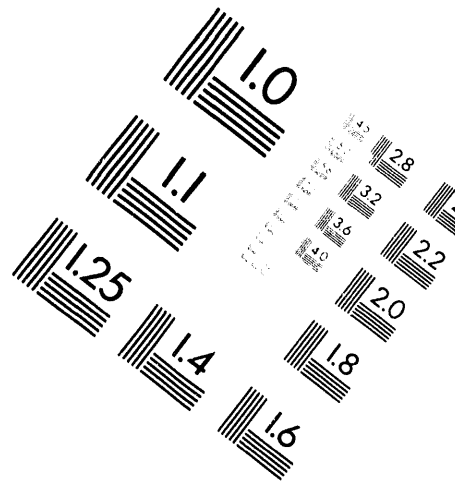
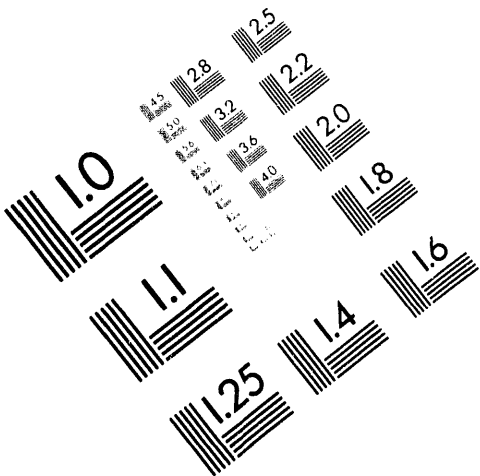




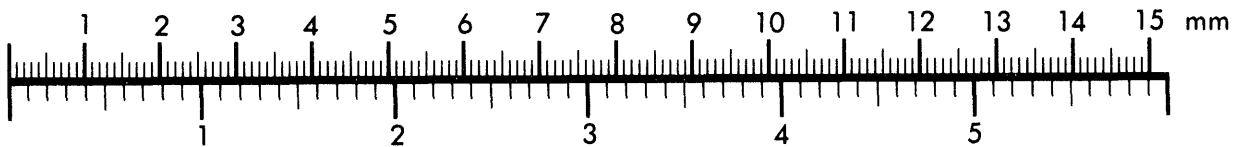
AIM

Association for Information and Image Management

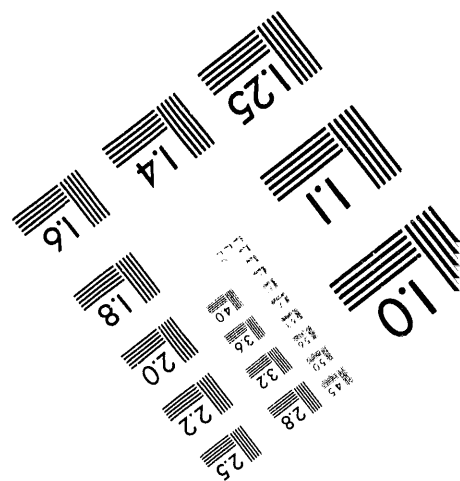
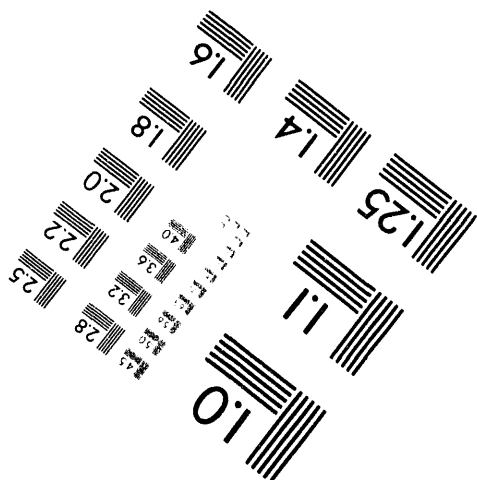
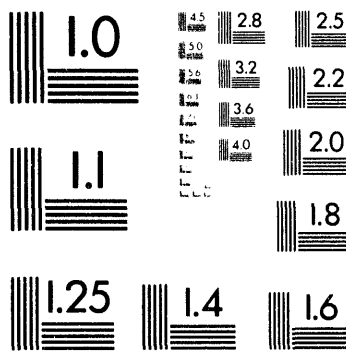
1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202



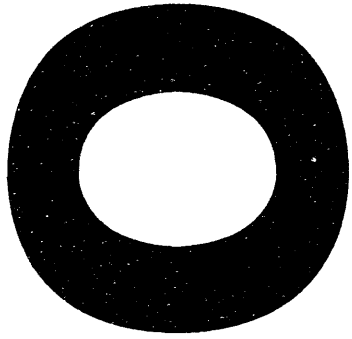
Centimeter



Inches



MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.



DOE/PC/92521--T133

TECHNICAL REPORT
1 December 1993 through 28 February 1994

Project Title: COAL COMBUSTION UNDER CONDITIONS
OF BLAST FURNACE INJECTION

DOE Contract Number: DE-FC22-92PC92521 (Year 2)

ICCI Project Number 93-1/2.1A-2P.

