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DOE/MC/27362 -- 5690
(DE97005416)

Blast Furnace Granular Coal Injection Project

Annual Report
January 1 - December 31, 1996

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

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

By
Bethlehem Steel Corporation
Bethlehem, Pennsylvania

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1.0 INTRODUCTION

This 1996 annual report describes the Blast Furnace Granular Coal Injection project being implemented at the Burns Harbor Plant of Bethlehem Steel Corporation. 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 use the British Steel technology[1,2] for granular coal injection in blast furnaces. The project is to assess a broad range of technical issues associated with the use of coal for injection into blast furnaces. To achieve the program objectives, the project is divided into the following three Phases:

Phase I	-	Design
Phase II	-	Construction and Start-Up
Phase III	-	Operation

Preliminary Design (Phase I) began in 1991 with detailed design commencing in 1993. Construction at the Burns Harbor Plant (Phase II) began in August 1993 and was completed at the end of 1994. The facility start-up was carried out from January to October, 1995. The demonstration test program (Phase III) began in November 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 previously 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.

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, 1995 and 1996 Clean Coal Technology Conferences.[3,4,5,6]

3.0 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.

4.0 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.

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 furnace silos in January 1996. This work greatly improved the product coal flow to the injectors and full operation of both mills and full utilization of the system on both furnaces began in mid-January 1996.

A brief description of the facility modifications made during 1996 is in the Appendix.

5.0 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. During 1995 a smooth transition from natural gas to coal was accomplished even while major modifications were made to the coal preparation facility. By mid-1995 the coal preparation and delivery systems were operating as designed. The injection rate on C furnace was increased through the summer months and was over 200 lbs/ton for September, October and November. The injection rate on D furnace was kept in the range of 145-150 lbs/ton during the second half of 1995. The facility started up with high volatile coal but during the latter part of 1995 low volatile coal was successfully used; five different low volatile coals were evaluated. The experience with the low volatile coals led to the exclusive use of low volatile coal during 1996. Successful operating practices were also developed during 1996 in order to reach higher levels of coal injection and lower coke rates than during the previous year.

Much progress was made during the year on both C and D furnace, particularly with respect to the amount of coal injected per ton of hot metal and the resulting furnace coke rate. Figure 2 shows the yearly average coal and coke usage for C furnace in 1995 and the monthly increases during 1996. The "54 NG" in 1995 indicates that 54 pounds/NTHM of natural gas was injected during the year. Slightly more than 100 pounds/NTHM of coal was injected on C furnace in 1995 with a coke rate of 770 pounds of coke/NTHM. The chart shows steady increases in coal and dramatic decreases in the coke rate throughout 1996. The keys to this progress were development of successful operating practices and the use of low volatile coal. Coke rates were sustained on C at levels well below 700 pounds/NTHM. Figure 3 shows much the same result on D furnace but at lower levels of injected coal.

Tables 1A and 1B show the C furnace monthly operating data for 1996. Tables 2A and 2B show the monthly data for D furnace.

The sustained use of granulated low volatile coal during 1996 for both furnaces is discussed in the following as well as the operating practices developed during the year. In addition, coal/coke replacement values, furnace refractory temperatures, thermal loads and refractory wear during the period are reviewed.

5.1 FURNACE OPERATING CONDITIONS

The C and D blast furnaces at Bethlehem's Burns Harbor Plant 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 and 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 two bell IHI design, is the same on both furnaces. This top has rotational distribution capability but it has limited capability for changing the radial distribution of the raw materials. 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, however, the furnace stack region on C furnace has closely spaced cooling plates. The stack cooling plates on the D furnace are not as closely spaced. The heavily cooled C furnace was specifically designed for the rigors of coal injection and to provide increased production capability compared to D furnace.

In December 1995, severe cold weather caused coal handling and preparation problems that were not experienced during the milder months of the year. The most severe problem was due to moisture condensing on the inside walls of the prepared coal silos. As a result, coal injection on C furnace was stopped in mid-December.

The C furnace operation returned to normal on January 5, 1996, when natural gas, used during December when alterations were being made to the product coal silos, was, replaced with granulated coal. The coal rate was quickly increased to approximately 250 pounds/NTHM. The ensuing three months of the period were consistent and stable. Coke rates remained well below 700 pounds/NTHM despite the steady reduction in the sinter portion of the furnace burden. Sinter was reduced on both furnaces during February and March and put to stock in anticipation of a sinter plant repair outage.

The D furnace operation remained consistent throughout the first quarter except for eight days in mid-January when the product coal silos were insulated and gas and coal were coinjected. Coal rates were increased during each successive month and coke rates were reduced.

The reliable operation of the coal preparation and injection equipment during the second quarter of the year allowed incremental increases in the injected coal rate on both furnaces. More importantly, operator confidence in the coal system led to coke rate reductions on the furnaces to new low levels. Major operating conditions remained consistent. The largest change that occurred was an increase in burden sinter percentage when the sinter plant repair was completed.

The coal rate on C reached 272 pounds/NTHM in June with a record low coke rate of 660 pounds/NTHM. The D furnace operation was consistent during this time. Injected coal rates were maintained at 185-198 pounds/NTHM and coke rates were reduced. The June coke rate of 712 pounds/NTHM on D furnace was also a record low.

The D furnace operation was characterized by increased hot metal production. Production increased from 6510 NTHM/day in April to 6772 NTHM/day for June. This was accomplished by increased wind volume in June and slight increases in oxygen enrichment.

The coal injection rate on the C furnace remained relatively constant for each month during the third quarter. The average monthly injection rate ranged from 269 - 274 pounds/NTHM. The furnace coke rate declined each month during the quarter, primarily due to an increase in hot blast temperature from 2074° F in July to 2090° F in September. On D furnace the injected coal rates increased slightly each month. In August and September the coal rate for D exceeded 200 pounds/NTHM for the first time since the coal injection facility start-up. The furnace coke rate was reduced as the coal was added.

Major operating conditions, on a monthly average basis, remained consistent for each furnace during the third quarter. However, the monthly average furnace delay time was high during July and September on both furnaces. This is shown on the summary of operations, Tables 1B and 2B. The average delay time on C furnace through the first six months of the year averaged 42 minutes; on the D furnace the average was 55 minutes. In July and September the delay rates on C were 106 and 75 minutes, respectively. On D furnace the delay rate in September was 79 minutes. In addition, the frequency of unscheduled delays was greater than normal on both furnaces during these months. Furnace delays are noted as the average amount of time that the furnace is not operating during the month. A major contributing factor to the increased delay time and frequency, particularly in September, was the large number of tuyere failures on both furnaces. In September, twenty-one tuyeres failed on C and seventeen tuyeres failed on D furnace.

The coal injection rate on C furnace during October and November was stable at 264 and 261 pounds/NTHM. The furnace coke rate was also constant at 661 and 665 pounds/NTHM, respectively. In December the coal rate increased to 274 pounds/NTHM and the coke rate increased slightly to 668 pounds/NTHM. The major furnace operating variables were relatively constant during the fourth quarter.

The monthly average coal rate on D furnace, previously about 200 pounds/NTHM, decreased during November and December to 192 and 181 pounds/NTHM. However, the decrease was due to the removal of all coal from the furnace on November 30 - December 3 due to a furnace outage that was unrelated to coal injection. With the return to normal operation, the coal rate was approximately 200 pounds/NTHM. Average operating conditions on D during the quarter, disregarding the four day cessation of coal injection, were reasonably constant.

Although the major operating variables on C furnace were constant, the permeability factor, an indicator of burden conditions and operational stability, declined steadily during the period to a yearly low value of 1.13. Conversely, the permeability on D furnace increased during the same period to yearly high values. Figure 4 shows a plot of the average monthly permeability value for each furnace in 1996.

Significant and notable changes were made to the blast furnace operation during the fourth quarter reporting period. The changes made and the affect on the furnaces are as follows:

<u>Coke Size</u>

On November 5, the size of coke charged to the furnaces was increased. Larger screen decks were installed at the coke oven screening station. Furnace coke size was increased from to +¾ inch to +1-¼ inch. The nut coke size was changed from ¾ by ¼ inches to 1-¼ by ½ inches. This change was made to increase the permeability of the burden column on both furnaces. The larger size coke in the coke layer portion of the charge should decrease the resistance of the burden to the reducing gas flow through the furnace. Operationally, an increase in permeability results in a decrease in blast pressure at a constant wind rate and provides a more stable operation.

Permeability is calculated from the blast rate, blast pressure and top pressure. The equation is:

Permeability = $(\text{Furnace Wind Rate})^2 / [(\text{Furnace Blast Pressure})^2 - (\text{Furnace Top Pressure})^2]$

The larger the permeability number the better the furnace burden movement and the better the reducing gas flow through the furnace column.

The C furnace permeability value, after steadily increasing from February to August, declined during the last quarter despite the increase in coke size.

Confounding this analysis of coke size and it's affect on permeability is the fact that the permeability on D furnace has increased substantially during the same period as the decline on C. The values on D during the fourth quarter represent yearly high values while on C we observe a yearly low value in December.

Coke Oven Coal Mix Change

On November 18 a major coal blend change was made at the coke plant. The coke produced from this change was on both furnaces during the entire month of December. The monthly average coke stability remained the same in December with the new blend compared to the old blend during October. Based on the stability and coke chemistry data, it appears that this coal change had no affect on furnace performance during the quarter.

In addition to these changes to the furnace operation, other operating practices evolved during the year. Table 3 shows the C furnace operating progression from natural gas in January 1995 to the use of high volatile coal in September 1995 and finally to the use of low volatile coal in July 1996. The moisture addition and oxygen enrichment levels have been highlighted to demonstrate the changes that were made over time to enhance the operation. Oxygen use increased from 24.4% with natural gas to 26.2% with high volatile coal and settled at 26.6% with low volatile coal. Steam additions also increased from 3.7 grs/SCF with gas to 16.3 grs/SCF with low volatile coal.

The success of these operating changes during 1996 are evident in the furnace coke rates shown in the table. The coke rate has been reduced dramatically compared to the experience with natural gas and from the use of high volatile coal.

5.2 FURNACE SULFUR BALANCE

Blast furnace slag chemistry and volume is a determining factor in the final sulfur content in the hot metal. The blast furnace slag must be of such a chemistry that it can carry the sulfur supplied by the burden material, including the sulfur contributed by the injected coal. Injected coal is the second largest contributor of sulfur to the blast furnace process. The blast furnace slag is the largest output variable for the sulfur. Changes in slag chemistry would be apparent should there be a significant change in the chemistry of the injected coal.

The primary sulfur inputs for the furnace are the furnace coke and the injected coal. There are secondary sulfur input materials that do contribute an appreciable amount of sulfur compared to the total. The primary outputs for the sulfur are the hot metal and the slag. Secondary outputs are the flue dust and filter cake waste products of the process. All of the sulfur input materials are accurately weighed as is the quantity of hot metal. The blast furnace slag quantity, pounds/NTHM, is a value that is calculated from the raw material input weights. Flue dust and filter cake quantities are based on the number of trucks filled with each material on a daily basis. The filter cake from both furnaces is collected at a central location. Therefore, for this balance, the total quantity has been apportioned based on the ratio of hot metal production for each furnace.

