTHM	478	496
Roger Ore, lb/NTHM	0	220
Ore Burden	2592	2920
Scrap, lb/NTHM	356	140
BOF Slag, lb/NTHM	74	44

The hot metal demand during the Base Period was much higher than the Test Period; therefore, in order to meet the production demand, scrap charges to the furnace were increased substantially: 356 lb/NTHM vs 140 lb/NTHM. This high scrap consumption, in turn, reduced the iron requirement from the ore burden: 2,592 lb/NTHM for the Base Period vs 2,920 lb/NTHM for the Test Period.

A review of the individual Test Periods in Table 22 shows that all periods during COM injection show lower specific scrap charges and higher ore burden charges than the Base Period, the closest being Test Period IVC: 356 lb scrap and 2,592 lb ore per NTHM for the Base Period vs 240 lb scrap and 2,665 lb ore per NTHM for the Test Period IVC.

Because the reduction and melting of iron ore would require more energy than melting of iron scrap, the specific coke consumption during the Test Period was considerably higher than during the Base Period. The inverse relationship between the scrap usage and coke consumption is illustrated in Figure 49 for the COM trials.

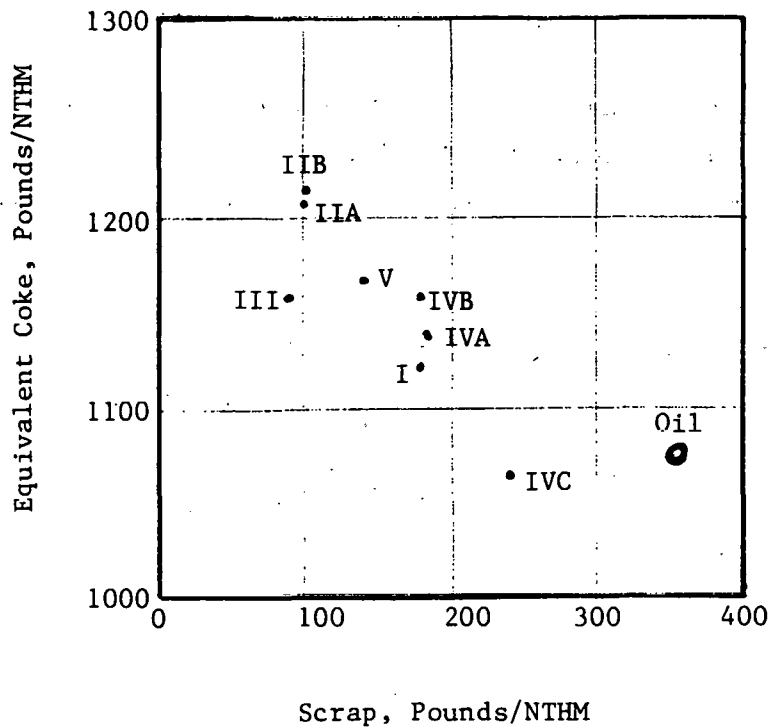


FIGURE 49. SCRAP USAGE VERSUS
EQUIVALENT COKE CONSUMPTION

The following two points also need to be considered when comparing metallic burdens for the Base versus Test Period:

(1) The coke consumption during the Test Period was increased on account of ore burden make up: 100% pellets burden for the Base Period vs 7.6% iron ore plus 92.4% pellets burden for the Test Period.

(2) The variations in the ore burden were necessitated by the availability of the materials. The exception to the rule was from September 7 to 15, 1981 when the hot metal specifications on merchant pig iron required lower hot metal manganese than before: 0.58% Mn vs 0.94% Mn. This was accomplished by reducing the amount of manganese-rich Wabush pellets in the ore burden. The daily variations in the ore burden and hot metal chemistry are given in Tables 33 and 34.

TABLE 33. SUMMARY OF BLAST FURNACE COM INJECTION TRIALS AT 'B' FURNACE ON A DAILY BASIS FOR THE BASE PERIOD
(To Be Continued On Page 123)

Dates For Base Period	Hot Metal Prod. NTPD	Oper. Delays		Coke Oil Injection			Hot Metal Analysis				Hot Metal Runner Temp. °F	Slag		
		Lost Time	Slack Wind	Rate, Wet	SI	S	P	Mn	CaO	MgO		Basi- city B/A		
		Min/ Day	Min/ Day	Lb/ Cal/ NTM Day	GPM	% Wt	% Wt	% Wt	% Wt	% Wt		% Wt		
March 30, 1981	1284	31	18	1092	7830	6.0	2.00	.031	.045	.71	2801	35.97	17.90	1.30
March 31, 1981	1570	0	0	972	8160	6.0	1.73	.038	.041	.70	2786	35.90	18.86	1.26
April 1, 1981	1490	0	0	1073	8160	6.0	1.66	.029	.046	.72	2781	35.95	16.69	1.25
April 2, 1981	1571	0	0	1057	8160	6.0	1.50	.023	.048	.75	2748	36.40	16.54	1.36
April 3, 1981	1267	32	20	1175	7620	6.0	1.88	.018	.046	.74	2798	37.70	17.37	1.37
April 4, 1981	1376	30	80	1082	7800	6.0	1.88	.028	.049	.76	2770	36.21	17.85	1.29
April 5, 1981	1443	0	0	1100	8160	6.0	1.93	.022	.048	.75	2801	36.46	17.66	1.30
April 6, 1981	1349	0	0	1168	8160	6.0	2.02	.023	.048	.76	2775	36.39	16.27	1.32
April 7, 1981	1444	0	0	1124	8160	6.0	1.85	.028	.051	.83	2791	36.44	17.46	1.30
April 8, 1981	1491	0	0	1097	8160	6.0	1.76	.022	.033	.79	2792	35.70	17.08	1.32
April 9, 1981	1437	0	0	1164	8160	6.0	1.65	.030	.047	.83	2771	36.21	16.97	1.25
April 10, 1981	1517	0	0	1127	8160	6.0	1.64	.032	.050	.83	2795	36.74	16.21	1.27
April 11, 1981	1472	0	0	1136	8160	6.0	1.63	.034	.049	.84	2791	37.16	17.27	1.31
April 12, 1981	1205	192	40	1133	6630	6.0	1.60	.017	.051	.78	2740	37.34	15.84	1.44
April 13, 1981	1486	0	50	1175	8160	6.0	1.68	.022	.048	.82	2809	36.06	18.19	1.31
April 14, 1981	1315	0	0	1179	8160	6.0	1.98	.022	.052	.84	2788	37.04	17.01	1.36
April 15, 1981	1543	0	0	1068	8160	6.0	1.70	.021	.054	.87	2811	37.57	16.97	1.33
April 16, 1981	1580	25	0	973	7800	6.0	1.70	.024	.054	.84	2804	36.75	16.46	1.36
April 17, 1981	1170	180	30	1220	6840	6.0	1.77	.027	.050	.91	2767	36.82	17.02	1.32
April 18, 1981	1061	0	0	1264	8160	6.0	1.79	.031	.046	.92	2756	37.36	17.11	1.33
April 19, 1981	1417	0	0	1181	8160	6.0	1.85	.014	.046	1.05	2864	38.64	17.25	1.47
April 20, 1981	1495	0	0	1078	8160	6.0	1.62	.016	.048	1.06	2802	37.39	18.69	1.39
April 21, 1981	1303	68	17	1246	7680	6.0	2.01	.027	.044	1.02	2765	35.76	17.24	1.30
April 22, 1981	1378	0	0	1160	8160	6.0	1.72	.031	.044	1.02	2763	36.56	17.46	1.32
April 23, 1981	1384	0	0	1209	8160	6.0	1.84	.023	.043	.98	2775	37.51	16.98	1.39
April 24, 1981	1319	0	0	1259	8160	6.0	1.84	.018	.043	.98	2826	36.60	18.19	1.37
April 25, 1981	1375	0	0	1217	8160	6.0	1.66	.025	.044	.97	2790	36.97	16.36	1.35
April 26, 1981	1367	0	0	1125	8160	6.0	2.07	.033	.044	1.02	2774	38.86	14.07	1.31

TABLE 33. SUMMARY OF BLAST FURNACE COM INJECTION TRIALS AT 'B' FURNACE ON A DAILY BASIS FOR THE BASE PERIOD
(Continued From Page 122)

Dates For Base Period	Ore Burden				Scrap LB/ NTHM	Wind Rate (X1000) SCFM	Blast Temp. °F	Blast Humidity Grains/ SCF	Top Gas Temp. °F	Blast Furnace Gas					Heating Value BTU/ SCF
	Total LB/ NTHM	Roger Ore % Wt	Erie Pellets % Wt	Wabush Pellets % Wt						CO ₂ % Vol.	CO % Vol.	H ₂ % Vol.	N ₂ % Vol.	CO/ CO ₂ Ratio	
March 30, 1981	2565	0	87.5	12.5	348	53.7	1800	11.1	337	15.2	25.6	2.6	57.2	1.68	89.5
March 31, 1981	2265	0	87.5	12.5	308	52.8	1806	10.9	253	14.2	25.3	2.5	58.1	1.81	88.1
April 1, 1981	2368	0	87.5	12.5	322	55.0	1819	9.7	237	16.0	21.8	2.8	59.4	1.36	77.9
April 2, 1981	2340	0	87.5	12.5	318	53.8	1825	8.0	250	15.1	26.9	1.9	56.2	1.78	91.7
April 3, 1981	2785	0	87.5	12.5	379	56.4	1800	14.3	380	14.0	24.6	2.8	58.6	1.76	87.0
April 4, 1981	2544	0	87.5	12.5	346	56.3	1800	14.4	360	13.6	24.9	1.7	59.9	1.83	84.5
April 5, 1981	2706	0	87.5	12.5	355	55.8	1800	14.8	357	-	-	-	-	-	-
April 6, 1981	2747	0	85.7	14.3	374	53.6	1800	15.8	347	14.0	26.8	0.7	58.4	1.92	88.3
April 7, 1981	2655	0	83.3	16.7	357	53.8	1800	16.0	310	15.3	24.0	1.8	58.9	1.57	82.2
April 8, 1981	2606	0	83.3	16.7	343	55.8	1800	15.1	347	15.0	25.5	2.8	56.7	1.70	89.9
April 9, 1981	2811	0	83.3	16.7	367	52.3	1800	14.8	277	13.2	25.3	2.9	58.6	1.92	89.6
April 10, 1981	2601	0	83.3	16.7	348	57.0	1850	12.7	250	15.1	23.2	2.9	58.8	1.54	82.8
April 11, 1981	2683	0	83.3	16.7	361	57.0	1850	11.1	290	14.2	24.7	2.7	58.3	1.74	87.1
April 12, 1981	2588	0	83.3	16.7	349	55.4	1825	7.5	243	16.6	24.0	2.7	56.7	1.45	84.7
April 13, 1981	2800	0	83.3	16.7	377	55.2	1800	8.3	293	13.8	21.7	3.6	60.9	1.57	79.7
April 14, 1981	2689	0	83.3	16.7	362	57.0	1800	8.5	370	17.0	26.6	3.3	53.1	1.56	94.8
April 15, 1981	2503	0	83.3	16.7	337	52.9	1800	11.0	327	-	-	-	-	-	-
April 16, 1981	2200	0	81.8	18.2	296	53.2	1800	8.6	293	15.1	23.8	2.0	59.1	1.58	82.1
April 17, 1981	2791	0	76.7	23.3	383	53.0	1800	11.1	293	14.3	24.2	2.1	59.4	1.69	83.6
April 18, 1981	2735	0	75.0	25.0	396	45.8	1800	10.5	423	12.8	24.7	2.3	60.2	1.93	85.9
April 19, 1981	2607	0	75.0	25.0	381	54.5	1800	13.5	360	12.7	23.5	3.5	60.3	1.86	85.4
April 20, 1981	2349	0	75.0	25.0	343	53.4	1800	11.5	367	13.5	25.3	1.7	59.4	1.87	86.2
April 21, 1981	2743	0	75.0	25.0	396	54.5	1800	14.3	380	12.6	24.6	3.0	59.8	1.95	87.5
April 22, 1981	2515	0	75.0	25.0	367	54.0	1800	12.5	390	12.8	24.8	2.9	59.5	1.94	87.9
April 23, 1981	2642	0	75.0	25.0	382	57.0	1800	13.1	393	12.5	24.4	2.9	60.2	1.95	86.6
April 24, 1981	2846	0	75.0	25.0	397	57.0	1800	13.4	397	12.3	26.9	2.7	57.1	2.19	94.0
April 25, 1981	2723	0	75.0	25.0	378	52.6	1806	11.5	370	12.2	28.8	2.1	56.5	2.36	98.5
April 26, 1981	2568	0	75.0	25.0	351	55.1	1800	13.4	416	12.2	27.4	2.6	57.8	2.25	95.3

TABLE 34. SUMMARY OF BLAST FURNACE COIL INJECTION TRIALS AT 'B' FURNACE ON A DAILY BASIS FOR THE TEST PERIOD
(To Be Continued On Page 125)

Dates For Test Period	Hot Metal Prod.	Oper. Lost Time	Delays Slack Wind	Coke Rate Wet	COIL Injection		Hot Metal Analysis				Hot Metal Runner Temp °F	Slag CaO % Wt	Slag MgO % Wt	Slag Basicity B/A	
					NTHM	Gal/Day	GPM	Si % Wt	S % Wt	P % Wt					Mn % Wt
Period I															
August 20, 1981	1142	46	33	1174	7587	5.3	1.59	.034	.049	.80	2780	37.77	14.29	1.27	
August 21, 1981	965	238	20	1198	2278	1.6	1.62	.022	.045	.83	2765	38.41	14.28	1.32	
August 22, 1981	1131	0	0	1207	6457	4.5	1.64	.023	.048	.83	2798	38.34	14.28	1.32	
August 23, 1981	1089	109	25	1163	4687	3.3	1.59	.028	.048	.86	2732	36.06	16.04	1.31	
August 24, 1981	1237	0	0	1153	6046	4.2	1.59	.043	.044	.82	2730	36.61	15.27	1.24	
Period II															
August 25, 1981	1259	0	0	1114	10975	7.6	1.58	.023	.046	.87	2779	38.73	15.89	1.37	
August 26, 1981	1057	66	28	1257	11399	7.9	1.70	.017	.046	.81	2768	38.77	14.51	1.37	
August 27, 1981	1226	8	8	1134	9356	6.5	1.63	.031	.048	.90	2761	38.28	14.65	1.30	
August 28, 1981	935	233	55	1250	10949	7.6	1.76	.018	.047	.91	2763	38.64	14.48	1.33	
August 29, 1981	1082	0	0	1341	16493	11.5	1.75	.033	.046	.86	2744	37.25	14.06	1.23	
August 30, 1981	1033	0	0	1405	11011	7.6	1.60	.044	.047	.87	2750	35.93	14.80	1.20	
August 31, 1981	1200	0	0	1148	6510	4.5	1.93	.038	.043	.82	2796	37.45	14.27	1.24	
September 1, 1981	1235	0	0	1185	5898	4.1	1.79	.019	.043	.88	2794	38.88	14.32	1.33	
September 2, 1981	1208	60	15	1252	5898	4.1	1.57	.031	.039	.78	2768	37.14	15.67	1.32	
September 3, 1981	1100	43	17	1308	9852	6.8	1.76	.030	.041	.83	2772	36.90	16.49	1.32	
September 4, 1981	1106	0	0	1323	10103	7.0	1.86	.028	.040	.85	2782	37.49	14.85	1.33	
September 5, 1981	1168	66	21	1064	14734	10.2	1.47	.038	.032	.78	2752	37.97	14.70	1.31	
September 6, 1981	1122	10	23	1217	15636	10.9	1.61	.040	.025	.74	2749	39.24	15.20	1.39	
September 7, 1981	959	119	45	1270	13308	9.2	1.84	.020	.026	.62	2759	39.47	15.43	1.39	
September 8, 1981	1098	0	0	1255	13829	9.6	1.82	.020	.026	.63	2766	39.08	14.76	1.39	
September 9, 1981	1131	0	0	1283	14659	10.2	1.72	.020	.027	.51	2791	38.09	15.94	1.40	
Period III															
September 10, 1981	1126	0	0	1245	7220	5.0	2.04	.024	.024	.51	2759	37.87	15.53	1.34	
September 11, 1981	1106	0	0	1279	7788	5.4	1.77	.022	.027	.49	2787	38.39	15.10	1.37	
September 12, 1981	1372	0	0	1121	8762	6.1	1.42	.031	.026	.53	2766	37.94	15.14	1.33	
September 13, 1981	1252	0	0	1100	8525	5.9	1.67	.031	.025	.65	2778	38.54	14.65	1.36	
September 14, 1981	1004	371	27	1066	4755	3.3	1.84	.021	.029	.65	2805	38.37	15.34	1.39	
September 15, 1981	989	160	67	1231	6531	4.5	1.53	.035	.032	.67	2889	36.36	15.53	1.25	
September 16, 1981	1185	55	44	1183	6752	4.7	1.70	.035	.030	.76	2765	37.33	14.44	1.28	
Period IV															
September 17, 1981	1248	43	25	1133	14224	9.9	1.58	.036	.030	.73	2769	37.66	14.23	1.35	
September 18, 1981	1403	0	0	1026	13581	9.4	1.52	.050	.032	.74	2726	36.81	14.35	1.23	
September 19, 1981	1335	0	0	1115	20941	14.5	1.45	.033	.034	.84	2745	38.74	14.60	1.38	
September 20, 1981	1284	0	0	1092	19829	13.8	1.43	.026	.034	.85	2761	38.35	14.70	1.34	
September 21, 1981	1403	0	0	1078	16600	11.5	1.58	.024	.032	.84	2788	38.70	14.69	1.37	
September 22, 1981	1460	0	0	1078	3321	2.3	1.63	.030	.035	.89	2782	38.31	15.36	1.35	
September 23, 1981	1356	0	0	1098	3078	2.1	1.53	.030	.034	.85	2760	37.77	14.67	1.29	
September 24, 1981	1396	0	0	1057	13311	9.2	1.43	.032	.040	.89	2738	38.34	14.48	1.33	
September 25, 1981	1172	0	0	1165	19856	13.8	1.42	.020	.034	.85	2751	38.47	14.02	1.31	
September 26, 1981	1049	100	11	1091	20639	14.3	1.37	.030	.032	.85	2735	37.56	14.61	1.30	
September 27, 1981	1141	27	50	1154	18457	12.8	1.74	.019	.035	.94	2759	38.84	14.62	1.40	
September 28, 1981	1344	0	0	1025	23258	16.2	1.80	.018	.039	.89	2792	38.08	14.52	1.35	
September 29, 1981	1152	0	0	1207	17577	12.2	1.80	.025	.034	.86	2782	37.91	14.83	1.30	
September 30, 1981	1114	0	0	1204	20309	14.1	1.66	.032	.031	.83	2739	38.64	14.17	1.32	
October 1, 1981	1058	135	54	1256	70	-	1.92	.016	.028	.83	2781	38.67	15.29	1.34	
October 2, 1981	1107	0	0	1200	23891	16.6	1.85	.029	.029	.82	2752	37.78	14.29	1.28	

TABLE 34. SUMMARY OF BLAST FURNACE COM INJECTION TRIALS AT 'B' FURNACE ON A DAILY BASIS FOR THE TEST PERIOD
(Continued From Page 124)

Dates For Test Period	Ore Burden			Scrap LB/ NTHM	Wind Rate (X1000) SCFM	Blast Temp. °F	Blast Humi- dity Grains/ SCF	Top Gas Temp. °F	Blast Furnace Gas				CO/ CO ₂ Ratio	Heating Value BTU/ SCF	
	Total	Roger Ore	Erie Pellets						Wabush Pellets	CO ₂	CO	H ₂			N ₂
	LB/ NTHM	% Wt	% Wt						% Wt	% Vol.	% Vol.	% Vol.			% Vol.
Period I															
August 20, 1981	2835	20.8	62.5	16.7	175	53.6	1800	13.2	347	-	-	-	-	-	
August 21, 1981	2953	20.8	62.5	16.7	182	53.7	1800	13.3	370	-	-	-	-	-	
August 22, 1981	2966	20.8	62.5	16.7	180	53.2	1800	13.5	413	12.9	24.2	2.8	60.1	1.88 85.6	
August 23, 1981	2905	20.8	52.5	16.7	175	53.7	1800	13.5	353	14.9	22.3	2.8	60.0	1.50 79.5	
August 24, 1981	2854	20.8	52.5	16.7	171	54.0	1800	12.6	347	12.8	25.0	1.8	60.4	1.95 85.5	
Period II															
August 25, 1981	2670	20.8	62.5	16.7	146	53.7	1800	12.9	360	14.3	22.3	3.4	60.0	1.56 81.2	
August 26, 1981	3181	20.8	62.5	16.7	146	54.7	1800	15.3	347	14.3	23.0	2.9	59.8	1.29 82.1	
August 27, 1981	2879	20.8	62.5	16.7	86	53.6	1800	14.4	383	13.0	22.1	3.6	61.3	1.71 81.0	
August 28, 1981	3168	20.8	62.5	16.7	94	53.6	1800	14.3	300	14.6	22.1	2.8	60.6	1.52 78.7	
August 29, 1981	3334	20.8	62.5	16.7	102	54.0	1800	15.3	403	14.2	23.0	3.7	59.2	1.62 84.1	
August 30, 1981	3545	20.8	62.5	16.7	107	54.3	1800	15.2	413	14.4	22.3	2.9	60.5	1.55 79.5	
August 31, 1981	2858	20.8	62.5	16.7	86	56.0	1800	14.8	420	10.7	18.4	4.5	66.5	1.78 71.6	
September 1, 1981	2938	20.8	62.5	16.7	88	56.0	1800	14.9	393	13.3	22.8	3.4	60.5	1.73 82.8	
September 2, 1981	2952	20.8	62.5	16.7	92	56.2	1806	13.3	333	14.6	19.3	3.0	63.2	1.34 70.3	
September 3, 1981	3269	20.8	62.5	16.7	83	54.5	1800	13.3	327	15.6	20.9	3.8	59.6	1.34 77.9	
September 4, 1981	3342	19.9	68.3	16.8	100	52.9	1800	10.2	323	13.6	24.2	2.5	59.7	1.78 84.8	
September 5, 1981	2707	0	79.2	20.8	81	51.0	1800	12.7	487	13.0	20.4	3.7	62.8	1.60 75.0	
September 6, 1981	3027	0	83.6	16.4	91	56.0	1800	11.9	483	13.0	20.2	5.3	61.5	1.55 79.7	
September 7, 1981	3195	0	87.5	12.5	96	54.0	1800	14.2	497	13.4	21.8	5.9	58.9	1.63 86.5	
September 8, 1981	3184	0	89.2	10.8	96	56.0	1800	15.8	460	11.9	23.1	4.2	60.9	1.94 85.9	
September 9, 1981	3151	0	91.7	8.3	95	56.0	1800	15.7	440	13.6	22.1	4.8	59.4	1.63 84.5	
Period III															
September 10, 1981	3135	0	91.7	8.3	94	56.0	1800	15.4	433	13.1	23.2	3.7	60.1	1.78 84.8	
September 11, 1981	3251	0	89.3	10.7	98	56.0	1800	13.9	467	13.6	20.7	3.5	62.2	1.52 76.3	
September 12, 1981	2792	0	87.5	12.5	84	54.5	1800	14.3	375	14.0	20.2	3.3	62.6	1.46 73.9	
September 13, 1981	2660	0	86.5	13.5	80	56.0	1800	12.7	340	-	-	-	-	-	
September 14, 1981	2653	0	87.5	12.5	80	54.5	1800	11.8	297	15.5	20.7	1.9	61.9	1.34 71.8	
September 15, 1981	2896	0	85.8	14.2	87	52.3	1800	12.4	343	15.5	25.6	2.3	56.4	1.64 93.6	
September 16, 1981	2923	0	83.3	16.7	108	52.1	1800	12.6	390	16.2	23.7	2.2	58.0	1.46 82.2	
Period IV															
September 17, 1981	2965	0	83.3	16.7	264	52.3	1802	12.4	337	15.2	24.0	2.7	57.5	1.52 84.8	
September 18, 1981	2575	0	82.2	17.8	231	55.7	1738	12.1	320	14.3	21.3	3.6	60.7	1.53 78.5	
September 19, 1981	2692	0	79.2	20.8	243	56.0	1920	10.3	320	14.7	21.0	4.2	60.2	1.43 79.0	
September 20, 1981	2749	0	79.2	20.8	248	56.0	1800	12.8	413	-	-	-	-	-	
September 21, 1981	2683	0	79.2	20.8	242	55.9	1812	11.4	350	14.6	22.3	4.8	58.3	1.53 85.1	
September 22, 1981	2669	0	79.2	20.8	240	56.0	1800	11.5	350	14.0	24.3	3.4	58.3	1.74 87.6	
September 23, 1981	2726	0	79.2	20.8	246	52.7	1800	11.7	280	17.3	24.6	1.9	56.2	1.41 84.2	
September 24, 1981	2569	0	79.2	20.8	232	53.7	1800	8.6	297	16.0	22.8	2.8	58.4	1.42 81.1	
September 25, 1981	2724	0	79.2	20.8	253	54.0	1804	10.4	427	12.3	25.3	3.2	59.1	2.06 90.4	
September 26, 1981	2654	0	79.2	20.8	130	53.2	1800	11.7	463	12.7	24.7	2.4	60.2	1.94 86.1	
September 27, 1981	2892	0	79.2	20.8	88	55.3	1800	13.3	467	14.4	25.9	3.4	56.3	1.80 92.8	
September 28, 1981	2750	0	79.2	20.8	83	54.0	1800	13.1	447	14.3	25.2	3.7	56.8	1.76 91.3	
September 29, 1981	3064	0	79.2	20.8	93	54.0	1800	15.6	427	14.6	24.9	3.6	56.9	1.71 90.0	
September 30, 1981	3111	0	79.2	20.8	94	54.0	1800	9.8	493	12.2	23.9	4.7	59.2	1.92 89.8	
October 1, 1981	3057	0	79.2	20.8	93	53.9	1800	9.8	347	15.9	25.5	2.6	56.1	1.61 89.1	
October 2, 1981	2925	0	83.1	16.9	89	50.8	1779	12.1	457	14.3	25.3	4.6	56.5	1.80 92.2	

Flux Stone

Flux stone additions were dependent on the amount of coke ash and gangue constituents introduced to the furnace with the burden, and aimed to yield a slag basicity of 1.30 for proper hot metal sulfur control.

