THE UNIVERSITY OF MICHIGAN
COLLEGE OF ENGINEERING
Department of Chemical and Metallurgical Engineering

Final Report

PROCESS VARIABLES IN GRAY AND DUCTILE IRON PRODUCTION FROM A BASIC CUPOLA

R. A. Flinn
P. K. Trojan
J. E. Brokloff
D. L. Sponseller
W. B. Pierce

ORA Project 04599

under contract with:

THE BUDD COMPANY
DETROIT, MICHIGAN

administered through:

OFFICE OF RESEARCH ADMINISTRATION   ANN ARBOR

April 1962

PREFACE

The authors express their appreciation to the Budd Company and in particular to Mr. Earl Morrison for monetary support of this investigation.

The authors also wish to thank the following individuals who helped in the various experimental phases of this investigations: Messrs. D. Ashby, B. Avitzur, B. Bruss, J. Judd, H. Kunsmann, C. Riva, F. Rote, G. Tuffnell, and M. Weins.

TABLE OF CONTENTS

TABLE OF CONTENTS (Concluded)

LIST OF ILLUSTRATIONS

Table Page

Figure

LIST OF ILLUSTRATIONS (Concluded)

SUMMARY

It is often highly profitable to replace an acid-lined cupola with a basic-lined cupola because steel scrap ($25-$35/ton) can then be substituted in the charge for higher priced pig iron ($55-$60/ton). In addition, because of the refining action of the basic cupola, the resulting metal is very low in sulfur and can be used for either gray iron or nodular iron production.

The purpose of this research is to investigate for The Budd Company the advantages and optimum conditions for melting in their new water-cooled basic cupola. By using the 30-in.-diam experimental cupola at Michigan, a large number of variables can be investigated in detail with accuracy, at low cost, and without disturbing production at the plant.

This report summarizes the results of ten experimental heats. The data indicate the importance of many variables in optimizing operations. The chief commercial interest lies in the problems of carburization (which determines the amount of steel substituted for pig) and desulfurization (which determined the suitability of the metal for nodular iron production). The discussion takes up these points first, followed by consideration of general conditions for good cupola operation and a review of the properties of the gray and nodular irons which were produced.

The data show the significance of coke ratio, type of steel charge, calcium carbide additions, and cupola design (at well and dam) for carburization. It is possible to use charges composed entirely of steel and foundry returns (no pig iron). Desulfurization is affected by slag basicity, slag volume, and cupola design. Values as low as .006% S were obtained. This represents the lowest sulfur level ever reported for cupola operation. The experiments provide a good deal of operating data concerning smooth basic cupola operation. The basic iron from the cupola can be inoculated either with ferrosilicon to produce a good grade of gray iron or with magnesium alloy to produce nodular iron of excellent properties.

Recommendations for future work are included.

I. INTRODUCTION

In the foundry modernization program at The Budd Company, a basic cupola is being used to replace the acid-lined cupola as a melting instrument. This will enable the foundry to replace pig iron with less expensive steel scrap such as punchings, turnings, and bales. In addition, the basic cupola refines the metal, removing sulfur, and therefore provides excellent base metal for the production of gray iron or nodular iron for wheels and drums.

The purpose of these experiments in the small (30-in.-diam) cupola at Michigan was to determine the principal variables of importance in the Budd operation. The same metal, coke, and flux materials were employed in practically all cases.

Before discussing the actual experiments, a short review of the chemistry of the basic cupola may be helpful. The elements of principal concern are carbon, sulfur, phosphorus, silicon, and manganese. Since the work is directed principally at carbon and sulfur control, we will consider only these elements here.

A. CARBON

In practically all cupola operations, acid or basic, there is some gain in carbon as the liquid metal comes in contact with the incandescent coke. There is, however, a wide variation in the actual amount of carbon dissolved and it is this point which requires careful control.

The driving force leading to solution of carbon can be shown by the following data for the maximum solubility of carbon in a 2% silicon cast iron at various temperatures:

°F	Max % Carbon
2200	4.0
2400	4.7
2600	5.2

In an acid-lined cupola the carbon dissolved from the coke is limited because the slag forms a protective film over much of the coke surface. To attain a level of 3.6% carbon in brakedrums, for example, it is necessary to employ approximately 40% pig iron containing about 4.2% carbon.

By contrast, in a basic-lined cupola the slag does not coat the coke and much higher carbon solution is obtained. For example, it is shown in the body of this report that a cupola charge can be made up entirely of low-cost steel scrap (65%) and normal foundry returns, gates, and risers (35%). This will have an average carbon content of 1.3%, but due to carburization in the cupola, it will produce liquid iron with 3.6-4.0% carbon as desired. This replacement of 40% pig iron in the charge with steel will result in a saving of $12.00 per ton of metal melted, assuming a cost differential of $30.00 per ton between pig iron and steel. To control this carbon solution to acceptable limits is one of the objectives of this work, and this point will receive fuller attention in the discussion.

B. SULFUR

It is desirable to produce iron with minimum sulfur for two reasons. In gray iron, sulfur increases chill depth leading to hard spots. This can be minimized by manganese additions. In nodular iron, sulfur must be removed before magnesium can be dissolved in the iron. If magnesium itself is used for this purpose, much heavier additions of inoculant are needed. Furthermore, the magnesium sulfide which is formed is a fertile source of cope surface inclusions.

To reduce the sulfur content of the metal there are the following possibilities:

(1) Lower the ingoing sulfur in metal charge, coke, and flux.

(2) Maximize the amount of sulfur in the slag.

By using steel (.03% average S) versus foundry pig iron (.12% average S), the ingoing sulfur is appreciably reduced. The coke usually contains .5-.8% sulfur and therefore a low coke ratio is helpful in lowering the ingoing sulfur.

The most important point in sulfur control, however, is the slag. To express the efficiency of a given slag in removing sulfur, the <u>distribution ratio</u> is used:

$$\text{Distribution ratio} = \frac{\%\ \text{sulfur in slag}}{\%\ \text{sulfur in metal}} .$$

For example, a good basic slag would contain .20% S when the metal was .01% S, giving a ratio of 20:1. The factors which lead to good desulfurization are a high ratio of bases to acids in the slag as given by the molar ratio

$$\frac{CaO + 2/3\ MgO}{SiO_2 + Al_2O_3}$$

and a low iron oxide content. Bases such as CaO and MgO are important because the sulfur is then held more tenaciously by the slag, perhaps as calcium or magnesium sulfide. The low iron oxide is important because a high iron oxide favors the breakup of the otherwise stable sulfides and then the sulfur reverts of the metal.

By contrast, in an acid cupola the iron oxide in the slag and low basicity give poor desulfurization ratios, of the order of 1:1 to 5:1.

II. PROCEDURE

Throughout these experiments, the 30-in.-diam basic cupola in the Cast Metals Laboratory at Michigan was used. It has been found that this cupola is the smallest unit which gives consistent, reproducible data which are representative of larger operations. When cupolas of smaller diameters have been used, the large ratio of wall surface to cross-sectional areas results in unrepresentative data, a strong tendency for charge hangup in the stack, and other effects. The melting rate per square foot of hearth area, air and coke consumption, and other operating characteristics of the 30-in. cupola are representative of the commercial range.

Many variables were studied in the course of this investigation; however, certain operating characteristics were maintained constant to establish a reference base. Therefore the elements common to all heats will be discussed first after which the variables will be enumerated to outline the scope of the research.

A. CUPOLA AND AUXILIARY EQUIPMENT

The cupola and runner are sketched in Figs. 1 and 2. The lining above the tuyeres is "Gundol" (double burned dolomite) while the well and runner lined with "High-Al-Ram-G" (high percent alumina and graphite). It should be noted that slag can be removed from both the front and back of the cupola as desired. Figure 3 is a detailed sketch of the back-slagging holes.

A Roots-Connersville blower was used with the characteristics below (12 x 42 in.):

Inlet volume: 2500 cfm
Inlet pressure: 0 psig
Discharge pressure: 1 psig
Blower speed: 335 rpm
Brake horsepower: 13.2

The actual delivery volume of air was determined by measurement of the blower speed. Provision was also made for oxygen enrichment of the blast, although it was not used in this series of experiments.

B. CHARGING EQUIPMENT

The cupola was charged by a conical drop bottom bucket which was loaded and transported on the charging floor by a one-half ton electric hoist. The charge bucket was 26-in. ID x 24 in. high with a 2-in. supporting flange 5 in. wide. A three-point support arrangement was used to hold the bucket in the cupola when the charge was dropped.

C. METAL HANDLING

Metal from the cupola ran directly into a 3000-lb forehearth lined with Shamva-Mullite. Most of the metal was then pigged into two sizes, 75 lb and 30 lb. The smaller pigs were used for the next heat to approximate the normal inplant scrap returns. Some metal was also withdrawn in hand ladles to supply the induction furnaces for duplexing and to provide metal for subsequent magnesium treatment. In the latter heats a runner extension was devised so that the forehearth could be bypassed and liquid metal could be run directly into a hand ladle. In this way metal at 2800°F could be tested in the nodular iron treatment.

D. PATCHING AND CUPOLA REPAIR

There was always a certain amount of burned out refractory which had to be replaced after each heat. In most instances hand patching was all that was necessary; however, a new layer of "Gundol" was blown in approximately every third heat. Below is a representative burn out for each heat based upon 1 to 1-1/2-hr operation.

Height Above Lip (doorsill), in.	Thickness Lost, in.
12 (High-Al-Ram G)	1/4
Top of tuyeres (Gundol)	1-1/2
36 (Gundol)	1
48 (Gundol)	1/2
72 (Gundol)	0 to 1/4

After every heat the dam and slag notch in the runner were completely removed and replaced.

E. CHARGES

The charges, varied somewhat for each heat, are given in Appendix I. However, an effort was made to maintain a 65% steel charge with the balance scrap returns and lump 50% ferrosilicon. In this way the ingoing carbon and silicon were approximately 1.3% and 1.5%, respectively, for each heat except for the deviations noted in Appendix I. The scrap returns were pigs poured from the previous heat while the steel was automotive scrap from the Budd Co. approximating a good quality SAE 1008.

The total metallics in each charge was 400 lb while nonmetallics varied from 85 to 115 lb. Approximately seven charges were required to fill the cupola. The coke used was 3-1/2 x 4 in. of the following analysis:

Coke Analysis, %	
Free Carbon	91
Volatile Matter	0.9
Ash	7.6
Sulfur	0.5

Ash Analysis	
SiO_2	53.00
Fe_2O_3	4.70
Al_2O_3	35.65
CaO	2.10
MgO	1.47
SO_3	1.58
Inert	1.50

F. MELTING

Continuous performance plots for each heat are included in Appendix I and are fully discussed in the following section. For simplification, the tables of chemical analyses do not include Mn or P which ranged from 0.22-0.32 Mn and 0.012 to 0.028 P.

G. DUCTILE AND DUPLEX IRONS

In the production of nodular cast iron, two inoculation procedures were used, transfer and plunging. In the transfer technique the cupola metal was tapped on to Noduloy 8-C (46.1% Si, 9.6% Mg, 1.14% Ca, 0.64% Ce) after which it was transfered to a ladle containing late silicon as 85% ferrosilicon (aluminum bearing).

Plunging was accomplished in a special deep ladle and plunging bell as shown in Fig. 4. The ladle was lined with Shamva-Mullite and approximately 150 lb of metal were treated each time. For this quantity of metal, .88 lb of No. 2 Sil-Mag-M were used (61.6% Si, 3.6% Ca, 22.4% Mg, 1.50% rare earths). The treated metal was then used to pour spiders, drums, wedge castings, chill wedges, microspecimens, etc.

Metal to be duplexed for gray iron was placed in a 60-lb capacity 50-kw, 3000 cycle induction furnace. Steel, 50% ferrosilicon, and ferromanganese were then added for chemical control after which the metal was tapped with a late silicon addition as 85% ferrosilicon (aluminum bearing).

More complete information is included in the next section, in Tables I, II, and III, and Appendix II.

III. RESULTS AND DISCUSSION

A short summary of the data from the ten cupola heats are given in Table I. Using this table and the individual heat sheets of Appendix I the data may be reviewed under the following sections:

A. Carburization and carbon control.
B. Desulfurization.
C. Important operating characteristics of the basic cupola.
D. Properties of gray and nodular irons.

A. CARBURIZATION AND CARBON CONTROL

The data of Table I indicates that it is possible to reach the desired level of carbon while using only steel and foundry returns in the cupola. The ratio of approximately 65% steel, 35% returns was selected for this investigation in view of present practice at the Budd Co. but a still higher steel ratio can probably be used.

The important variables affecting carbon content in these tests are (1) time after tap, (2) amount of coke in charge, (3) calcium carbide in charge, (4) design of cupola bottom, and (5) type of metal charge (bales vs. punchings).

1. Time After Tap.--There is a trend toward higher carbon at the beginning of the heat than at, for example, 20 min after tapping, because the cupola is not tapped until about 25 min after the blast is turned on. Metal begins to enter the well of the cupola about 5 min after the blast is on. This early metal has a longer contact time with the coke and therefore shows greater carburization. While only a small amount of early metal is involved, the carbon could be reduced by using a shorter time interval between blast on and tap.

2. Amount of Coke in Charge.--In the last four heats (7-10) the coke was reduced from 17.5 to 15% of the metal charge weight. This resulted in a generally lower carbon level, particularly as the cupola approached steady-state operation. It is true that other variables were changed at the same time, such as spar and lime, but the lower carbon is due to the combined effect of these variables and is in line with observations of general practice.

Besides economic reasons, it is advisable to strive for minimum coke level because of several effects. Excess coke reduces melting rate since the extra material has to be burned away before the metal higher in the stack reaches the melting zone. Furthermore the sulfur and ash of the excess coke must be removed by the slag. The melting temperature was also adequate at the lower coke levels.

3. Calcium Carbide in Charge.—In most cases 1.5% calcium carbide was used in the flux charge to promote basic, reducing conditions. Heat No. 7 vs. Heat No. 8, for example, shows that the carbon level is reduced when the carbide is removed.

The use of calcium carbide in the cupola is receiving increased attention since the satisfactory development of a cheaper, lower melting point grade in West Germany. While the standard grade was used in these experiments, a sample of the new type should be tested.

4. Design of Cupola Bottom.—In all heats except No. 9 the cupola bottom was in the shape of a bowl as shown in Fig. 5. In Heat No. 9, the bottom was sloped upward in all directions from the tap hole at a pitch of 1 in./ft. In the latter case there was a much smaller bath of metal in contact with coke. This resulted in lower carbon content. At the 20-min mark, for example, the carbon was 3.37% in Heat No. 9 compared with 3.94% in Heat No. 8. This technique provides, therefore, another method of carbon control.

5. Type of Metal Charge (Punchings vs. Bales).—Metal punchings (approximately 1/4-in. thick) were used in all charges except No. 10 in which small bales were employed. From the preliminary data on this single heat, it appears that the bales result in lower carbon content. Even though the bale is madeup of light strips and sheets, it is a relatively large mass to heat and melt. The thermal conductivity is much lower than in a solid piece of metal because of the many spaces and the contact resistance of the surfaces. Because of these effects, the center of the bale reaches the melting zone at a lower temperature than the punching, for example. As a result the carbon is somewhat lowered. Further experiments, varying the bale dimensions, should be helpful in assessing the effects of both briquettes and bales.

B. DESULFURIZATION

The data of Table I and the appendixes indicate that very low sulfur contents (< .01% S) can be obtained consistently with modest amounts of limestone and other flux. This liquid metal is ideal for the production of ductile iron at minimum cost. A lower manganese level is suggested since for the standard gray iron manganese is contained as manganese sulfide.

The variables affecting desulfurization will be discussed here under (1) slag composition—basicity and FeO content; (2) calcium carbide; and (3) slag depth.

1. Slag Composition—Basicity and FeO Content.—In most discussions of desulfurization the basicity of the slag is considered to be a predominant variable. Actually the data of this report indicate that good desulfurization can be attained with relatively low basicity provided the iron oxide content of the slag is low. An examination of Table I and Appendix II shows that in Heat Nos. 1, 2, and 3 the basicity was comparable to that of later heats but the iron oxide was over 2%. This effect was produced by an air leak discussed in Section C. The combined effect of increased FeO and lowered basicity is seen in Heat No. 7, in which 1.3% FeO and .8 basicity result in the highest sulfur level of the group Heat Nos. 5-10. Figure 6 is a complete plot of all heats.

2. Calcium Carbide.—In all heats except No. 7, 6 lb of calcium carbide per charge was added. This modest (1-1/2%) addition leads to higher carbon and lower sulfur. Further work is needed to explore the effect of replacing the calcium carbide with an equivalent amount of calcium in the form of limestone since the omission of the carbide led to a severe decrease in basicity in Heat No. 7. As seen from the log sheet for this heat, the basicity never exceeded 1.0 in the samples taken from the front of the cupola.

3. Slag Depth.—One of the interesting new developments in this research was the indication that the depth of slag inside the cupola may be important in controlling desulfurization. The variation in dam height and tap-hole dimensions may be summarized as follows:

Heat	Dam Height Above Top of Tap-Hole	Tap-Hole
1	2 in.	1.5 in. diam
2	2-3/4	1.5 in. diam
3	2	1 x 2 sq
4	3	1.5 x 3.5 sq
5	4	1.5 x 3.5 sq
6	4	1.5 x 3.5 sq
7	5	1.5 x 3.5 sq
8	5	1.5 x 3.5 sq
9	5	1.5 x 3.5 sq
10	5	1.5 x 3.5 sq

The degree of desulfurization which was accomplished in the latter heats with a modest flux charge may be the result of the high slag layer in the cupola. Occasional analyses were taken from the top of this layer (see Appendix I) and in most cases these were higher in FeO. This indicates that the upper portion of the slag layer can protect the lower region from oxidation and therefore produces better desulfurization. This point needs further investigation.

C. IMPORTANT OPERATING CHARACTERISTICS OF THE BASIC CUPOLA

In the course of the investigation a number of operating problems were successfully overcome. Since these problems may recur at the Budd Co., a discussion here may be helpful. These subjects, which are not necessarily interrelated, will be reviewed in the following order: (1) charge materials; (2) dam and tap-hole relationships; (3) tap-hole procedure; (4) cupola well design; (5) bed height; (6) operating ratios.

1. Charge Materials.—To reach the desirable operating characteristics of the later heats, a number of changes in charge materials were necessary.

The original source of fluorspar provided material which was at most 50% fluorspar (CaF_2) mixed with limestone and other impurities, even galena (PbS). Some of the difficulties in the early heats in obtaining a fluid slag can be traced to this. In later heats a better grade of briquetted fluorspar (94% CaF_2, 6% inert organic bond) was employed satisfactorily.

The dolomitic limestone of the earlier heats was replaced by a calcite limestone. The former appeared to breakdown into a powdery material after standing and this probably leads to greater losses during melting. Secondly, the higher percentage of calcium in the standard limestone should give higher desulfurization.

2. Dam and Tap-Hole Relationships.—In the design of a front slagging spout, the critical dimension is the elevation of the lip of the dam in the runner above the top of the tap-hole. The liquid in this portion of the runner provides a seal which prevents the cupola gases from blowing through the tap-hole.

In the past it has been customary merely to balance the pressure inside the cupola with a proper height of liquid metal outside the cupola. For example, with a cupola pressure 16 oz per sq in. (gage), a dam height of 4-in. would be used. (One cubic inch of liquid metal weighs approximately 1/4 lb; therefore 4 in of metal head outside the cupola would provide an equalizing pressure of 16 oz per sq in.) When a dam is designed under these conditions, relatively little slag is retained in the cupola. For example, if slag builds up inside the cupola, the pressure inside the cupola is the gas pressure plus that of the slag and therefore slag flows out until only the gas pressure remains to balance the metal head outside.

In later heats the dam height was increased to 5 in. to allow for the development of a thicker slag layer inside the cupola. This investigation should be continued as it may be possible to reduce the flux charge considerably by more effective use of the slag.

3. Tap-Hole Procedure.—All the preceding discussion is predicated on the use of a tap-hole of very large dimensions so that it does not affect

the flow rate of metal and slag. In the later heats (4-10) this condition was attained by using a 1.5-in.-high, 3.5-in.-wide pattern against which Hi Al-Ram G was rammed. After the pattern was removed, the lining was torch dried. To make sure the full cross section of the hole would be operative during the heat, a careful botting procedure was employed. First a 3/8-in.-thick layer of fresh ramming mix was applied to the outside of the hole. This was then backed with pure dry silica sand to within 3/8 in. of the inside of the hole. Then ramming mix was applied to seal the inside of the hole.

When it was desired to tap the cupola, the outer seal and then the sand were removed. Following this it was simple to knock through the inner seal and make certain the entire hole was open. In the earlier heats in which a smaller tap-hole was used, it was difficult to clear the passage, and consequently a variable amount of metal and slag was retained in the cupola during the heat. The tap-hole construction rather than the dam height controlled the level of metal and led to retention of slag in the cupola.

4. Cupola Well Design.—In general the bowl type of design shown in Fig. 5 was employed. This was used from the beginning since maximum carburization was aimed for in the early heats. To indicate the effect of sloping the floor of the well so that much less metal was retained in the cupola another design was used in Heat No. 9. In this case there was a straight pitch of 1 in./ft toward the bottom of the tap-hole from all directions. This design led to lower carbon contents and slightly higher metal temperatures, as would be expected.

In every case the rammed sand bottom was covered with a 1/4-in.-thick layer of Gundol, rammed in place as a dry mix. This was to prevent contamination of the slag by silica. Observation of the bottom sand after dropping the bottom showed that this procedure was successful since the Gundol had sintered in place and no attack was evident.

5. Bed Height.—The bed height in the early heats, Nos. 1 and 2, of 56 in. was reduced to 48 in. in later heats because the slow initial melting rate indicated that the first few minutes were occupied in burning out excess coke before the metal could reach the melting zone. In the later heats 5% of the bed was madeup with calcium carbide. This resulted in good reducing and desulfurizing conditions in the early slag and was far more effective than merely placing a similar amount on top of the bed.

6. Operating Ratios.—It is important to establish that the melting characteristics of a pilot cupola are close to those of the plant cupola with which it is being compared. Therefore, to use a common denominator the characteristics of the Michigan cupola are compared with several others in Table II.

It is difficult to have an exact duplication between cupolas due to the large number of variables, many of which have been pointed out in the previous discussion. In fact, two cupolas in the same plant run under identical conditions can be expected to result in some variation in the normal operating ratios.

The data of Table II indicate that the Michigan cupola compares favorably with the plant cupolas. Below are a few conclusions which explain the differences in operating characteristics.

(a) More coke is required in a water-cooled cupola due to higher heat losses.

(b) The presence of more stone requires more coke for melting.

(c) A saving in coke can be appreciated by the addition of calcium carbide.

(d) The required amount of limestone and fluorspar is less in a lined cupola due to erosion of the lining.

D. PROPERTIES OF GRAY AND NODULAR IRONS

Although the principal objective of the research was the investigation of cupola operations, some samples of gray and nodular iron were poured for examination. These interesting data have been divided into three sections: (1) microstructures; (2) test drums and spiders; and (3) duplexed gray iron.

1. Microstructures.--Microstructures and physical properties are summarized in Table III. For nodular cast iron, tensile samples were taken from 1-in. "Y" blocks as shown in Fig. 7. The tensile samples for the gray cast iron were obtained according to ASTM Specification (a48-60T).

A few general trends are evident from an examination of the table:

(a) The degree of nodularity is important to physical properties and often more indicative than the metal chemistry.

(b) Flake graphite occurring after magnesium treatment has rounded lips and the material still possesses some elongation.

(c) High sulfur irons present more difficulty with nodularity than metal lower in sulfur.

(d) It is more difficult to control the magnesium recovery in the transfer technique than in plunging.

(e) High residual magnesium in a low sulfur iron may result in poorer nodularity.

(f) The presence of free carbide in nodular iron can still give elongations greater than 5% if ferrite is also present.

These experiments should be continued with engineering evaluation of the relative performance of the many interesting and potentially useful new structures which were developed.

2. Test Drums and Spiders.—All the previous results about cupola operation and processing variations to the liquid metal must produce high quality castings. Therefore, as a check on casting quality and machinability of the final product, several castings were poured which were ultimately tested in the Budd Laboratories. Table III is a summary of the microstructures and hardnesses.

The brake drums were poured in furfural molds from both nodular and gray iron. The hardnesses and the photomicrographs (Figs. 19-21) were taken from the thin inner flange of each drum where the chill problem would be most severe. Several conclusions are apparent from the microstructures and properties:

(a) Castings were still machinable as cast even though some carbide was present.

(b) Higher pouring temperatures resulted in less carbide.

(c) The pouring temperature effect may be more pronounced in furfural molds as compared to green sand.

(d) In the gray cast iron drum, under-cooled graphite was present close to the mold interface.

Nodular cast iron truck spiders were also studied for characteristic properties. In this case green sand molds were used. Tensile samples were machined from the runners and were tested at the Budd Laboratories. The castings had predominantly pearlitic matrices and were machinable in the as-cast condition. The machinability was somewhat surprising as the carbon equivalent was lower than anticipated. As a final index of casting quality a nodular iron truck spider from Heat No. 10 (not included in Table III) was tested in fatigue. The fatigue life was measurably greater than would be found in materials currently used for this application.

The importance of pouring commerical castings can therefore be appreciated. However, before these findings can be fully utilized, more Budd castings should be poured from the cupola as this will be the normal melting instrument.

3. Duplexed Gray Iron.—In the final cupola heat, 50 lb of metal were duplexed to the induction furnace. The effects of holding time and post-inoculant treatment were investigated. These data have been summarized in

Table IV. Chill samples of two types were taken from the induction furnace at regular intervals with either 85% FeSi or 65% CaSi used as a late addition. Since the silicon level was low for Heat No. 10, the more slowly cooled wedge chill provided better quantitative information. General conclusions are:

(a) An increase in holding time increased the chill depth.

(b) CaSi was a more effective post-inoculant than FeSi.

(c) CaSi did a more effective job of removing the deleterious effects of increased holding time in the furnace.

IV. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK

The data of this portion of the investigation indicate that the original objective—substitution of steel scrap for pig iron—can be satisfactorily attained in the basic cupola. Many of the important details for conducting this operation have been indicated by the supporting data. These include factors in cupola design such as well, runner and tap-hole construction, flux calculations, metal-coke ratios, and so forth as discussed in the previous section.

To optimize the basic operation at the Budd Co., it is important to explore the following variables in further detail in the experimental cupolas.

1. Minimum flux percentage for satisfactory operation. In the present work the flux was reduced during the later heats, but it is believed that further drastic reductions can be accomplished if they are accompanied by experimentation with dam height and runner design. In other words, the objective would be to accomplish greater refining per unit weight of flux by retaining a deeper slag layer in the cupola.

2. Further reduction of coke is possible and the exploration of metal temperature—coke ratio should be studied in more detail.

3. The conditions for minimum silicon and manganese loss should be explored.

4. The use of bales in place of punchings should receive further investigation to determine the role of bale size and its effect on stack pressure and analysis control. The use of briquetted borings should also be explored.

5. The experimental details of oxygen enrichment of the blast should be investigated since it may be possible to reduce carbon pickup and increase the temperature during start up of the cupola.

6. Since gray iron and ductile iron castings have somewhat different requirements for hot metal, the best operating practice for each should be clearly defined by experimentation.

7. An unusual series of microstructures was developed in test bars and castings and these should receive further laboratory and field testing.