Principal Investigator: John C. Crelling, Professor
Department of Geology
Southern Illinois University
Carbondale, IL 62901
(618) 453-7361

Project Manager: Frank Honea, ICCI

ABSTRACT

A potentially new use for Illinois coal is its use as a fuel injected into a blast furnace to produce molten iron as the first step in steel production. Because of its increasing cost and decreasing availability, metallurgical coke is now being replaced by coal injected at the tuyere area of the furnace where the blast air enters. The purpose of this study is to evaluate the combustion of coal during the blast furnace injection process and to delineate the optimum properties of the feed coal. This investigation is significant to the use of Illinois coal in that the limited research to date suggests that coals of low fluidity and moderate to high sulfur and chlorine contents are suitable feedstocks for blast furnace injection. This proposal is a follow-up to one funded for the 1992-93 period. It is intended to complete the study already underway with the Armco Inc. Steel Company and to initiate a new cooperative study along somewhat similar lines with the Inland Steel Company. The results of this study will lead to the development of a testing and evaluation protocol that will give a unique and much needed understanding of the behavior of coal in the injection process and prove the potential of Illinois coals for such use. During this quarter a sample of the feed coal that is being used for injection into the No. 7 Blast Furnace of Inland Steel has been analyzed petrographically and compared to both the Herrin No. 6 coal and Armco feed coal. Additional characterization is underway and an advanced program of pyrolysis and reactivity testing has been initiated. The acquisition of additional samples of blast furnace burden material including, coke, iron ore, metallic iron, limestone, and slag as well as the char of the injected coal has been inevitably delayed because of problems at both the Inland and Armco blast furnaces. However, it is expected that these samples will soon be available.

"U.S. DOE Patent Clearance is NOT required prior to the publication of this document."

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

EXECUTIVE SUMMARY

A potentially new use for Illinois coal is its use as a fuel injected into a blast furnace to produce molten iron as the first step in steel production. Because of its increasing cost and decreasing availability, metallurgical coke is now being replaced by coal injected at the tuyere area of the furnace where the blast air enters. The purpose of this study is to evaluate the combustion of coal during the blast furnace injection process and to delineate the optimum properties of the feed coal. This investigation is significant to the use of Illinois coal in that the limited research to date suggests that coals of low fluidity and moderate to high sulfur and chlorine contents are suitable feedstocks for blast furnace injection.

Until now the limited experience in North America with coal injection systems has resulted in a lack of research and published literature on the subject. This has not been the case outside of North America, however. Coal injection research has been particularly strong in the United Kingdom and Japan. blast furnace coal injection has been successful around the world and its use is expanding rapidly. Coal injection results in: 1) reduced demand for metallurgical coke; 2) increased blast furnace efficiency; 3) reduced operating costs. It has also been reported that in regard to the feed coal low fluidity was desirable. While there are no major problems at the current rates of coal injection, the complete combustion of the injected coal is a problem for operation at greatly increased rates of injection. This serious lack of understanding about the behavior of injected coal must be overcome, if higher injection rates are to be achieved.

This study is unique in that it will be the first North American effort to directly determine the nature of the combustion of coal injected into a blast furnace. The Amanda furnace of Armco and the No. 7 Blast Furnace of Inland Steel are two of the three blast furnaces in North America currently using coal injection and are, therefore, two of the three full-scale testing facilities available. The third system is at the Gary Works of U.S. Steel. The fact that the coal injection systems at both Inland Steel and U.S. Steel have been installed in the last twelve months is significant in that it demonstrates the importance that the American steel industry gives to this process. It is also significant that all three installations are located in the mid-west adjacent to the Illinois Basin Coalfield.

The significance for the Illinois coal industry is that all of the published work to date and all of the industrial experience to date suggests that Illinois coal is an ideal feedstock for blast furnace injection and that some of the commercial drawbacks of Illinois coal such as its rank and

high sulfur and chlorine content may not be a disadvantage for use in blast furnace injection. Specifically:

Rank - the low rank of Illinois bituminous coal has limited its use as a coking coal in the steel industry. The published literature suggests that the low rank and consequent low fluidity are desirable for coal injection.

High Sulfur Content - while this is the biggest problem in marketing Illinois coal, the high sulfur content is not perceived as a major problem for blast furnace injection. Experience in the industry using high sulfur fuel injectants (oil and coal) suggests that the injected sulfur has an increased tendency to enter the slag instead of the iron compared with sulfur in coke charged into the top of the furnace. The Japanese report mentioned above also supports this idea.

High Chlorine Content - while the high chlorine content of Illinois coals is recognized as a growing problem, it should not be a drawback and may even be an advantage in coal injection. This is because chlorine is commonly added to the blast furnace in the form of CaCl_2 to control alkali content.

If it is proven that as expected Illinois coal is suitable for coal injection, the size of the potential market becomes important. At this time the one furnace at Armco is injecting about a quarter of a million tons of coal a year. The system, recently put on line at the end of this year at the Gary Works of U.S. Steel, will use about five times that amount and the projected start-up of a system this summer at Inland Steel should use three times as much as the Armco plant is currently using.

The overall objective of this study is to determine the nature of coal combustion during coal injection at blast furnaces operated by Armco Inc. and the Inland Steel Company. The specific objectives are:

1. To collect from an active blast furnace samples of the injected coal, the combustion char, coke, hot metal, dust, and slag.
2. To characterize the collected materials with respect to their basic chemical, physical and petrographic properties.
3. To determine the reactivity of the char in various gas compositions characteristic of the lower part of the furnace such as (CO , CO_2 , H_2 , H_2O , air).
4. To determine the nature of coal char reaction with

both the iron ore and hot metal in the blast furnace.

5. To determine the partition ratio of sulfur in the slag and hot metal.

6. To synthesize the data gathered to optimize the coal selection and combustion.

7. To inject Illinois Basin coal directly into one or more active blast furnaces and determine its suitability for such use.

The results of this study will lead to the development of a testing and evaluation protocol that will give a unique and much needed understanding of the behavior of coal in the injection process and prove the potential of Illinois coals for such use.

During this quarter a sample of the feed coal that is being used for injection into the No. 7 Blast Furnace of Inland Steel has been analyzed petrographically and compared to both the Herrin No. 6 coal and Armco feed coal. The results of the maceral and reflectance analyses are given in tables 1 and 2 respectively. The Armco feed coal is SIU 2294 and the Inland feed coal is SIU 2380. The Illinois coal used for comparison is labeled IBCSP 101. The results show that the Inland feed coal is more like the Illinois Basin sample, with an high vitrinite content and low contents of liptinite and inertinite. The reflectance of the Inland feed coal is also similar to the Illinois Basin sample.

