BLAST FURNACE GRANULAR COAL INJECTION PROJECT

Annual Report
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1.0 INTRODUCTION

This 1997 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 British Steel technology[1,2] that uses granular coal to provide a portion of the fuel requirements of blast furnaces. The project will demonstrate/assess a broad range of technical and economic issues associated with the use of coal for injection into blast furnaces. 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 the Burns Harbor Plant (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 7,000 tons per day of molten iron with the injected fuel providing about 15% 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% of the total funding requirements for the demonstration project with the DOE providing the remaining 21.7%. 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 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 and 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. In 1997 the coal facility became more consistent and coal was injected at higher levels on both furnaces. The coke rate on the furnaces also was lower during 1997 as a consequence of the higher coal rates. Figures 2 and 3 show the progression of increased coal injection rates during 1997 as well as the reduction in furnace coke rates. Tables 1A and 1B provide the monthly operating summary for 1997 on C furnace and Tables 2A and 2B show the same information for D furnace.

4.1 FURNACE OPERATING CONDITIONS

The operation of the furnaces during January was marked by numerous delays and lengthy shutdown periods. On C furnace there were eleven days during the month that the furnace had shutdown periods of 100 minutes or more. The monthly average delay in minutes/day, shown on Table 1A, was 118. Even going back as far as July 1992, there has not been as high a monthly average delay period. The primary causes for the outages were a mechanical breakdown and repair of the burden filling equipment on January 12-14, the failure of the cyclone separator at the coal injection facility on January 19 and a gas line collapse on January 24. In addition, ten tuyeres failed and had to be changed during the month. The coke rate was increased on C to 716 pounds/NTHM in January compared to 668 pounds/NTHM in December 1996. The increase was partially in response to a reduction in the injected coal rate due to the coal injection facility problem. Increases in coke were also necessary to adequately accommodate the lengthy shutdown periods.

The D furnace operation was similar to C, with ten days of outages of 100 minutes or more. The gas line collapse on January 24 also affected the D furnace. Twelve tuyere failures on D furnace were the primary reason for the delays.

The most disruptive incident, from a coal injection standpoint, was the failure of the cyclone housing on the #1 Coal Preparation Mill. The cyclone housing is at the very top of the grinding mill circuit. On January 19th, the steel housing failed, opening up a hole and allowing air to be sucked into the inert atmosphere of the grinding system. The resultant high oxygen level in the mill caused the emergency abort system and the fire suppression system to activate. After operators isolated the #1 Mill from the rest of the system, coal injection was re-established on both furnaces using only the #2 Mill. The coal rate was reduced primarily on C furnace due to this incident. The repair to the steel housing included the application of a fiberglass and epoxy material to the interior steel surface to minimize further wear from the abrasion of coal particles. A similar application of this abrasion resistant material was also done to the #2 Mill cyclone separator during early February as a preventive maintenance measure.

During February the operation was stabilized on both furnaces. Delay time was decreased, coke rates were reduced and productivity increased. Tuyere losses were still high, six on C and nine on D, but manageable.

March was notable for a sustained period of high productivity on the furnaces. The low delay rate on each furnace allowed for a combined average daily production level exceeding 14,000 TPD for the first time since February 1995. The low delay rate on C furnace was accomplished in large part by the loss of only three tuyeres for the month. D furnace also recorded only three tuyere losses.

Combined furnace production increased substantially during the second quarter. The increased demand for hot metal began in February and furnace production increased since then to match steelmaking capacity. The C furnace averaged more than 7,200 NTHM/day for the March to June period. The average tonnage of 7,479 NTHM/day in June is the highest production during this campaign. Operations maintained the overall fuel rate during the quarter to around 940 pounds/NTHM. Both injected coal and coke rates were constant at approximately 270 pounds/NTHM and 670 pounds/NTHM, respectively. The increase in production on the furnace was accomplished primarily by the reduction in furnace delays. In addition, slight increases in oxygen enrichment helped. Figure 4 shows the increased production trends and reductions in delay periods for 1997 and the last six months of 1996. The decrease in overall delay time, and especially the unscheduled delays, was aided by fewer tuyere losses on both furnaces. Only one tuyere loss occurred on C furnace in June and D furnace had no failures.

The D furnace operation during this quarter was similarly consistent in terms of productivity, overall fuel rate and delay periods. The coal injection rate remained at approximately 200 pounds/NTHM during the period. Production increases were accomplished by slight increases in both wind rates and enrichment oxygen levels.

Reduced demand for hot metal and some necessary maintenance activities at the blast furnace resulted in lower iron production during July and August. In September, C and D furnaces produced a combined daily average production rate of over 14,300 NTHM/day. The increase in productivity during September is a result of lower delays and reductions in coke rates at higher coal injection levels.

In September, the C furnace production averaged 7,493 NTHM/day, an increase of 250 NT per day from August. Although there was a slight increase in the oxygen enrichment rate, the reduction in the furnace coke rate to below 660 pounds/NTHM had the greatest effect on the increased production. An increase in the coal injection rate aided the coke reduction. The incremental reduction in coke is noticeable during the third quarter as are the increases in coal injection.

The D furnace operation was similar to C during this three month period. Productivity was lower during July and August than during the month of June. September's production increased to 6,877 NTHM/day primarily due to an increase in oxygen enrichment and a slight decrease in the coke rate.

In October, the combined production of the furnaces averaged over 14,000 NTHM/day with good fuel rates and relatively high coal injection rates. The coke rate on C furnace during October averaged 659 pounds/NTHM and D was 705 pounds/NTHM at coal injection rates of 259 and 201 pounds/NTHM, respectively. The good productivity was a result of the low coke rates and the low monthly average delay rate. The daily delay rate was 24 minutes on C furnace and 40 minutes on D.

During November, major maintenance on C furnace, particularly stockhouse repairs, and the operating problems associated with the lengthy shutdown periods from November 11-17 caused a decline in average productivity to 6,167 NTHM/day. The delay time also increased on D furnace as a result of high tuyere losses during the month.

During December, the operation began to return to normal, however, tuyere losses were high on C and the delays associated with the tuyere changes did not allow for a return to full productivity. The D furnace operation did improve with production levels at over 6,800 NTHM/day and a furnace coke rate of 698 pounds/NTHM.

During the third quarter several major operating parameters were modified. Beginning in November 1996, the furnace coke size was increased to +1¼" from +¾". On July 15, 1997 the furnace coke size was changed back to + ¾". In addition, the large amount of nut coke that had accumulated during the increased coke size trial was added to the furnace in larger than normal quantities to reduce the inventory. A detailed analysis on the use of larger sized coke and increased quantities of nut coke are shown in the following section.

A trial in which granulated coal and greater quantities of natural gas were injected together began on C furnace on October 24. The trial was to continue for thirty days. However, the problems on the furnace beginning on November 11 caused the trial to be discontinued after seventeen days. Despite the brevity of the trial, the results were encouraging. The detailed analysis of the trial is discussed later.

Coke Size Analysis

On November 5, 1996 a coke size change was made at the screening station of the Coke Ovens to provide a larger coke for the blast furnace. The bottom size of the coke was increased from ¾" to 1-¾". The increased coke size affected both furnaces. One of the expected benefits to the furnace operation was an increase in the permeability in the furnace. Improved permeability should provide an opportunity to increase the injected coal rate and further reduce the furnace coke rate. Increased permeability should also result in lower furnace blast pressure, enabling operators to increase the furnace wind rate. The following analysis of the performance with the larger coke encompasses approximately four months of use with larger coke. January 1997 should be ignored as a data point due to the operating difficulties previously described.

The increased coke size constitutes a major change to the blast furnace process. The benefits of the larger coke should be reflected by a substantial or notable improvement in the process variables that are affected by coke size. However, in a comparison of ten months of operating data prior to the change and five months of data following the change, there was no measurable or quantifiable improvement in the operation of either furnace.

After the change in November 1996, permeability on both furnaces, with the exception of D furnace during April 1997, did not reach previous high values, furnace blast pressure has not been significantly reduced, and wind rates have not increased. In fact, on C furnace, blast pressures increased at lower wind rates after the coke change.

The furnace coke rates, while very good, did not improve and injected coal rates on both furnaces remained the same during the entire evaluation period.

In general, the combined furnace productivity remained approximately the same. Although the combined furnace production reached a fifteen month high during March 1997, statistically, it appears that the low monthly furnace delay rate was the primary reason for the productivity increase.

Figure 6 shows the C and D furnace monthly average permeability values for the last two years of operation. The larger the value the better the gas flow through the furnace. This plot shows that, despite the larger coke on the furnaces since November 5, neither furnace has had an increase in permeability that matches previous high values prior to the coke size increase.

Figure 7 shows the amount of injected coal on each furnace. The increased coke size has not led to an increase in injected coal. Another conclusion can be made by comparing Figures 6 and 7. At the levels of coal injection on C and D to date, it does not appear that permeability is adversely affected by the quantity of injected coal.

The furnace results with the larger coke were disappointing. Permeability should have returned to at least the previous levels seen on each furnace in mid-1996. The operating difficulties experienced in January may have clouded some of the operating results. However, the conclusion from this period of time is that process improvements were negligible with the larger sized coke.

Nut Coke Usage

As a result of the trial with larger size furnace coke, there was a large accumulation of -1¼" coke in inventory. After the size change back to furnace coke sized to +¾", this large inventory was reclaimed and rescreened to produce a large quantity of nut coke of a nominal size -¾". Nut coke was charged to the furnace in larger than normal quantities to reduce the inventory. The tons per month of nut coke consumed on the furnaces is shown in Figure 5.

The following discussion refers to the results on C furnace with the use of nut coke. The results on C furnace are the same for D furnace.

The initial response on C furnace to the increase in nut coke was, as expected, a reduction in the permeability. Figure 6 shows that in August 1997 the permeability dropped compared to July 1997. A subsequent reduction in nut coke in September resulted in an improvement in the permeability but not to the previous level shown for June and July. Figure 8 shows the increased blast pressure that accompanied the reduction in permeability. This is also an expected outcome of the use of nut coke.

The reduction in furnace permeability with the use of nut coke did not have a deleterious affect on furnace wind rates or furnace production. Figure 9 shows that the operators were able to maintain the total wind rate despite the reduced permeability. Production increases are noted during August and September in Figure 4, despite the increased quantity of nut coke. The coke rate also improved despite nut coke usage. Usually an increase in blast pressure and the reduction of furnace permeability does not allow operators to reduce the coke rate and increase production.

The return to a smaller furnace coke size and increasing the nut coke usage on both furnaces did not adversely affect the productivity or fuel rate on either furnace. In addition, there was no indication of adverse thermal load activity on either furnace during this period.

Co-injection of Natural Gas and Granulated Coal

Coal injection has enabled operators to reduce furnace coke rates to lower levels than were possible with natural gas injection. Figures 2 and 3 show the progression of lower furnace coke rates on C and D furnaces since coal injection came on stream in January 1995. With coal injection, furnace permeability was adversely affected and necessitated increases in levels of enrichment oxygen and blast moisture in order to maintain productivity and acceptable burden movement. This trial was done to assess the effect of adding a substantial amount of natural gas while maintaining a constant amount of granular coal. The natural gas was injected on six tuyeres through the coal lances. Granulated coal was used on the remaining 22 tuyeres. This is not the ideal way to coinject fuels, but major renovations to the furnace blowing stock are necessary to inject coal and gas through the same tuyere. Although the time period was brief and marred by delays, a review of the data shows signs of improved operation. The relevant data during the trial period is compared in Table 7 to a base period in September 1997, a very good operating month.

The comparison of the two periods shown on Table 7 lead to the following observations:

- The furnace coke rate was 11 pounds/NTHM lower during the trial period. This suggests that coal and gas in combination can support a lower coke rate.
- Operations was able to increase the furnace wind rate by about 4600 SCFM during the trial.
- Even though the wind rate was increased, the furnace blast pressure was lower during the co-injection period and the furnace permeability was higher.
- It was possible to reduce the moisture additions by 8 grs/SCFM of wind and still maintain good burden movement.
- The third period was brief because of a breakdown of the C furnace stockhouse equipment. The trial will be repeated for a longer period when time permits.

4.2 HIGHER ASH INJECTED COAL TRIAL

The objective of this trial is to quantify the effect of ash content in the injected coal on the blast furnace operation.

The Burns Harbor C furnace operation immediately prior to the trial period was characterized by high production levels and a steady-state for the major operating variables. During the first half of 1997 the operation was run to achieve maximum furnace production rates. This is unlike most of 1996 when the primary focus was to maximize coal injection levels and achieve low furnace coke rates.

The trial period began on May 28, 1997 and concluded June 23, 1997. The trial period is compared to two previous operating periods: a pre-trial period from May 1 - May 27, 1997, and the previously conducted October 1996 base period.

