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A STUDY OF FERROALLOY FURNACE PRODUCT FLEXIBILITY

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A STUDY OF FERROALLOY FURNACE PRODUCT FLEXIBILITY

by

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TABLE OF CONTENTS

	Page
OVERVIEW AND EXECUTIVE SUMMARY	v
BACKGROUND AND INTRODUCTION	1
SUBTASK STATEMENTS AND RESPONSES	6
Subtask 1: Describe, in General, Ferroalloy Furnace Designs and How These Designs Vary According to the Product Being Produced	6
Subtask 2: Define The Parameters Which Must Be Considered When Switching Products in Both Open and Sealed Ferroalloy Furnaces	12
Subtask 3: Identify and Compare General Procedures for Changing From One Product to Another in Open and Sealed Ferroalloy Furnaces	26
Subtask 4: Identify Deviations from Optimum Conditions and Other Penalties (Including Economics) Which Are Involved in Switching Products in Open and Sealed Furnaces	29
Subtask 5: Do Case Studies of the Product Families Which are Most Frequently Interchanged Based on Typical Open and Sealed Furnaces	33
Subtask 6: Draw Conclusions, Where Possible, on the Limitations to Flexibility Which Would Be Encountered in the Domestic Ferroalloys Industry if all Future Capacity Expansion Were to Consist of Sealed Furnaces	35
Subtask 7: Make Recommendations for Additional Research, Development, and Possible Demonstration Programs Which Could be Undertaken by EPA to Aid in the Solution of the Product Flexibility Problem Identified in Subtask 6	40
Battelle's Recommendations Relative to Open and Sealed Ferroalloy Furnaces	41
Battelle's Suggestions for Possible Research Projects	43
Possible Research Projects	44
SUMMARY AND CONCLUSIONS	47
References	51
APPENDIX: MITSUBISHI RESEARCH INSTITUTE REPORT ON SEALED FERROALLOY FURNACES OPERATIONS IN JAPAN	A-0.1

LIST OF TABLES

		Page
Table 1.	Furnace Design and Operation Data for Selected Ferroalloy.	18

LIST OF FIGURES

Figure 1.	Schematic Illustration of Electric-Arc Ferroalloy Furnace	7
Figure 2.	K-Factor Versus Electrode Powder Density for Selected Ferroalloys.	13
Figure 3.	Curves Relating Furnace Loads, Voltages, "K" Factors, and Electrode Currents	15
Figure 4.	Furnace Load Versus Electrode Diameter.	24

OVERVIEW AND EXECUTIVE SUMMARY

This program was undertaken to provide the U. S. Environmental Protection Agency (EPA) with insight into (1) the extent to which the U. S. ferroalloy industry uses furnace-product flexibility, (2) the effect of ferroalloy-furnace design (specifically a comparison of open versus totally sealed furnaces) on product flexibility, and (3) research and development areas which could enhance product flexibility in sealed furnaces and/or make sealed ferroalloy furnaces more practical in the U. S. industry.

With one exception, all ferroalloy furnaces are of the "open" type in the United States. Elsewhere, particularly in Japan, many ferroalloy furnaces are of the "sealed" type. An EPA study has indicated that the sealed ferroalloy furnaces offer the potential to be operated with lower pollution of the atmosphere than the other types of furnaces. In light of this advantage, the question has been raised as to why sealed ferroalloy furnaces are not presently utilized to a greater degree in the United States. Reservations about the "flexibility" of sealed furnaces relative to open furnaces have been one of the primary deterrents cited concerning the lack of adoption of sealed furnaces in the United States.

Flexibility of a ferroalloy furnace is the term selected to describe the ability to change the furnace from the production of one type or family of ferroalloys to another family requiring different smelting conditions. Furnaces with high flexibility can be used to manufacture a wide variety of ferroalloys, usually with only short changeover periods and/or low loss of production occurring during product switches. Furnaces with low flexibility are generally designed to produce ferroalloys under conditions that are optimum for a specific type or family. Low flexibility furnaces do not readily lend themselves to product conversions, as product changes in these furnaces may incur significant penalties in technology, changeover time, and costs.

Based upon an extensive literature review and numerous interviews with representatives of ferroalloy companies, it is concluded that the U. S. ferroalloy industry has used and is likely to continue utilizing high furnace-product flexibility to remain competitive in a changing domestic and international marketplace.