Additional characterization is underway and an advanced program of pyrolysis and reactivity testing has been initiated. The acquisition of additional samples of blast furnace burden material including, coke, iron ore, metallic iron, limestone, and slag as well as the char of the injected coal has been inevitably delayed because of problems at both the Inland and Armco blast furnaces. However, it is expected that these samples will soon be available.

OBJECTIVES

The overall objective of this study is to determine the nature of coal combustion during coal injection at blast furnaces operated by Armco Inc. and the Inland Steel Company. The specific objectives are:

1. To collect from an active blast furnace samples of the injected coal, the combustion char, coke, hot metal, dust, and slag.
2. To characterize the collected materials with respect to their basic chemical, physical and petrographic properties.
3. To determine the reactivity of the char in various gas compositions characteristic of the lower part of the furnace such as (CO, CO₂, H₂, H₂O, air).
4. To determine the nature of coal char reaction with both the iron ore and hot metal in the blast furnace.
5. To determine the partition ratio of sulfur in the slag and hot metal.
6. To synthesize the data gathered to optimize the coal selection and combustion.
7. To inject Illinois Basin coal directly into one or more active blast furnaces and determine its suitability for such use.

INTRODUCTION AND BACKGROUND

Purpose

A potentially new use for Illinois coal is its use as a fuel injected into a blast furnace to produce molten iron as the first step in steel production. Because of its increasing cost and decreasing availability metallurgical coke is now being replaced by coal injected at the tuyere area of the furnace where the blast air enters. The purpose of this study is to evaluate the combustion of coal, especially Illinois coal, during the blast furnace injection process and to delineate the optimum properties of the feed coal. This investigation is significant to the use of Illinois coal in that the limited research to date suggests that coals of low fluidity and moderate to high sulfur and chlorine contents are suitable feedstocks for blast furnace injection. This study is a follow-up to one funded for the 1992-93 period. It will complete the study already underway with the Armco

Inc. steel company and to initiate a new cooperative study along somewhat similar lines with the Inland Steel Company.

The Blast Furnace Process

A major step in steelmaking is changing iron ore into a form that can be used to make the various kinds of steel. This is primarily done in the blast furnace, which basically receives iron ore and reduces it to molten iron saturated with carbon (4.5-5.0%), which can then be processed to make steel.

The blast furnace (see Figures 1 and 2) is a steel shell, lined with brick, where iron ore, coke and limestone are charged into the top, and very hot air is blown into the bottom. A pool of molten iron and slag accumulates in the bottom where it is drawn off every few hours. Once started, the furnace operates continuously, usually for a campaign of ten years or more. The average North American furnace produces about 4000 tons of molten iron per day. Large furnaces are capable of producing 10,000 tons per day or more. The ore must be heated to a very high temperature and chemically purified. Coke, a carbon product made in large ovens from coal, serves to remove oxygen from the iron oxides and provides additional heat for the furnace process. Limestone helps remove the impurities and form a slag, which then separates from the molten iron.

Another main ingredient is air, thirty-five to forty-five thousand cubic feet per ton of iron produced. The air is heated in large stoves and is then injected as a hot blast into the lower part of the furnace. The hot air fans the coke, the coke burns and reduces the ore from oxides of iron to metallic iron, which then will flow and settle to the bottom of the furnace.

The process in the furnace generates great quantities of hot, dirty gas. The gas exits at the top and is directed down to gas cleaning and cooling equipment. The gas is then suitable to be burned to heat the stoves or redirected for other uses in the steel plant.

There are usually three or four stoves to supply the hot blast to the furnace. The stoves are tall steel cylinders, lined with brick and nearly filled with a type of brick called checkerwork. The checker bricks store heat produced by burning the by-product gas from the furnace. The hot gas passes through the many small passageways in the bricks until they are thoroughly heated. Then combustion is stopped and a cold blast of clean air is blown through the stove, picking up the heat to make the hot blast for the furnace. The stoves are alternately cycled in this manner, one "on blast"

while the others are "on gas" so there is always a continuous hot blast for the furnace.

