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Blast Furnace Granular Coal Injection Project

Annual Report
January - December 1995

May 1995

Work Performed Under Contract No.: DE-FC21-91MC27362

For
U.S. Department of Energy
Office of Fossil Energy
Morgantown Energy Technology Center
Morgantown, West Virginia

By
Bethlehem Steel Corporation
Bethlehem, Pennsylvania

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DOE/MC/27362 – 5241 **BLAST FURNACE GRANULAR COAL INJECTION PROJECT** **DOE**

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TABLE OF CONTENTS

1.0 INTRODUCTION

This annual report describes the Blast Furnace Granular Coal Injection project being implemented at Bethlehem Steel Corporation's (BSC) Burns Harbor Plant. The project is receiving cost-sharing from the U.S. Department of Energy (DOE), and is being administrated by the Morgantown Energy Technology Center in accordance with the DOE Cooperative Agreement No. DE-FC21-91MC27362.

This installation is the first in the United States to employ British Steel technology[1,2] that uses granular coal to provide part of the fuel requirement of blast furnaces. The project will demonstrate/assess a broad range of technical/economic issues associated with the use of coal for this purpose. To achieve the program objectives, the demonstration project is divided into the following three Phases:

Phase I	-	Design
Phase II	-	Construction
Phase III	-	Operation

Preliminary Design (Phase I) began in 1991 with detailed design commencing in 1993. Construction at Burns Harbor (Phase II) began in August 1993 and was completed at the end of 1994. The demonstration test program (Phase III) started in the fourth quarter of 1995.

2.0 BACKGROUND

Bethlehem Steel Corporation's Burns Harbor Plant operates two blast furnaces which produce molten iron in support of steelmaking operations. The furnaces are fueled with coke as part of the raw materials charged through the top of the furnace. The coke was supplemented by natural gas injected along with the combustion air through ports (tuyeres) near the base of the furnace. Each furnace produces about 7000 tons per day of molten iron with the injected fuel providing about 15 percent of the total fuel requirements.

Because of the uncertainty of the long-term supply and cost of natural gas, Bethlehem submitted a proposal in response to DOE's CCT-III solicitation to demonstrate the conversion for, optimization of, and commercial performance characteristics of granular coal as a supplemental fuel for steel industry blast furnaces. Operating blast furnaces with coal injected directly through the tuyeres into the combustion zone as a supplemental fuel will result in reduced coke consumption, and thereby, decrease the environmental emissions associated with cokemaking. The environmental problems normally associated with the combustion of coal will also be virtually eliminated by direct injection of coal into the blast furnaces as the potential contaminants, e.g., sulfur, are captured in the blast furnace slag.

Economic benefits will be realized by the reduced demand for coke, the primary blast furnace fuel, and for natural gas and oil, the "conventional" supplementary fuels. Presuming that: (a) the granular coal injection system can be successfully operated at rates of several hundred pounds of coal injected per net ton of hot metal (liquid pig iron produced by the blast furnaces), and that (b) costs for the competing supplemental fuels, natural gas and oil, escalate in a manner projected by the U.S. Department of Energy (DOE), then the annual operating cost savings should make this an attractive investment as well as a technical advancement.

Bethlehem's Blast Furnace Granular Coal Injection System Demonstration Project was one of 13 demonstration projects accepted for funding in the Clean Coal Technology Program third round of competition. A cooperative agreement with a total estimated cost of $143,800,000 was awarded to Bethlehem on November 26, 1990. Under this cooperative agreement, Bethlehem would provide 78.3 percent of the total funding requirements for the demonstration project with the DOE providing the remaining 21.7 percent. As project details were refined, the cost estimate was increased from $143,800,000 to $190,650,000. Major project milestone dates are shown in Figure 1. Additional details on the project were presented at the 1993, 1994 and 1995 Clean Coal Technology Conferences.[3,4,5]

3.0 TECHNOLOGY DESCRIPTION

The ironmaking blast furnace is at the heart of integrated steelmaking operations. As shown in Figure 2, the raw materials are charged to the top of the furnace through a lock hopper arrangement to prevent the escape of pressurized hot reducing gases. Air needed for the combustion of coke to generate the heat and reducing gases for the process is passed through stoves and heated to 1500-2300°F. The heated air (hot blast) is conveyed to a refractory-lined bustle pipe located around the perimeter of the furnace. The hot blast then enters the furnace through a series of ports (tuyeres) around and near the base of the furnace. The molten iron and slag are discharged through openings (tapholes) located below the tuyeres. The molten iron flows to refractory-lined ladles for transport to the basic oxygen furnaces.

A schematic of the various zones inside the blast furnace is shown in Figure 3. As can be seen, the raw materials, which are charged to the furnace in batches, create discrete layers of ore and coke. As the hot blast reacts with and consumes coke at the tuyere zone, the burden descends in the furnace resulting in a molten pool of iron flowing around unburned coke just above the furnace bottom (bosh area). Reduction of the descending ore occurs by reaction with the rising hot reducing gas that is formed when coke is burned at the tuyeres.

The cohesive zone directly above the tuyeres is so called because here the partially reduced ore is being melted and passes through layers of unburned coke. The coke layers provide the permeability needed for the hot gases to pass through this zone to the upper portion of the furnace. Unlike coal, coke has the high temperature properties needed to retain its integrity in this region and is the reason that blast furnaces cannot be operated without coke in the burden.

The hot gas leaving the top of the furnace is cooled and cleaned. Since it has a significant heating value (80-100 Btu/scf), it is used to heat the hot blast stoves. The excess is used to generate steam and power and for other uses within the plant.

Over the years many injectants (natural gas, tar, oils, etc.) have been used in blast furnaces to reduce the amount of coke used. Their use is a matter of economics with each location making choices by considering the costs of coke and injectants. Natural gas has been a common injectant used in this country. Recent technological developments in Europe and Asia, where coal has been widely used as an injectant, have established that the highest levels of injection and subsequent displacement of coke can be obtained by using coal.

The joint development between British Steel and Simon-Macawber of a process for the injection of granular coal into blast furnaces began in 1982 on the Queen Mary Blast Furnace at the Scunthorpe Works.(1,2) The objective of the development work was to inject granular coal into the furnace and test the performance of the Simon-Macawber equipment with a wide range of coal sizes and specifications. Based on Queen Mary's performance, coal injection systems were installed on Scunthorpe's Queen Victoria, Queen Anne and Queen Bess blast furnaces and on furnaces 1 and 2 at the Ravenscraig Works.

Bethlehem decided to utilize the Simon Macawber Blast Furnace Granular Coal Injection (BFGGI) System, because unlike more widely used systems that utilize only pulverized coal, it is capable of injecting both granular and pulverized coal. Bethlehem believes that the Simon Macawber system offers a variety of technical and economic advantages which make this system potentially very attractive for application in the US basic steel industry. A schematic showing the application of the technology to the blast furnace is shown in Figure 4. Some of the advantages of this technology include:

- The injection system has been used with granular coal as well as with pulverized coal. No other system has been utilized over this range of coal sizes.
- The potential costs for granular coal systems are less than for pulverized systems.
- Granular coal is easier to handle in pneumatic conveying systems. Granular coals are not as likely to stick to conveying pipes if moisture control is not adequately maintained.
- Research tests conducted by British Steel indicate that granular coal is less likely to pass through the coke bed. Coke replacement ratios obtained by British Steel have not been bettered in any other installation.
- Granular coal's coarseness delays gas evolution and temperature rise associated with coal combustion in the raceway. Consequently, it is less likely to generate high temperatures and gas flows at the furnace walls which result in high heat losses, rapid refractory wear and poor utilization of reducing gases.
- System availability has exceeded 99 percent during several years of operation at British Steel.
- The unique variable speed, positive displacement Simon-Macawber injectors provide superior flow control and measurement compared to other coal injection systems.

4.0 INSTALLATION DESCRIPTION

The coal preparation and injection facility has been retrofitted to the C and D blast furnaces at the Burns Harbor Plant. The Plant is located in Porter County, Indiana on the south shore of Lake Michigan.

A simplified flow diagram of the coal handling system at Burns Harbor is shown in Figure 5. The Raw Coal Handling Equipment and the Coal Preparation Facility includes the equipment utilized for the transportation and preparation of the coal from an existing railroad car dumper until it is prepared and stored prior to conveying into the Coal Injection Facility; the Coal Injection Facility delivers the prepared coal to the blast furnace tuyeres.

Raw Coal Handling. Coal for this project is transported by rail from coal mines to Burns Harbor similar to the way in which the plant now receives coal shipments for the coke ovens. The coal is unloaded using an existing railroad car dumper, which is currently part of the blast furnace material handling system. A modification to the current conveyor was made to enable the coal to reach either the coke ovens or the coal pile for use at the Coal Preparation Facility.

This modification required a new 60-inch wide transfer conveyor from the existing conveyor and to a junction house. There the coal is transferred to a new 60-inch wide stockpile conveyor for the raw coal storage pile. The coal pile is formed with a radial stacker capable of building a 10-day storage pile (approximately 28,000 tons). The material handling system from the car dumper to the coal storage pile is sized at 2,300 tons per hour to match the output of the car dumper.

Raw Coal Reclaim. The raw coal reclaim tunnel beneath the coal storage pile contains four reclaim hoppers in the top of the tunnel. The reclaim hoppers, which are directly beneath the coal pile, feed a 36-inch wide conveyor in the tunnel. The reclaim conveyor transports the coal at a rate of 400 tons per hour above ground to the south of the storage pile. A magnetic separator is located at the tail end of the conveyor to remove tramp ferrous metals. The conveyor discharges the coal onto a vibrating screen to separate coal over 2 inches from the main stream of minus 2-inch coal. The oversized coal passes through a precrusher which discharges minus 2-inch coal. The coal from the precrusher joins the coal that passed through the screen and is conveyed from ground level by a 36-inch wide plant feed conveyor to the top of the building that houses the Coal Preparation Facility.

Coal Preparation. The plant feed conveyor terminates at the top of the process building that houses the Coal Preparation Facility. Coal is transferred to a distribution conveyor, which enables the coal to be discharged into either of two steel raw coal storage silos. The raw coal silos are cylindrical with conical bottoms and are completely enclosed with a vent filter on top. Each silo holds 240 tons of coal, which is a four-hour capacity at maximum injection levels. Air cannons are located in the conical section to loosen the coal and insure that mass flow is maintained through the silo.

Coal from each raw coal silo flows into a feeder which controls the flow of coal to the preparation mill. In the preparation mill, the coal is ground to the desired particle size. Products of combustion from a natural gas fired burner are mixed with recycled air from the downstream side of the process and are swept through the mill grinding chamber. The air lifts the ground coal from the mill vertically through a classifier where oversized particles are circulated back to the mill for further grinding. The proper sized particles are carried away from the mill in a 52-inch pipe. During this transport phase, the coal is dried to 1-1.5% moisture. The drying gas is controlled to maintain oxygen levels below combustible concentrations. There are two grinding mill systems; each system produces 30 tons per hour of pulverized coal or 60 tons per hour of granular coal.