The blast furnace also produces large quantities of gas. The gas exits the top of the furnace, is cleaned and used as a fuel in the hot blast stoves and for boiler underfiring. Special gas sampling and testing during October,1996 shows an average of 3.1 grains of sulfur per 100 scf during the month. Table 4 shows the sulfur balance on C furnace during the month of October 1996. The balance shows a reconciliation of the furnace sulfur input to output of 99.2%.

5.3 COKE REPLACEMENT ANALYSIS

The quantity of furnace coke that is replaced by an injected fuel is an important aspect of the overall value of the injectant on the blast furnace process. A detailed analysis of the furnace coke/granulated coal replacement value for the C and D furnaces at the Burns Harbor Plant was completed after the second quarter.

The replacement ratio for a blast furnace injected fuel is defined as the amount of furnace coke that is replaced by one pound of the injectant. However, there are many furnace operating factors, in addition to the injectant, that affect the reported coke rate. In order to calculate an accurate value for the injected coal's role in the process, all other blast furnace operating variables that result in coke rate changes, positively or negatively, must be accounted for. After accounting for coke changes caused by all variables other than the coal, we attribute the remaining coke difference to the injected coal.

This evaluation uses monthly average furnace operating results compared to an appropriate base period for each furnace to develop the replacement ratio. This evaluation included twenty five months of data on both furnaces from June 1995 through June 1996 on C furnace and April 1995 through June 1996 on D furnace. The more monthly operating data available, the more accurate and appropriate the replacement value determination will be.

The corrected furnace coke rate and the amount of coal injected were used for a linear regression analysis of the twenty five sets of data from the C and D operation. Figure 5 shows the results of the calculations. The slope of the best fit line is the replacement value of the injected coal. This indicates that one pound of coal replaces 0.96 pounds of coke.

During the twenty five months of this initial evaluation, there were some isolated instances of no coal injection and extensive furnace repair periods which have not been deleted from the monthly data. In addition, five different coals were used during these months and each coal had different chemical and physical characteristics. The period of usage of these five coals was such that there was not enough time to make individual coal evaluations.

After 1996 additional coal/coke replacement evaluation work was done. This evaluation was performed with 1996 data and with only low volatile coal.

The same rationale for determining the adjusted coke rate was used for this analysis. February 1996 was used for the base month calculations on both furnaces. January was eliminated from the analysis due to the use of a small amount of natural gas on each furnace. Therefore, the linear regression comprises twenty data points, ten months for each furnace.

The results of the regression for the low volatile coal is shown in Figure 6. This indicates that one pound of coal replaces 1.07 pounds of coke. These results are significantly better than the original analysis. More importantly, the furnace coke rate achieved with the exclusive use of low volatile coal on each furnace is lower than the coke rates in Figure 5.

5.4 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 within the furnace. Refractory temperatures and calculated 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, causes more gas flow to be diverted to the furnace wall. The loss of central flow is also 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, we would expect an increase in refractory wear with significant increases in thermal loads.

Refractory temperatures and thermal load values should gradually increase as a furnace campaign continues. High refractory wear is often attributed to brick fracture as a result of rapid and sudden temperature changes. Large monthly increases or decreases in thermal loads are possibly deleterious to furnace refractories. The goal is to stabilize the operation and reduce the magnitude of fluctuations of the thermal loads.

C Furnace

Figure 7 shows the inwall refractory temperatures at four elevations on C furnace for 1996. The thermocouples are embedded in the refractory lining of the furnace at various brick depths. The general trend during the year has been a reduction in average temperatures.

The thermal load data for C furnace during 1996 is shown on Figure 8. The thermal load values remained constant during the first three months of the year despite higher coal injection rates. Beginning in April, however, the thermal loads started to increase. During April, May and June most of the thermal loads at each elevation increased. The increases were most apparent at rows 11-20. Each monthly increase at this row was statistically significant. This location is a furnace elevation that has come under scrutiny as an area of high refractory wear as well as the highest thermal load location on the furnace. The variability of the thermal loads between the eight measured quadrants do not usually result in monthly statistically significant value differences. The increases during this period correspond to the measured refractory lining loss that occurred on the furnace. The refractory loss and the injected coal rate during this period and for the year at row 11 and 15 are shown in Figure 9.

In July the thermal loads, although remaining higher than during the first three months of the year, began to decrease. During the remainder of 1996 the monthly increase or decrease at each elevation was less. Also, as seen in Figure 9, the refractory thickness on C furnace was more stable during the last half of the year.

D Furnace

Figure 10 shows the inwall refractory temperatures on D furnace during 1996. These inwall refractory temperatures remained steady during the first three months of 1996 and the calculated thermal loads throughout the furnace, shown in Figures 11, 12 and 13, were also steady. This is encouraging since the highest amount of coal during the first quarter was 179 pounds/NTHM, and occurred in March 1996.

Refractory temperatures and thermal loads on D furnace increased steadily during April, May and June at all elevations except at rows 11, 16 and 24. However, none of the increases were statistically significant.

The thermal loads at all elevations on D furnace were devoid of any significant changes throughout the remainder of the year despite the incremental increase in coal injection and a corresponding decrease in the furnace coke rate.

There was very little thermal load variability during 1996 on D furnace, certainly not in the same magnitude as the C furnace. This is important when the thermal load is compared to refractory wear. The refractory measurements for D are shown in Figure 14. During 1996 the D refractory wear pattern indicated slow wear during the year, with no large losses during any particular period.

6.0 SUMMARY

The year 1996 was a period of developing proper operating practices on both furnaces in order to take full advantage of the injected coal process.

The coal injection facility performed very well during the entire year even while engineering modifications were being made. Although there were periods of time when coal was removed from the furnace, it was removed primarily for operating problems not related to the coal facility.

The use of low volatile coal exclusively and the proper levels of furnace oxygen enrichment and moisture additions allowed operators to achieve yearly record low coke rates on both of the furnaces.

Despite the success, there is continued concern over permeability, refractory wear and high thermal loads on the C furnace. The D furnace operation in 1996 appears to have stabilized at a constant coal injection rate.

7.0 REFERENCES

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APPENDIX

CONSTRUCTION ACTIVITIES FOR YEAR 1996

First Quarter

- Completed insulating the four product coal silos.
- Repairs were made to the leaking upper construction joint on #1 baghouse.
- The stainless steel bag cages in each baghouse failed due to stress corrosion cracking and were replaced with epoxy coated cages.
- The standard baghouse explosion panels were replaced with insulated panels to reduce condensation inside the baghouse.
- A heated enclosure was installed around each baghouse dust hopper and dense phase transport system to reduce condensation inside the process equipment.
- Higher starting torque motors were installed on the product coal feeders to prevent unexpected motor overload trips.
- Temporary heaters and insulation were installed on the precrusher chutes to prevent cold weather freeze up.
- A pressure transmitter was installed on the dense phase transfer system to sense if coal dust is actually being transferred.
- Heaters were installed in the oxygen analyzer cabinets to maintain a constant temperature.

Second Quarter

- A new larger capacity product coal screen constructed of mild steel with epoxy coated interior surfaces to withstand corrosion and erosion was installed on #1 mill to replace the originally installed screen.
- A new spinner separator and mill expansion joint was installed on the #1 mill.

Third Quarter

- A new larger capacity product coal screen constructed of mild steel with epoxy coated interior surfaces to withstand corrosion and erosion was installed on #2 mill to replace the originally installed screen.

- A new spinner separator and mill expansion joint was installed on the #2 mill.

Fourth Quarter

- Air cannons were installed on the chute from #7 to #68 conveyor to prevent chute blockages.

- Permanent heaters and insulation were installed on the precrusher area chutes.

TABLE 1A
Burns Harbor C Furnace
Summary of Operations

	Jan-96	Feb-96	Mar-96	Apr-96	May-96	Jun-96
Prod, NTHM/d	7038	7096	7278	7301	7328	7306
Delays, Min/d	53	59	38	29	26	48
Coke Rate, lbs/NTHM	678	670	677	678	675	660
Nat. Gas Rate, lbs/NTHM	18	1.0	0	0	0.7	0
Inj. Coal Rate, lbs/NTHM	223	253	256	259	265	272
Total Fuel Rate, lbs/NTHM	919	923	933	936	941	932
Burden:						
Sinter, %	33.1	32.1	28.6	32.4	35.0	35.9
Pellets, %	66.2	67.7	71.1	67.3	64.7	63.9
Misc., %	.6	.2	.3	.3	.3	.3
BOF Slag, lbs/NTHM	0	6	65	2	0	0
Blast Conditions:						
Dry Air, SCFM	150,300	145,300	145,600	145,400	144,800	144,600
Blast Pressure, psig	39.3	39.3	39.2	39.2	39.1	39.2
Permeability	1.20	1.14	1.16	1.16	1.17	1.18
Oxygen in Wind, %	25.2	26.0	26.3	26.3	26.6	26.7
Temp, F	2074	2075	2081	2080	2075	2074
Moist., Grs/SCF	9.2	14.0	15.5	16.9	17.0	15.4
Flame Temp, F	4030	3974	3962	3931	3928	3974
Top Temp, F	221	205	212	229	237	241
Top Press, psig	13.9	13.5	13.6	13.7	14.0	14.4
Coke:						
H2O, %	5.1	5.3	5.1	4.9	4.7	4.8
Hot Metal:						
Silicon, %	.45	.43	.41	.45	.44	.46
Standard Dev.	.107	.095	.099	.095	.093	.130
Sulfur, %	.045	.044	.048	.046	.043	.039
Standard Dev.	.018	.016	.018	.016	.016	.015
Phos., %	.070	.074	.079	.075	.071	.072
Mn., %	.42	.43	.44	.43	.45	.45
Temp., F	2741	2728	2735	2734	2724	2724
Slag:						
SiO2, %	37.41	37.20	37.33	37.65	37.64	37.03
Al2O3, %	8.73	8.94	8.72	8.62	8.63	9.05
CaO, %	38.08	37.91	37.56	37.58	37.90	38.15
MgO, %	12.38	12.43	12.67	12.61	12.23	12.19
Mn., %	.45	.50	.66	.54	.58	.51
Sulfur, %	1.24	1.28	1.26	1.32	1.32	1.33
B/A	1.09	1.09	1.09	1.08	1.08	1.09
B/S	1.35	1.35	1.35	1.33	1.33	1.36
Volume, lbs/NTHM	443	439	445	432	434	444