In comparing the product flexibility of open and sealed furnaces, it is concluded that sealed ferroalloy furnaces are less flexible than

comparable, open-hooded furnaces, because (1) it has not yet been demonstrated feasible to smelt all the common ferroalloys in sealed furnaces, and (2) a sealed-furnace operation generally requires greater charge preparation and attention to operating details than a comparable, open-hooded furnace on the same product. U. S. ferroalloy producers are reluctant to install sealed furnaces until either (1) a long-term market demand is assured for that particular sealed-furnace product and/or (2) it has been demonstrated feasible to smelt essentially all the ferroalloys, specifically the high-silicon-content ferroalloys, under sealed-furnace conditions.

Battelle investigators recommend that EPA (1) conduct a cross-media assessment of the overall (i.e., air, water, solid waste, etc.) environmental characteristics of open-hooded and sealed ferroalloy furnaces to define future policy statements, and (2) assist in evaluating the design and performance of baghouses used with ferroalloy furnaces with the objective of securing methods for lowering the annual total emissions from existing and future ferroalloy furnaces.

The investigators also formulated two suggestions for additional programs aimed at increased utilization of sealed ferroalloy furnaces and/or lower furnace emissions from U. S. operations. These suggested programs involve (1) determination of whether the substitution of iron-ore pellets (as used in Japan) for ferrous scrap (as used in the U. S.) decreases the need for stoking and improves the ease of operation in the smelting of 50 and 75 percent ferrosilicon alloys, and (2) research directed at insuring that sealed furnaces are safe operations through the development of improved furnace-monitoring techniques and devices.

A STUDY OF FERROALLOY FURNACE PRODUCT FLEXIBILITY

BACKGROUND AND INTRODUCTION

There are three basic types of electric-arc ferroalloy furnaces with respect to the design and operation of the furnace offgas system. These three types are the open, the semiclosed, and the totally closed furnace. The totally closed furnace is herein referred to as the "sealed" furnace. In the operation of the open ferroalloy furnaces, the carbon monoxide by-product released during smelting is burned above the mix and the products of combustion (and the large volume of diluting/cooling excess air) are then cleaned to remove particulate matter. In the semiclosed and sealed furnace operations, a cover is placed over the furnaces to collect the carbon monoxide-rich offgas, without combustion. This is done to clean a minimum amount of gas per ton of product and/or to collect the carbon monoxide for its fuel value. While both the semiclosed and sealed furnaces are equipped with covers to exclude air from the furnace interior, they differ in the design of the seals between the furnace cover and the movable-electrode columns. In the semiclosed furnace, the mix being charged is used to achieve a quasi-seal between the furnace cover and the electrodes. More positive seals are utilized with the sealed furnaces. The sealing performance of mix seals on semiclosed furnaces is not considered satisfactory by furnace operators or the EPA[1] and it is, therefore, anticipated that new U. S. ferroalloy furnaces will be either of the open or sealed design.

Based upon U. S. Environmental Protection Agency (EPA) studies of the emissions associated with ferroalloy furnaces, it has been reported that sealed furnaces equipped with appropriate air-pollution-control devices release significantly less particulate emissions than open-hooded furnaces with their air-pollution-control devices[1, 2]. EPA has emphasized the advantages (from air-pollution and energy standpoints) of sealed furnaces compared with open-hooded furnaces and has considered setting air standards which would encourage the use of sealed furnaces[2, 3]. U. S. ferroalloy producers have expressed reluctance to install sealed furnaces, indicating that the use of sealed furnaces would lower the producers' product flexibility (i.e., their ability to change from one ferroalloy type to another in one furnace).

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(1) References are listed on page 51

To give a greater insight into the issue of furnace-product flexibility, EPA, under a basic ordering agreement, requested that Battelle's Columbus Laboratories (BCL) conduct a study of ferroalloy furnace-product flexibility. The specific objectives of the BCL study were

(1) To compare the flexibility of open and totally closed (sealed) ferroalloy furnaces as it relates and applies to the U. S. ferroalloy industry, so that the significance of product flexibility can be ascertained

(2) To identify existing technology and applied engineering practices which can be used to achieve additional flexibility in sealed furnaces without further research and development efforts

(3) To develop, where warranted, recommendations for an additional program which could be undertaken by EPA to (a) make sealed furnaces practical in the domestic industry if they are not at the present time and/or (b) develop or demonstrate techniques or systems to allow both ferroalloy product flexibility and lower furnace emissions from U. S. ferroalloy furnaces.