The prepared coal is then screened to remove any remaining oversize material. Below the screens, screw feeders transport the product coal into one of four 180-ton product storage silos and then into a weigh hopper in two-ton batches. The two-ton batches are dumped from the weigh hopper into the distribution bins which are part of the Coal Injection Facility.

Coal Injection. The Coal Injection Facility includes four distribution bins located under the weigh hoppers described above. Each distribution bin contains 14 conical-shaped pant legs. Each pant leg feeds an injector which allows small amounts of coal to pass continually to an injection line. Inside the injection line, the coal is mixed with high-pressure air and is carried through approximately 600 feet of 1-1/2-inch pipe to an injection lance mounted on each of the 28 blowpipes at each furnace. At the injection lance tip, the coal is mixed with the hot blast and carried into the furnace raceway. The 14 injectors at the bottom of the distribution bin feed alternate tuyeres. Each furnace requires two parallel series of equipment, each containing one product coal silo, one weigh hopper, one distribution bin and 14 injector systems.

5.0 PROJECT TEST PLAN

The objective of the test program is to determine the effect of coal grind and coal type on blast furnace performance. The start-up operation was conducted with a high volatile coal from eastern Kentucky with 36% volatile matter, 8% ash and 0.63% sulfur. The coal preparation system has been operated to provide granular coal with nominal size of 30% minus 200 mesh (74 microns).

A trial will be conducted to determine the effect of using pulverized coal with a nominal size of 80% minus 200 mesh. The results of this trial will be of great interest to blast furnace operators and could have a significant effect on the type of coal injection facilities that will be installed in the future.

Another series of trials will be conducted to determine the effect of coal types and coal chemistry on furnace performance. The important furnace performance parameters that will be closely monitored during these trials are coke rate, raw material movement in the furnace, pressure drop in the furnace, gas composition profiles, iron analyses and slag analyses. All results of the blast furnace trials will be evaluated and documented in a comprehensive report.

6.0 CONSTRUCTION ACTIVITIES

Construction of the Coal Injection Facility was completed in December 1994 and the first coal was injected into D furnace on December 18. Modifications to the facility continued throughout 1995 while the operation continued. Early 1995 was particularly difficult as the coal injection rate was ramped up and the coal grinding system was required to deliver more coal. The difficulties in the early part of the year were the usual start-up type problems and none of the facility modifications resulted in a change to the basic granular coal injection concept or the facility flowsheet. A listing of these facility modifications is contained in the Appendix.

In early December 1995, coal handling and preparation problems were experienced as a result of cold weather. Moisture condensation in the prepared coal silos caused coal to build-up on the silo walls and also caused blocked injectors. These problems became so severe that coal injection was stopped in mid-December in order to rectify the situation. The coal silos for C furnace were cleaned and insulated to eliminate the moisture condensation. The same procedure was followed for the D furance silos in January 1996.

Additional facility problems developed in the baghouse, the coal product screens and the coal screw conveyors. Solutions to these problems were being developed at the end of 1995.

7.0 BLAST FURNACE OPERATIONS

The granulated coal injection facility at Bethlehem Steel's Burns Harbor blast furnaces has been operating since January 1995. The effects on the furnace operation with granulated coal as the injected fuel has been very different than the previous experience at the blast furnace when natural gas was used as the auxiliary injected fuel.

The preparation and planning for an efficient changeover from natural gas to coal injection was successfully completed. The furnace operating conditions and furnace process results with granulated coal injection are discussed and compared to periods of natural gas injection in the following. The use of five different coals and general process results during 1995 is also reviewed for each furnace. In addition, furnace refractory temperatures, thermal loads and refractory wear are discussed and compared to previous experience.

7.1 FURNACE OPERATING CONDITIONS

The C and D blast furnaces are medium sized furnaces with hearth diameters of 38.25 and 35.75 feet, respectively. The working volume of C furnace is 88,838 cubic feet, D furnace has a working volume of 84,456 cubic feet. Both furnaces have twenty eight tuyeres, a two taphole casthouse configuration and a conveyor fed raw material charging system. The furnace top, a double bell and hopper design, is the same on both furnaces. This top has rotational distribution capability but it does not allow close control of burden distribution as can be done with a Paul-Wurth top. Prior to the C furnace reline in 1994 the two furnaces were approximately identical. However, during the reline period C furnace was enlarged slightly and the refractory cooling system was upgraded to a high density plate cooling configuration. The bosh and mantle regions of both furnaces utilize stave cooling. The furnace stack region on C furnace has closely spaced cooling plates, however, the stack cooling plates on the D furnace are not as closely spaced. The high density cooling on C furnace was specifically designed for the rigors of coal injection and to provide increased production capability compared to D furnace.

The Burns Harbor coke plant does not produce sufficient coke to completely supply the blast furnaces. Various domestic suppliers have been used over the years to supplement coke production. As a result of having to purchase expensive outside coke, blast furnace personnel developed very successful operating practices using natural gas as an auxiliary injected fuel substitute for coke.

The natural gas on C and D furnace is injected through individual pipes located on each of the twenty eight tuyeres. The successful natural gas injection practices that were developed over the years have proven to be considerably different than the operating practices necessary to inject granulated coal efficiently. The natural gas practice included 130-160 pounds/NTHM of gas, low levels of oxygen enrichment and minimum amounts of blast moisture. These practices result in low flame temperatures at the tuyere level. Flame temperatures at the tuyere with natural gas are in the range of 3600-3750 F. Blast furnace coke rates with natural gas were 740-800 pounds/NTHM.

A review of blast furnace operating practices at other coal injection facilities was completed prior to the planning stage for the start-up of the Burns Harbor system. In addition, extensive computer modeling of the furnace operating parameters using coal and gas together preceded actual coal usage. The D furnace was designated as the start-up furnace.

The start-up plan was to put granulated coal on D through two tuyeres with the remaining tuyeres on natural gas. As the operators became confident with the reliability of the injection system and as normal start-up difficulties were resolved, additional tuyeres would have gas taken off and coal put on. The changeover of tuyeres would be done in groups of two. The gradual switch from gas to coal on the furnace also allowed a gradual increase in the coal grinding circuit operating rate.

With this fundamental plan decided upon, a relatively constant furnace coke rate was chosen and then adjusted based on the amount of coal being injected and the total number of tuyeres on coal. The operating parameters that were used initially, low blast moisture and low oxygen enrichment, were essentially the same that had been successful with natural gas. In fact, since natural gas was going to be on a substantial number of tuyeres during the start-up, it was deemed necessary to begin in this manner.

Coal injection began on D furnace in mid-December, primarily to test the coal grinding and preparation circuits. Significant operations began on January 19 with four tuyeres on coal at a total rate of 20 pounds/NTHM. The coal rate and number of tuyeres was increased quickly to 70 pounds/NTHM through ten tuyeres. Although coal was used during January for a limited time and on a small number of tuyeres, three interrelated furnace operating parameters were adversely affected: furnace wind rate, furnace blast pressure and burden permeability.

Furnace wind rates had to be reduced because of the high blast pressure. The burden permeability, a measure of the blast furnace gas flow resistance through the ore and coke layers within the furnace, was seriously reduced. Various problems in the coal grinding and preparation system throughout January, February and March precluded any detailed assessment of full coal usage on either C or D furnace.

On February 9 coal injection started on C furnace with four tuyeres at an overall rate of 25 pounds/NTHM. The remaining twenty four tuyeres had natural gas. These conditions were maintained throughout February and March.

Operating difficulties with the coal system continued through most of March. However, on March 29 D furnace began using coal on twenty six tuyeres at a rate in excess of 100 pounds/NTHM and natural gas injection was curtailed. During April, the first full month with coal injection, we were able to observe the effects on the furnace in comparison to a natural gas operation. Table 1 shows some key operating variables with a natural gas operation on D in November 1994 compared to April 1995. The coal rate in April of 150 pounds/NTHM resulted in an increase in furnace blast pressure and a slight decrease in burden permeability. The most significant operating change that was observed with the use of coal was an increase in the amount of blast moisture added to the furnace. This increase was necessary to maintain proper burden movement through the furnace. We also note in Table 1, the increase in sulfur content of the blast furnace slag. Injected coal brings sulfur into the furnace that the natural gas does not, therefore, slag chemistry must be adjusted by the operators to compensate for the coal sulfur. In addition, the slag volume or amount of slag produced in the furnace must be increased to accommodate the changes made in the chemistry. The changes made in chemistry and volume enabled hot metal quality to be maintained. Also notable is the increase in the furnace coke rate that was necessary with the coal injection. The increase of 55 pounds/NTHM of coke from November 1994 to April 1995 was necessary to support hot metal temperature and hot metal silicon levels.

On May 12, the coal rate on C furnace was increased to approximately 140 pounds/NTHM through twenty six tuyeres and natural gas was curtailed. Also during May, C furnace was designated as the coal evaluation test furnace. This was done because of the enhanced refractory cooling system and the more extensive instrumentation that was added to C during the 1994 reline. Secondly, increased refractory wear on the D furnace, discussed later, became apparent. In response to the increased refractory wear the D furnace coal injection rates remained at approximately 140 pounds/NTHM throughout the balance of 1995.

The C furnace operation in July is summarized in Table 1 and represents another refinement in the operating conditions on the furnace. Tuyere flame temperature was increased to ascertain the affects on the operation. The flame temperature increase of 210 F, compared to the D operation in April, was accomplished by increasing the oxygen enrichment. One of the goals of this change was to eliminate or reduce the amount of carbon char that was carrying over from the furnace top to the blast furnace gas cleaning system. The char was floating, in increasing quantity, on the dirty water separation tank of the gas cleaning system. It was thought that increased oxygen at the tuyere would promote more complete combustion of the injected coal. Over time the increased oxygen did reduce the quantity of carbon char carryover.

Another milestone on C furnace was reached in September. The coal injection rate averaged more than 200 pounds/NTHM and the furnace coke rate was stabilized at less than 800 pounds/NTHM. The operating conditions for this month are shown on Table 1. Notable during this period is the fact that when the coal facility became more reliable the furnace operators were able to make changes in the operating conditions more quickly and observe the results. The blast moisture was reduced during the month and flame temperatures were increased. These changes resulted in a furnace coke rate that now resembles the historical natural gas operation. Although burden permeability is lower than desired, the furnace blast pressure has been reduced from July. Slag chemistry, demonstrated by slag sulfur content and slag volume, was also fine tuned during this period. The stability of the operation, since no injected coal system interruptions occurred, is apparent by the excellent hot metal silicon and sulfur content standard deviation values.

During November, C furnace achieved a Burns Harbor record coke rate of 694 pounds/NTHM at a coal injection rate of 210 pounds/NTHM. This period is also shown on Table 1. Unfortunately, the injection facility difficulties in December required that all coal be removed from C while the D furnace maintained its now standard level of coal injection of 139-150 pounds/NTHM.

Monthly average coal injection and furnace coke rates for 1995, on each furnace, are shown on Figures 6 and 7. In addition the use and amount of natural gas that was required through the year is shown in pounds/NTHM.