Trial Coal Selection

During the entire year of 1996 the injection coal used on both furnaces was the low volatile, high carbon content Buchanan/Virginia Pocahontas. The coal is designated by two names based on two different mine sites and the point of shipment to the plant. However, both coals are from the same seam and are very similar chemically.

The typical analysis of Virginia Pocahontas in October 1996 and the Buchanan coal used on the furnaces immediately prior to the trial period are shown in Table 3. For a good furnace trial, one that would assess only ash content, it is important to use a coal that only varies in ash so that there would be no confounding issues such as sulfur content or large differences in volatile matter. The coal supplier of the Buchanan coal suggested that ash content could be increased at the mine site cleaning station if one of the usual coal cleaning steps was eliminated. Trials were run at the mine and subsequent coal analysis confirmed that the ash content could be increased by this method. The average analysis of the four train trial coal is also shown on Table 3. The trial coal is 2.4% higher in ash than the coal used for the October 1996 base and is 3.0% higher in ash than the coal used during the furnace period immediately prior to the trial.

Also shown in Table 3 is the average size distribution of the final injection product coal during the trial period. The average size distribution satisfies the definition of granular coal; 100% is -4 Mesh, 98% is -7 Mesh and less than 30% is -200 Mesh.

C Furnace Operations

The primary concern of the furnace operators, both before and during a blast furnace trial is to maintain a consistent operating practice so that a valid comparison of the trial variable being analyzed can be properly compared and assessed. In addition, if more than one comparison base operating period is compatible with the trial period it should be utilized to validate and support the trial results. Table 4 shows the operating results for the higher ash trial period on C furnace and the two operating periods that are used to make the comparative analysis.

The amount of injected coal used during each period is similar. In addition, the general blast conditions during the periods are comparable. The wind rates only vary from 135,370 SCFM to 137,000 SCFM. Blast pressure, top pressure and moisture additions are similar.

The primary change in the operation, as expected, was the increase in the blast furnace slag volume. The increase from 448 pounds/NTHM in the low ash period to 461 pounds/NTHM during the trial is significant. Even more noticeable is the increase from 424 pounds/NTHM slag volume during the October 1996 period. The general conclusion from Table 4 is that higher ash content in the injected coal can be adjusted for by the furnace operators and does not adversely affect overall furnace operations.

Furnace Coke Rate Results

The primary reason for this coal trial is to determine the coke rate penalty to the blast furnace that results from the use of higher ash injection coal. In order to assess the comparative furnace coke rate during a trial all the blast furnace variables that affect the furnace coke rate that are different from the base to the trial must be adjusted by using coke correction factors. The only variables that are not corrected or adjusted are those affected by the operating variable that is being assessed. After accounting for all operational coke differences between the base period and the trial period, we attribute the coke remaining unaccounted for as a consequence of the variable being studied. Since the higher ash coal causes an increase in the furnace slag volume and does contribute to higher furnace coke usage, we have not adjusted the coke for changes in the slag volume.

Two comparisons were made using the above logic. Table 5 shows the results of the first comparison. Here, we have corrected the higher ash trial to the May 1 - May 27, 1997 pre-trial period. The largest adjustment necessary is for the difference in the injected coal amount of seven pounds of coke. Generally, the total adjusted coke amount for the period comparison is small. That is indicative of a successful trial operation. The conclusion from this table is that a 3% increase in injected coal ash results in a nine pound per NTHM increase in the furnace coke rate with a coal injection rate of 270 pounds/NTHM.

Table 6 shows the values from the second comparative period. As with the previous analysis, only small adjustments are required to establish the overall corrected coke rate. This comparison substantiates the first results. The 2.4% increase in coal ash from the October 1996 base period to the trial period results in a coke penalty of eight pounds per NTHM.

These results will allow operators to assess different ash content of various coals and economically determine which coal to purchase.

4.3 FURNACE THERMAL CONDITIONS AND LINING WEAR

The use of injected coal caused changes in the thermal conditions on both blast furnaces at Burns Harbor. The increases in the thermal measurements as a result of coal injection were particularly noticeable during the introduction of coal injection in 1996. During 1997 the coal injection operating practices were stabilized and it became apparent that improved operating conditions can positively impact the thermal conditions. The Thermal Load System at Burns Harbor is used 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 causes more gas to be diverted to the furnace wall. The increased wall flow is indicated by increases in thermal loads and also may suggest an increase in refractory wear.

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 inside the furnace. The goal is to stabilize the operation and reduce the magnitude of fluctuations of the thermal loads.

C Furnace

Figure 10 shows the in-wall refractory temperatures at four elevations on C furnace for 1997. The thermocouples are embedded in the refractory lining of the furnace at various brick depths. The in-wall temperatures have been fairly consistent with the exception of March.

Figure 11 shows the thermal load values for C furnace at five elevations. Rows 11-20, shown on this chart as the solid black bar, had the highest value throughout most of the year and has been the highest refractory wear area in the furnace. The other four elevations were consistent for all of the monthly periods.

Figure 12 shows the refractory thickness at three elevations in the furnace. Beginning in January 1997 we observe little or no refractory wear during the year compared to large loss of refractory during the middle of 1996.

D Furnace

The refractory temperatures and the calculated thermal load values are shown on Figures 13, 14, 15 and 16. All of these values for the entire year are the model of consistency as they were for most of 1996. The amount of injected coal and the general operating conditions on the furnace have changed very little during the last two years.

Figure 17 shows the refractory wear measurements for D furnace since 1992. In addition, the injected coal rate is shown. There has been no refractory wear at the three elevations shown during all of 1996 and 1997. We also note that since April 1996 the coal injection rate has remained constant.

5.0 SUMMARY

The blast furnace operation with coal injection significantly matured during 1997. Coal injection at Burns Harbor has enabled lower coke rates and higher production levels than when other injectants were used.

However, in order to take advantage of the positive aspects of coal injection, the operation had to be altered to make coal injection perform properly. The oxygen enrichment level on the furnaces had to be increased to provide proper coal combustion at the tuyere and the moisture addition level was increased to aid in proper burden movement.

The coal injection facility performed well, however, design shortcomings have appeared. The major example of this was the cyclone failure in January 1997.

Our technical understanding of granular coal injection has improved as a result of trials with higher ash coal, large sized coke and coinjection of coal and natural gas. The important trials with pulverized coal and high volatile coal are planned for 1998.

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TABLE 1A
Burns Harbor C Furnace
Summary of Operation

	January 97	February 97	March 97	April 1997	May 1997	June 1997
Production, NTHM/day	6026	6944	7296	7365	7230	7479
Delays, Min/day	118	54	15	30	51	18
Coke Rate, lbs/NTHM	716	684	674	670	673	674
Nat. Gas Rate, lbs/NTHM	5.1	4.0	1.2	3.0	.4	4.0
Inj. Coal Rate, lbs/NTHM	248	253	266	262	269	261
Total Fuel Rate, lbs/NTHM	969	941	941	935	942	939
Burden:						
Sinter, %	32.0	34.1	31.6	21.5	28.1	34.9
Pellets, %	68.0	65.6	68.1	78.1	71.7	64.9
Misc., %	0	.3	.3	.3	.2	.2
BOF Slag, lbs/NTHM	0	0	25	132	46	0
Blast Conditions:						
Dry Air, SCFM	128,369	138,529	136,421	135,794	135,604	135,622
Blast Pressure, psig	37.1	40.0	39.1	38.9	38.2	38.2
Permeability	1.08	1.13	1.19	1.21	1.25	1.24
Oxygen in Wind, %	26.8	27.0	27.9	28.4	28.5	28.6
Temp, F	2075	2079	2074	2055	2040	2008
Moist., Grs/SCF	17.1	18.9	20.5	20.3	20.4	20.4
Flame Temp, F	3955	3928	3968	3983	3999	3938
Top Temp, F	246	210	196	192	196	200
Top Press, psig	15.3	17.1	17.1	17.1	17.0	16.6
Coke:						
H2O, %	4.7	4.8	4.6	4.7	4.8	5.0
Hot Metal, %:						
Silicon	.67	.56	.51	.50	.51	.49
Standard Dev.	.212	.147	.108	.131	.112	.103
Sulfur	.029	.032	.040	.045	.039	.035
Standard Dev.	.013	.016	.017	.022	.015	.012
Phos.	.066	.071	.073	.073	.070	.073
Mn.	.41	.44	.45	.45	.43	.46
Temp., F	2753	2715	2730	2735	2740	2733
Slag, %:						
SiO2	35.62	35.68	36.11	36.04	36.11	36.16
Al2O3	9.81	9.89	9.74	9.61	9.45	9.90
CaO	39.92	39.92	39.60	38.83	38.95	39.38
MgO	11.21	11.13	11.27	11.86	11.95	11.31
Mn	.40	.37	.43	.47	.42	.46
Sul	1.54	1.52	1.47	1.40	1.45	1.40
B/A	1.11	1.12	1.11	1.11	1.12	1.10
B/S	1.42	1.43	1.41	1.41	1.41	1.40
Volume, lbs/NTHM	428	434	458	459	449	466

TABLE 1B

Burns Harbor C Furnace

Summary of Operation

	July 97	August 97	September 97	October 97	November 97	December 97
Production, NTHM/day	7096	7231	7493	7259	6167	7061
Delays, Min/day	61	31	20	24	182	57
Coke Rate, lbs/NTHM	664	663	654	659	693	662
Nat. Gas Rate, lbs/NTHM	1.0	13.0	1.0	8.0	40.0	5.0
Inj. Coal Rate, lbs/NTHM	271	261	274	259	200	285
Total Fuel Rate, lbs/NTHM	935	937	929	926	933	952
Burden:						
Sinter, %	33.9	33.0	33.6	32.9	32.1	33.7
Pellets, %	66.0	66.9	66.2	66.8	67.6	65.9
Misc., %	.2	.2	.2	.3	.4	.4
BOF Slag, lbs/NTHM	9	20	27	17	7	0
Blast Conditions:						
Dry Air, SCFM	137,826	135,453	135,836	138,494	138,296	136,456
Blast Pressure, psig	38.5	39.3	39.1	38.8	38.1	39.1
Permeability	1.24	1.17	1.20	1.24	1.23	1.18
Oxygen in Wind, %	27.9	28.1	28.3	27.6	27.1	27.5
Temp, F	2034	2099	2099	2100	2098	2103
Moist., Grs/SCF	18.2	19.4	19.7	17.8	13.7	21.5
Flame Temp, F	3997	3957	4023	4011	3936	3926
Top Temp, F	211	205	205	209	205	216
Top Press, psig	16.8	17.1	17.3	17.3	16.3	17.3
Coke:						
H_2O, %	5.1	5.4	5.3	5.2	5.1	4.9
Hot Metal, %:						
Silicon	.49	.50	.51	.53	.58	.53
Standard Dev.	.114	.111	.119	.111	.205	.148
Sulfur	.035	.036	.035	.030	.034	.032
Standard Dev.	.013	.013	.017	.011	.023	.019
Phos.	.073	.058	.058	.062	.067	.073
Mn.	.48	.38	.38	.43	.45	.49
Temp., F	2738	2715	2694	2729	2723	2727
Slag, %:						
SiO_2	35.87	36.35	36.72	35.95	35.71	35.66
Al_2O_3	9.82	9.49	9.29	9.36	9.46	9.77
CaO	39.60	40.11	40.46	40.15	39.78	39.55
MgO	11.31	11.05	11.05	11.18	11.48	11.38
Mn	.45	.37	.36	.36	.40	.45
Sul	1.53	1.59	1.61	1.57	1.56	1.53
B/A	1.11	1.12	1.12	1.13	1.13	1.12
B/S	1.42	1.41	1.40	1.43	1.44	1.43
Volume, lbs/NTHM	455	446	446	442	434	455