To achieve the above objectives, seven subtasks were formulated by EPA for which responses were to be prepared by BCL.

The subtask statements, as presented in the Work Statement, were:

(1) "Describe, in general, ferroalloy furnace designs and how these designs vary according to the product being produced.

(2) Define the parameters which must be considered when switching products in both open and totally enclosed ferroalloy furnaces.

(3) Identify and compare general procedures for changing from one product family to another in open and totally enclosed ferroalloy furnaces (and semienclosed furnaces, if these appear relevant).

(4) Identify deviations from optimum conditions and other penalties (including economics) which are involved in switching products in open and totally enclosed furnaces.

(5) Do case studies of the product families which are most frequently interchanged based on typical open and totally enclosed (sealed) ferroalloy furnaces.

(6) Draw conclusions, where possible, on the limitations to flexibility which would be encountered in the domestic ferroalloy industry if all future capacity expansion were to consist of totally enclosed furnaces.

(7) Make recommendations for additional research, development, and possible demonstration programs which could be undertaken by EPA to aid in the solution of the product flexibility problem identified in Subtask 6."

The Battelle-prepared responses for each subtask inquiry are given sequentially in the following text. Following the last subtask response (No. 7), a summary and conclusion section is presented.

As part of this study, Mitsubishi Research Institute, Inc. (MRI), on a subcontract basis conducted a study of sealed ferroalloy furnace operations in Japan. A series of questions concerning Japanese sealed ferroalloy furnace operations was formulated by BCL personnel and presented to MRI for answering. The complete MRI report (with the question-answer format) is presented in the Appendix. Because most of the sealed furnaces in the world are in Japan, the MRI report was used to give BCL personnel additional insight on the flexibility of sealed furnaces.

Prior to addressing the Subtask questions and responses, it is appropriate to define what is meant in this report by "ferroalloys" and to clarify the intended meaning of furnace flexibility. Listings of ferroalloys and their corresponding chemical analyses are available in the literature[1, 7]. For the purposes of this study, primary attention is directed at those ferroalloys produced in the greatest quantities, that is the manganese, silicon, and chromium families of alloys, including standard ferromanganese (Std FeMn), silicomanganese (SiMn), ferrosilicon

(50 FeSi and 75 FeSi), silicon metal (Si), ferrochromium (FeCr), and ferrochrome-silicon (FeCrSi)*. Other ferroalloys, such as the rare-earth silicides and calcium silicide, etc., are introduced and included as specific entries in the presentation of the flexibility issue.

Flexibility is defined as the "capability of responding or conforming to changing or new situations"[4]. Furnace flexibility herein refers to the capability for changing or adjusting particular ferroalloy furnaces to produce different ferroalloy products. It is important to note that a time-frame is not inherently defined as part of the "flexibility" statement; no qualifying statement as to the length of time required to respond to the changing situation is included in the flexibility definition.

Based upon our review of the literature and on interviews with ferroalloy-industry representatives, it appears advantageous to consider at least two types of flexibility, that is, short-term and long-term, when discussing ferroalloy furnace flexibility. Short-term flexibility as presented here, refers to the capability of carrying out product changes in a given furnace within or over a period of several months. Long-term flexibility relates to the capability and/or practice of effecting a product change in a furnace on an annual or longer-term basis. These time-frame generalizations to the flexibility statement are not absolute, but are introduced as relative guidelines to simplify the discussion of ferroalloy-furnace flexibility.

The U. S. ferroalloy industry utilizes both short-term and long-term furnace flexibility. For example, one ferroalloy plant visited during this study produces a variety of speciality ferroalloy products and typically produces about ten different alloys in a given furnace per year. While this example of short-term furnace flexibility may represent the most product changes in a given furnace, other

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* The cited group of ferroalloys accounts for about 75 percent of the approximately 2 million tons of ferroalloys produced in the U. S. ferroalloy furnaces annually.

ferroalloy plants also utilize relatively small open furnaces to produce a variety of specialty products on a similar short-term flexibility basis.

As indicated in several communications between EPA and the U. S. ferroalloy industry, practically all (if not all) of the U. S. ferroalloy companies have used and expect to continue utilizing long-term furnace flexibility to remain economically competitive in a changing product-demand marketplace. Examples of U. S. ferro-alloy company's long-term furnace flexibility practice are presented in the "Statement on Proposed Air Quality Standards for High Carbon Ferromanganese" prepared by the Ferroalloys Association[5].