7.2 FURNACE THERMAL CONDITIONS AND LINING WEAR

Thermal conditions on both furnaces have changed significantly with the use of coal injection compared to natural gas injection. The Thermal Load System is used at Burns Harbor as an indication of the gas flow conditions at the furnace wall. Refractory temperatures and thermal loads increase as the reducing gases formed at the tuyere ascend and move along the refractory lined furnace walls. A loss of central gas flow, indicated by a decrease in permeability, usually causes more gas flow to be diverted to the furnace wall. The loss of central flow may also be indicated by an increase in refractory temperature and thermal loads. Refractory wear is related to gas wall flow, refractory temperature and thermal loads. In general, an increase in refractory wear is expected with significant increases or variations in thermal loads.

Figure 8 shows the monthly average C furnace inwall refractory temperatures for 1995. January was a month of all natural gas injection at a rate of 140 pounds/NTHM. This period is used as the basis for the gas and coal comparative observations. As coal went on the furnace in appreciable amounts, beginning in May, we notice an increase in the inwall temperatures. The C furnace thermal loads during the same periods are in Figure 9 and show increases at all furnace elevations except the bosh and mantle. Figures 10-13 show the D furnace refractory temperatures and thermal load data for the year. Data for November 1994 on D is also included as a reference point. The D furnace operation in November was an all natural gas injection period at a rate of 140 pounds/NTHM. The inwall refractory temperatures and thermal loads have increased on D with the use of coal injection.

The high density stack cooling configuration on C furnace was designed to withstand increased thermal loads associated with coal injection practices. D furnace does not have this cooling configuration. When the thermal loads increased on D we noticed an increased rate of refractory wear several months after the initial coal injection periods. This rate of refractory wear and the use of coal on D furnace is shown in Figure 14. In July, as a result of these measurements, the use of coal on D furnace was limited to a maximum of 150 pounds/NTHM.

Neither the C or D furnace is equipped with burden distribution equipment. This equipment has been demonstrated to have the capability to reduce furnace gas wall flow. However, burden distribution can be improved on a two bell top design by varying the height of the furnace burden material at which coke and ore are dumped into the furnace. This strategy can change the burden profile based on different rebound characteristics of the ore or coke off the furnace wall. When the furnace operating personnel observed higher thermal loads and increased refractory temperatures during the initial coal injection periods in April, burden filling was altered on both furnaces using various filling sequences in an attempt to reduce or stabilize the thermal increases. The trials continued through September. At the completion of this work a detailed analysis of the thermal data results for each furnace and each sequence was completed. The trial results enabled a new filling sequence to be implemented on each furnace.

Operators have been unable to reduce the thermal conditions on either furnace to the natural gas base period. However, we note that the thermal data for C and D furnace in November 1995 show a lessening in the rate of thermal rise. In fact, at several locations there are actual decreases in the values. This was accomplished despite an increase in the overall rate of injected coal.

7.3 COALS USED IN 1995

Five coals were used at the Burns Harbor furnaces in 1995. Sydney, a high volatile coal, was used during the first ten months of operation. Four low volatile coals were used during the remainder of the year. Table 2 shows the coal used, the time period of use and the analysis of each coal.

The primary difference between Sydney coal and the other four is the volatile matter and the carbon. The short period usage of the low volatile coals precludes a detailed analysis of furnace operations with each coal. However, we point out that the record setting coke rate periods on C furnace and the lessening of thermal loads on both furnaces coincide with the use of the low volatile type coals. Tables 3 and 4 show furnace results during the time of each coal usage. The Virginia Pocahontas and Buchanan coal periods were combined since these two coals are very similar and are mined from the same coal seam but at a different location.

8.0 SUMMARY

The year 1995 was a transition for the GCI project. Construction was completed in late 1994 and 1995 was devoted to working out equipment problems and starting coal injection in the blast furnaces. Early 1995 was particularly difficult because of equipment start-up problems and the new experience of coal injection in furnaces that previously had easy-to-use natural gas.

Mid-year was the time for learning how to deal with coal as the only injected fuel. The most dramatic change from natural gas to coal injection is the reduced permeability and, thus, the need for higher blast pressures in order to maintain production levels. The lower permeability furnace also required higher blast moisture levels and modified furnace filling practices for both furnaces.

Increased refractory lining wear in D furnace was a cause for concern in mid-year and, as a result, the coal injection rates were limited to 150 pounds/NTHM. The coal injection rate on C furnace increased steadily through mid-year and reached over 200 pounds/NTHM in September.

The coal used during start-up and through mid-October was the high volatile Sydney from eastern Kentucky. A switch to the low volatile Virginia Pocahontas coal was made in mid-October. Other low volatile coals were used for the remainder of 1995.

Use of low volatile coals made a significant improvement in coke replacement and overall furnace performance. As a result, low volatile Virginia Pocahontas has been selected as the standard for injection at Burns Harbor and all other test coals will be compared to it.

The year ended with coal handling and preparation problems brought on by the severely cold weather in early December. The most serious of the coal handling problems was caused by water condensation on the inside walls of the prepared coal silos. This caused coal to cake on the walls and eventually to block the injectors. The problem has been solved by insulating the coal silos.

The transition from GCI construction to full operation has been completed and the project has moved into Phase III for coal testing. The GCI facility and the blast furnace operation are now prepared to evaluate alternative coals and to make the granular versus pulverized coal comparison.

9.0 REFERENCES

1. D. S. Gathergood, "Coal Injection Into the Blast Furnace", International Iron & Steel Institute Committee on Technology, April 26, 1988.

2. D. S. Gathergood and G. Cooper, "Blast Furnace Injection - Why Granular Coal"? Steel Technology International, 1988.

3. D. Kwasnoski and L. L. Walter, "Blast Furnace Granular Coal Injection", Second Annual Clean Coal Technology Conference, Atlanta, GA, September 1993.

4. D. Kwasnoski and L. L. Walter, "Blast Furnace Granular Coal Injection", Third Annual Coal Technology Conference, Chicago, IL, September 1994.

5. L. L. Walter, R. W. Bouman and D. G. Hill, "Blast Furnace Granular Coal Injection", Fourth Annual Clean Coal Technology Conference, Denver, September 1995.

APPENDIX

CONSTRUCTION ACTIVITIES FOR YEAR 1995

First Quarter

- Six additional air cannons were installed on the conical section of each of the two raw coal silos to prevent intermittent flow to the grinding mills due to coal sticking to the silo walls.

- Vibrating feeders were installed on three of the raw coal chutes feeding the reclaim conveyor in the tunnel under the coal storage pile to prevent coal from sticking and bridging over the chute. The fourth opening was originally provided with a vibrating feeder.

Second Quarter

- The precrusher feed and discharge chute and precrusher by-pass chute were modified to provide a free flow of coal without sticking and plugging. A vibrating bar screen was added upstream of the precrusher.

- A larger actuator was installed on the #7 to #68 conveyor flop gate to prevent the gate from getting stuck when coal accumulates around the edges.

- Modifications were made to the process control system to make the grinding mills easier to operate from the man-machine interface.

- Self cleaning filters were installed on the inlet air supply to the injection air compressors.

Third Quarter

- An extension was installed on the north stack of the car dumper emissions control baghouse to make it suitable for particulate testing in compliance with EPA Method 5.

- An experimental slider joint was installed on #2 product coal screen as a possible solution to the short-lived flexible screen boots. The slider joint was later ruled ineffective and removed.

- Lifting monorails and hoist were installed above the product screens to assist in maintaining the screens.

- Access platforms were installed at various valve and instrumentation locations.

- Permanent maintenance supports were installed for the radial stacker.

- An uninterruptible power supply was installed for critical instrumentation to provide for a safe shutdown in the event of a power supply failure.

- Instrumentation was installed on the product coal screens to sense a malfunction and automatically shut down the grinding circuit.

Fourth Quarter

- Additional nitrogen was added to the product coal screens to maintain a neutral pressure inside the screen.
- Coal was taken off of the furnaces, product coal silos were emptied, built up coal on the silo walls was removed and vacuumed out. Three inch thick insulation was installed on the exterior surface of the silo to prevent condensation from occurring on the silo interior walls.
- Chrome-carbide wear plates were installed in the mill windbox to replace the abrasive resistant plates supplied with the mill.
- Repairs were made to the leaking upper construction joint on #2 baghouse.
- Process control modifications were installed to allow the operator to select from a menu which will automatically set up the proper mill operating parameters for changes in coal properties.
- Repairs were made to the refractory lining in the heater combustion chamber.

TABLE 1

BURNS HARBOR BLAST FURNACE RESULTS WITH COAL INJECTION

	D Furnace Nov-94	D Furnace Apr-95	C Furnace Jul-95	C Furnace Sep-95	C Furnace Nov-95
Natural Gas Rate, lbs/NTHM	140	-	-	-	-
Injected Coal Rate, lbs/NTHM	-	150	150	210	210
Furnace Coke Rate, lbs/NTHM	743	798	821	745	694
Blast Conditions:					
Reported Wind, SCFMx100	1710	1740	1650	1640	1630
Oxygen Enrichment, %	+4.0	+2.4	+5.5	+5.2	+4.6
Moisture, Grs/SCF	6.0	16.0	18.0	8.5	7.6
Blast Pressure, PSI	38.0	38.6	39.3	38.9	39.4
Flame Temperature, F	3685	3793	4012	4062	3996
Top Temperature, F	240	252	223	213	210
Hot Metal Chemistry:					
% Silicon; Mean, S.D.*	.52 , .165	.56 , .136	.59 , .133	.62 , .104	.45 , .087
% Sulfur; Mean, S.D.	.040 , .017	.041 , .015	.043 , .021	.035 , .01	.041 , .013
Slag %:					
SiO2	37.74	36.31	36.17	36.57	37.26
Al2O3	9.64	9.70	9.74	9.50	8.73
CaO	36.50	38.21	38.17	37.71	38.17
MgO	12.20	12.08	12.28	12.31	12.28
Sulfur	.87	1.09	1.28	1.19	1.25
Slag Volume, lbs/NTHM	393	437	426	437	428
Furnace Permeability	1.52	1.50	1.32	1.30	1.26
Top Gas Analysis: **					
CO%	21.44	22.59	25.26	24.20	22.95
CO2%	21.04	21.60	22.70	23.25	23.14
H2%	7.33	3.05	3.54	3.13	3.15
BTU/CF	92.83	82.62	92.78	88.06	84.09

* S.D. = The monthly standard deviation

** Spot checks for H2S have been in the range of 7 to 74 ppm

TABLE 2

Coals Used at Burns Harbor in 1995

Coal Dates Used	Sydney Jan - Oct	Va. Pocahontas Oct 13-Nov 8	Buchanan Nov 9-Nov 26	Falcon Energy Nov 27-Dec 20	Maple Meadow Dec 21-Dec 31
Vol. Matter, %	36.00	18.00	19.55	16.50	18.40
C(%)	78.0	87.0	87.0	86.0	85.3
O(%)	7.00	1.40	1.52	2.20	3.07
H2(%)	5.4	4.4	4.2	4.2	4.0
N2(%)	1.50	1.12	1.21	1.30	1.5
Cl(%)	.200	.200	.220	.050	.110
Ash, %	7.50	5.30	5.16	5.75	5.50
H2O(inher.), %	3.0	1.5	1.5	1.5	1.4
Sulfur, %	.63	.80	.75	.58	.77
GHV, BTU/lb	13900	14900	15029	14550	14775
HGI	46	100	101	94	90
Phos. (P2O5),%	.010	.004	.005	.020	.022
Alkali, % (Na2O,K2O)	.03, .21	.07 , .09	.05 , .08	.07, .05	.04, .13
SiO2 (%)	4.15	2.11	1.79	2.12	2.77
Al2O3 (%)	2.45	1.34	1.16	1.47	1.81
CaO (%)	.12	.35	.62	.60	.12
MgO (%)	.06	.09	.10	.14	.05