TABLE 2A
Burns Harbor D Furnace
Summary of Operation

	January 97	February 97	March 97	April 1997	May 1997	June 1997
Production, NTHM/day	6344	6415	6854	6636	7033	6821
Delays, Min/day	90	86	39	106	36	68
Coke Rate, lbs/NTHM	734	719	716	714	712	718
Nat. Gas Rate, lbs/NTHM	1.3	2.0	1.0	3.0	.4	7.0
Inj. Coal Rate, lbs/NTHM	204	199	204	199	201	193
Total Fuel Rate, lbs/NTHM	939	920	921	915	913	918
Burden:						
Sinter, %	32.3	33.3	30.6	20.5	26.9	33.8
Pellets, %	67.6	66.5	69.1	79.2	73.0	66.0
Misc., %	0	.3	.3	.3	.2	.2
BOF Slag, lbs/NTHM	0	0	27	143	52	0
Blast Conditions:						
Dry Air, SCFM	144,371	147,186	145,587	144,847	144,178	146,221
Blast Pressure, psig	39.1	39.9	39.8	38.1	37.6	37.9
Permeability	1.22	1.21	1.22	1.34	1.37	1.36
Oxygen in Wind, %	25.1	24.7	25.3	25.6	25.8	25.5
Temp, F	2081	2072	2095	2096	2094	2079
Moist., Grs/SCF	19.6	18.8	21.3	21.2	21.3	19.7
Flame Temp, F	3888	3876	3897	3916	3940	3903
Top Temp, F	266	234	211	204	217	236
Top Press, psig	17.0	17.2	17.3	17.1	17.1	16.9
Coke:						
H_2O, %	5.0	5.1	4.6	4.7	4.8	4.8
Hot Metal, %:						
Silicon	.62	.56	.50	.48	.50	.49
Standard Dev.	.140	.122	.095	.109	.111	.125
Sulfur	.032	.033	.040	.043	.045	.041
Standard Dev.	.017	.012	.014	.015	.017	.016
Phos.	.068	.070	.073	.074	.069	.073
Mn.	.41	.43	.44	.45	.41	.45
Temp., F	2695	2711	2716	2685	2684	2687
Slag, %:						
SiO_2	35.58	35.87	36.21	36.33	36.40	36.39
Al_2O_3	9.81	9.91	9.77	9.64	9.43	9.95
CaO	39.71	39.72	39.57	38.62	38.89	39.34
MgO	11.06	11.15	11.31	11.89	11.94	11.35
Mn	.39	.37	.42	.49	.43	.46
Sul	1.52	1.50	1.46	1.36	1.44	1.38
B/A	1.09	1.11	1.11	1.10	1.11	1.09
B/S	1.41	1.42	1.41	1.39	1.40	1.39
Volume, lbs/NTHM	436	428	451	460	444	457

TABLE 2B
Burns Harbor D Furnace
Summary of Operation

	July 97	August 97	September 97	October 97	November 97	December 97
Production, NTHM/day	6717	6704	6878	6862	6808	6888
Delays, Min/day	72	65	54	40	66	48
Coke Rate, lbs/NTHM	709	702	697	705	701	698
Nat. Gas Rate, lbs/NTHM	2.0	6.0	3.0	4.0	2.0	5.0
Inj. Coal Rate, lbs/NTHM	201	202	207	201	212	218
Total Fuel Rate, lbs/NTHM	912	910	907	909	915	921
Burden:						
Sinter, %	32.8	31.9	32.6	32.0	32.4	32.8
Pellets, %	37.0	67.9	67.2	67.7	67.2	66.8
Misc., %	.2	.2	.2	.3	.4	.4
BOF Slag, lbs/NTHM	11	20	28	18	6	1
Blast Conditions:						
Dry Air, SCFM	145,464	145,881	145,658	146,384	145,346	144,268
Blast Pressure, psig	38.9	39.6	39.5	39.3	39.3	38.6
Permeability	1.27	1.24	1.25	1.28	1.24	1.25
Oxygen in Wind, %	25.2	25.4	25.5	25.4	25.6	25.6
Temp, F	2088	2079	2093	2088	2090	2096
Moist., Grs/SCF	19.0	18.6	19.3	19.3	19.0	21.6
Flame Temp, F	3937	3923	39.44	3946	3977	3894
Top Temp, F	236	225	228	228	218	239
Top Press, psig	17.2	17.3	17.4	17.5	16.9	16.3
Coke:						
H2O, %	5.2	5.5	5.3	5.2	5.1	5.0
Hot Metal, %:						
Silicon	.49	.51	.48	.51	.51	.52
Standard Dev.	.133	.110	.108	.089	.110	.117
Sulfur	.040	.036	.043	.035	.037	.038
Standard Dev.	.021	.011	.015	.009	.014	.022
Phos.	.073	.058	.058	.063	.069	.073
Mn.	.46	.37	.36	.42	.45	.48
Temp., F	2674	2668	2672	2702	2689	2693
Slag, %:						
SiO2	35.94	36.67	36.89	36.25	35.80	35.61
Al2O3	9.85	9.60	9.23	9.37	9.46	9.77
CaO	39.64	40.20	40.30	40.14	39.76	39.57
MgO	11.31	11.13	10.98	11.27	11.43	11.36
Mn	.46	.37	.37	.37	.41	.44
Sul	1.51	1.60	1.57	1.56	1.57	1.53
B/A	1.11	1.11	1.11	1.13	1.13	1.12
B/S	1.42	1.40	1.39	1.42	1.43	1.43
Volume, lbs/NTHM	448	438	441	436	440	449

TABLE 3

INJECTION COAL ANALYSIS
BURNS HARBOR HIGHER ASH COAL TRIAL

Coal	Va. Pocahontas October 1996	Buchanan 6 Train Average Prior to Trial	High Ash Buchanan 4 Train Trial Average
Volatile Matter, %	18.00	19.79	18.75
Sulfur, %	.78	.82	.75
Ash, %	5.30	4.72	7.70
Ultimate Analysis, %			
Carbon	87.10	87.04	84.32
Oxygen	1.23	1.94	2.24
Hydrogen	4.20	4.27	3.88
Nitrogen	1.21	1.21	1.12
Chlorine	.170	.140	.120
Total Moisture, %	5.30	6.77	6.46
GHV, BTU/lb (dry)	14974	15086	14425
Ash Analysis, %			
SiO2	41.50	32.39	41.69
Al2O3	23.58	22.76	23.33
CaO	7.36	10.10	8.27
MgO	1.69	2.05	1.75

C FURNACE PRODUCT COAL SIZING
May 28 - June 23, 1997

		MEAN %	CUM %
+4 Mesh		0	
-4 Mesh	+8 Mesh	.3	0.3
-8 Mesh	+16 Mesh	1.8	2.1
-16 Mesh	+30 Mesh	7.4	9.5
-30 Mesh	+50 Mesh	15.1	24.6
-50 Mesh	+100 Mesh	27.0	51.6
-100 Mesh	+200 Mesh	34.0	85.6
-200 Mesh	+325 Mesh	13.6	99.2
-325 Mesh		.8	100.0
TOTAL		100.0	

TABLE 4

BURNS HARBOR C FURNACE
SUMMARY OF COAL TRIAL OPERATIONS

	HIGH ASH TEST May 28 - June 23, 1997	LOW ASH BASE May 1 - May 27, 1997	PREVIOUS BASE October 1996
Production, NTHM/day	7437	7207	6943
Delays, Min/day	23	55	71
Coke Rate, lbs/NTHM	674	673	661
Nat. Gas Rate, lbs/NTHM	5.0	0	0
Inj. Coal Rate, lbs/NTHM	262	269	264
Total Fuel Rate, lbs/NTHM	940	942	925
Burden %:			
Sinter	34.9	27.0	35.9
Pellets	64.9	72.8	63.8
Misc.	.2	.2	.3
BOF Slag, lbs/NTHM	0	53	5
Blast Conditions:			
Dry Air,SCFM	135,370	135,683	137,000
Blast Pressure, psig	38.3	38.2	38.8
Permeability	1.23	1.25	1.19
Oxygen in Wind, %	28.6	28.5	27.3
Temp, F	2012	2046	2067
Moist., Grs/SCF	20.7	20.4	19.8
Flame Temp, F	3953	4002	3841
Top Temp, F	199	195	226
Top Press, psig	16.6	17.0	16.9
Coke:			
H2O, %	5.0	4.9	5.0
Hot Metal, %:			
Silicon	.49	.51	.50
Standard Dev.	.097	.116	.128
Sulfur	.035	.040	.040
Standard Dev.	.012	.015	.014
Phos.	.073	.069	.072
Mn.	.46	.42	.43
Temp., F	2733	2741	2734
Slag, %:			
SiO2	36.21	36.08	36.54
Al2O3	9.91	9.43	9.63
CaO	39.40	38.86	39.03
MgO	11.32	12.03	11.62
Mn	.45	.42	.46
Sul	1.40	1.45	1.39
B/A	1.10	1.12	1.10
B/S	1.40	1.41	1.39
Volume, lbs/NTHM	461	448	424

TABLE 5

BURNS HARBOR C FURNACE
ADJUSTED COKE RATE COMPARISON

Coke Correction Variables:	BASE 5/1/97 - 5/27/97	HIGH ASH TRIAL 5/28/97 - 6/23/97
Natural Gas, lbs/NTHM	0	5.0
Coke Correction, lbs coke		+6.0
Injected Coal, lbs/NTHM	269	262
Coke Correction, lbs coke		-7.0
Burden:		
Pellets, %	72.8	64.9
Coke Correction, lbs coke		+6.3
Sinter,%	27.0	34.9
Coke Correction, lbs coke		+6.3
Wind Volume, SCFM	135,683	135,370
Coke Correction, lbs coke		+.3
Added Moisture, Grs./SCFM Wind	20.4	20.7
Coke Correction, lbs coke		-.9
Iron Silicon Content, %	.51	.49
Coke Correction, lbs coke		+2.0
Iron Sulfur Content, %	.040	.035
Coke Correction, lbs coke		-2.5
Iron Manganese Content, %	.42	.46
Coke Correction, lbs coke		-1.0
Coke Ash, %	7.70	7.50
Coke Correction, lbs coke		+4.0
Blast Temperature, F	2046	2012
Coke Correction, lbs coke		-5.1
TOTAL COKE CORRECTIONS: lbs. coke	BASE	+8.4
Reported Furnace Coke Rate,lbs/NTHM	673	674
Corrected Furnace Coke Rate,lbs/NTHM		682
Coke Rate Difference from the BASE		**+ 9 Pounds of Coke/NTHM**

TABLE 6

BURNS HARBOR C FURNACE
ADJUSTED COKE RATE COMPARISON

Coke Correction Variables:	BASE October 1996	HIGH ASH TRIAL 5/28/97 - 6/23/97
Natural Gas, lbs/NTHM	0	5.0
Coke Correction, lbs coke		+6.0
Injected Coal, lbs/NTHM	264	262
Coke Correction, lbs coke		-2.0
Burden:		
Pellets, %	63.8	64.9
Coke Correction, lbs coke		-.9
Sinter,%	35.9	34.9
Coke Correction, lbs coke		-.8
Wind Volume, SCFM	137,000	135,370
Coke Correction, lbs coke		+1.7
Added Moisture, Grs./SCFM Wind	19.8	20.7
Coke Correction, lbs coke		-2.6
Iron Silicon Content, %	.50	.49
Coke Correction, lbs coke		+1.0
Iron Sulfur Content, %	.040	.035
Coke Correction, lbs coke		-2.5
Iron Manganese Content, %	.43	.46
Coke Correction, lbs coke		-.8
Coke Ash, %	7.70	7.50
Coke Correction, lbs coke		+4.0
Blast Temperature, F	2067	2012
Coke Correction, lbs coke		-8.3
TOTAL COKE CORRECTIONS: lbs. coke	BASE	-5.2
Reported Furnace Coke Rate,lbs/NTHM	661	674
Corrected Furnace Coke Rate,lbs/NTHM		669
Coke Rate Difference from the BASE		**+ 8 Pounds of Coke/NTHM**