Because the metallic burden included more ore burden and less scrap during the Test Period than the Base Period, the Test Period required 101 lbs more flux stone per net ton of hot metal than the Base Period (See Table 35).

TABLE 35. FLUX STONE CONSUMPTION - BASE VERSUS TEST PERIOD

<u>Item</u>	<u>Base Period</u>	<u>Test Period</u>
Dolomite Stone, lb/NTHM	235	261
Calcite Stone, lb/NTHM	100	175
Total, lb/NTHM	335	436

Another reason for higher flux stone consumption during the Test Period was that the BOF slag charges during the Test Period were less than during the Base Period: 74 lb/NTHM vs 44 lb/NTHM. Because BOF slag is a source of calcined flux, any flux deficiency due to BOF slag addition had to be made up by flux stone addition.

The flux stone consumptions during the individual Test Periods, which are shown in Table 22, were also much higher than during the Base Period. Since the calcination of flux stone requires considerable energy, the use of larger amounts of flux stone increases coke consumption in a blast furnace. This direct relationship between the flux stone and coke consumption is illustrated in Figure 50 for the COM trials.

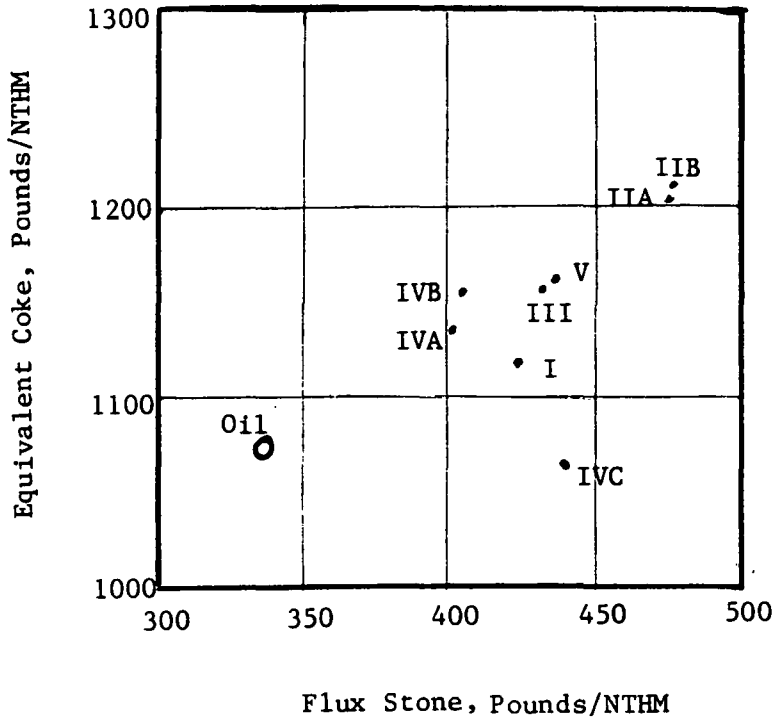


FIGURE 50. FLUX STONE USAGE VERSUS, EQUIVALENT COKE CONSUMPTION

VII.5.6 Slag Volume And Slag Chemistry

As a result of larger amounts of gangue introduction to the furnace, and correspondly larger amounts of flux stone requirements, the slag volume during the Test Period was on the average 86 lb/NTHM more than during the Base Period: 430 lbs/NTHM vs 516 lbs/NTHM.

The chemical compositions of slag during both periods were fairly constant as summarized in Table 36.

TABLE 36. CHEMICAL COMPOSITION OF SLAG -- BASE VERSUS TEST PERIOD

Item	Base Period	Test Period
CaO,% actual analysis	36.80	38.00
MgO,% actual analysis	17.11	14.85
Bases to Acids Ratio (CaO%+MgO%)/(SiO ₂ %+Al ₂ O ₃)	1.33	1.32
SiO ₂ ,% calculated	33.08	33.75
Al ₂ O ₃ ,% calculated	7.45	6.29
S,% calculated	2.54	1.83

Data concerning individual Test Periods can be found in Table 22. Because of similarities previously mentioned between the ore and scrap charges during the Base Period and Test Period IVC, it could be expected that slag volumes would be somewhat equal for these periods. Silicon content during the Test Period IVC was much lower than the Base Period, 1.78% vs 1.51% Si, which also contributed to higher slag volume during the Test Period IVC.

Because smelting gangue and flux constituents to form slag requires energy, the larger amounts of such materials ending up in the slag during the Test Period, as compared to the Base Period, necessitated more coke consumption during the Test Period. This direct relationship can be seen in Figure 51.

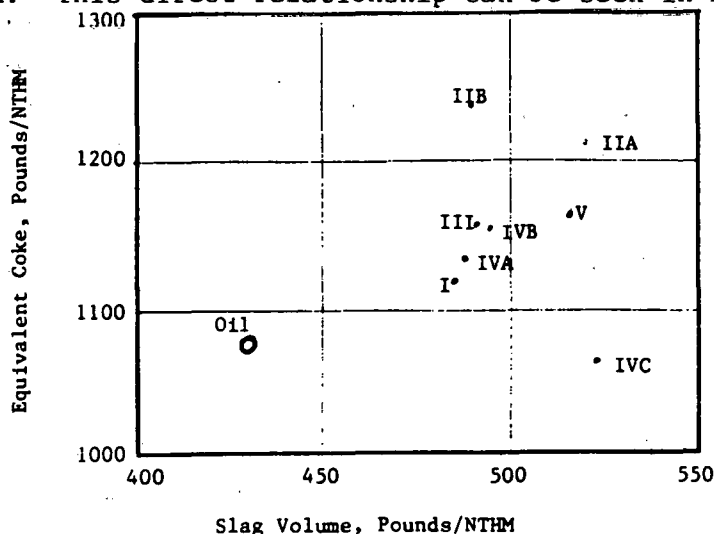


FIGURE 51. SLAG VOLUME VERSUS EQUIVALENT COKE CONSUMPTION

VII.5.7

Hot Metal Chemistry

Hot metal chemical composition was already discussed under the heading of Hot Metal Product Quality in Section VII.5.2. Here it needs to be mentioned once more with respect to its relationship with the coke consumption.

As shown in Table 37, the lower silicon, lower manganese, lower phosphorous, but higher sulfur contents during the Test Period (compared to the Base Period) were helpful in reducing the coke consumption during the Test Period.

TABLE 37. HOT METAL CHEMISTRY -- BASE VERSUS TEST PERIOD

<u>Item</u>	<u>Base Period</u>	<u>Test Period</u>
Si, %	1.78	1.66
S, %	0.025	0.028
Mn, %	0.86	0.79
P, %	0.047	0.036

Hot metal chemical compositions during the individual Test Periods, which are also shown in Table 22, bore the same relationship to the Base Period as the Test Period. Test Period IVC contained the lowest hot metal silicon, 1.51%, which was a significant factor in reducing the coke rate and increasing the hot metal production during this period. The direct relationship between the hot metal silicon and coke consumption is illustrated in Figure 52.

VII.5.8

Hot Metal Temperature

Hot metal temperature during the COM injection Test Period was 23°F lower than during the Base Period: 2787°F vs 2764°F. Some of this temperature drop can be attributed to lower hot metal silicon. Whether the water content of the COM product injected to the furnace could be partly responsible for this phenomenon will be discussed separately in Section VII.8 under the Theoretical Discussion On Combustion.

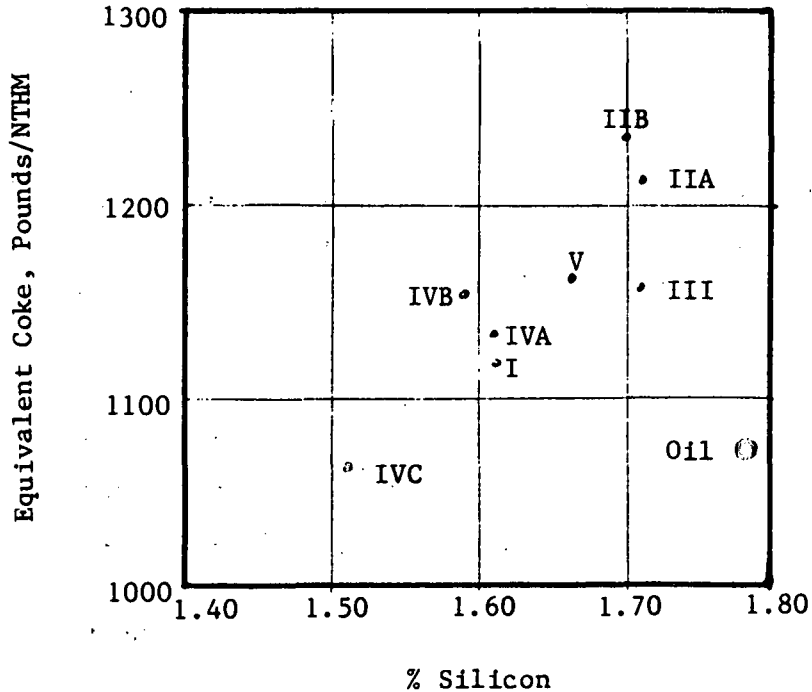


FIGURE 52. HOT METAL SILICON VERSUS EQUIVALENT COKE CONSUMPTION

VII.5.9 Other Operating Variables

VII.5.9.1 Wind Rate And Furnace Permeability

Wind rates during the Base and Test Periods depended on the hot metal production demands. Wind rate was maintained at an average of 54,400 SCFM during the Base Period and at an average of 54,300 SCFM during the Test Period.

During the Base Period, the blast air pressure was about 23 psi while the top pressure varied between 5.6 and 7.4 psi, corresponding to a pressure drop in the furnace between 15.6 and 17.4 psi. In contrast, the blast air pressure for the

Test Period was about 25 psi and the top pressure was about 9.3 psi, corresponding to a 15.7 psi pressure drop in the furnace.

The furnace permeability was not hindered due to COM injection. For example, during the 44 day Test Period, no slips or hanging in the furnace due to COM injection were experienced, except for one incident on October 1st. This incident is discussed in Section VII.5.10, Operating Delays.

When the hot metal demand was high during September 17 to 24, 1981, the wind rate could be increased from about 54,000 SCFM to about 57,000 SCFM without affecting the ability to increase hot metal production (Table 34). This result again illustrates that COM injection had no adverse effect on the furnace permeability.

VII.5.9.2 Furnace Top Pressure

The higher top pressures observed during the Test Period (5.6 to 7.4 psi versus 9.3 psi) require some explanation. The increase in top pressure was gradual from April, 1981 to October, 1981.

After the furnace was banked on October 31, 1981 for business reasons, an inspection of the blast furnace gas venturi scrubber revealed a clogged venturi with an effective opening of about 25% of the total area.

Therefore, the clogging of the venturi, not the COM injection, was the cause of the higher top pressures.

VII.5.9.3 Total Oxygen In Blast Air

During the course of the trials, blast air was not enriched with oxygen.

VII.5.9.4 Blast Temperature

The hot blast stoves were operated to provide straight heat to the blast furnace at 1800°F. Due to slight deviations from this course, which was not a frequent occurrence, the blast temperature averaged 1806°F for the Base Period and 1801°F for the Test Period.

Therefore, blast temperature for all practical purposes was not a big factor in the coke consumption differential between these periods.

VII.5.9.5 Blast Humidity

Blast humidity during the Base Period averaged 12.1 grains per SCF of dry blast air. Immediately at the beginning of the COM injection test, blast humidity was lowered to compensate for the moisture introduced to the furnace with the COM. However, once the furnace established thermal equilibrium for the new operating conditions, blast humidity was increased to its previous levels in order to give the furnace operators a leverage to rectify any abrupt changes in cast-to-cast hot metal silicon content. Thus, the blast humidity during the Test Period was very close to that during the Base Period: 12.1 vs 13.0 grains per SCF of dry air.

The similarity of the blast humidity during these periods, however, can be misleading. Because the Base Period consumed large quantities of scrap, its wind requirement per NTHM was much lower than the wind requirement for the Test Period. Hence, the specific blast moisture consumption was only 89.9 lb/NTHM for the Base Period vs 112.6 lb/NTHM for the Test Period. That is, the amount of blast moisture introduced to the furnace was actually increased on account of additional water introduction with COM. This fact certainly contributed to

the increased coke consumption during the Test Period as can be seen in Figure 53.

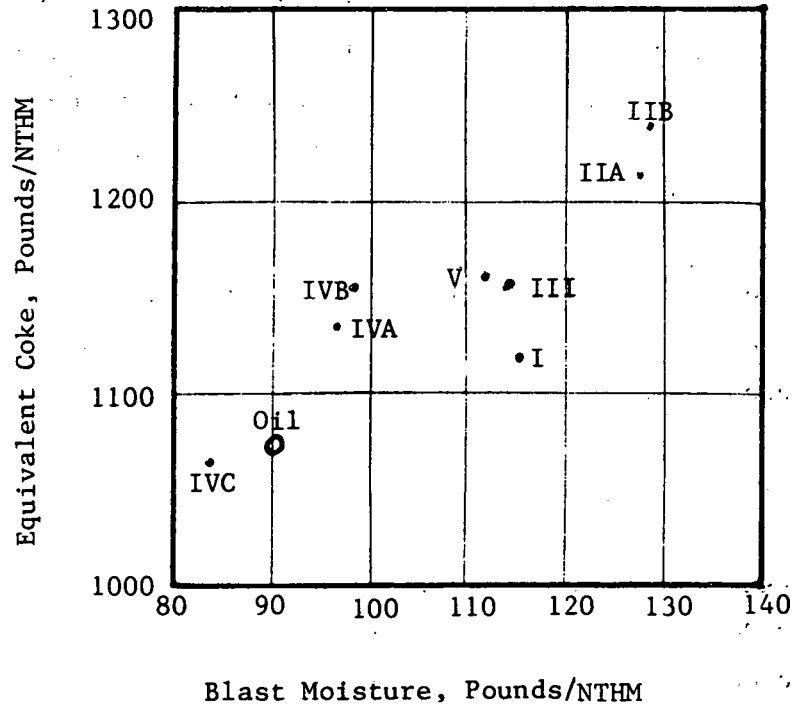


FIGURE 53. BLAST MOISTURE VERSUS EQUIVALENT COKE CONSUMPTION

Therefore, with more uniform quality of feed materials, better weighing and charging practices, and improved furnace instrumentation, one may not need to vary blast moisture to control hot metal silicon, thereby making more efficient use of COM as a blast fuel.

VII.5.9.6 Blast Furnace Gas Temperature

Average top gas temperature was 328°F during the Base Period but considerably higher during the Test Period (387°F) despite the fact that water was added to the coke charges to keep the top gas temperature low.

Top gas temperature can be used as a measure of thermal efficiency of a blast furnace. Higher top gas temperatures can be interpreted as a lower thermal efficiency in the stack which may be the result of channelling of the gas flow in the furnace, not filling the furnace to the stockline, using excessive amounts of coke, etc. In these trials, the cause of higher top gas temperatures can be traced to excessive coke usage. This cause and effect relationship observed between the top gas temperature and the fuel consumption is illustrated in Figure 54.

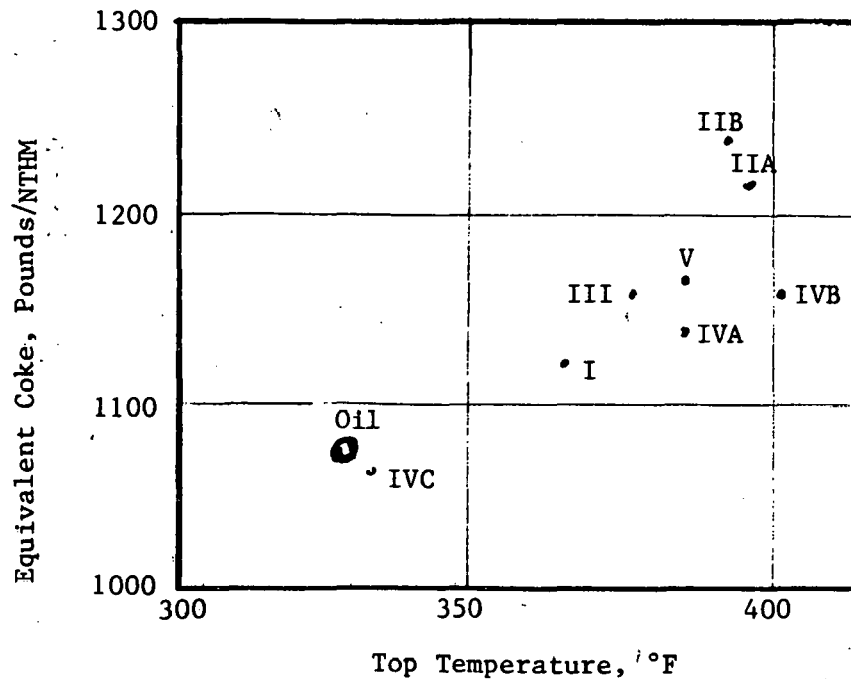


FIGURE 54. TOP GAS TEMPERATURE VERSUS EQUIVALENT COKE CONSUMPTION

Although the furnace operators were aware of the fact that the coke charges were excessive, they were reluctant to reduce them in order to insure that the furnace would not be chilled if the COM injection were interrupted suddenly. As a matter of fact, there were frequent interruptions in the COM injection at the beginning of the Test Period due to lines plugging, lances plugging, pump failure, etc. These interruptions in COM injection justify the actions taken by the furnace operators.

As the operators became more confident in the reliability of the COM injection by September 13, 1981, they reduced the coke rate somewhat, thus lowering the top gas temperature. This lasted about 10 days until the complete stoppage of COM injection to the furnace during September 22 and 23, 1981 due to the Gorator failure. Although details of the operating data can be found in Table 34, progression of the effect of the fuel rate on top gas temperature from September 22, 1981 and on can be followed easily in Table 38. On September 22 and 23, 1981 the furnace was kept operating without increasing the coke charges substantially, so that top gas temperature was reduced down to 280°F, then to 297°F. Following the resumption of COM injection to the furnace on September 24, 1981, not enough compensation was made to the coke charges, so that daily top gas temperatures from then on averaged between 427°F and 493°F to the end of the Test Period. The only exception was a 347°F top gas temperature encountered on October 1, 1981 when COM injection was again interrupted for most of the day on account of plugging of the COM return line.

TABLE 38. EFFECT OF FUEL RATE ON TOP GAS TEMPERATURE

<u>Date</u>	<u>Coke, wet lb/NTHM</u>	<u>COM lb/NTHM</u>	<u>Top Gas Temp., °F</u>
September 21, 1981	1078	114	350
September 22, 1981	1078	22	350
September 23, 1981	1098	22	280
September 24, 1981	1057	92	297
September 25, 1981	1165	164	427
--	--	--	--
October 1, 1981	1256	1	347
October 2, 1981	1200	209	457

VII.5.9.7 Blast Furnace Gas Heating Value

Blast furnace gas heating value for the Base Period was slightly lower than that for the Test Period: 86.2 vs 83.1 BTU/SCF. However, because the wind requirement per net ton of hot metal was much higher during the Test than the Base Period, the blast furnace gas generation per net ton of hot metal was also higher for the Test Period. Consequently, the specific heating value of the top gas was 7.08 million BTU/NTHM for the Test Period versus 6.38 million BTU/NTHM for the Base Period, a fact which also accounts for more fuel consumption during the Test Period emanating from different furnace practices during the Base and Test Periods.

VII.5.10 Operating Delays

Operating delays were defined by: (1) lost time when no wind was blown into the furnace because of operational problems or maintenance and (2) slack wind, the time interval during which the wind blown was brought from zero to the ordered wind rate. Thus the total operating delay was considered to be the sum of 100% of the lost time and 50% of the slack wind time.

The operating delays totaled 1.70% of the operating time during

the Base Period and 3.43% during the Test Period, which is summarized in Table 39.

TABLE 39. OPERATING DELAYS -- BASE VERSUS TEST PERIOD

Operating Delays	Base Period Test Period	
Lost Time, min/day	19.9	42.9
Slack Wind, min/day	9.1	12.9
Total, min/day	24.5	49.4
% of Operating Time	1.70%	3.43%

The average operating delays during the individual Test Periods are also shown in Table 40.