TABLE 3

Furnace Results with Coals Used at Burns Harbor in 1995
Burns Harbor D Furnace

	Jan-95	9/10-10/10	10/19-11/24	11/26-12/20
	Natural Gas	Sydney	Buch/Poco	Falcon Energy
Natural Gas Rate, lbs/NTHM	141	-	-	61
Injected Coal Rate, lbs/NTHM	-	212	153	129
Furnace Coke Rate, lbs/NTHM	741	728	767	713
Blast Conditions:				
Reported Wind, SCFMx100	1737	1609	1574	1646
Oxygen Enrichment, %	2.9	4.5	3.4	3.7
Moisture, Grs/SCF	3.7	7.9	13.9	5.7
Blast Pressure, PSI	38.9	39.3	38.8	38.7
Flame Temperature, F	3544	4283	4014	3821
Top Temperature, F	262	214	224	224
Hot Metal Chemistry:				
% Silicon; Mean, S.D.	.44 , .091	.62 , .070	.58 , .057	.48 , .099
% Sulfur; Mean, S.D.	.043 , .012	.032 , .005	.037 , .008	.038 , .011
Slag %:				
SiO2	38.02	36.62	37.31	37.88
Al2O3	8.82	9.60	8.87	8.49
CaO	37.28	37.80	37.91	37.73
MgO	12.02	12.15	12.18	12.52
Sulfur	.85	1.21	1.31	1.21
Slag Volume, lbs/NTHM	394	436	427	427
Furnace Permeability	1.57	1.23	1.26	1.36
Top Gas Analysis:				
CO%	20.82	24.11	22.89	22.54
CO2%	20.70	23.21	22.84	22.58
H2%	6.63	3.10	2.70	4.44
BTU/CF	88.57	87.66	82.44	86.96

TABLE 4

Furnace Results with Coals Used at Burns Harbor in 1995
Burns Harbor D Furnace

	Nov-94 Natural Gas	9/10-10/10 Sydney	10/17-11/24 Buch/Poco	11/26-12/19 Falcon Energy	12/20-12/31 Maple Meadow
Natural Gas Rate, lbs/NTHM	140	-	-	-	-
Injected Coal Rate, lbs/NTHM	-	149	153	128	152
Furnace Coke Rate, lbs/NTHM	743	815	767	787	762
Blast Conditions:					
Reported Wind, SCFMx100	1710	1606	1574	1546	1519
Oxygen Enrichment, %	4	4.7	3.4	2.5	2.4
Moisture, Grs/SCF	6	13.5	13.9	15.4	16.7
Blast Pressure, PSI	38	38.5	38.8	38.9	38.8
Flame Temperature, F	3685	4075	4014	3909	3876
Top Temperature, F	240	219	224	211	232
Hot Metal Chemistry:					
% Silicon; Mean, S.D.	.52 , .165	.64 , .100	.58 , .057	.56 , .088	.55 , .071
% Sulfur; Mean, S.D.	.040 , .017	.039 , .014	.037 , .008	.036 , .008	.041 , .019
Slag %:					
SiO2	37.74	36.62	36.81	37.64	37.79
Al2O3	9.64	9.63	9.07	8.69	8.64
CaO	36.50	37.72	38.15	37.65	37.68
MgO	12.20	12.12	12.31	12.61	12.52
Sulfur	.87	1.22	1.31	1.28	1.28
Slag Volume, lbs/NTHM	393	442	427	430	431
Furnace Permeability	1.52	1.28	1.26	1.27	1.19
Top Gas Analysis:					
CO%	21.44	24.79	22.89	22.50	22.62
CO2%	21.04	23.07	22.84	22.85	22.72
H2%	7.33	3.09	2.70	2.69	2.66
BTU/CF	92.83	89.80	82.44	81.12	81.42

FIGURE 1

PROJECT MILESTONE DATES

Begin Detailed Construction Engineering	April 1, 1993
Received State Environmental Construction Permit	August 4, 1993
Start Construction	August 31, 1993
90% Design Review	January 12, 1994
50% Construction Review	June 1994
100% Construction Review	December 1994
Begin Coal Testing Demonstration	November 1995
Complete Coal Testing Demonstration	July 1998