TABLE 7
Burns Harbor C Furnace
GAS/COAL TRIAL EVALUATION

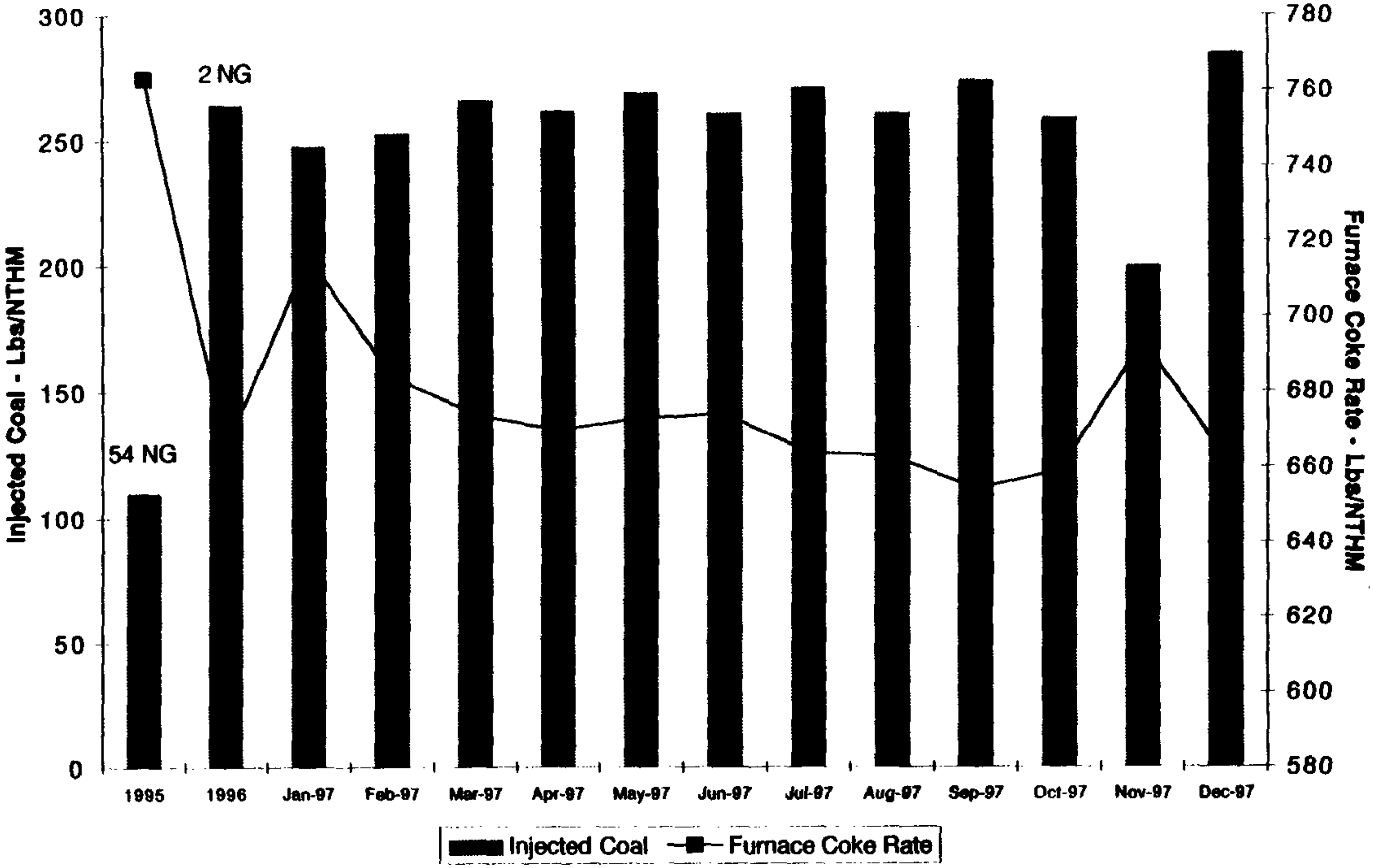
	BASE PERIOD SEPT 97	TRIAL PERIOD 10/24-11/10
Production, NTHM/day	7493	6869
Delays, Min/day	20	100
Coke Rate, lbs/NTHM	**654**	**643**
Nat. Gas Rate, lbs/NTHM	1.0	29.0
Inj. Coal Rate, lbs/NTHM	274	251
Total Fuel Rate, lbs/NTHM	929	924
Burden:		
Sinter, %	33.1	31.7
Pellets, %	65.2	66.9
Misc., %	.2	.2
BOF Slag, lbs/NTHM	27	0
Blast Conditions:		
Dry Air, SCFM	135,800	140,400
Blast Pressure, psig	39.1	38.7
Permeability	1.20	1.28
Oxygen in Wind, %	28.3	27.4
Temp, F	2099	2101
Moist., Grs/SCF	19.7	11.8
Flame Temp, F	4023	3969
Top Temp, F	205	203
Top Press, psig	17.3	17.3
Coke:		
H2O, %	5.3	5.1
Hot Metal, %:		
Silicon	.52	.53
Sulfur	.036	.031
Phos.	.058	.067
Mn.	.38	.46
Temp., F	2694	2725
Slag, %:		
SiO2	36.72	35.96
Al2O3	9.29	9.56
CaO	40.46	38.38
MgO	11.05	12.10
Mn	.36	.14
Sul	1.61	1.44
B/A	1.12	1.12
B/S	1.40	1.44
Volume, lbs/NTHM	446	432
Top Gas Analysis:		
CO, %	25.70	24.82
CO2, %	25.08	24.39
H2, %	4.88	5.19