TABLE I

SUMMARY OF DATA FROM CUPOLA HEATS

Heat No.	1	2	3	4	5	6	7	8	9	10
Metal Charge										
% Returns (1)	30	33.5	34.5	34.4	31.5	34.2	34.2	34.2	34.2	34.2
% Steel (2)	67	62	64	64	65	64	64	64	64	64
Carbon in	1.34	1.32	1.34	1.24	1.28	1.47	1.46	1.33	1.38	1.29
Silicon in	.72	.99	.99	1.01	1.51	1.51	1.49	1.49	1.53	1.49
Returns	0	.27	.09	.15	.06	.23	.27	.34	.38	.27
50% FeSi	.72	.72	.90	.86	1.45	1.28	1.22	1.15	1.15	1.22
Non-Metallics (% metal)										
Coke	17.5	17.0	17.2	17.2	17.6	17.1	14.6	14.6	14.6	14.6
Limestone (3)	5.0	4.8	6.1	7.4	7.6	7.3	4.4	4.4	4.4	4.4
Spar (4)	2.5	2.4	2.5	2.5	2.5	2.4	1.2	1.2	1.2	1.2
CaC_2	1.5	1.4	1.5	1.5	1.5	1.5	0	1.5	1.5	1.5
Metal Characteristics										
Maximum temperature	2750	2700	2700	2660	2825	2750	2730	2750	2780	2830
Carbon after:										
10 min	3.80	3.90	3.40	3.99	4.24	--	3.92	3.95	3.44	4.41
20 min	3.74	3.86	3.40	3.98	4.21	4.37	3.73	3.94	3.37	3.69
Sulfur after:										
10 min	.080	.058	.080	.026	.007	--	.040	.028	.019	.006
20 min	.078	.056	.070	.010	.009	.013	.032	.020	.021	.010
Minimum	.077	.047	.037	.010	.007	.009	.029	.017	.016	.006
Slag Characteristics										
Time (5)	23	19	60	6	15	12	9	5	6	18
FeO	3.45	4.5	2.2	1.7	.9	.95	2.25	3.1	.55	.95
Basicity	.98	1.34	.60	1.35	1.06	1.19	.91	.60	1.4	1.97
Maximum desulfurization ratio	2.7	12.0	15.1	60.0	100	63.0	23.4	49	37.2	81.0

---

(1) In early heats Sorel pig was used rather than actual returns.

(2) All heats except No. 10 used punchings (No. 10 used bales).

(3) The first three heats used dolomitic stone; the rest used a high calcium stone.

(4) The first three heats used a 50% CaF_2 spar; the rest used a 95% CaF_2 spar.

(5) Time was measured from tap until first slag.

TABLE II

COMPARISON OF CUPOLA OPERATIONS

	Budd Co. (1)	International Harvester (2)	Ford Motor Co. (3)	Michigan (4)
I. Operating Data				
A. Ingoing Carbon	3.25	1.90	2.34	1.33
B. Outgoing Carbon	3.40-3.75	3.60-3.90	3.90	3.95
C. Metal Temperature	2800-2900	2700-2800	2700-2800	2650-2750
D. Air Temperature	600-725	Ambient	Ambient	Ambient
II. Operating Data/Sq Ft/Min (lb)				
A. Melting Rate	22.3	20.9	16.6	14.8
B. Total Coke Wt	2.30	3.38	2.51	3.18
1. Coke wt for combustion	2.24-2.28	2.96-3.01	2.25	1.79
2. Coke wt for solution in iron	0.02-0.04	0.37-0.42	0.26	0.39
C. Stone Wt	0.75	1.64	1.48	0.65
D. Spar Wt	0	0.46	0.55	0.18
E. Carbide Wt	0	0	0	0.22
F. Air Wt	24.5-26.2	27.8	20.1	27.3
III. Operating Ratios				
A. Air Wt/Total Coke Wt	10.6 to 11.4:1	8.2:1	8.0:1	12.5:1
B. Air Wt/Metal Wt	1.1 to 1.2:1	1.3:1	1.2:1	1.85:1
C. Metal Wt/Coke Wt for Combustion	9.8 to 10.0:1	7.0:1	7.4:1	8.3:1
D. Metal Wt/Total Coke Wt	9.7:1	6.2:1	6.6:1	6.8:1
E. Metal Wt/Non-Metallic Wt	29.7:1	10.0:1	8.2:1	14.1:1
1. Metal wt/stone wt	29.7:1	12.8:1	11.2:1	22.8:1
2. Metal wt/spar wt	--	45.2:1	30.0:1	81.8:1
3. Metal wt/carbide wt	--	--	--	28.2:1
F. Metal Wt/Slag Wt	23:1	12.0:1	8.3:1	9.9:1

---

(1) Acid-lined; acid slag; cascade water-cooled.
(2) Unlined; basic slag; cascade water-cooled.
(3) Unlined; basic slag; cascade water-cooled.
(4) Basic-lined; basic slag; noncooled; Heat No. 8.

TABLE III

SUMMARY OF NODULAR AND GRAY IRON PROPERTIES

Sample (1)	Figure	Treatment (2) (Pouring Temperature)	Analyses					Physical Properties				Microstructure (3)
			C	Si	Mn	S	Mg (% Recovery)	Tensile	Yield	Elong., %	BHN	
1-D1	8	2% Transfer (*)	3.69	1.35	.21	.057	*	69,500	52,900	22	167	α (H.T.), S.G.
3-D1	9	3% Transfer (*)	3.30	1.85	.21	.070	.032 (11)	47,500	32,500	13	125	α (H.T.), S.G., F.G.
3-D2	10	2.5% Transfer (2360)	3.32	1.61	.21	.052	.027 (11)	16,500	16,500	2	75	α (H.T.), F.G.
5-D1	11	3% Transfer (2400)	3.96	2.62	.29	.005	.045 (16)	68,000	33,750	22	164	α, S.G., (P)
5-D3	12	1% Transfer (2370)	4.20	1.11	.28	.009	.026 (27)	44,500	25,500	6	154	α, S.G., F.G., P, Ca
6-D1	13	2.5% Transfer (*)	3.85	1.88	.29	.008	.080 (33)	58,000	37,500	22	146	α, S.G. (P)
6-D2	14	2% Transfer (2325)	3.96	1.76	.27	.006	.050 (26)	58,250	36,500	20	146	α, S.G. (P)
8-D2	15	.6% Plunge (2250)	3.97	1.83	.30	.015	.085 (65)	101,750	53,000	4	240	P, S.G., (α)
9-D1	16	.6% Plunge (2400)	3.74	1.55	.29	.008	*	82,250	39,500	12	172	α, S.G., P
2-G1	17	Duplex Gray (2600)	3.25	1.47	.25	.051	-	17,000	-	-	124	P, F.G. (α)
5-G1	18	Duplex Gray (2600)	3.76	1.38	.89	.010	-	27,000	-	-	143	P, F.G. (Ca)
6-Dr-Cu	19	Drum (Nodular) (*)	3.85	1.88	.29	.008	*	*	*	*	176	α, P, S.G., Ca
7-Dr-Cu-1	20	Drum (Nodular) (2300)	3.63	2.22	.27	.010	*	*	*	*	222	α, P, S.G., Ca
7-Dr-Cu-2	21	Drum (Gray) (2300)	3.57	1.83	.73	.040	-	*	*	*	160	α, P, F.G. (Ca)
9-Sp-I	22	Spider (Induction) (2400)	3.72	1.42	.33	.007	*	83,900 (+)	44,800 (+)	4 (+)	205 (+)	α, P, S.G.
9-Sp-Cu	23	Spider (Cupola) (2400)	3.74	1.55	.29	.008	*	*	48,100 (+)	*	210 (+)	α, P, S.G.

* Data not taken
\+ Data taken on runner system
(1) First digit refers to cupola heat number
(2) Transfer alloy was Noduloy 8-C
Plunging alloy was Sil-Mag-M-No. 2

(3) α ferrite
P pearlite
Ca Carbide
S.G. speroidal graphite
F.G. flake graphite
( ) minor constituent
H.T. heat-treated

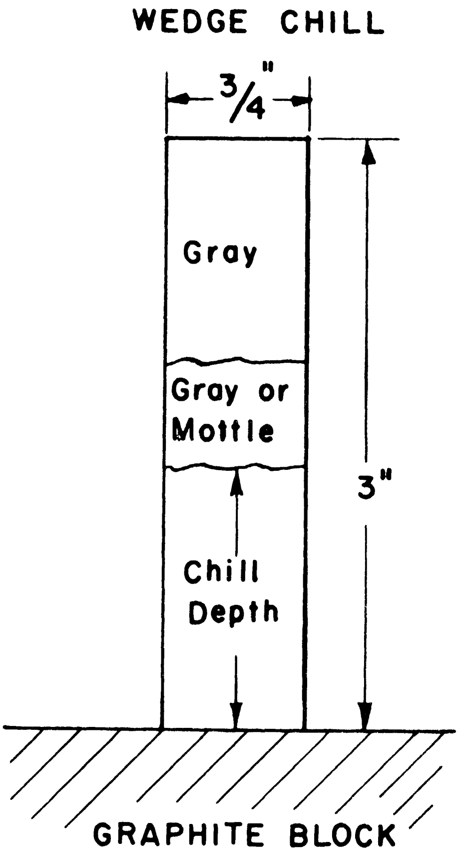
TABLE IV

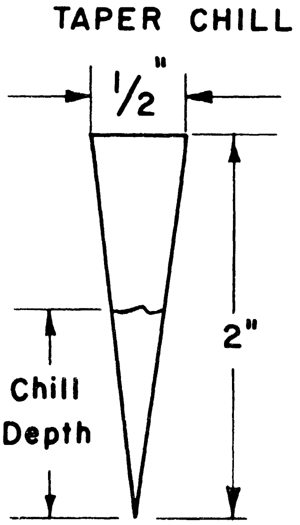
DUPLEX-GRAY IRON

(Heat No. 10)

In preheated induction furnace at 6:01 p.m.
All chills taken at 2750°F
Comparison of 65% CaSi and 85% FeSi

Time, p.m.	Sample No.	Taper Chill	Wedge Chill		Late Silicon
			Chill Depth, in.	Gray or Mottle Depth, in.	
6:21	1	White	1.6	0.1	None
6:21	2	White	1.6	0.4	0.20 as FeSi
6:21	3	Slight mottle	1.6	0.8	0.20 as CaSi
6:36	4	Greater mottle than No. 3	1.3	0.8	0.40 as FeSi
6:36	5	0.8 in. chill	1	2	0.40 as CaSi
6:51	6	Very little mottle	1.4	0.7	0.40 as FeSi
6:51	7	0.8 in. chill	1	2	0.40 as CaSi





NOTE: Both chills are poured in core sand molds

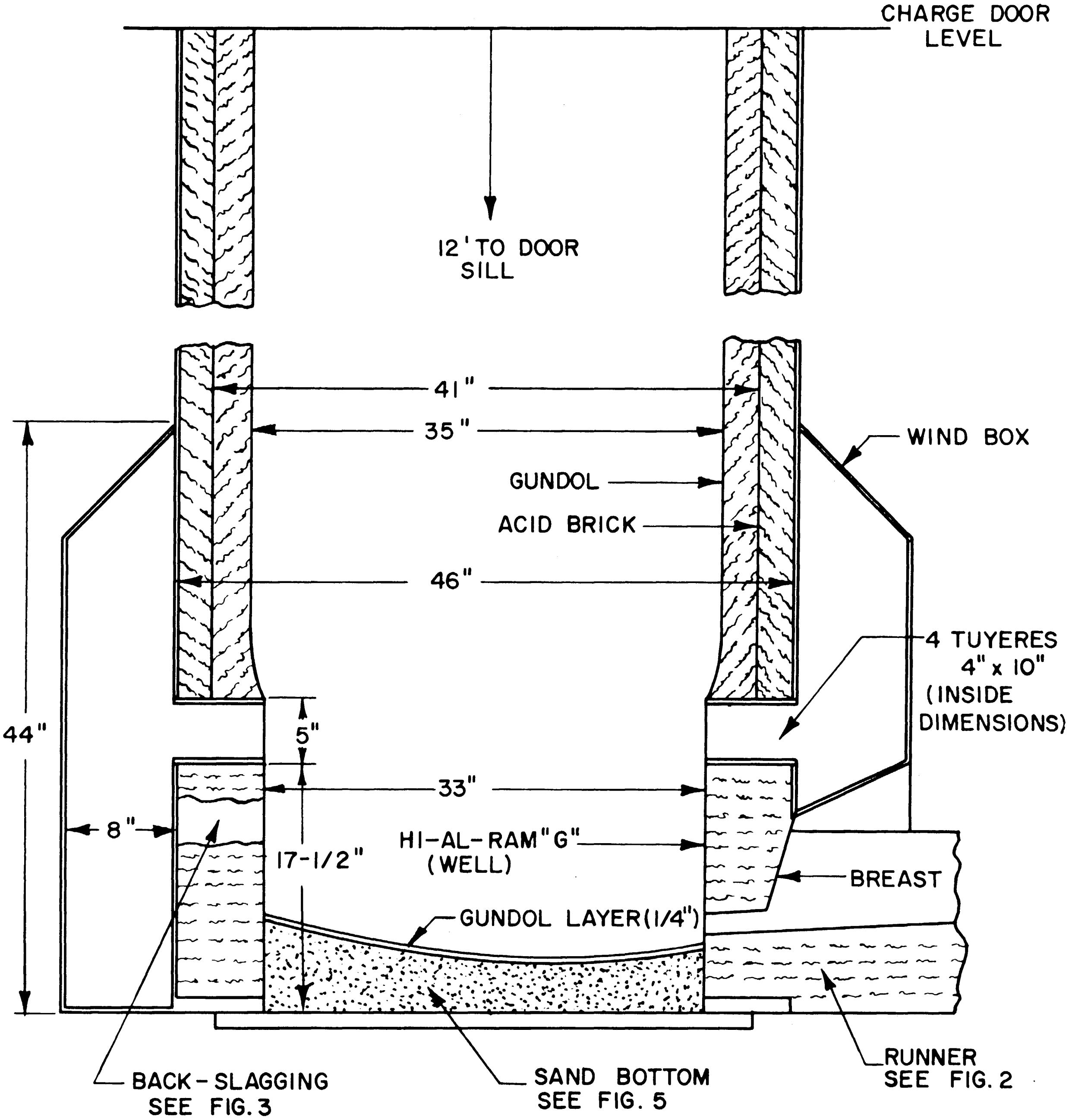


Fig. 1. Cross section of the Michigan Cupola.

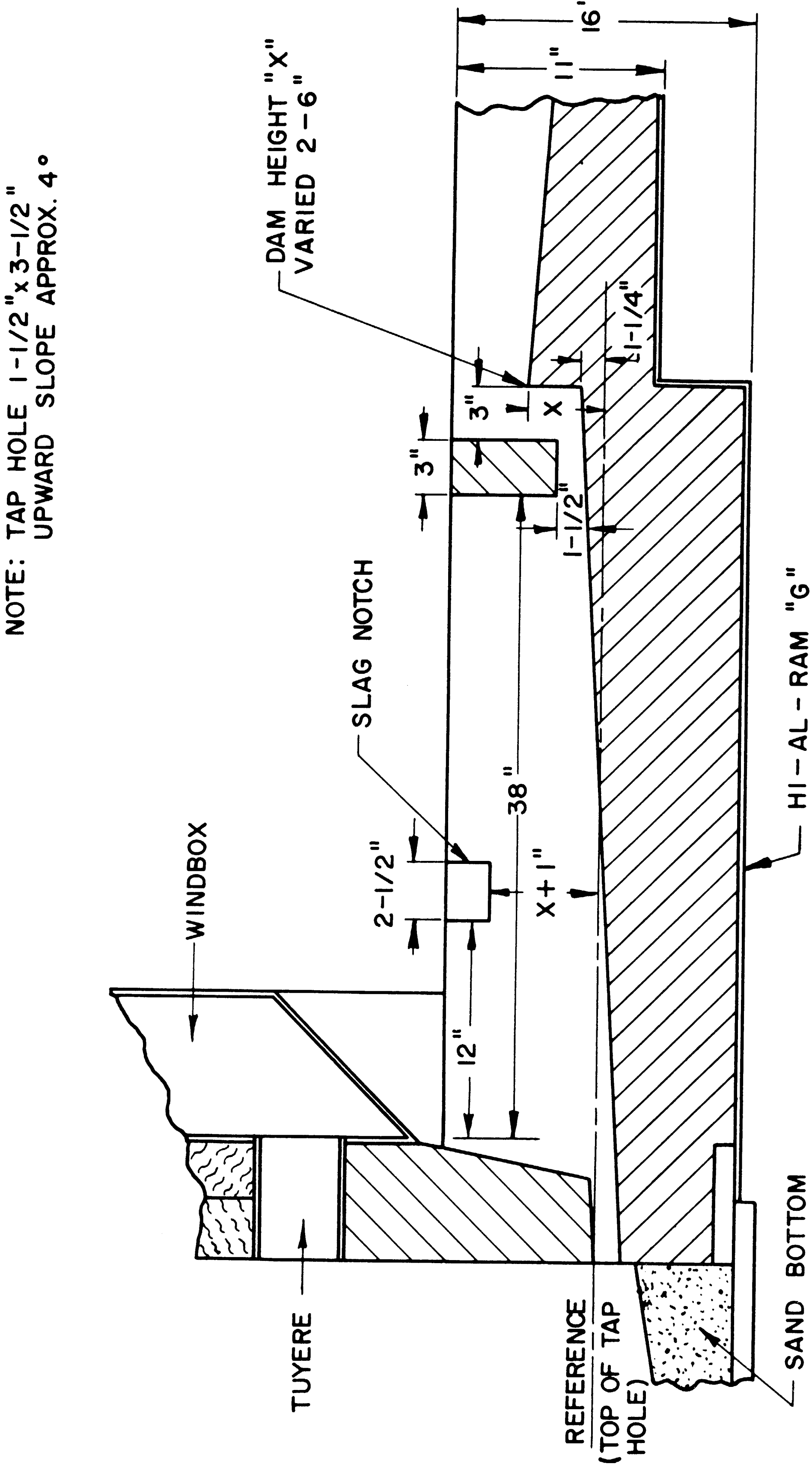


Fig. 2. Runner system of the Michigan Cupola.

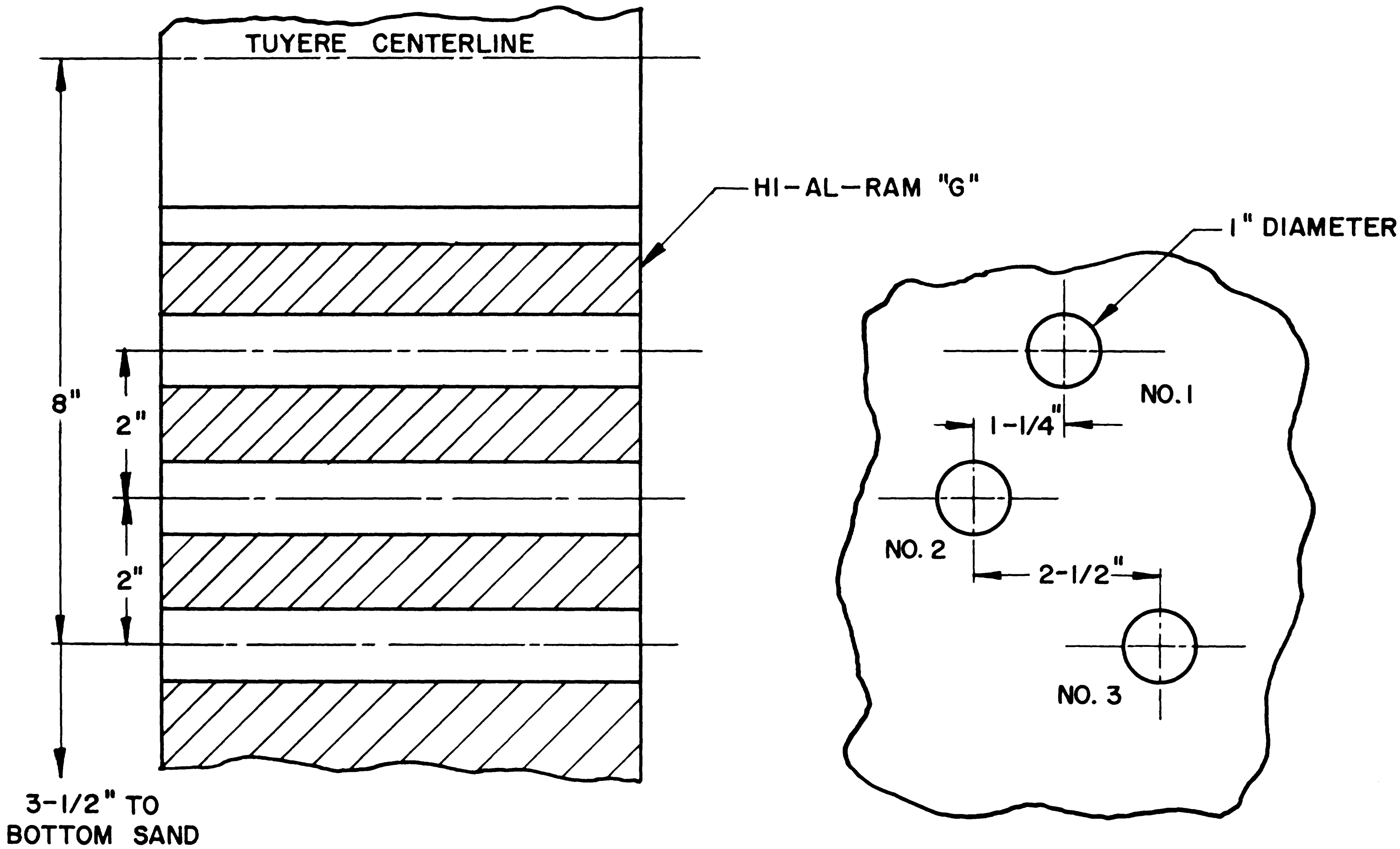


Fig. 3. Back-slagging arrangement.

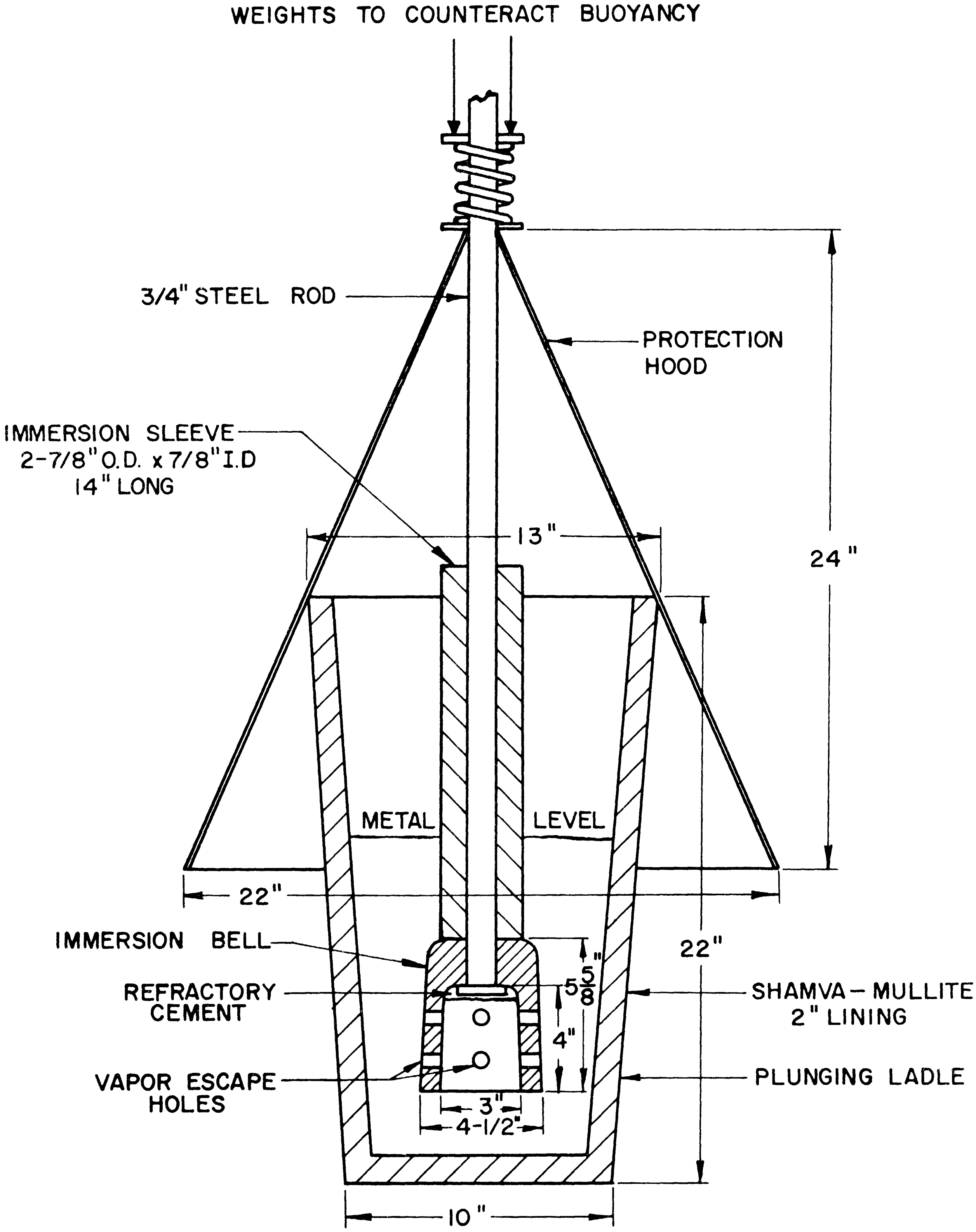
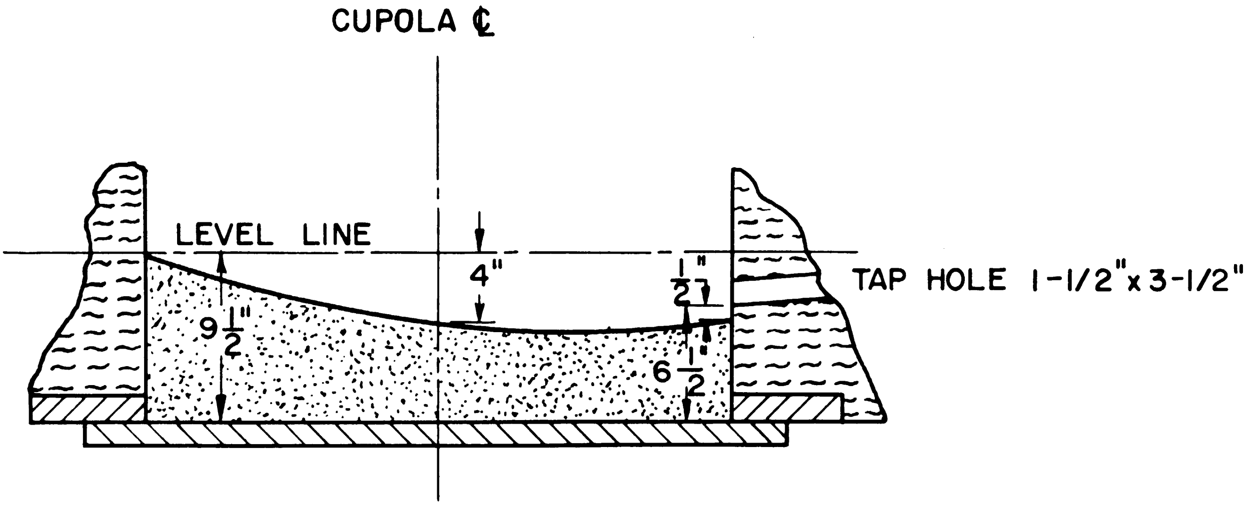
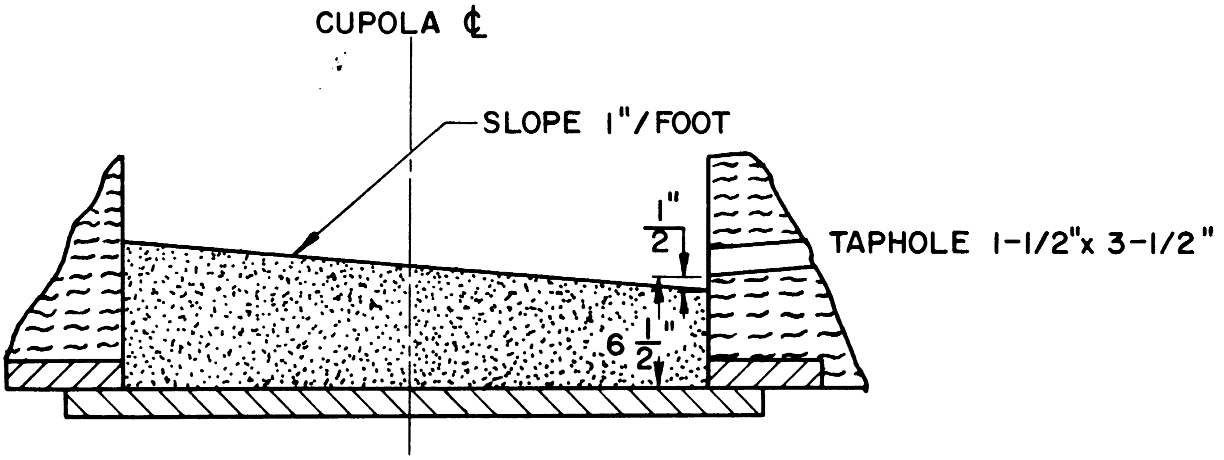


Fig. 4. Plunging apparatus to treat 150 lb of metal. Alloy can is not in the bell.