FIGURE 2

THE BLAST FURNACE COMPLEX

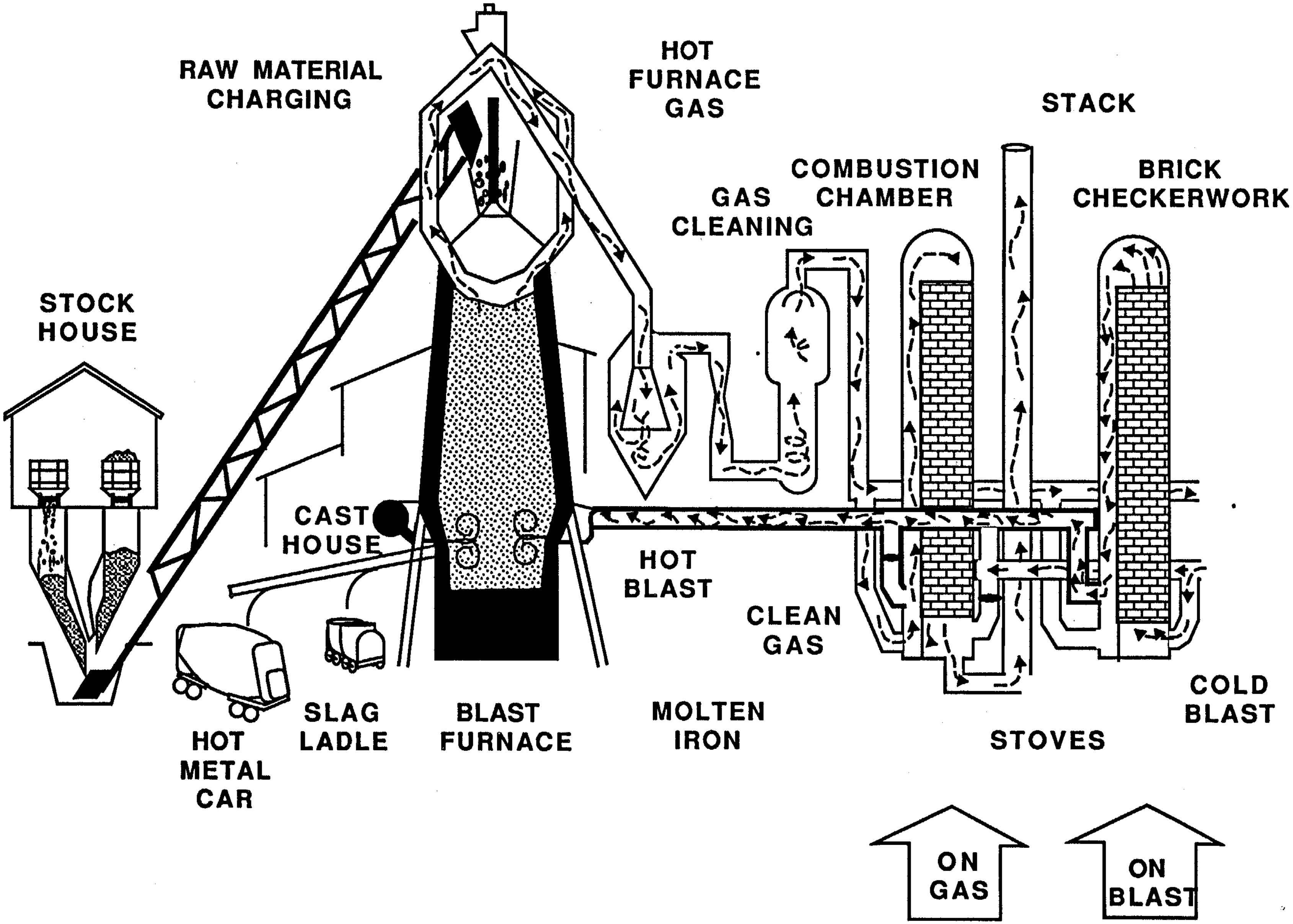


FIGURE 3

ZONES IN THE BLAST FURNACE

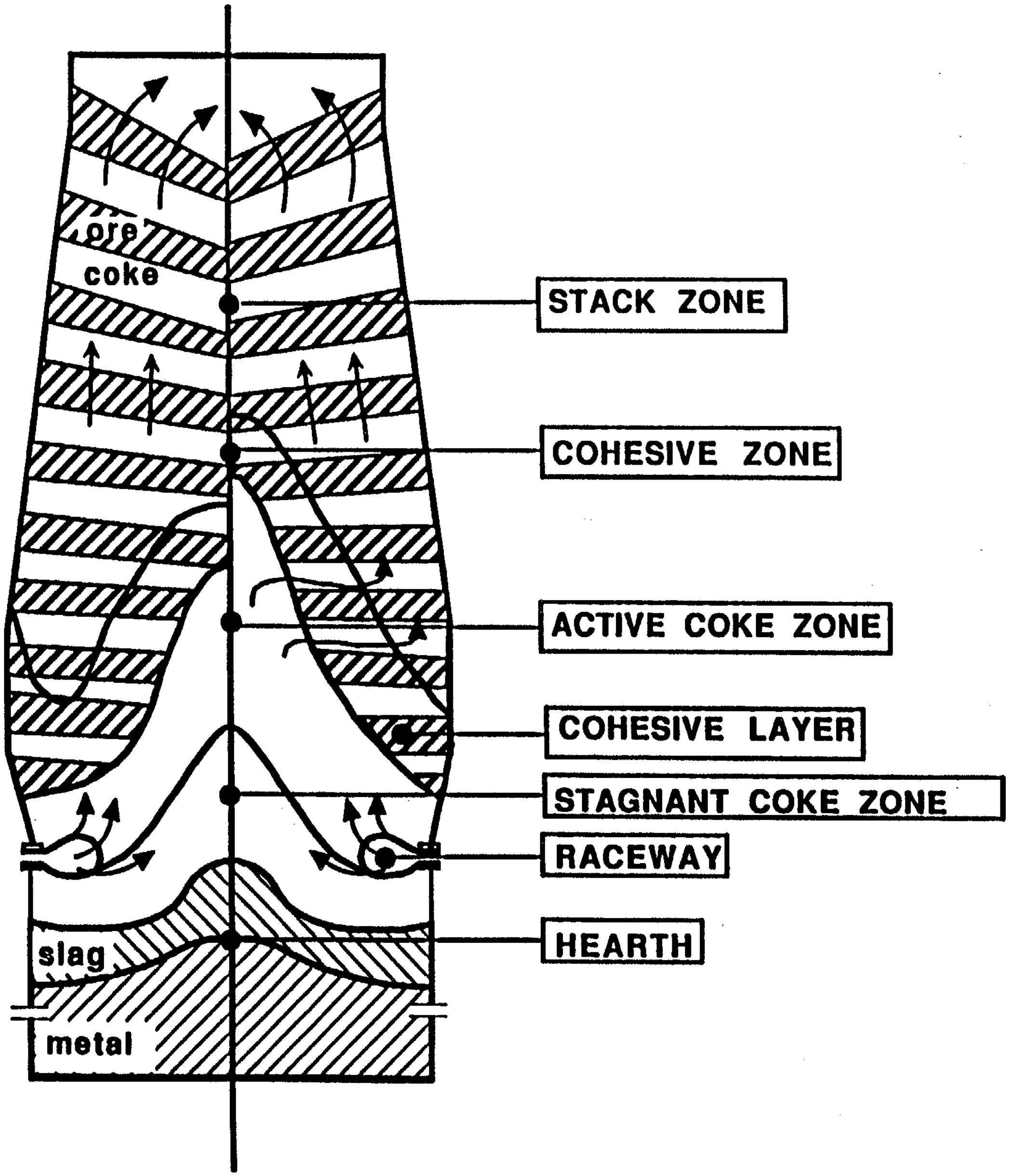


FIGURE 4
APPLICATION OF COAL INJECTION

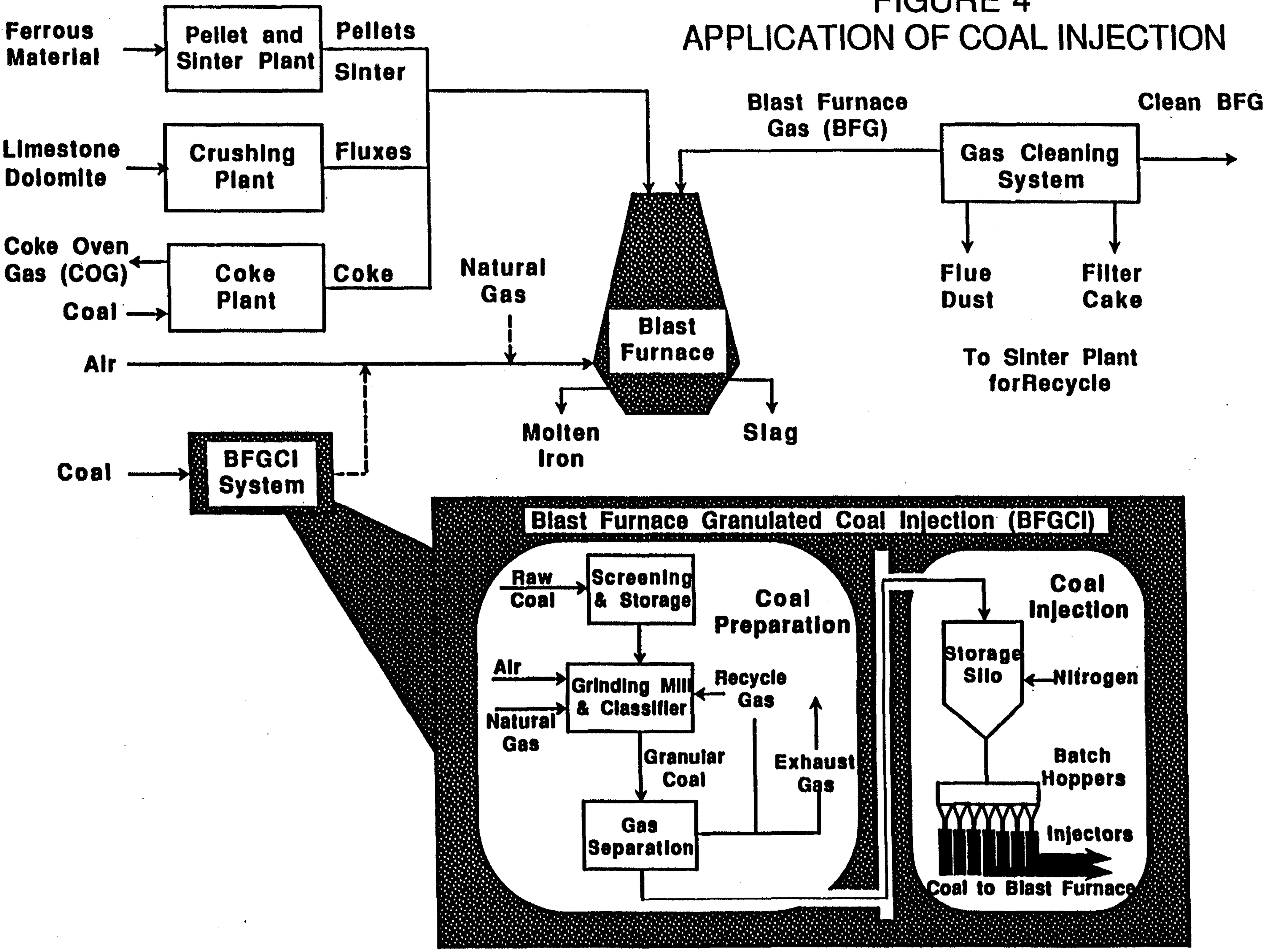


FIGURE 5. COAL PREPARATION AND INJECTION FACILITIES
BURNS HARBOR PLANT

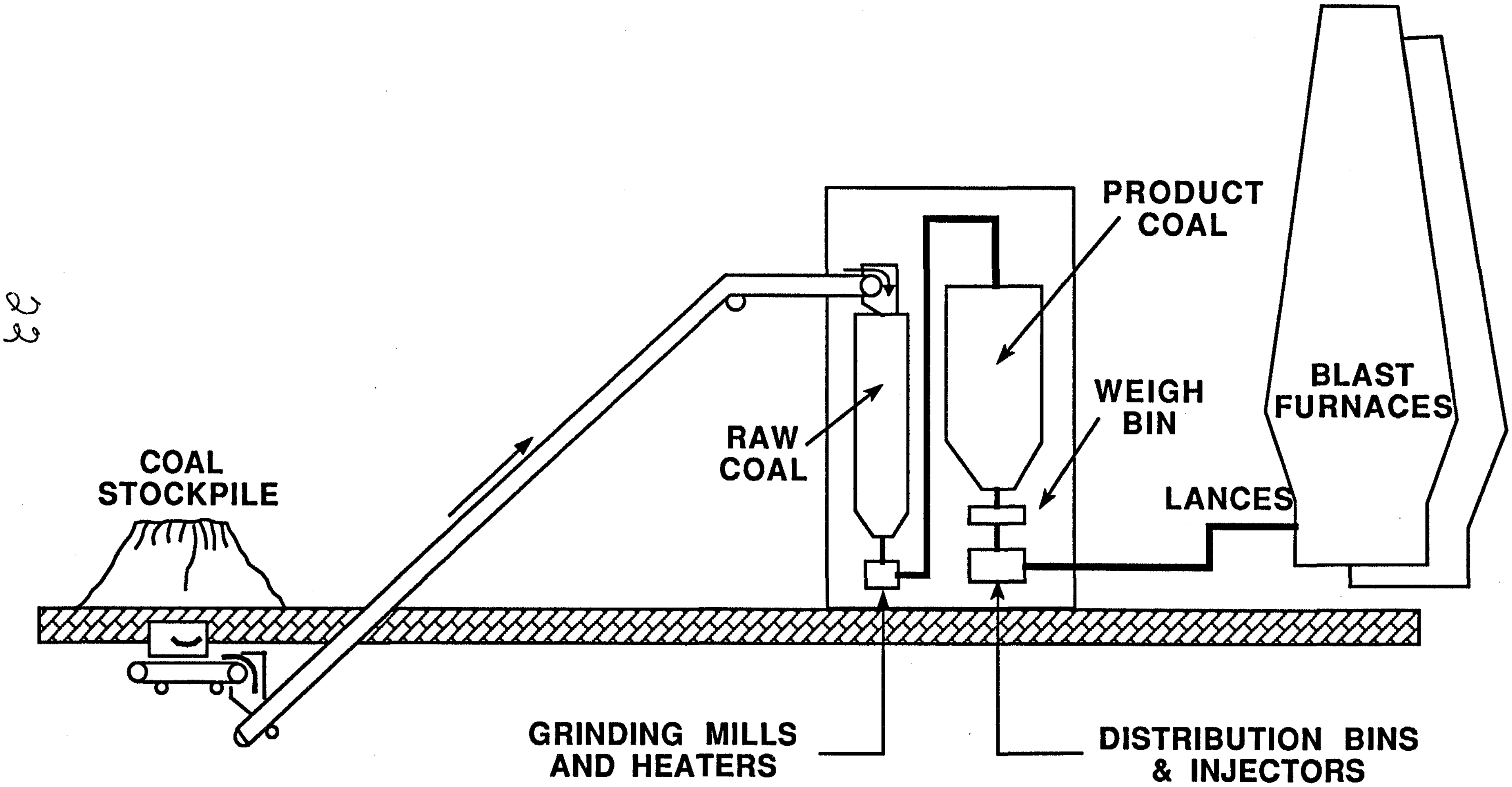