TABLE 40. OPERATING DELAYS -- TEST PERIODS

Operating Delays	Test Periods						
	I	II	IIB	III	IVA	IVB	IVC
Lost Time, Min/day	78.6	37.8	41.9	83.7	19.1	13.1	0
Slack Wind, Min/day	15.6	13.2	15.2	19.7	8.8	6.6	0
Total, Min/day	86.4	44.4	49.5	93.6	23.5	16.4	0
% Of Oper Time	6.00%	3.08%	3.44%	6.94%	1.63%	1.14%	0%

Details of the operating delays for the Base and Test Periods are given in Table 41.

Although the operating delays for the Test Period were about twice as high as during the Base Period, the reasons for the longer operating delays during the Test Period were not related to COM injection except on two occasions, one of which was of minor nature, but the other one was somewhat troublesome:

- (1) On September 6, 1981: 10-minute lost time for changing Nos. 6 and 8 COM injection lances which were burnt and stuck to the blow pipe, followed by a 21-minute slack wind to bring the furnace back on to the full wind.

TABLE 41.

'B' FURNACE OPERATING DELAYS - BASE VERSUS TEST PERIOD

Trial Periods And Dates	Lost Time, Min.	Slack Wind, Min.	Remarks
<u>Base Period</u>			
March 30, 1981	31	18	LT-Changed No.5 Tuyere (Burnt) SW-Furnace Start-Up
April 3, 1981	32	20	LT-Changed No.3 Tuyere (Burnt) SW-Furnace Start-Up
April 4, 1981	30	80	LT-Changed No.2 Tuyere (Burnt) SW-Furnace Off Rod & Start-Up
April 12, 1981	192	40	LT-Burnt Mud Gun Nose & Iron On Track SW-Furnace Start-Up
April 13, 1981	0	50	SW-Torpedo Ladle On Ground Blocking Third Position 'B' Lead
April 16, 1981	25	0	LT-Defective Brush Holder Skip Hoist Motor
April 17, 1981	180	30	LT-Repair Defective Brush Holder Skip Hoist Motor SW-Furnace Start-Up
April 21, 1981	68	17	LT-Repair Brush Holders To Hoist Motor Reseat Nos. 3 & 4 Blowpipes SW-Furnace Start-Up
<u>Total</u>	<u>608</u>	<u>255</u>	
<u>Test Period</u>			
August 20, 1981	46	33	LT-No Stop At Tap Hole Mud Gun Nose (Burnt) SW-Furnace Start-Up
August 21, 1981	238	20	LT-Changed Skip Bearings & Patched Venturi SW-Furnace Start-Up
August 23, 1981	109	25	LT-Reseat No.1 Blow Pipe, Replaced Piping & Packing On Bosh PiateOver No. 1 Tuyere SW-Furnace Start-Up
August 26, 1981	66	28	LT-Changed Nos. 4 & 8 Blowpipes SW-Furnace Start-Up
August 27, 1981	8	8	LT-Changed Nos. 3 & 4 Flapper Valves SW-Furnace Start-Up
August 28, 1981	233	55	LT-Scrap Car Off At Pig Casting Machine Bldg Lead Blocking 'B' Furnace SW-Furnace Start-Up (Twice)
September 2, 1981	60	15	LT-Bad Stop At Taphole SW-Furnace Start-Up
September 3, 1981	43	17	LT-Reseat No. 1 Blowpipe SW-Furnace Start-Up
September 5, 1981	66	21	LT-Changed No. 2 Tuyere (Burnt) SW-Furnace Start-Up
September 6, 1981	10	23	LT-Changed Nos. 6 & 8 COM Injection Lances (Burnt Off And Stuck In Blowpipes) SW-Furnace Start-Up
September 7, 1981	119	45	LT-Patched Hole In Venturi; Reseat No.1 Blowpipe SW-Furnace Start-Up
September 14, 1981	371	27	LT-Changed Nos. 3 & 5 Blowpipes; No Stop At Taphole SW-Furnace Start-Up
September 15, 1981	160	67	LT-Cleaned And Changed Mud Gun Nose; Changed No.1 Blowpipe SW-Furnace Start-Up (Twice)
September 16, 1981	55	44	LT-Changed No. 6 Tuyere (Burnt); Changed No. 2 Blowpipe SW-Furnace Start-Up
September 17, 1981	43	25	LT-Changed No. 7 Tuyere (Worn) SW-Furnace Start-Up
September 26, 1981	100	11	LT-Repairs To Venturi SW-Furnace Start-Up
September 27, 1981	27	50	LT-Reseat No. 1 Blowpipe SW-Furnace Start-Up
October 1, 1981	135	54	LT-Changed No. 7 Blowpipe, Gooseneck, Bottleg, Slurry Plug; Changed No. 6 Tuyere (Burnt); Reseat No. 1 Blowpipe SW-Furnace Start-Up
<u>Total</u>	<u>1889</u>	<u>568</u>	

(2) October 1, 1981: 78-minute lost time for changing No. 7 blow pipe, gooseneck, and bootleg which were filled with COM, followed by 54-minute slack wind to bring the furnace back to full wind.

The first operating delay due to COM is self-explanatory, but the second one requires some explanation.

On September 30, 1981, the average COM injection to the furnace was about 14.1 gpm. Routine inspection of the lances at 4:30 P.M. during the 3 P.M. to 11 P.M. shift on this date showed that the COM injection to all of the six tuyeres was normal.

Of these six tuyeres, Nos. 3, 4, 5, 6, and 8 were equipped with 3/8-inch pipe lance of 0.5 inch I.D. and No. 7 was equipped with a 1/2-inch pipe lance of 0.625 inch I.D. The incoming COM feed line was splitting the COM into two directions: one line was feeding lance Nos. 6, 5, 4, and 3 and then taking back the excess COM to the return line, and the other line was feeding lance Nos. 7 and 8 and then taking the excess COM back to the return line.

At about 9:00 p.m. on September 30, 1981, pressures in the COM lines in the cast house were observed to be higher than normal, and COM consumption since 8:00 p.m. was high. This indicated a restriction in the COM return line. No. 7 blow pipe was filled with COM, and No. 8 blow pipe had hot spots. COM was taken off the furnace and the circle pipe and lances were purged with steam. Efforts to open the 3-inch return line with steam were unsuccessful; pipefitters opened it the following day. Shortly before midnight on September 30, 1981, it became apparent that No. 7 blow pipe was plugged. No blast air was entering into the furnace through No. 7 tuyere.

The furnace started hanging in the early hours of October 1, 1981. The furnace was taken out of service between 5:00 A.M.

and 7:15 A.M. to replace No. 7 blow pipe. When the blow pipe, gooseneck, and bootleg were removed and inspected, it was observed that the coal from COM had carbonized and clogged them. It was evident that the plugging problem at No. 7 tuyere was precipitated by the clogging of the COM return line. On September 30, 1981 the pump was delivering 26.0 gpm of COM to the furnace. With a 14.1 gpm of COM being injected to the furnace, 11.9 gpm of COM was recycling back to the storage tank through the 3-inch diameter return line at a speed of 0.51 foot per second. Due to the settling of the coal particles from COM at such low speeds, the return line was gradually plugged. Once the return line was plugged, whatever quantity of COM that was pumped to the furnace was injected to the furnace through six tuyeres.

Assuming that 26 gpm COM delivered to the furnace was entering the furnace through six tuyeres and assuming that COM injection rates through these lances were proportional to area of the lance openings, then 19.81 gpm of COM must have been injected to the furnace through lance Nos. 3, 4, 5, 6, and 8 at the rate of 3.96 gpm per lance, and 6.19 gpm of COM must have been injected through lance No. 7 alone.

It was theorized that the clogging of No. 7 blow pipe must have been the result of excessive COM injection through lance No. 7 that brought about oxygen deficiency in blown air to react with coke carbon, lowered adiabatic flame temperature, and decreased drastically heat availability above 2800°F.

Under the normal operating conditions, that is, when delivering 54,000 SCF of blast air per minute through ten tuyeres and 14.1 gallons of COM per minute through six tuyeres, about 24% of the oxygen of the blast air would be consumed by reacting with the carbon from COM to form carbon monoxide; and about 76% of the oxygen of the blast air would be available to react

with the coke carbon. In comparing the coke consumption in the raceway in front of each tuyere, the coke mass in front of tuyere Nos. 3, 4, 5, 6, 7, and 8 would be combusted at a rate of about 76% of the coke combustion rate in front of tuyere Nos. 1, 2, 9, and 10 where there was no COM injection. That is, the rate of descent of coke in front of the tuyeres with COM injection would be 76% as fast as (or 1.32 times slower than) the descent of coke in front of the tuyeres with no COM injection. Relevant calculations are given in Appendix B.

If this methodology is extended to the COM injection to the furnace immediately after the plugging of the COM return line on September 30, 1981, the values shown in Table 42 would result.

TABLE 42. OXYGEN AVAILABLE AND RATE OF COKE DESCENT

Tuyere No.	COM Injection gpm/Tuyere	O ₂ Available, % Of Total O ₂ In Blast Air		Rate Of Coke Descent, Times Slower Than The Rate Of Descent Of Coke In Front Of Tuyeres With No COM Injection
		For COM	For Coke	
1, 2,				
9 & 10	0	0	100.0	1.0
3, 4, 5,				
6 & 8	3.96	40.4	59.6	1.7
7	6.19	63.2	36.8	2.7

From the foregoing arguments, it could be concluded that the furnace was tolerating the COM injection when the COM carbon was consuming 24.0% of the oxygen input, and the coke in the raceway in front of the tuyeres with COM injection was descending 1.3 times slower than the coke in front of tuyeres with no COM injection. However, when the oxygen availability for the coke carbon was severely curtailed because of high COM injection rates, the furnace reacted by developing hanging problems.

Besides the insufficient oxygen availability to combust coke in front of tuyere No. 7, the raceway must have been chilled because of excessive COM injection rate on September 30, 1981. The adiabatic flame temperature in front of tuyere No. 7, for example, is calculated to be 3120°F as opposed to 3340°F in front of tuyere Nos. 3, 4, 5, 6, and 8 and 3720°F in front of tuyere Nos. 1, 2, 9, and 10. Also, the heat availability above 2800°F, which is critical for melting iron and slag and supplying energy for high temperature reactions, must have been curtailed severely in front of tuyere No. 7. Theoretical calculations indicate that the heat availability above 2800°F, expressed in terms of BTU/1000 SCF of dry blast air, was 10,500 BTU for 6.19 gpm COM injection through tuyere No. 7 as opposed to 16,900 BTU for 3.96 gpm COM injection per lance through tuyere Nos. 3, 4, 5, 6, and 8, and 28,400 BTU for tuyere Nos. 1, 2, 9, and 10 where there was no COM injection.

Although the operating delay due to COM injection on October 1, 1981 was 78-minutes lost time and 59-minutes slack wind, its effects on blast furnace performance were far greater than the operating delay allocated to it.

In any event, this furnace problem toward the very end of the trial should be considered to be a fortunate experience to bring into perspective the importance of proper design of the COM injection system in regard to selecting proper pump capacity and proper pipe and lance diameters.

VII.6 Determination Of Coke Replacement Value Of COM

VII.6.1 Methods Followed

In determining coke replacement value of COM, four methods were followed. The first one was relatively simple and involved finding the oil-to-COM replacement ratio based on the

respective heating values and then determining coke-to-COM replacement ratio from the known relationship between coke and oil. The other three methods involved the analysis of the Base and Test Periods according to Flint Carbon Rate Formula. Flint Carbon Rate Formula is an empirical equation developed by the United States Steel Corporation through multiple regression analysis of actual practice data of numerous blast furnaces spanning a 20 year period⁽¹⁾. The multiple regression equation is explained as follows:

$$\text{Carbon Rate, } \frac{\text{lb}}{\text{NTHM}} = K + C_1 V_1 + C_2 V_2 + \dots + C_n V_n + A$$

where K is a carbon constant, lb C/NTHM, determined for an individual furnace from the past data;
 V_1 to V_n are the linear variables influencing the carbon rate;
 C_1 to C_n are the carbon coefficients for variables V_1 to V_n ;
A is a curvilinear variable involving hot metal sulfur content.

The definition and discussion of individual parameters and the examples for the application of this formula can be found in Flint's paper.

This carbon rate formula has been updated and revised by the U.S. Steel Corporation from time to time. The revised formula, presented by the U.S. Steel Corporation at the Blast Furnace Technical Committee of American Iron and Steel Institute in 1977, was utilized in the evaluation of COM injectant in this study.

(1) Flint, R.V., "Effect of Burden Materials and Practices on Blast Furnace Coke Rate," Regional Technical Meetings of the American Iron and Steel Institute, 1961, pp 1 - 36.

The carbon rate formula was especially useful in theoretical equalization of those variables that could not be maintained constant during the Base and Test Periods. It is through this theoretical equalization that the value of COM, as blast furnace fuel, could be extracted from the collected data without being affected by the actual differences observed on carbon rate influencing variables between these periods. However, before proceeding with this analysis, it would be appropriate to discuss the reliability of the data that will be used in these calculations.

VII.6.2 Evaluation Of Data Reliability

VII.6.2.1 Carbon Balance - Base And Test Periods

Carbon balances for the Base and Test Periods are summarized in Table 43. The carbon input to the furnace during the 28 day long Base Period was 1009.0 lb/NTHM. Out of this amount, 2.6 pounds of carbon/NTHM could not be accounted for in the carbon output. The unaccounted for carbon corresponds to a minus 0.26% of the total carbon input which can be considered remarkably good.

The carbon balance was also remarkably good for the 44-day Test Period. The carbon input during this period was 1106.9 lb/NTHM out of which only 8.6 lb C per NTHM could not be accounted for. This unaccounted for carbon corresponds to a minus 0.78% of the total carbon input.

VII.6.2.2 Iron Balance

Iron balances for the Base and Test Periods are summarized in Table 44. The iron input to the blast furnace during the Base Period amounted to 1918.3 lb/NTHM and only 24.3 lb iron/NTHM or 1.27% of the iron input could not be accounted for.

TABLE 43. CARBON BALANCE FOR COM INJECTION TRIALS

<u>Carbon Balance</u>	<u>Base Period</u> <u>lb Carbon/NTHM</u>	<u>Test Period</u> <u>lb Carbon/NTHM</u>
<u>Input:</u>		
Coke	931.1	985.2
Fuel Oil	38.0	-
COM	-	70.7
C From Stone, CaCO ₃	24.5	33.6
C From Stone, MgCO ₃	15.4	17.4
Total Input	<u>1009.0</u>	<u>1106.9</u>
<u>Output:</u>		
Hot Metal	83.8	84.5
Iron Runner Scrap	0.8	0.8
Flue Dust And Filter Cake	21.5	30.4
Blast Furnace Gas	905.5	999.8
Unaccounted For	- 2.6	- 8.6
Total Output	<u>1009.0</u>	<u>1106.9</u>
<u>Unaccounted For:</u>		
lb/NTHM	- 2.6	- 8.6
% Of Total Input	- 0.26%	- 0.78%

TABLE 44. IRON BALANCE FOR THE COM INJECTION TRIALS

Iron Balance	Base Period	Test Period
	1b Fe/NTHM	1b Fe/NTHM
<u>Input:</u>		
Ore Burden	1627.9	1817.1
Iron Scrap	264.1	105.9
All Other	26.3	24.2
Total Input	<u>1918.3</u>	<u>1947.2</u>
<u>Output:</u>		
Hot Metal	1862.0	1865.2
Iron Runner Scrap	18.6	18.7
Slag	1.3	1.6
Flue Dust & Filter Cake	12.1	16.9
Unaccounted For	24.3	44.8
Total Output	<u>1918.3</u>	<u>1947.2</u>
<u>Unaccounted For:</u>		
1b/NTHM	+24.3	+44.8
% Of Total Input	+1.27%	+2.30%

The unaccounted for iron during the Test Period was 44.8 lb/NTHM or 2.30% of the total iron input of 1949.2 lb/NTHM.

These inaccuracies in iron balances could be considered within the realm of practical operations and may emanate from weighing problems or from difficulties in obtaining representative samples for chemical analysis for the input and output materials.

VII.6.2.3 Hydrogen Balance

Hydrogen balances for the Base and Test Periods are given in Table 45. For the Base Period, 7.06 lb. of H_2 /NTHM are unaccounted for, that is, 16.83 lb. of H_2 input/NTHM minus 9.77 lb of H_2 accounted for in the top gas. If we assume that this unaccounted for hydrogen content was effectively utilized in reducing iron oxides in the furnace, the hydrogen gas utilization becomes 42.0%. This value is quite consistent with the 40% hydrogen gas utilization values reported in literature.

For the Test Period, the total hydrogen input to the furnace was 20.73 lb/NTHM, 15.30 lb of which came out of the furnace intact with the top gas. If the remaining hydrogen content is considered to be converted to H_2O in the reduction of iron oxides, the hydrogen gas utilization for this period becomes 26.2%. This hydrogen gas utilization value, which is much lower than the commonly reported values, might be attributable to (1) high top temperatures coupled with water additions to the furnace top to cool the top gas; or (2) water leak to the furnace from the cooling members which was not accounted for; or (3) inaccuracies in the measurement of hydrogen content of the top gas.

TABLE 45. HYDROGEN BALANCE FOR THE COM INJECTION TRIALS

<u>Hydrogen Balance</u>	Base Period <u>lb H₂/NTHM</u>	Test Period <u>lb H₂/NTHM</u>
<u>Input:</u>		
Blast Humidity	9.99	12.51
Fuel Oil	4.96	-
COM	-	6.90
Coke	<u>1.88</u>	<u>1.32</u>
Total Input	16.83	20.73
<u>Output:</u>		
Blast Furnace Gas	9.77	15.30
H ₂ Used In Iron Ore Reduction	<u>7.06</u>	<u>5.43</u>
Total	16.83	20.73
<u>Hydrogen Gas Utilization Efficiency:</u>	42.0%	26.2%

VII.6.2.4 Oxygen Balance

Oxygen balances for the Base and Test Periods, given in Table 46, show unaccounted for oxygen corresponding to 10.2% for the Base Period and 12.9% for the Test Period. Although these values are somewhat high, they are not surprising because of the fact that ordinarily about 10% discrepancy is noted between the wind ordered and reported and the wind actually delivered to the furnace.

VII.6.3 Determination Of Carbon And Coke Coefficients For COM

VII.6.3.1 Through Comparison Of Heating Values Of Oil And COM

The heating values of No. 6 fuel oil and COM used during the Base and Test Periods were determined to be 18,652 BTU/pound of fuel oil and 15,548 BTU/pound of COM. Based on these heating values, one pound of COM can replace 0.833 pound of fuel oil. From the known relationship between the coke and oil, 1.25 lb coke/lb of oil, and from the heating replacement value of COM, it can be determined that 1.04 lb coke can be replaced by one pound of COM. This relationship can be summarized as follows:

$$15,548 \text{ BTU/lb of COM} \div 18,652 \text{ BTU/lb of oil} = 0.833 \frac{\text{lb of oil}}{\text{lb of COM}}$$

$$0.833 \frac{\text{lb of oil}}{\text{lb of COM}} \times \frac{1.25 \text{ lb of coke}}{\text{lb of oil}} = 1.04 \frac{\text{lb of coke}}{\text{lb of COM}}$$

VII.6.3.2 Through The Use Of Given Carbon Coefficients

The revised carbon rate formula states the carbon coefficients for fuel oil, coal and water injected with coal. By utilizing these carbon coefficients with the appropriate COM components, a 1.06 lb. coke replacement value can be determined for each

TABLE 46. OXYGEN BALANCE FOR COM INJECTION TRIALS

<u>Oxygen Balance</u>	<u>Base Period</u> lb O ₂ /NTHM	<u>Test Period</u> lb O ₂ /NTHM
<u>Input:</u>		
Ore Burden - Iron Oxides	699.5	780.8
Scrap - Iron Oxides	7.6	3.0
All Other Iron Oxides	7.5	6.9
Blast Humidity	79.9	100.1
Fuel Oil Moisture	-	-
COM Moisture	-	5.4
Blast Air	972.7	1133.7
Hot Metal SiO ₂ → Si	40.6	37.8
MnO → Mn	5.0	4.6
P ₂ O ₅ → 2P	1.2	0.9
Slag CaO → CaS	5.4	4.7
Stone CaCO ₃ → CaO	79.2	89.6
Stone MgCO ₃ → MgO		46.3
Total	1898.6	2213.8
<u>Output:</u>		
Flue Dust And Filter Cake Iron Oxides	5.2	7.3
Top Gas CO	765.6	824.3
Top Gas CO ₂	881.3	1015.1
Tuyere H ₂ Reacted To H ₂ O	52.1	81.6
Unaccounted For	194.4	285.5
Total	1898.6	2213.8
<u>Unaccounted For:</u>		
lb/NTHM	194.4	285.5
% Of Total Input	10.2%	12.9%

pound of COM injection. This is shown in Table 47.

TABLE 47. CARBON COEFFICIENT FOR COM

<u>Material</u>	<u>Carbon Coefficient Material lb C/lb Material</u>	<u>Carbon Coefficient Material lb/lb COM</u>	<u>Carbon Coefficient lb C/lb COM</u>
Low Volatile Coal	- 0.75	0.4795	- 0.3596
Fuel Oil	- 0.90	0.4759	- 0.4283
Water	+ 0.55	0.0446	+ 0.0245
			<hr/>
			- 0.7634

At a 72% effective carbon in coke, this theoretical carbon replacement value corresponds to 1.06 lb. coke per pound of COM. (Note: Effective carbon in coke means carbon available for other reactions after internal carbon requirements are satisfied for slagging coke ash, calcining and slagging flux stone required for coke ash, and slagging coke sulfur.)

The coke rate analysis for the Base and Test Period are given in Table 48. This table was prepared by using information provided in Appendix C, regarding specific material consumption and material chemical analysis. In the preparation of Table 48, first the furnace carbon constant, K, was determined for 'B' Furnace. To do this, the calculated coke consumption for the Base Period was taken to be equal to the actual coke consumption. Then the furnace carbon constant, K, was determined by subtracting the carbon requirements for listed variables from the carbon rate, that is, carbon provided by the coke. (It should be noted that the carbon rate equation given in Section VII.6.1 can be arranged as follows:

$$K = \text{Carbon Rate} - C_1 V_1 - C_2 V_2 - C_n V_n - A$$

The furnace carbon constant was then applied to the Test Period as well as to the Test Sub-Periods to determine the calculated coke rate, where the carbon coefficient for COM was computed to be - 0.7634 lb C/lb of COM.

TABLE 48.