TABLE 1B
Burns Harbor C Furnace
Summary of Operations

	Jul-96	Aug-96	Sep-96	Oct-96	Nov-96	Dec-96
Prod, NTHM/d	6870	7320	7140	6943	7281	7024
Delays, Min/d	106	37	75	71	25	61
Coke Rate, lbs/NTHM	660	649	638	661	665	668
Nat. Gas Rate, lbs/NTHM	2.0	0	0	0	0	0
Inj. Coal Rate, lbs/NTHM	269	274	273	264	261	274
Total Fuel Rate, lbs/NTHM	931	923	911	925	926	942
Burden:						
Sinter, %	35.2	32.5	34.5	35.9	34.4	32.6
Pellets, %	64.7	67.2	65.2	63.8	65.3	67.3
Misc., %	.2	.3	.3	.3	.3	.1
BOF Slag, lbs/NTHM	0	0	12	5	20	18
Blast Conditions:						
Dry Air, SCFM	143,000	143,600	140,700	137,000	136,900	136,000
Blast Pressure, psig	38.6	38.4	39.0	38.8	39.4	39.6
Permeability	1.19	1.24	1.22	1.19	1.16	1.13
Oxygen in Wind, %	26.6	26.6	26.9	27.3	27.5	27.5
Temp, F	2074	2077	2090	2067	2076	2074
Moist., Grs/SCF	16.3	16.7	18.0	19.8	20.1	19.1
Flame Temp, F	3949	3948	3911	3841	3940	3940
Top Temp, F	244	247	245	226	219	229
Top Press, psig	14.4	15.2	16.8	16.9	17.0	16.9
Coke:						
H_2O, %	5.1	5.0	4.8	5.0	4.8	5.0
Hot Metal:						
Silicon, %	.49	.53	.55	.50	.50	.56
Standard Dev.	.130	.135	.139	.128	.121	.152
Sulfur, %	.040	.038	.043	.040	.042	.035
Standard Dev.	.020	.017	.019	.014	.019	.016
Phos., %	.072	.064	.073	.072	.074	.070
Mn., %	.44	.38	.43	.43	.43	.42
Temp., F	2726	2730	2721	2734	2730	2734
Slag:						
SiO_2, %	37.04	37.00	36.92	36.54	36.52	36.04
Al_2O_3, %	8.91	9.00	9.73	9.63	9.54	9.80
CaO, %	38.56	38.79	38.86	39.03	39.17	39.34
MgO, %	11.94	11.64	11.86	11.62	11.39	11.39
Mn., %	.50	.47	.46	.46	.45	.41
Sulfur, %	1.31	1.43	1.41	1.39	1.43	1.49
B/A	1.10	1.10	1.09	1.10	1.10	1.11
B/S	1.36	1.36	1.37	1.39	1.38	1.41
Volume, lbs/NTHM	434	424	426	424	435	440

TABLE 2A
Burns Harbor D Furnace
Summary of Operations

	Jan-96	Feb-96	Mar-96	Apr-96	May-96	Jun-96
Prod, NTHM/d	6394	6546	6621	6510	6683	6772
Delays, Min/d	60	30	46	83	59	52
Coke Rate, lbs/NTHM	771	753	736	714	723	712
Nat. Gas Rate, lbs/NTHM	12	1.3	.2	0	0	0
Inj. Coal Rate, lbs/NTHM	136	164	179	196	185	198
Total Fuel Rate, lbs/NTHM	919	918	915	910	913	911
Burden:						
Sinter, %	32.6	31.3	28.4	32.5	34.3	34.7
Pellets, %	66.2	68.4	71.2	67.3	65.4	65.0
Misc., %	1.2	.3	.3	.3	.3	.3
BOF Slag, lbs/NTHM	0	7	65	2	0	0
Blast Conditions:						
Dry Air, SCFM	151,400	151,200	149,200	146,900	146,800	148,100
Blast Pressure, psig	38.7	38.9	38.7	38.4	38.8	39.5
Permeability	1.26	1.23	1.19	1.18	1.17	1.16
Oxygen in Wind, %	23.2	23.3	23.8	24.2	24.4	24.4
Temp, F	2068	2068	2077	2077	2079	2087
Moist., Grs/SCF	15.5	15.2	18.2	20.1	20.3	18.9
Flame Temp, F	3919	3913	3869	3882	3819	3863
Top Temp, F	220	223	217	230	216	223
Top Press, psig	15.8	15.3	14.2	14.2	14.5	15.0
Coke:						
H2O, %	4.7	4.6	5.2	4.9	4.7	4.7
Hot Metal:						
Silicon, %	.53	.50	.47	.50	.48	.52
Standard Dev.	.117	.103	.092	.104	.099	.124
Sulfur, %	.036	.038	.039	.037	.040	.035
Standard Dev.	.014	.014	.013	.012	.017	.012
Phos., %	.07	.072	.078	.074	.070	.071
Mn., %	.43	.43	.45	.44	.45	.45
Temp., F	2722	2712	2715	2720	2703	2702
Slag:						
SiO2, %	37.12	37.14	37.21	37.39	37.40	37.11
Al2O3, %	8.93	9.09	8.84	8.77	8.72	9.13
CaO, %	38.12	37.85	37.64	37.73	38.01	38.07
MgO, %	12.40	12.43	12.67	12.64	12.24	12.19
Mn., %	.44	.47	.61	.51	.52	.49
Sulfur, %	1.28	1.29	1.29	1.34	1.34	1.32
B/A	1.10	1.09	1.09	1.09	1.09	1.09
B/S	1.36	1.35	1.35	1.35	1.34	1.35
Volume, lbs/NTHM	438	433	442	431	427	434

TABLE 2B
Burns Harbor D Furnace
Summary of Operations

	Jul-96	Aug-96	Sep-96	Oct-96	Nov-96	Dec-96
Prod, NTHM/d	6623	6725	6753	6919	6543	6758
Delays, Min/d	60	50	79	34	112	72
Coke Rate, lbs/NTHM	715	709	693	705	715	720
Nat. Gas Rate, lbs/NTHM	0	0	0	0	3	13
Inj. Coal Rate, lbs/NTHM	199	206	207	198	192	181
Total Fuel Rate, lbs/NTHM	916	915	900	904	910	914
Burden:						
Sinter, %	34.0	32.4	34.0	35.0	33.6	32.2
Pellets, %	65.9	67.6	65.7	64.7	66.3	67.7
Misc., %	0.1	0	0.3	0.3	0.1	0.1
BOF Slag, lbs/NTHM	0	0	13	5	20	19
Blast Conditions:						
Dry Air, SCFM	148,200	146,800	146,000	145,354	146,090	145,823
Blast Pressure, psig	38.9	38.0	39.0	38.3	38.1	38.5
Permeability	1.21	1.27	1.27	1.31	1.34	1.31
Oxygen in Wind, %	24.3	24.6	25.0	25.1	25.1	25.3
Temp, F	2095	2093	2096	2098	2088	2088
Moist., Grs/SCF	19.4	19.5	20.7	21.6	21.0	20.4
Flame Temp, F	3855	3883	3857	3811	3872	3842
Top Temp, F	236	243	246	230	234	237
Top Press, psig	15.3	15.6	17.1	17.1	17.2	17.1
Coke:						
H2O, %	4.9	4.9	5.0	5.3	5.1	5.3
Hot Metal:						
Silicon, %	.51	.53	.54	.50	.48	.55
Standard Dev.	.095	.103	.106	.092	.104	.112
Sulfur, %	.039	.038	.041	.041	.047	.034
Standard Dev.	.012	.013	.012	.012	.018	.014
Phos., %	.071	.063	.073	.071	.074	.070
Mn., %	.43	.37	.43	.43	.42	.43
Temp., F	2697	2706	2714	2695	2688	2700
Slag:						
SiO2, %	37.26	37.56	36.80	36.81	36.67	36.10
Al2O3, %	8.92	8.98	9.78	9.70	9.58	9.82
CaO, %	38.26	38.88	38.87	38.91	38.99	39.25
MgO, %	11.97	11.69	11.79	11.57	11.28	11.35
Mn., %	.53	.43	.45	.45	.45	.41
Sulfur, %	1.29	1.40	1.39	1.38	1.40	1.44
B/A	1.09	1.09	1.09	1.09	1.09	1.10
B/S	1.35	1.35	1.38	1.37	1.37	1.40
Volume, lbs/NTHM	426	423	425	420	431	438

TABLE 3

Burns Harbor C Furnace
PROGRESSION OF RESULTS FOR COAL INJECTION

	C Furnace January 1995 Natural Gas	C Furnace September 1995 High VM Coal	C Furnace July 1996 Low VM Coal
Natural Gas Rate, lbs/NTHM	141	-	-
Injected Coal Rate, lbs/NTHM	-	210	269
Furnace Coke Rate, lbs/NTHM	741	745	660
Adjusted Furnace Production NTHM/d	7567	7494	7417
Blast Conditions:			
Reported Wind, SCFMx100	1764	1640	1540
Oxygen Enrichment, %	24.4	26.2	26.6
Moisture, Grs/SCF	3.7	8.5	16.3
Blast Pressure, PSI	38.9	38.9	38.6
Flame Temperature, F	3620	4062	3949
Top Temperature, F	263	213	244
Hot Metal Chemistry:			
% Silicon; Mean, S.D.*	.44 , .091	.62 , .104	.49 , .130
% Sulfur; Mean, S.D.*	.043 , .012	.035 , .010	.039 , .020
Slag :			
SiO2, %	38.02	36.57	37.04
Al2O3, %	8.82	9.50	8.91
CaO, %	37.28	37.71	38.56
MgO, %	12.02	12.31	11.94
Sulfur, %	0.85	1.19	1.31
Slag Volume, lbs/NTHM	394	437	434
Furnace Permeability	1.57	1.22	1.19
Top Gas Analysis:			
CO%	20.82	24.20	23.52
CO2%	20.70	23.25	24.04
H2%	6.63	3.13	4.31
BTU/CF	88.57	88.06	89.70

* S.D. = The monthly standard deviation

TABLE 4

BURNS HARBOR C FURNACE SULFUR BALANCE

SULFUR INPUT:	October 1996	SULFUR OUTPUT:	October 1996
Material;		Material;	
Furnace Coke, Sulfur Analysis	.69%	Blast Furnace Slag, Sulfur Analysis	1.39%
Tons Coke Used	71,085.0	Total Tons Produced	45,626.6
Tons Sulfur In	490.5	Tons Sulfur Out	634.2
Injected Coal,Sulfur Analysis	.78%	Blast Furnace Iron,Sulfur Analysis	.040%
Tons Coal Used	28,409.0	Total Tons Produced	215,220.0
Tons Sulfur In	221.6	Tons Sulfur Out	86.1
Sinter, Sulfur Analysis	.02%	Flue Dust,Sulfur Analysis	.450%
Tons Sinter Used	121,282.6	Total Tons Produced	1,076.1
Tons Sulfur In	24.3	Tons Sulfur Out	4.8
Pellets,Sulfur Analysis	.01%	Filter Cake,Sulfur Analysis	.482%
Tons Pellets Used	215,306.5	Total Tons Produced	2,570.60
Tons Sulfur In	21.5	Tons Sulfur Out	12.4
Scrap,Sulfur Analysis	.23%	Top Gas, Sulfur Content	3.1 Grs./100 scf
Tons Scrap Used	3,981.7	Total Gas Produced, MMCF	108,246
Tons Sulfur In	9.2	Tons Sulfur Out	23.9
BOF Slag,Sulfur Analysis	.07%		
Tons BOF Used	530.2		
Tons Sulfur In	.4		
TOTAL TONS of SULFUR IN:	**767.5**	TOTAL TONS of SULFUR OUT:	**761.4**
		SULFUR OUT/SULFUR IN	**.992**