DEPRESSED SAND BOTTOM



STRAIGHT PITCH SAND BOTTOM

Fig. 5. Two varieties of sand bottoms used in the experimental runs. Note: Pitch as shown is the same in all directions toward the tap hole (bottom is covered with 1/4" Gundol).

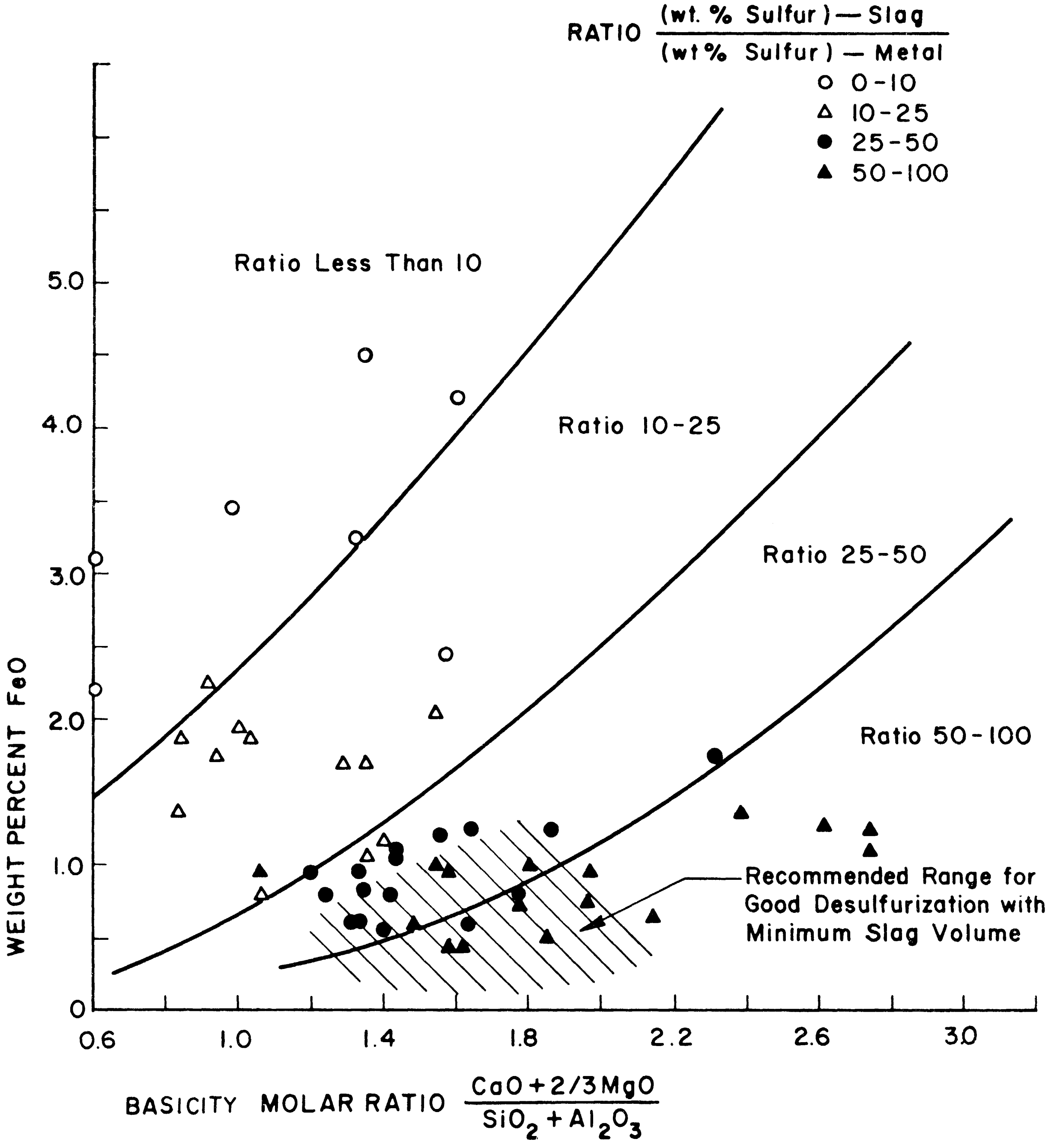


Fig. 6. Effect of slag analysis on desulfurization.

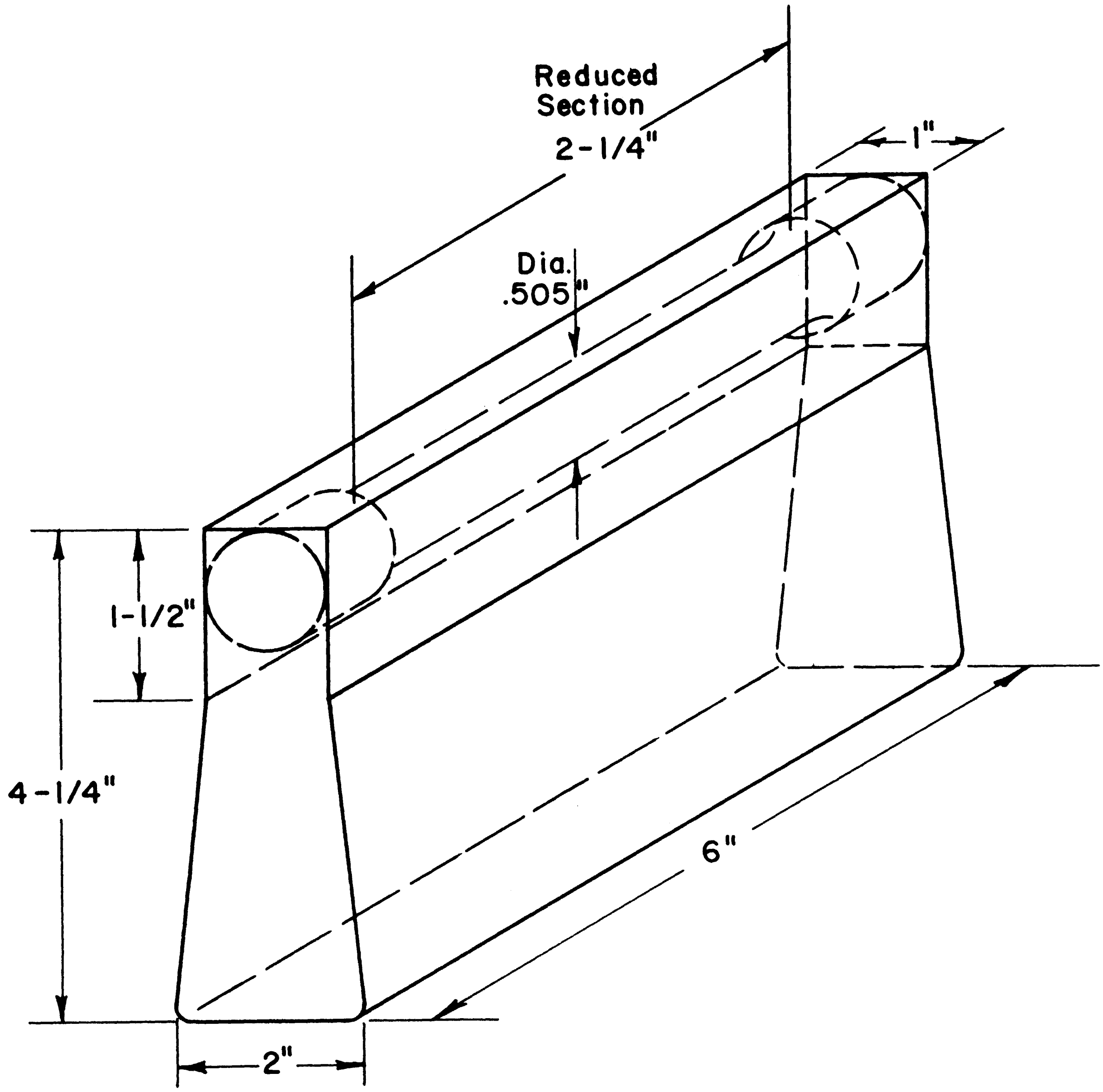


Fig. 7. Location of a tensile specimen in a standard one-inch "Y" block.

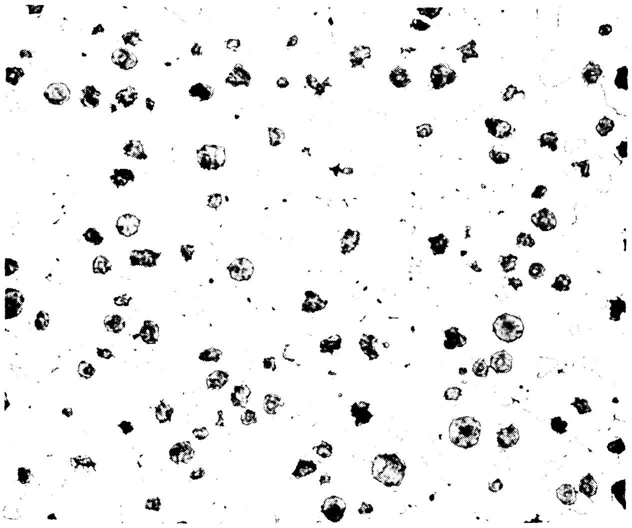


Fig. 8. 100X; 5% nital 1-D1; ferrite, spheroidal graphite (2% Noduloy 8-C).

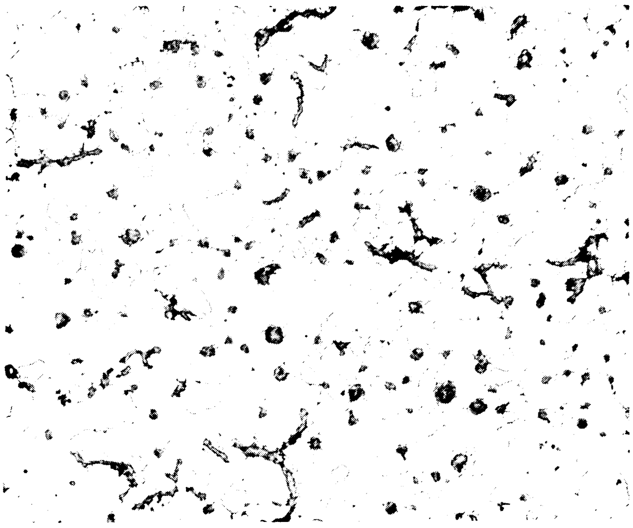


Fig. 9. 100X; 5% nital 3-D1; ferrite, spheroidal graphite, and flake graphite (3% Noduloy 8-C).

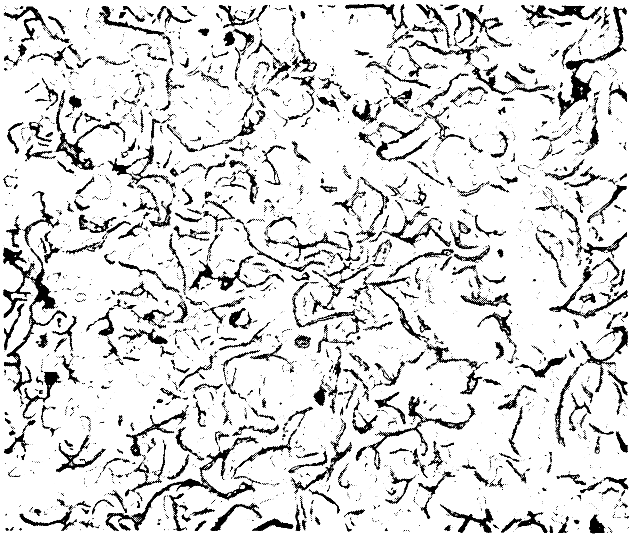


Fig. 10. 100X; 5% nital 3-D2; ferrite, flake graphite (2-1/2% Noduloy 8-C).

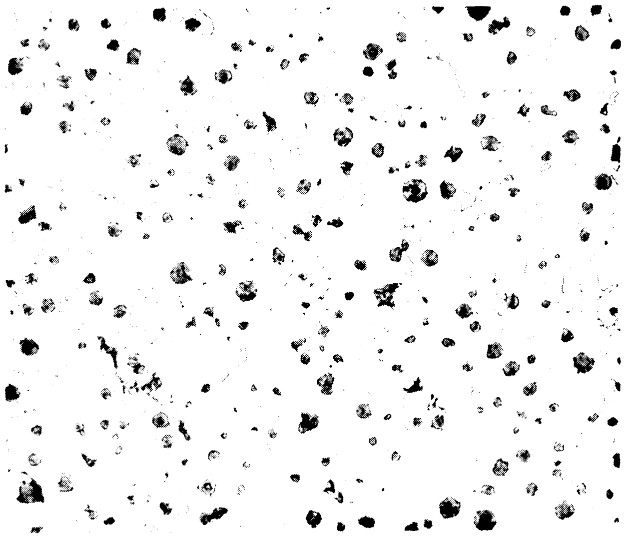


Fig. 11. 100X; 5% nital 5-D1; ferrite, spheroidal graphite, pearlite (3% Noduloy 8-C).

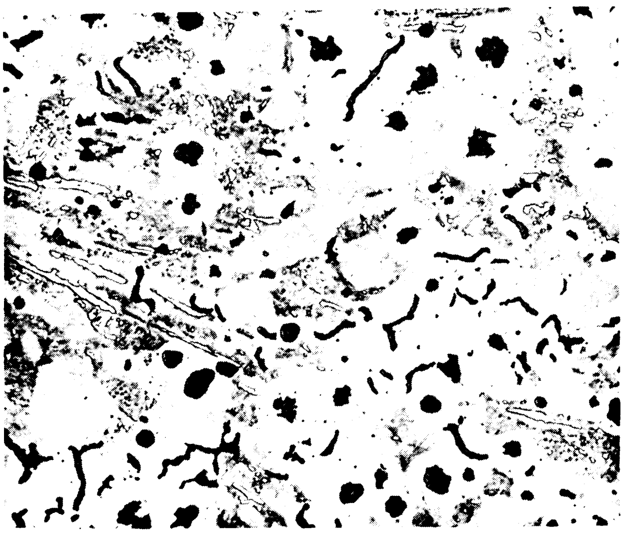


Fig. 12. 100X; 2% nital 5-D3; ferrite, spheroidal and flake graphite, pearlite, carbide (1% Noduloy 8-C).

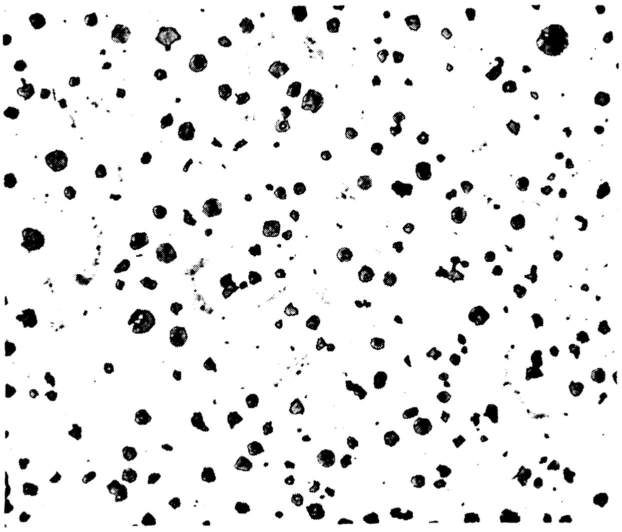


Fig. 13. 100X; 2% nital 6-D1; ferrite, spheroidal graphite, pearlite (2-1/2% Noduloy 8-C).

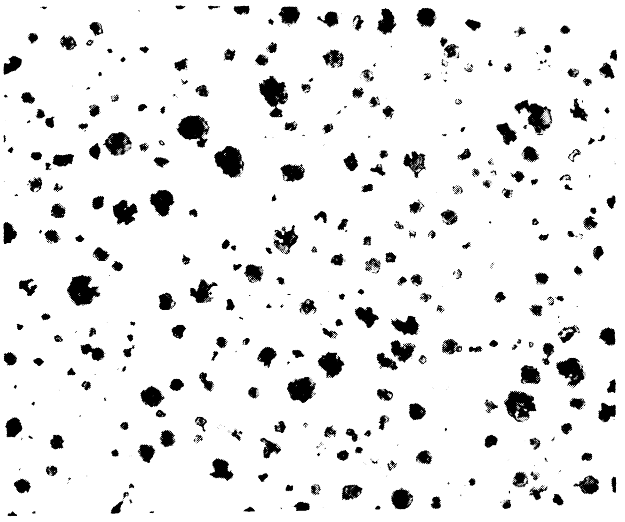


Fig. 14. 100X; 2% nital 6-D2; ferrite, spheroidal graphite, pearlite (2% Noduloy 8-C).

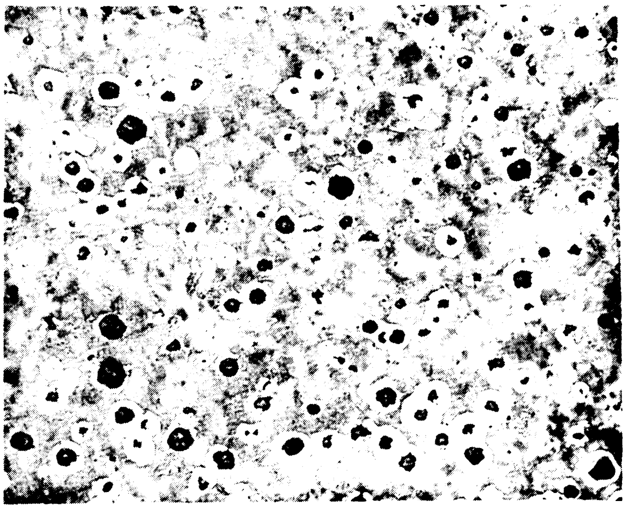


Fig. 15. 100X; 2% nital 8-D2; ferrite, spheroidal graphite, pearlite (plunge 0.6% SIL-MAG-M).

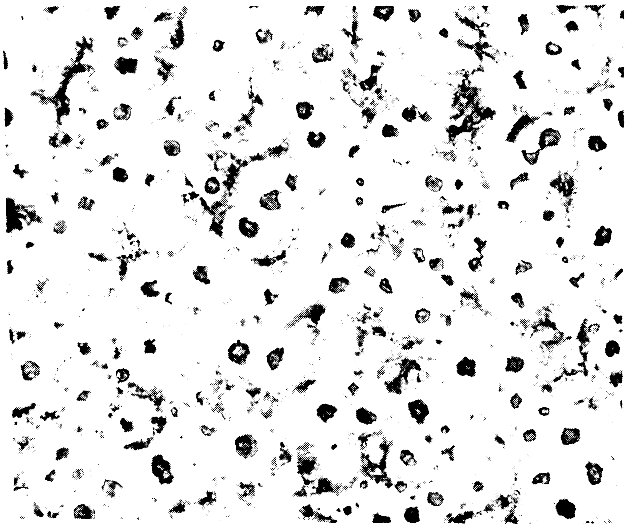


Fig. 16. 100X; 2% nital 9-D1; ferrite, spheroidal graphite, pearlite (plunge 0.6% SIL-MAG-M).

Fig. 17. 100X; 2% nital 2-G1; ferrite, flake graphite, pearlite (duplexed to induction furnace).

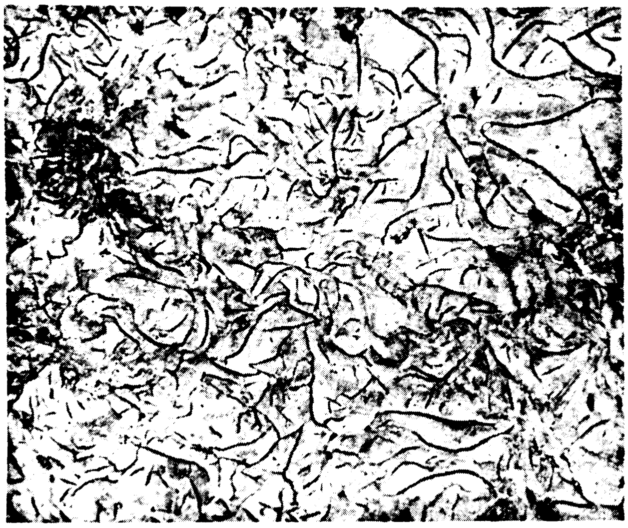


Fig. 18. 100X; 2% nital 5-G1, flake graphite, pearlite, carbide (duplexed to induction furnace).

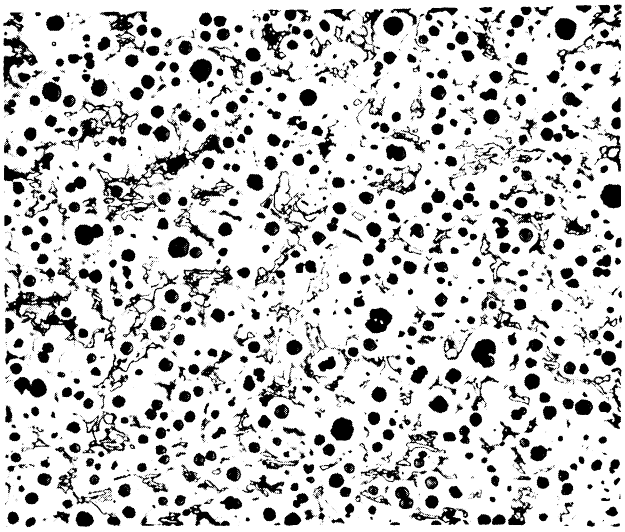


Fig. 19. 100X; 2% nital 6-Dr-Cu; nodular brake drum, ferrite, spheroidal graphite, pearlite, carbide (2-1/2% Noduloy 8-C).

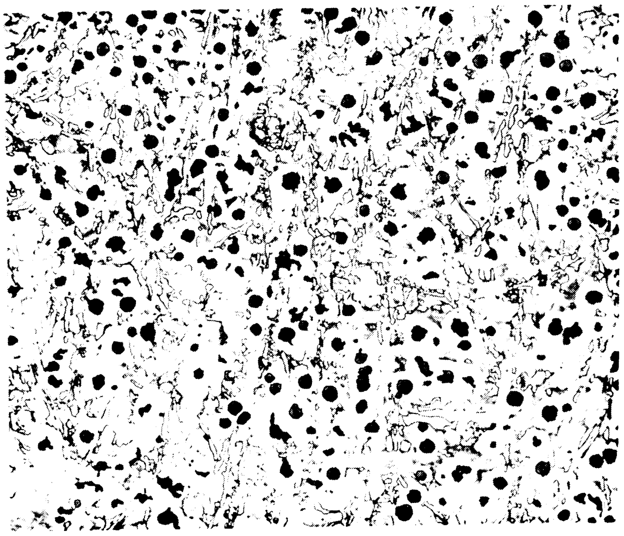


Fig. 20. 100X; 2% nital 7-Dr-Cu-1 (nodular brake drum); ferrite, spheroidal graphite, pearlite, carbide (2-1/2% Noduloy 8-C).

Fig 21. 100X; 2% nital 7-Dr-Cu-2 (flake brake drum); ferrite, flake graphite, pearlite, carbide (direct from forehearth).

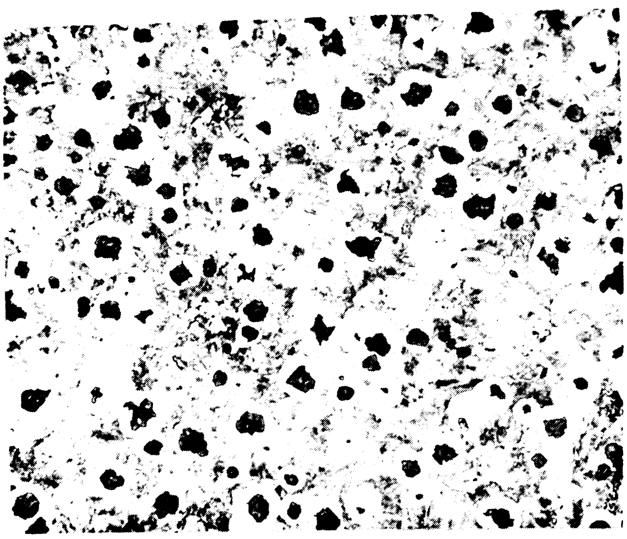


Fig. 22. 100X; 2% nital 9-Sp-I (nodular truck spider); ferrite, spheroidal graphite, pearlite (plunging from induction furnace).

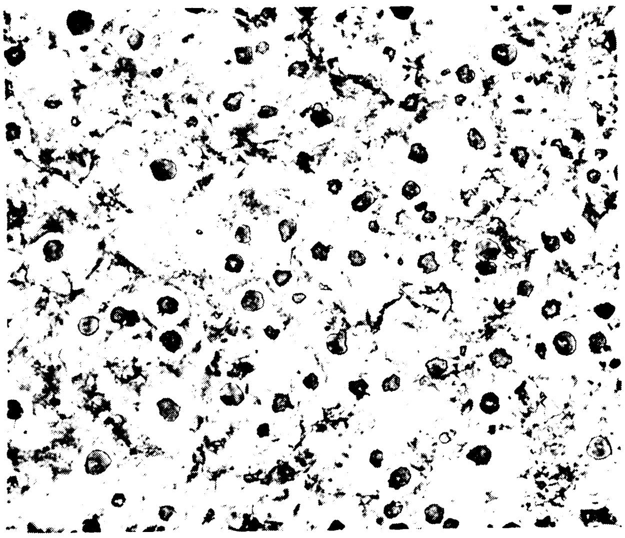


Fig. 23. 100X; 2% nital 9-Sp-Cu (nodular truck spider); ferrite, spheroidal graphite, pearlite (plunging from cupola).