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	1998

FIGURE 2



Burns Harbor C Furnace - 1997 Injected Coal and Coke Rate Performance

FIGURE 3

Burns Harbor D Furnace - 1997 Injected Coal and Coke Rate Performance

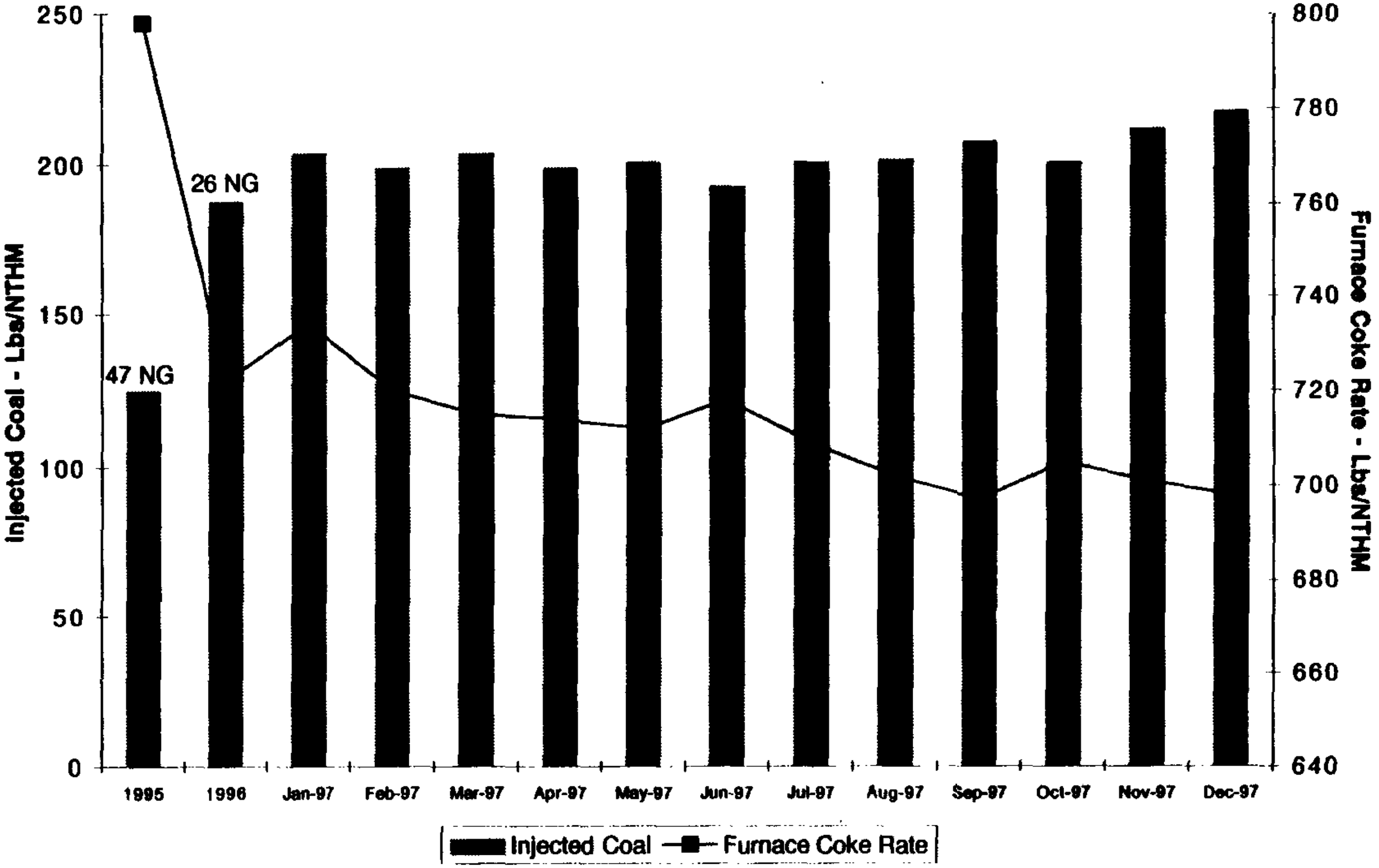


FIGURE 4

Burns Harbor C and D Furnace - Combined Production & Delay Rate

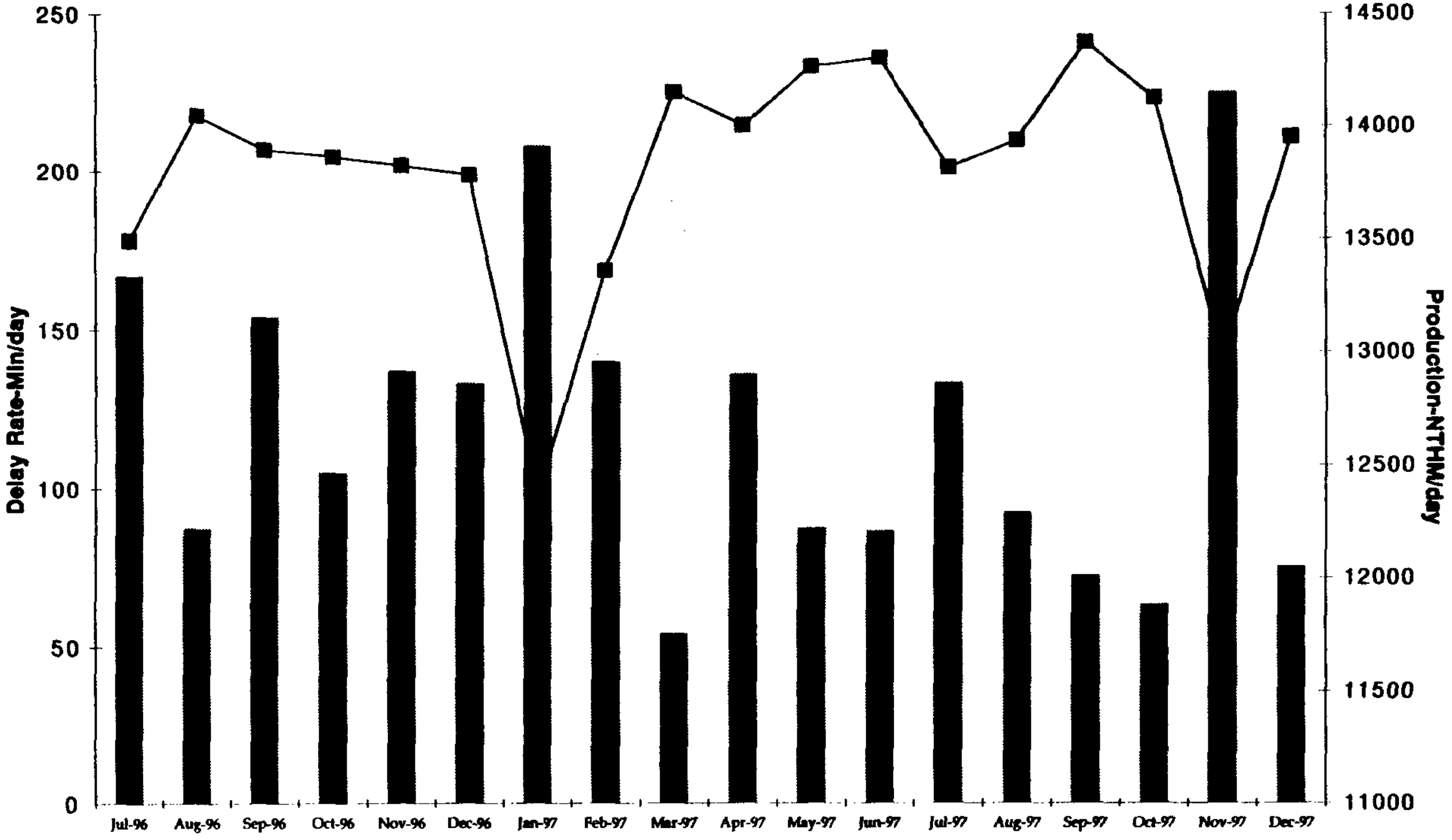


FIGURE 5

Burns Harbor C and D Furnace - Nut Coke Consumption

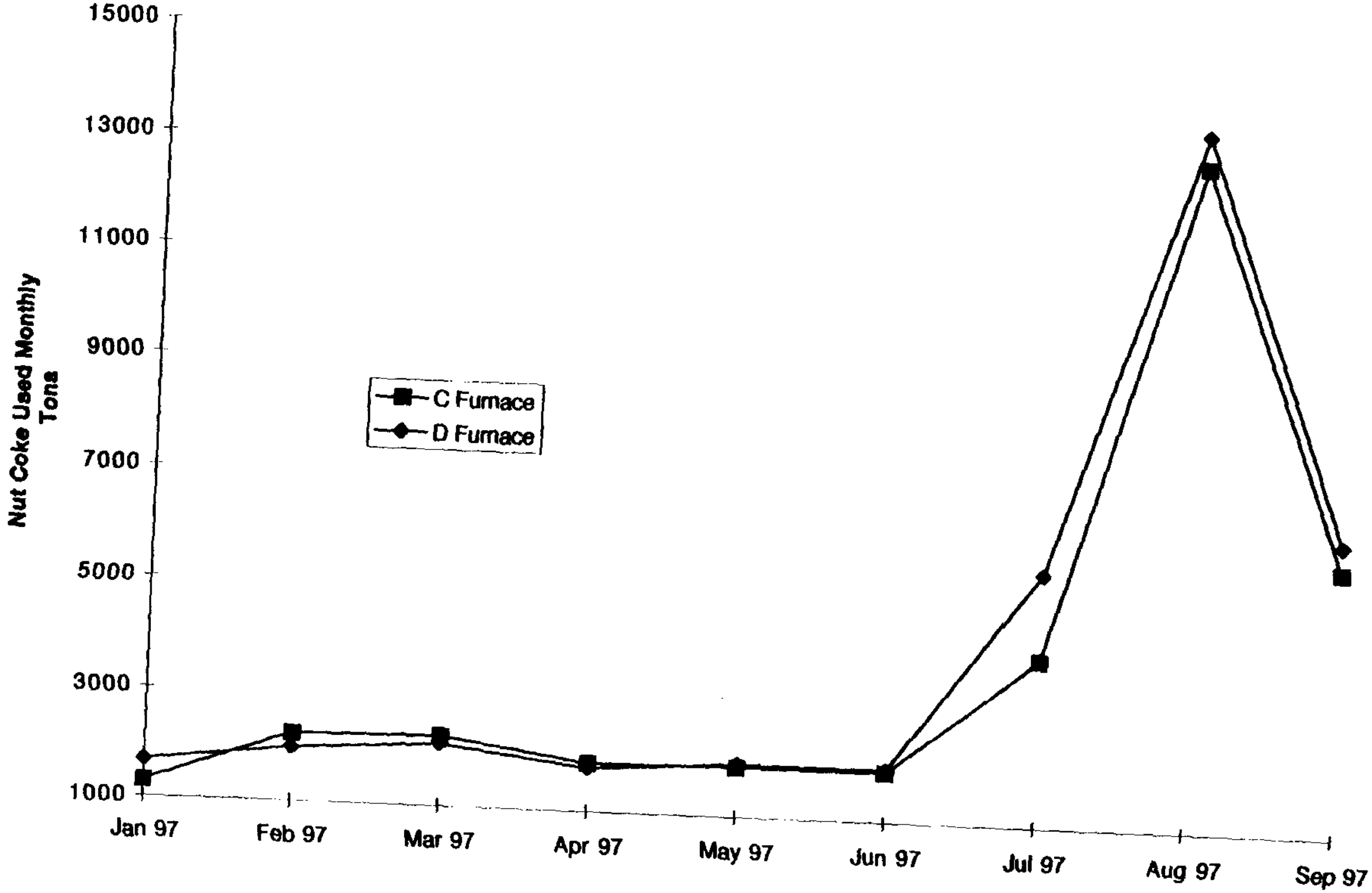


FIGURE 6

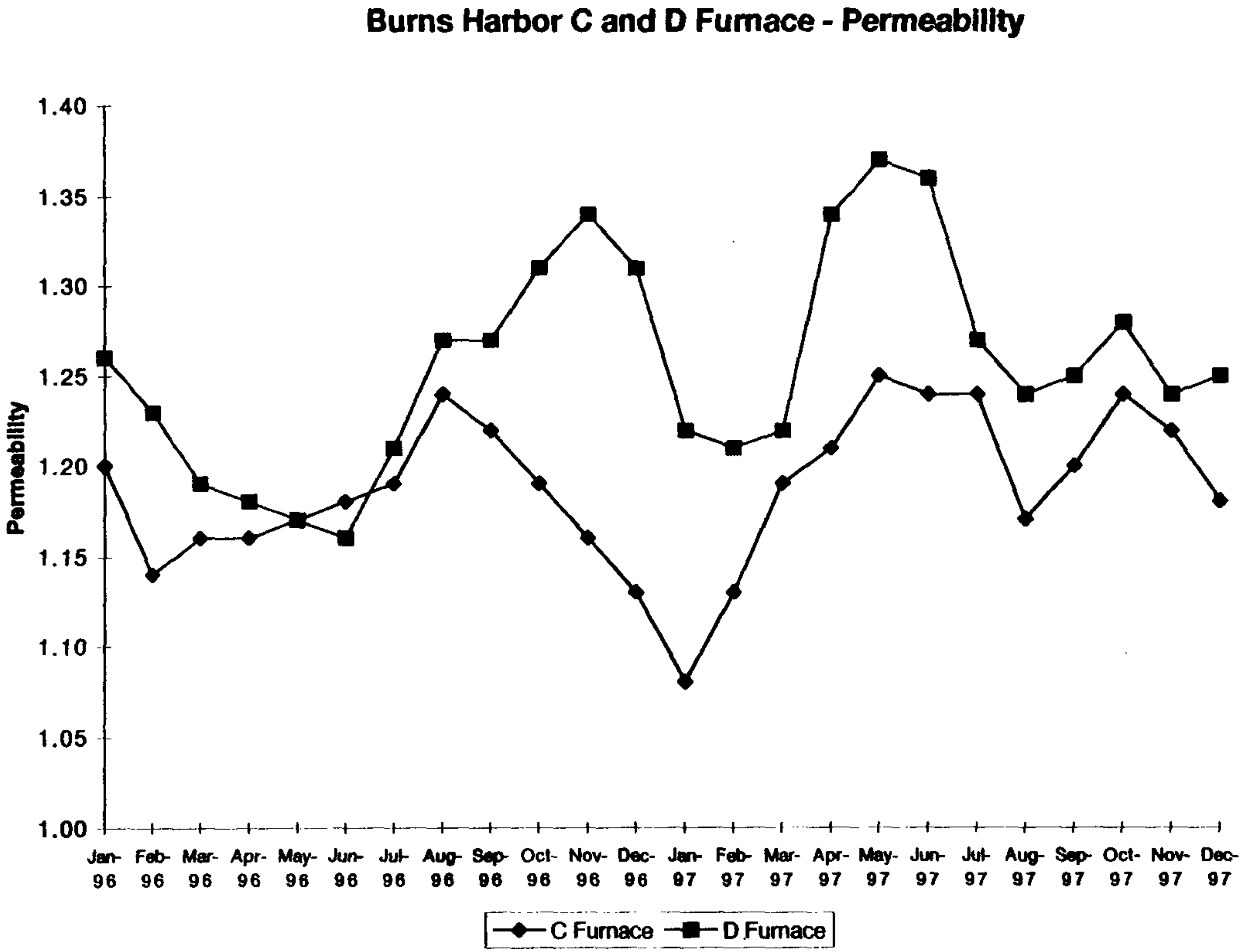

Burns Harbor C and D Furnace - Permeability
Permeability
1.40
1.35
1.30
1.25
1.20
1.15
1.10
1.05
1.00
Jan-96
Feb-96
Mar-96
Apr-96
May-96
Jun-96
Jul-96
Aug-96
Sep-96
Oct-96
Nov-96
Dec-96
Jan-97
Feb-97
Mar-97
Apr-97
May-97
Jun-97
Jul-97
Aug-97
Sep-97
Oct-97
Nov-97
Dec-97
C Furnace
D Furnace

