TECHNICAL REPORT
September 1 through November 30, 1994

Project Title: **PILOT PLANT TESTING OF ILLINOIS COAL FOR BLAST FURNACE INJECTION**

DOE Cooperative Agreement Number: DE-FC22-92PC92521 (Year 3)
ICCI Project Number: 94-1/5.1A-2P.
Principal Investigator: John C. Crelling, Department of Geology, Southern Illinois University at Carbondale
Project Manager: Frank I. Honea, Illinois Clean Coal Institute

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 Illinois coal in the blast furnace injection process in a new and unique pilot plant test facility. 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 unique in that it is the first North American effort to directly determine the nature of the combustion of coal injected into a blast furnace. This proposal is a follow-up to one funded for the 1993-94 period. It is intended to complete the study already underway with the Armco and Inland steel companies and to demonstrate quantitatively the suitability of both the Herrin No. 6 and Springfield No. 5 coals for blast furnace injection. The main feature of the current work is the testing of Illinois coals at CANMET's (Canadian Centre for Mineral and Energy Technology) pilot plant coal combustion facility. This facility simulates blowpipe-tuyere conditions in an operating blast furnace, including blast temperature (900° C), flow pattern (hot velocity 200 m/s), geometry, gas composition, coal injection velocity (34 m/s) and residence time (20 ms). The facility is fully instrumented to measure air flow rate, air temperature, temperature in the reactor, wall temperature, preheater coil temperature and flue gas analysis. During this quarter a sample of the Herrin No. 6 coal (IBCSP 112) was delivered to the CANMET facility and testing is scheduled for the week of 11 December 1994. Also at this time, all of the IBCSP samples are being evaluated for blast furnace injection using the CANMET computer model.

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

TECHNICAL REPORT
September 1 through November 30, 1994

Project Title: **PILOT PLANT TESTING OF ILLINOIS COAL FOR BLAST FURNACE INJECTION**

DOE Cooperative Agreement Number: DE-FC22-92PC92521 (Year 3)
ICCI Project Number: 94-1/5.1A-2P.
Principal Investigator: John C. Crelling, Department of Geology, Southern Illinois University at Carbondale
Project Manager: Frank I. Honea, Illinois Clean Coal Institute

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 Illinois coal in the blast furnace injection process in a new and unique pilot plant test facility. 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 unique in that it is the first North American effort to directly determine the nature of the combustion of coal injected into a blast furnace. This proposal is a follow-up to one funded for the 1993-94 period. It is intended to complete the study already underway with the Armco and Inland steel companies and to demonstrate quantitatively the suitability of both the Herrin No. 6 and Springfield No. 5 coals for blast furnace injection. The main feature of the current work is the testing of Illinois coals at CANMET's (Canadian Centre for Mineral and Energy Technology) pilot plant coal combustion facility. This facility simulates blowpipe-tuyere conditions in an operating blast furnace, including blast temperature (900° C), flow pattern (hot velocity 200 m/s), geometry, gas composition, coal injection velocity (34 m/s) and residence time (20 ms). The facility is fully instrumented to measure air flow rate, air temperature, temperature in the reactor, wall temperature, preheater coil temperature and flue gas analysis. During this quarter a sample of the Herrin No. 6 coal (IBCSP 112) was delivered to the CANMET facility and testing is scheduled for the week of 11 December 1994. Also at this time, all of the IBCSP samples are being evaluated for blast furnace injection using the CANMET computer model.

DISCLAIMER

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 overall purpose of this study is to evaluate the combustion of Illinois coal, during the blast furnace injection process and to determine the suitability of Illinois coal to become a feed coal in this process. This investigation is significant to the use of Illinois coal in that the 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 1993-94 period. It is intended to complete the study already underway with the Armco and Inland Steel Companies and to test the Herrin No. 6 and Springfield No. 5 seams for use as blast furnace injection feed coals. The proposed test is to be done in a new and unique pilot plant test facility.