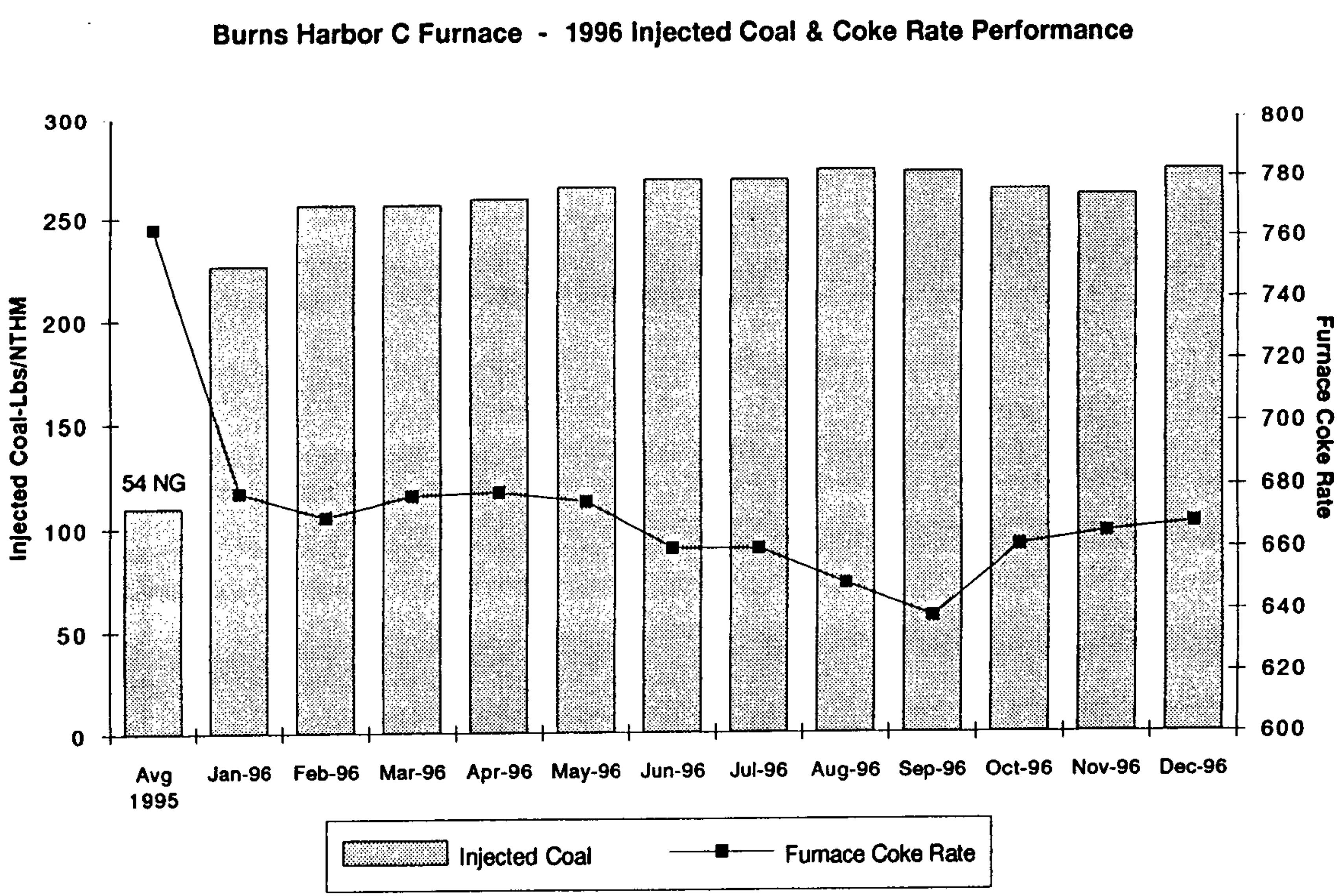
SULFUR INPUT: October 1996 **SULFUR OUTPUT:** October 1996

FIGURE 1

PROJECT MILESTONE DATES

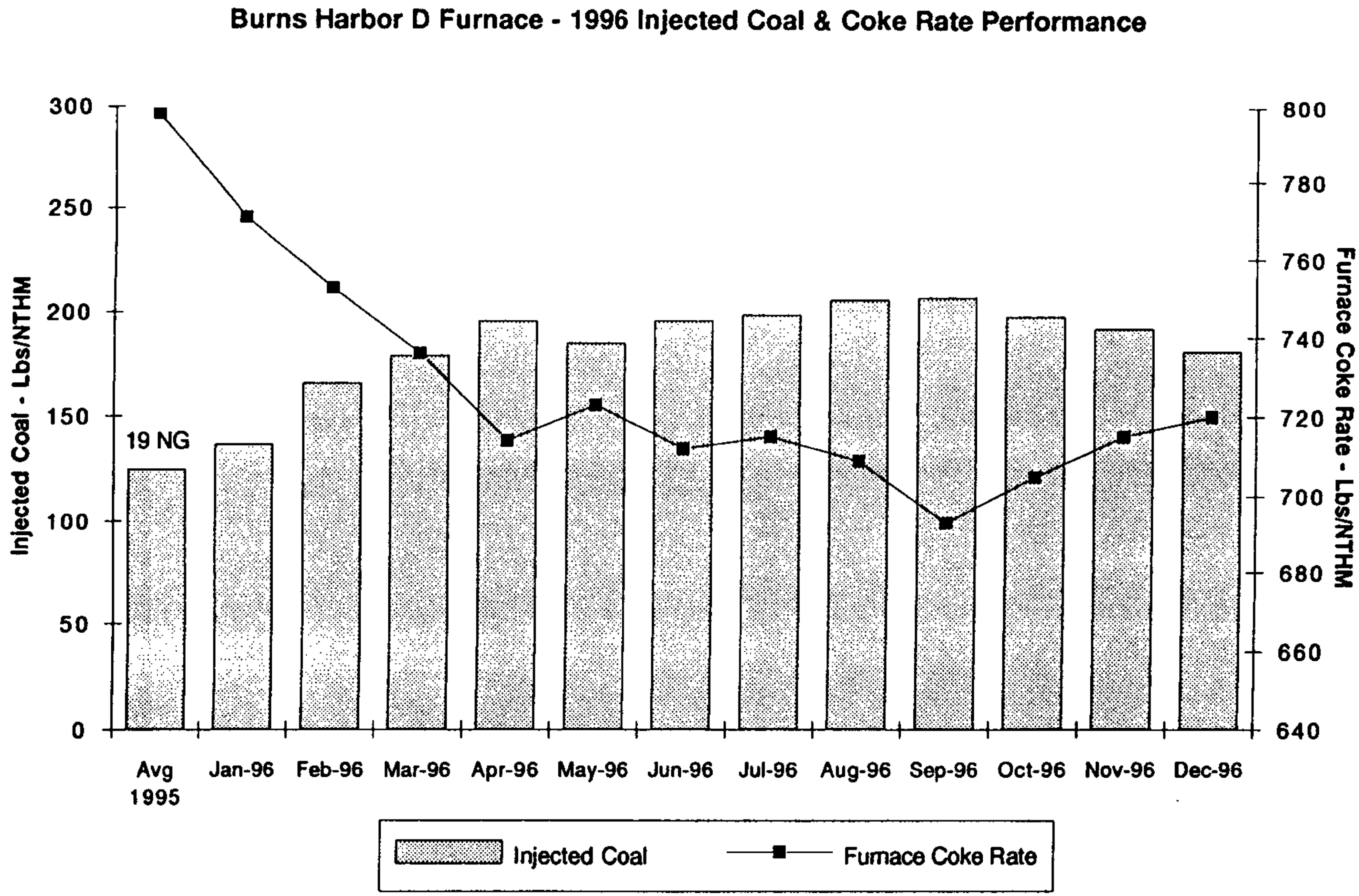
Begin Detailed Construction Engineering	April 1, 1993
Received State Environmental Construction Permit	August 4, 1993
Start Construction	August 31, 1993
90% Design Review	January 12, 1994
50% Construction Review	June 1994
100% Construction Review	December 1994
Begin Coal Testing Demonstration	November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

FIGURE 2



Burns Harbor C Furnace - 1996 Injected Coal & Coke Rate Performance
Injected Coal-Lbs/NTHM
300
250
200
150
100
50
0
Furnace Coke Rate
800
780
760
740
720
700
680
660
640
620
600
54 NG
Avg 1995
Jan-96
Feb-96
Mar-96
Apr-96
May-96
Jun-96
Jul-96
Aug-96
Sep-96
Oct-96
Nov-96
Dec-96
Injected Coal
Furnace Coke Rate

FIGURE 3



Burns Harbor D Furnace - 1996 Injected Coal & Coke Rate Performance
Injected Coal - Lbs/NTHM
300
250
200
150
100
50
0
Furnace Coke Rate - Lbs/NTHM
800
780
760
740
720
700
680
660
640
19 NG
Avg 1995
Jan-96
Feb-96
Mar-96
Apr-96
May-96
Jun-96
Jul-96
Aug-96
Sep-96
Oct-96
Nov-96
Dec-96
Injected Coal
Furnace Coke Rate