APPENDIX I

OPERATING DATA

HEAT NO. 1

1. Metallics/Charge

Sorel Pig	120 lb
Steel Punchings	274 lb
50% FeSi	5.75 lb
75% FeMn	0.60 lb

2. Nonmetallics/Charge

Coke	70 lb
Stone (Dolomitic)	20 lb
Spar (50% CaF_2)	10 lb
CaC_2	6 lb

3. Bed

a. Height	56 in.
b. Nonmetallics	15 lb CaC_2; 20 lb spar on top
c. Burn in time	6-1/2 hr

4. Runner and Bottom

a. Dam height	2-3/4 in.
b. Tap-hole	1-1/2 in. diam
c. Bottom	Depressed 1/2 in. below tap-hole; bowl shape

5. Analyses Samples

a. Metal	From forehearth
b. Slag	From slag notch

6. Comments

a. Problem in tapping	Metal froze under dam
b. Blast on until tap	12 min

A. Operating Data

1. Inside Diameter at Tuyeres (in.); (Area-sq ft)

   31 in. (5.25 sq ft)

2. Temperature Range

   2600-2740°F

3. Total Carbon, Ingoing

   1.34%

4. Total Carbon, Outgoing (Range)

   3.65-3.83%

5. Metal Melting Rate lb/min

   84 lb/min

6. Nonmetallics (Exclusive of Bed)—Rate

Coke	14.7 lb/min
Stone	4.2 lb/min
Spar	2.1 lb/min
Carbide	1.25 lb/min

7. Air Weight

   2250 cfm at STP
   182 lb/min

8. Air Pressure

   11 to 12 oz

B. Operating Data/Sq Ft/Min

1. Melting Rate/sq ft/min, lb

   16.0

2. Total Coke wt/sq ft/min, lb—2.80
   - a. Coke wt/sq ft/min for combustion—2.37-240
   - b. Coke wt/sq ft/min for solution in iron—0.40-0.43

3. Nonmetallics/sq ft/min, lb

Stone	0.80
Spar	0.40
Carbide	0.24

4. Air wt/sq ft/min, lb

    34.7

C. Operating Ratios

1. Air wt/Total Coke wt

    12.4:1

2. Air wt/Metal wt

    2.2:1

3. True Coke Ratio—Metal wt/Coke wt for Combustion

    6.68 to 6.75:1

4. Apparent Coke Ratio—Metal wt/Total Coke wt

    5.72:1

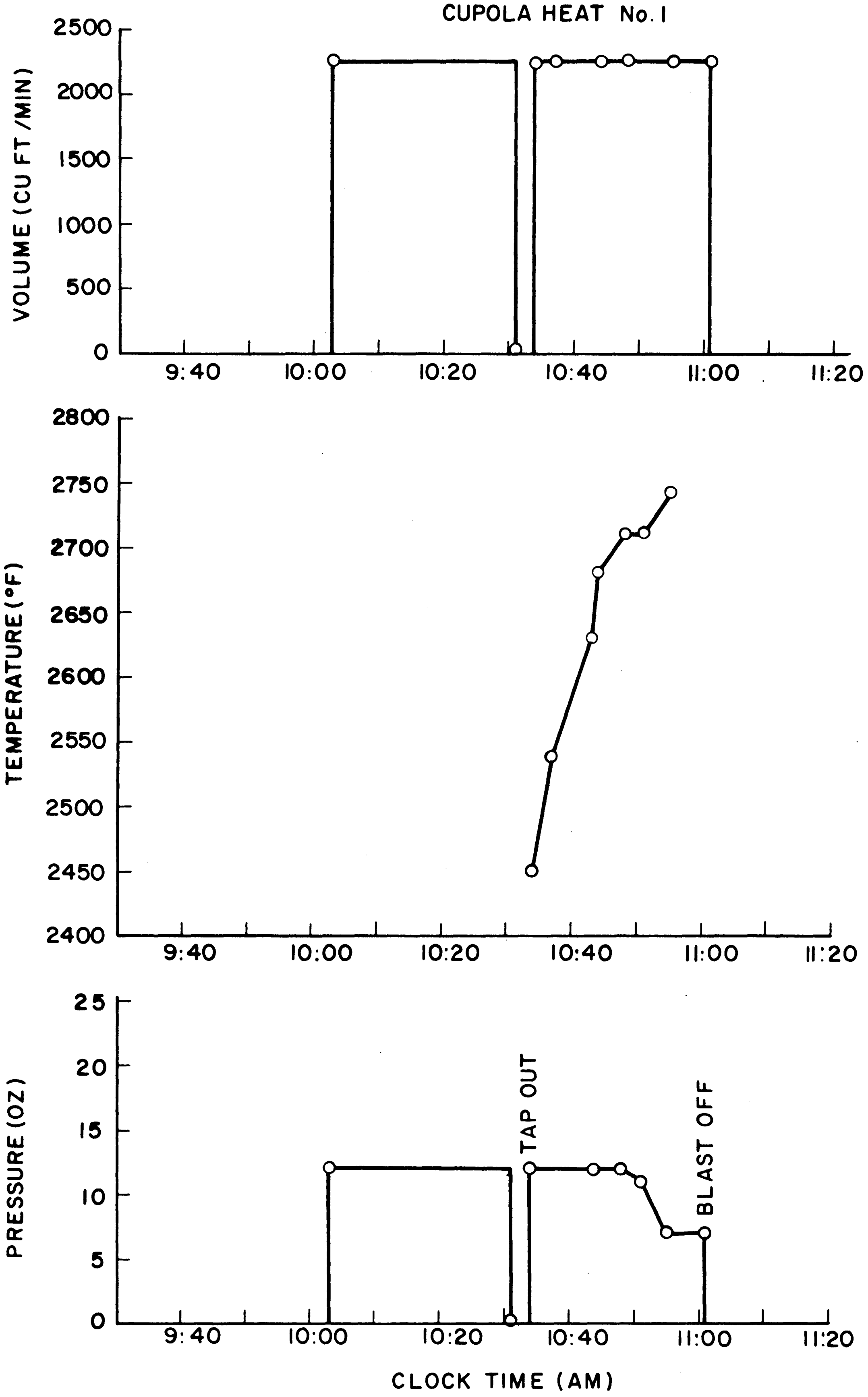
5. Nonmetallics—Total Metal wt/wt Stone + Spar + Carbide—11.1:1

    a. Metal wt/Stone wt—20.0:1
    b. Metal wt/Spar wt—40.0:1
    c. Metal wt/Carbide wt—67.2:1

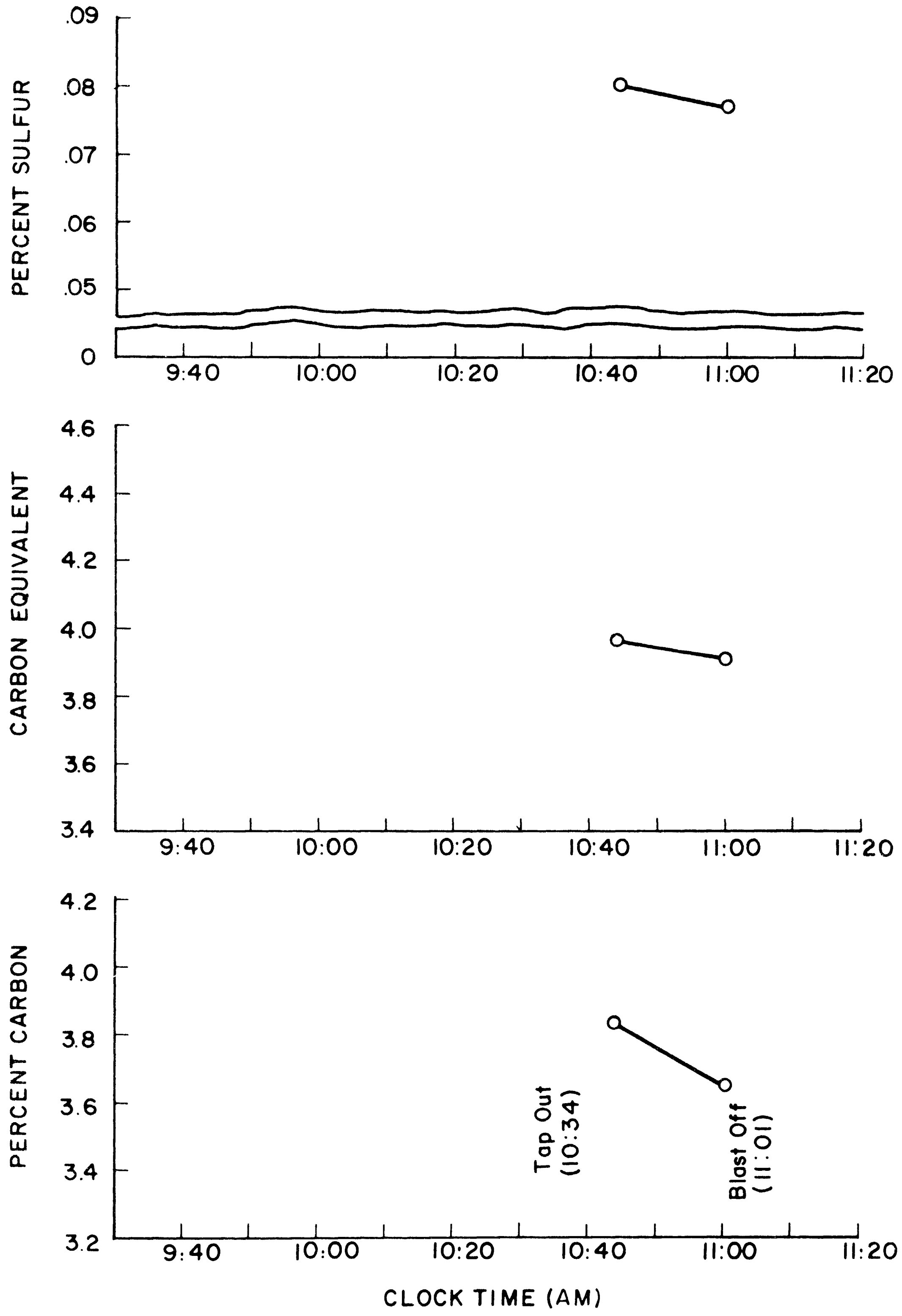
6. Approximate Metal wt/Slag wt

    8.25:1

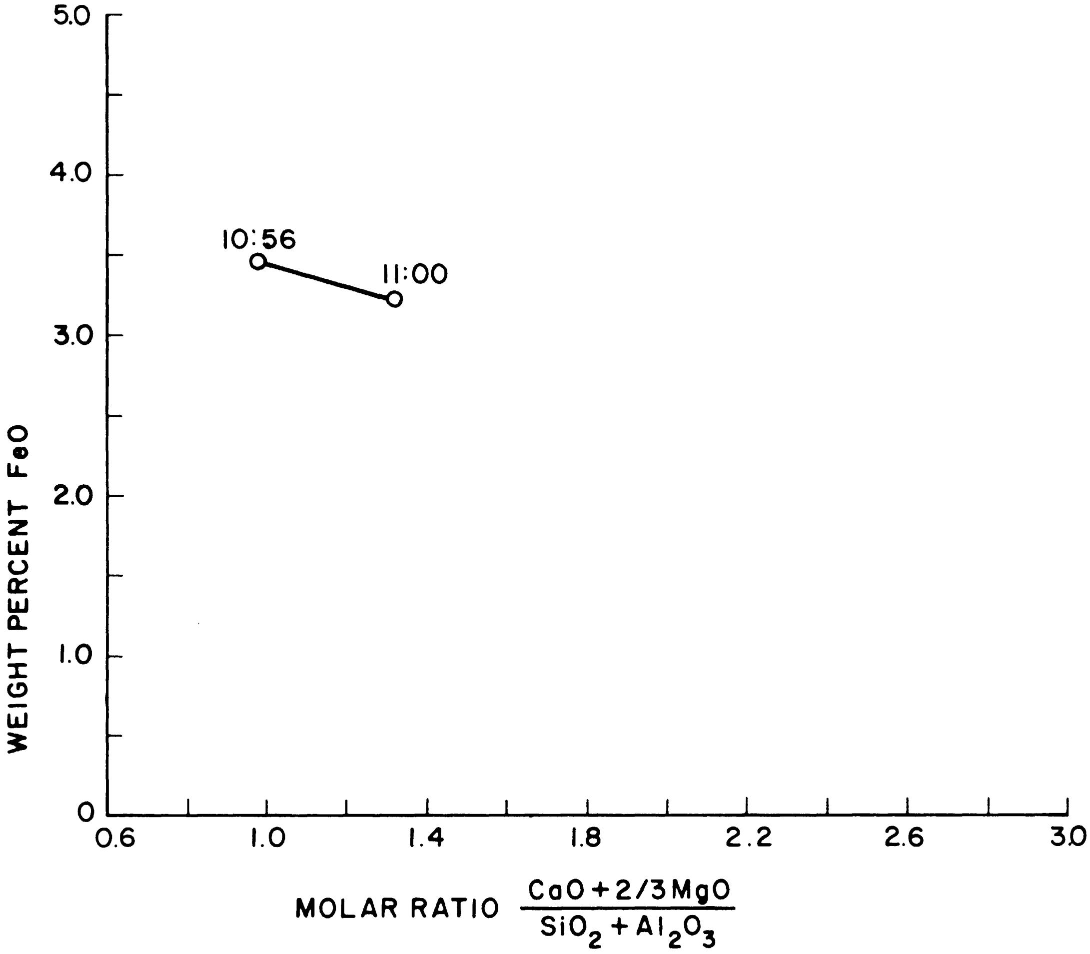
CUPOLA HEAT No. 1



CUPOLA HEAT NO. 1



CUPOLA HEAT NO. 1



HEAT NO. 2

1. Metallics/Charge

Scrap Returns	140 lb
Steel Punchings	260 lb
50% FeSi	6 lb
75% FeMn	13 lb

2. Nonmetallics/Charge

Coke	70 lb
Stone (Dolomitic)	20 lb
Spar (50% CaF_2)	10 lb
CaC_2	6 lb

3. Bed

a.	Height	56 in.
b.	Nonmetallics	50 lb stone, 20 lb spar, 15 lb CaC_2 on top
c.	Burn in time	3 hr

4. Runner and Bottom

a.	Dam height	2-3/4 in.
b.	Tap-hole	1-1/2 in. diam
c.	Bottom	Depressed 1/2 in. below tap-hole; bowl shape

5. Chemical Analyses Samples

a.	Metal	From forehearth
b.	Slag	From front slag notch

6. Comments

   a. Breast became hot
   b. Blast on until tap—16 min

A. Operating Data

1. Inside Diameter at Tuyeres (in.); (Area-sq ft)

   31 in. (5.25 sq ft)

2. Temperature Range

   2600-2700°F

3. Total Carbon, Ingoing

   1.32%

4. Total Carbon, Outgoing (Range)

   3.62-3.91

5. Metal Melting Rate lb/min

   62 lb/min

6. Nonmetallics Rate (Exclusive of Bed)

Coke	10.3 lb/min
Stone	2.95 lb/min
Spar	1.47 lb/min
Carbide	0.89 lb/min

7. Air Weight

   2000 cfm at STP
   162 lb/min

8. Air Pressure

   10 oz

B. Operating Data/Sq Ft/Min

1. Melting Rate/sq ft/min, lb

   11.8

2. Total Coke wt/sq ft/min, lb—1.96

   a. Coke wt/sq ft/min for combustion—1.62-1.67
   b. Coke wt/sq ft/min for solution in iron—0.29-0.34

3. Nonmetallics/sq ft/min, lb

Stone	0.56
Spar	0.28
Carbide	0.17

4. Air wt/sq ft/min, lb

   31.0

C. Operating Ratios

1. Air wt/Total Coke wt

   15.8:1

2. Air wt/Metal wt

   2.6:1

3. True Coke Ratio—Metal wt/Coke wt for Combustion

   7.1 to 7.3:1

4. Apparent Coke Ratio—Metal wt/Total Coke wt

   6.03:1

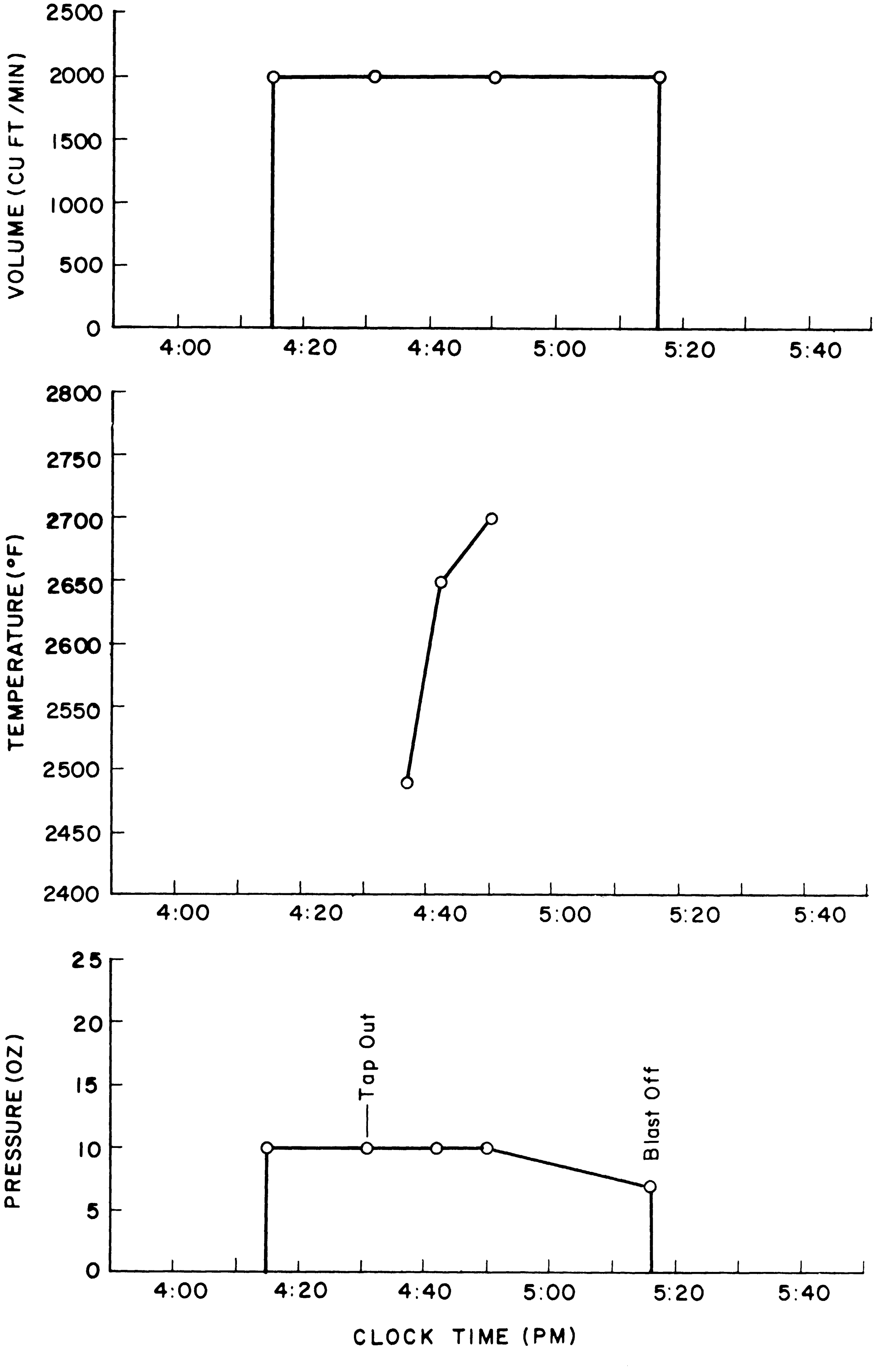
5. Nonmetallics—Total Metal wt/wt Stone + Spar + Carbide—11.7:1

   a. Metal wt/Stone wt—21.1:1
   b. Metal wt/Spar wt—42.2:1
   c. Metal wt/Carbide wt—69.5:1

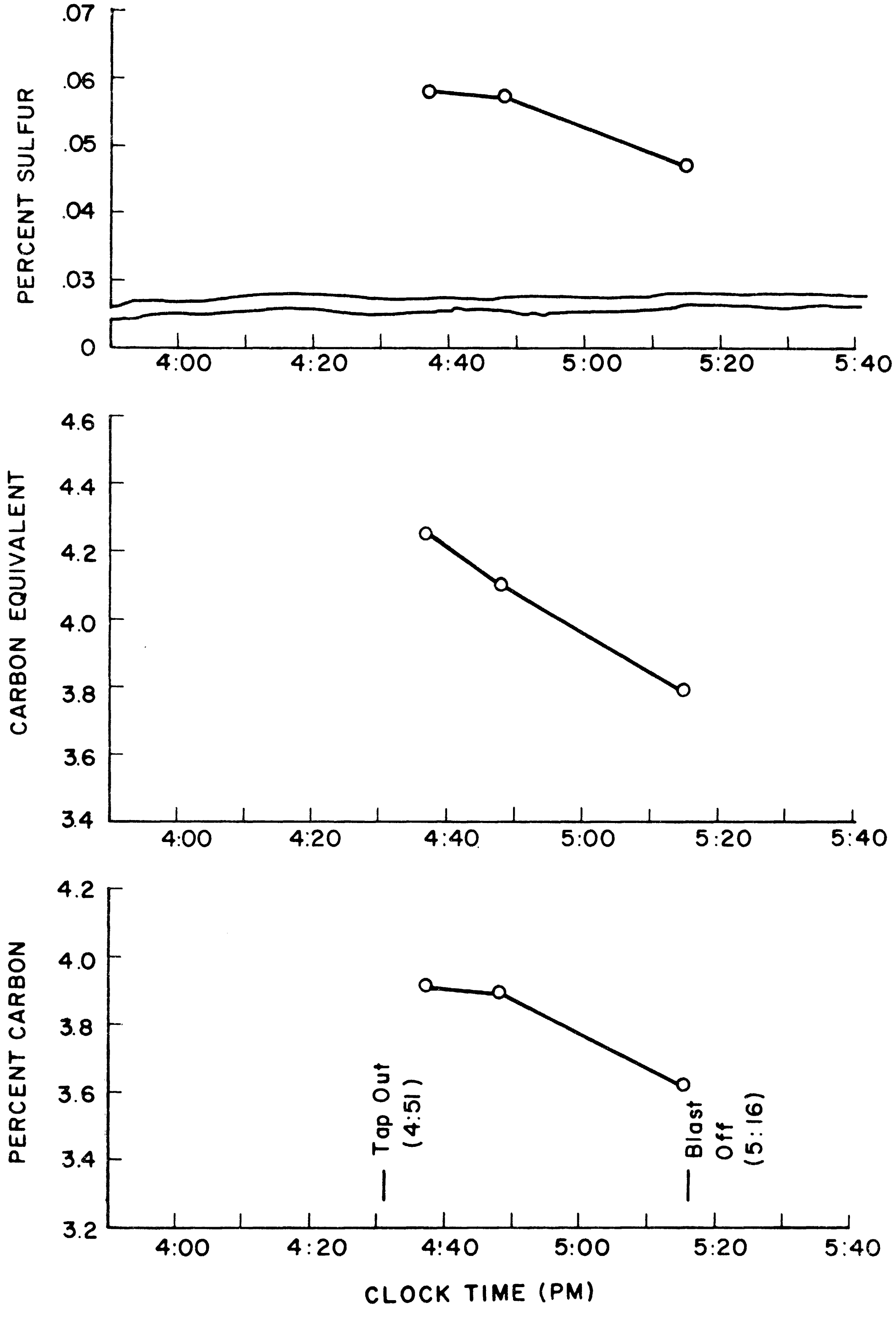
6. Approximate Metal wt/Slag wt

   8.5:1

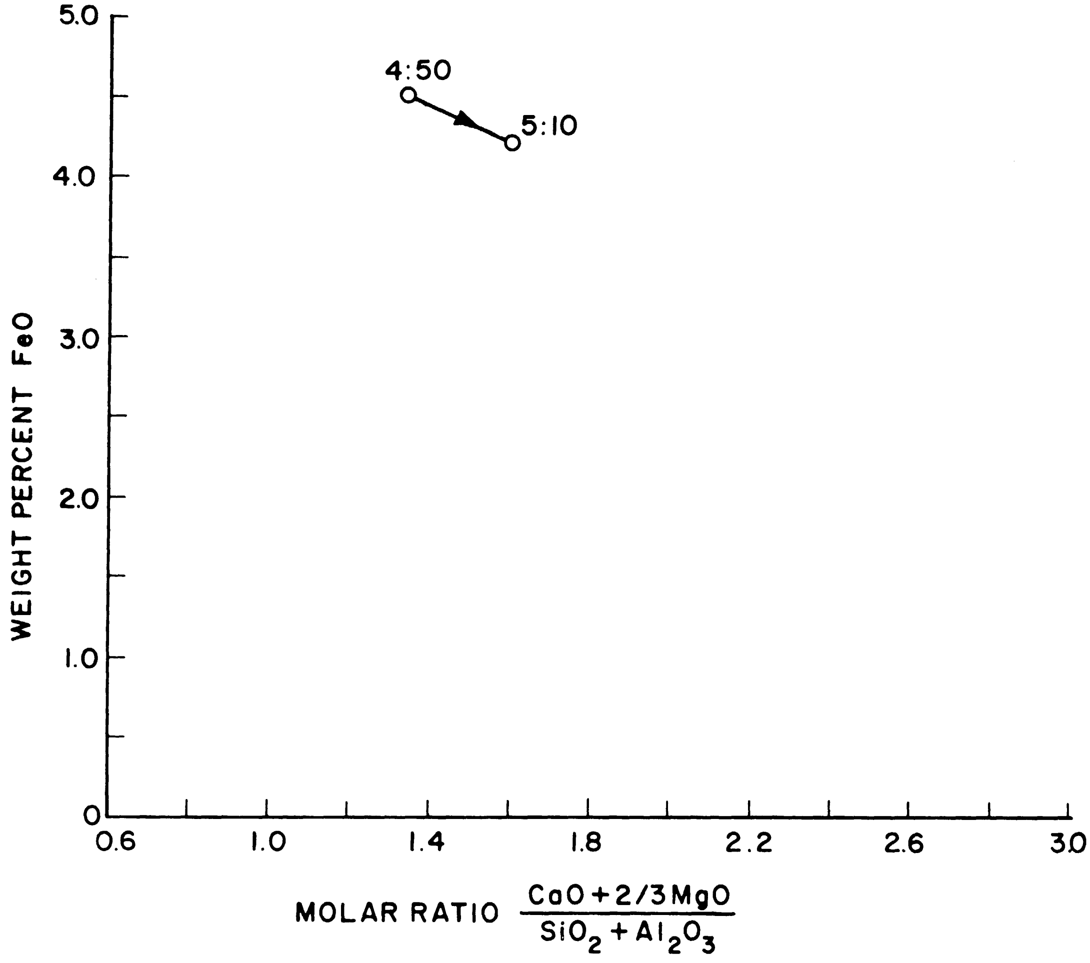
CUPOLA HEAT NO. 2



CUPOLA HEAT No. 2



CUPOLA HEAT No. 2



HEAT NO. 3

1. Metallics/Charge

Scrap Returns	100 lb
Sorel Pig	40 lb
Steel Punchings	260 lb
50% FeSi	7.25 lb

2. Nonmetallics/Charge

Coke	70 lb
Stone (Dolomitic)	25 lb
Spar (50% CaFE)	10 lb
CaC_2	6 lb

3. Bed

a. Height	48 in. (thought to be incorrectly measured)
b. Nonmetallics	50 lb stone, 20 lb spar, 15 lb CaC_2 on top
c. Burn in time	5-1/2 hr

4. Runner and Bottom

a. Dam height	2 in.
b. Tap-hole	1 in. x 2 in. (rectangular)
c. Bottom	Depressed 1/2 in. below tap-hole; bowl shape

5. Chemical Analyses Samples

a. Metal	From forehearth
b. Slag	From front and back slaggers

6. Comments

   a. Breast was blowing
   b. Spar was a poor grade
   c. Bed was low
   d. Blast on until tap—16 min

A. Operating Data

1. Inside Diameter at Tuyeres (in.); (Area-sq ft)

   31 in. (5.25 sq ft)

2. Temperature Range

   2600-2700°F

3. Total Carbon, Ingoing

   1.34%

4. Total Carbon, Outgoing

   3.45%

5. Metal Melting Rate lb/min

   65 lb/min

6. Nonmetallics Rate (Exclusive of Bed)

Coke	11.1 lb/min
Stone	3.98 lb/min
Spar	1.60 lb/min
Carbide	0.96 lb/min

7. Air Weight (Average)

   1650 cfm at STP
   133 lb/min

8. Air Pressure

   6 to 10 oz

B. Operating Data/Sq Ft/Min

1. Melting Rate/sq ft/min, lb

   12.4

2. Total Coke wt/sq ft/min, lb—2.11

   a. Coke wt/sq ft/min for combustion—1.83
   b. Coke wt/sq ft/min for solution in iron—0.28