SUMMARY OF COKE RATE ANALYSIS - 'B' FURNACE (Continued On Page 153)

Variable	Unit Of Measure	Carbon Coefficient	Base Period				Test Period					
			Carbon		Carbon		I		IIA		IIB	
			Units	NTHM	Units	NTHM	Units	NTHM	Units	NTHM	Units	NTHM
Carbon Constant	LB/NTHM		698.85		698.85		698.85		698.85		698.85	
Slag From Coke, Ash	"	+0.60	65.68	39.41	67.63	40.58	63.36	39.81	66.88	40.13		
Slag From Uncalcined Stone	"	+0.45	170.29	76.63	216.24	93.31	242.14	108.96	243.16			
Slag - All Other	"	+0.15	194.53	29.18	201.13	30.17	214.50	32.18				
Minus 20 Mesh Fe Materials	"	+0.12	105.11	12.61	99.09	11.89	103.78	12.45	104.47	12.		
Plus 20 Mesh-Minus 1/8 in.	"	+0.08	26.40	2.11	21.15	1.69	19.52	1.56	19.03	1.52		
Plus 1/8 in.-Minus 3/8 in.	"	+0.04	227.35	9.09	277.39	11.10	258.59	10.34	252.41	10.10		
Plus 3/8 in.-Minus 1 in.	"	0	2211.66	0	2323.81	0	2563.37	0		-0-		
Plus 1 in.-Minus 2 in.	"	+0.03	45149	13.59	398.85	11.96	271.16	8.14	260.08	7.80		
Charged Sulfur	"	+5.00	11.758	35.27	10.66	31.98	12.574	37.72	12.769	38.31		
Charged Free Metallics	"	-0.25	320.40	-80.10	132.31	-33.08	71.37	-17.84	73.41			
Charged Combined Water	"	+0.50	0	0	0	0	0	0	0	0		
Silicon	Percent	+110.0	1.78	195.80	1.61	177.10	1.71	18.810	1.70	187.00		
Manganese	"	+20.0	.86	17.20	0.83	16.60	0.79	15.80	0.78	15.60		
Phosphorous	"	+20.0	.047	0.94	0.047	.940	0.039	0.78	0.038	0.76		
Sulfur	"	(1)	.025	-0.015	0.030	-4.10	0.028	-2.82	0.028	-2.74		
Coal-Oil Mixture	LB/NTHM	-0.7637			43.6	-33.29	87.2	-66.60	101.8	-77.74		
Fuel Oil	LB/NTHM	-0.90	43.6	-39.24								
Wind Rate	CFM/ CFWV	+70.0	2.01	140.70	1.98	138.82	2.01	140.88	2.00	140.00		
Hot Blast Temperature	°F	(2)	1806	-273.38	1800	-272.50	1800	-272.50	1800	-272.50		
Blast Humidity	LB/NTHM	+0.40	89.93	35.77	115.66	46.2	127.65	51.06	128.45	51.33		
Days On Stack Lining	Day	+0.02	676.0	13.52	8.09	16.18	818	16.36	818	16.36		
Coke Stability	% Below 52	+4.0										
	% Above 52	-4.0	3.3	-13.20	1.8	-7.2	2.5	-10.00	2.5	019.00		
Top Pressure	PSIG	-1.0	5.41	-5.41	5.41	-5.41	5.41	-5.41	5.41	-5.41		
Carbon-Flue Dust & Filter Cake	LB/NTHM	+1.0	21.58	21.58	30.20	30.20	26.94	26.94	27.02	27.02		
Total Carbon From Coke	LB/NTHM			931.06		1002.05		91.99				
Fixed Carbon In Coke	Percent			91.46		91.59		91.99				
Calculated Coke Rate	LB/NTHM			1018.0		1094.06		1103.12				
Actual Coke Rate	"			1018.0		1073.48		1126.15				
Unaccounted For Coke	"			0		20.63		(23.03)				

(1) LB Carbon/NTHM = ((0.013)/(Dec. S + 0.232 x (Dec. Si)²)) - 40.2

(2) LB Carbon/NTHM = (0.0000625T² - 0.375 T + 20C) x (1.0 - 2.8 (R-0.21))
Where T is blast temperature, °F and R is decimal oxygen in blown wind

TABLE 48.

SUMMARY OF COKE RATE ANALYSIS - 'B' FURNACE
(Continued From Page 152)

Variable	Unit Of Measure	Carbon Coefficient	Test Period									
			III		IVA		IVB		IVC		V	
			Units	LB C/ NTHM	Units	LB C/ NTHM	Units	LB C/ NTHM	Units	LB C/ NTHM	Units	LB C/ NTHM
Carbon Constant	LB/NTHM		698.85	698.85	698.85	698.85	698.85	698.85	698.85	698.85	698.85	
Slag From Coke, Ash	"	+0.60	64.86	38.92	62.28	37.37	67.4	40.44	69.38	41.63	65.82	39.49
Slag From Uncalcined Stone	"	+0.45	219.27	98.67	204.06	91.83	224.4	100.98	222.33	100.05	221.32	99.59
Slag - All Other	"	+0.15	206.87	31.03	221.66	33.25	246.2	36.93	231.29	34.69	228.86	34.33
Minus 20 Mesh Fe Materials	"	+0.12	65.57	7.87	65.82	7.90	90.9	10.90	111.33	13.36	96.69	11.60
Plus 20 Mesh-Minus 1/8 In.	"	+0.08	14.13	1.13	3.35	0.27	11.7	0.99	28.34	2.27	15.48	1.24
Plus 1/8 In.-Minus 3/8 In.	"	+0.04	174.93	7.10	155.53	6.22	285.4	11.42	137.23	5.49	208.08	8.32
Plus 3/8 In.-Minus 1 In.	"	0	2816.96	0	2538.34	0	2503.0	0	2363.15	0	2521.73	0
Plus 1 In.-Minus 2 In.	"	+0.03	126.85	3.81	241.19	7.24	241.5	7.25	304.96	9.15	263.03	7.89
Charged Sulfur	"	+3.00	11.59	34.78	10.00	30.00	10.92	32.76	11.46	34.27	10.31	30.93
Charged Free Metallics	"	-0.25	57.96	-14.49	118.99	-29.75	116.28	-29.07	216.0	-54.0	95.31	-23.83
Charged Combined Water	"	+0.50	0	0	0	0	0	0	0	0	0	0
Silicon	Percent	+110.0	1.71	188.10	1.61	177.10	1.59	174.9	1.51	166.10	1.66	182.60
Manganese	"	+20.0	0.61	12.20	0.84	16.80	0.84	16.8	0.84	16.80	0.72	15.80
Phosphorous	"	+20.0	0.26	0.52	0.033	0.66	0.034	0.68	0.034	0.68	0.036	0.72
Sulfur	"	(1)	0.028	-2.83	0.028	-1.98	0.029	-2.91	0.032	-5.34	0.028	-2.40
Coal-Oil Mixture	LB/NTHM	-0.7637	56.10	-42.82	112.6	-85.96	136.2	-103.98	84.6	-64.58	87.50	-66.81
Fuel Oil	LB/NTHM	-0.90										
Wind Rate	CFM/ CFWV	+70.0	2.02	141.16	2.00	140.00	2.00	140.00	2.04	142.81	2.01	140.70
Hot Blast Temperature	°F	(2)	1800	-272.50	1801	-272.94	1804	-273.10	1810	-274.00	1801	-272.50
Blast Humidity	LB/NTHM	+0.40	114.23	45.6	96.35	33.54	98.34	39.33	83.32	33.33	112.6	45.04
Days On Stack Lining	Day	+0.02	83.0	16.6	845	16.9	845	16.90	838	16.76	827	16.54
Coke Stability	% Below 52	+4.0										
	% Above 52	-4.0	3.3	-13.20	1.5	-6.00	2.4	-9.60	3.3	-13.2	2.2	-8.80
Top Pressure	PSIG	-1.0	5.41	-5.41	5.41	-5.41	5.41	-5.41	5.41	-5.41	5.41	-5.41
Carbon-Flue Dust & Filter Cake	LB/NTHM	+1.0	26.23	26.23	26.26	26.26	26.26	26.26	27.02	27.02	27.02	27.02
Total Carbon From Coke	LB/NTHM			1001.41		927.15		931.27		926.83		980.64
Fixed Carbon In Coke	Percent			92.00		91.87		91.87		92.19		91.68
Calculated Coke Rate	LB/NTHM			1088.49		1009.30		1013.68		1005.35		1069.63
Actual Coke Rate	LB/NTHM			1099.15		1020.60		1017.13		977.54		1074.65
Unaccounted For Coke	LB/NTHM			(10.66)		(11.30)		(3.45)		27.81		(5.02)

$$(1) \text{ LB Carbon/NTHM} = (0.013)/(\text{Dec. } S + 0.232 \times (\text{Dec. } Si)^2) - 40.2$$

$$(2) \text{ LB Carbon/NTHM} = (0.0000625T^2 - 0.375 T + 200) \times (1.0 - 2.8 (R-0.21))$$

Where T is blast temperature, °F and R is decimal oxygen in blown wind

The calculated rate formula is compared with the actual coke rates for the Base and Test Periods in Table 49.

TABLE 49. CALCULATED VERSUS ACTUAL COKE RATES-BASE AND TEST PERIODS

<u>Item</u>	<u>Base Period</u>	<u>Test Period</u>
Calculated Coke Rate, lb/NTHM	1018	1070
Actual Coke Rate, lb/NTHM	<u>1018</u>	<u>1075</u>
Difference From Actual, lb/NTHM	0	(5)

It should be noted that the difference between the calculated and actual coke rates for the Base Period is zero because the furnace constant was determined by assuming the calculated coke rate to be equal to the actual coke rate. The minus 5 lb. coke difference per NTHM between the calculated and actual coke rates for the 44-day long Test Period shows that the carbon coefficient ascribed to COM was quite satisfactory and needed only a slight correction to make the calculated and actual coke rates identical.

As for the individual Test Periods, the difference between the calculated and actual coke rates varied from - 42 lb/NTHM for the Test Period IIB to + 28 lb coke/NTHM for the Test Period IVC, as shown in Table 50. These large discrepancies should be expected because satisfactorily accurate carbon rate analysis can not be obtained from blast furnace tests of short duration.

Table 50. CALCULATED VERSUS ACTUAL COKE RATES-TEST SUB-PERIODS

<u>Item</u>	<u>Test Sub-Periods</u>						
	<u>I</u>	<u>IIA</u>	<u>IIB</u>	<u>III</u>	<u>IVA</u>	<u>IVB</u>	<u>IVC</u>
Calculated Coke Rate/lb NTHM	1094	1103	1093	1088	1009	1014	1005
Actual Coke Rate/lb/NTHM	<u>1073</u>	<u>1126</u>	<u>1135</u>	<u>1099</u>	<u>1021</u>	<u>1017</u>	<u>977</u>
Difference from Actual, lb/NTHM	21	(23)	(42)	(11)	(12)	(3)	28

VII.6.3.3 Through Coke Rate Analysis

Carbon coefficient or coke coefficient for COM can be determined through coke rate analysis by using two different methods, both based on the Base and Test Period data.

VII.6.3.3.1 Method I In this approach, the furnace carbon constant was again derived using the Base Period. Then, this furnace carbon constant was used in the Test Period. The carbon required for the Test Period was taken equal to the carbon supplied to the furnace with the coke carbon. Finally, the carbon requirement for COM, which is the difference between the carbon required and the sum of carbon-consuming items in the carbon rate formula, excluding the COM injection, was determined. This is briefly highlighted in Table 51, and presented in detail in Table 52.

TABLE 51. METHOD I DETERMINATION OF CARBON COEFFICIENT OF COM

<u>Item</u>	<u>lb C/NTHM</u>
Carbon requirement for the Test Period including furnace carbon constant but excluding COM	1047.45
Carbon requirement for COM (Balance)	- 62.21
Total Carbon Required	985.24
Total Carbon Supplied: $1074.65 \frac{\text{lb. coke}}{\text{NTHM}} \times 91.68\% \text{ C} =$	985.24

Since 87.50 lb of COM/NTHM replaces 62.21 lb of carbon/NTHM, the carbon coefficient of COM must be -0.7110 lb C/lb of COM. At 72% effective carbon in coke, this carbon coefficient then corresponds to 0.99 lb of coke replacement per lb of COM injection.

TABLE 52. DETERMINATION OF CARBON COEFFICIENT OF COM THROUGH COKE RATE ANALYSIS - METHOD 1

Variable	Units Of Measure	Carbon Coefficient	Base Period		Test Period	
			Units	LB/C Per NTHM	Units	LB/C Per NTHM
Carbon Constant	LB/NTHM			698.85		698.85
Slag From Coke Ash	"	+0.60	65.68	39.41	65.82	39.49
Slag From Uncalcined Stone	"	+0.45	170.29	76.63	221.32	99.59
Slag - All Other	"	+0.15	194.53	29.18	228.86	34.33
Metallic Raw Materials Size						
Minus 20 Mesh	"	+0.12	105.11	12.61	96.69	11.60
Plus 20 Mesh-Minus 1/8 Inch	"	+0.08	26.40	2.11	15.48	1.24
Plus 1/8 Inch - Minus 3/8 Inch	"	+0.04	227.31	9.09	208.08	8.32
Plus 3/8 Inch - Minus 1 Inch	"	-	2211.66	0	2521.73	0
Plus 1 Inch - Minus 2 Inch	"	+0.03	451.47	13.54	263.03	7.89
Charged Sulfur	"	+3.00	11.758	35.27	10.309	30.93
Charged Free Metallics	"	-0.25	320.40	-80.10	95.31	-23.83
Charged Combined Water	"	+0.50	0	0	0	0
Silicon	Percent	+110.0	1.78	195.80	1.66	182.60
Manganese	"	+20.0	.86	17.20	0.79	15.80
Phosphorous	"	+20.0	.047	0.94	0.036	0.72
Sulfur	"	(1)		-0.02		-2.40
Coal-Oil Mixture	LB/NTHM	-0.7110 ⁽⁴⁾			87.50	-62.21 ⁽³⁾
Fuel Oil	"	-0.90	43.60	-39.24		
Wind Rate	CFM/CFWV	+70.0	2.01	140.70	2.01	140.70
Hot Blast Temperature	°F	(2)	1806	-273.38	1801	-272.50
Blast Humidity	LB/NTHM	+0.40	89.93	35.97	112.6	45.04
Days On Stack Lining	Day	+0.02	676	13.52	827	16.54
Coke Stability	%<52	+4.0				
	%>52	-4.0	3.3	-13.20	2.2	-8.80
Top Pressure	PSIG	-1.0	5.41	-5.41	5.41	-5.41
Carbon-Flue Dust & Filter Cake	LB/NTHM	+1.0	21.58	21.58	27.02	27.02
Total Carbon From Coke	LB/NTHM			931.06		985.24
Fixed Carbon In Coke	Percent			91.46		91.68
Calculated Coke Rate	LB/NTHM			1018.0		1074.65
Actual Coke Rate	"			1018.0		1074.65
Unaccounted Coke	"			0		0

(1) $LB\ C/NTHM = (.013/ (Dec.S + .732 (Dec. Si)^2)) - 40.2$

(2) $LB\ C/NTHM = (0.0000625T^2 - .375 T + 200) \times (1.0 - 2.8 (R-.21))$

Where T is temperature of hot blast in °F and R is decimal oxygen in blast.

(3) From Carbon Balance

(4) From -62.21 lb C/NTHM Divided By 87.50 lb COM/NTHM

VII.6.3.3.2 Method II This method is based on: (1) making appropriate adjustments to the carbon requirement for the Test Period to account for the furnace practice differences between the Base and Test Periods, then (2) determining coke coefficient for COM by reporting the total fuel consumptions during these periods.

The actual fuel consumption during these periods was as shown in Table 53.

TABLE 53. FUEL CONSUMPTION

<u>Fuel</u>	<u>Base Period</u>	<u>Test Period</u>
Coke, lb/NTHM	1018.0	1074.7
Fuel oil, lb/NTHM	43.6	-
COM, lb/NTHM	-	87.5

To compare the operating conditions of the Test Period to the operating conditions prevailing during the Base Period, with the exception of the auxiliary fuel injectants, certain adjustments have to be made to the Test Period. These adjustments to the Test Period, along with the other individual Test Periods, are summarized in Table 54.

TABLE 54. ADJUSTMENTS TO BASE PERIOD

<u>Carbon Requirement Factor</u>	<u>Carbon Adjustment lb C/NTHM</u>	<u>Coke Adjustment at 91.68% C, lb Coke/NTHM</u>
Coke Ash, Coke Sulfur, Coke Stability	+ 0.14	+ 0.15
Uncalcined CaCO ₃ and MgCO ₃	+ 22.96	+ 25.04
Slag from All Other	+ 5.15	+ 5.62
Ore Burden Size Distribution	- 8.30	- 9.05
Charged Free Metallics	+ 56.27	+ 61.38
Hot Metal Chemistry	- 17.20	- 18.76
Wind Rate, Blast Temp, Blast Humidity, Days On Lining	+ 12.97	+ 14.15
Flue Dust and Filter Cake	+ 5.44	+ 5.93
Total Adjustment	+ 77.43	+ 84.46

The above adjustments could be further highlighted by ranking factors effecting the increase and decrease in coke consumption during the Test Period as compared to the Base Period. This is shown in Table 55.

TABLE 55. HIGHLIGHTS OF ADJUSTMENT OF TEST PERIOD TO BASE PERIOD CONDITIONS

<u>Item</u>	<u>Coke Adjustment, lb/NTHM</u>
<u>Factors Effecting An Increase</u>	
<u>In Coke Consumption</u>	
Less Scrap Charges	+ 61
More Flux Stone Usage	+ 25
Operating Practices (Especially Blast Humidity)	+ 14
More Gangue Constituent in Burden	+ 6
Flue Dust And Filter Cake	+ 6
Sub total	+112
<u>Factors Effecting A Decrease</u>	
<u>In Coke Consumption</u>	
Hot Metal Chemistry (Especially lower Silicon content)	- 19
Less Fines in the Ore Burden	- 9
Sub total	- 28
<u>Net Coke Adjustment</u>	+ 84

That is, the coke rate for the Test Period had to be increased by 112 lb/NTHM due to less scrap charged, more flux stone usage, etc., and to be decreased by 28 lb/NTHM due to hot metal chemistry and less fines in the ore burden, resulting in an additional 84 lb coke requirement per net ton of hot metal as compared to the coke rate of the Base Period.

Now the coke coefficient for COM can be found by equating the fuel consumption for the Base and Test Periods for identical furnace operating conditions, as shown in Table 56.

TABLE 56. COMPARISON OF FUEL CONSUMPTION-BASE PERIOD VERSUS TEST PERIOD ADJUSTED TO BASE PERIOD CONDITIONS

<u>Item</u>	<u>Base Period</u>	<u>Test Period</u>	<u>Difference</u>
Coke, lb/NTHM	1018.0	990.2	- 27.8
Fuel oil, lb/NTHM	43.6	-	- 43.6
COM, lb/NTHM	-	87.5	+ 87.5

The table indicates that under the identical operating conditions, 87.5 lb of COM/NTHM would have replaced 27.8 lb of coke/NTHM and 43.6 lb of fuel oil/NTHM. By ascribing 1.25 lb coke replacement value per pound of fuel oil, the coke coefficient for COM is found to be 0.94 lb coke/lb COM.

Summarizing, the four calculation methods produced lb coke/lb COM replacement ratios of 1.04, 1.06, 0.99 and 0.94, respectively. A replacement ratio of 1 lb coke/ 1 lb COM is accepted as the test result.

VII.7 Combustion Of COM

VII.7.1 Observations Through Peephole

Observations were made through the peephole of the blow pipe to qualitatively assess the combustion characteristics of the COM. The injection lance entered the blow pipe in a horizontal plane, passing through the axis of the blow pipe at an angle of 16.25° to the axis of the blow pipe. The tip of the lance was set at the center of the blow pipe, at a distance 24 inches from the tip of the tuyere. This distance, which was found to be the optimum location for fuel oil injection for this furnace, was not changed for COM injection.

Observations through the peepholes showed similar signs for the combustion of COM and the combustion of fuel oil. In the

combustion zone, concentric circles were observed: A dark smaller circle propagating from the tip of the lance, indicating the incomplete combustion of COM, surrounded by a much brighter circle, representing the complete combustion of injected COM. The depth of penetration of COM in the raceway, until it was completely reacted with the oxygen of the blast air to form carbon monoxide, was not measured.

VII.7.2 Soot In Venturi Scrubber And Gas Cooler Water

Water exiting from the blast furnace venturi scrubber and gas cooler had a coloration varying from dark gray to pitch black, indicating the presence of varying amounts of soot. This was also the case during the fuel oil injection period. In contrast, when there was no auxiliary fuel injection to the furnace, no COM or fuel oil, the water took a light grayish appearance due to the presence of lime.

The particulates in the furnace intake water were 4.4 grains per gallon of water for the Base Period and 2.2 grains per gallon for the Test Period. The particulates in the venturi scrubber water showed a slight increase during the COM injection period, as compared to the fuel oil injection period: 67.0 vs 78.1 grains of solids per gallon of water. However, the content of solids in the gas cooler water was much higher for the COM injection period than for the fuel oil injection period: 7.5 vs 21.5 grains of solids per gallon of water.

Because no chemical analysis were performed on these particulate solids, it could not be ascertained that the increase in solids content was necessarily due to more soot formation from the combustion of COM than from the combustion of fuel oil.

Carbon In Blast Furnace Flue Dust And Filter Cake

Day to day measurement of the weight of the flue dust and filter cake generated, and the sampling and chemical analysis of these materials on a daily basis, could have shed some light onto the combustion efficiency of COM at different COM injection rates. However, as explained before, the weights of the flue dust and filter cake are only estimated values for the month, and the monthly chemical analyses reported for these materials are the analyses run on monthly samples composited from four individual samples taken once a week from the flue dust and filter cake piles.

As for the amount of the flue dust and filter cake generated, the estimates for the Test Period were higher than the Base Period. This might be the result of more wind requirement per net ton of hot metal during the Test Period than the Base Period. The use of increased amount of ore burden during the Test Period could be cited as another factor. Table 57 illustrates a comparison of flue dust and filter cake quantities generated during the Base and Test Period.

TABLE 57. FLUE DUST AND FILTER CAKE GENERATION -
BASE VERSUS TEST PERIOD

<u>Item</u>	<u>Base Period</u>	<u>Test Period</u>
B Fce. Flue Dust, lb/NTHM	32	35
B Fce. Filter Cake, lb/NTHM	<u>29</u>	<u>31</u>
Total, lb/NTHM	61	66

As a result, the carbon loss to the flue dust and filter cake was 5.44 lb. per NTHM more during the Test Period than during the Base Period: 21.58 lb/NTHM vs 27.02 lb/NTHM.

In the future, a better accounting of the flue dust and filter cake carbon would help clarify COM combustion efficiency.

Blast air and injectants introduced into a furnace through the tuyeres react with the coke in the bosh zone and form the bosh gas. Bosh gas characteristics can be defined as its temperature, chemical composition, heat content above certain temperatures and its volume for a given volume of wind blown. These values can be determined theoretically as a function of blast temperature, blast moisture, amount of auxiliary fuel injection for a given wind volume, oxygen enrichment of blast air, and the water introduced into the furnace with the auxiliary fuel injectants.

Bosh gas characteristics for the Base and Test Period conditions were determined using the conditions prevailing during these periods, as shown in Table 58.

TABLE 58. FACTORS DETERMINING BOSH GAS PROPERTIES

<u>Item</u>	<u>Base Period</u>	<u>Test Period</u>
Blast Temperature, °F	1806	1801
Blast Moisture, grains/SCF	12.1	13.0
Fuel oil, lb/NTHM	43.6	-
COM, lb/NTHM	-	87.5
Oxygen Enrichment Of Blast Air, %	0	0
Water In Auxiliary Fuel Injectants, % By Weight	0	6.14

Under the Base and Test Period conditions, a 43.6 lb fuel oil injection per net ton of hot metal through six tuyeres corresponds to 0.791 lb fuel oil injection per 1,000 SCF of dry wind. Similarly, an 87.5 lb COM injection per net ton of hot metal through six tuyeres during the Test Period corresponds to 1.357 lb COM/1,000 SCF of dry wind. At 6.14% water in the COM product, this injection rate corresponds to 1.274 lb dry COM /1,000 SCF dry wind and 0.583 grains of water/SCF dry wind.