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 is 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 No. 7 Blast Furnace of Inland Steel (put on line in 1993) 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 CANMET pilot plant test facility which just started operations in 1993 is unique in North America. It is currently testing all commercial coals in Canada for blast furnace injection and has just become available for testing non-Canadian coals. Because it is so well instrumented, it is superior in many aspects to actual blast furnace systems which are designed for production and, therefore, lack much in state of the art instrumentation.

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 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.

This proposal is a follow-up to one funded for the 1993-94 period. It is intended to complete the study already underway with the Armco and Inland Steel Companies and to test the Herrin No. 6 and Springfield No. 5 seams for use as blast furnace injection feed coals. The proposed test is to be done in a new and unique pilot plant test facility.

The specific objectives of this final phase of the project are:

1. To test the blast furnace injection performance of both the Herrin No. 6 and Springfield No. 5 in the CANMET pilot plant test facility.

2. To collect from the test facility samples of the injected coal, the combustion char, and slag at intermediate and final stages for chemical analysis, scanning electron microscopy and optical microscopic analysis, char microstructure analysis, and coal burnout analysis (ash technique).

3. To determine the TGA reactivity of chars generated under blowpipe-tuyere conditions at simulated raceway conditions (temperature1500° C, gas composition: CO_2 10%, O_2%, N_2 88%; and CO_2 10%, O_2 5%, N_2 85%).

4. To evaluate the cooling and coke replacement characteristics of coal used for blast furnace injection through the use of a computer model of the blast furnace/coal injection process.

5. To synthesize and evaluate the data gathered from the pilot plant tests and to compare it with the results of the studies at both the Armco and Inland steel companies.

6. To use all of these results to demonstrate the suitability of Illinois coal for use in blast furnace injection using both analysis results and computer models.

During this quarter a 300 pound sample of Herrin No.6 coal was shipped to the CANMET facility in Ottawa, Canada. It is now being prepared for testing which is scheduled for the week of 11 December 1994. In addition, all of the samples of the IBCSP coal samples are being evaluated for their blast furnace performance with the CANMET computer model. Data from the test and the computer analysis will be available during the next quarter.

OBJECTIVES

This study is a follow-up to one funded for the 1993-94 period. It is intended to complete the study already underway with the Armco and Inland Steel Companies and to test the Herrin No. 6 and Springfield No. 5 seams for use as blast furnace injection feed coals. The main feature is the testing of Illinois coals in a new and unique pilot plant test facility.

The specific objectives of this final phase of the project are:

1. To test the blast furnace injection performance of both the Herrin No. 6 and Springfield No. 5 in the CANMET pilot plant test facility.

2. To collect from the test facility samples of the injected coal, the combustion char, and slag at intermediate and final stages for chemical analysis, scanning electron microscopy and optical microscopic analysis, char microstructure analysis, and coal burnout analysis (ash technique).

3. To determine the TGA reactivity of chars generated under blowpipe-tuyere conditions at simulated raceway conditions (temperature 1500°C, gas composition: CO_2 10%, O_2%, N_2 88%; and CO_2 10%, O_2 5%, N_2 85%).

4. To evaluate the cooling and coke replacement characteristics of coal used for blast furnace injection through the use of a computer model of the blast furnace/coal injection process.

5. To synthesize and evaluate the data gathered from the pilot plant tests and to compare it with the results of the studies at both the Armco and Inland steel companies.

6. To use all of these results to demonstrate the suitability of Illinois coal for use in blast furnace injection using both analysis results and computer models.

INTRODUCTION AND BACKGROUND

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 overall purpose of this study is to evaluate the combustion of Illinois coal, during the blast furnace injection process and to determine the suitability of Illinois coal to become a feed coal in this process. This investigation is significant to the use of Illinois coal in that the 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 1993-94 period. It is intended to complete the study already underway with the**

Armco and Inland Steel Companies and to test the Herrin No. 6 and Springfield No. 5 seams for use as blast furnace injection feed coals.

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 Figure 1) 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.