3. Nonmetallics/sq ft/min, lb

Stone	0.76
Spar	0.31
Carbide	0.18

4. Air wt/sq ft/min, lb

   25.4

C. Operating Ratios

1. Air wt/Total Coke wt

   12.0:1

2. Air wt/Metal wt

   2.05:1

3. True Coke Ratio—Metal wt/Coke wt for Combustion

   6.8:1

4. Apparent Coke Ratio—Metal wt/Total Coke wt

   5.9:1

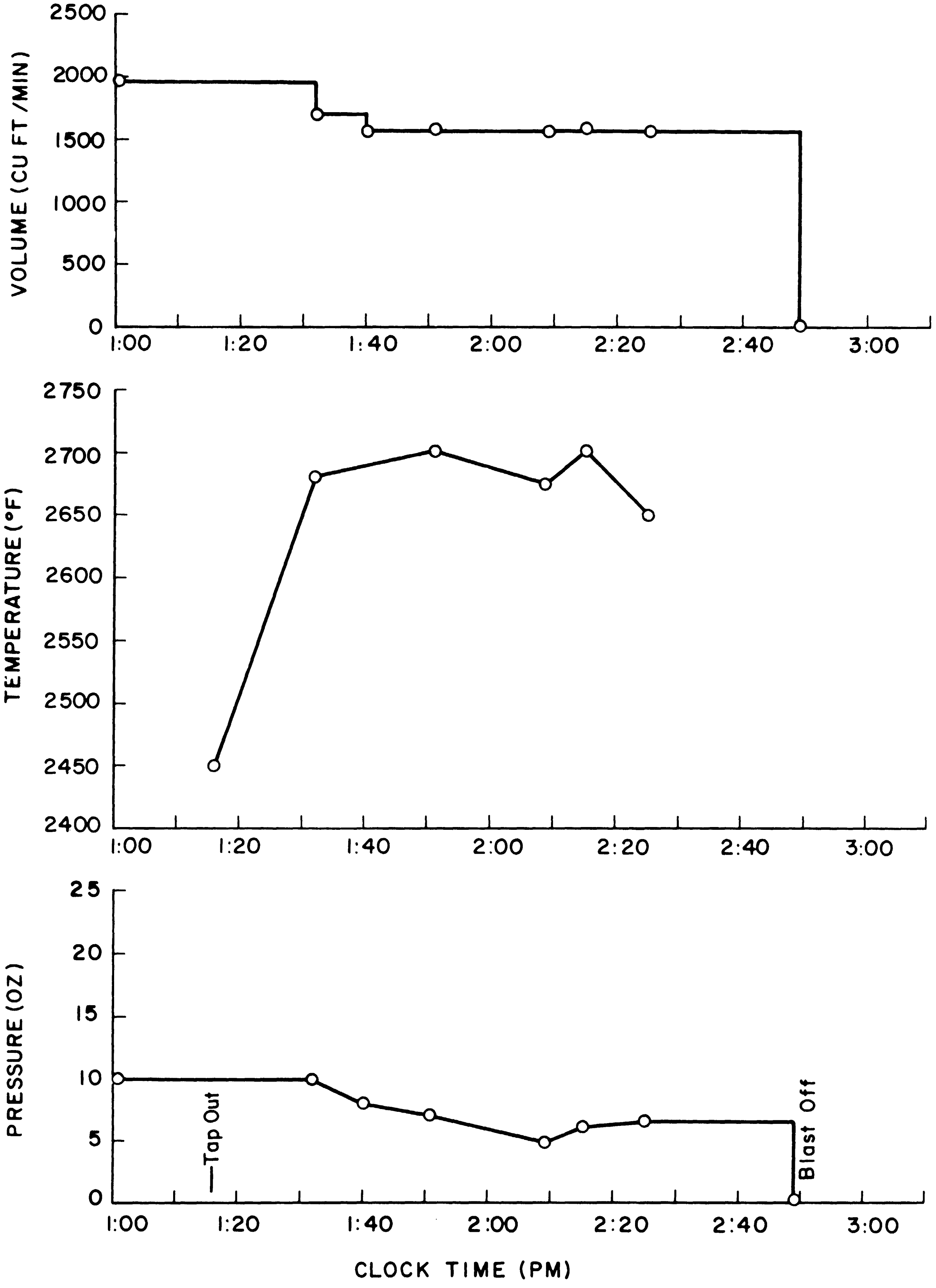
5. Nonmetallics—Metal wt/wt Stone + Spar + Carbide—9.9:1

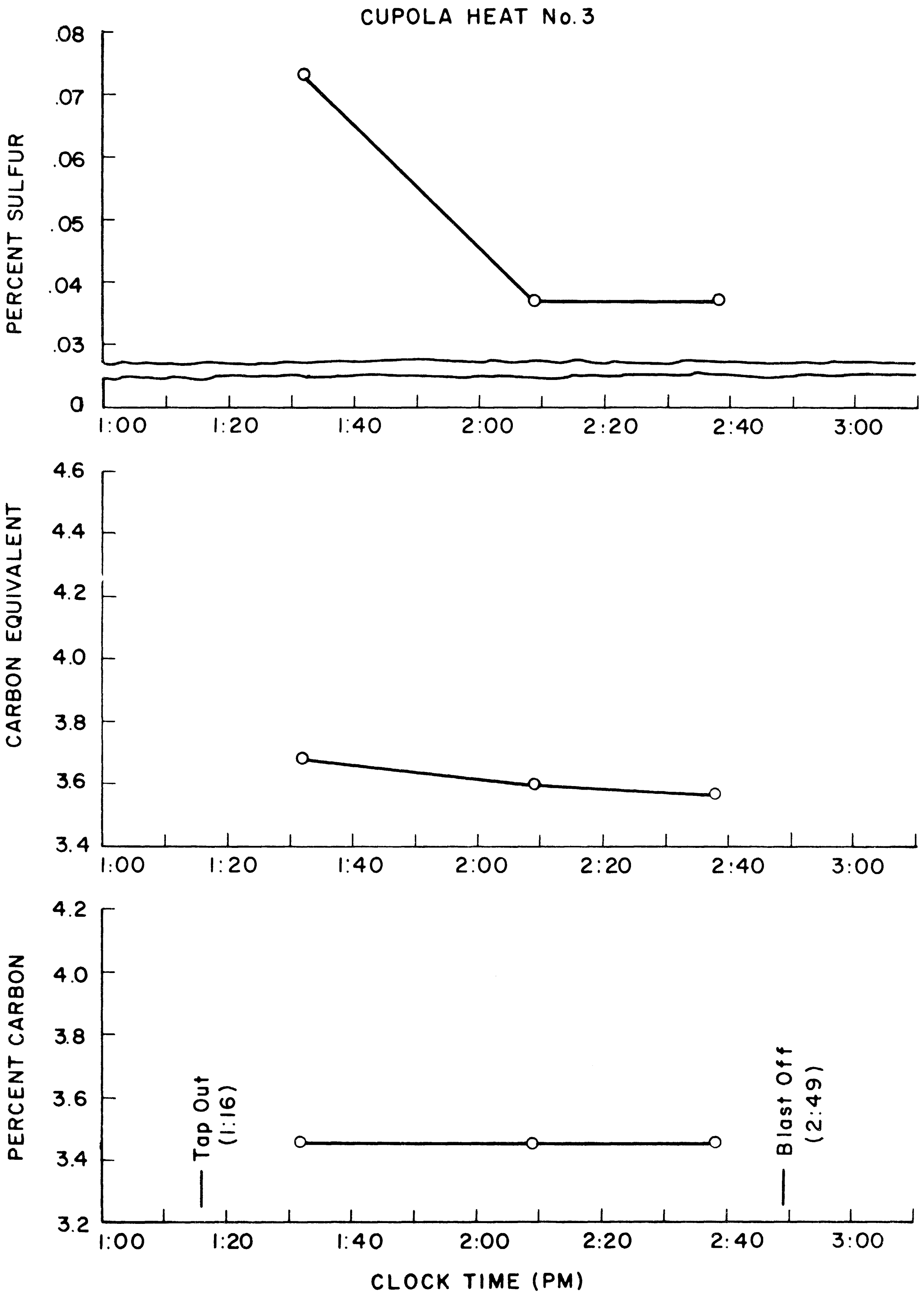
   a. Metal wt/stone wt—16.3:1
   b. Metal wt/spar wt—40.0:1
   c. Metal wt/carbide wt—69.0:1

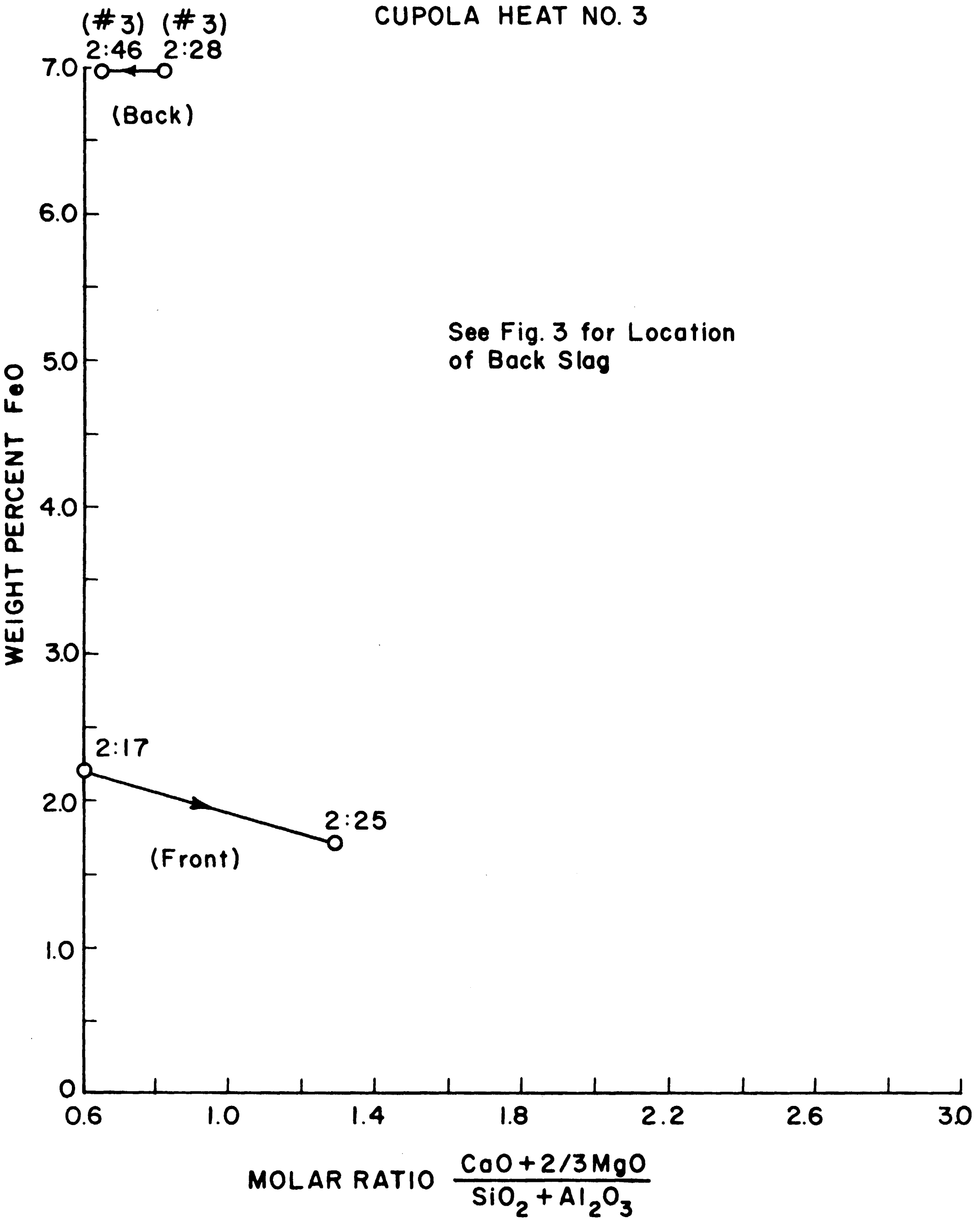
6. Approximate Metal wt/Slag wt

   7.5:1

CUPOLA HEAT NO. 3




CUPOLA HEAT No. 3
PERCENT SULFUR
.08
.07
.06
.05
.04
.03
0
1:00
1:20
1:40
2:00
2:20
2:40
3:00
CARBON EQUIVALENT
4.6
4.4
4.2
4.0
3.8
3.6
3.4
1:00
1:20
1:40
2:00
2:20
2:40
3:00
PERCENT CARBON
4.2
4.0
3.8
3.6
3.4
3.2
Tap Out (1:16)
Blast Off (2:49)
1:00
1:20
1:40
2:00
2:20
2:40
3:00
CLOCK TIME (PM)


CUPOLA HEAT NO. 3
(#3) (#3)
2:46 2:28
(Back)
See Fig. 3 for Location of Back Slag
2:17
2:25
(Front)
WEIGHT PERCENT FeO
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0
0.6
1.0
1.4
1.8
2.2
2.6
3.0
MOLAR RATIO $\frac{CaO + 2/3 MgO}{SiO_2 + Al_2O_3}$

HEAT NO. 4

1. Metallics/Charge

Scrap Returns	140 lb
Steel Punchings	260 lb
50% FeSi	7 lb

2. Nonmetallics/Charge

Coke	70 lb
Stone (Non-dolomitic)	30 lb
Spar (95% CaF_2)	10 lb
CaC_2	6 lb

3. Bed

a. Height	48 in.
b. Nonmetallics	50 lb stone, 20 lb spar, 15 lb CaC_2 on top
c. Burn in time	3-1/2 hr

4. Runner and Bottom

a. Dam height	3 in.
b. Tap-hole	1 in. x 2 in. (rectangular)
c. Bottom	Depressed 1/2 in. below tap-hole; bowl shape

5. Chemical Analyses Samples

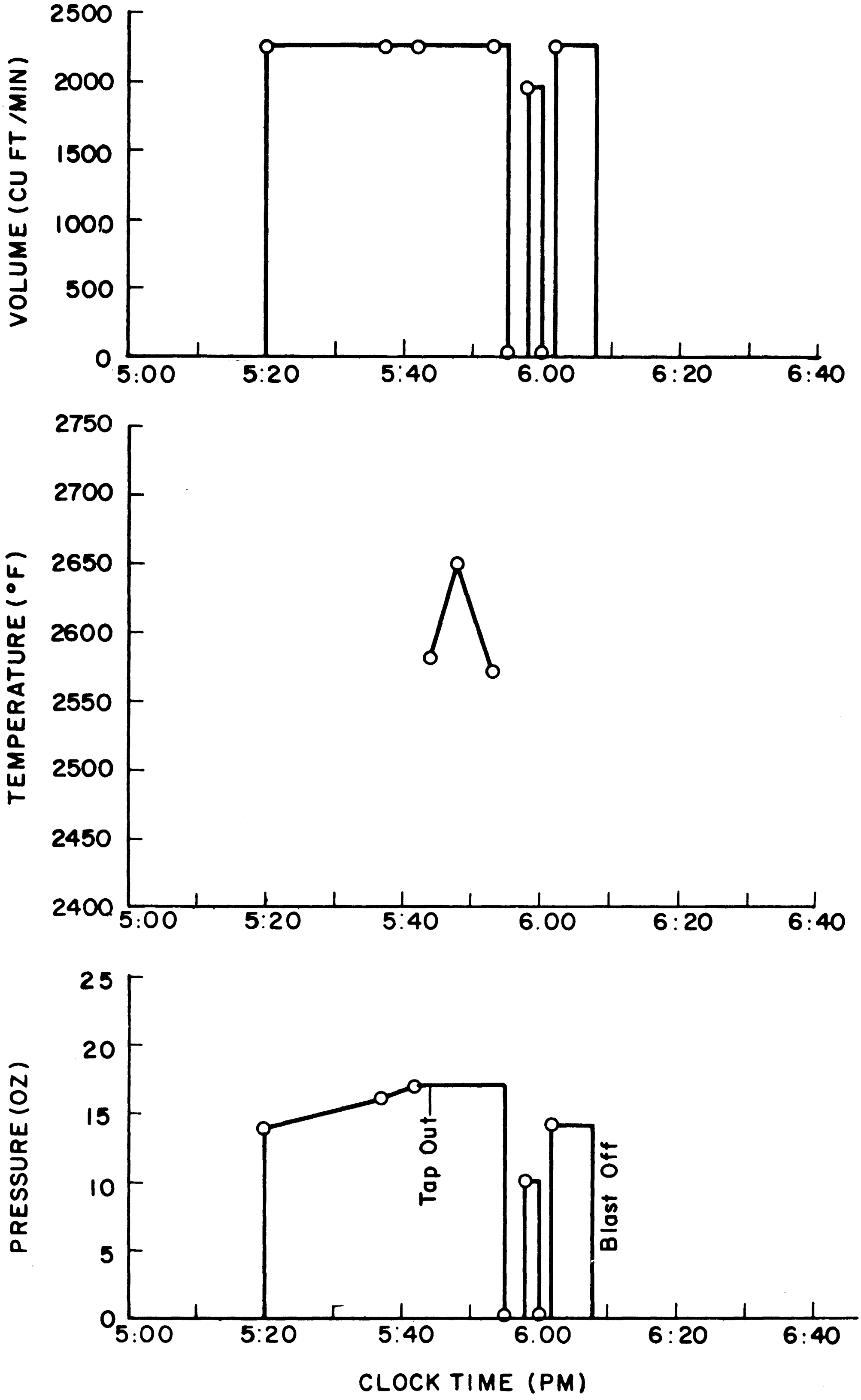
a. Metal	From forehearth and pigs
b. Slag	From front slagger

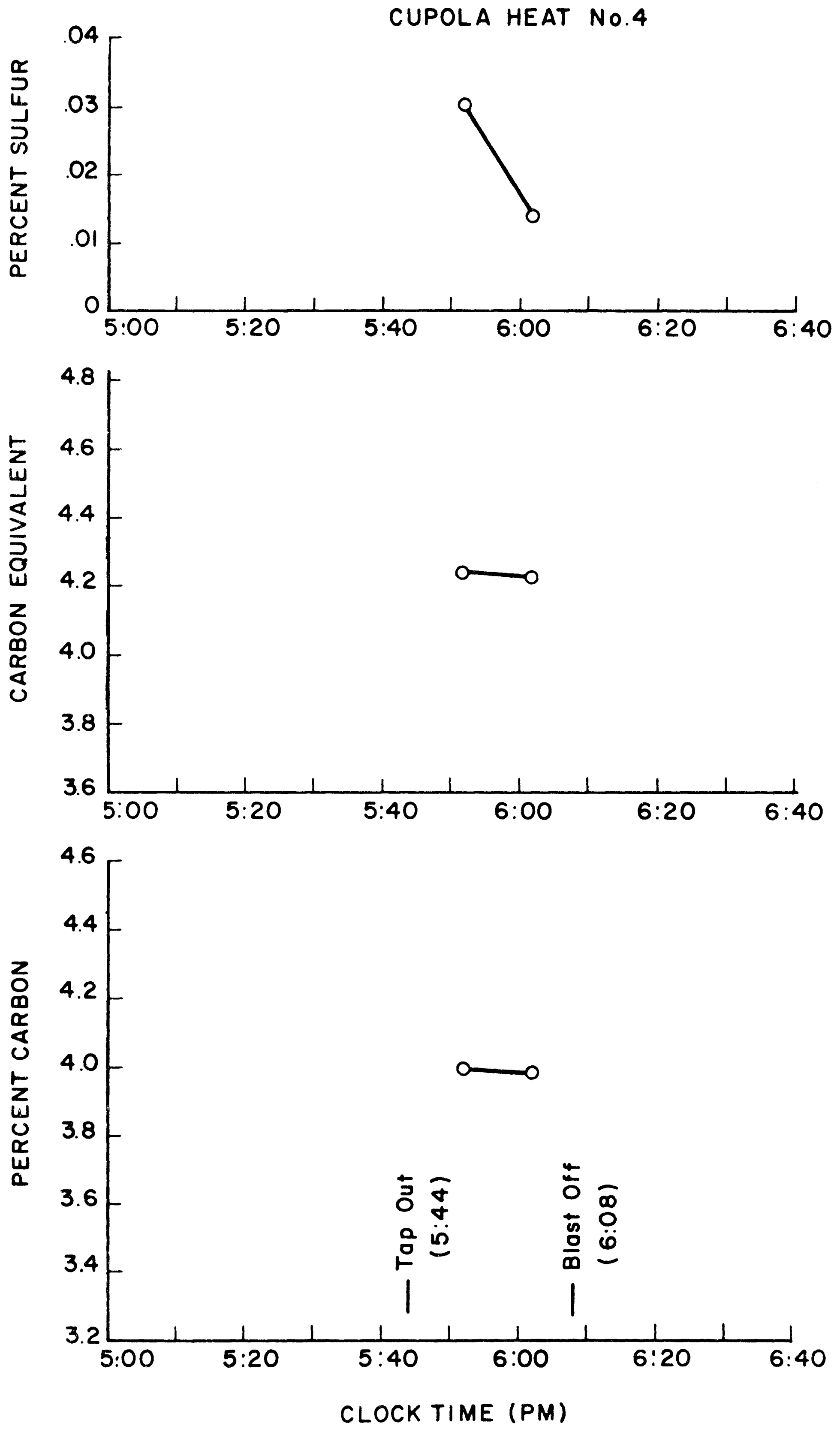
6. Comments

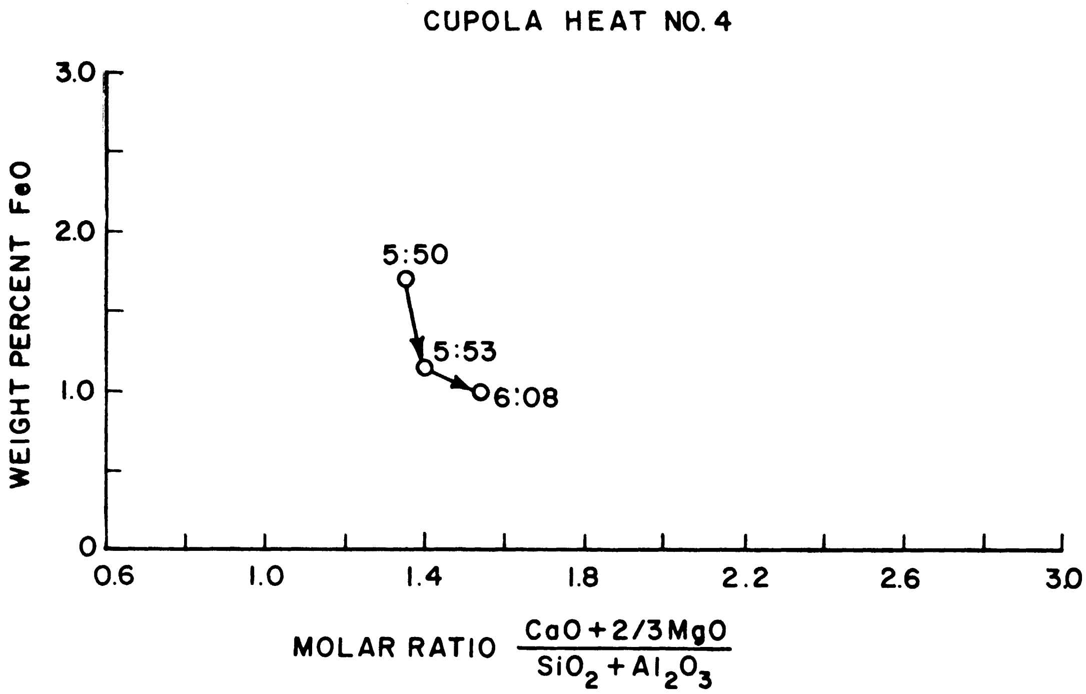
   a. Hi-Al Ram G refractory was of a poor grade and caused difficulty with ramming breast.
   b. Metal ran into windbox through breast—short run
   c. Blast on until tap—24 min

Data incomplete due to metal run out into windbox.

CUPOLA HEAT NO. 4




CUPOLA HEAT No.4
PERCENT SULFUR
.04
.03
.02
.01
0
5:00
5:20
5:40
6:00
6:20
6:40
CARBON EQUIVALENT
4.8
4.6
4.4
4.2
4.0
3.8
3.6
5:00
5:20
5:40
6:00
6:20
6:40
PERCENT CARBON
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
Tap Out (5:44)
Blast Off (6:08)
5:00
5:20
5:40
6:00
6:20
6:40
CLOCK TIME (PM)


CUPOLA HEAT NO. 4
WEIGHT PERCENT FeO
3.0
2.0
1.0
0
0.6
1.0
1.4
1.8
2.2
2.6
3.0
MOLAR RATIO $\frac{CaO + 2/3 MgO}{SiO_2 + Al_2O_3}$
5:50
5:53
6:08

HEAT NO. 5

1. Metallics/Charge

Scrap Returns	50 lb
Sorel Pig	75 lb
Steel Punchings	260 lb
50% FeSi	11.5 lb

2. Nonmetallics/Charge

Coke	70 lb
Stone (High Ca)	30 lb
Spar (95% CaF_2)	10 lb
CaC_2	6 lb

3. Bed

a.	Height	48 in.
b.	Nonmetallics	60 lb stone, 20 lb spar, 20 lb CaC_2 on top
c.	Burn in time	2-1/2 hr

4. Runner and Bottom

a.	Dam height	4 in.
b.	Tap-hole	1-1/2 in. x 3-1/2 in. (rectangular)
c.	Bottom	Depressed 1/2 in. below tap-hole; bowl shape

5. Chemical Analyses Samples

a.	Metal	Runner and forehearth
b.	Slag	Front and back slaggers

6. Comments

a. Windbox cut away at the breast to facilitate ramming
b. Blast on until tap—23 min
c. Difficulty with tapping—cupola off 12 min

A. Operating Data

1. Inside Diameter at Tuyeres (in.); (Area-sq ft)

   33 in. (5.94 sq ft)

2. Temperature Range

   2600-2800°F

3. Total Carbon, Ingoing

   1.28%

4. Total Carbon, Outgoing

   4.20-4.24

5. Metal Melting Rate

   93 lb/min

6. Nonmetallics Rate (Exclusive of Bed)

Coke	16.6 lb/min
Stone	7.1 lb/min
Spar	2.37 lb/min
Carbide	1.42 lb/min

7. Air Weight (Average)

   2050 cfm at STP
   166 lb/min

8. Air Pressure

   14-19 oz

B. Operating Data/Sq Ft/Min

1. Melting Rate/sq ft/min, lb

   15.6

2. Total Coke wt/sq ft/min, lb—2.80

   a. Coke wt/sq ft/min for combustion—2.34
   b. Coke wt/sq ft/min for solution in iron—0.46

3. Nonmetallics/sq ft/min, lb

Stone	1.20
Spar	0.40
Carbide	0.24

4. Air Weight/sq ft/min, lb

28.0

C. Operating Ratios

1. Air wt/Total Coke wt

10.0:1

2. Air wt/Metal wt

1.8:1

3. True Coke Ratio—Metal wt/Coke wt for Combustion

6.7:1

4. Apparent Coke Ratio—Metal wt/Total Coke wt

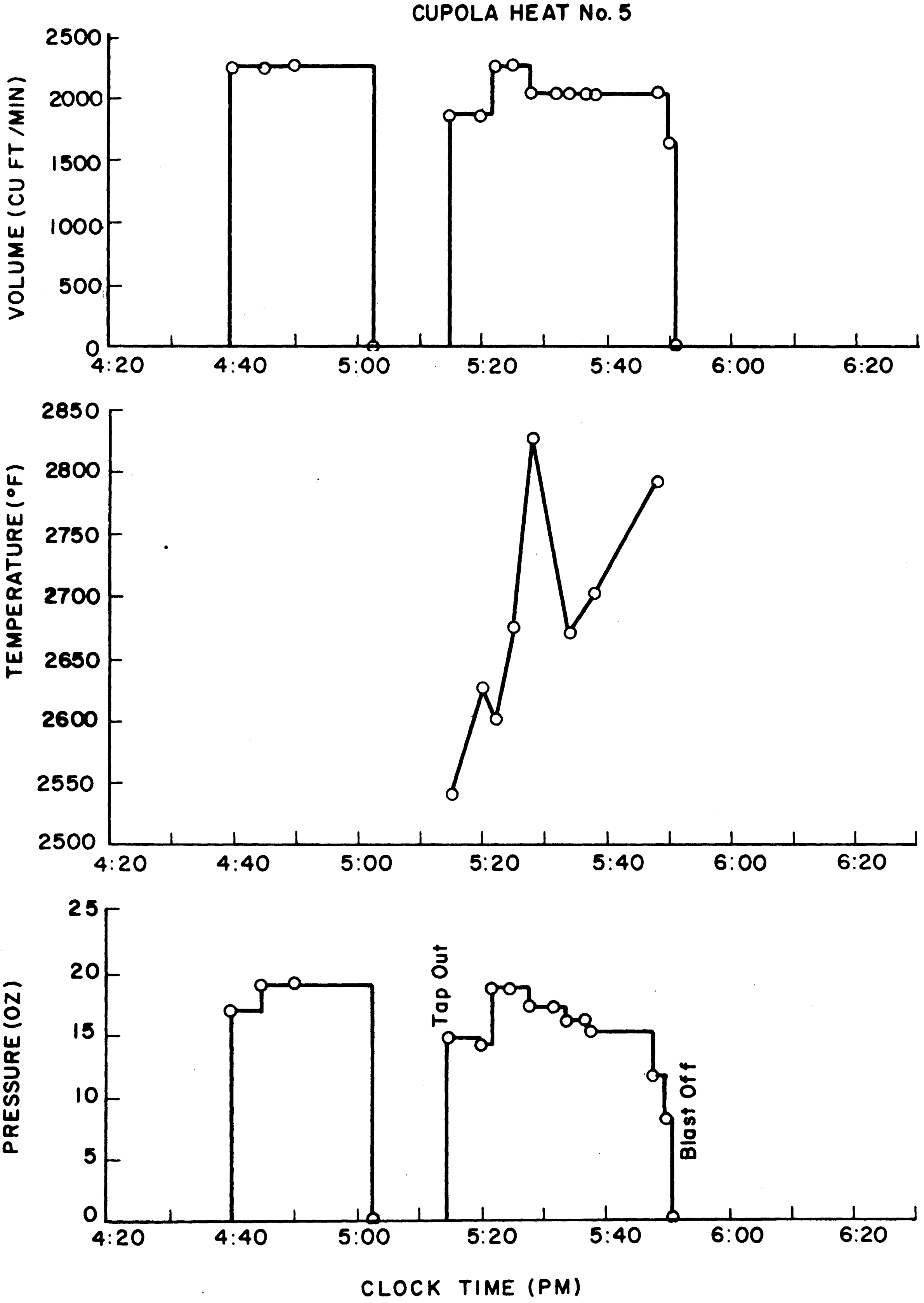
5.6:1

5. Nonmetallics—Total Metal wt/wt Stone + Spar + Carbide—8.5:1

   a. Metal wt/stone wt—13.0:1
   b. Metal wt/spar wt—39.0:1
   c. Metal wt/carbide wt—65.0:1