Throughout the theoretical calculations, water input to the furnace with COM was treated separately from the water input to the furnace with the blast air, taking into account the fact that COM moisture was introduced to the furnace at about 170°F in liquid state whereas blast moisture was introduced at about 1,800°F, in gaseous state.

These theoretical calculations were also repeated for hypothetical cases involving no auxiliary fuel injection as well as for auxiliary fuel injection rates per lance other than the average rates mentioned for the Base and Test Periods. The results are discussed and graphically illustrated below.

VII.8.1 Adiabatic Flame Temperature

Adiabatic flame temperatures for the Base and Test Periods were calculated to be 3,656°F and 3,593°F respectively. Of 63°F temperatures difference between these periods, 14°F was due to the differences in starting blast temperatures and blast humidities, and 49°F was due to the injection of more COM than fuel oil to the furnace.

If equal amounts of COM and fuel oil were injected to the furnace under identical operating conditions, say 1.32 gpm/lance, the difference between the adiabatic flame temperatures would narrow down to 12°F; 3,605°F for fuel oil and 3,593°F for COM.

Again, if the amounts of COM and fuel oil injected were to replace equivalent amounts of coke in the furnace, say 1.32 gpm COM/lance and about 1.06 gpm fuel oil/lance, then the adiabatic flame temperatures would have been 3,622°F for fuel oil and 3,593°F for COM. These slight adiabatic flame temperature differences can be tolerated by the furnace as was proven during the 44-day long COM injection trial.

As mentioned in Operating Delays, Section VII.5.10, one of the reasons for No. 7 blow pipe clogging with COM on September 30, 1981 was the excessive COM injection. The COM injection at 6.19 gpm must have chilled the raceway by as much as 600°F with an adiabatic flame temperature of 3,120°F, in contrast to 3,720°F in the raceways in front of Nos. 1, 2, 9, and 10 tuyeres through which no COM was injected, Figure 55.

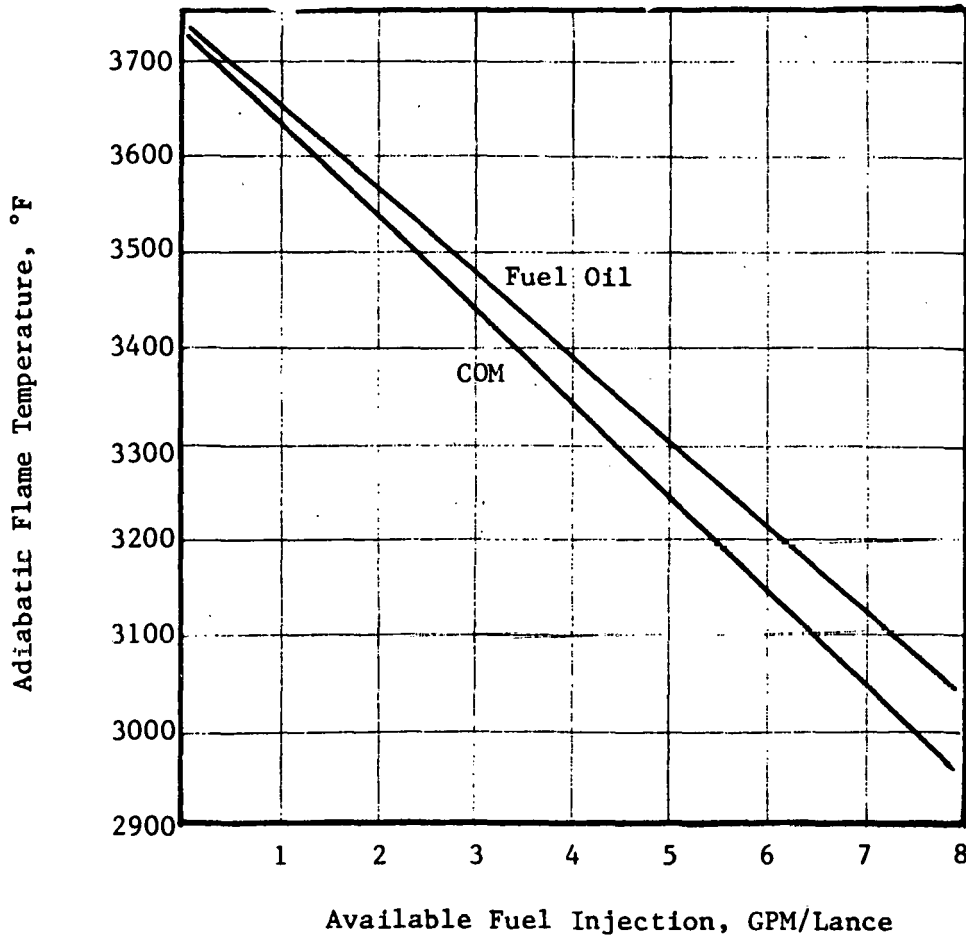


FIGURE 55. ADIABATIC FLAME TEMPERATURE VERSUS FUEL INJECTION RATE

VII.8.2 Heat Content Of Bosh Gas

Heat contents of bosh gas were calculated, using datum temperatures of 77°F and 2,800°F, for the conditions described above. The results are illustrated in Figures 56 and 57.

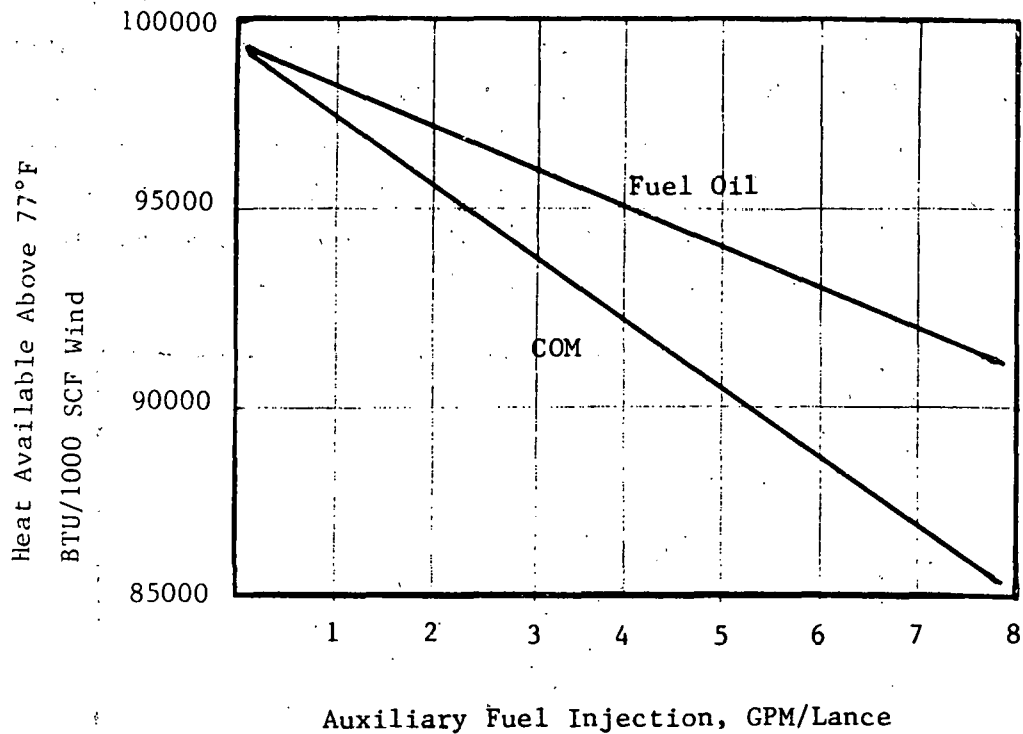


FIGURE 56. HEAT AVAILABLE ABOVE 77°F VERSUS FUEL INJECTION

Heat availability for the bosh gas above 77°F decreases more rapidly for COM than fuel oil as the injection rates are increased. However, the critical heat input is the heat availability above 2,800°F, which falls, for both injectants, at an equally fast rate but much faster than the heat availability above 77°F.

For example, as shown in Table 59, increasing the COM injection rate from one gpm/lance to three gpm/lance would reduce heat availability above 77°F by 2.8%, but heat availability above 2,800°F would be reduced by 22.7%.

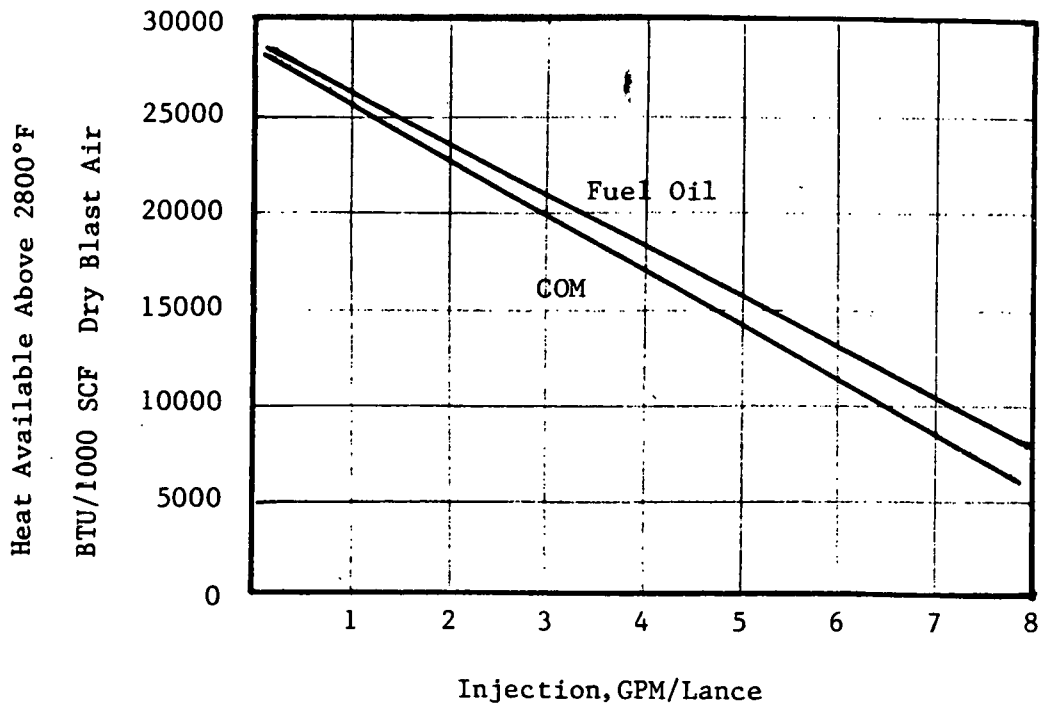


FIGURE 57. HEAT AVAILABLE ABOVE 2800°F VERSUS FUEL INJECTION

TABLE 59. HEAT AVAILABLE ABOVE 77°F AND 2,800°F

Item	1.0 gpm/ lance	3.0 gpm/ lance	% Difference
Heat available above 77°F BTU/1,000 SCF Wind	96,800	94,100	2.8%
Heat available above 2,800°F, BTU/1,000 SCF Wind	25,500	19,700	22.7%

Referring to the October 1, 1981 operating delay, the inability to control COM injection at No. 7 tuyere resulted in an injection rate increase from 2.35 to 6.19 gpm. As a result, the high temperature heat input to that raceway was reduced by about 50%, from 21,500 BTU to 10,500 BTU/1,000 SCF of dry wind.

Bosh Gas Composition

As can be seen from Figures 58 and 59, CO% in the bosh gas decreases and H₂% increases as the COM or fuel oil injection rates are increased. Because the hydrogen content of fuel oil is higher than that of COM, for the same injection rates, bosh gas contains more H₂% but less CO% for fuel oil than for COM.

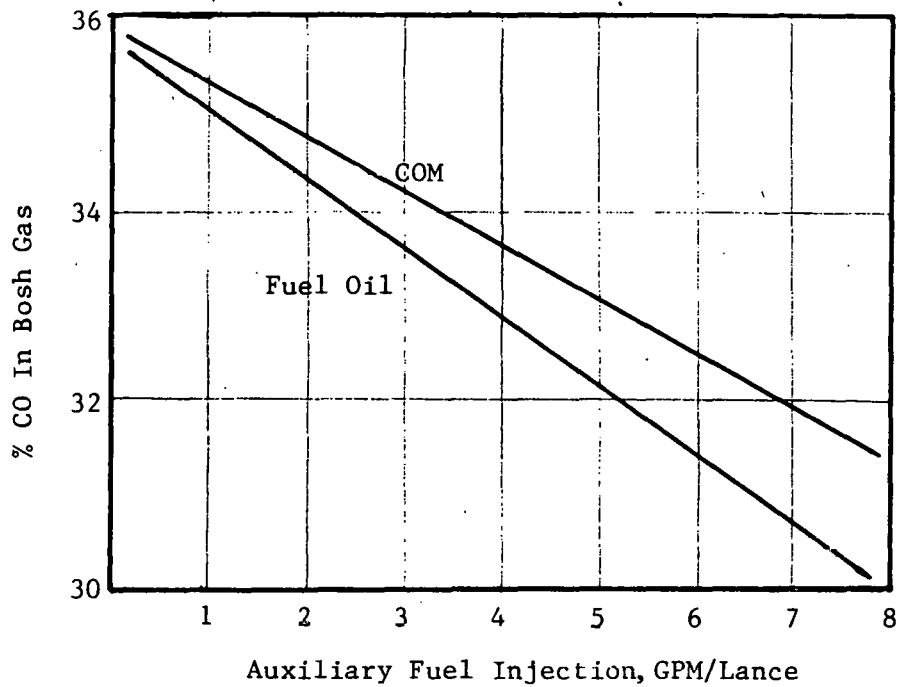


FIGURE 58. CO IN BOSH GAS VERSUS FUEL INJECTION

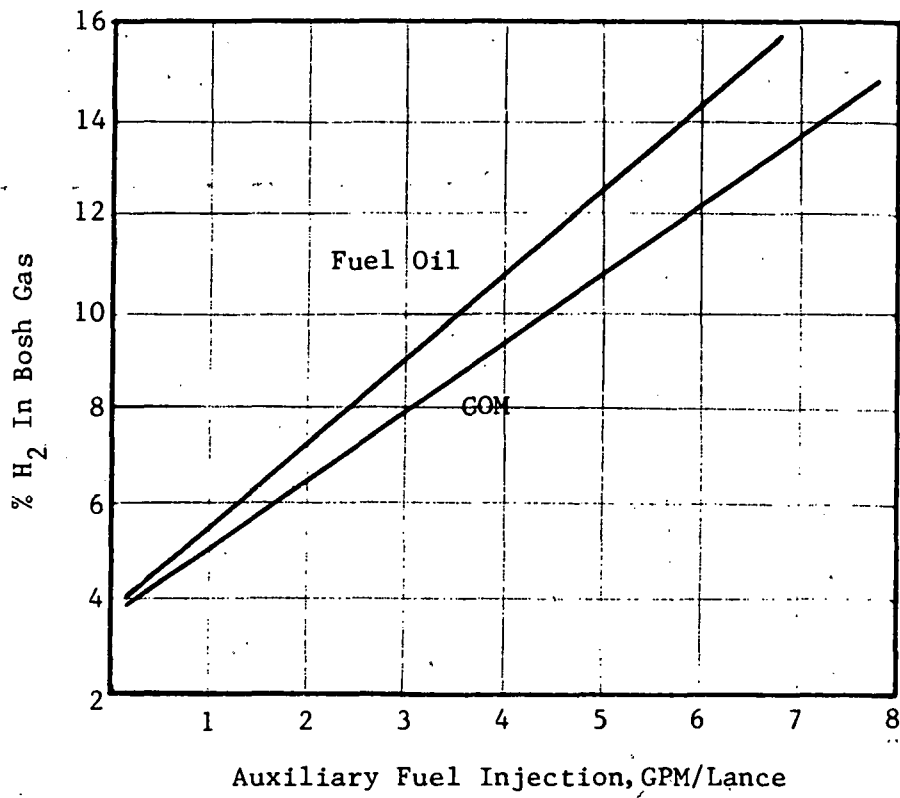


FIGURE 59. H₂ IN BOSH GAS VERSUS FUEL INJECTION

The reducing power of the bosh gas, that is, % CO + % H₂, increases as the injectant rates are increased.

VII.8.4 Bosh Gas Volume

Bosh gas volume generated for a given volume of wind may be critical in overcoming the resistance of the burden to the reducing gas flow with the available blast pressure. An excessive bosh gas volume would require either higher blast pressures, if available, or curtailment of the wind rate.

Bosh gas volume per 1,000 SCF of dry wind increases with increasing fuel oil and COM injections, but more so with COM injection than fuel oil injection, as can be seen in Figure 60.

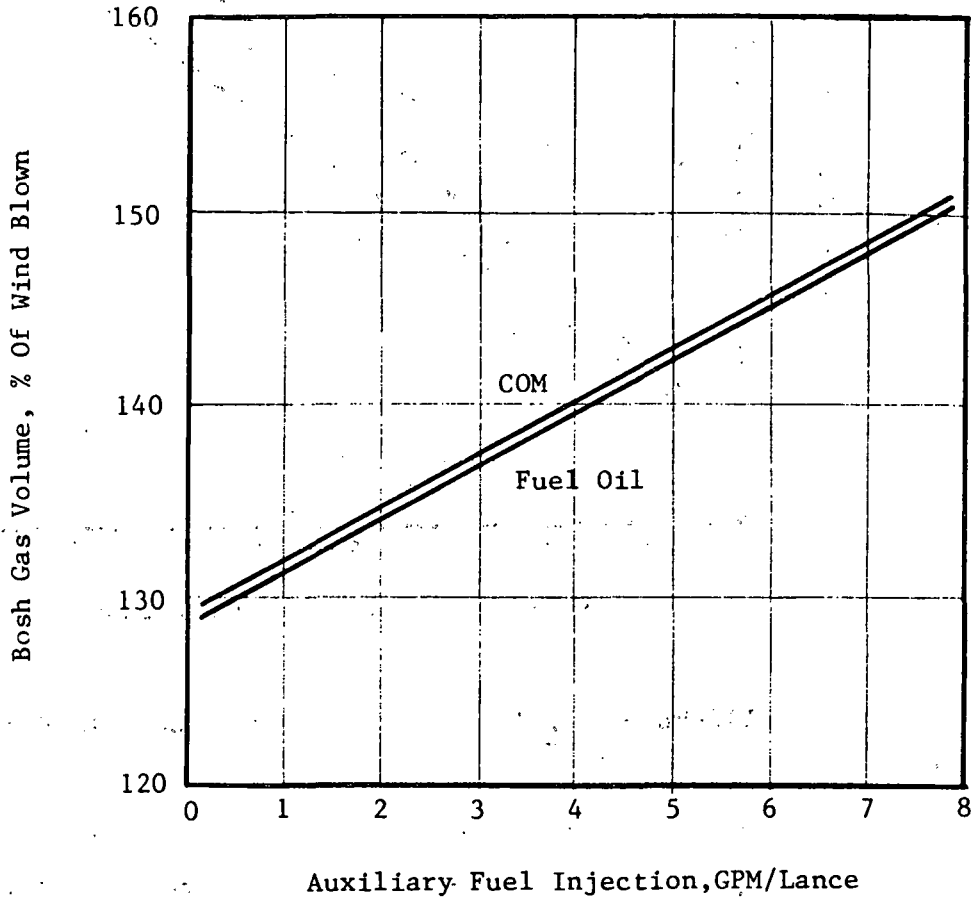


FIGURE 60. BOSH GAS VOLUME VERSUS FUEL INJECTION

VII.8.5 Oxygen Potential Of Blast Air

Bosh gas properties are also effected by the oxygen content of blast air. Because blast air was not enriched with oxygen during the blast furnace trials, the effect of oxygen enrichment on bosh gas properties was naturally zero.

Oxygen enrichment of blast air would increase the adiabatic flame temperature and heat availability. Thus it would allow

the injection of COM at higher rates.

If the oxygen potential of blast air is defined as the oxygen available in blast air to react with coke carbon after the oxygen requirement is satisfied for combusting the carbon of the auxiliary fuel injectants to carbon monoxide, then it follows that as the auxiliary fuel injection for a given blast volume increases, the oxygen available to combust the coke decreases. This point is illustrated in Figure 61 for fuel oil and COM injection.

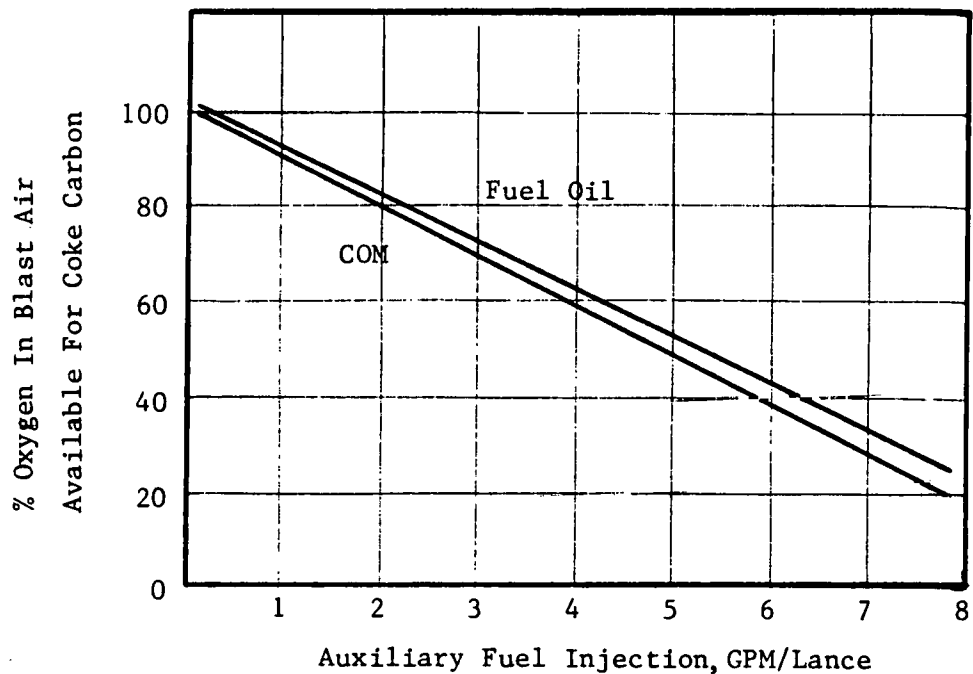


FIGURE 61. % OXYGEN IN BLAST AIR VERSUS FUEL INJECTION

The influence of blast air oxygen potential on the rate of coke descent at the raceway was noted at Section VII.5.10, Operating Delays.

VII.8.6

General Remarks

From the comparison of the bosh gas characteristics for fuel oil injection and COM injection, it can be seen that COM can be used as effectively as fuel oil and be subject to similar limitations with respect to maximum injection rates. That is, COM injection rates, like fuel oil injection rates, should not exceed 2.0 gpm per lance or 3.4 lb/1,000 SCF of dry wind for the furnace under consideration.

The use of dryer coal, and/or reduction of the amount of water emulsifier mixture in the COM preparation, may be helpful not only in improving the bosh gas characteristics and allowing higher COM injection rates, but also in increasing the coke coefficient value of COM. Similarly, oxygen enrichment of blast air would also allow the use of COM at higher injection rates.

VII.9

Economics Of COM Production

VII.9.1

Cost Of COM Production During The Test Period

The economics of operating the COM plant were calculated, based on the 44 days of testing. Taking into account the coal, oil, and emulsifier costs, replacement parts for the disperser and pumps, material handling cost, energy costs, research and maintenance labor, cost of COM production was 72.73 cents per gallon, excluding the finance charges for the COM plant. This cost is broken down in Table 60 and given in detail in Table 61.