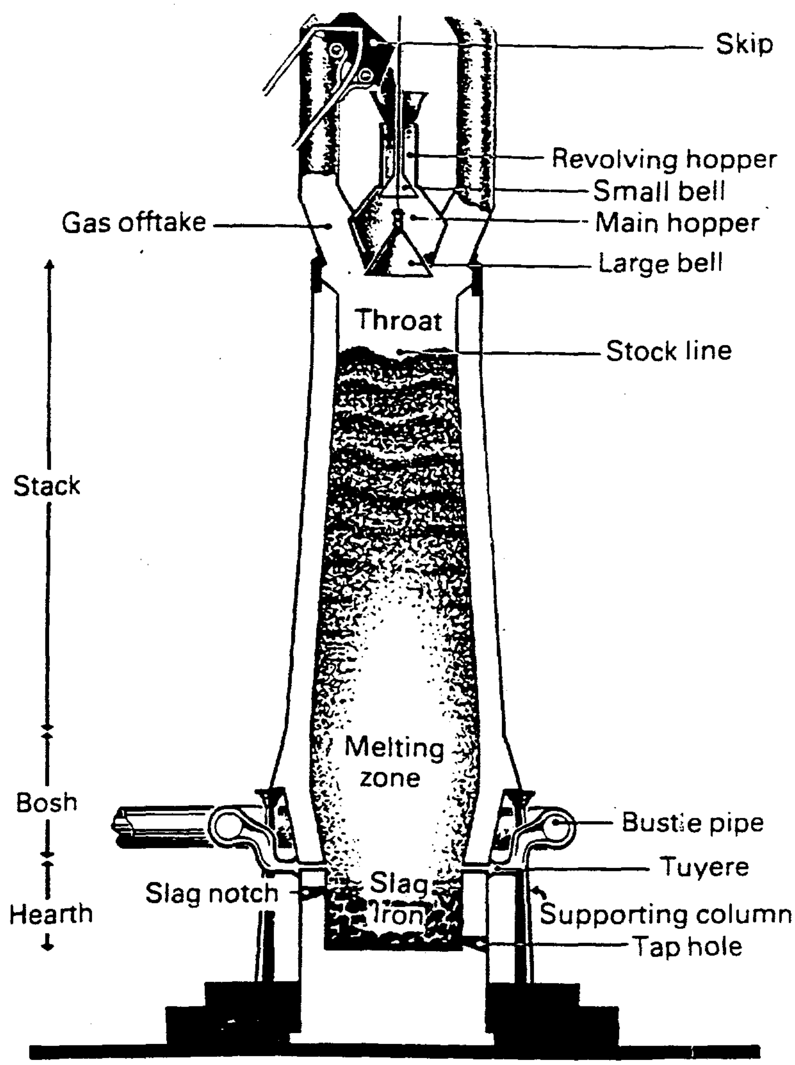

Figure 1. Cross section of a typical blast furnace. Note the location of the tuyeres around the base of the furnace (after Long 1968).

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 reduces 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 2). Thus, ideally, only the products of combustion - CO_2 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.