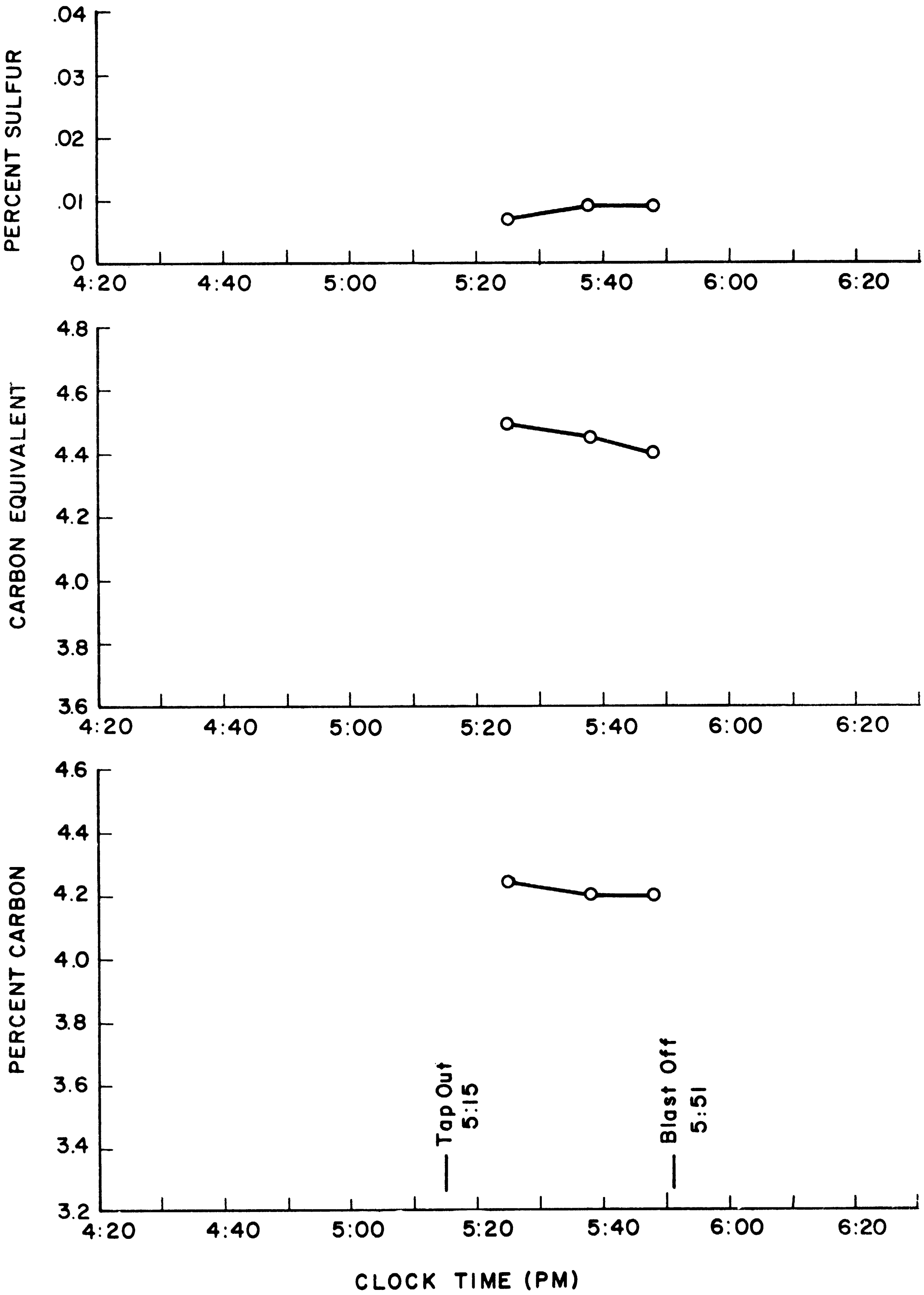
6. Approximate Metal wt/Slag wt

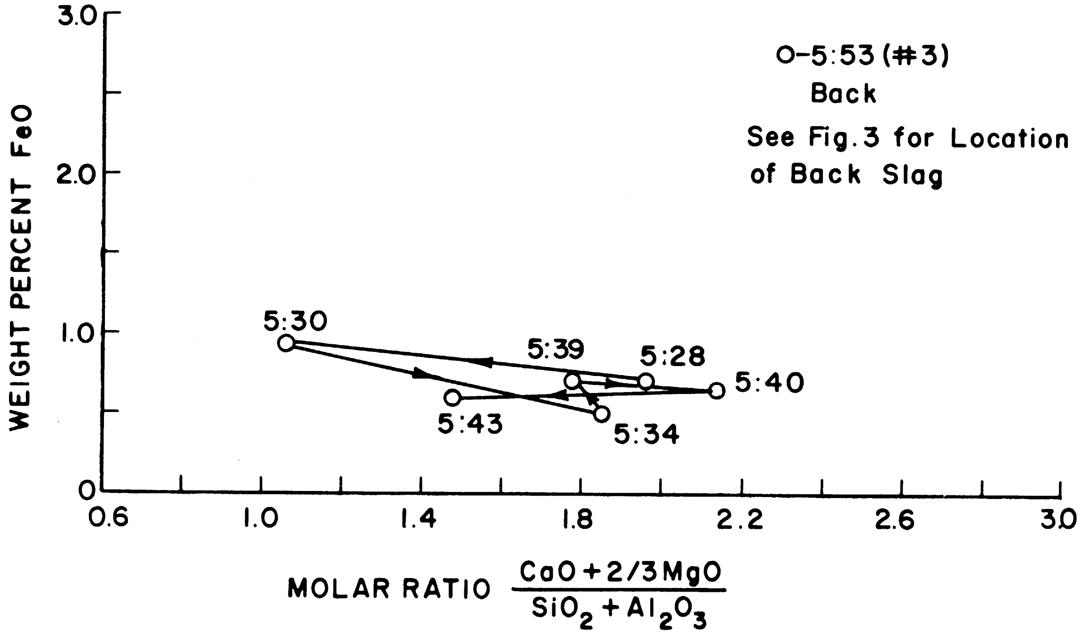
6.6:1



CUPOLA HEAT No. 5
VOLUME (CU FT/MIN)
2500
2000
1500
1000
500
0
TEMPERATURE (°F)
2850
2800
2750
2700
2650
2600
2550
2500
PRESSURE (OZ)
25
20
15
10
5
0
Tap Out
Blast Off
4:20
4:40
5:00
5:20
5:40
6:00
6:20
CLOCK TIME (PM)

CUPOLA HEAT No. 5





CUPOLA HEAT No. 5

O–5:53 (#3)
Back
See Fig. 3 for Location of Back Slag

HEAT NO. 6

1. Metallics/Charge

Scrap Returns	140 lb
Steel Punchings	260 lb
50% FeSi	10.5 lb

2. Nonmetallics/Charge

Coke	70 lb
Stone (High Ca)	30 lb
Spar (95% CaF_2)	10 lb
CaC_2	6 lb

3. Bed

a. Height	48 in.
b. Nonmetallics	60 lb stone, 20 lb spar, 20 lb CaC_2 on top
c. Burn in time	4 hr

4. Runner and Bottom

a. Dam height	4 in.
b. Tap-hole	1-1/2 in. x 3-1/2 in. (rectangular)
c. Bottom	Depressed 1/2 in. below tap-hole; bowl shape

5. Chemical Analyses Samples

a. Metal	Runner, forehearth, and pig molds
c. Slag	Front and back slaggers

6. Comments

a. Metal Kished
b. Blast on until tap—21 min

A. Operating Data

1. Inside Diameter at Tuyeres (in.); (Area-sq ft)

   33 in. (5.94 sq ft)

2. Temperature Range

   2600-2750°F

3. Total Carbon, Ingoing

   1.47%

4. Total Carbon, Outgoing

   4.08-4.36%

5. Metal Melting Rate lb/min

   80 lb/min

6. Nonmetallics Rate (Exclusive of Bed)

Coke	13.6 lb/min
Stone	5.8 lb/min
Spar	1.94 lb/min
Carbide	1.17 lb/min

7. Air Weight (Average)

   2050 cfm at STP
   166 lb/min

8. Air Pressure

   12-19 oz

B. Operating Data/Sq Ft/Min

1. Melting Rate/sq ft/min, lb

   13.4

2. Total Coke wt/sq ft/min, lb—2.29

   a. Coke wt/sq ft/min for combustion—1.90-1.94
   b. Coke wt/sq ft/min for solution in iron—0.35-0.39

3. Nonmetallics/sq ft/min, lb

Stone	0.98
Spar	0.33
Carbide	0.20

4. Air wt/sq ft/min, lb

28.0

C. Operating Ratios

1. Air wt/Total Coke wt

12.2:1

2. Air wt/Metal wt

2.09:1

3. True Coke Ratio—Metal wt/Coke wt for Combustion

6.9 to 7.1:1

4. Apparent Coke Ratio—Metal wt/Total Coke wt

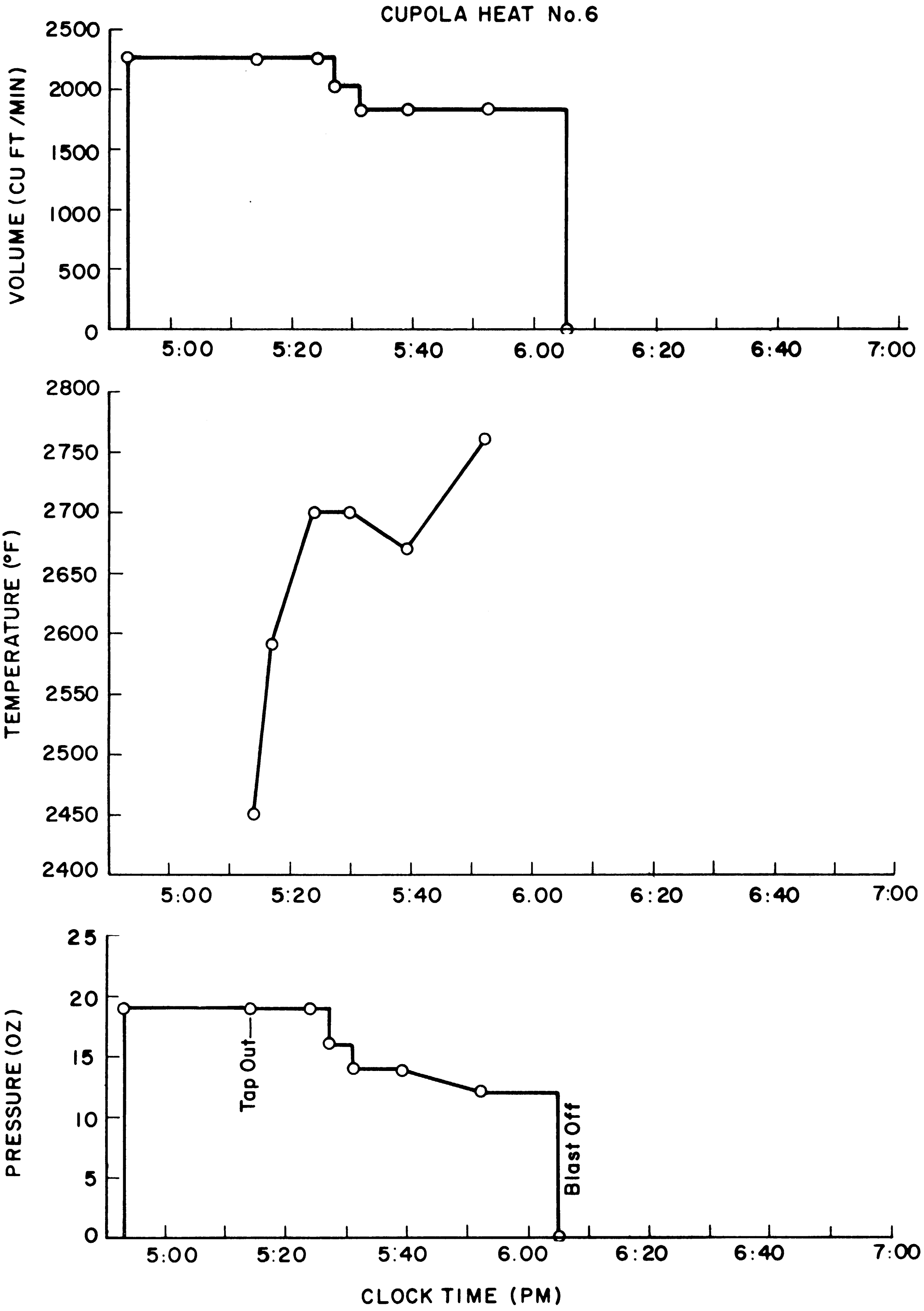
5.85:1

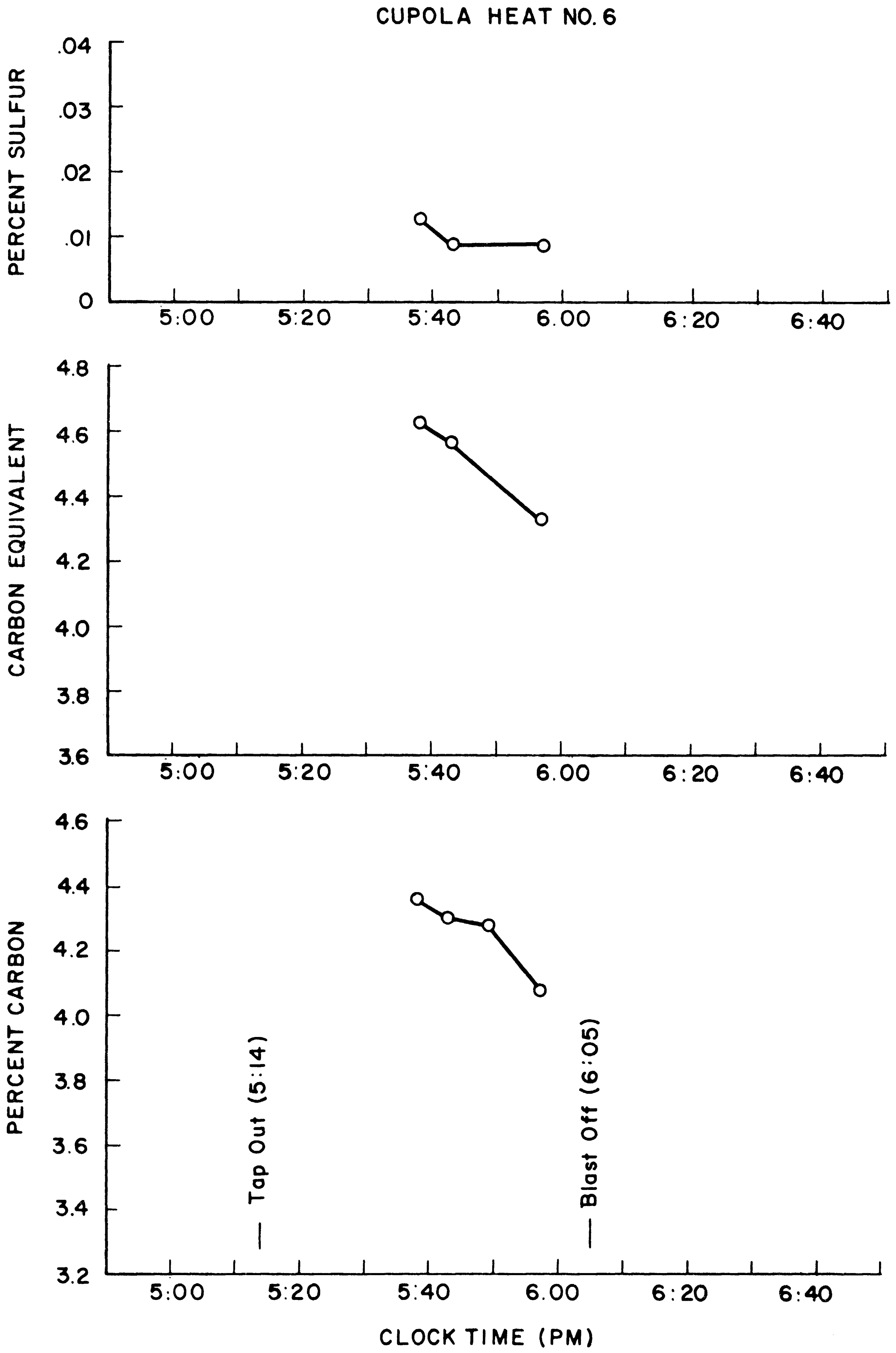
5. Nonmetallics—Total Metal wt/wt Stone + Spar + Carbide—8.9:1

   a. Metal wt/stone wt—13.7:1
   b. Metal wt/spar wt—40.6:1
   c. Metal wt/carbide wt—67.0:1

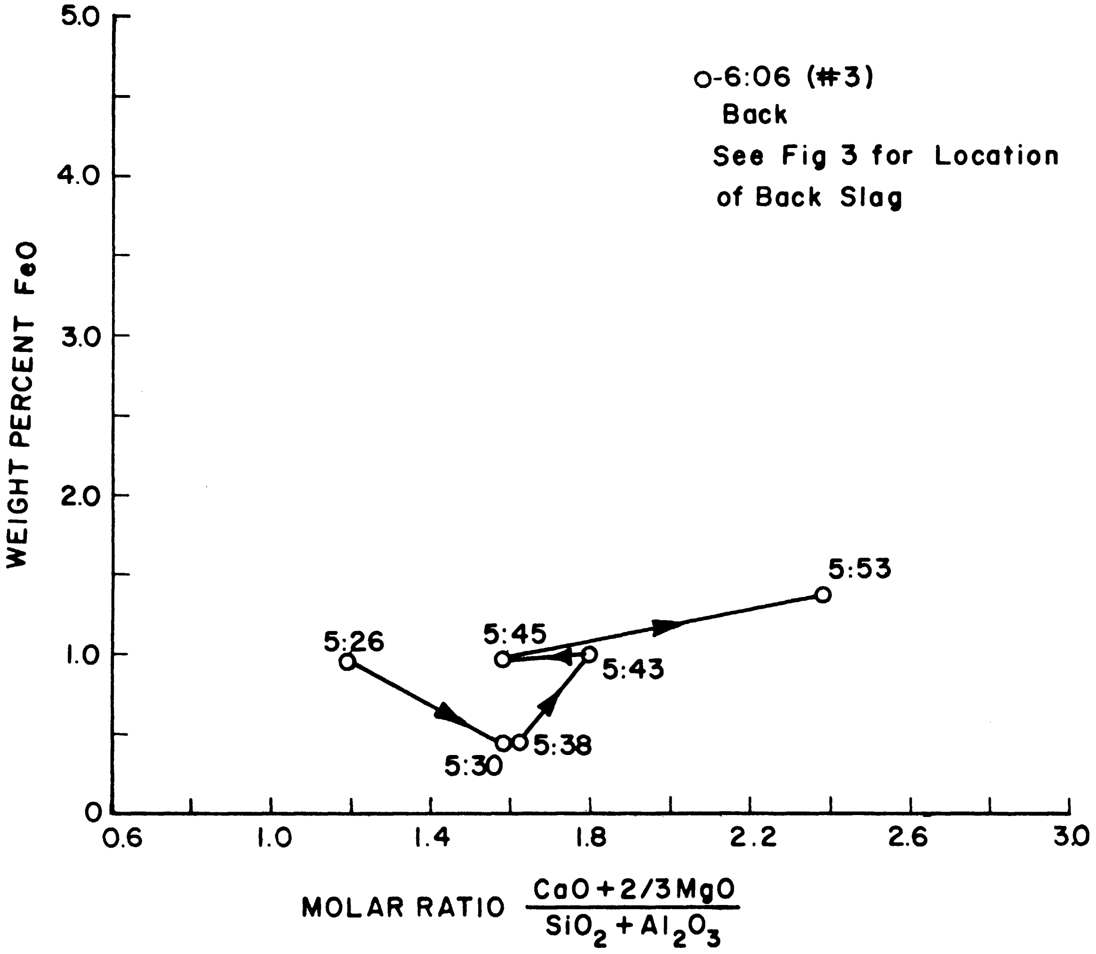
6. Approximate Metal wt/Slag wt

6.9:1


CUPOLA HEAT No.6
VOLUME (CU FT /MIN)
2500
2000
1500
1000
500
0
5:00
5:20
5:40
6.00
6:20
6:40
7:00
TEMPERATURE (°F)
2800
2750
2700
2650
2600
2550
2500
2450
2400
5:00
5:20
5:40
6.00
6:20
6:40
7:00
PRESSURE (OZ)
25
20
15
10
5
0
Tap Out
Blast Off
5:00
5:20
5:40
6.00
6:20
6:40
7:00
CLOCK TIME (PM)


CUPOLA HEAT NO. 6
PERCENT SULFUR
.04
.03
.02
.01
0
5:00
5:20
5:40
6.00
6:20
6:40
CARBON EQUIVALENT
4.8
4.6
4.4
4.2
4.0
3.8
3.6
5:00
5:20
5:40
6.00
6:20
6:40
PERCENT CARBON
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
Tap Out (5:14)
Blast Off (6:05)
5:00
5:20
5:40
6.00
6:20
6:40
CLOCK TIME (PM)

CUPOLA HEAT No. 6



HEAT NO. 7

1. Metallics/Charge

Scrap Returns	140 lb
Steel Punchings	260 lb
50% FeSi	10 lb

2. Nonmetallics/Charge

Coke	60 lb
Stone (High Ca)	18 lb
Spar (95% CaF_2)	5 lb

3. Bed

a. Height	48 in.
b. Nonmetallics	45 lb stone, 15 lb spar, 15 lb CaC_2 on top
c. Burn in time	6-1/2 hr

4. Runner and Bottom

a. Dam height	5 in.
b. Tap-hole	1-1/2 in. x 3-1/2 in. (rectangular)
c. Bottom	Depressed 1/2 in. below tap-hole; bowl shape

5. Chemical Analyses Samples

a. Metal	Forehearth and pig molds
b. Slag	Front and back slaggers

6. Comments

   a. Metal came out of front slagger while slag was still in the cupola

   b. Blast on until tap—22 min

A. Operating Data

1. Inside Diameter at Tuyeres (in.); (Area-sq ft)

   34 in. (6.3 sq ft)

2. Temperature Range

   2600-2750°F

3. Total Carbon, Ingoing

   1.46%

4. Total Carbon, Outgoing

   3.70-4.05

5. Metal Melting Rate

   86 lb/min

6. Nonmetallics Rate (Exclusive of Bed)

Coke	12.5 lb/min
Stone	3.76 lb/min
Spar	1.05 lb/min
Carbide	None

7. Air Weight (Average)

   2175 cfm at STP
   176 lb/min

8. Air Pressure

   14-18 oz

B. Operating Data/Sq Ft/Min

1. Melting Rate/sq ft/min, lb

   13.6

2. Total Coke wt/sq ft/min, lb—1.99

   a. Coke wt/sq ft/min for combustion—1.64-1.68
   b. Coke wt/sq ft/min for solution in iron—0.31-0.35