TABLE 60. SUMMARY OF COST OF COM PRODUCTION

<u>Item</u>	<u>c Per Gallon</u>
Material	56.26
Replacement parts and maintenance	2.13
Material handling	4.11
Utilities	1.22
Labor	9.01
Total, excluding finance charges	72.73

TABLE 61. COST OF COM PRODUCTION

<u>Item</u>	<u>Cost Of COM</u>	
	<u>c/gal</u>	<u>\$/100 lb.</u>
<u>Material Cost</u>		
47.9% Olga Coal by wt. at \$63.85 per net ton....		1.529
47.6% No. 6 fuel oil at \$0.62 per gallon		
at 8.0 lb. per gallon at 60°F.....		3.689
0.5% emulsifier at \$10.00 per gallon		
at 8.33 lb. per gallon		0.600
Total		5.818
	<u>c/gal</u>	<u>c/gal</u>
<u>Total Material Cost</u> at 5.818c per pound and at 9.67 lb per gal...		56.26
<u>Replacement Parts And Maintenance</u>		
<u>Gorator Parts:</u>		
Includes 4 rotor blades, three sets of liner bars, wear resistant bolts, and labor for Gorator parts replacement..	1.24	
<u>Disperser Blades:</u>		
New blades and labor for installation.	0.77	
<u>Worthington Steam Pump - Labor for clean out and maintenance.....</u>		
	0.12	
Total	2.13	2.13
<u>Material Handling</u>		
Delivery of coal	0.31	
Pneumatic and conveyor filling of coal hopper.....	3.80	
Total	4.11	4.11
<u>Energy Costs</u>		
Steam and electrical costs for pumps, disperser, and miscellaneous COM equipment		1.22
<u>Labor Costs for Operating COM Plant</u>		
96 hours of millwright labor per week	3.10	
Research labor for operating COM plant (65% of time spent making batches and working in COM Plant).....	5.91	
Total Labor	9.01	9.01
<u>Total COM Cost, excluding finance charges.....</u>		72.73

Estimated Future Cost Of COM Production

By using Illinois coal instead of Olga coal (\$40.00 vs \$63.85/NT), COM cost can be reduced by about 7.8¢ per gallon, from 72.7¢ to 64.9¢ per gallon. COM cost can be reduced an additional 8.2¢ per gallon, lowering the cost to 56.7¢ per gallon, by streamlining the COM production process, as shown in Table 62.

TABLE 62. COM/ CONVERSION COST

<u>Item</u>	<u>Test</u> <u>¢/gal</u>	<u>Streamlined</u> <u>¢/gal</u>
Replacement Parts & Maint.	2.13	1.06
Material Handling	4.11	1.50
Energy Cost	1.22	1.22
Labor Cost	9.01	4.50
Total	16.47	8.28
Reduction In Conversion Cost As Compared to Test	0	8.19

It should be noted that the cost of the emulsifier makes up about 10% of the total COM cost: 5.80¢/gallon. By using reduced amounts of emulsifier, or less expensive emulsifiers, it is possible to reduce the cost of emulsifier by about one-half, or about 3¢ per gallon of COM, thus bringing the cost of COM production down to 53.7¢ per gallon.

Early laboratory tests had shown that stable COM products can be produced containing up to 70% coal. Up to 65% coal in COM was found to be pumpable with conventional pumps. However, when the COM contained 70% coal, it appeared that special pumps might be needed to handle such a product.

When the raw material cost differential between a COM product of 65-30-5 mixture and a COM product of composition identical to the test program COM is combined with the cost reduction features explained above, namely, using cheaper coal, using less and/or cheaper emulsifier, and streamlining the process,

a 65-30-5 COM product can be produced at a cost of 48.8¢ per gallon. Such a product can be used competitively against fuel oil as a blast furnace injectant. For example, for the cost of materials given here, the use of such a COM product as blast furnace injectant instead of fuel oil for equivalent coke replacement would yield \$0.15 benefit per gallon of COM used, excluding finance charges for the capital required for the COM plant.

VII.9.3

Comparison Of COM Cost

In this section COM cost will be compared with the cost of fuel oil and the cost of coke as a function of coal, fuel oil and coke prices. In this comparison, the following replacement ratios were taken, on the basis of the results obtained from the COM injection trials.

1 lb of COM = 1 lb of Coke = 0.80 lb of Fuel Oil

It appears that a 65-30-5 COM mixture would have about the same coke replacement value as the test COM (47.9 - 47.6 - 4.5). This is illustrated in Table 63.

TABLE 63. COKE REPLACEMENT VALUE OF 65-30-5 COM

<u>Item</u>	<u>lb Material/ lb COM</u>	<u>lb C/ lb Matl</u>	<u>lb C/ lb COM</u>
65% High Volatile Coal	0.65	- 0.80	- 0.5200
30% No. 6 Fuel Oil	0.30	- 0.90	- 0.2700
5% Water	0.05	+ 0.55	+ 0.0275
			- 0.7625

The carbon replacement value of the 65-30-5 COM mixture is calculated to be - 0.7625 lb of carbon per lb of COM. At 72% effective carbon in coke, this corresponds to 1.06 lb of coke per lb of COM, which is conservatively assumed to be 1 lb of coke per 1 lb of COM.

The production of COM, excluding finance charges for the COM plant, can be expressed in a general formula as follows:

$$\text{Cost of COM} = \text{Cost of Coal} + \text{Cost of Oil} + \text{Cost of Emulsifier} + \text{Cost of Conversion}$$

More specifically, the COM costs for the 47.9 - 47.5 - 4.5 mixture and the 65-30-5 mixture, which will be called COM J and COM K respectively, can be expressed in terms of cents per gallon as follows:

$$\text{COM J} = 0.2316 x + 0.5754 y + 11.18$$

$$\text{COM K} = 0.3348 x + 0.3862 y + 11.37$$

Where x is the cost of coal in terms of dollars per net ton and y is the cost of fuel oil in terms of cents per gallon, and where the densities of COM J, COM K, and fuel oil are 9.67, 10.3, and 8.0 lb/gallon respectively.

These COM costs are graphically illustrated in Figures 62 and 63 as a function of coal and fuel oil prices. These figures also illustrate the break-even lines for COM costs compared with fuel oil and coke prices. To give examples of how these figures can be used, consider point A on the break-even line, and point B on the line representing a coal cost at \$40/NT in Figure 62. Point A indicates that if COM is produced at 77.4¢ per gallon when fuel oil sells at 80¢ per gallon, COM will break-even with fuel oil as a blast furnace injectant. One gallon of COM J having a density of 9.67 lb/gallon and a coke replacement ratio of 1 lb coke/lb COM would replace 9.67 lb of coke. The same amount of coke, at a replacement ratio of 1.25 lb of coke/lb of fuel oil, can be replaced by 7.736 lb of fuel oil which corresponds to 0.967 gallons at a density of 8.0 lb/gallon.

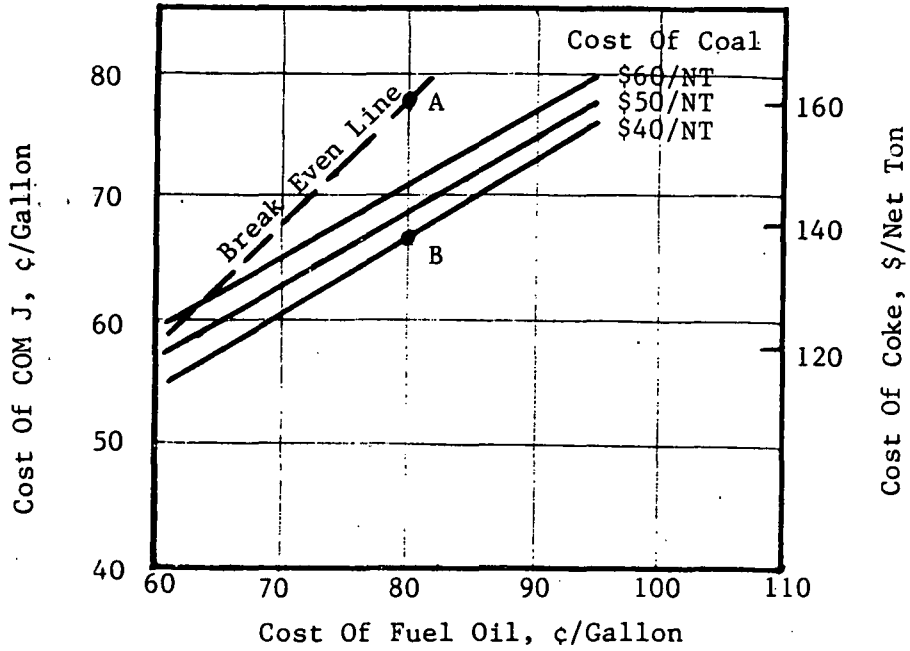


FIGURE 62. COST OF COM J VERSUS COST OF FUEL OIL

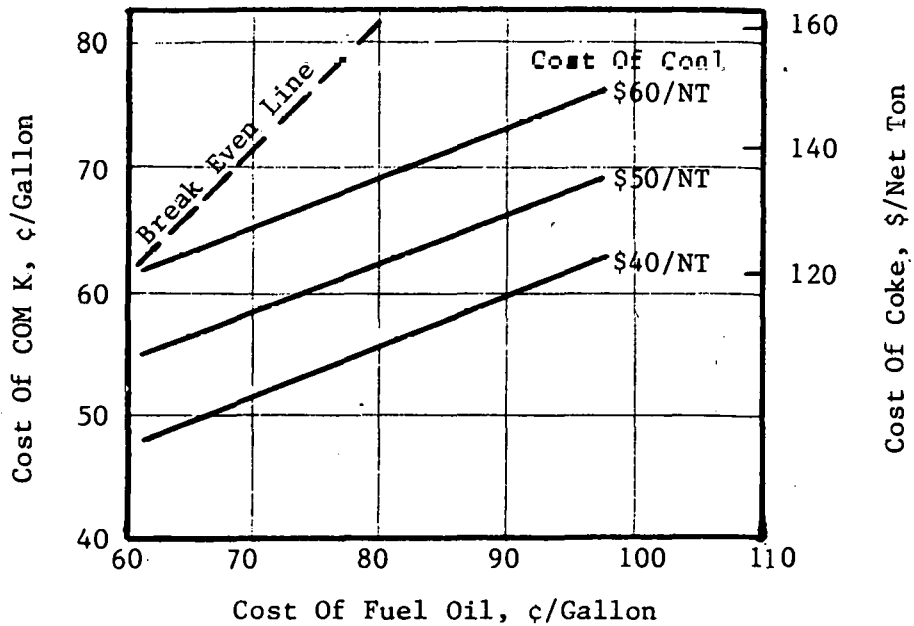


FIGURE 63. COST OF COM K VERSUS COST OF FUEL OIL

Thus, one gallon of COM J would replace 0.967 gallons of fuel oil. Hence, the break-even cost of COM J becomes 77.4¢/gallon when the fuel oil sells at 80¢/gallon:

$$(80\text{¢/gal. of oil}) \times (0.967 \text{ gal. of oil/gal of COM J}) = 77.4\text{¢/gal. of COM J}$$

Point B on the line representing coal cost at \$40 per net ton indicates that when fuel oil sells for 80¢/gallon, COM J can be produced at a cost of 66.5¢/gallon according to the equation given on page 175. Because point B lies below the break-even line, COM J at this point can yield an economic benefit (excluding finance charges) of about 11¢ per gallon of COM injected to the blast furnace:

One gallon of COM J at 66.5¢/gallon :	66.5¢
0.967 gallon of fuel oil at 80.0¢/gallon:	<u>77.4¢</u>
Difference:	10.9¢

In order for COM J to replace coke economically at point B, coke must be selling at about \$138 per net ton or more, which is also shown in Figure 62.

VII.9.4

Conservation Of Fuel Oil As A Result Of COM Usage

COM J, which has the COM composition utilized during the COM injection trials, has a capacity to conserve 40.5% of the fuel oil injected into the blast furnace. This is shown in Table 64.

TABLE 64. FUEL OIL CONSERVED BY COM J

<u>Item</u>	<u>COM J</u>	<u>Fuel Oil</u>	<u>Fuel Oil Conserved</u>
COM J, 1b/100 lb Coke	100	-	-
Fuel Oil In COM J @ 47.6%, 1b/100 lb Coke	47.6	-	-
Fuel Oil, 1b/100 lb Coke	-	80	-
Fuel Oil Conserved, 1b/ 100 lb Coke	-	-	32.4
Fuel Oil Conserved, % (32.4 lb/80.0 lb)	-	-	40.5%

Similarly, fuel oil conservation through the use of COM K can be found to be 62.5% of fuel oil otherwise injected to the blast furnace to replace an equivalent amount of coke.

In determining the gallons of fuel oil conserved during the COM injection trial period, the following can be said:

- . The COM injection was 87.5 lb/NTHM
- . It contained 47.6% fuel oil by weight or 41.65 lb fuel oil/NTHM
- . COM had a replacement value of 0.8 lb oil/lb of COM.
Therefore, 87.5 lb COM/NTHM replaced 70.0 lb fuel oil/NTHM,
hence conserved 28.35 lb fuel oil/NTHM.
- . At 8 lb/gal, this fuel oil conservation would amount to
3.544 gallons/NTHM.
- . During the 44 day Test Period, 51,539 NTHM were produced,
therefore, fuel oil conservation during the Test Period
was 182,640 gallons.
- . Extrapolating these results to two-furnace level operation
at an annual iron production of 1,100,000 net tons would
yield 3,898,000 gallons of fuel oil conservation per year.

If the results obtained from Test Period IVB are taken into consideration, where the COM injection rate was the highest at 136.2 lb/NTHM or 13.0 gpm, and these results are extrapolated to 1.1 million net tons of hot metal production a year, fuel oil conserved would amount to 6,068,000 gallons a year.

Furthermore, injecting COM K to the furnaces at the rate of 136.2 lbs per NTHM could conserve about 9.4 million gallons of fuel oil per year.

SECTION VIII

SUMMARY AND RECOMMENDATIONS

VIII.1 Summary

During the 44 day trial, approximately 485,000 gallons of COM (or about 600 batches) were produced and injected into 'B' Furnace. As the test progressed, equipment and piping modifications resulted in a smooth COM processing operation. Only once was a major COM transport line plugged between the COM Plant and the furnace. Plugging of the lances, hoses and circle pipe was a more frequent and persistent problem. However, circle pipe plugging was all but eliminated following piping modifications. Lance and hose plugging incidents were reduced as well by removing most of the 90° elbows between the circle pipe and injection lances, and through proper selection of lance diameter.

COM of consistent quality was produced and was injected into the furnace with no major problem. Hot metal quality was maintained during the injection period.

Blast furnace operating results, especially coke rate and productivity, were compared for 28 days of operation with the injection of No. 6 fuel oil versus 44 days of operation with COM. Carbon and iron mass balance calculations were performed for both the Base Period (No. 6 oil injection) and the Test Period (COM injection). The Base Period selected was April, 1981. During this period, the burdening and operating practices were consistent, and the fuel oil injection rate was maintained constant at about 5.3 gpm. It should be noted that the Base Period was a record tonnage month for 'B' Furnace, i.e., 1,397 NTHM per day.

During the 44 days of COM injection, four major time periods were extracted for the purpose of material balance calculations -- Period I, 3.8 gpm; Period II, 7.6 gpm; Period III, 5.0 gpm; and Period IV, 10.8 gpm. Some of these major periods were then subdivided as shown in Table 65.

TABLE 65. COM INJECTION PERIODS

	<u>No. Of Days</u>	<u>Oil or COM Injection Rate</u>
Base Period	28	5.3 gpm oil
Test Period I	5	3.8 gpm COM
IIA	16	7.6
IIB	13	8.7
III	7	5.0
IVA	16	10.8
IVB	13	13.0
IVC	7	9.0
V	44	7.9

All of these periods were analyzed metallurgically and all charging data, raw material chemistries and operating data were utilized to determine the calculated coke rate (utilizing the Flint Carbon Rate Formula). The calculated coke rate was then compared to the actual coke rate for each period. The following conclusions were generated from the Coke Rate Analysis:

1. Test Period IVC was very similar to the Base Period operating conditions, and yielded similar fuel consumptions.

	<u>Base Period</u>	<u>Test Period IVC</u>
Coke, lb/NTHM	1018	978
Fuel Oil, lb/NTHM	44	-
COM, lb/NTHM	-	85
Total Coke Equivalent, lb/NTHM	1072	1063

2. Productivity during Period IVC was very similar to the record base month -- 1,397 NTHM per day for Base Period versus 1,377 NTHM per day for Test Period IVC.
3. Total fuel consumption during other Test Periods was higher than the Base Period as a result of differences in the operating conditions between the Base Period and Test

Period. The differences in operating conditions were dictated by business conditions (i.e., iron chemistry and production requirements). Through the use of the Flint Carbon Rate Formula, it was determined that the generally higher fuel consumption during the Test Period could be attributable to the following conditions:

- . Less Scrap Charge
- . More Flux Stone
- . Operating Practice (especially blast humidity)
- . More Gangue Constituent In Burden
- . Soot In Flue Dust And Filter Cake

The corrected fuel consumption figures, in total coke equivalents, are:

- . 1,072.5 lb/NTHM for the Base Period
- . 1,077.7 lb/NTHM for the entire 44 day Test Period

The coke rate evaluation, according to four different methods of calculation, yielded a coke replacement ratio of approximately one pound of coke per one pound of COM injected. The cost of COM for the trial, including research and plant labor and replacement parts, was \$0.73 per gallon for COM (compared to \$0.62 per gallon for oil). If a lower cost Illinois coal had been used, the COM cost would have been near break-even with No. 6 oil. Incorporation of some of the recommended COM plant modifications, plus reduced maintenance and labor costs, would be expected to reduce COM production costs approximately 15% below the present No. 6 oil price. Lower cost emulsifier and higher coal concentrations in the COM could provide substantial additional savings.

Based on the average injection of 87.5 pounds of COM per NTHM, 182,640 gallons of No. 6 oil were conserved in producing 51,539 tons of hot metal during the 44 day trial. Such a performance converts to an annual savings of 3.9

million gallons of No. 6 oil at 1.1 million tons of hot metal production a year at the Chicago Plant.

VIII.2

Specific Recommendations

1. Load the coal into the storage hopper using a front-end loader and belt conveyor rather than a pneumatic truck or crane and bucket. In the future, a railroad hopper car unloading station might be justified for more direct transfer of coal to the storage hopper.
2. Provide a shelter to cover the top of the coal conveyor and the opening into the hopper. Also, provide high and low level sensors on the hopper. With these modifications, the front-end loader operator could fill the storage hopper without assistance.
3. Consider the use of a crusher or breaker to provide some coal size reduction before the coal enters the coal storage hopper, but principally to reduce the number of damagingly large and hard bodies reaching the disperser and pumps.
4. COM operations have been carried on during the winter, but coal was not loaded by belt conveyor. Consider the handling of frozen coal during wintertime.
5. Increase the volume of the coal batch weigh hopper. It was not possible to safely contain the desired 4,000 pounds of coal in the present hopper. Even larger batch weights would be desirable if the coal content of the COM were increased.
6. Improve the accuracy and repeatability of oil and water-emulsifier batch measurement. Disperser draining is controlled by the same type of sensor and should be corrected in a similar manner.

7. Disperser blades with tougher tungsten carbide inserts were ordered to overcome insert breakage; however, they were received too late for evaluation. If the tougher inserts are successful in extending blade life, increase disperser speed by means of belt and pulley changes. This should allow a reduction in processing time or an improvement in coal grinding.
8. Consider the installation of up to three more Gorator grinding pumps. A vertically mounted pump could be mounted under each disperser, and the third new Gorator pump could be placed in the suction line to the injection pump.
9. Investigate methods of extending the service life of Gorator rotors and liner bars.
10. Improve the regulation of COM temperature at the in-line heat exchanger.
11. Relocate or modify all instruments that are not working properly. Specific items requiring attention include: storage tank thermocouple, densitometer, and viscometer.
12. Add new thermocouples and pressure sensors to aid in detecting and diagnosing system upsets. Record signals from these sensors using the existing multipoint recorder. Points where additional thermocouples would have been useful during the test include:
 - a) Suction line of the local recirculation loop
 - b) Circle pipe
 - c) Circle pipe outlet to return line
13. Further investigate flowmeters for COM. If only one flowmeter is used, as in the present arrangement, install an in-line heater to maintain the temperature of the recirculated COM.

14. Install a larger COM injection pump to reduce pressure fluctuations and to allow adequate flow velocity in the 3-inch diameter return line from the furnace. A 45 gpm pump would be suitable for maintaining a velocity in excess of 0.66 FPS in the return line from 'B' Furnace.
15. Enlarge the circle pipe to 2-1/2 inches diameter from the tee of the 4-inch COM delivery line to past the second lance on each side of the tee. Step down to 2 inches diameter past the second lance on each side. Use 2-inch return lines from the ends of the circle pipe to the main 3-inch return line to storage. Avoid "dead ends" on the circle pipe.
16. Remove all 90° bends between the circle pipe and the lances.
17. Use one-inch flexible hoses between the circle pipe and the lances, and use lances made of 3/8 inch Schedule 40 pipe.
18. Make available a sufficient amount of steam to adequately purge the circle pipe and lances.
19. Maintain a COM temperature of 165-185°F.
20. Based on the results of the COM injection trials, it is recommended that COM injection trials should be continued for longer periods of time to assess the coke replacement value of COM more accurately. In future trials, the furnace operations during the Base and Test Periods should be maintained as near to identical as possible. COM products prepared using a 50-45-5 (coal-oil-water and emulsifier) mixture and up to 65-30-5 mixtures should be included. A 65-30-5 COM mixture could reduce oil dependency by 62.5% while enhancing the economic acceptance of COM as a blast furnace fuel.