FIGURE 4

Burns Harbor C and D Furnace
Permeability 1996

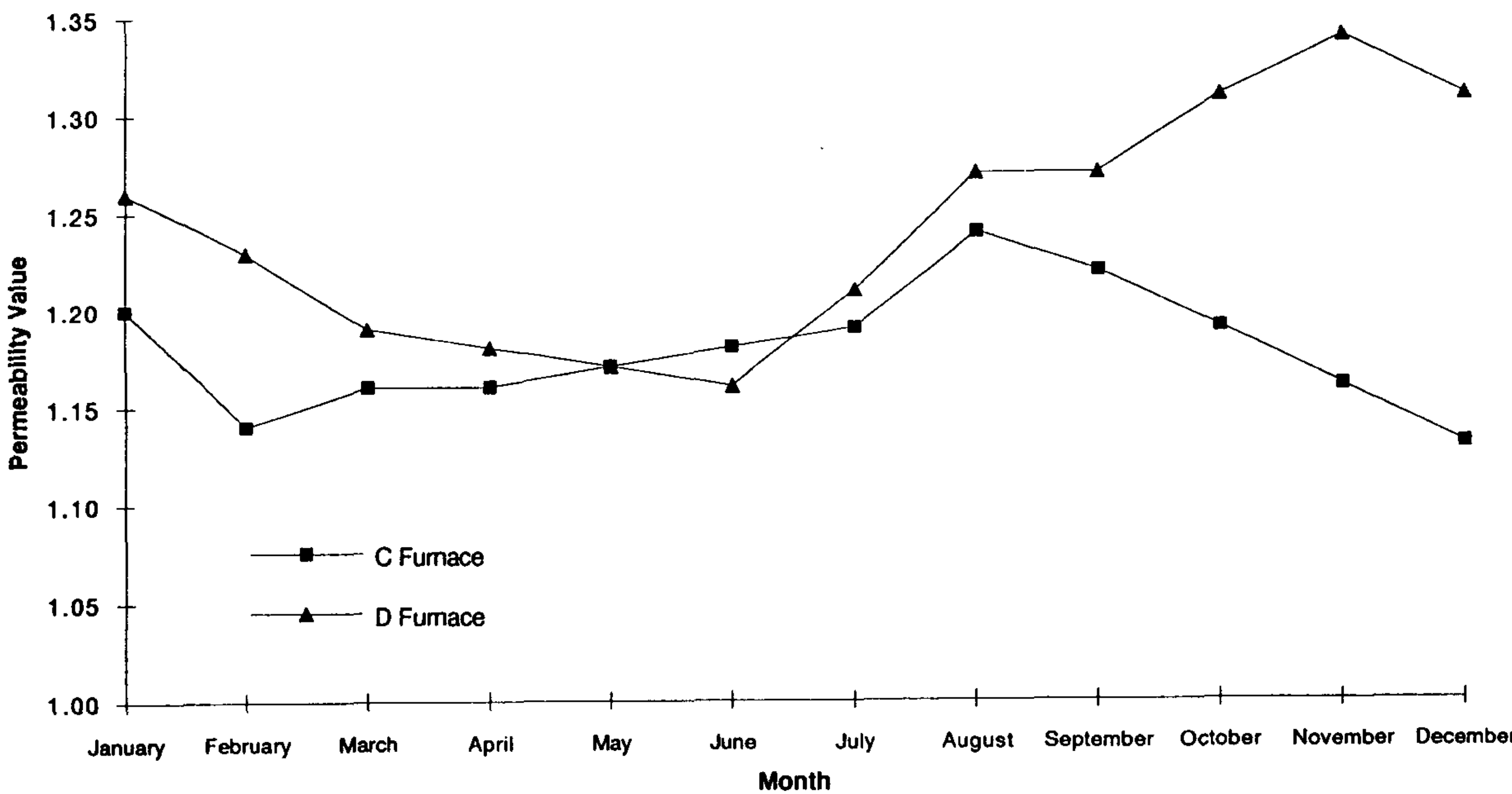
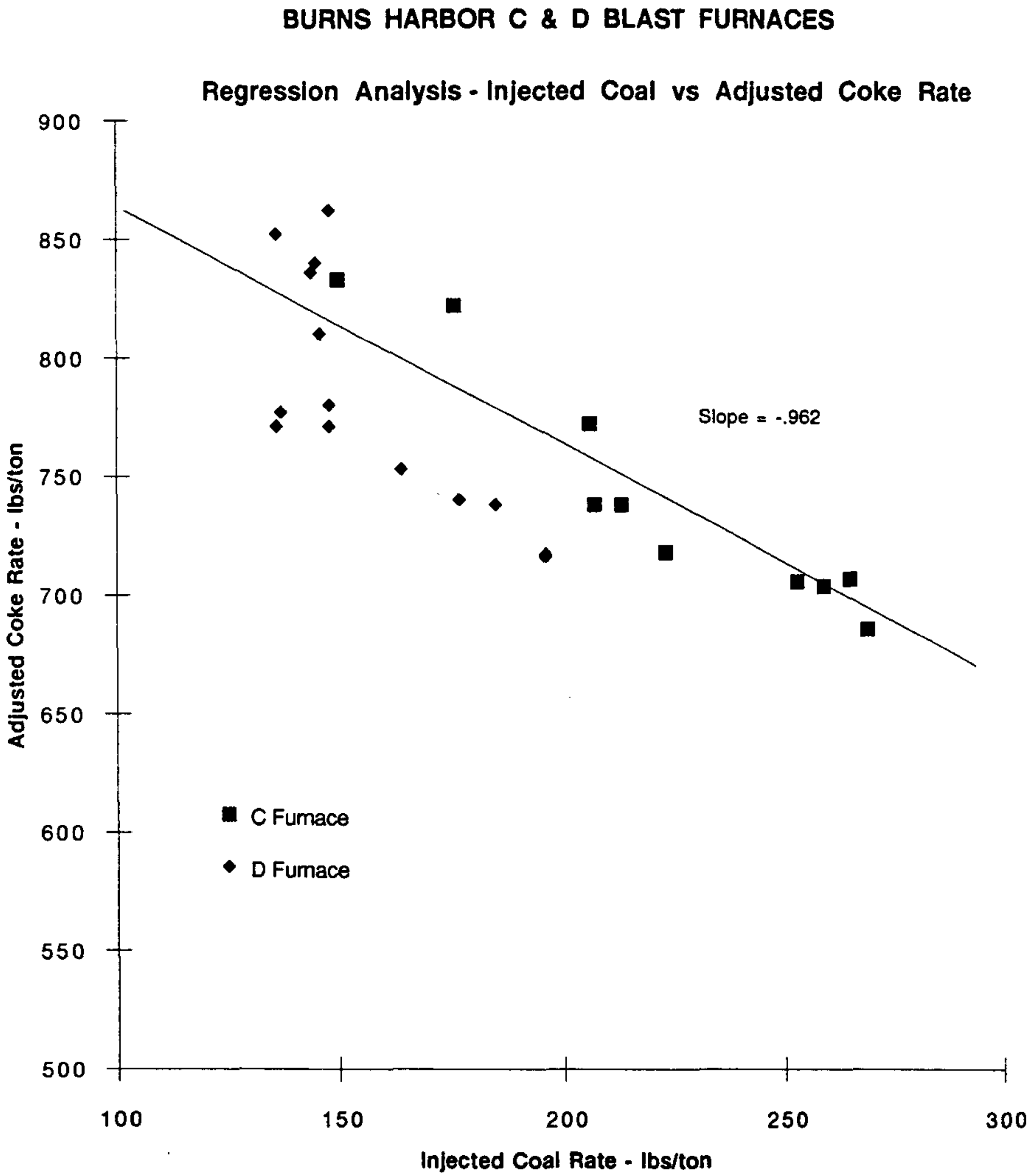


FIGURE 5



BURNS HARBOR C & D BLAST FURNACES
Regression Analysis - Injected Coal vs Adjusted Coke Rate
Adjusted Coke Rate - lbs/ton
900
850
800
750
700
650
600
550
500
Slope = -.962
C Furnace
D Furnace
100
150
200
250
300
Injected Coal Rate - lbs/ton

FIGURE 6

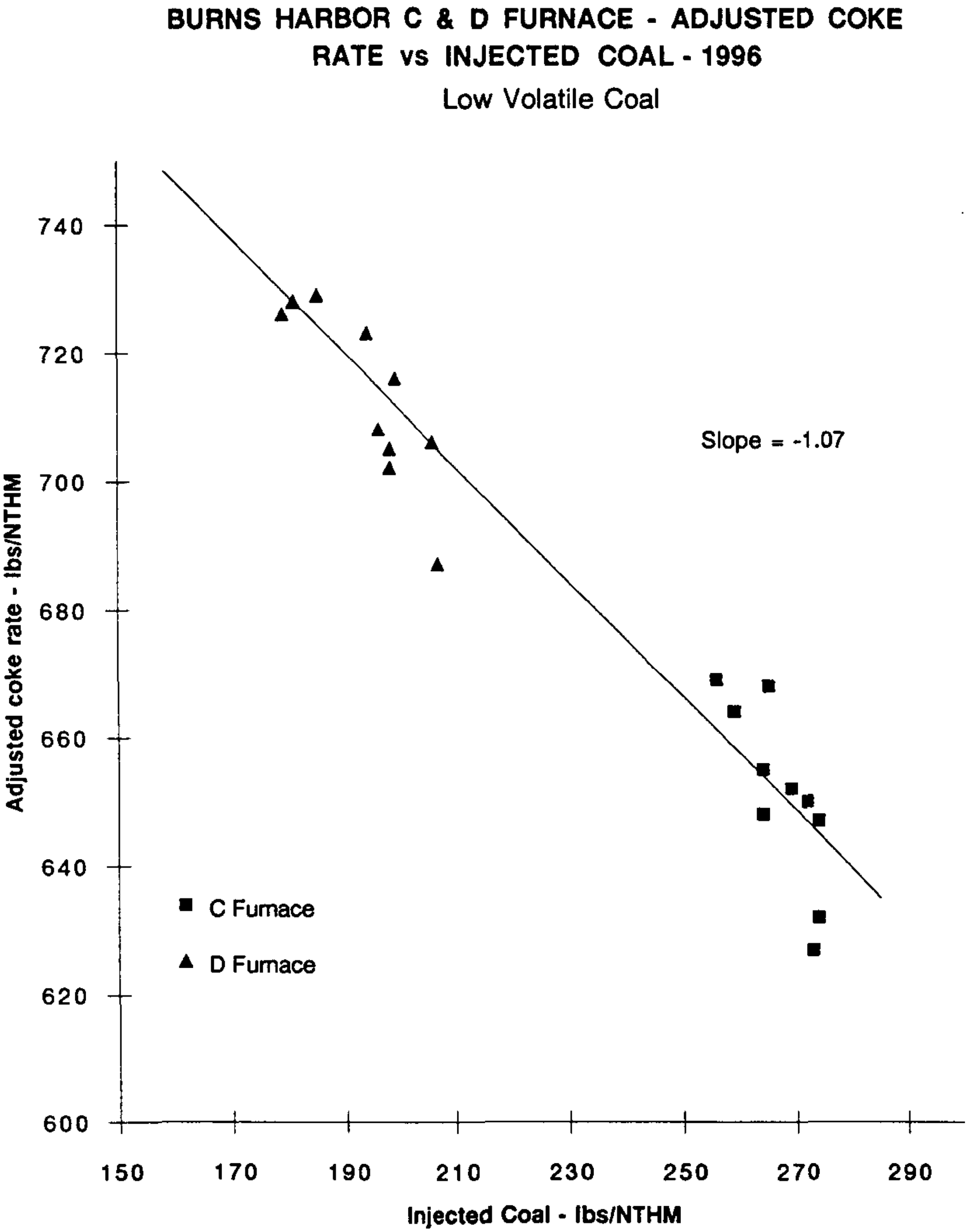

BURNS HARBOR C & D FURNACE - ADJUSTED COKE RATE vs INJECTED COAL - 1996
Low Volatile Coal
Slope = -1.07
Adjusted coke rate - lbs/NTHM
Injected Coal - lbs/NTHM
C Furnace
D Furnace
600
620
640
660
680
700
720
740
150
170
190
210
230
250
270
290