3. Nonmetallics/sq ft/min, lb

Stone	0.60
Spar	0.17

4. Air wt/sq ft/min, lb

   28.0

C. Operating Ratios

1. Air wt/Total Coke wt

   14.1:1

2. Air wt/Metal wt

   2.06:1

3. True Coke Ratio—Metal wt/Coke wt for Combustion

   8.1 to 8.3:1

4. Apparent Coke Ratio—Metal wt/Total Coke wt

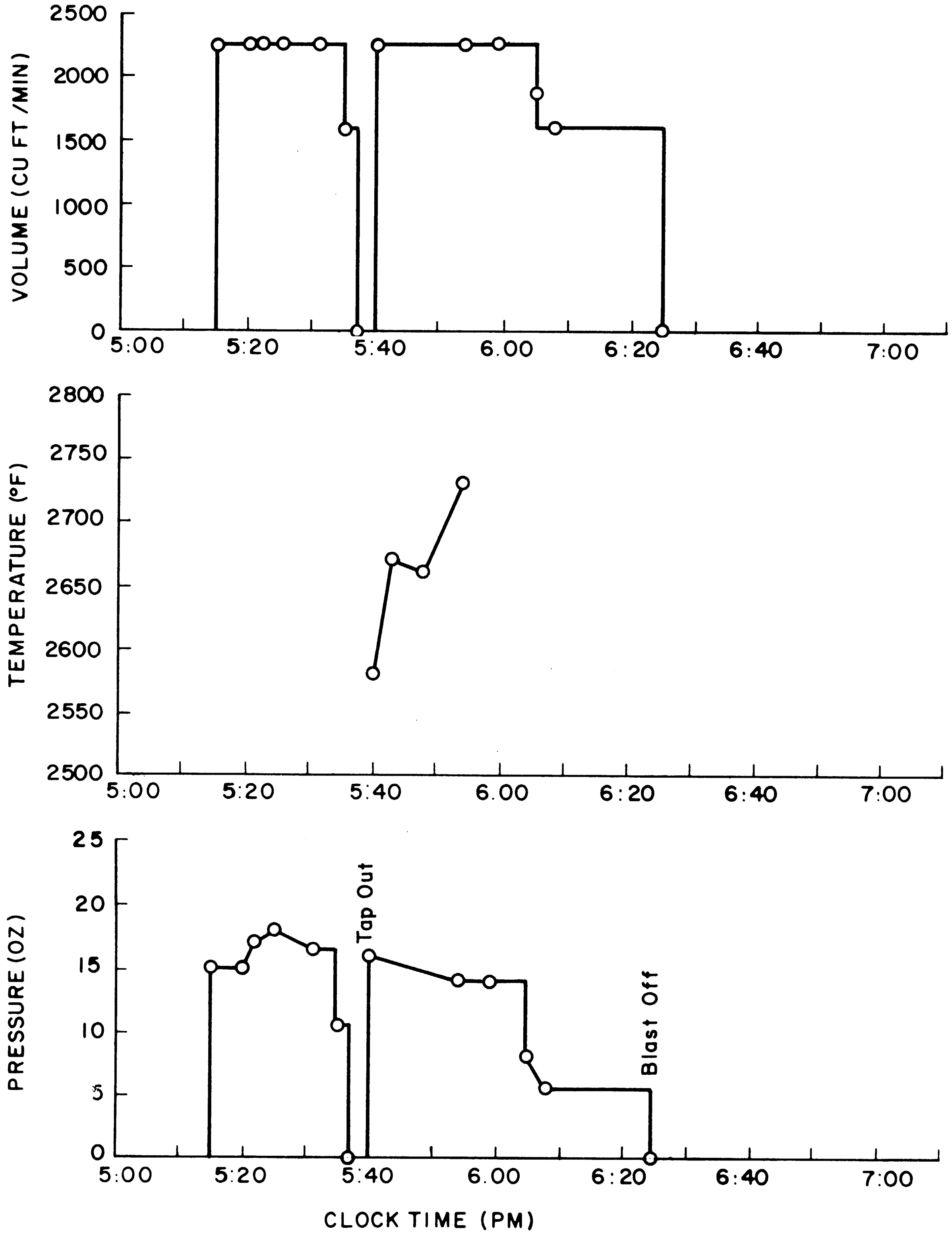
   6.85:1

5. Nonmetallics—Total Metal wt/wt Stone + Spar—17.7:1
   a. Metal wt/stone wt—22.7:1
   b. Metal wt/spar wt—80.0:1

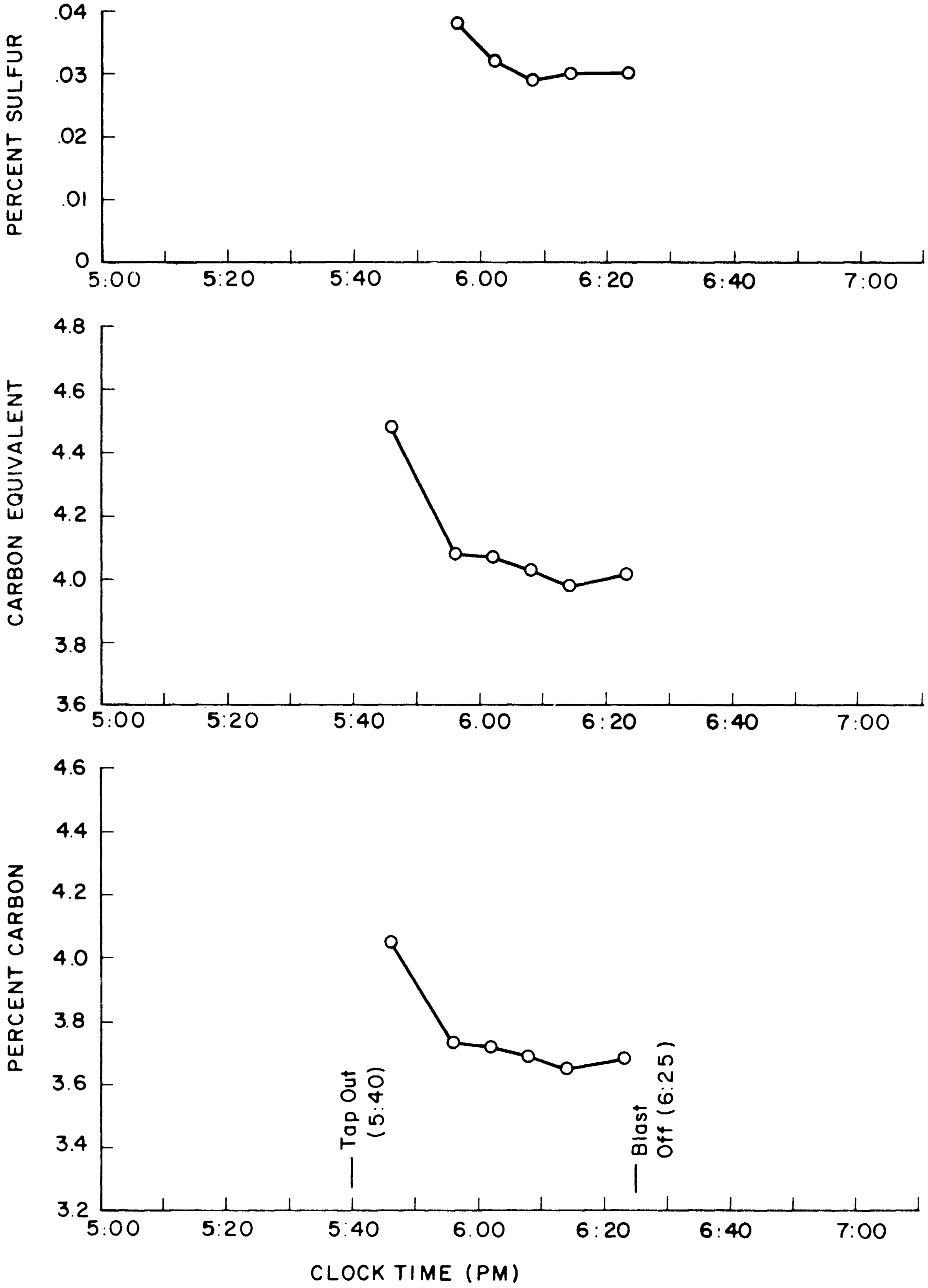
6. Approximate Metal wt/Slag wt

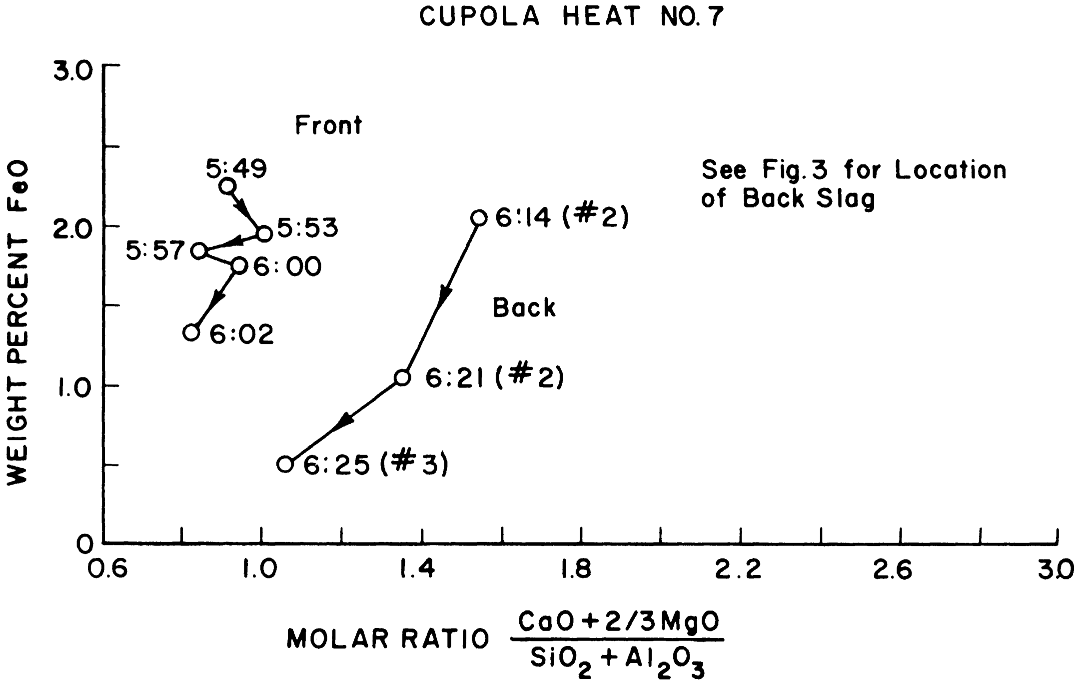
   11.6:1

CUPOLA HEAT NO. 7



CUPOLA HEAT No.7




CUPOLA HEAT NO. 7
WEIGHT PERCENT FeO
3.0
2.0
1.0
0
0.6
1.0
1.4
1.8
2.2
2.6
3.0
MOLAR RATIO $\frac{CaO + 2/3 MgO}{SiO_2 + Al_2O_3}$
Front
5:49
5:53
5:57
6:00
6:02
Back
6:14 (#2)
6:21 (#2)
6:25 (#3)
See Fig. 3 for Location of Back Slag

HEAT NO. 8

1. Metallics/Charge

Scrap Returns	140 lb
Steel Punchings	260 lb
50% FeSi	9.5 lb

2. Nonmetallics/Charge

Coke	60 lb
Stone (High Ca)	18 lb
Spar (95% CaF_2)	5 lb
CaC_2	6 lb

3. Bed

a. Height	48 in.
b. Nonmetallics	5 % by wt CaC_2 added with bed coke. 45 lb stone, 15 lb spar, 15 lb CaC_2 on top of bed
c. Burn in time	4 hr

4. Runner and Bottom

a. Dam height	5 in.
b. Tap-hole	1-1/2 in. x 3-1/2 in. (rectangular)
c. Bottom	Depressed 1/2 in. below tap-hole; bowl shape

5. Chemical Analyses Samples

a. Metal	From runner
b. Slag	Front and back slaggers

6. Comments

   a. Blast on until tap—20 min

A. Operating Data

1. Inside Diameter at Tuyeres (in.); (Area-sq ft)

   35 in. (6.67 sq ft)

2. Temperature Range

   2650-2750°F

3. Total Carbon, Ingoing

   1.33%

4. Total Carbon, Outgoing

   3.95%

5. Metal Melting Rate, lb/min

   99 lb/min

6. Nonmetallics Rate (Exclusive of Bed)

Coke	14.5 lb/min
Stone	4.35 lb/min
Spar	1.21 lb/min
Carbide	1.45 lb/min

7. Air Weight

   2250 cfm at STP
   182 lb/min

8. Air Pressure

   14-19 oz

B. Operating Data/Sq Ft/Min

1. Melting Rate/sq ft/min, lb

   14.8

2. Total Coke wt/sq ft/min, lb—2.18
   - a. Coke wt/sq ft/min for combustion—1.79
   - b. Coke wt/sq ft/min for solution in iron—0.39

3. Nonmetallics/sq ft/min, lb

Stone	0.65
Spar	0.18
Carbide	0.22

4. Air wt/sq ft/min, lb

27.3

C. Operating Ratios

1. Air wt/Total Coke wt

12.5:1

2. Air wt/Metal wt

1.85:1

3. True Coke Ratio—Metal wt/Coke wt for Combustion

8.3:1

4. Apparent Coke Ratio—Metal wt/Total Coke wt

6.8:1

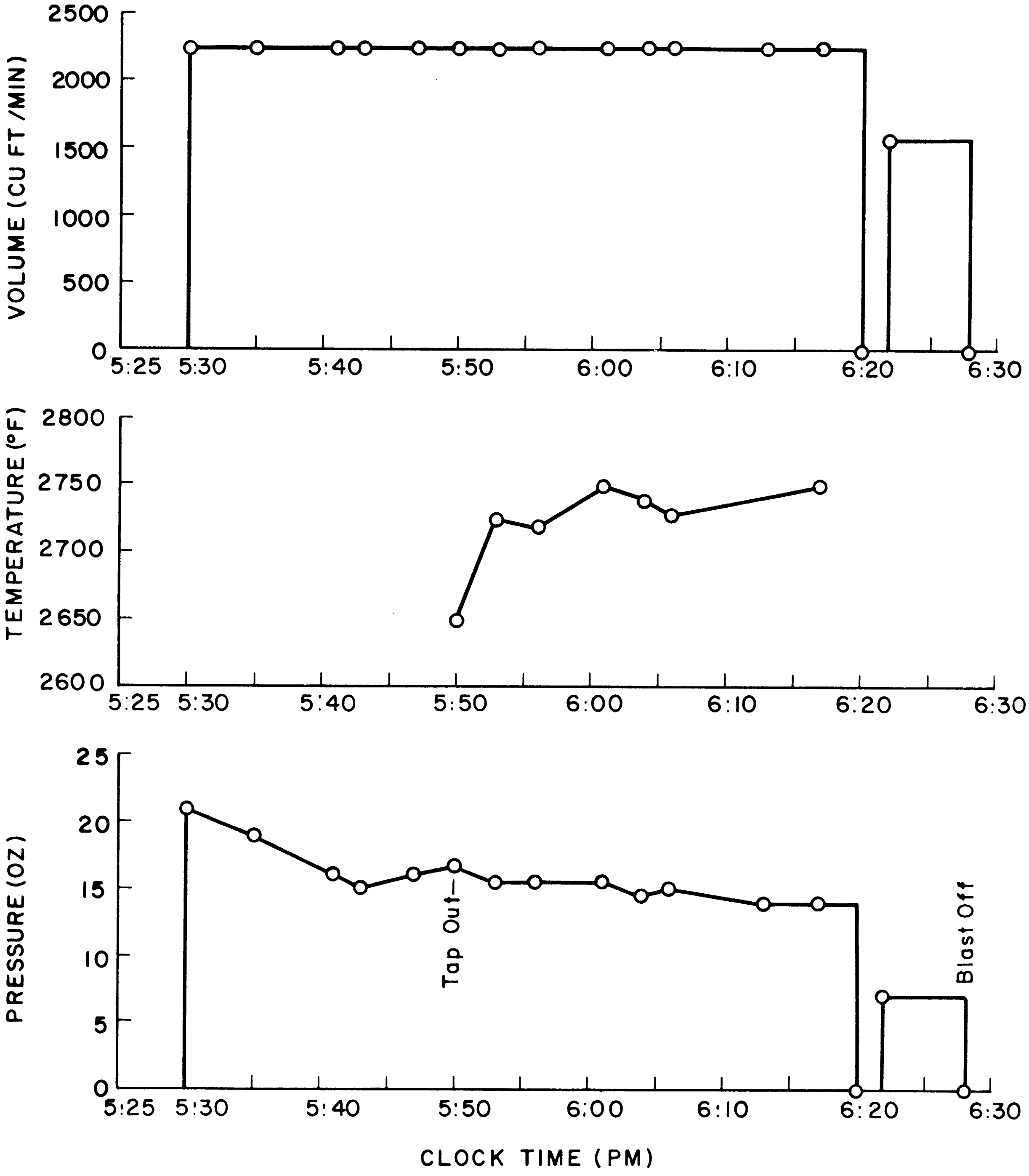
5. Nonmetallics—Metal wt/wt Stone + Spar + Carbide—14.1:1

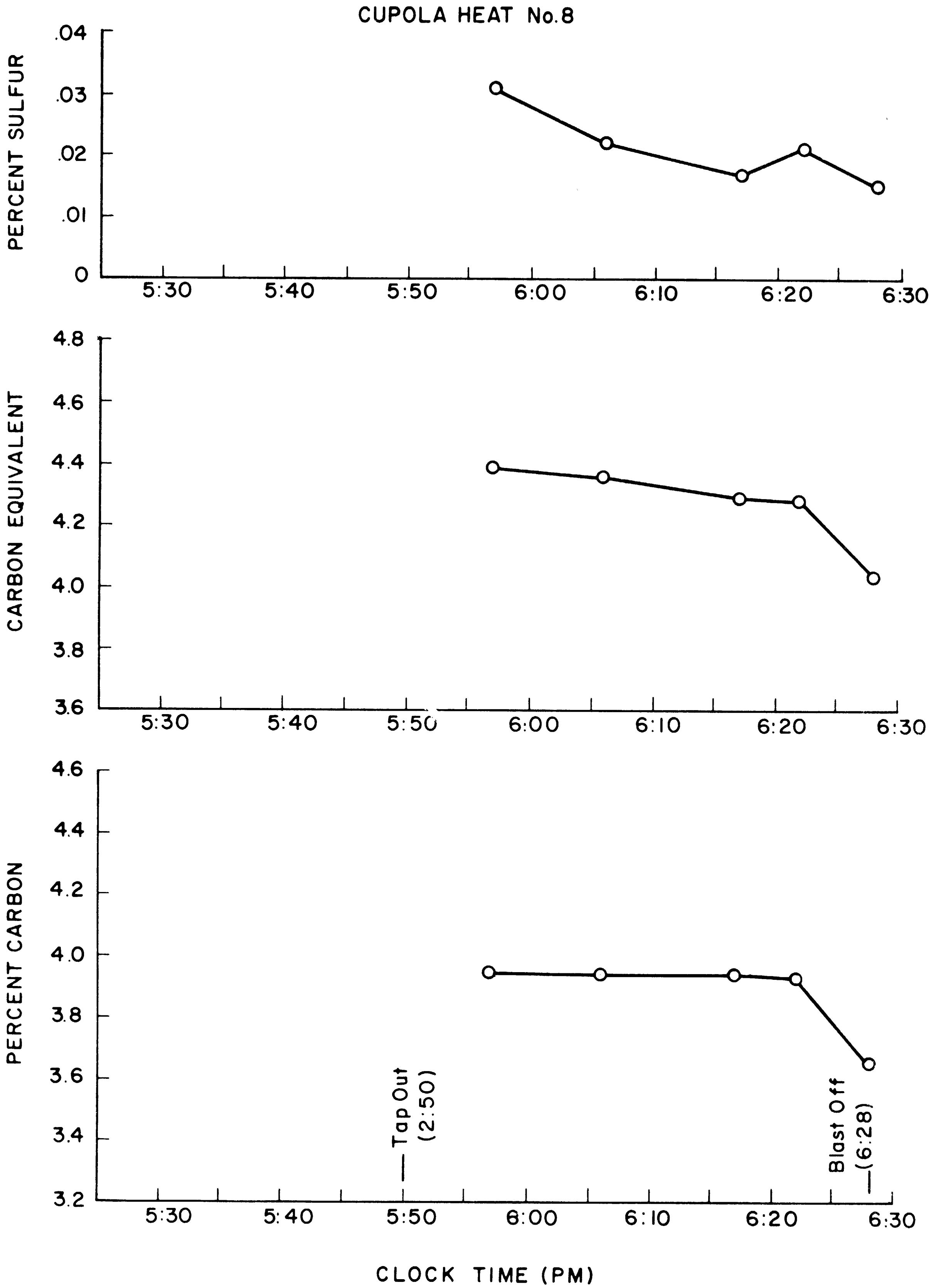
   a. Metal wt/stone wt—22.8:1
   b. Metal wt/spar wt—81.8:1
   c. Metal wt/carbide wt—68.2:1

6. Approximate Metal wt/Slag wt

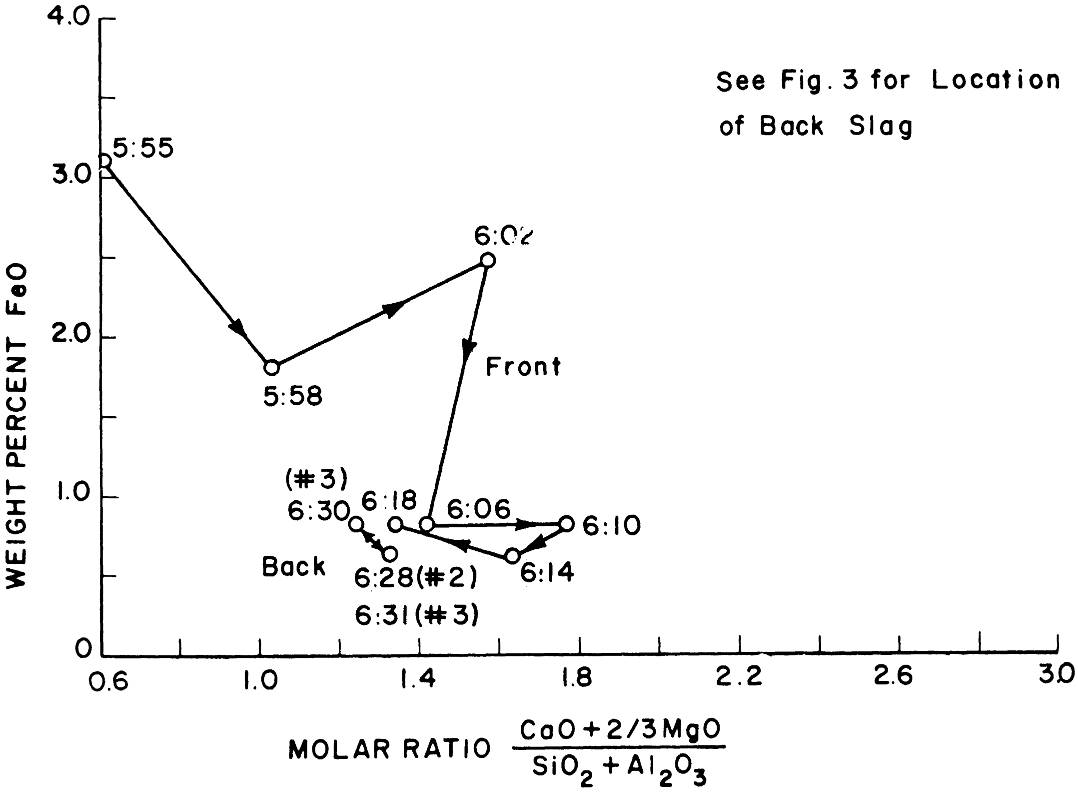
9.9:1

CUPOLA HEAT NO. 8




CUPOLA HEAT No.8

CUPOLA HEAT No. 8



See Fig. 3 for Location of Back Slag

HEAT NO. 9

1. Metallics/Charge

Scrap Returns	140 lb
Steel Punchings	260 lb
50% FeSi	9.5 lb

2. Nonmetallics/Charge

Coke	60 lb
Stone (High Ca)	18 lb
Spar (95% CaF_2)	5 lb
CaC_2	6 lb

3. Bed

a. Height	48 in.
b. Nonmetallics	5% by wt CaC_2 added with bed coke; 45 lb stone, 15 lb spar, 15 lb CaC_2 on top of bed
c. Burn in time	2 hr

4. Runner and Bottom

a. Dam height	5 in.
b. Tap-hole	1-1/2 in. x 3-1/2 in. (rectangular)
c. Bottom	Straight pitch of 1 in./ft to bottom of tap-hole (1/2 in.)

5. Chemical Analyses Samples

a. Metal	From runner
b. Slag	Front and back slaggers

6. Comments

   a. Short burn in time
   b. Different bottom design
   c. Blast on until tap—19 min

A. Operating Data

1. Inside Diameter of Tuyeres (in.); (Area-sq ft)

   35 in. (6.67 sq ft)

2. Temperature Range

   2750-2800°F

3. Total Carbon, Ingoing

   1.38%

4. Total Carbon, Outgoing

   3.40-3.80%

5. Metal Melting Rate, lb/min

   83 lb/min

6. Nonmetallics Rate (Exclusive of Bed)

Coke	12.2	lb/min
Stone	3.65	lb/min
Spar	1.02	lb/min
Carbide	1.22	lb/min

7. Air Weight

   1850 cfm at STP
   150 lb/min

8. Air Pressure

   12-17 oz

B. Operating Data/Sq Ft/Min

1. Melting Rate/sq ft/min, lb

   12.4

2. Total Coke wt/sq ft/min, lb—1.86

   a. Coke wt/sq ft/min for combustion--1.56-1.61
   b. Coke wt/sq ft/min for solution in iron—0.25-0.30

3. Nonmetallics/sq ft/min, lb

Stone	0.55
Spar	0.15
Carbide	0.18

4. Air wt/sq ft/min, lb

   22.5

C. Operating Ratios

1. Air wt/Total Coke wt

   12.3:1

2. Air wt/Metal wt

   1.81:1

3. True Coke Ratio—Metal wt/Coke wt for Combustion

   7.7 to 8.0:1

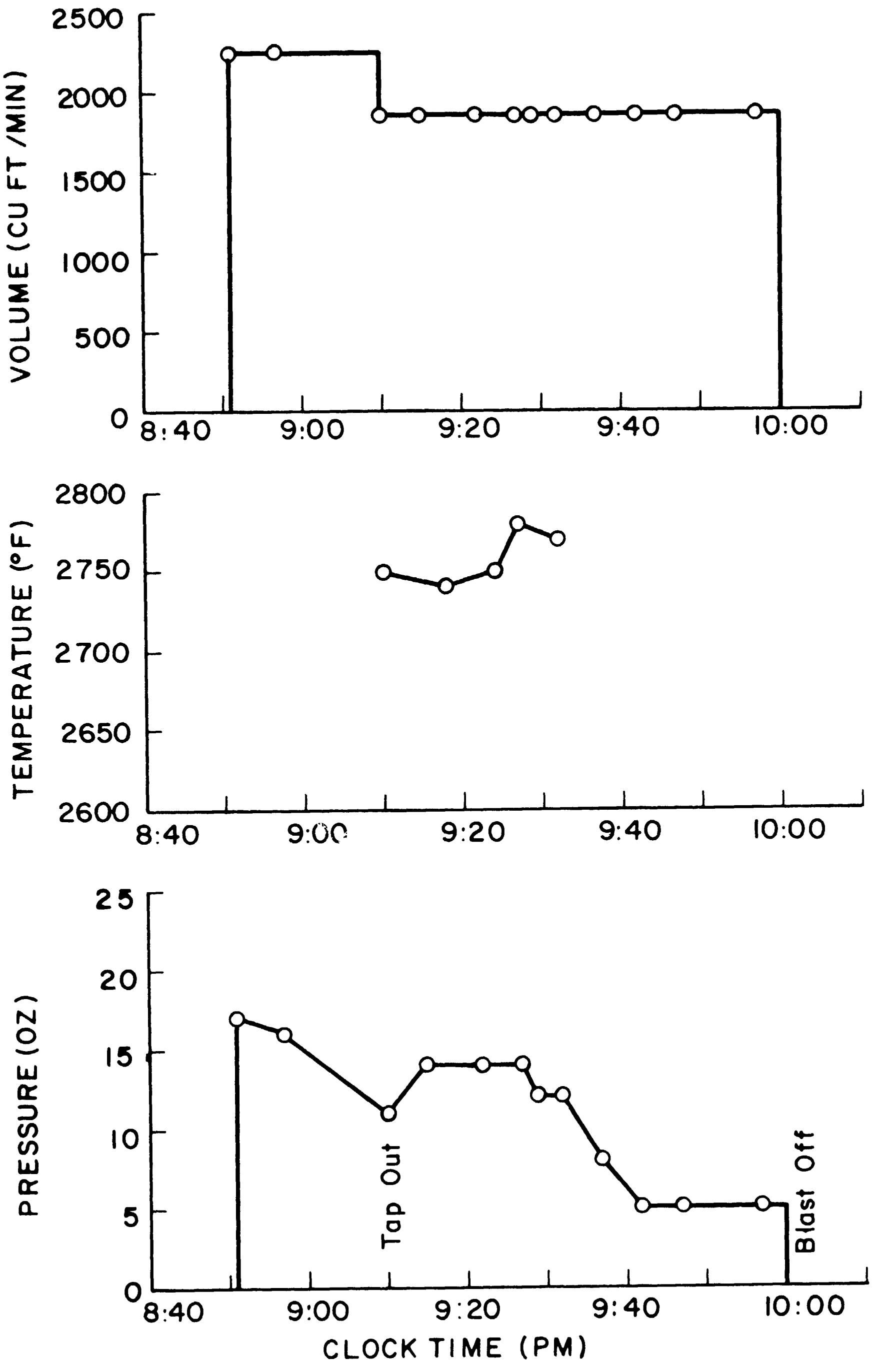
4. Apparent Coke Ratio—Metal wt/Total Coke wt

   6.7:1

5. Nonmetallics—Total Metal wt/wt Stone + Spar + Carbide—14.1:1
   a. Metal wt/stone wt—22.7:1
   b. Metal wt/spar wt—81.5:1
   c. Metal wt/carbide wt—68.1:1