APPENDIX A

LANCE OBSERVATION REPORTS

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Total No. of Lances Open	3	3	3	3	3	3	3	3	4	4	3	4	3	4	3	3	4	3	3	4	3	3	2	3	2	3	2	0	2	1	2	1	1	0				
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Time	12:20 AM	2:20 AM	3:45 AM	6:10 AM	10:00 AM	3:00 PM	7:00 PM	8:30 PM	9:30 PM	10:50 PM	12:15 AM	1:00 AM	1:35 AM	3:20 AM	4:45 AM	5:50 AM	6:35 AM	4:30 PM	6:30 PM	8:30 PM	11:00 PM	12:45 AM	2:00 AM	3:00 AM	3:30 AM	4:45 AM	5:30 AM	6:45 AM	5:30 PM	6:00 PM	6:30 PM	7:30 PM	9:40 PM	10:00 PM	11:50 PM			
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Injection Rate GPM	76												4.5						41													
Time	5:00 AM	6:00 AM	7:00 AM	9:30 AM	10:20 AM	11:30 AM	2:00 PM	4:15 PM	5:30 PM	6:50 PM	8:00 PM	9:45 PM	10:45 PM	12:00 PM	1:00 AM	2:00 AM	3:00 AM	4:00 AM	4:30 AM	5:30 AM	6:30 AM	3:00 PM	6:30 PM	7:30 PM	11:10 PM	1:40 AM	3:00 AM	5:00 AM	7:00 AM	10:00 AM	12:30 PM	11:50 PM
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Injection Rate GPM	10.9								9.2								9.6																	
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Time	12:10 AM	1:30 AM	3:30 AM	5:00 AM	6:30 AM	9:40 AM	10:15 AM	11:50 AM	2:30 PM	5:50 PM	7:00 PM	8:30 PM	10:50 PM	11:00 PM	12:30 AM	2:00 AM	2:30 AM	4:15 AM	5:00 AM	6:30 AM	7:30 AM	8:00 AM	9:00 AM	1:30 PM	1:50 PM	2:00 PM	7:10 PM	7:50 PM	8:30 PM	9:30 PM	10:00 PM	12:00 Mid.	
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Injection Rate GPM	9.2												13.8																						
Time	1:45 AM	3:00 AM	4:20 AM	5:15 AM	6:10 AM	7:30 AM	10:00 AM	11:30 AM	3:40 PM	4:15 PM	5:15 PM	6:15 PM	8:00 PM	8:25 PM	9:10 PM	10:35 PM	11:20 PM	12:30 AM	1:50 AM	3:15 AM	4:30 AM	6:30 AM	7:30 AM	9:00 AM	10:00 AM	11:00 AM	2:45 PM	3:50 PM	5:50 PM	6:35 PM	6:50 PM	7:30 PM	9:00 PM	10:00 PM	11:00 PM
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Total No of Lances Oper	4	6	6	6	6	6	5	5	5	6	5	6	6	6	6	5	4	5	6	2	2	5	5	4	6	6	6	6	6	5	4	6		
Injection Rate GPM	16.2												12.2												14.1									
Time	6:10 PM	6:25 PM	7:15 PM	8:30 PM	10:00 PM	11:00 PM	11:40 PM	12:00 PM	12:30 AM	1:05 AM	2:00 AM	3:15 AM	3:40 AM	4:10 AM	7:50 AM	9:35 AM	10:35 AM	11:30 AM	2:30 PM	3:30 PM	4:15 PM	4:45 PM	5:40 PM	6:45 PM	8:00 PM	9:10 PM	10:00 PM	11:20 PM	12:35 AM	2:10 AM	3:30 AM	5:15 AM	7:00 AM	9:40 AM
	September 28												September 29												September 30									

Time	Injection Rate GPM	No. of Lances Open	No. 13	4	5	6	7	8	9	10
2:20 P.M.	14.1	5	000	0	000	000	000	000	000	Pulled
4:30 P.M.		6	0	000	000	000	000	000	000	Pulled
5:50 P.M.		4	0	000	000	000	000	000	000	
9:20 P.M.		0	5	4	4	5	5	5	5	4
11:30 P.M.	16.6	5	4	4	5	5	5	5	4	
12:30 A.M.		4	5	5	5	5	4	4	6	
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1:10 A.M.	4	5	5	5	5	4	4	6		
2:30 A.M.	4	5	5	5	5	4	4	6		

Oct. 30

October 1

October 2

Oct. 3

All Lances Pulled Test Ended

APPENDIX B

CALCULATION OF

RATE OF DESCENT OF COKE IN FRONT OF TUYERES

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APPENDIX B

CALCULATIONS RELATING TO THE RATE OF DESCENT OF COKE IN FRONT OF TUYERES

WITH AND WITHOUT COM INJECTION

- (1) Oxygen From Blast Air Per Tuyere
- a) Wind Rate : 54,000 SCFM
 - b) No. of Tuyeres : 10
 - c) Wind Rate/Tuyere : 5,400 SCFM/tuyere
 - d) Oxygen Rate/Tuyere : 1,128 SCF of O₂/min/tuyere
at 20.9% O₂ in blast air
 - e) No. of lb-mole O₂/min/tuyere : 2.98 lb-mole oxygen/
min/tuyere at 379 SCF
O₂/lb-mole O₂
- (2) Carbon From COM Per Tuyere
- a) COM Injection Rate : 14.1 gpm
 - b) No. Of Injection Lances : 6
 - c) COM Injection Rate/Tuyere : 2.35 gpm/tuyere, or at 9.0
lb/gal, 21.15 lb/min/tuyere
 - d) Carbon Injection Rate/Tuyere : 17.19 lb/min/tuyere
at 81.28% C in COM
 - e) No. of lb-mole C/min/tuyere : 1.43 lb-mole C/min/
tuyere at 12 lb C/lb-
mole C
- (3) Oxygen Requirement For Carbon From COM
- The oxygen requirement for COM carbon to react with oxygen to form CO is 0.715 lb-mole O₂/min/tuyere (that is, 1/2 of 1.43 lb-mole C/min/tuyere) or 24.0% of the total oxygen provided by blast air for that tuyere (0.715 lb-mole O₂/min/tuyere) ÷ (2.98 lb-mole O₂/min/tuyere).

(4) Oxygen Available To React With Carbon From Coke

With the use of 0.715 lb-mole O_2 /min/tuyere out of the 2.98 lb-mole O_2 input/min/tuyere for reaction with COM, 2.265 lb-mole O_2 /min/tuyere would remain to react with carbon from coke. This would correspond to 76.0% of the total oxygen input through that tuyere.

(5) Comparison Of Coke Consumption And Coke Descent

Tuyeres with no COM injection would consume 2×2.98 lb-mole C/min/tuyere from coke. Tuyeres with COM injection would consume 2×2.265 lb-mole C/min/tuyere from coke. Hence, the rate of descent of coke in front of tuyeres with COM injection would be 76% as fast as (or 1.32 times slower than) the rate of descent of coke in front of tuyeres with no COM injection.

In these calculations, oxygen contributions from blast moisture and COM moisture were ignored for the purpose of simplification. Although the quantity of oxygen introduced with the blast moisture and the COM is small, the reaction of water with carbon is simply endothermic. Because of this fact, when the COM injection rate exceeds a certain limit, which was the case for No. 7 tuyere on September 30, 1981, the combustion of COM and coke, and hence the furnace operation in general, are expected to deteriorate.

APPENDIX C

CHEMICAL ANALYSIS AND SPECIFIC WEIGHTS FOR MATERIAL BALANCE

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TABLE C-1. CHEMICAL ANALYSIS, PERCENT BY WEIGHT NATURAL BASIS.
BASE PERIOD FROM MARCH 30 TO APRIL 26, 1981.

Material	H ₂ O	Fe	P	Mn	SiO ₂	Al ₂ O ₃	CaO	MgO	S	Si	C
Erie Pellets	3.00	62.61	.015	.240	6.06	.34	.44	.44	.004		
Wabush Pellets	2.75	63.67	.009	1.900	3.01	.27	.13	.04	.005		
Roger Ore	6.48	55.17	.090	.610	3.71	.62	.46	.13	.016		
BOF Slag	-	13.51	.286	3.93	17.62	3.83	39.39	7.26	.258		
Scrap	6.81	74.19	.161	.54	5.90	.50	1.25	.47	.42		
(1),(2) Coke	10.11	1.04	.006	.015	3.82	1.67	.21	.10	.696		
Fuel Oil					.04				.890		
Coal-Oil-Mixture											
Dolomite		0.64	.028	.010	1.09	.20	28.44	21.32	.170		
Calcite		1.23	.016	.030	1.21	.28	47.31	1.53	.097		
Olivine		9.97	.008	.023	38.77	1.80	2.70	37.27	.003		
Flue Dust	-	18.47	.035	.26	7.78	1.70	4.56	2.35	.49	-	
Filter Cake	24.52	16.05	.043	.23	5.32	1.31	4.11	1.77	.43		
Hot Metal (3)		93.10	.047	.86					.025	1.78	4.188
Iron Runner Scrap		93.10	.047	.86					.025	1.78	4.188
Slag (Calculated)		30		.50	33.08	7.45	36.58	17.32	2.539		
(1) Proximate Analysis of Coke % Dry Weight Basis: 1.32% Volatile Matter, 90.14% Fixed Carbon, 8.51% Ash, .774% Sulfur											
(2) Coke Stability, ASTM %: 55.3											
(3) %C = 4.700 - 0.28 × (%Si + %P), and the balance is %Fe.											

TABLE C-2. MATERIALS BALANCE 'B' BLAST FURNACE, SPECIFIC WEIGHTS, LB/NTHM.
BASE PERIOD FROM MARCH 30 TO APRIL 26, 1981

Material	lb/nthm	Fe	P	Mn	SiO ₂	Al ₂ O ₃	CaO	MgO	S
Erie Pellets	2114	1323.6	.310	5.07	128.10	7.19	9.30	9.30	.085
Wabush Pellets	478	304.3	.043	9.08	14.39	1.29	.62	.19	.024
Roger Ore	0								
BOF Slag	74	10.0	.212	2.91	13.04	2.87	29.15	5.37	1.386
Scrap	356	264.1	.573	1.92	21.00	1.78	4.45	1.67	1.495
Coke	1122.5	11.8	.968	.17	43.26	18.91	2.38	1.13	7.882
Fuel Oil	43.6				.02				.388
Coal-Oil-Mixture	0								
Delamite Stone	235	1.5	.066	.02	2.56	.47	66.83	50.10	.400
Cakite Stone	100	1.2	.016	.03	1.21	.28	47.31	1.53	.097
Olivine	18	1.8	.001	.00	6.98	.32	.49	6.71	.001
Sub-Total		1918.3	1.289	19.20	230.56	39.11	160.53	76.00	11.758
Flue Dust Dry	32	5.9	.011	.08	2.49	.54	1.46	.75	.157
Filter Cake Dry	29	6.2	.017	.08	2.04	.50	1.58	.68	.165
Sub-Total		1906.2	1.261	19.04	226.03	32.07	157.49	74.57	11.436
Hot Metal	2000	1862.0	.740	17.20	76.18 ⁽¹⁾				.500
Iron Runner Scrap	20	18.6	.009	.17	.76 ⁽¹⁾				.005
Slag lb/nthm (balance)		25.6	.312	1.67	149.09	32.07	157.49	74.57	10.931
% (analyzed)							36.80	17.11	
% (calculated)		.3 ⁽²⁾		.5 ⁽²⁾	33.08	7.45	36.58	17.32	2.539
lb/nthm (calc.)	430.5	1.3		2.20	142.41	32.07	157.49	74.57	10.931
									B/A = 1.33 ⁽³⁾
Fe, P, Mn and SiO ₂ unaccounted		24.3	.312	(.53)	6.68				

(1) Si in iron is given as SiO₂

(2) % Fe and % Mn in slag assumed to be 0.3% and 0.5% respectively

(3) Slag B/A = (CaO + MgO) / (SiO₂ + Al₂O₃)

TABLE C-3. CHEMICAL ANALYSIS, PERCENT BY WEIGHT NATURAL BASIS.
TEST PERIOD I, AUGUST 20 - 24, 1981.

Material	H ₂ O	Fe	P	Mn	SiO ₂	Al ₂ O ₃	CaO	MgO	S	Si	C
Erie Pellets	3.00	62.61	.015	.240	6.06	.34	.44	.44	.004		
Wabush Pellets	2.75	63.67	.009	1.900	3.01	.27	.13	.04	.005		
Roger Ore	6.48	55.17	.090	.610	3.71	.62	.46	.13	.016		
BOF Slag		13.51	.286	3.930	17.62	3.88	39.39	7.26	.258		
Scrap	2.44	83.53	.167	.60	6.41	1.04	1.34	.40	.126		
(1),(2) Coke	8.90	1.03	.006	.015	3.78	1.65	.21	.10	.864		
Fuel Oil											
Coal-Oil-Mixture	4.89								.65		
Dolomite		.64	.028	.010	1.09	.20	28.44	21.32	.170		
Calcite		1.23	.016	.030	1.21	.28	47.31	1.53	.097		
Olivine		9.97	.008	.023	38.77	1.80	2.70	37.27	.003		
Flue Dust	⊖	22.27	.049	.35	6.45	1.43	3.26	1.98	.61	-	50.40
Filter Cake	27.26	21.79	.150	.48	6.57	1.60	4.25	2.08	.42		39.42
Hot Metal (3)	(3)	92.247	.047	.83					.030	1.61	4236
Iron Runner Scrap		92.247	.047	.83					.030	1.61	4236
Slag (Calculated)		.30		.50	33.50	7.00	37.98	14.27	1.99		

(1) Proximate Analysis of Coke % Dry Weight Basis:

.38 % Volatile Matter, 91.21 % Fixed Carbon, 8.41 % Ash, .864 % Sulfur

(2) Coke Stability, ASTM %: 53.8

(3) %C = 4.700 - 0.28 × (%Si + %P), and the balance is Fe.

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TABLE C-4. MATERIALS BALANCE 'B' BLAST FURNACE, SPECIFIC WEIGHTS, LB/NTHM TEST PERIOD I, AUGUST 20-24, 1981.

Material	Lb/nthm	Fe	P	Mn	SiO ₂	Al ₂ O ₃	CaO	MgO	S
Erie Pellets	1813	1135.12	.272	4.351	109.26	6.16	7.98	7.98	.073
Wabush Pellets	483	307.53	.044	9.18	14.54	1.30	.63	.19	.024
Roger Ore	604	333.23	.544	3.68	22.41	3.75	2.78	.79	.097
BOF Slag	44	5.94	.126	1.73	7.75	1.71	17.33	3.19	.114
Scrap	176	147.01	.294	1.06	11.28	1.83	2.36	.70	.222
Coke	1178.3	12.14	.071	.18	44.54	19.44	2.47	1.18	9.270
Fuel Oil									
Coal-oil-Mixture	43.6								.270
Dolomite Stone	254	1.63	.071	.03	2.77	.51	72.74	54.15	.432
Calcite Stone	171	2.16	.027	.05	2.07	.48	80.90	2.62	.166
Olivine	0								
Sub-Total									
Flue Dust, Dry	36	8.02	.018	.13	2.32	.52	1.17	.71	.220
Filter Cake, Dry	31	9.16	.065	.21	2.83	.69	1.83	.89	.180
Sub-Total		192.752	1.367	19.92	209.48	33.97	184.19	69.20	10.268
Hot Metal	2000	1844.82	.940	16.6	68.9 ⁽¹⁾				.600
Iron Runner Scrap	20	18.45	.009	0.2	0.7 ⁽¹⁾				.006
Slag lb/nthm (balance)		64.25	.418	3.12	139.88	33.97	184.19	69.20	9.662
% (analyzed)							37.44	14.83	
% (calculated)		.30 ⁽²⁾		.50 ⁽²⁾	33.50	7.00	37.98	14.27	1.99
Lb/nthm (calc.)	485	1.46		2.43	162.46	33.97	184.19	69.20	9.662
									B/A = 1.29 ⁽³⁾
Fe, P, Mn and SiO ₂ unaccounted		62.9	.418	.69	(22.6)				

(1) Si in iron is given as SiO₂

(2) % Fe and % Mn in slag assumed to be 0.3% and 0.5% respectively.

(3) Slag B/A = (CaO + MgO) / (SiO₂ + Al₂O₃)

TABLE C-5. CHEMICAL ANALYSIS, PERCENT BY WEIGHT NATURAL BASIS.
TEST PERIOD IIA, AUGUST 25-SEPTEMBER 9, 1981.

Material	H ₂ O	Fe	P	Mn	SiO ₂	Al ₂ O ₃	CaO	MgO	S	Si	C
Erie Pellets	3.00	62.61	.015	.240	6.06	.34	.44	.44	.004		
Wabush Pellets	2.75	63.67	.009	1.900	3.01	.27	.13	.04	.005		
Boger Ore	6.48	55.17	.090	.610	3.71	.62	.46	.13	.016		
BOF Slag	2.58	13.51	.286	3.930	17.62	3.88	39.39	7.26	.258		
Scrap	2.41	79.04	.185	.483	6.43	.91	3.01	1.21	.203		
Coke (1),(2)	8.71	.97	.006	.014	3.54	1.55	.19	.10	.871		
Fuel Oil											
Cook-Oil-Mixture	4.62								.764		
Dolomite		.64	.028	.010	1.09	.20	28.44	21.32	.170		
Calcite		1.23	.016	.030	1.21	.28	47.31	1.53	.097		
Olivine		9.97	.008	.023	38.77	1.80	2.70	37.27	.003		
Flue Dust	0	22.30	.049	.35	6.10	1.41	3.76	2.08	.485	-	49.76
Filter Cake	30.73	20.39	.150	.38	6.20	1.61	4.25	2.25	.380		23.38
Hot Metal (3)		93.223	.039	.79					.028	1.71	4.210
Iron Runner Scrap		93.223	.039	.79					.028	1.71	4.210
Slag (Calculated)		.30		.50	33.64	6.27	38.19	14.89	2.25		
(1) Proximate Analysis of Coke % Dry Weight Basis: .68% Volatile Matter, 91.31% Fixed Carbon, 8.01% Ash, .954% Sulfur											
(2) Coke Stability, ASTM %: 54.5											
(3) %C = 4.700 - 0.28 x (%Si + %P), and the balance is Fe.											

TABLE C-6. MATERIALS BALANCE 'B' BLAST FURNACE, SPECIFIC WEIGHTS, LB/NTHM
TEST PERIOD II A, AUGUST 25-SEPTEMBER 9, 1981.

Material	Lb/NTHM	Fe	P	Mn	SiO ₂	Al ₂ O ₃	CaO	MgO	S		
Erie Pellets	2151	1346.7	.323	5.16	130.35	7.31	9.46	9.46	.086		
Wabush Pellets	486	309.4	.044	9.23	14.63	1.31	.63	.19	.024		
Roger Ore	447	246.6	.402	2.73	16.58	2.77	2.06	.58	.072		
BOF Slag	32	4.3	.092	1.26	5.64	1.24	12.60	2.32	.083		
Scrap	100.3	79.3	.186	.48	6.45	.91	3.02	1.21	.204		
Coke	1233.6	12.0	.074	.17	43.67	19.12	2.34	7.23	10.745		
Fuel Oil											
Coal-Oil-Mixture	87.2				2.75				.688		
Dolomite Stone	287	1.8	.080	.03	3.13	.57	81.62	61.19	.488		
Cakite Stone	190	2.3	.030	.06	2.30	.53	89.89	2.91	.184		
Olivine	0										
Sub-Total		2002.4	1.231	19.12	225.5	33.76	201.62	79.09	12.574		
Flue Dust, Dry	34	7.6	.017	.12	2.07	.48	1.28	.71	.165		
Filter Cake, Dry	30	8.8	.065	.16	2.69	.70	1.82	.97	.165		
Sub-Total		1986.0	1.149	18.84	220.74	32.58	198.52	77.41	12.244		
Hot Metal	2000	1864.5	.780	15.80	73.29 ⁽¹⁾				.560		
Iron Runner Scrap	20	18.6	.008	.16	7.3 ⁽¹⁾				.006		
Slag Lb/NTHM (balance)		102.9	.361	2.88	146.81	32.58	198.52	77.41	11.678		
% (analyzed)							38.08	15.00			
% (calculated)		.30 ⁽²⁾		.50 ⁽²⁾	33.64	6.27	38.19	14.89	2.25		
Lb/NTHM (calc.)	520	1.56		2.60	174.80	32.58	198.52	77.41	11.678	B/A = 1.33 ⁽³⁾	
Fe, P, Mn and SiO ₂ unaccounted		101.34	.361	.28	(28.06)						

(1) Si in iron is given as SiO₂

(2) % Fe and % Mn in slag assumed to be 0.3% and 0.5% respectively

(3) Slag B/A = (CaO + MgO) / (SiO₂ + Al₂O₃)

TABLE C-7. CHEMICAL ANALYSIS, PERCENT BY WEIGHT NATURAL BASIS.

TEST PERIOD IIB, AUGUST 25 - SEPTEMBER 9, 1981 EXCLUDING
AUGUST 31, SEPTEMBER 1 AND 2.

Material	H ₂ O	Fe	P	Mn	SiO ₂	Al ₂ O ₃	CaO	MgO	S	Si	C
Erie Pellets	3.00	62.61	.015	.240	6.06	.34	.44	.44	.004		
Wabush Pellets	2.75	63.67	.009	1.900	3.01	.27	.13	.04	.005		
Roger Ore	6.48	55.17	.090	.610	3.71	.62	.46	.13	.016		
BOF Slag	2.58	13.51	.286	3.930	17.62	3.88	39.39	7.26	.258		
Scrap	2.41	79.04	.185	.483	6.43	.91	3.01	1.21	.203		
(1),(2) Coke	8.71	.97	.006	.014	3.54	1.55	.19	.10	.871		
Fuel Oil											
Coal Oil Mixture	4.62				2.92				.764		
Dolomite		.64	.028	.010	1.09	.20	28.44	21.32	.170		
Calcite		1.23	.016	.030	1.21	.28	47.31	1.53	.097		
Olivine		9.97	.008	.023	38.77	1.80	2.70	37.27	.003		
Flue Dust	0	22.30	.049	.35	6.10	1.41	22.30	2.08	.485	-	49.61
Filter Cake	30.73	20.39	.150	.38	6.20	1.61	20.39	2.25	.380		23.38
Hot Metal ⁽³⁾		93.241	.038	.78					.028	1.70	4.213
Iron Runner Scrap		93.241	.038	.78					.028	1.70	4.213
Slag (Calculated)		.30		.50	33.85	6.15	36.89	16.34	2.20		
(1) Proximate Analysis of Coke % Dry Weight Basis: .68% Volatile Matter, 91.31% Fixed Carbon, 8.01% Ash, .954% Sulfur											
(2) Coke Stability, ASTM %: 54.5											
(3) %C = 4.700 - 0.28 × (%Si + %P), and the balance is Fe.											

TABLE C-8 MATERIALS BALANCE 'B' BLAST FURNACE, SPECIFIC WEIGHTS, LB/NTHM
 TEST PERIOD II B, AUGUST 25 - SEPTEMBER 9, 1981 EXCLUDING
 AUGUST 31, SEPTEMBER 1 AND 2.

Material	U/nthm	Fe	P	Mn	SiO ₂	Al ₂ O ₃	CaO	MgO	S
Erie Pallets	2229	1395.58	.334	5.353	135.08	7.58	9.81	9.81	.089
Wabush Pallets	485	308.80	.044	9.220	14.60	1.31	.63	.19	.024
Reger Ore	404	222.89	.364	2.461	14.99	2.51	1.86	.53	.065
BOF Slag	29	3.92	.083	1.140	5.11	1.13	11.42	2.11	.075
Scrap	103.2	81.57	.191	.498	6.64	0.94	3.12	1.25	.210
Coke	1243.2	12.06	.075	.174	44.01	19.27	2.36	1.24	10.828
Fuel Oil									
Coal-Oil-Mixture	101.8				3.07				.802
Dolomite Stone	288	1.84	.081	.029	3.14	.58	81.91	61.40	.490
Calcite Stone	191	2.35	.031	.057	2.31	.54	90.36	2.92	.185
Olivine	28	2.79	.002	.006	10.86	.50	0.76	10.44	.001
Sub-Total		2031.80	1.205	18.938	239.81	34.36	202.28	89.89	12.769
Flue Dust Dry	34	7.58	.017	.119	2.07	.48	1.28	.71	.165
Filter Cake Dry	30	8.77	.065	.163	2.66	.69	1.82	.97	.163
Sub-Total		2015.45	1.123	18.656	235.08	33.19	199.18	88.21	12.441
Hot Metal	2000	1864.82	.760	15.600	72.76 ⁽¹⁾				.560
Iron Runner Scrap	20	18.65	.008	.156	7.3 ⁽¹⁾				.006
Slag lb/nthm (balance)		131.99	.355	2.90	161.59	33.19	199.18	88.21	11.875
% analyzed							38.14	15.06	
% calculated		0.3 ⁽²⁾		0.5 ⁽²⁾	33.85	6.15	36.89	16.34	2.20
lb/nthm (calc.)	540	1.62		2.70	182.79	33.19	199.18	88.21	11.875
									B/R = 1.33 ⁽³⁾
Fe, P, Mn and SiO ₂ unaccounted		130.37	.355	.20	21.20				

(1) Si in iron is given as SiO₂

(2) % Fe and % Mn in slag assumed to be 0.3% and 0.5% respectively

(3) Slag B/R = (CaO + MgO) / (SiO₂ + Al₂O₃)

TABLE C-9. CHEMICAL ANALYSIS, PERCENT BY WEIGHT NATURAL BASIS.
TEST PERIOD III, SEPTEMBER 10-16, 1981.