FIGURE 7

Burns Harbor C and D Furnace - Coal Injection Rates

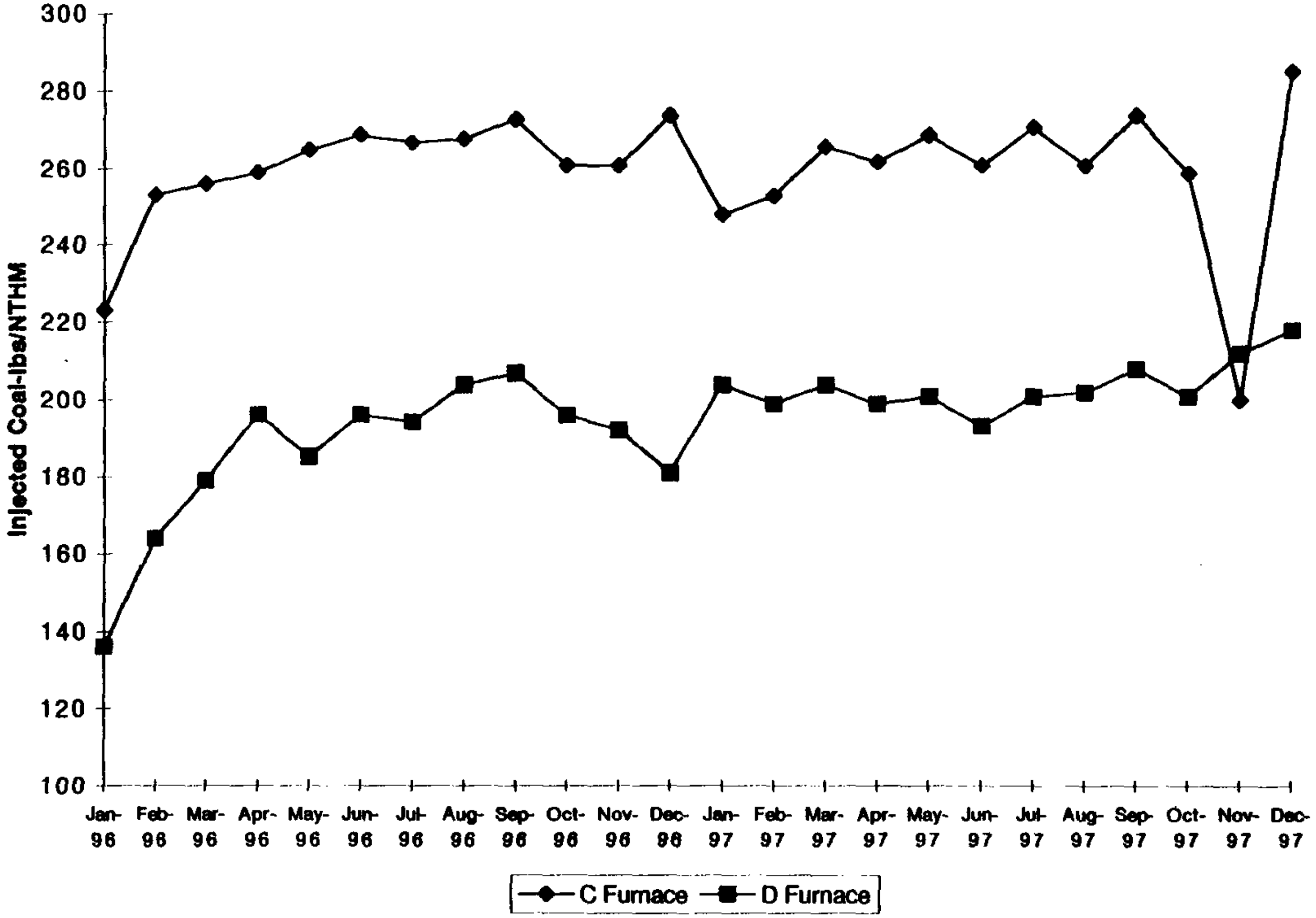


FIGURE 8

Burns Harbor C and D Furnace - Blast Pressure

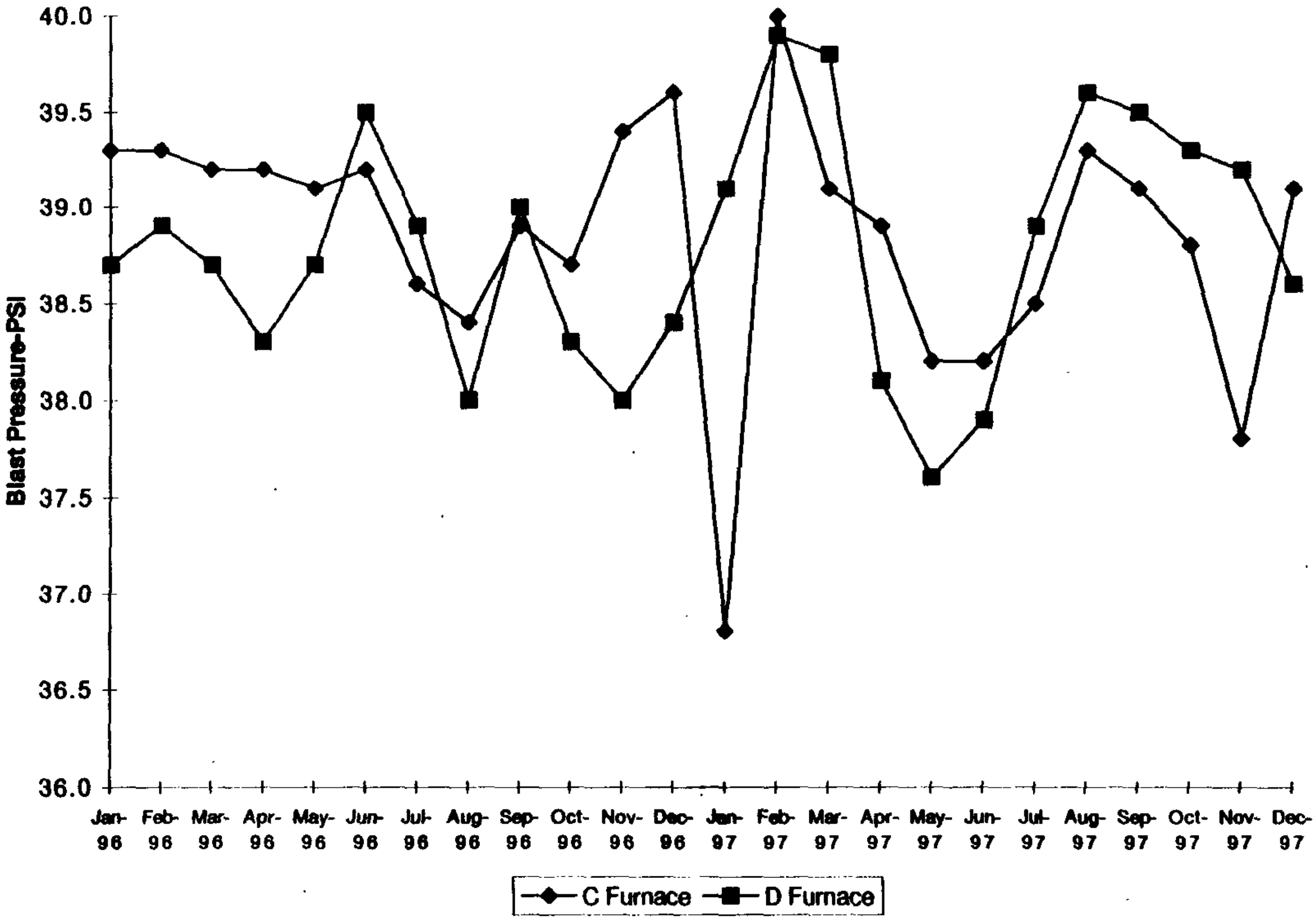


FIGURE 9

Burns Harbor C and D Furnace - Wind Rate