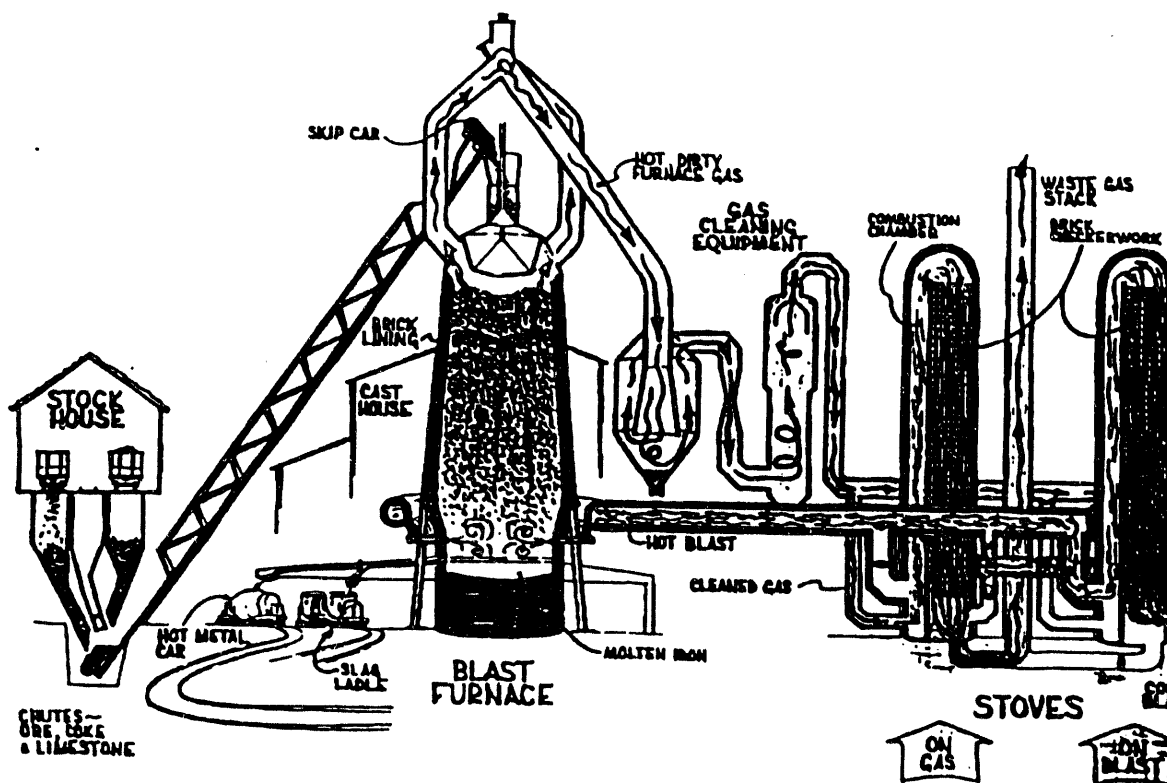


Figure 1. Diagram of a blast furnace plant.

The base of the furnace is enclosed by the cast house, where the molten iron is "cast", by drilling an opening in the tap-hole; an opening in the furnace hearth filled with clay. The clay is replaced after the completion of the cast until enough iron accumulates to be cast again. The iron flows out into runners and is directed to railroad cars that are large, brick-lined tank cars (pugh ladles). The slag is skimmed from the molten iron in the runner and directed into slag pits or slag ladles located next to each furnace.

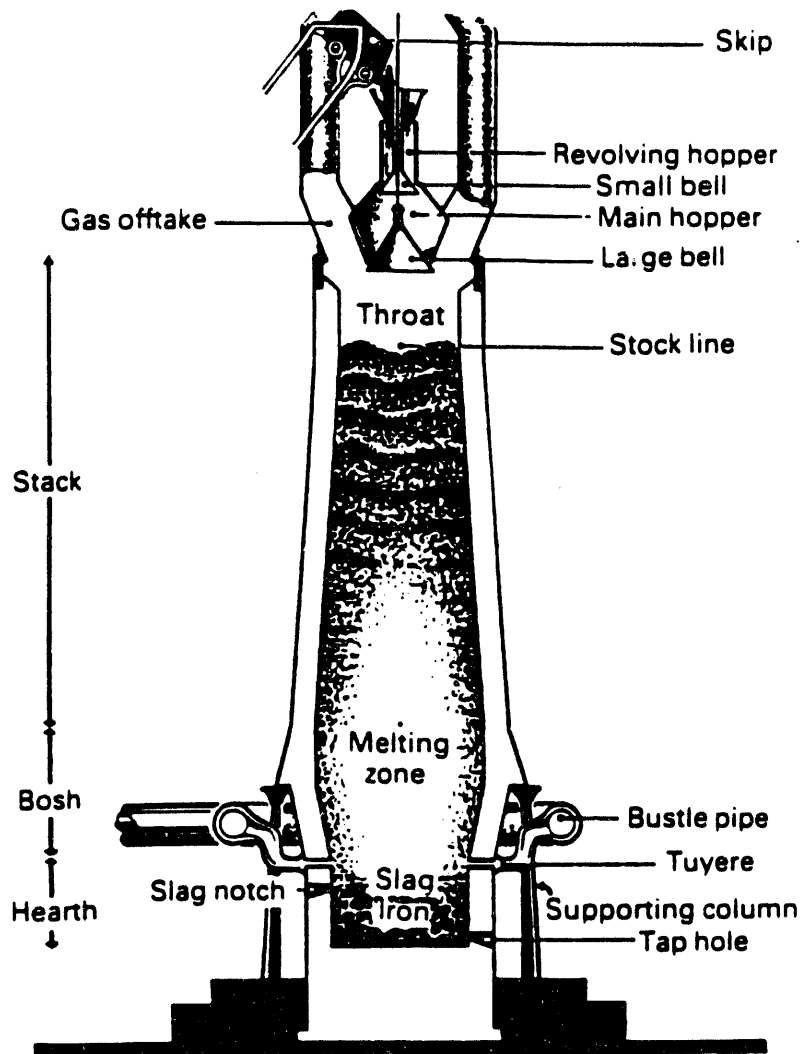


Figure 2. Cross section of a typical blast furnace. Note the location of the tuyeres around the base of the furnace (after Long 1968).

Blast Furnace Injection

Hydrocarbons, oil, natural gas, and coal, have been injected into blast furnaces for over forty years to decrease coke demand and increase furnace productivity. While all injected fuels have an endothermic effect that reduce the temperature at the tuyere, coal has the smallest such effect of all injected fuels and is, therefore, the most suitable for use. For example, a flame temperature compensation of 100°F is typically required for the injection of 40 pounds of coal, 24

pounds of fuel oil, and 15 pounds of natural gas (Carmichael 1992). Coal is the only injected fuel that has the ability to reduce coke use rates by as much as 40% and on a \$/pound basis coal has the lowest cost.

In all systems of coal injection, the coal is fed into the hot blast air in the tuyere where the coal, in the ideal case, is combusted before it enters into the raceway of the furnace (see Figure 3). Thus, ideally, only the products of combustion - CO₂ and heat - leave the tuyeres. However, in practice the combustion is not always complete and both uncombusted coal and char as well as ash are produced.