Material	H ₂ O	Fe	P	Mn	SiO ₂	Al ₂ O ₃	CaO	MgO	S	Si	C
Erie Pellets	3.00	62.61	.015	.240	6.06	.34	.44	.44	.004		
Wabush Pellets	2.75	63.67	.009	1.900	3.01	.27	.13	.04	.005		
Roger Ore	6.48	55.17	.090	.610	3.71	.62	.46	.13	.016		
BOF Slag	0	13.51	.286	3.930	17.62	3.88	39.39	7.26	.258		
Scrap	3.42	71.58	.062	.525	6.60	1.06	4.31	1.50	.235		
Coke (1),(2)	6.28	.99	.006	.015	3.64	1.59	.20	.10	.872		
Fuel Oil											
Cook-Oil-Mixture	7.03				2.68				.67		
Dolemite		.64	.028	.010	1.09	.20	28.44	21.32	.170		
Calcite		1.23	.016	.030	1.21	.28	47.31	1.53	.097		
Olivine		9.97	.008	.023	38.77	1.80	2.70	37.27	.003		
Flue Dust	0	22.33	.049	.35	5.65	1.39	4.25	2.17	.36	-	48.94
Filter Cake	34.21	18.99	.150	.29	5.84	1.61	4.58	2.41	.34		18.34
Hot Metal (3)		93.413	.026	.61					.028	1.71	4.213
Iron Runner Scrap		93.413	.026	.61					.028	1.71	4.213
Slag (Calculated)		.30		.50	31.52	6.16	36.53	16.43	2.19		

(1) Proximate Analysis of Coke % Dry Weight Basis:
.89 % Volatile Matter, 91.11% Fixed Carbon, 8.00% Ash, 0.93% Sulfur

(2) Coke Stability, ASTM %: 55.3

(3) %C = 4.700 - 0.28 x (%Si + %P), and the balance is Fe.

TABLE C-10. MATERIALS BALANCE 'B' BLAST FURNACE, SPECIFIC WEIGHTS, LB/NTHM TEST PERIOD III, SEPTEMBER 10-16, 1981.

Material	lb/NTHM	Fe	P	Mn	SiO ₂	Al ₂ O ₃	CaO	MgO	S
Erie Pellets	2533	1585.9	.380	6.08	153.50	8.61	11.15	11.15	.101
Wabush Pellets	364	231.8	.033	6.92	10.96	0.98	.47	.14	.018
Roger Ore	0								
BOF Slag	22	3.0	.063	.86	3.88	.85	8.67	1.60	.057
Scrap	900	64.4	.056	.47	5.94	.95	3.88	1.35	.212
Coke	1172.8	11.6	.070	.018	42.69	19.65	2.35	1.17	10.227
Fuel Oil									
Coal-Oil-Mixture	56.1				1.47				.369
Dolomite Stone	257	1.6	.072	.03	2.80	.51	73.09	54.79	.437
Calcite Stone	175	2.2	.028	.05	2.12	.49	82.79	2.68	.170
Olivine	26	2.6	.002	.01	10.08	.47	.70	9.69	.001
Sub-Total		1903.1	.704	14.60	233.44	31.51	183.10	82.57	11.592
Flue Dust, Dry	36	8.0	.018	.13	2.03	.50	1.53	.78	.130
Filter Cake, Dry	31	8.9	.071	.14	2.75	.76	2.16	1.13	.160
Sub-Total		1886.2	.615	14.33	228.66	30.25	179.41	80.66	11.302
Hot Metal	2000	1868	.52	12.20	73.19 ⁽¹⁾				.560
Iron RUNDRI Scrap	20	19	.01	.12	.73 ⁽¹⁾				.010
Slag lb/NTHM (balance)		(0.8)	.085	2.02	154.74	30.25	179.41	80.66	10.732
% (analyzed)							37.83	15.10	
% (calculated)		0.3 ⁽²⁾		0.50 ⁽²⁾	31.52	6.16	36.53	16.43	2.19
lb/NTHM (calc.)	491	1.47		2.46	165.29	30.25	179.41	80.66	10.732
									B/A = 1.33 ⁽³⁾
Fe, P, Mn and SiO ₂ unaccounted		(2.27)	.085	(.44)	(0.55)				

(1) Si in iron is given as SiO₂

(2) % Fe and % Mn in slag assumed to be 0.3% and 0.5% respectively.

(3) Slag B/A = (CaO + MgO) / (SiO₂ + Al₂O₃)

TABLE C-11. CHEMICAL ANALYSIS, PERCENT BY WEIGHT NATURAL BASIS.
TEST PERIOD IV A, SEPTEMBER 17-OCTOBER 2, 1981.

Material	H ₂ O	Fe	P	Mn	SiO ₂	Al ₂ O ₃	CaO	MgO	S	Si	C
Erie Pellets	3.00	62.61	.015	.240	6.06	.34	.44	.44	.004		
Wabush Pellets	2.75	63.67	.009	1.900	3.01	.27	.13	.04	.005		
Roger Ore	6.48	55.17	.090	.610	3.71	.62	.46	.13	.016		
BOF Slag	2.58	13.51	.286	3.93	17.62	3.88	39.39	7.26	.258		
Scrap	3.42	71.58	.062	0.52	6.60	1.06	43.2	1.50	.235		
Coke (1),(2)	8.72	1.00	.006	.015	3.67	1.60	.20	.10	.723		
Fuel Oil											
Coal-Oil-Mixture	5.36				5.79				.594		
Dolomite		.64	.028	.010	1.09	.20	28.44	21.32	.170		
Calcite		1.23	.016	.030	1.21	.28	47.31	1.53	.097		
Olivine		9.97	.008	.023	38.77	1.80	2.70	37.27	.003		
Flue Dust	0	22.33	.049	.35	5.65	1.39	4.25	2.17	.36	-	48.94
Filter Cake	34.21	18.99	.150	.29	5.84	1.61	4.58	2.41	.34		18.34
Hot Metal (3)		93.249	.033	.84					.028	1.61	4.240
Iron Runner Scrap		93.249	.033	.84					.028	1.61	4.240
Slag (Calculated)		.30		.50	32.59	6.30	36.72	15.99	1.87		
(1) Proximate Analysis of Coke % Dry Weight Basis: 1.25% Volatile Matter, 90.62% Fixed Carbon, 8.11% Ash, .792% Sulfur											
(2) Coke Stability, ASTM %: 53.5											
(3) %C = 4.700 - 0.28 × (%Si + %P), and the balance is Fe.											

TABLE C-12. MATERIALS BALANCE 'B' BLAST FURNACE, SPECIFIC WEIGHTS, LB/NTHM TEST PERIOD IV A, SEPTEMBER 17-OCTOBER 2, 1981.

Material -	Lb/NTHM	Fe	P	Mn	SiO ₂	Al ₂ O ₃	CaO	MgO	S
Erie Pellets	2226	1393.70	.334	5.342	134.90	7.57	9.80	9.80	.089
Wabush Pellets	561	357.19	.051	10.663	16.89	1.56	.73	.22	.028
Reger Ore	0								
BOF Slag	42	5.67	.120	1.651	7.40	1.63	16.54	3.05	.108
Scrap	184.7	132.21	.115	.960	12.19	1.96	7.98	2.77	.434
Coke	1118.1	11.18	.067	.168	41.03	17.89	2.24	1.12	8.084
Fuel Oil									
Coal-Oil-Mixture	112.6				6.72				.689
Dolomite Stone	240	1.54	.067	.024	2.62	.48	68.26	51.17	.408
Calcite Stone	162	1.99	.026	.049	1.96	.45	76.64	2.48	.157
Olivine	25	2.49	.002	.006	9.69	.45	.68	9.32	.001
Sub-Total		1905.97	.782	18.863	233.40	31.99	182.87	79.93	9.998
Flue Dust, Dry	36	8.04	.018	.126	2.03	.50	1.53	.78	.130
Filter Cake, Dry	31	8.93	.071	.136	2.74	.76	2.15	1.13	.160
Sub-Total		1889.0	.693	18.601	228.63	30.73	179.19	78.02	9.708
Hot Metal	2000	1865	.660	16.80	68.9 ⁽¹⁾				.560
Iron Runner Scrap	20	19	.007	.17	0.7 ⁽¹⁾				.006
Slag lb/NTHM (balance)		5.0	.026	1.63	159.03	30.73	179.19	78.02	9.142
% (analyzed)							38.16	14.59	
% (calculated)		0.30 ⁽²⁾		0.50 ⁽²⁾	32.59	6.30	36.72	15.99	1.87
Lb/NTHM (calc.)	488	1.46		2.44	162.66	30.73	179.19	78.02	9.142
									B/A = 1.33 ⁽³⁾
Fe, P, Mn and SiO ₂ unaccounted		3.54	.026	(.81)	(3.63)				

(1) Si in iron is given as SiO₂

(2) % Fe and % Mn in slag assumed to be 0.3% and 0.5% respectively

(3) Slag B/A = (CaO + MgO) / (SiO₂ + Al₂O₃)

TABLE C-13. CHEMICAL ANALYSIS, PERCENT BY WEIGHT NATURAL BASIS.
 TEST PERIOD II B, SEPTEMBER 17-OCTOBER 2, 1981 EXCLUDING
 SEPTEMBER 22, 23 AND OCTOBER 1.

Material	H ₂ O	Fe	P	Mn	SiO ₂	Al ₂ O ₃	CaO	MgO	S	Si	C
Erie Pellets	3.00	62.61	.015	.240	6.06	.34	.44	.44	.004		
Wabush pellets	2.75	63.67	.009	1.900	3.01	.27	.13	.04	.005		
Roger Ore	6.48	55.17	.090	.610	3.71	.62	.46	.13	.016		
BOF Slag	2.58	13.51	.286	3.93	17.62	3.88	39.39	7.26	.258		
Scrap	3.42	71.58	.062	.52	6.60	1.06	4.32	1.50	.235		
(1,2)											
Coke	8.72	1.00	.006	.015	3.67	1.60	.20	.10	.723		
Fuel Oil											
Cool Oil Mixture	5.36				5.79				.594		
Dolomite		.64	.028	.010	1.09	.20	28.44	21.32	.170		
Calcite		1.23	.016	.030	1.21	.28	47.31	1.53	.097		
Olivine		9.97	.008	.023	38.77	1.80	2.70	37.27	.003		
Flue Dust	0	22.33	.049	.35	5.65	1.39	4.25	2.17	.36	-	48.94
Filter Cake	34.21	18.99	.150	.29	5.84	1.61	4.58	2.41	.34		18.34
Hot Metal (3)		92.62	.034	.84					.029	1.59	4.245
Iron Runner Scrap		93.262	.034	.84					.029	1.59	4.245
Slag (Calculated)		.30		.50	33.53	6.30	36.67	15.93	1.74		
(1) Proximate Analysis of Coke % Dry Weight Basis:											
		1.25 % Volatile Matter,	90.62 % Fixed Carbon,	8.11 % Ash,	.792 % Sulfur						
(2) Coke Stability, ASTM %:		53.5									
(3) % C = 4.700 - 0.28 x (% Si + % P), and the balance is Fe.											

TABLE C-14. MATERIALS BALANCE 'B' BLAST FURNACE, SPECIFIC WEIGHTS, LB/NTHM
 TEST PERIOD IV B, SEPTEMBER 17 - OCTOBER 2 EXCLUDING SEPTEMBER 22, 23 AND OCTOBER 1.

Material	Lb/NTHM	Fe	P	Mn	SiO ₂	Al ₂ O ₃	CaO	MgO	S
Erie Pellets	2230	1376.23	.335	5.352	135.14	7.58	9.18	9.18	.089
Wabush Pellets	556	354.01	.050	10.564	16.74	1.50	.72	.22	.028
Roger Ore	0								
BOF Slag	42	5.67	.120	1.651	17.40	1.63	16.54	3.05	.108
Scrap	180.5	129.20	.112	.939	11.91	1.91	7.78	2.71	.424
Coke	1114.3	11.14	.067	.167	40.90	17.83	2.23	1.11	8.056
Fuel Oil									
Coal-Oil-Mixture	136.2				.43				.045
Dolomite Stone	242	1.55	.068	.024	2.64	.48	68.83	51.59	.411
Calcite Stone	163	2.01	.026	.049	1.97	.46	77.12	2.49	.158
Olivine	25	2.49	.002	.006	9.69	.45	.68	9.32	.001
Sub-Total		1902.27	.780	18.752	236.82	31.78	183.08	79.67	9.320
Flue Dust, Dry	36	8.04	.018	.126	2.03	.50	1.53	.78	.130
Filter Cake, Dry	31	8.93	.071	.136	2.74	.76	2.15	1.13	.160
Sub-Total		1885.30	.691	18.490	232.05	30.52	179.40	77.76	9.030
Hot Metal	2000	1865.24	.680	16.800	68.05 ⁽¹⁾				.580
Iron Runner Scrap	20	18.65	.007	.168	.68 ⁽¹⁾				.006
Slag lb/NTHM (balance)		1.41	.004	1.522	163.32	30.52	179.40	77.76	8.444
% (analyzed)							38.14	14.47	
% (calculated)		0.30 ⁽²⁾		.50 ⁽²⁾	33.53	6.30	36.67	15.93	1.74
Lb/NTHM (calc.)	495	1.49		2.48	164.55	30.52	179.40	77.76	8.444
									B/A = 1.33 ⁽³⁾
Fe, P, Mn and SiO ₂ unaccounted		(.08)	.004	(.96)	(1.23)				

(1) Si in iron is given as SiO₂

(2) % Fe and % Mn in slag assumed to be 0.3% and 0.5% respectively.

(3) Slag B/A = (CaO + MgO) / (SiO₂ + Al₂O₃)

TABLE C-15. CHEMICAL ANALYSIS, PERCENT BY WEIGHT NATURAL BASIS.
TEST PERIOD IV C, SEPTEMBER 18-24, 1981.

Material	H ₂ O	Fe	P	Mn	SiO ₂	Al ₂ O ₃	CaO	MgO	S	Si	C
Erie Pellets	3.00	62.61	.015	.240	6.06	.34	.44	.44	.004		
Wabush Pellets	2.75	63.67	.009	1.900	3.01	.27	.13	.04	.005		
Roger Ore	6.48	55.17	.090	.610	3.71	.62	.46	.13	.016		
BOF Slag	2.58	13.51	.286	3.93	17.62	3.88	39.39	7.26	.258		
Scrap	3.42	71.58	.062	.52	6.60	1.06	4.32	1.50	.235		
Coke (1),(2)	9.26	1.16	.007	.017	4.24	1.85	.23	.12	.904		
Fuel Oil											
Coal-Oil-Mixture	5.36				5.79				.594		
Dolomite		.64	.028	.010	1.09	.20	28.44	2.32	.170		
Calcite		1.23	.016	.030	1.21	.28	47.31	1.53	.097		
Olivine		9.97	.008	.023	38.77	1.80	2.70	37.27	.003		
Flue Dust	0	22.33	.049	.35	5.65	1.39	4.25	2.17	.36	-	48.94
Filter Cake	34.21	18.99	.150	.29	5.84	1.61	4.58	2.41	.34		18.34
Hot Metal (3)		93.316	.034	.84					.032	1.51	4268
Iron Runner Scrap		93.316	.034	.84					.032	1.51	4268
Slag (Calculated)		.30		.50	33.44	6.28	36.97	15.85	2.37		

(1) Proximate Analysis of Coke % Dry Weight Basis:

1.17 % Volatile Matter, 91.02 % Fixed Carbon, 7.81 % Ash, .82 % Sulfur

(2) Coke Stability, ASTM %: 55.3

(3) %C = 4.700 - 0.28 × (%Si + %P), and the balance is Fe.

TABLE C-16. MATERIALS BALANCE 'B' BLAST FURNACE, SPECIFIC WEIGHTS, LB/NTHM TEST PERIOD IV C, SEPTEMBER 18-24, 1981.

Material	Lb/NTHM	Fe	P	Mn	SiO ₂	Al ₂ O ₃	CaO	MgO	S
Erie Pellets	2121	1328.0	.318	5.09	128.53	7.21	9.33	9.33	.085
Wabush Pellets	544	346.4	.049	10.34	16.37	1.47	.71	.22	.027
Roger Ore	0								
BOF Slag	40	5.4	.114	1.57	7.05	1.55	15.76	2.90	.103
Scrap	240.0	171.8	.149	1.25	15.84	2.54	10.37	3.60	.564
Coke	1077.3	12.5	.075	.18	45.68	19.93	2.48	1.29	9.739
Furn Oil									
Coal-oil-Mixture	84.6				5.95				.611
Dolomite Stone	262	1.7	.073	.03	2.86	.52	74.51	55.86	.445
Calcite Stone	176	2.2	.028	.05	2.13	.49	83.27	2.69	.171
Olivine	24	2.4	.002	.01	9.30	.43	.65	8.94	.001
Sub-Total		1870.4	.808	18.52	233.71	34.14	197.08	84.83	11.746
Flue Dust, Dry	36	8.0	.018	.10	2.00	.50	1.50	.80	.130
Filter Cake, Dry	31	9.0	.071	.10	2.80	.80	2.20	1.10	.160
Sub-Total		1853.4	.719	18.32	228.91	32.84	193.38	82.93	11.456
Hot Metal	2000	1866.3	.680	16.80	64.63 ⁽¹⁾				.640
Iron Runner Scrap	20	18.7	.007	.17	.65 ⁽²⁾				.006
Slag Lb/NTHM (balance)		(31.6)	.032	1.35	163.63	32.84	193.38	82.93	10.81
% (analyzed)							38.15	14.69	
% (calculated)		.30 ⁽²⁾		.50 ⁽²⁾	33.44	6.28	36.97	15.85	2.37
Lb/NTHM (calc.)	523	1.60		2.60	174.91	32.84	193.38	82.93	10.81
Fe, P, Mn and SiO ₂ unaccounted		(33.20)	.032	(1.25)	(11.28)				

B/A = 1.33⁽³⁾

(1) Si in iron is given as SiO₂
 (2) % Fe and % Mn in slag assumed to be 0.3% and 0.5% respectively.
 (3) Slag B/A = (CaO + MgO) / (SiO₂ + Al₂O₃)

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TABLE C-17 CHEMICAL ANALYSIS, PERCENT BY WEIGHT NATURAL BASIS.
TEST PERIOD V, AUGUST 20-OCTOBER 2, 1981.

Material	H ₂ O	Fe	P	Mn	SiO ₂	Al ₂ O ₃	CaO	MgO	S	Si	C
Erie Pellets	3.00	62.61	.015	.240	6.06	.34	.44	.44	.004		
Wabush Pellets	2.75	63.67	.009	1.900	3.01	.27	.13	.04	.005		
Roger Ore	6.48	55.17	.090	.610	3.71	.62	.46	.13	.016		
BOF Slag	0	13.51	.286	3.930	17.62	3.88	39.39	7.26	.258		
Scrap	2.94	75.65	.119	.518	6.52	1.00	3.50	1.27	.211		
(1),(2) Coke	8.40	1.01	.006	.015	3.70	1.61	.20	.10	.728		
Fuel Oil											
Coal-Oil Mixture	5.30				3.93				.673		
Dolomite		.64	.028	.010	1.09	.20	28.44	21.32	.170		
Calcite		1.23	.016	.030	1.21	.28	47.31	1.53	.097		
Olivine		9.97	.008	.023	38.77	1.80	2.70	37.27	.003		
Flue Dust	0	22.30	.049	.35	5.40	1.40	3.96	2.12	.434	-	49.37
Filter Cake	32.15	19.82	.150	.34	6.05	1.61	4.42	2.31	.364		21.32
Hot Metal ⁽³⁾		93.261	.036	.79					.028	1.66	4.225
Iron Runner Scrap		93.261	.036	.79					.028	1.66	4.225
Slag (Calculated)		.30		.50	33.75	6.29	36.87	16.00	1.83		
(1) Proximate Analysis of Coke % Dry Weight Basis: .88% Volatile Matter, 90.80% Fixed Carbon, 8.14% Ash, .795% Sulfur											
(2) Coke Stability, ASTM %: 54.2											
(3) %C = 4.700 - 0.28 × (%Si + %P), and the balance is Fe.											

TABLE C-18. MATERIALS BALANCE 'B' BLAST FURNACE, SPECIFIC WEIGHTS, LB/NTHM TEST PERIOD V, AUGUST 20-OCTOBER 2, 1981.

Material	lb/nthm	Fe	P	Mn	SiO ₂	Al ₂ O ₃	CaO	MgO	S
Erie Pallets	2204	1379.9	.331	5.290	133.56	7.49	9.70	9.70	.088
Wabush Pallets	496	315.8	.045	9.424	14.93	1.34	.64	.20	.025
Roger Ore	220	121.4	.198	1.342	8.16	1.36	1.01	.29	.035
BOF Slag	44	5.9	.126	1.729	7.75	1.71	17.33	3.19	.114
Scrap	140	05.9	.167	.725	9.13	1.40	4.90	1.78	.295
Coke	1173.2	11.8	.007	.176	43.41	18.89	2.35	1.17	8.541
Fuel Oil									
Coal-oil-Mixture	87.5				3.48				.596
Dolomite Stone	261	1.7	.073	.026	2.84	.52	74.23	55.65	.444
Calcite Stone	175	2.2	.028	.053	2.12	.49	82.79	2.68	.170
Olivine	26	2.6	.002	.006	10.08	.47	.70	9.69	.001
Sub-Total		1947.2	1.040	18.771	235.46	33.67	193.65	84.35	10.309
Flue Dust, Dry	35	7.8	.017	.123	2.07	.49	1.39	.74	.152
Filter Cake, Dry	31	9.1	.069	.155	2.76	.74	2.02	1.06	.166
Sub-Total		1930.3	.959	18.493	230.63	32.44	190.24	82.55	9.991
Hot Metal	2000	1865.2	.720	15.80	71.05 ⁽¹⁾				.560
Iron Runner Scrap	20	18.7	.007	.16	.71 ⁽¹⁾				.006
Slag lb/nthm (balance)		46.4	.227	2.533	158.87	32.44	190.24	82.55	9.425
% (analyzed)							38.00	14.85	
% (calculated)		.30 ⁽²⁾		.50 ⁽²⁾	33.75	6.29	36.87	16.00	1.83
lb/nthm (calc.)	516	1.55		2.58	174.22	32.44	190.24	82.55	9.425
									B/A = 1.32 ⁽³⁾
Fe, P, Mn and SiO ₂ unaccounted		44.85	.227	(.047)	(15.35)				

(1) Si in iron is given as SiO₂

(2) % Fe and % Mn in slag assumed to be 0.3% and 0.5% respectively.

(3) Slag B/A = (CaO + MgO) / (SiO₂ + Al₂O₃)