FIGURE 6

BURNS HARBOR C FURNACE - COAL INJECTION & FURNACE COKE RATE

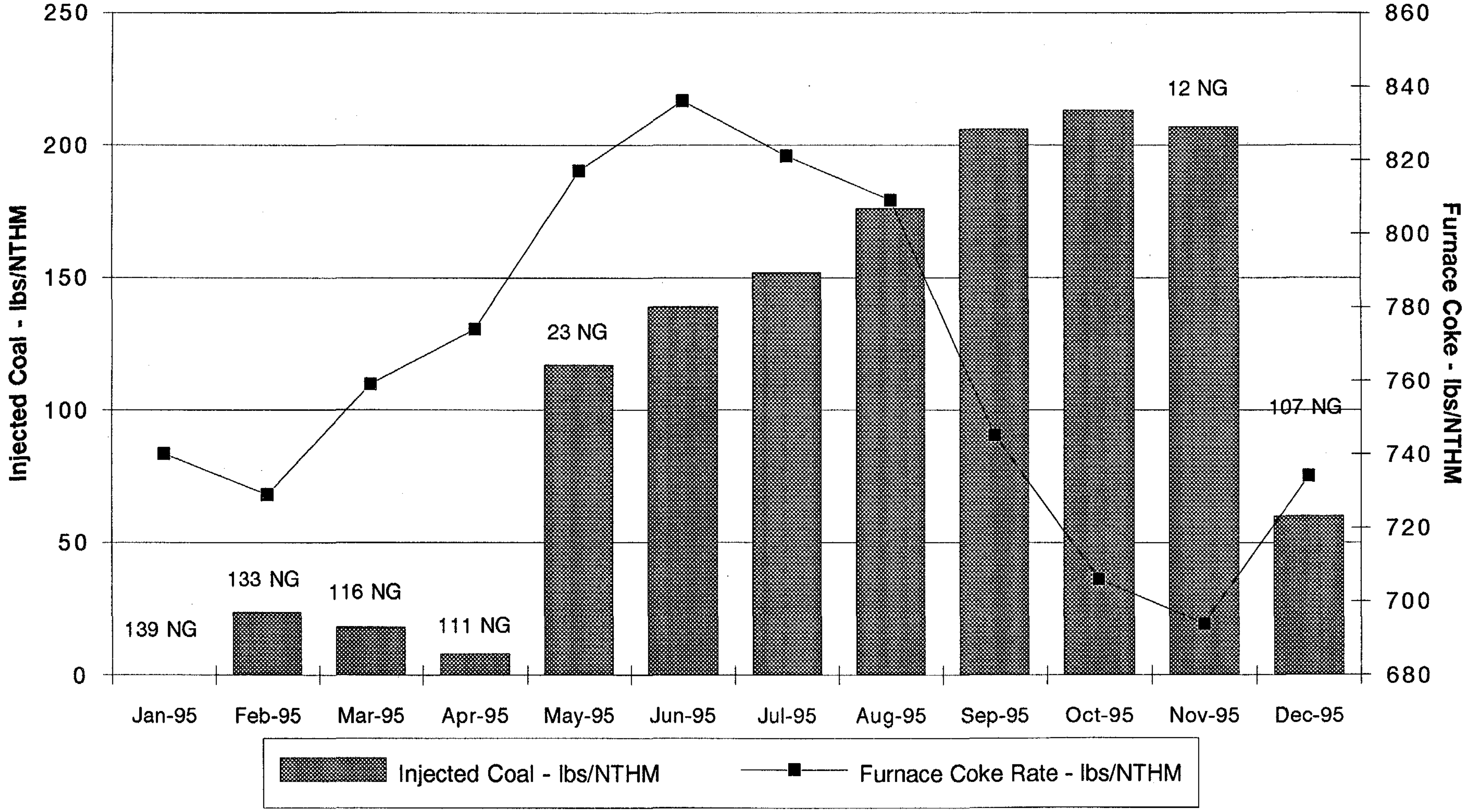


FIGURE 7

BURNS HARBOR D FURNACE - COAL INJECTION & FURNACE COKE RATE

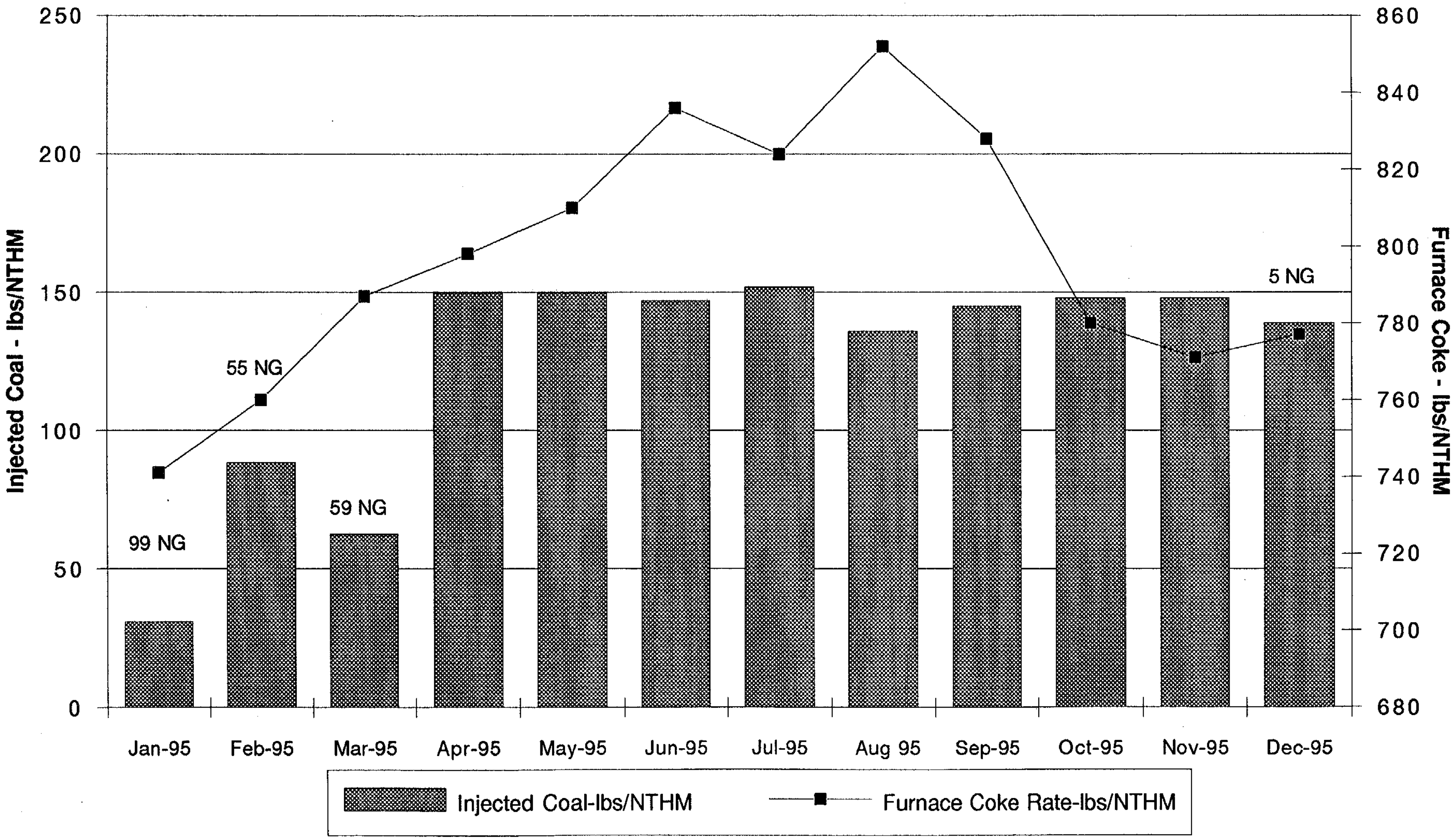


FIGURE 8

BURNS HARBOR C FURNACE - INWALL REFRACTORY TEMPERATURE

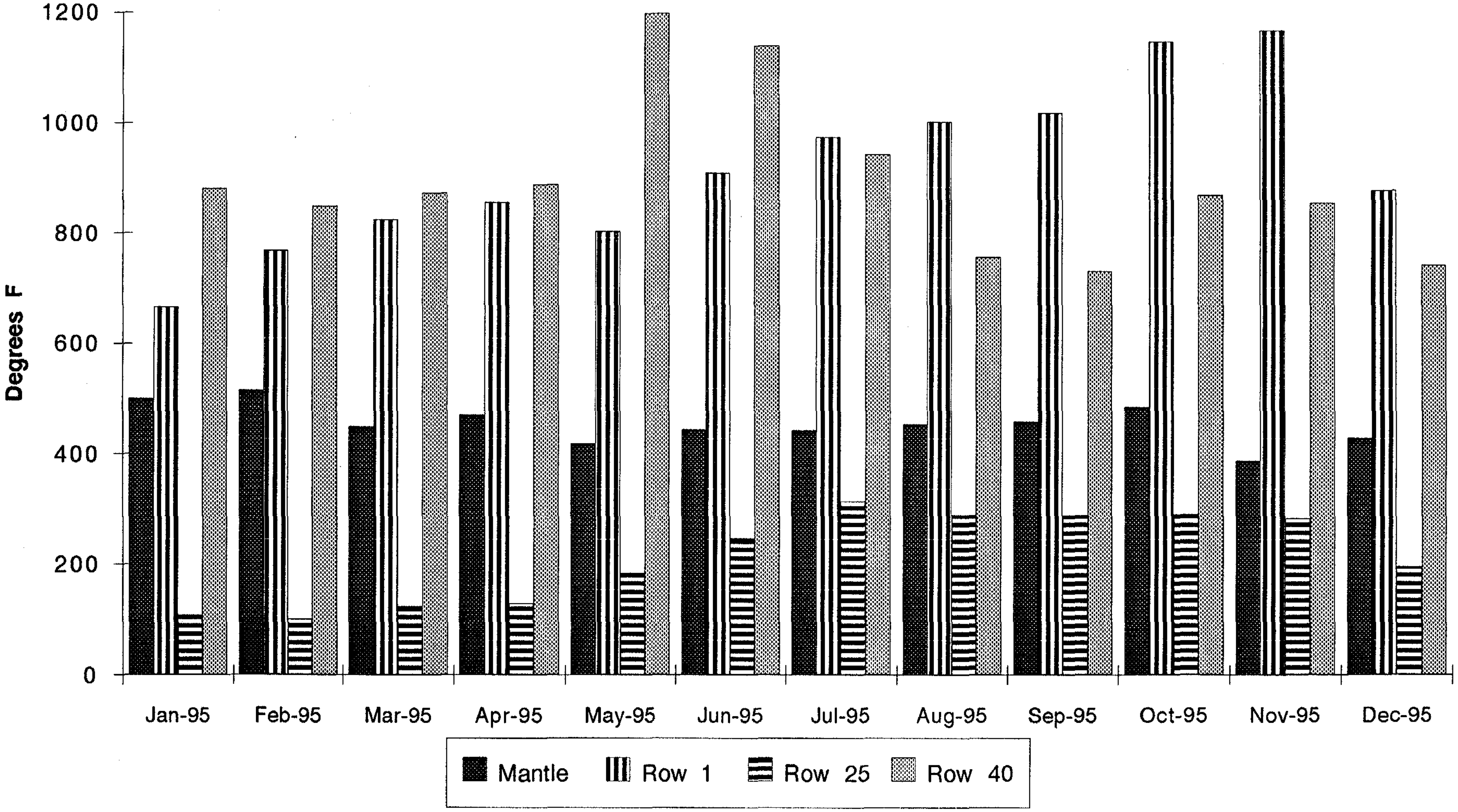