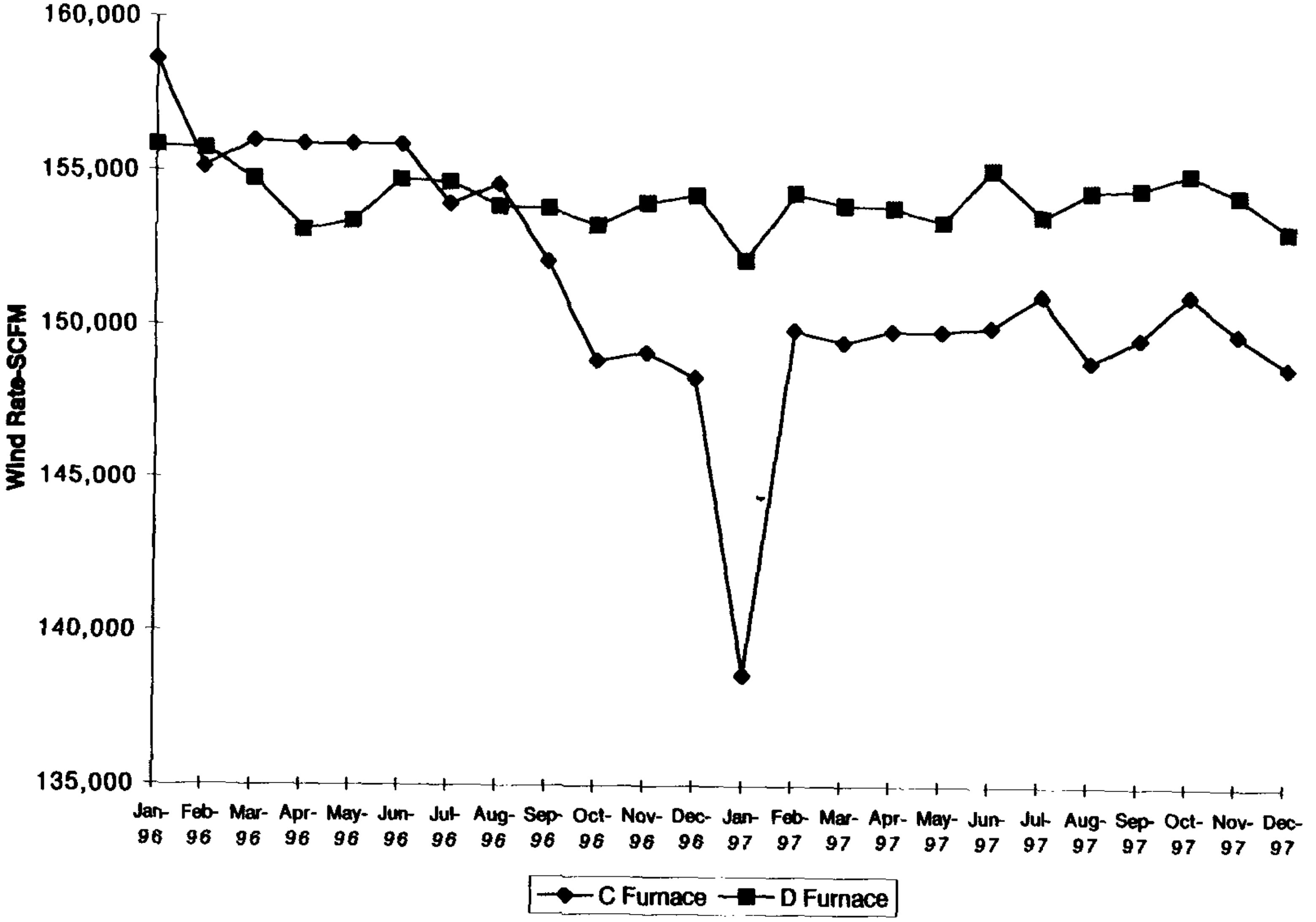


FIGURE 10

BURNS HARBOR C FURNACE - INWALL REFRACTORY TEMPERATURE

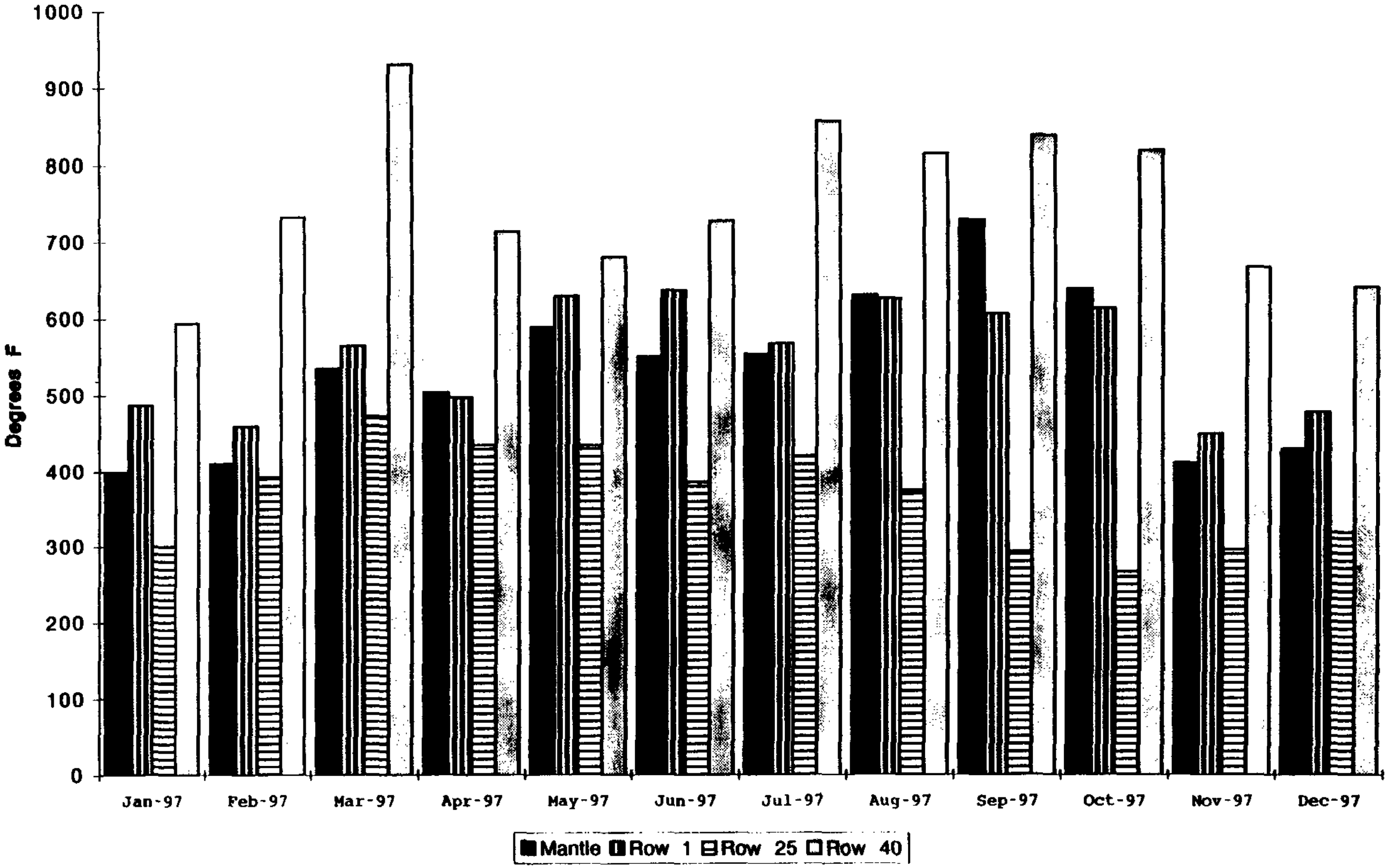


FIGURE 11

BURNS HARBOR C FURNACE THERMAL LOADS

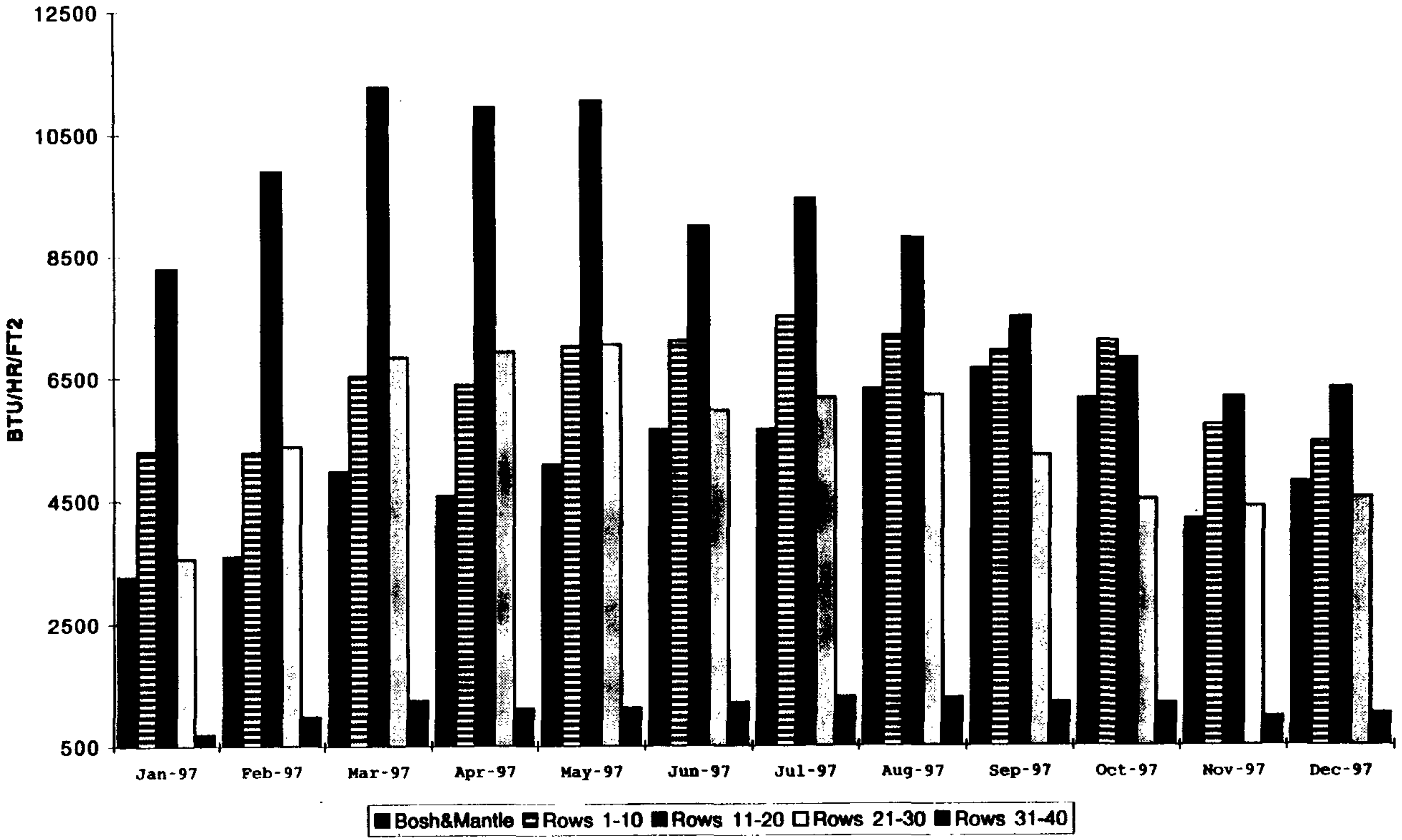
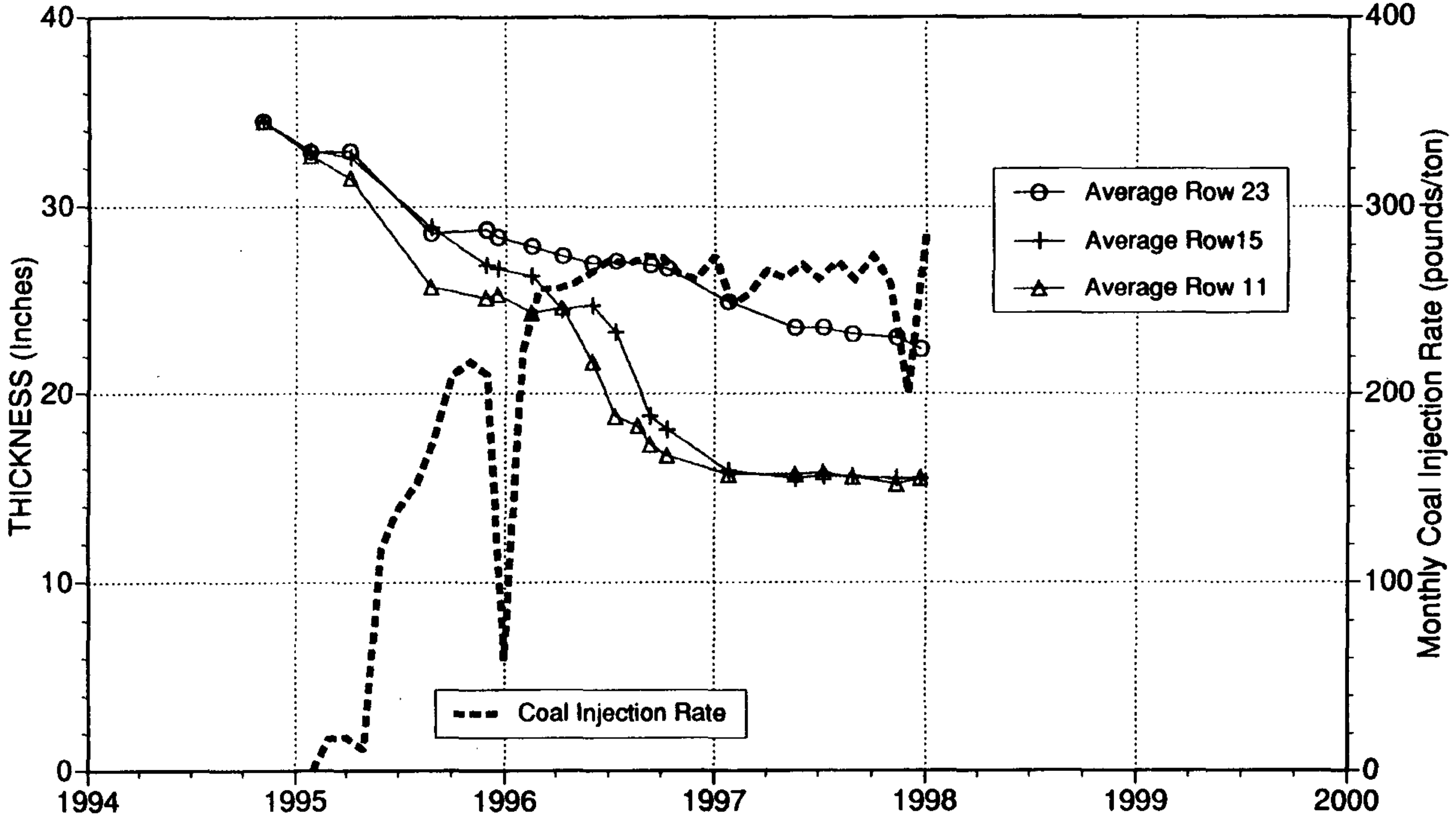