FIGURE 7

BURNS HARBOR C FURNACE - INWALL REFRACTORY TEMPERATURE - 1996

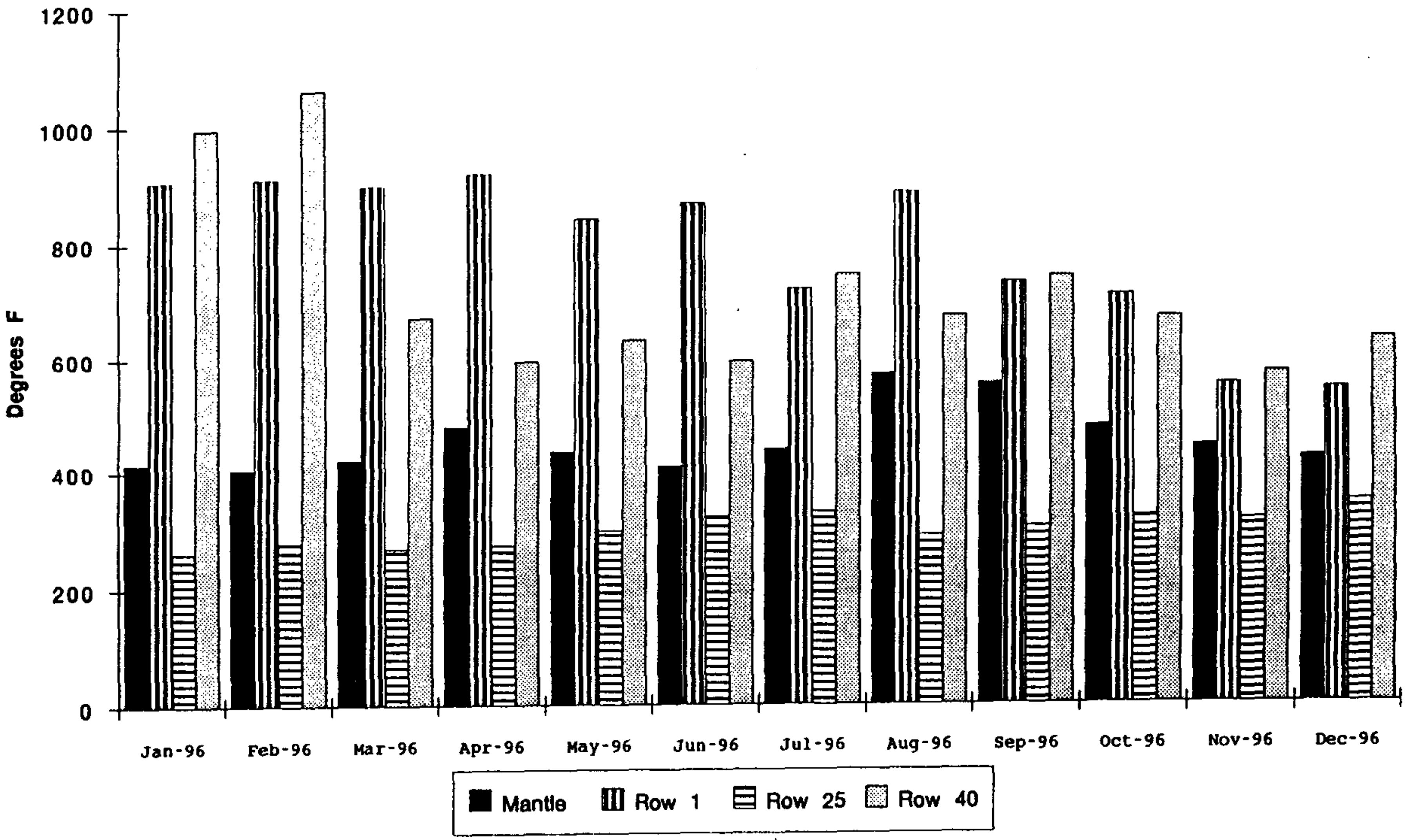


FIGURE 8

BURNS HARBOR C FURNACE THERMAL LOADS - 1996

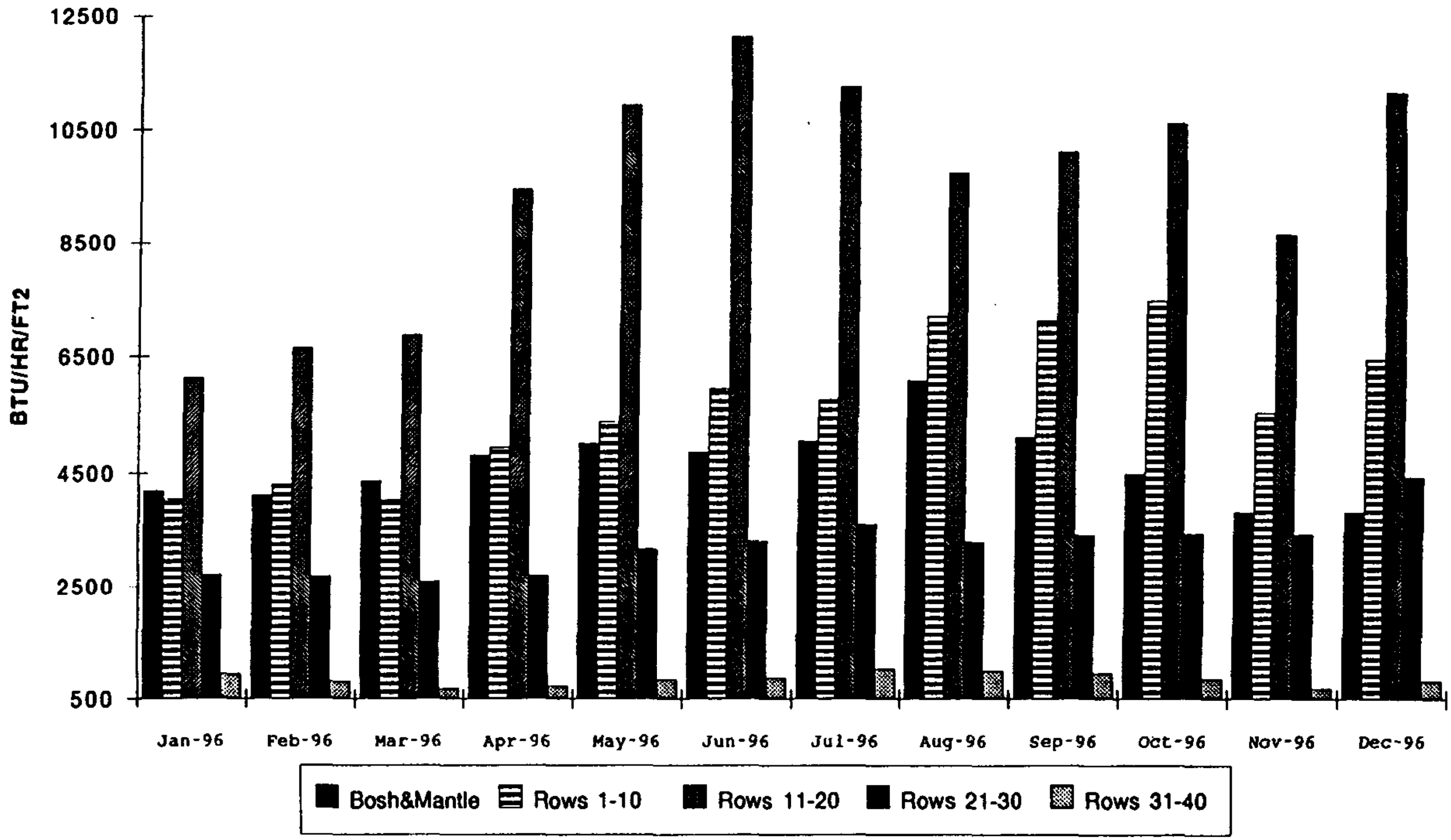
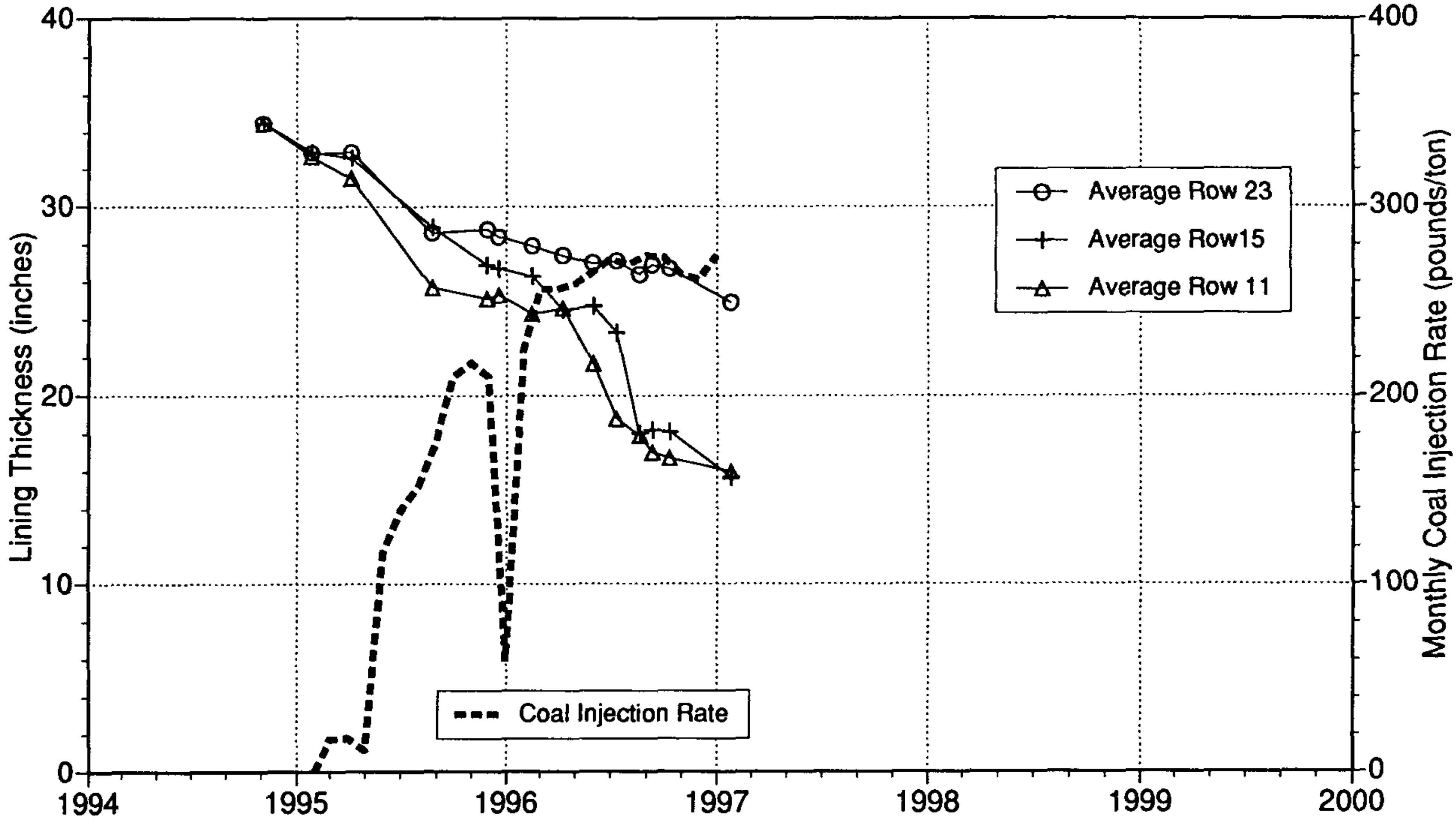