FIGURE 9

BURNS HARBOR C FURNACE THERMAL LOADS

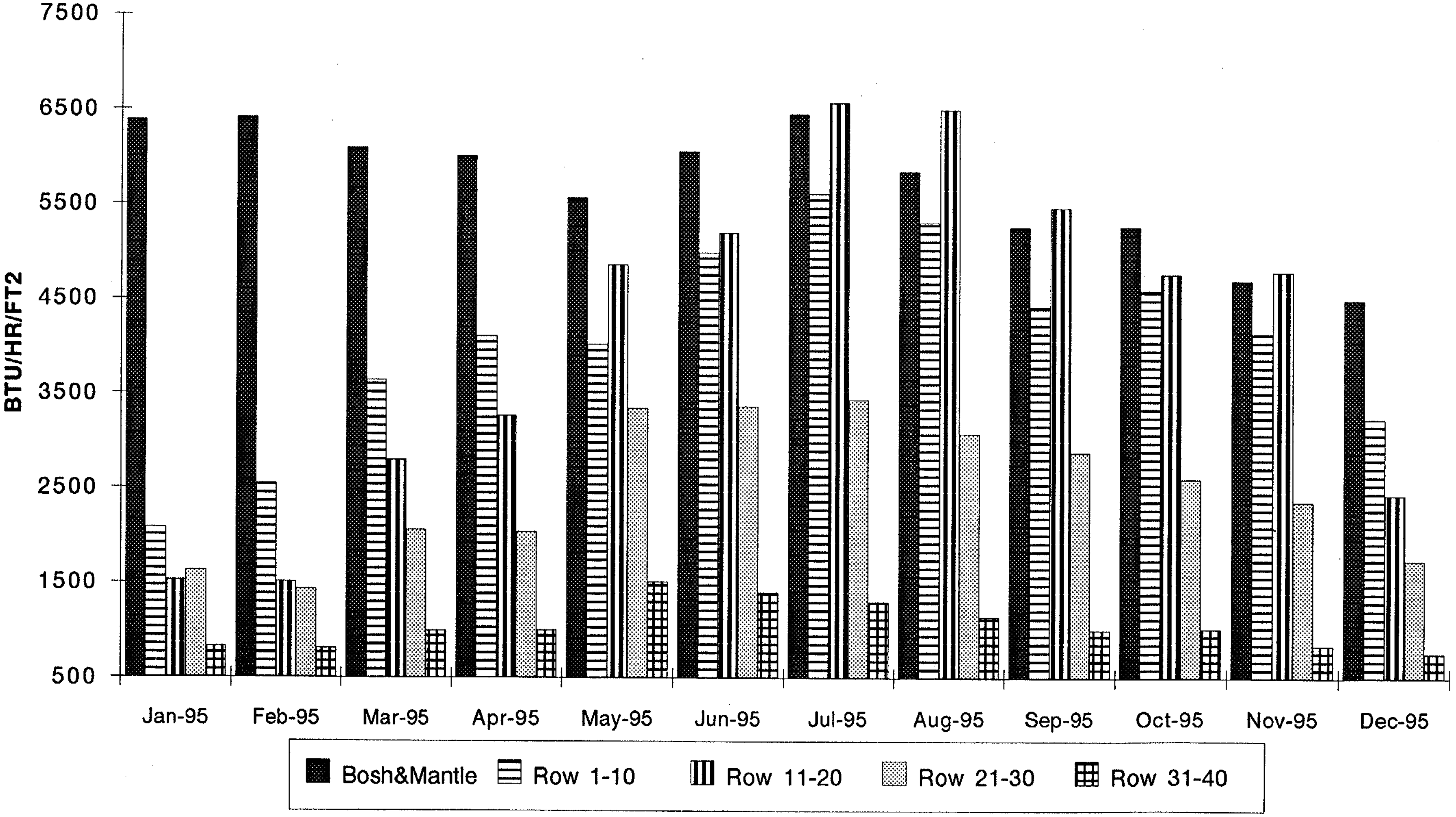


FIGURE 10

BURNS HARBOR D FURNACE - INWALL REFRACTORY TEMPERATURE

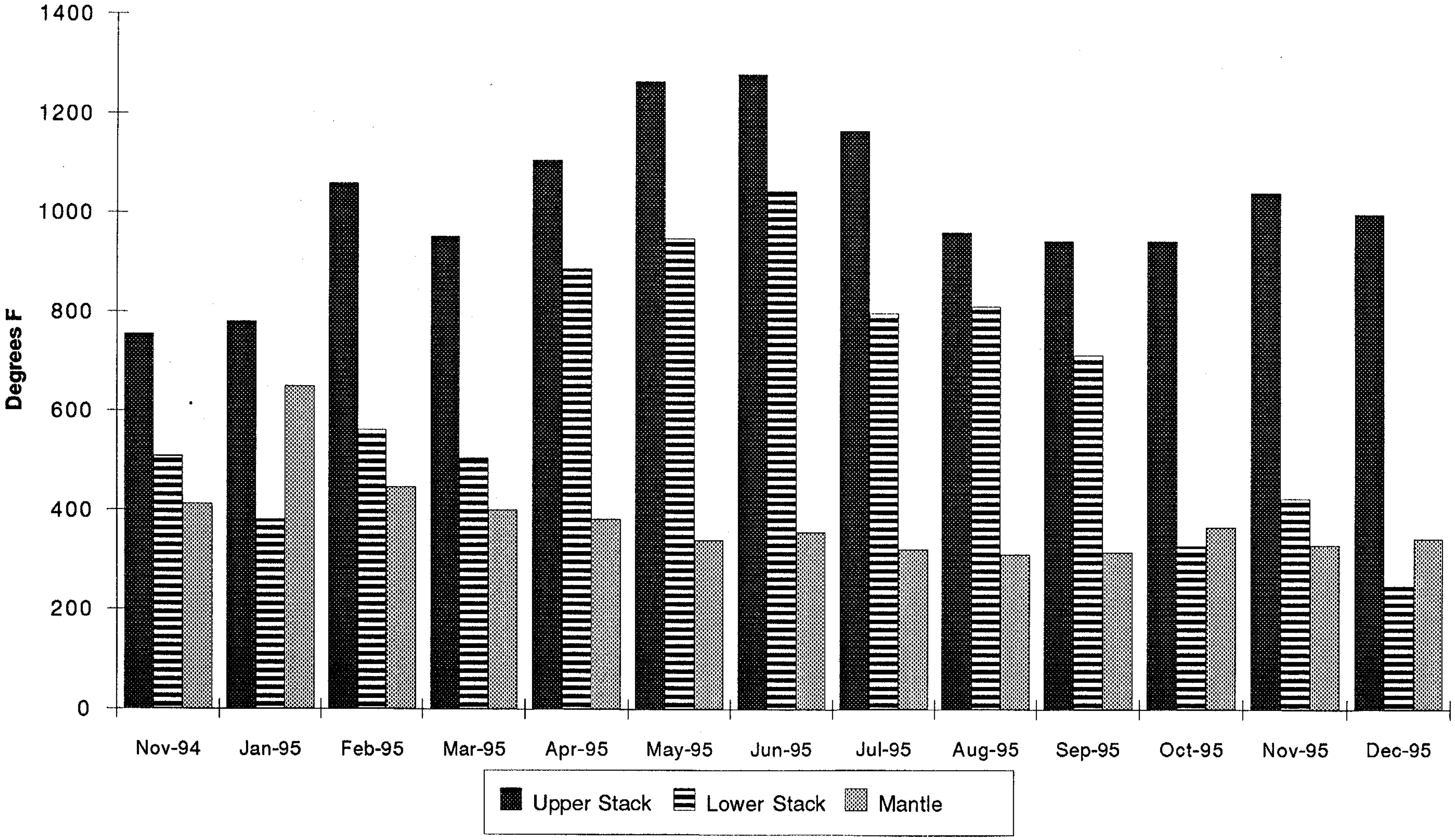


FIGURE 11

BURNS HARBOR D FURNACE THERMAL LOADS

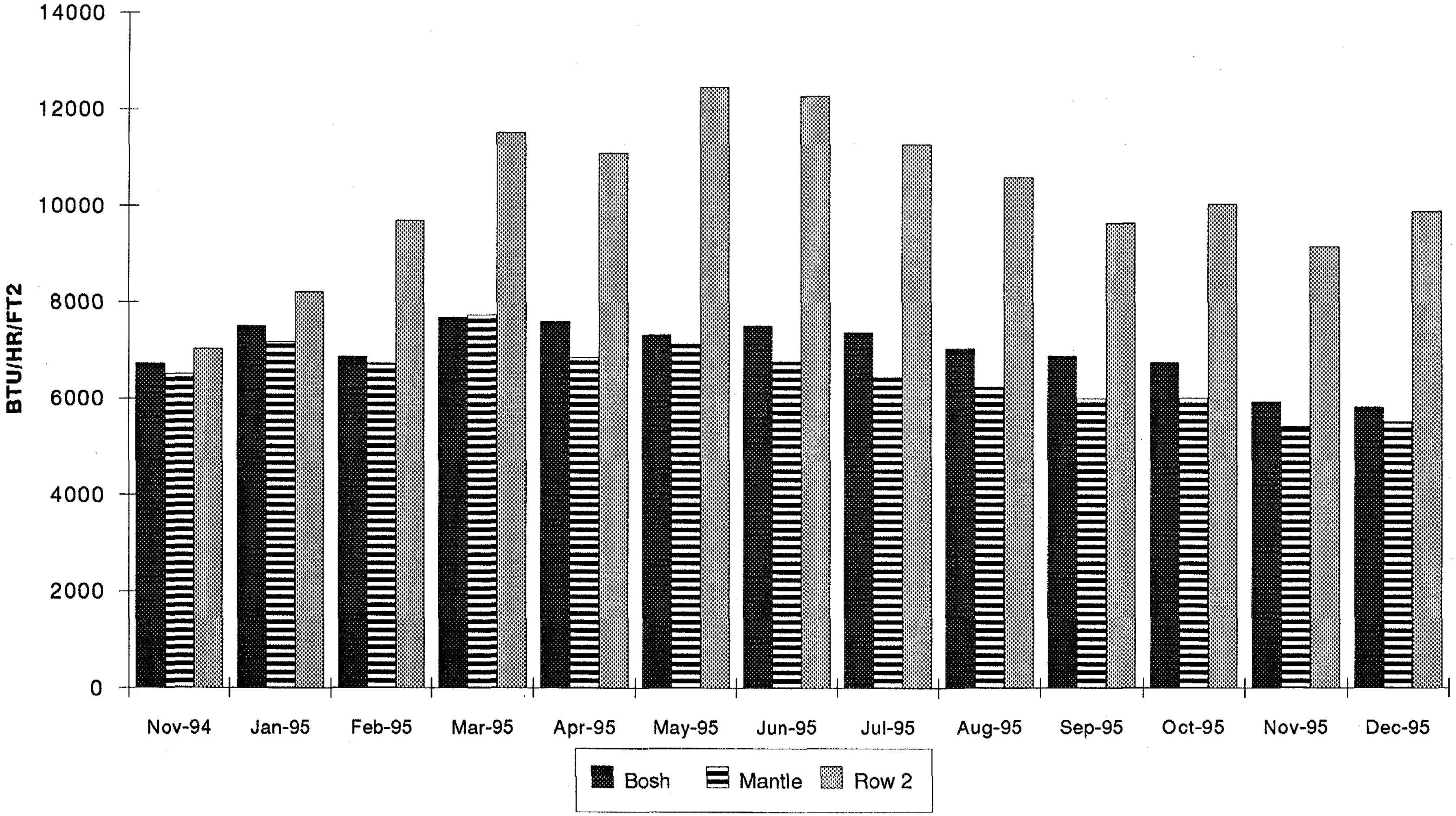


FIGURE 12

BURNS HARBOR D FURNACE THERMAL LOADS