FIGURE 12.
BURNS HARBOR "C" FURNACE—5TH CAMPAIGN
AVERAGE STACK LINING THICKNESS MEASUREMENTS



Date Blown In: 11/4/94
Date of Last Measurement: 12/22/97
RAS/JCM

FIGURE 13

BURNS HARBOR D FURNACE - INWALL REFRACTORY TEMPERATURE

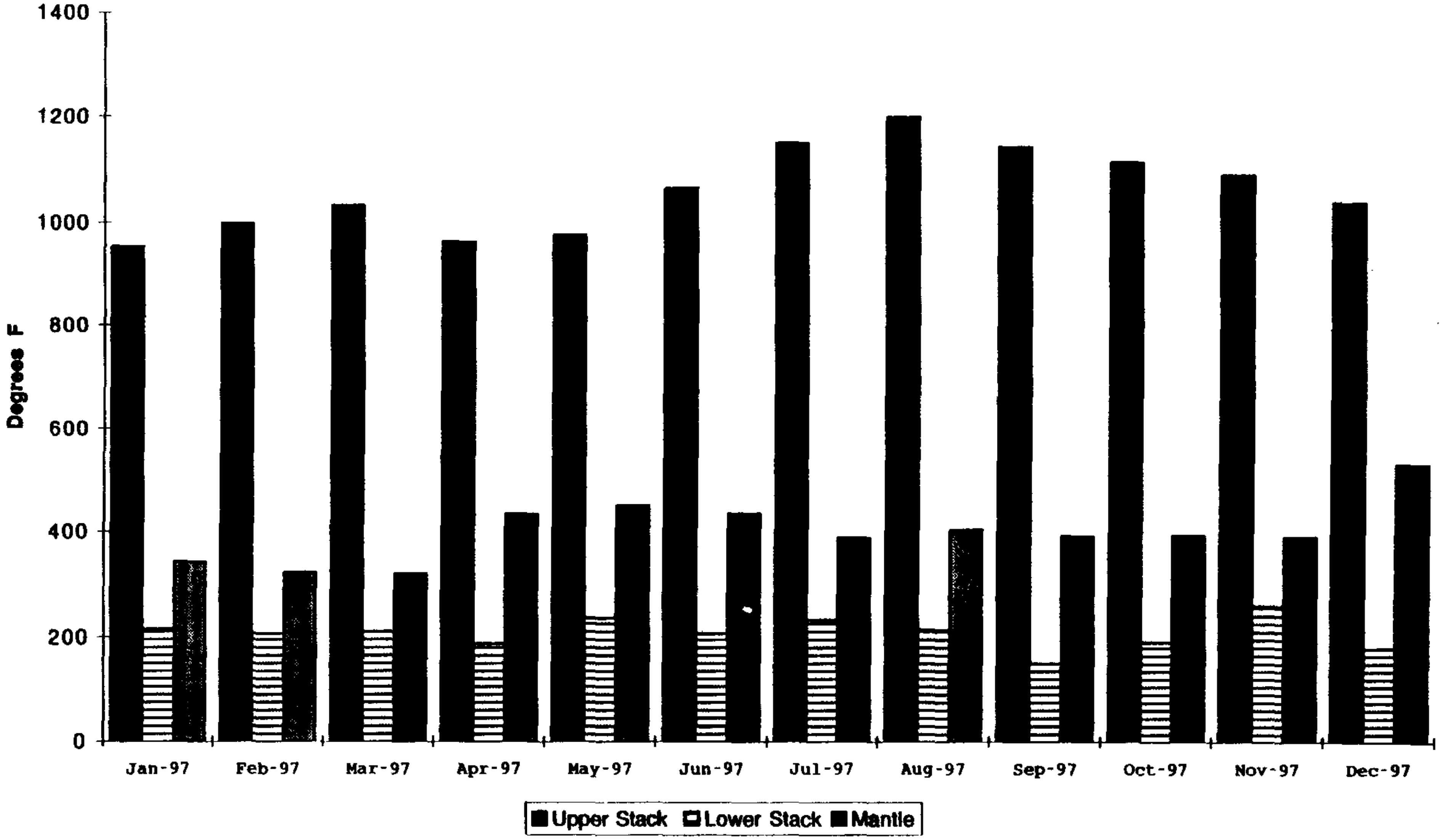


FIGURE 14

BURNS HARBOR D FURNACE - THERMAL LOADS

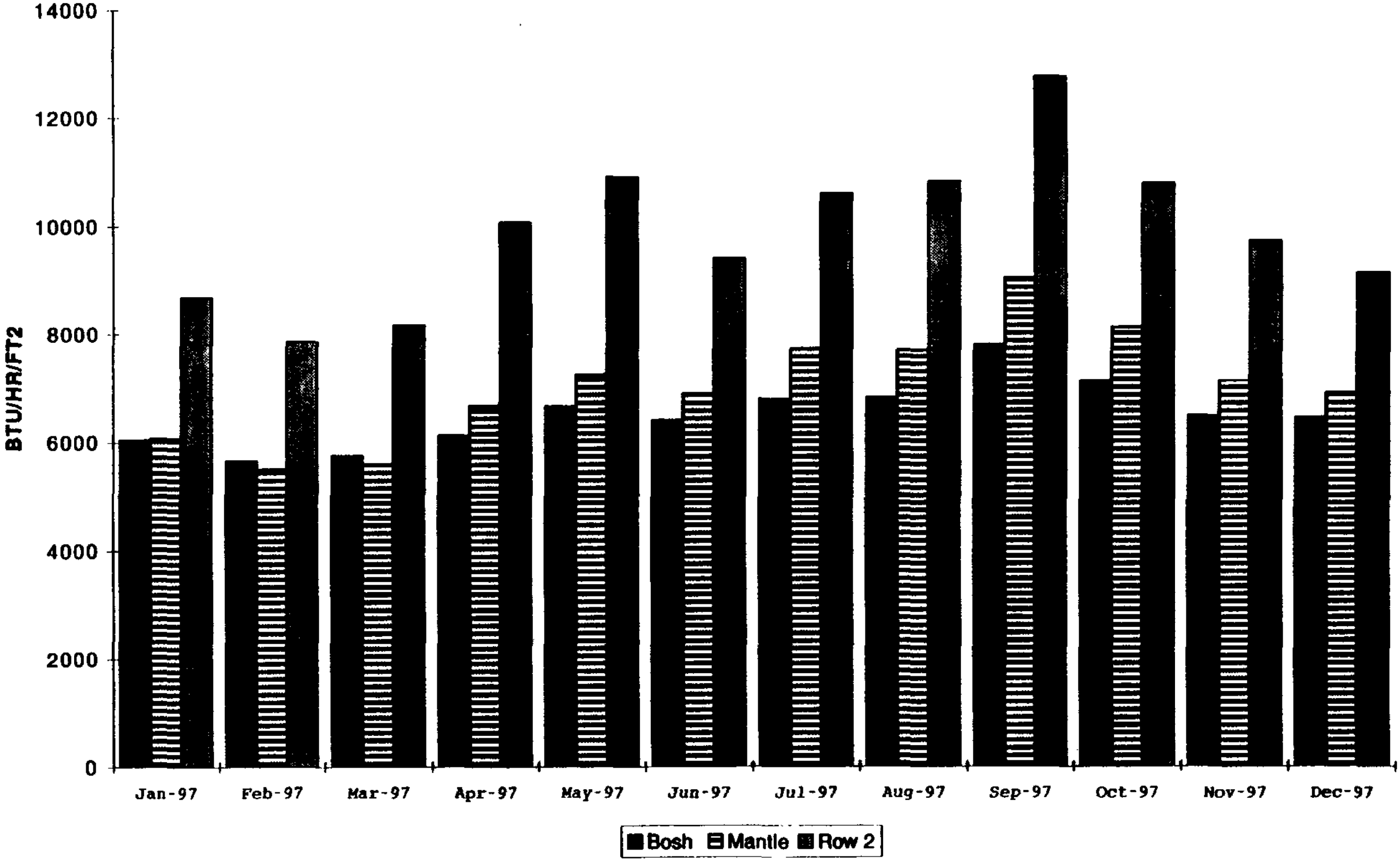


FIGURE 15

BURNS HARBOR D FURNACE - THERMAL LOADS

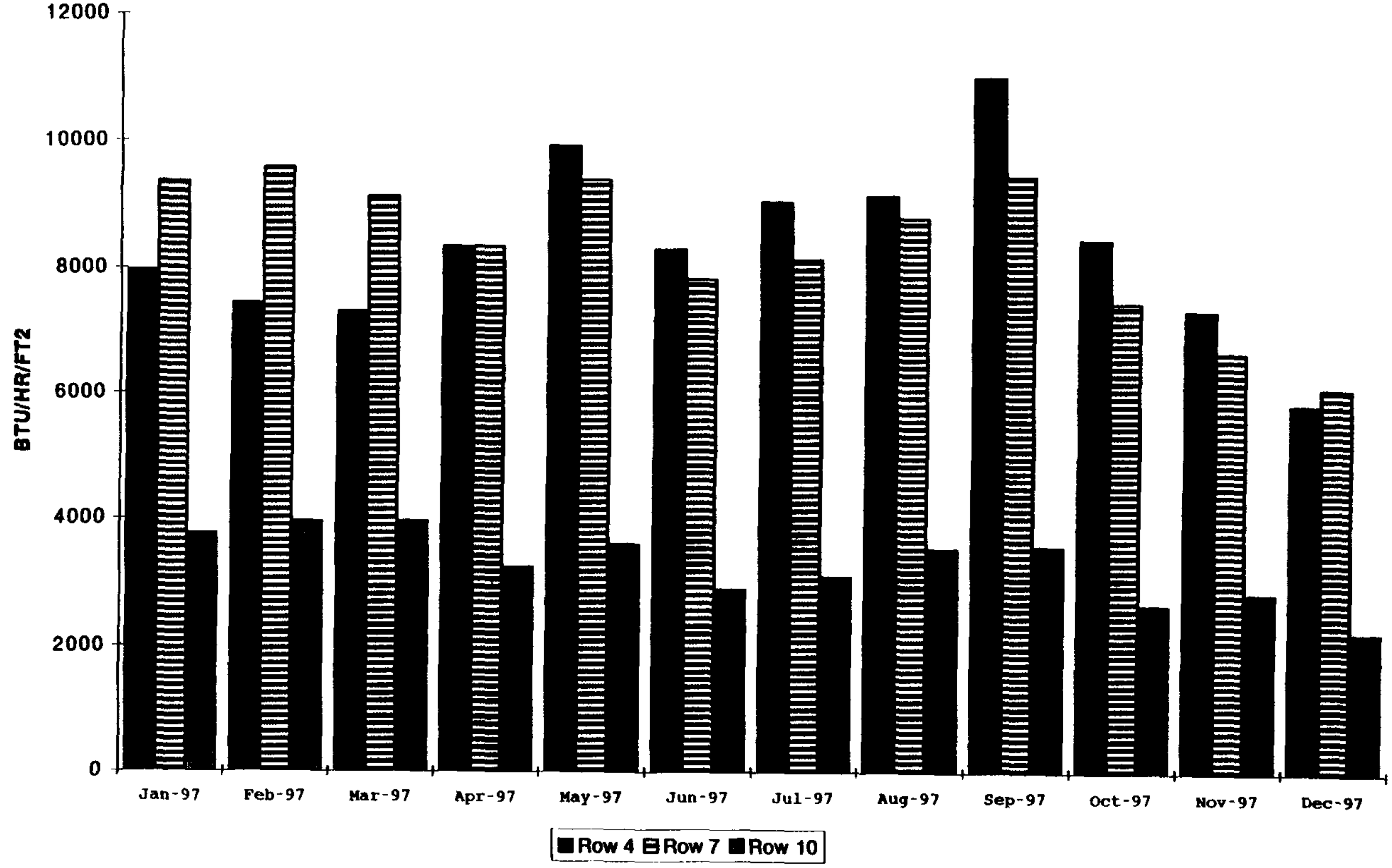


FIGURE 16

BURNS HARBOR D FURNACE - THERMAL LOADS

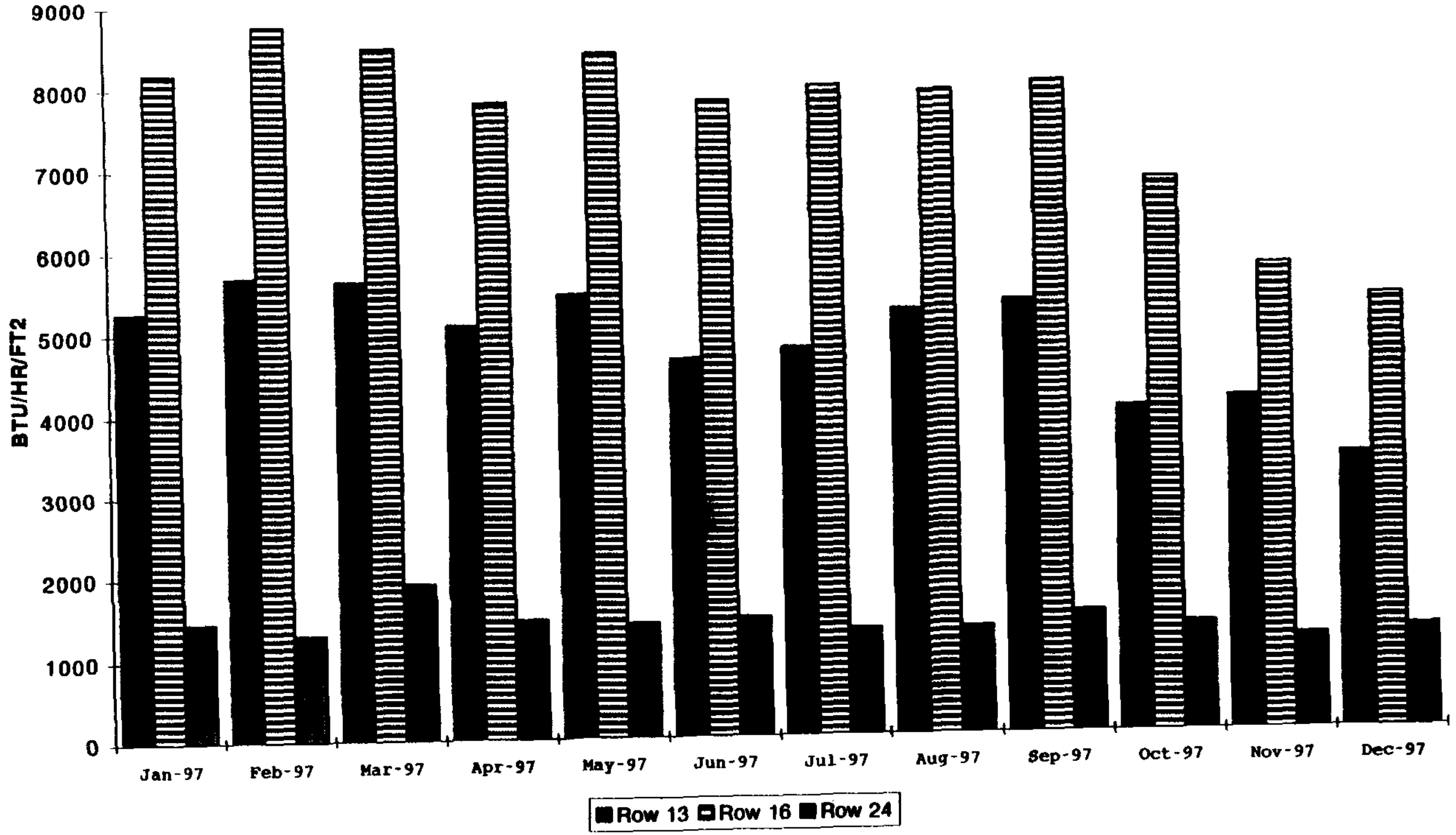
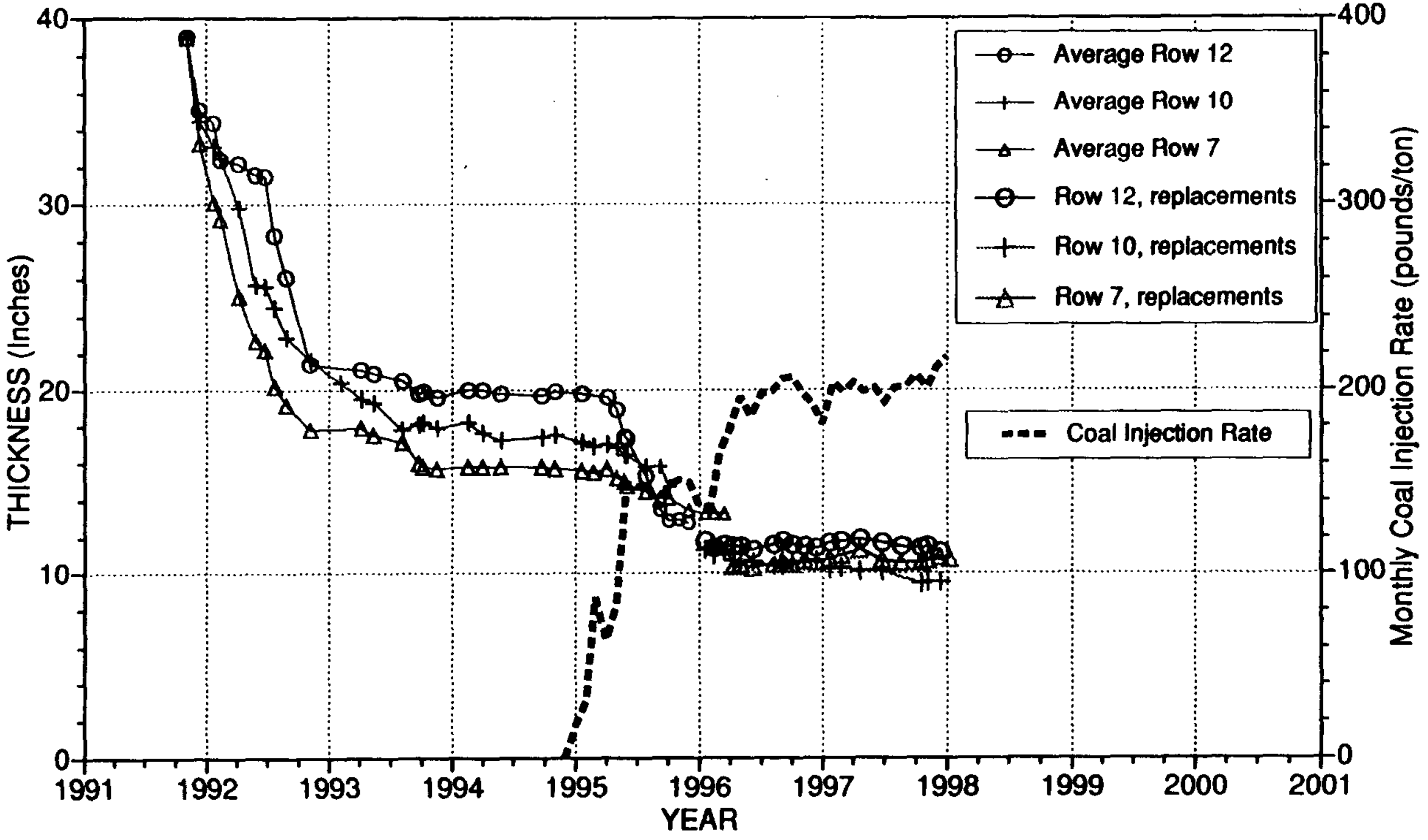


FIGURE 17.
BURNS HARBOR "D" FURNACE—5TH CAMPAIGN
AVERAGE STACK LINING THICKNESS MEASUREMENTS



Date Blown In: 11/4/91
Date of Last Measurement: 1/8/98
RAS/JCM