FIGURE 9.
BURNS HARBOR "C" FURNACE— 5TH CAMPAIGN
AVERAGE STACK LINING THICKNESS MEASUREMENTS



Date Blown In: 11/4/94
Date of Last Measurement: 1/24/97
RAS/JCM

FIGURE 10

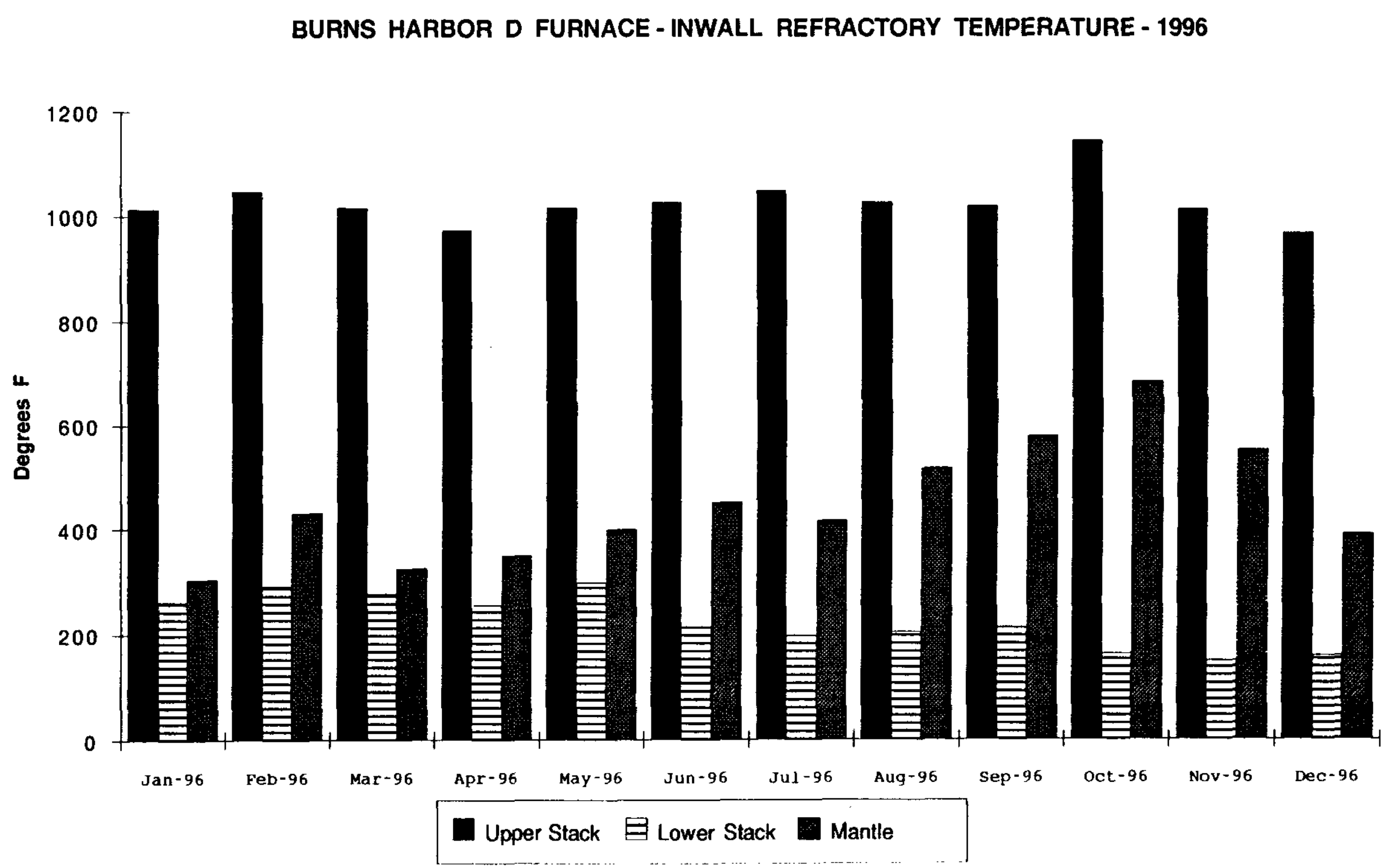

BURNS HARBOR D FURNACE - INWALL REFRACTORY TEMPERATURE - 1996
Degrees F
1200
1000
800
600
400
200
0
Jan-96
Feb-96
Mar-96
Apr-96
May-96
Jun-96
Jul-96
Aug-96
Sep-96
Oct-96
Nov-96
Dec-96
Upper Stack
Lower Stack
Mantle

FIGURE 11

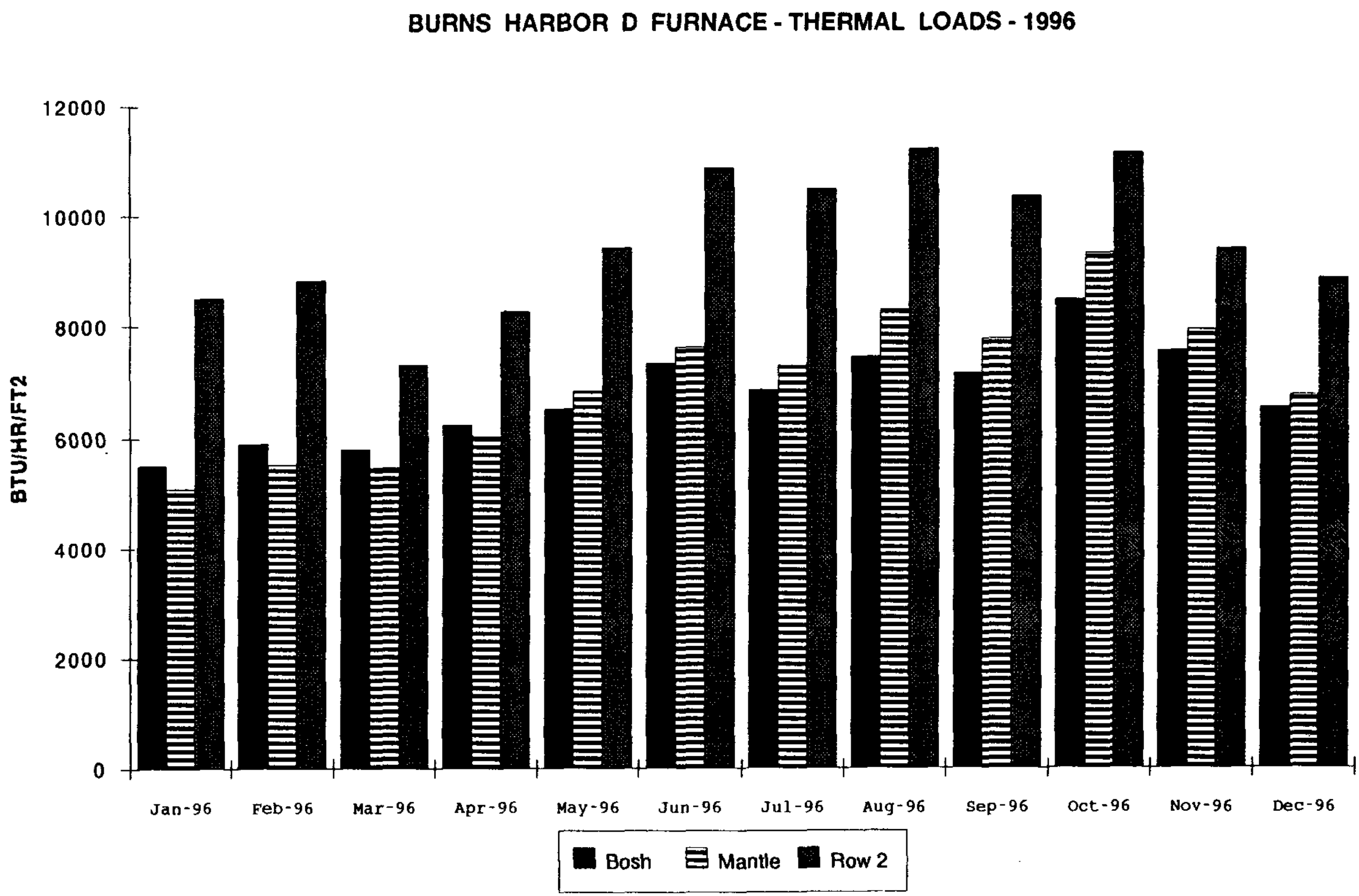

BURNS HARBOR D FURNACE - THERMAL LOADS - 1996
BTU/HR/FT2
12000
10000
8000
6000
4000
2000
0
Jan-96
Feb-96
Mar-96
Apr-96
May-96
Jun-96
Jul-96
Aug-96
Sep-96
Oct-96
Nov-96
Dec-96
Bosh
Mantle
Row 2