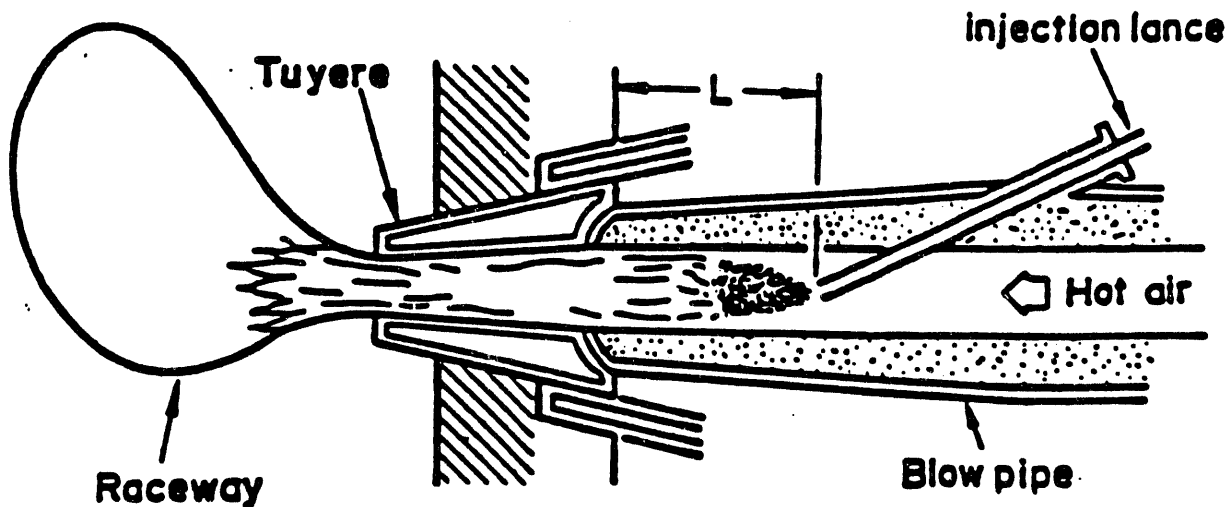


Figure 3. Cross-section of a tuyere with coal injection.

Armco System

Armco Inc. of Middletown, Ohio and Babcock & Wilcox of Barberton, Ohio, jointly developed and patented a system for efficiently injecting pulverized coal into the tuyere zone of the blast furnace. The combination of blast furnace operations experience at Armco, and the Babcock & Wilcox experience in the preparation and handling of pulverized coal in the boiler field led to the design of the first system in 1965. The system was installed on the Bellefonte blast furnace at Armco's Ashland Works, Kentucky. An improved version of the system was installed on the Amanda blast furnace at the Ashland Works in 1973, incorporating improved designs to further ensure safety and reliability. Operations experience with the system has surpassed a quarter of a century, a record unmatched by any other coal injection system. The result of long term experience and refinement is

a system designed to deliver coal to the blast furnace trouble-free, boasting an operational availability of nearly 100% while injecting over 21,000,000 tons of coal throughout the world through 1991.

Inland Steel System

When the first phase of this proposal was submitted in 1992 the only coal injection system in use in North America was the Armco/B&W system on the Amanda furnace at the Ashland, Kentucky plant. However, at the beginning of 1993 a coal injection system went online at the Gary Works of U.S. Steel in Indiana and a new system has been installed and is scheduled to go online this summer on the No.7 Blast Furnace (the largest in the Western Hemisphere) of the Inland Steel Co.

The Inland Steel Company chose the injection system design of Paul Wurth Company. The equipment includes coal discharge hoppers, pulverization, drying, pneumatic transport, and injection on all tuyeres in all three blast furnaces. The equipment will be capable of injection rates equal to 400 pounds per ton of hot metal for the No. 7 Blast Furnace, and 300 pounds per ton of hot metal at the smaller blast furnaces. Commercial operation on No. 7 Blast Furnace will begin this summer and will be quickly followed by start up on the other furnaces. Inland Steel Company will eventually consume about 750,000 tons/year of coal via blast furnace injection.

Review of Literature

Until now the limited experience in North America with coal injection systems has resulted in a lack of research and published literature on the subject. This has not been the case outside of North America, however. Coal injection research has been particularly strong in the United Kingdom and Japan.

The most recent review article by Carmichael (1992) concludes that the success of coal injection systems coming on line in the next two years should act as a stimulus for the rest of the North American steel industry to introduce the systems in the next five years. The UK work, (Wilmers 1989, Atkinson and Willmers 1990, Gathergood and Lochrie 1990, and Gathergood 1991), done mostly at British Steel generally concluded that the positive effects of improved blast furnace operation and reduced coke demand offset the minor problems of incomplete coal combustion and the carryover of fine particles. Other European work (Koen et al. 1985,

Graffeville et al. 1985, Poos and Ponghis 1990, and de Lassat de Pressigny et al. 1990) agree on the success of the coal injection but warn that the process of the coal combustion is the major limiting factor to the increase in the amount of coal injected. They recommend more research on the behavior of coal in these systems. A report on some Chinese experience (Shyng et al. 1990) again support the success of their coal injection system. They also report that the sulfur content of the hot metal decreased. The Japanese (Saino et al. 1990, Uenaka et al. 1990, and Takeda et al. 1990) experienced similar success. Takeda et al. also report that a low fluidity, high volatile bituminous coal seems to have advantages over other coals. Investigations into blast furnace injection of coal have also been reported by Hunty et al. (1991) in Canada and by Burgess et al, (1987) in Australia.