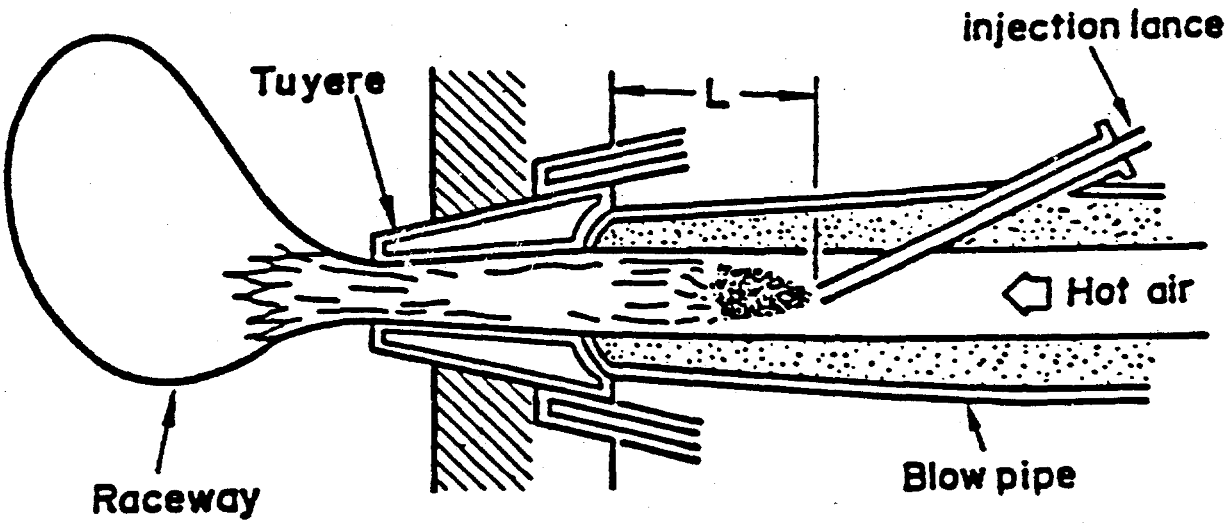

Figure 2. Cross-section of a tuyere with coal injection.

The suitability of coal for blast furnace injection is influenced by its combustibility, flame temperature (cooling effect) and coke replacement properties. Carbon, hydrogen, oxygen, volatile matter and ash (amount, composition, fusion temperature) have been recognized as major factors.

The most suitable coals have low cooling effect on the raceway, good combustibility and generate chars with high reactivity. Low cooling effect allows the injection of large quantities of coal without blast temperature compensation. Good combustibility and char reactivity result in efficient utilization of coal as a replacement for coke and for high productivity of the furnace.

Coals have different combustion properties and cooling effects, and the selection of a coal with the right characteristics is essential to efficient blast furnace operation. Volatile matter (VM) content is no longer considered sufficient to characterize coal for blast furnace injection. Other factors such as tar yield, char microstructure, macerals composition and catalytic effect of mineral matter must also be considered.

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 now online at 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 N0. 7 Blast Furnace began last 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.

CANMET Pilot Plant Coal Combustion Facility

The Canadian Centre for Mineral and Energy Technology (CANMET) Energy Research Laboratories in Ottawa offer unique services to coal producers and researchers. The services include a confidential evaluation service to determine the suitability of particular coals for blast furnace injection and an evaluation report which can assist in the marketing of suitable coals to blast furnace operators.

CANMET's pilot plant coal combustion facility simulates blowpipe-tuyere conditions in an operating blast furnace, including blast temperature (900° C), flow pattern (hot velocity 200 m/s), geometry, gas composition, coal injection velocity (34 m/s) and residence time (20 ms). This facility is fully instrumented to measure air flow rate, air temperature, temperature in the reactor, wall temperature, preheater coil temperature and flue gas analysis.

Cooling and coke replacement characteristics of coal used for blast furnace injection depend on carbon, hydrogen and oxygen contents. They are influenced by a complex interplay of chemical and physical processes and they can be predicted through the use of a computer model of the blast furnace/coal injection process.

CANMET's computer model is based on principles of conservation of mass and energy for the steady state continuous blast furnace process. It includes mass balance equations which account for carbon, oxygen and iron as well as enthalpy balance equations which account for chemical reactions in the bottom zone of the furnace as well as combustion zone.

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, Graffeviile et al. 1985, Poos and Ponghis 1990, and deLassat dePressigny 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.

RELEVANCE AND SIGNIFICANCE

This study is unique in that it was 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 No. 7 Blast Furnace of Inland Steel (put on line in 1993) 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 CANMET pilot plant test facility which just started operations in 1993 is unique in North America. It is currently testing all commercial coals in Canada for blast furnace injection and has just become available for testing non-Canadian coals. Because it is so well instrumented, it is superior in many aspects to actual blast furnace systems which are designed for production and, therefore, lack much in state of the art instrumentation.