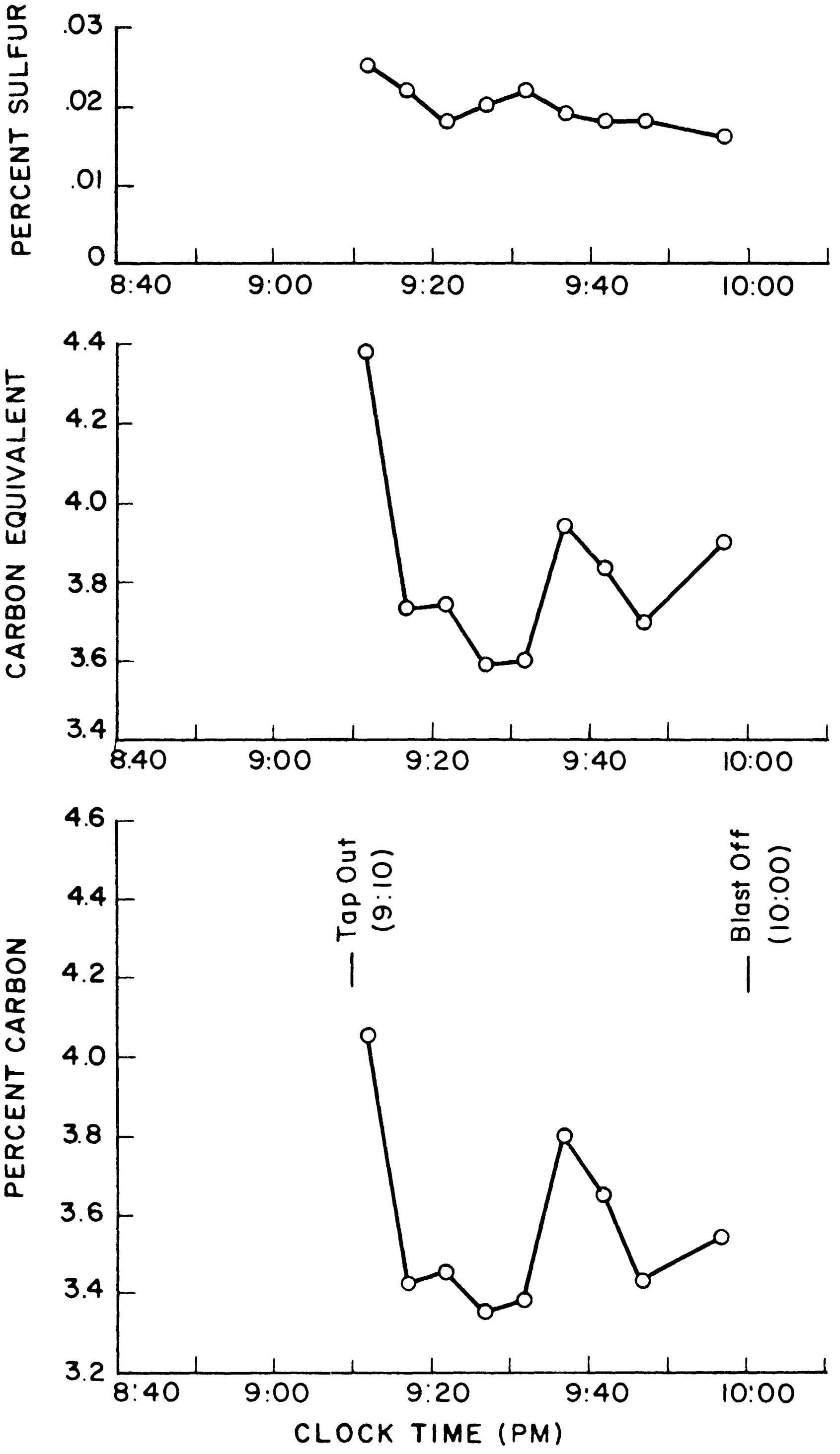
6. Approximate Metal wt/Slag wt

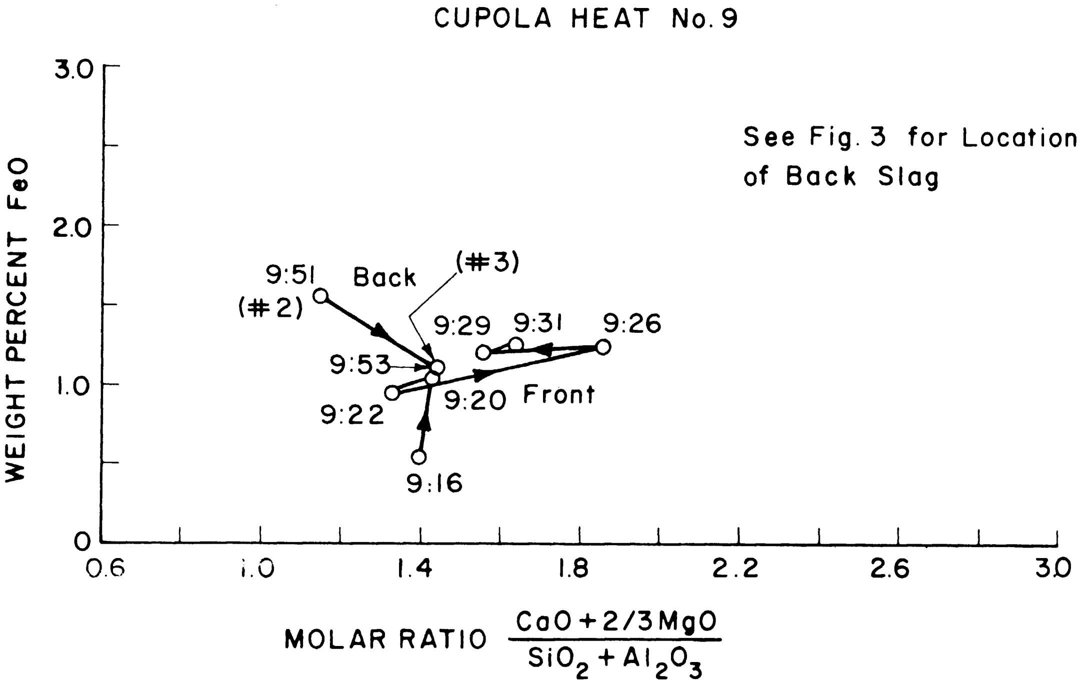
   9.6:1



CUPOLA HEAT NO. 9

CUPOLA HEAT No. 9




CUPOLA HEAT No. 9
See Fig. 3 for Location of Back Slag
WEIGHT PERCENT FeO
3.0
2.0
1.0
0
0.6
1.0
1.4
1.8
2.2
2.6
3.0
MOLAR RATIO $\frac{CaO + 2/3 MgO}{SiO_2 + Al_2O_3}$
9:51
(#2)
Back
(#3)
9:29
9:31
9:26
9:53
9:22
9:20
Front
9:16

HEAT NO. 10

1. Metallics/Charge

Scrap Returns	140 lb
Steel Bales	260 lb
50% FeSi	10 lb

2. Nonmetallics/Charge

Coke	60 lb
Stone (High Ca)	18 lb
Spar (95% CaF_2)	5 lb
CaC_2	6 lb

3. Bed

a. Height	48 in.
b. Nonmetallics	5% by wt CaC_2 added with bed coke; 45 lb stone, 15 lb spar, 15 lb CaC_2 on top of bed
c. Burn in time	5-1/2 hr

4. Runner and Bottom

a. Dam height	5 in.
b. Tap-hole	1-1/2 in. x 3-1/2 in.
c. Bottom	Depressed 1/2 in. below tap-hole; bowl shape

5. Chemical Analyses Samples

a. Metal	From runner
b. Slag	From front slag notch

6. Comments

   a. Bales were too large and had open burden

   b. Blast on until tap—21 min

A. Operating Data

1. Inside Diameter at Tuyeres (in.); (Area-sq ft)

   35 in. (6.67 sq ft)

2. Temperature Range

   2750-2830°F

3. Total Carbon, Ingoing

   1.29%

4. Total Carbon, Outgoing

   3.60-4.30%

5. Metal Melting Rate, lb/min

   76 lb/min

6. Nonmetallics Rate (Exclusive of Bed)

Coke	11.1 lb/min
Stone	3.34 lb/min
Spar	0.93 lb/min
Carbide	1.11 lb/min

7. Air Weight

   2150 cfm at STP
   174 lb/min

8. Air Pressure

   13-18 oz

B. Operating Data/Sq Ft/Min

1. Melting Rate/sq ft/min, lb

   11.4

2. Total Coke wt/sq ft/min, lb—1.67

   a. Coke wt/sq ft/min for combustion—1.33-1.41
   b. Coke wt/sq ft/min for solution in iron—0.26-0.34

3. Nonmetallics/sq ft/min, lb

Stone	0.50
Spar	0.14
Carbide	0.17

4. Air wt/sq ft/min, lb

31.8

C. Operating Ratios

1. Air wt/Total Coke wt

15.7:1

2. Air wt/Metal wt

2.29:1

3. True Coke Ratio—Metal wt/Coke wt for Combustion

8.1 to 8.5:1

4. Apparent Coke Ratio—Metal wt/Total Coke wt

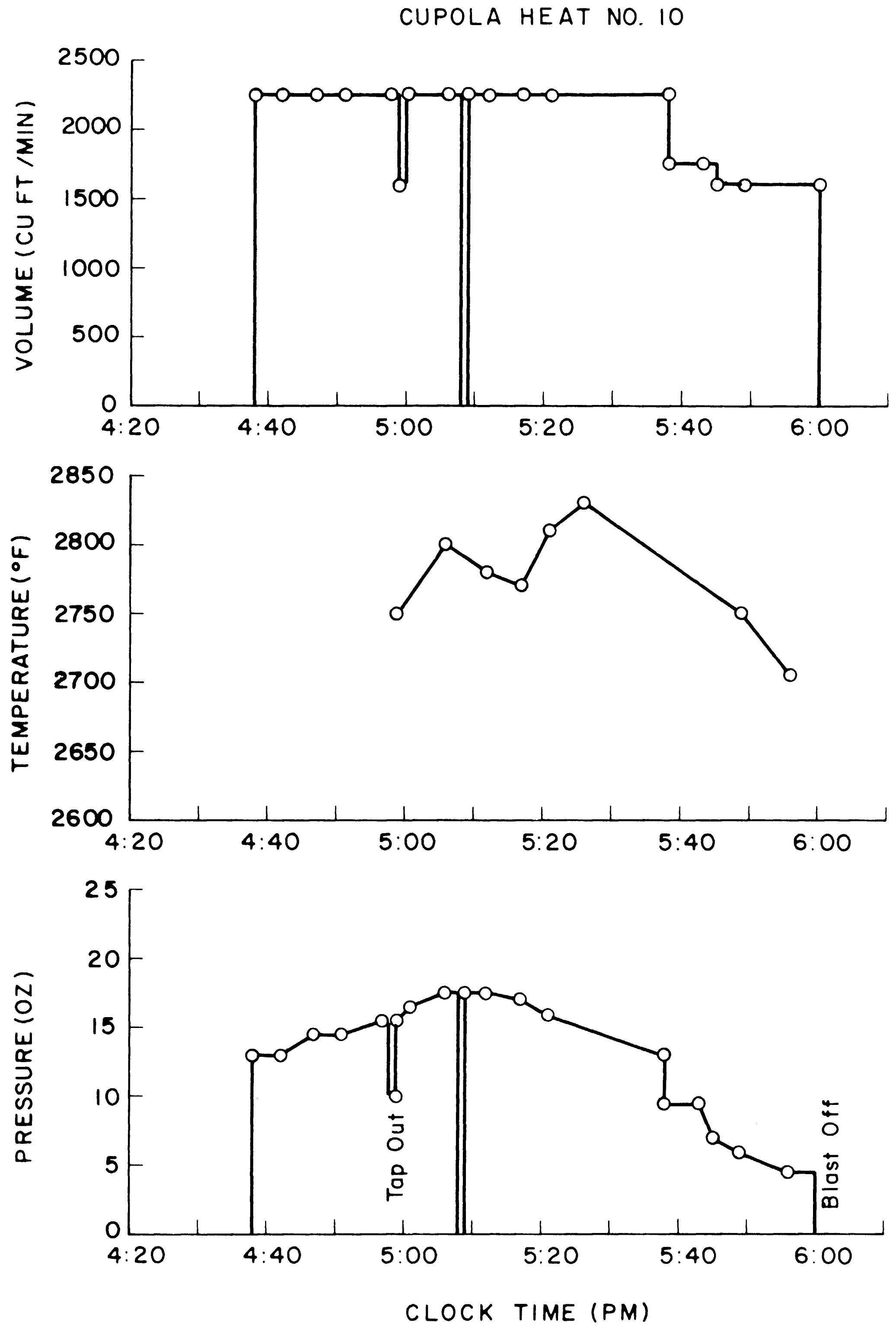
6.85:1

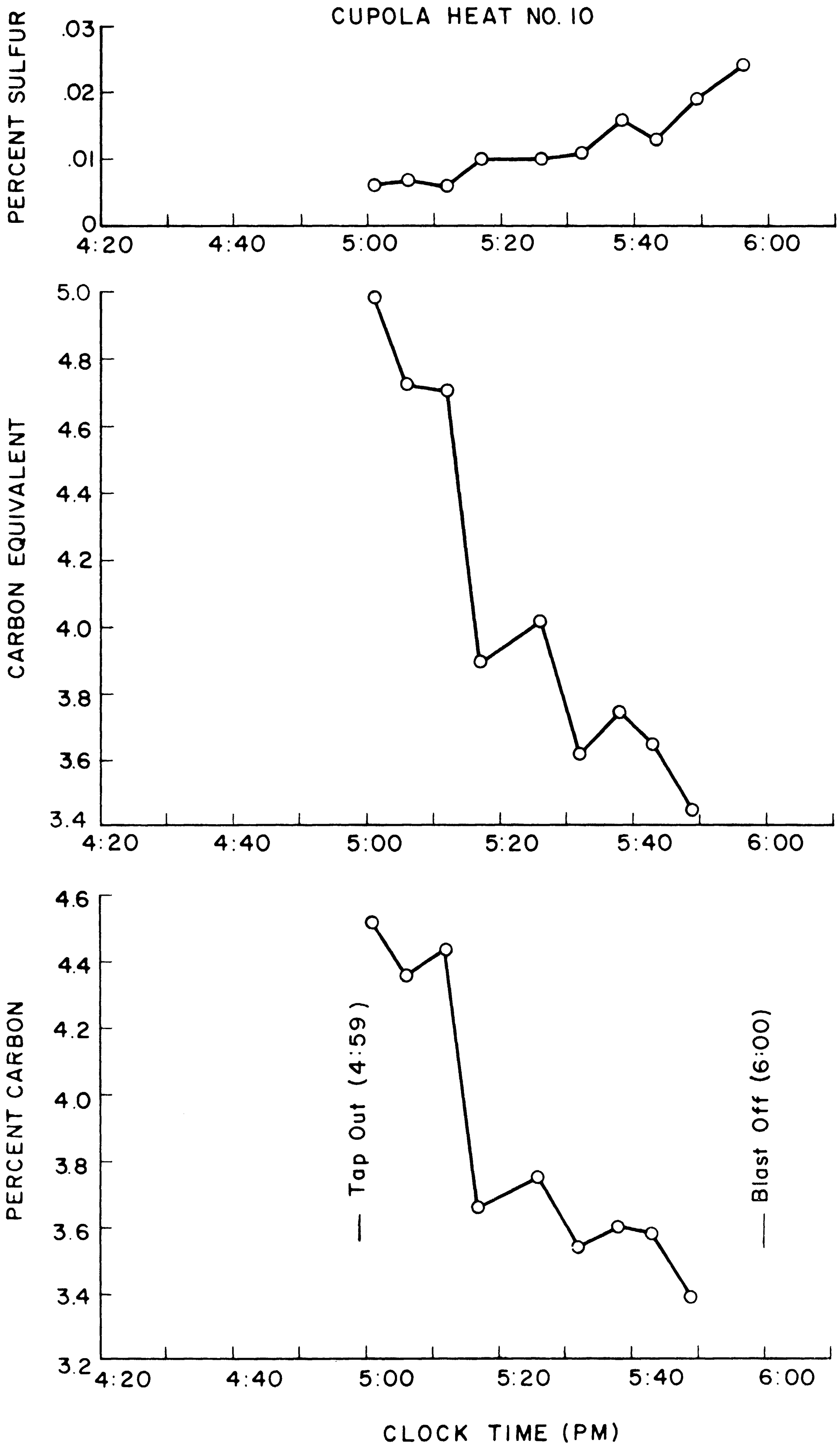
5. Nonmetallics—Metal wt/wt Stone + Spar + Carbide—14.1:1

a. Metal wt/stone wt—22.8:1
b. Metal wt/spar wt—81.8:1
c. Metal wt/carbide wt—68.5:1

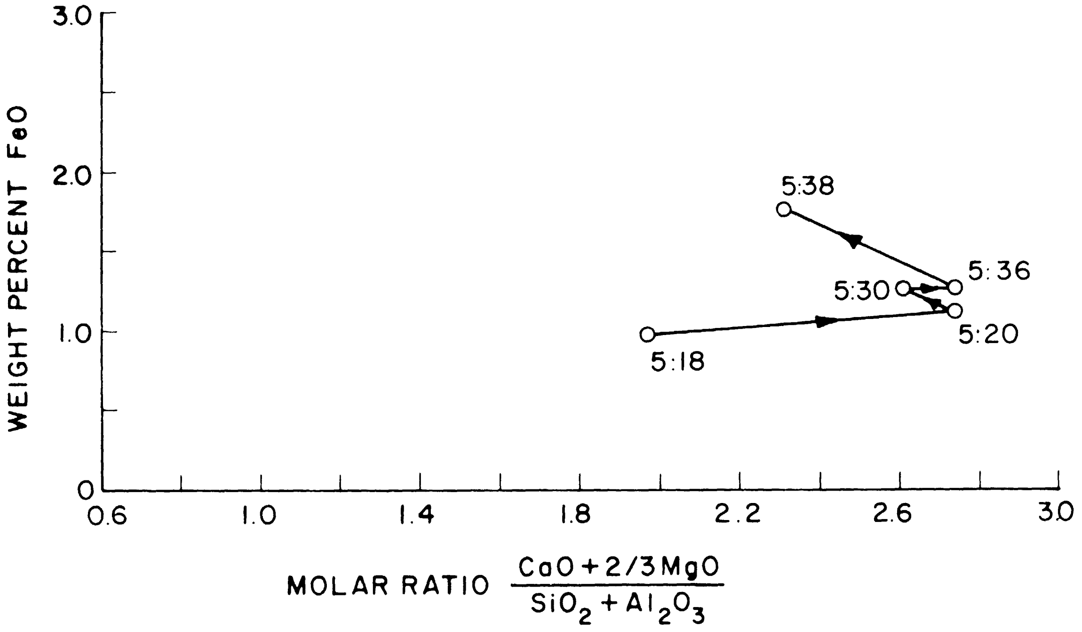
6. Approximate Metal wt/Slag wt

9.7:1


CUPOLA HEAT NO. 10
VOLUME (CU FT /MIN)
2500
2000
1500
1000
500
0
4:20
4:40
5:00
5:20
5:40
6:00
TEMPERATURE (°F)
2850
2800
2750
2700
2650
2600
PRESSURE (OZ)
25
20
15
10
5
0
Tap Out
Blast Off
CLOCK TIME (PM)


CUPOLA HEAT NO. 10
PERCENT SULFUR
.03
.02
.01
0
4:20
4:40
5:00
5:20
5:40
6:00
CARBON EQUIVALENT
5.0
4.8
4.6
4.4
4.2
4.0
3.8
3.6
3.4
PERCENT CARBON
4.6
4.4
4.2
4.0
3.8
3.6
3.4
3.2
Tap Out (4:59)
Blast Off (6:00)
CLOCK TIME (PM)

CUPOLA HEAT No. 10



APPENDIX II

SUMMARY OF CHEMICAL ANALYSES OF SLAG AND METAL

SUMMARY OF CHEMICAL ANALYSES OF SLAG AND METAL

Heat No.	Time After Tap (min)	Metal Analyses					Slag Analyses							Weight Ratio	Molar Ratio
		C	Si	Mn	S	P	FeO	SiO_2	Al_2O_3	CaO	MgO	MnO	S	$\frac{S(slag)}{S(metal)}$	$\frac{CaO + 2/3\ MgO}{SiO_2 + Al_2O_3}$
1*	10	3.83	.39	.21	.080	.022									
	23						3.45	25.8	23.2	29.9	7.08	1.23	.21	2.73	.98
	26	3.65	.80	.22	.077	.021	3.23	26.2	17.8	30.8	15.2	1.26	.21	2.73	1.32
2*	6	3.91	1.03	.21	.058	.019									
	17	3.89	.62	.23	.057	.040									
	19						4.5	26.9	19.3	38.6	9.7	.66	.46	8.1	1.34
	39						4.2	25.2	16.1	37.4	15.6	1.20	.36	12.0	1.60
	44	3.62	.37	.21	.047	.020									
3*	16	3.45	.68	-	.073	-									
	53	3.45	.42	-	.037	-									
	60						2.20	32.0	35.3	26.7	2.7	.72	.49	6.7	.595
	69						1.72	25.3	23.8	37.2	10.9	.70	.56	15.1	1.29
	72	3.45	.44	-	.037	-									
	82** (No. 3)						6.97**	31.4	24.9	21.9	14.1	.61	.04	1.08	.814
	90** (No. 3)						6.97**	35.4	25.8	22.3	9.1	.45	.04	1.08	.652
4	6						1.70	29.9	16.3	41.8	8.5	.63	.59	19.7	1.35
	8	3.99	.76	.22	.030	.015									
	9						1.15	28.0	18.5	42.2	9.1	.45	.70	23.3	1.40
	18	3.98	-	.24	.014	.013									
	24						1.01	24.3	20.9	46.2	6.7	.34	.84	60.0	1.54
5	10	4.24	.75	.23	.007	.020									
	13						.72	24.1	13.8	47.7	11.0	.25	.61	102.0	1.96
	15						.93	25.0	30.3	41.3	1.1	.19	.57	95.0	1.06
	19						.50	24.7	16.5	48.5	9.7	.15	.59	98.4	1.85
	23	4.20	.75	.28	.009	.018									
	24						.72	21.8	19.6	48.8	6.9	.18	.63	57.3	1.78
	25						.65	21.5	14.1	49.5	10.4	.17	.67	60.9	2.14
	28						.58	21.1	26.4	47.7	3.0	.16	.65	81.3	1.48
	33	4.20	.60	.28	.009	.018									
	38** (No. 3)						2.73**	20.1	13.8	44.2	17.4	.40	.55	68.8	2.30
6	12						.94	26.6	24.5	44.2	1.34	.25	.48	44.7	1.19
	16						.43	25.4	18.4	46.7	7.00	.21	.57	51.8	1.58
	24	4.36	-	.28	.013	.016	.43	22.2	19.1	41.4	9.6	.19	.58	52.7	1.62
	29	4.30	.81	.27	.009	.016	1.01	20.8	18.7	38.9	15.9	.23	.64	58.2	1.80
	31						.96	20.2	25.6	48.7	3.7	.23	.61	55.4	1.58
	35	4.28	-	.27	-	.014									
	39						1.36	19.0	11.2	33.5	25.1	.14	.69	62.8	2.38
	43	4.08	.74	.27	.009	.014									
	52** (No. 3)						4.60**	17.4	16.3	32.0	21.6	.65	.64	58.2	2.07

(Continued)

Heat No.	Time After Tap (min)	Metal Analyses					Slag Analyses							Weight Ratio	Molar Ratio
		C	Si	Mn	S	P	FeO	SiO_2	Al_2O_3	CaO	MgO	MnO	S	$\frac{S(slag)}{S(metal)}$	$\frac{CaO + 2/3\ MgO}{SiO_2 + Al_2O_3}$
7	6	4.05	1.30	.28	-	-									
	9						2.24	28.8	28.4	36.2	2.83	.56	.63	16.6	.915
	13						1.43	31.6	19.4	36.0	4.53	.53	.65	17.1	1.00
	16	3.73	1.04	.28	.038	.016									
	17						1.84	35.6	21.6	36.0	2.01	.59	.68	21.2	.843
	20						1.73	30.7	25.9	37.8	2.45	.58	.61	19.1	.937
	22	3.72	1.06	.29	.032	-	1.33	35.6	35.1	36.7	1.10	.54	.75	23.4	.813
	28	3.69	1.03	.29	.029	.014									
	34** (No. 2)	3.65	.99	.25	.030	-	2.04**	23.1	21.2	36.0	16.14	.63	.54	18.0	1.54
	41** (No. 2)						1.05**	23.7	24.9	37.8	11.14	.58	.66	22.0	1.35
	43	3.68	1.02	.25	.030	.019									
	45** (No. 3)						.79**	23.8	29.4	39.6	1.26	.48	.65	21.7	1.06
8	5						3.1	33.05	32.5	26.6	3.0	.45	.15	4.85	.605
	7	3.95	1.32	.28	.031	.045									
	8						1.86	28.9	24.7	35.1	7.19	.40	.45	14.5	1.03
	12						2.45	23.8	19.1	43.4	8.40	.45	.70	31.8	1.57
	16	3.94	1.25	.33	.022	.023	.79	22.3	24.7	45.4	3.74	.18	.77	35.0	1.42
	20						.79	21.1	20.1	45.4	9.81	.13	.75	34.1	1.77
	24						.61	20.7	23.5	43.5	9.54	.19	.78	45.9	1.63
	27	3.94	1.02	.31	.017	.027									
	28						.82	20.3	29.4	44.6	2.38	.19	.83	48.8	1.34
	32	3.93	1.05	.28	.021	.036									
	38** (No. 2)	3.65	1.13	.29	.015	.027	.61**	20.8	29.0	42.7	4.41	.28	.57	38.0	1.33
	40** (No. 3)						.79**	20.9	30.5	43.2	1.84	.26	.55	36.7	1.24
	41** (No. 3)						.61	21.0	28.8	44.2	2.63	.26	.61	40.6	1.32
9	2	4.05	.98	.26	.025	-									
	6						.56	27.5	18.6	45.9	4.35	.14	.65	29.5	1.40
	7	3.42	.92	.26	.022	.013									
	10						1.04	27.6	17.7	45.0	6.10	.31	.62	34.5	1.43
	12	3.45	.88	.29	.018	.016	.96	27.8	19.8	44.9	4.21	.32	.67	37.2	1.33
	16						1.25	27.1	10.3	46.7	11.72	.32	.58	26.0	1.86
	17	3.35	.72	.33	.020	.016									
	19						1.20	26.6	16.4	46.1	7.16	.32	.70	35.0	1.56
	21						1.25	26.4	14.7	46.0	8.27	.48	.66	30.0	1.64
	22	2.38	.65	.31	.022	.016									
	27	3.80	.43	.29	.019	.012									
	32	3.65	.55	.28	.018	.014									
	37	3.43	.82	.30	.018	.018									
	41** (No. 2)						1.53**	24.2	27.9	40.4	3.38	.63	.48	27.6	1.15
	43** (No. 3)						1.11**	24.8	21.4	45.9	4.66	.57	.54	31.8	1.44
	47	3.54	1.10	.43	.016	.022									

(Concluded)

Heat No.	Time After Tap (min)	Metal Analyses					Slag Analyses							Weight Ratio	Molar Ratio
		C	Si	Mn	S	P	FeO	SiO_2	Al_2O_3	CaO	MgO	MnO	S	$\frac{S(slag)}{S(metal)}$	$\frac{CaO + 2/3\ MgO}{SiO_2 + Al_2O_3}$
10	2	4.52	1.29	.31	.006	.012									
	7	4.36	1.10	.29	.007	.011									
	13	4.44	.81	.29	.006	.010									
	18	3.66	.71	.26	.010	.010									
	19						.94	23.02	14.02	28.97	8.98	.09	.64	64.0	1.97
	21						1.08	21.36	6.85	53.54	12.31	.10	.77	77.0	2.74
	27	3.75	.80	.29	.010	.012									
	31						1.23	22.08	5.76	50.57	15.49	.19	.89	81.0	2.61
	33	3.54	.24	.24	.011	.008									
	37						1.22	22.43	5.64	50.14	16.41	.16	.76	69.0	2.74
	39	3.60	.44	.25	.016	.010	1.72	22.28	11.18	49.11	13.86	.20	.75	46.9	2.31
	44	3.58	.21	.21	.013	.008									
	50	3.39	.19	.21	.019	.007									
	57	2.85	.10	.18	.024	.006									

*The first three heats used dolomitic stone; the rest used a high calcium stone.

**Refers to slag taken from the back. See Fig. 3 for exact location.

Note: All heats except No. 10 used steel punchings (No. 10 used bales).
All heats except No. 7 had a calcium carbide addition.