In summary, blast furnace coal injection has been successful around the world and its use is expanding rapidly. Coal injection results in:

1. Reduced demand for metallurgical coke;
2. Increased blast furnace efficiency;
3. Reduced operating costs;

It was also reported that in regard to the feed coal, low fluidity was desirable. While there are no major problems at the current rates of coal injection, the complete combustion of the injected coal is a problem for operation at greatly increased rates of injection. This serious lack of understanding about the behavior of injected coal must be overcome, if higher injection rates are to be achieved. A potentially new use for Illinois coal is its use as a fuel injected into a blast furnace to produce molten iron as the first step in steel production. Because of its increasing cost and decreasing availability, metallurgical coke is now being replaced by coal injected at the tuyere area of the furnace where the blast air enters. The purpose of this study is to evaluate the combustion of coal during the blast furnace injection process and to delineate the optimum properties of the feed coal. This investigation is significant to the use of Illinois coal in that the limited research to date suggests that coals of low fluidity and moderate to high sulfur and chlorine contents are suitable feedstocks for blast furnace injection.

EXPERIMENTAL PROCEDURES

The second phase of the overall blast furnace injection study will consist of the completion of the study with Armco and the initiation of a study with Inland Steel Company. By the end of this proposed project, August 1994, coals from the Illinois Basin should have been injected into the blast furnaces of both companies.

The collaboration with the Inland Steel Company is planned to be generally similar to the work already in progress with Armco Inc. with a few significant differences. While samples will be collected from both the tuyeres and the furnace center, the Inland collection system is different in that it collects samples from all tuyeres simultaneously and then processes the samples to enrich the coke content. Perhaps, the biggest difference is that the Inland injection system injects coal at about double the rates than the Armco system. The nature of the coal flow is also different. The Inland system uses less air in a pulsed or plug flow system. Both systems will also be using different coals.

Fundamental Considerations

Coke serves three functions in the operation of the blast furnace; first, it provides heat, second it provides the gases that reduce the iron ore oxide to metallic iron, and third, it is the only solid material in the reaction zone of the furnace, it helps support the burden in the furnace and maintain permeability. Injected coal can serve the first two functions and thus can replace significant amounts of coke. Therefore, fundamental considerations in evaluating the suitability of a given coal for injection is how well does it provide heat and gases and does it interfere with the furnace permeability. In addition, carbon in the blast furnace can also have a direct reaction with the iron in that the molten metal can take carbon into solution to the point that up to 5% of the metal leaving the furnace can be dissolved carbon. The fundamental question in this case is how does the coal char getting into the furnace react with the hot metal. These fundamental questions can only be answered by analyzing the petrographic and combustion properties of the injected coal and its associated char as outlined in the objectives section given above.

To accomplish the objectives stated above, the work will be broken down into the following tasks:

Task I - Sample Collection

All of the samples to be studied for this project will be

collected from the Amanda furnace at the Ashland Works by Armco personnel and from the Inland Steel Company furnaces by Inland personnel. Samples will be collected from the tuyeres of the active furnace as well as from the raceway (see Figure 3) and the area beyond. Samples of the coal, char, coke, slag, dust, and hot metal will be taken at varying distances into the center of the furnace. The samples will be collected whenever the furnace is down for maintenance or repair. During the second phase (year) of this project, it is anticipated that there may be 3-5 opportunities to sample the tuyeres at both furnaces. With each sampling there should be up to 10-15 samples collected from the transect across the tuyeres towards the center of the furnace, and each sample will be made up of whatever variety of materials; coal, char, slag, etc., present at that point.

Task II - Sample Characterization

Selected chemical and physical properties of all of the samples collected will be analyzed. For the coal, coke, char, and dust samples, proximate and ultimate analysis will be run as well as density and porosity measurements. The petrographic properties of the samples will also be determined including char morphology and ash deposition. Standard coal and coke petrographic techniques including point counting, reflectance analysis, mosaic structure analysis, and image analysis of particle size and shape will be used and the analysis will be done in the Coal Characterization Laboratory facilities at SIUC.

The char and coke reactivity in different gases and gas mixtures (Air, CO₂, H₂ and CO), will be determined on a thermogravimetric analyzer available at SIUC using standard methods where the reactivity (R) = $1/w_0 \cdot dw/dt$ with the actual rate of weight loss being dw/dt and with w_0 the initial sample weight.

The hot metal and the slag will be chemically analyzed in the individual company laboratories and special attention will be paid to the sulfur and chlorine contents.

Task III - Evaluation and Interpretation of Data

To gain an understanding of the effect of the combustion of the injected coal from the tuyere to the center of the furnace the variation with distance of the following sample parameters will be so examined: particle type concentration (especially char concentration); chemical composition; char morphology, reflectance; size distribution; and distribution of sulfur and chlorine. The partition ratio, (sulfur in the slag/sulfur in the hot metal) which is of special interest

for the use of high sulfur coal, will also be examined. Because one of the greatest problems with increased rates of injection is the increase in dust and fine material in the furnace and the exhaust gases, special attention will be paid to the distribution and composition of these materials.

Task IV - Testing of Illinois Coals

The purpose of this task is to actually test coals from Illinois in the blast furnace and evaluate their performance. Special attention needs to be given to the behavior of sulfur and chlorine. It must be noted that before this testing can be done the sampling and analysis detailed above must be completed and a dedicated coal injector must be made available.

RESULTS AND DISCUSSION

During the first phase of this project a number of the objectives were realized, specifically: 1) a blast furnace sampling system was developed and used successfully to collect samples inside an active furnace; 2) - two sets of blast furnace samples were collected and petrographic analysis showed that char derived from injected coal is entering the reduction zone of the furnace; 3) - a coal/char sampling probe was designed and fabricated; 4) - the completion of a program of reactivity experiments on the injected coal char, blast furnace coke and Herrin No.6 char. The results of the reactivity experiments indicate that Herrin No. 6 coal is similar or even superior to coals now being used in blast furnace injection and that additional testing is warranted.