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 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 last year at the Gary Works of U.S. Steel will use about five times that amount and the system at Inland Steel should use three times as much as the Armco plant is currently using.

EXPERIMENTAL PROCEDURES

RESEARCH APPROACH

First Phase (1992-93)

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 specific objectives of the 1992-93 project with Armco Inc. were:

1. To collect from an active blast furnace samples of the injected coal, the combustion char, coke, hot metal, dust, and slag.

2. To use this experience to develop a dedicated injector and sampling system.

3. To characterize the collected materials with respect to their basic chemical, physical and petrographic properties.

4. To determine the reactivity of the char in various gas compositions characteristic of the lower part of the furnace (CO, CO_2, H_2, H_2O, air).

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 use a dedicated injector to inject Illinois coal to directly determine its suitability for use in coal injection.

Because the original project was of necessity somewhat longer range than the strict one year usually allotted projects funded by ICCI, not all of the objectives were intended to be met in the first year.

Second Phase (1993-94)

The second phase of the overall blast furnace injection project included the completion of the study with Armco and the initiation of a study with Inland Steel Company. By the end of August 1994, coals from the Illinois Basin were successfully injected into the blast furnaces of Inland Steel.

The collaboration with the Inland Steel Company is 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.

(Final Phase) (1994-95)

The final phase of this study involves the testing of barrel quantities of two IBCSP samples - IBCSP 110 (Springfield No. 5 Seam) and IBCSP 112 (Herrin No. 6 Seam) in the Canmet Pilot Plant Test Facility and a final synthesis of all of the data collected.
To accomplish the objectives stated above the work has been broken down into the following tasks:

Task I - Pilot Plant Testing

CANMET's pilot plant coal combustion facility simulates blowpipe-tuyere conditions in an operating blast furnace, including blast temperature (900° C), flow pattern (hot velocity 200 m/s), geometry, gas composition, coal injection velocity (34 m/s) and residence time (20 ms). This facility is fully instrumented to measure air flow rate, air temperature, temperature in the reactor, wall temperature, preheater coil temperature and flue gas analysis.

Task II - Pilot Plant Sample Characterization

Samples will be taken at intermediate and final stages to evaluate coal burnout (ash technique); chemical thermogravimetric analysis (TGA), scanning electron microscopy and optical microscopic analysis will be done; the microstructure of chars will be identified based on microscopic analysis.

The TGA method will be used to evaluate char reactivity under simulated raceway conditions (temperature 1500° C, gas composition: CO_2 10%, O_2%, N_2 88%; and CO_2 10%, O_2 5%, N_2 85%).

Reactivity of chars generated under blowpipe-tuyere conditions will be compared with that of metallurgical coke.

Task III Computer Model Evaluation

Cooling and coke replacement characteristics of coal used for blast furnace injection depend on carbon, hydrogen and oxygen contents. They are influenced by a complex interplay of chemical and physical processes and they can be predicted through the use of a computer model of the blast furnace/coal injection process.

CANMET's computer model is based on principles of conservation of mass and energy for the steady state continuous blast furnace process. It includes mass balance equations which account for carbon, oxygen and iron as well as enthalpy balance equations which account for chemical reactions in the bottom zone of the furnace as well as combustion zone.

The computer model determines:

* cooling characteristics of specific coals: raceway adiabatic flame temperature (RAFT) change related to 1 kg of injectant (° C/kg);
* permissible amount of injected coal (kg/100° C change of RAFT);
* permissible injection rate relative to natural gas and oil at constant RAFT;
* replacement ratios of specific coals (defined as the ratio of mass of coke saved to the mass of an injected coal needed to replace it); and
* blast furnace response to specific coals: coke rate, RAFT, top gas composition.

Task IV - Final Evaluation of Illinois Coal

At the completion of tasks I, II, and III, the results of the testing on the two Illinois coals will be evaluated and compared to the results from the Armco and Inland Blast furnaces.