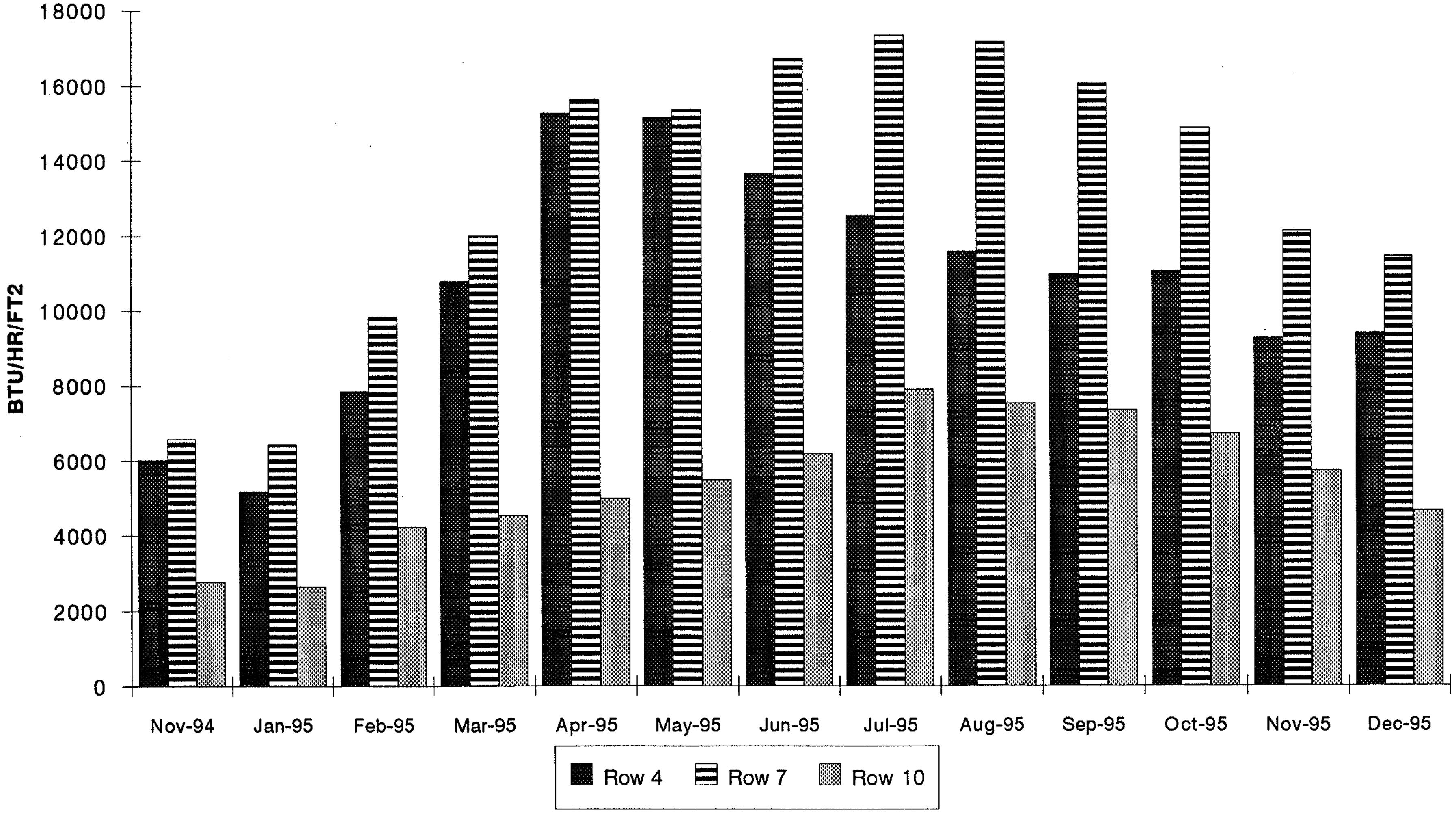
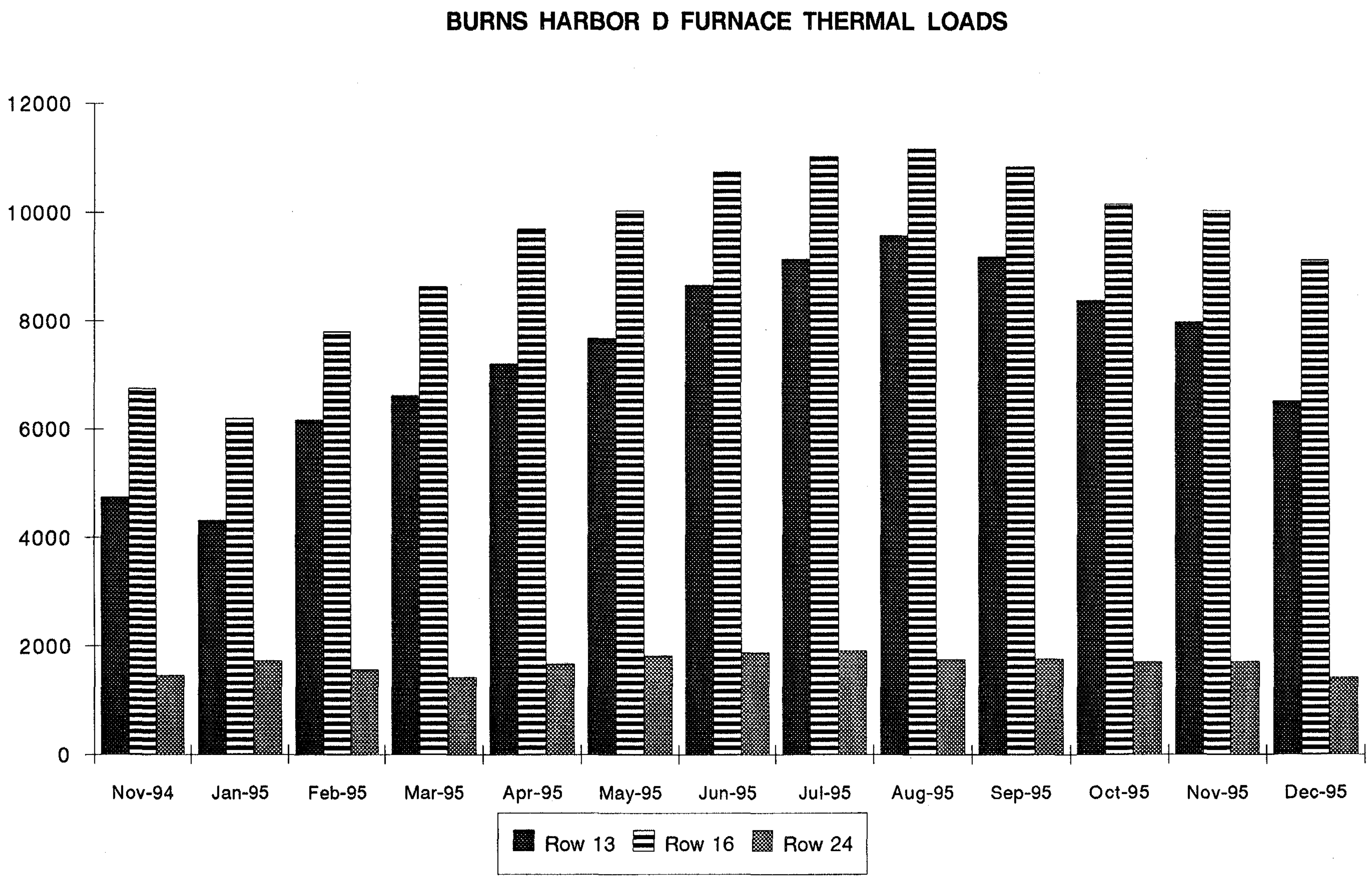
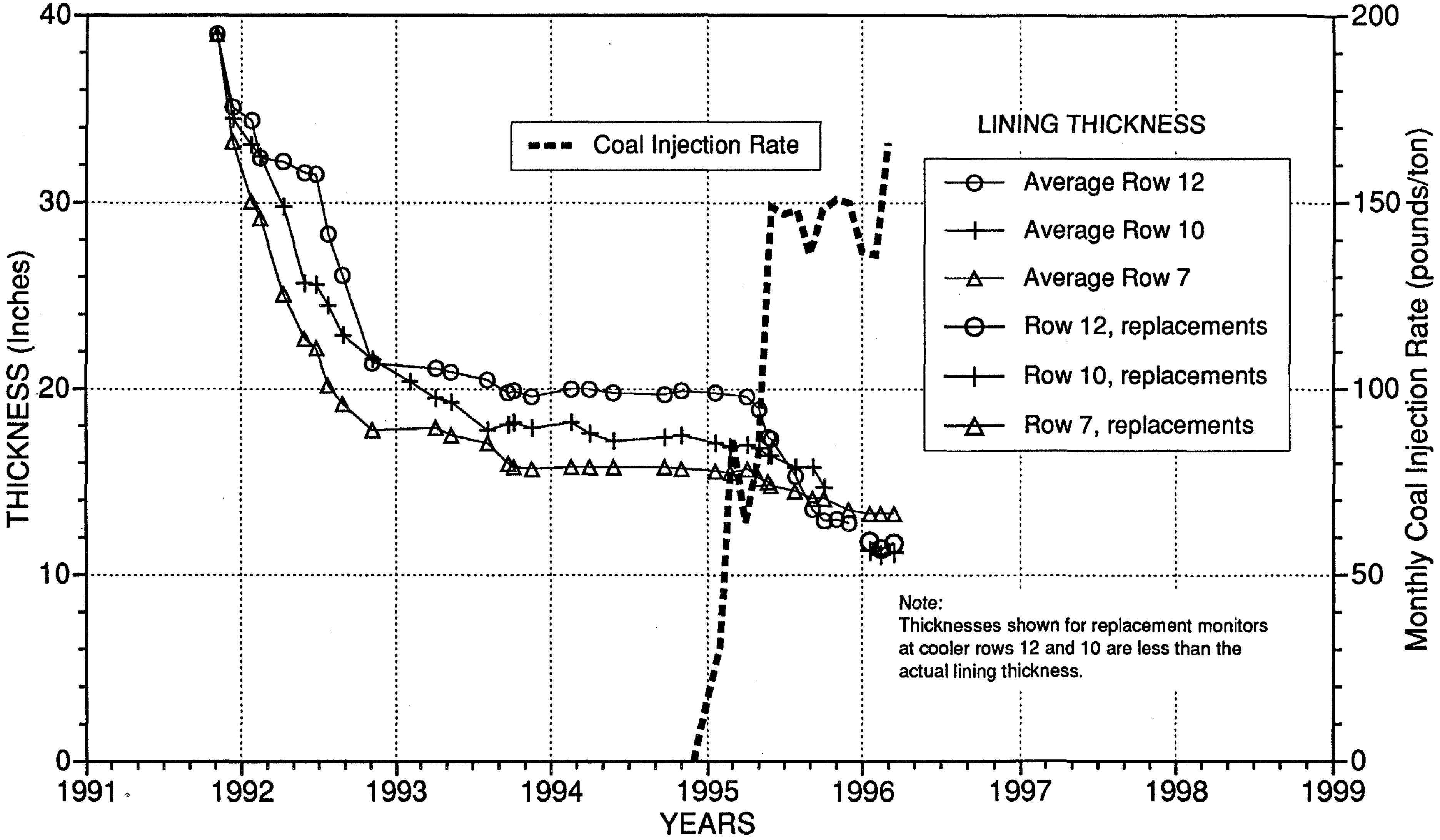


FIGURE 13



BURNS HARBOR D FURNACE THERMAL LOADS

Figure 14. BURNS HARBOR "D" FURNACE — 5TH CAMPAIGN AVERAGE STACK LINING THICKNESS MEASUREMENTS



Date Blown In: 11/4/91
Date of Last Measurement: 3/14/96
RAS/JCM