During the first phase of this project a number of the objectives were realized, specifically:

1. Sample Collection - a blast furnace sampling system was developed and used successfully to collect samples from inside an active furnace.

2. Sample Characterization - two sets of blast furnace samples were collected and analyzed petrographically. These analyses show that:

A. The coals currently being injected are typical Appalachian type coals with an higher inertinite content and reflectance than Illinois coals.

B. The material around the tuyere area of the furnace consisted of both the components charged into the

furnace, coke, iron ore, limestone, and coal as well as the products of the ironmaking process metallic iron, slag, altered coal, and char.

C. In the smallest size sample which is <200 mesh, there is evidence of some coal char derived from the injected coal. The char is expected in this fraction because the top size (200) mesh is the nominal size of the injected coal. The presence of char inside the furnace shows that not all of the coal is being totally combusted upon injection and that the reactivity of the char in the reducing environment of the blast furnace needs to be considered, because the purpose of coal injection is to produce heat and CO.

3. Coal Sampling Probe - a coal/char sampling probe was designed and fabricated during this phase of the project. This probe is to be placed downstream of the coal injection tube and collect samples of the combusted coal and coal char. The samples collected by this probe will be evaluated to determine the efficiency of the coal combustion by petrographic and reactivity analysis. The probe will be installed during a future maintenance down period on the blast furnace.

4. Reactivity Experiments - a major effort during this year was the completion of a program of reactivity experiments designed to characterize the combustion reactivity of the injected coal, its associated char, and the blast furnace coke and to compare it to the reactivity of a typical Illinois coal. Char was produced at 1000°C in a nitrogen atmosphere in an Entrained Flow Reactor (EFR) and then reacted in a thermogravimetric analyzer (TGA) in air and carbon dioxide over a range of temperatures.

The results of these reactivity experiments in air show that all three samples are similar and show only a mild trend (a slight increase in reactivity with increasing temperature). However, in carbon dioxide all three samples show a marked temperature dependence.

In summary, the results of the reactivity experiments indicate that Herrin No. 6 coal is similar or even superior to coals now being used successfully in blast furnace injection and that additional testing is warranted.

During this quarter a sample of the feed coal that is being used for injection into the No. 7 Blast Furnace of Inland Steel has been analyzed petrographically and compared to both the Herrin No. 6 coal and Armco feed coal. The results of the maceral and reflectance analyses are given in tables 1

and 2 respectively. The Armco feed coal is SIU 2294 and the Inland feed coal is SIU 2380. The Illinois coal used for comparison is labeled IBCSP 101. The results show that the Inland feed coal is more like the Illinois Basin sample, with an high vitrinite content and low contents of liptinite and inertinite. The reflectance of the Inland feed coal is also similar to the Illinois Basin sample.

Additional characterization is underway and an advanced program of pyrolysis and reactivity testing has been initiated. The acquisition of additional samples of blast furnace burden material including, coke, iron ore, metallic iron, limestone, and slag as well as the char of the injected coal has been inevitably delayed because of problems at both the Inland and Armco blast furnaces. However, it is expected that these samples will soon be available.

REFERENCES

- Atkinson, C.J., and Willmers, R.R., 1990, Blast furnace coal injection studies using a single tuyere raceway investigation rig: Reprinted from Fuel Processing Technology, Elsevier Science Publishers B.V., Amsterdam, 24, p. 107-115.
- Carmichael, I.F., 1992, An introduction to Blast furnace coal injection: Iron and Steel Making, v. 3, p. 67-73.
- de Lassat de Pressigny, Y., Picard, M., Prado, G., Aleboye, H., Simonin, O., 1990, Study of coal combustion with respect to Blast furnace injection: Ironmaking Conference Proceedings - AIME, p. 473-480.
- Graffeulle, F., Allaire, B., Lao, D., 1985, Coal injection practice in Usinor Dunkirk BF. 2: Ironmaking Proceedings - AIME, p. 449-461.
- Gathergood, D.S., and Lochrie, L., 1990, The economics of fossil fuel injection: Ironmaking Conference Proceedings - AIME, p. 481-487.
- Gathergood, D.S., 1991, Coal injection into the Blast furnace: The Coke Oven Managers' Year-Book, p. 129-147.
- Koen, W., Vogel, R.B., Toxopeus, H.L., and Flierman, G.A., 1985, Injection of coal into the Hoogovens Blast furnaces: Ironmaking Proceedings - AIME, p. 437-447.
- Poos, A., and Ponghis, N., 1990, Potentials and problems of high coal injection rates: Ironmaking Conference Proceedings - AIME, p. 443-453.

TABLE 1. RESULTS OF MACERAL ANALYSIS			
SAMPLE	SIU 2294	SIU 2380	IBCSP 101
Vitrinite	46.0%	55.8%	
Pseudovitrinite	28.4%	32.7%	
Total Vitrinite	74.4%	88.5%	88.0%
Fusinite	1.5%	1.9%	1.0%
Semifusinite	14.0%	4.7%	5.0%
Micrinite	2.7%	0%	1.0%
Total Inerts	18.2%	6.6%	7.0%
Sporinite	7.4%	4.9%	6.2%
Total Exinite	7.4%	4.9%	6.2%
Total	100.0%	100%	100.0%

TABLE 2. RESULTS OF REFLECTANCE ANALYSIS							
SAMPLE	SIU 2294			SIU 2380			IBCSP 101
	Vit.	P. Vit.	Combined	Vit.	P. Vit.	Combined	Combined
Maximum	0.71%	0.81%	0.75%	0.55%	0.60%	0.57%	0.46%
Random	0.66%	0.76%	0.71%	0.53%	0.59%	0.55%	
Bireflectance	0.08%	0.09%	0.0 8%	0.05%	0.05%	0.05%	
Minimum	0.63%	0.72%	0.67%	0.51%	0.57%	0.54%	