RESULTS AND DISCUSSION

During this quarter a 300 pound sample of Herrin No.6 coal was shipped to the CANMET facility in Ottawa, Canada. It is now being prepared for testing which is scheduled for the week of 11 December 1994. In addition, all of the samples of the IBCSP coal samples are being evaluated for their blast furnace performance with the CANMET computer model. Data from the test and the computer analysis will be available during the next quarter.

DISCLAIMER STATEMENT

This report was prepared by Dr. John C. Crelling of Southern Illinois University at Carbondale with support, impart by grants made possible by the U. S. Department of Energy Cooperative Agreement Number DE-FC22-92PC92521 and the Illinois Department of Engery through the Illinois Coal Development Board and the Illinois Clean Coal Institute.
Neither Dr. John C. Crelling of Southern Illinois University at Carbondale nor any of its subcontractors nor the U. S. Department of Energy, Illinois Department of Energy & Natural Resources, Illinois Coal Development Board, Illinois Clean Coal Institute, nor any person acting on behalf of either:

(A) Makes any warranty of representation, express or impled, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method or process disclosed in this report may not infringe privately-owned rights; or

(B) Assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in the report.

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 U. S. Department of Energy. The views and opinions of authors expressed herein do not necessarily state or reflect those of the U. S. Department of Energy.

Notice to Journalist and Publishers: If you borrow information from any part of this report, you must include a statement about the DOE and Illinois cost-sharing support of the project.

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.

Burgess, J.M., Cameron, D.B., Clark, C.J.C., and Scaife, P.H., 1987, Coal for blast furnace injection: in Coal Power '87, Australasian Institute of Mining and Metallurgy, Parkville, Victoria, Australia, p. 171-180.

Carmichael, I.F., 1992, An introduction to blast furnace coal injection: I&SM, v. 3, p. 67-73.

de Lassat de Pressigny, Y., Picard, M., Prado, G., Aleboyeh, H., Simonin, O., 1990, Study of coal combustion with respect to blast furnace injection: Ironmaking Conference Proceedings - AIME, p. 473-480.

Graffeuille, 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.

Hutny, W.P., Lee, G.K., Price,J.T., 1991, Fundamentals of coal combustion during injection into a blast furnace: Progress in Energy and Combustion Science, v. 17, part 4, p. 373-395.

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.

Saino, M., Yoshimoto, M., Serizawa, Y., Akimoto, E., Sakaguchi, Y., and Watanabe, Y., 1985, New pulverized coal injection system for Chiba No. 5 blast furnace: Ironmaking Proceedings - AIME, p. 463-472.

Shyng, Q.G., Chen, E.K., Wu, S.S., Lo, W.G., 1990, Coal injection in blast furnace of China steel corporation: Ironmaking Conference Proceedings - AIME, p. 331-339.

Takeda, K., Miyagawa, S., and Taguchi, S. 1990, Effect of coal properties oncombustibility of coal injected to blast furnace: Ironmaking Conference Proceedings - AIME, p. 455-465.

Uenaka, Toshiyuki; Tamura, Setsuo; Kuwano, Keiji; Yabata, Takeshi; and Noma, Fumio, 1985, Pulverized coal injection (PCI) in a blast furnace: Ironmaking Proceedings - AIME, p. 417-424.

Willmers, R. R., 1989, The effect of blast furnace coal injection upon bosh coke properties, coke combustion and furnace permeability: Ironmaking Conference Proceedings - AIME, p. 395-402.

PROJECT MANAGEMENT REPORT
September 1 through November 30, 1994

Project Title: **PILOT PLANT TESTING OF ILLINOIS COAL FOR BLAST FURNACE INJECTION**

DOE Cooperative Agreement Number: DE-FC22-92PC92521 (Year 3)
ICCI Project Number: 94-1/5.1A-2P.
Principal Investigator: John C. Crelling, Department of Geology
Southern Illinois University at Carbondale
Project Manager: Frank Honea, ICCI

COMMENTS

None.