FIGURE 12

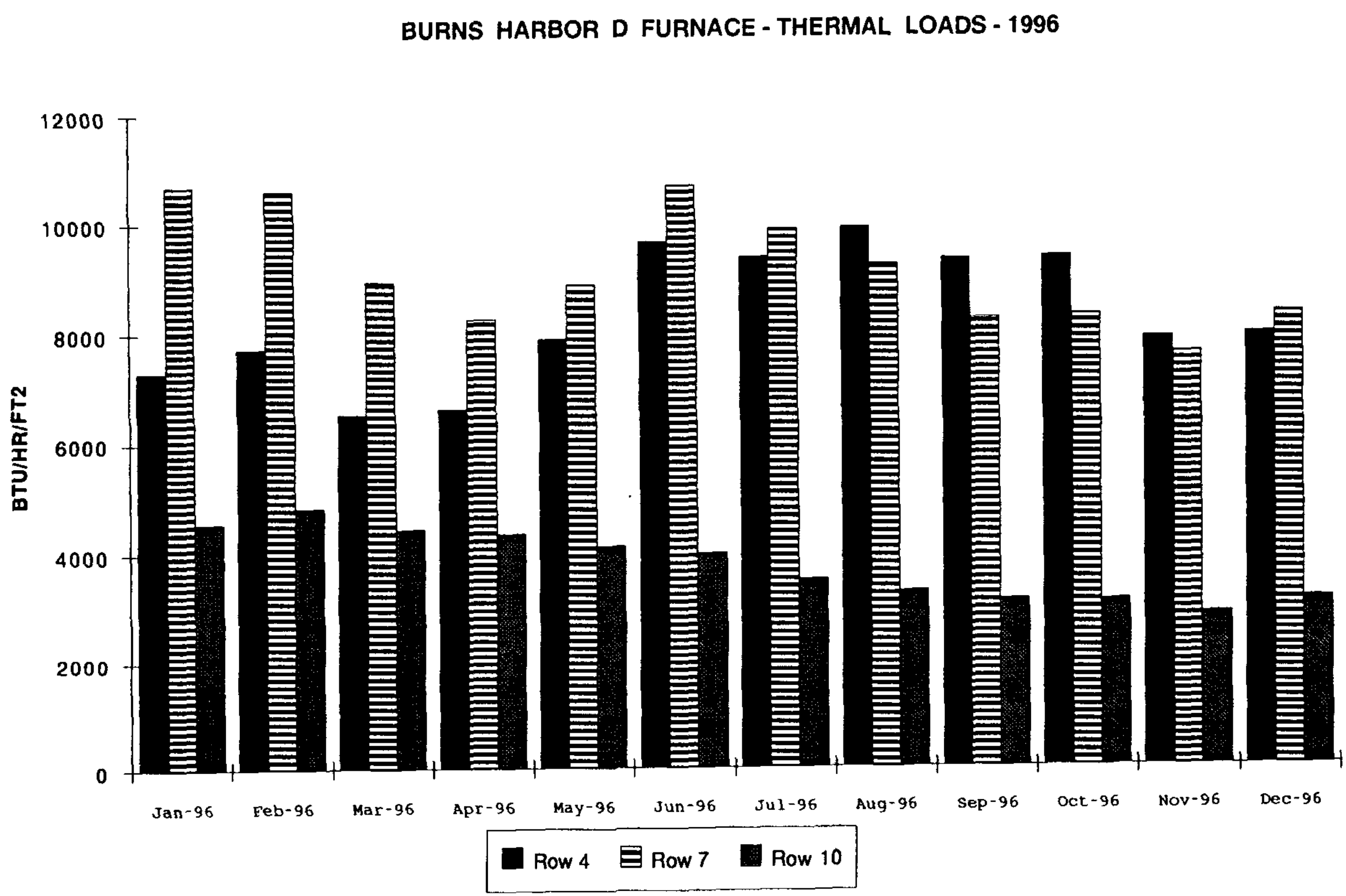

BURNS HARBOR D FURNACE - THERMAL LOADS - 1996
BTU/HR/FT2
12000
10000
8000
6000
4000
2000
0
Jan-96
Feb-96
Mar-96
Apr-96
May-96
Jun-96
Jul-96
Aug-96
Sep-96
Oct-96
Nov-96
Dec-96
Row 4
Row 7
Row 10

FIGURE 13

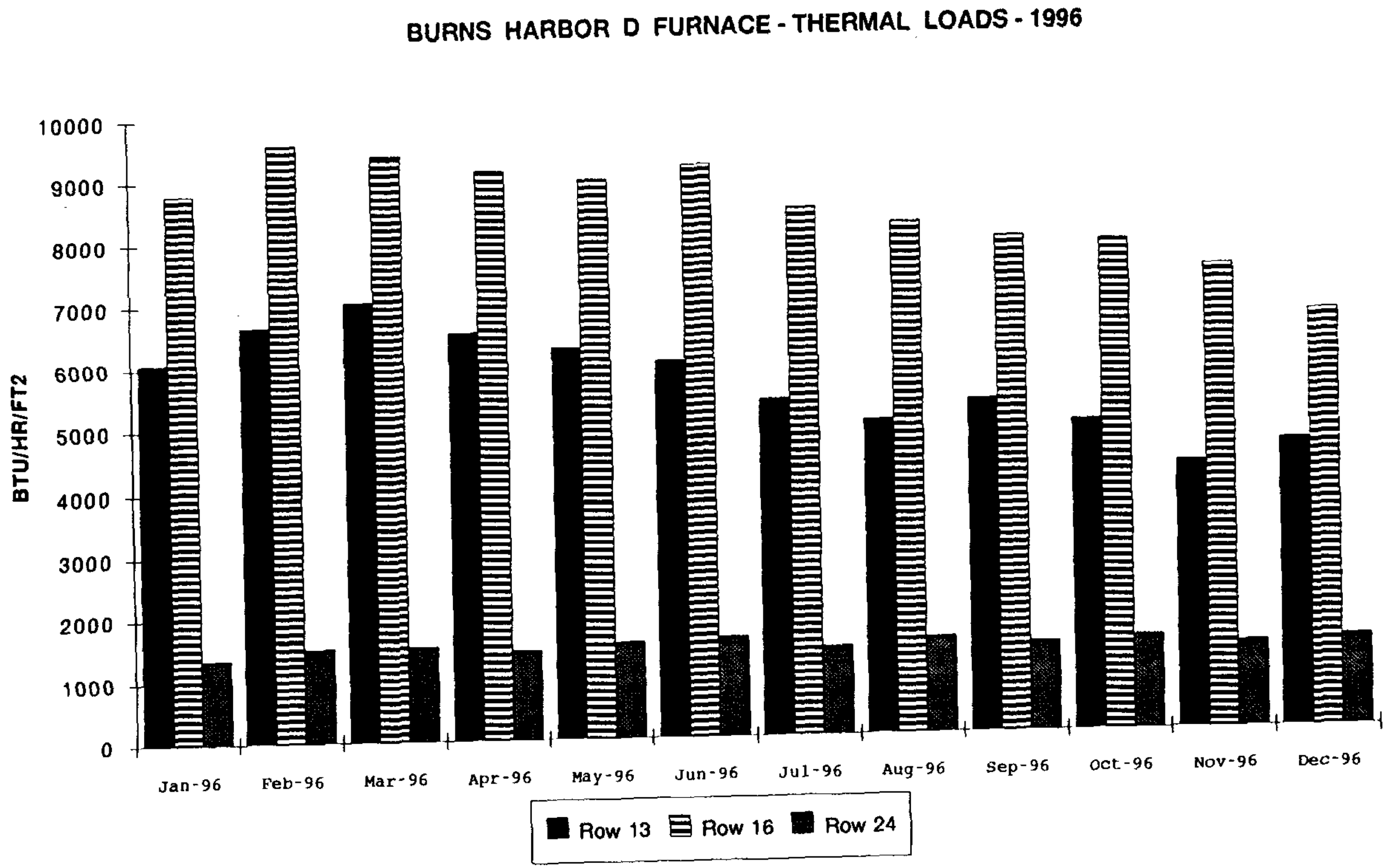
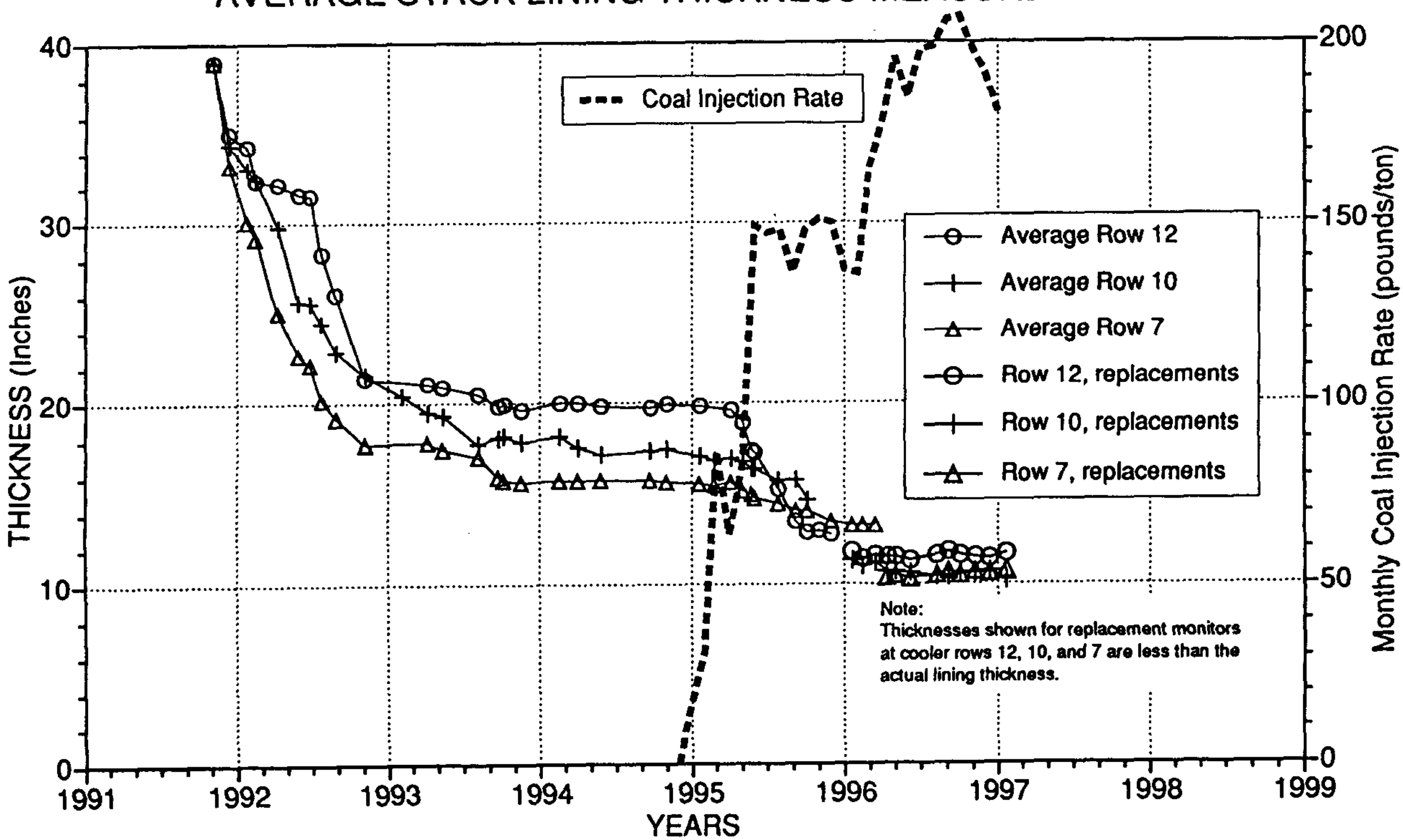

BURNS HARBOR D FURNACE - THERMAL LOADS - 1996
BTU/HR/FT2
10000
9000
8000
7000
6000
5000
4000
3000
2000
1000
0
Jan-96
Feb-96
Mar-96
Apr-96
May-96
Jun-96
Jul-96
Aug-96
Sep-96
Oct-96
Nov-96
Dec-96
Row 13
Row 16
Row 24

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



Date Blown In: 11/4/91
Date of Last Measurement: 2/25/97
RAS/JCM