PROJECT MANAGEMENT REPORT**1 December 1993 through 28 February 1994****Project Title: COAL COMBUSTION UNDER CONDITIONS
OF BLAST FURNACE INJECTION****DOE Contract Number: DE-FC22-92PC92521 (Year 2)****ICCI Project Number 93-1/2.1A-2P.****Principal Investigator: John C. Crelling, Professor
Department of Geology
Southern Illinois University
Carbondale, IL 62901
(618) 453-7361****Project Manager: Frank Honea, ICCI**

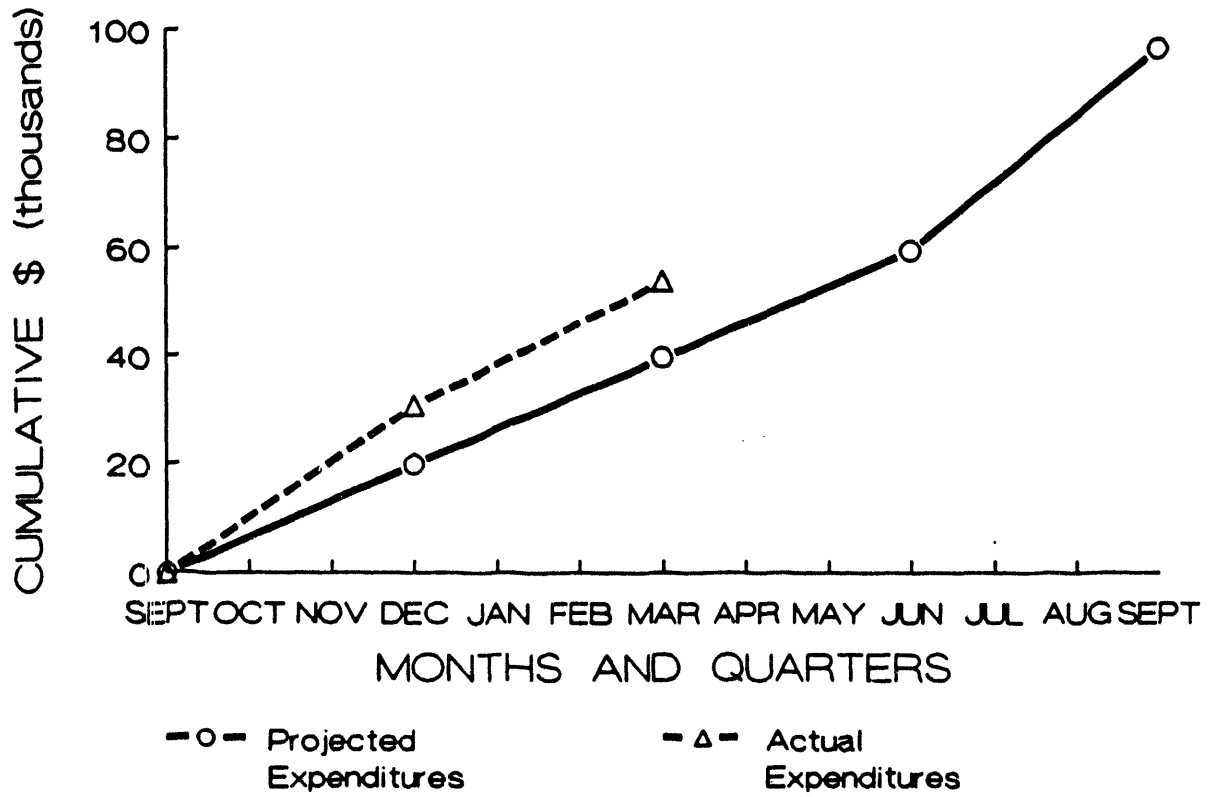
EXPENDITURES - EXHIBIT B

Cumulative Projected and Estimated Expenditures by Quarter

Quarter*	Types of Cost	Direct Labor	Fringe Benefits	Materials and Supplies	Travel	Major Equipment	Other Direct Costs	Indirect Costs	Total
Sept 1, 1993	Projected	10,116	2,195	2,375	1,000	0	2,375	1,806	19,867
to Nov 30, 1993	Estimated Actual	12,384	3,041	6,424	-0-	0	6,187	2,804	30,840
Sept 1, 1993	Projected	20,232	4,390	4,750	2,000	0	4,750	3,612	39,734
to Feb 28, 1994	Estimated Actual	25,212	6,906	8,978	-0-	0	8,012	4,911	54,019
Sept 1, 1993	Projected	30,348	6,584	7,125	3,000	0	7,125	5,418	59,600
to May 31, 1994	Estimated Actual								
Sept 1, 1993	Projected	53,642	11,244	9,500	4,000	0	9,500	8,789	96,675
to Aug 31, 1994	Estimated Actual								

*Cumulative by quarter.

COSTS BY QUARTER BLAST FURNACE INJECTION OF COAL



Total Illinois Clean Coal Institute Award \$96,675

=====

=====

SCHEDULE OF PROJECT MILESTONES

MONTH	S	O	N	D	J	F	M	A	M	J	J	A
TASK												
I. SAMPLE COLLECTION	■	■	■	■	X	X	X	X				
II. SAMPLE ANALYSIS			■	■	X	X	X	X	X	X	X	
III. DATA INTERPRETATION					X	X	X	X	X	X	X	X
IV. REPORTING			■			■			X			X

=====

=====

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DATE

FILMED

6/24/94

END