SUBTASK STATEMENTS AND RESPONSES

Subtask 1: Describe, in General, Ferroalloy Furnace Designs and How These Designs Vary According to the Product Being Produced

Design details for ferroalloy furnaces are presented in several texts on the theory and practices of electric-arc smelting[6-8]. While there are numerous minor design variations, most 3-electrode, 3-phase electric-arc furnaces are quite similar in their basic design. The basic smelting furnace consists of a cylindrical furnace shell, the interior of which is lined with insulating bricks and a carbon hearth. Electrical energy is continuously supplied to the reaction area through three vertically suspended prebaked carbon or self-baking (i.e., Soderberg) electrodes arranged in a delta formation. The mix material is batch fed to the top of the descending bed of charge material and the reaction products (i.e., ferroalloys and slags) are periodically or, in some cases, continuously tapped from the side of the furnace. A schematic illustration of a submerged-arc ferroalloy furnace is shown in Figure 1.

The upper portion of the furnace-charge materials may be thought of as a particle bed, with the hot carbon monoxide offgas ascending through and heating the descending mix components. The basic reaction which occurs within the furnace reaction zone is the high-temperature reduction of an oxide with carbon to yield the ferroalloy plus carbon monoxide. Large quantities of carbon monoxide are formed as part of the smelting reaction for all the ferroalloy smelting operations. The thermochemistry of the various ferroalloy smelting operations is described by Elyutin[9].

While generally quite similar in design, there are several furnace-design features which are associated with specific ferroalloys. For example, while the circular (or near circular) furnace shell with three electrodes in a triangular configuration is the predominate furnace of the industry, some companies prefer the so-called "packet" furnace with a rectangular crucible with in-line electrodes for the production of silicon metal*. Silicon metal is also produced in the 3-electrode, circular furnace common to other alloys. Because the comparison of packet versus circular or in-line versus

* Various in-line electrode furnaces have been proposed for smelting particular ferroalloys[10].

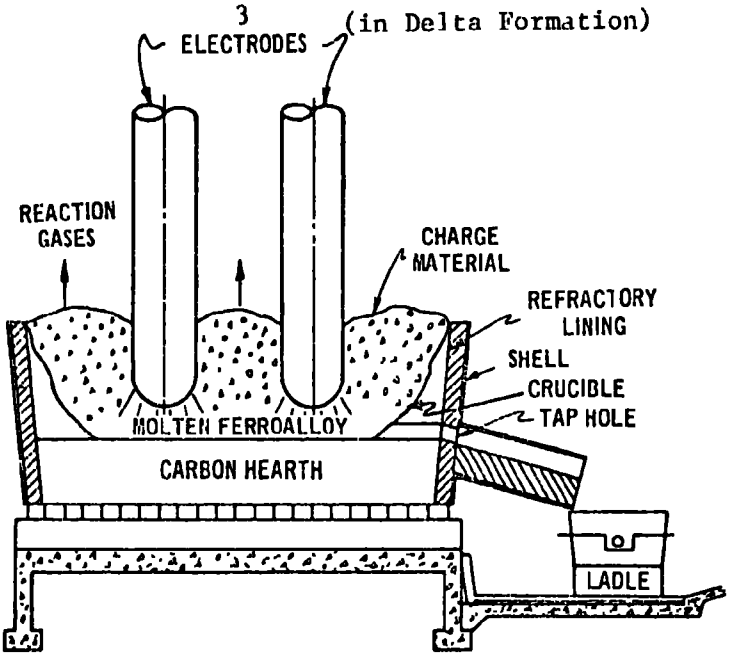

FIGURE 1. SCHEMATIC ILLUSTRATION OF ELECTRIC-ARC FERROALLOY FURNACE (1)
(Third electrode is not shown.)

delta electrode configuration is not a major issue in the comparison of open versus sealed furnaces, no further consideration will be given to the in-line electrodes or packet-type furnaces.

The taphole configuration is another furnace-design feature which depends somewhat on the particular type of ferroalloy produced. In smelting some ferroalloys, a slag is produced as a process by-product (e.g., in the smelting of Std. FeMn and FeCr), while little or no slag occurs in smelting other ferroalloys (e.g., silicon and ferrosilicon)*. For those cases wherein a slag by-product occurs, the tapholes may be situated in such a manner that the ferroalloy and the slag components can be tapped from separate sites to allow separation of the two portions. Such a tapping arrangement is not required for "dry" operations. Like the packet versus cylindrical furnaces, the issue of taphole configuration has only little to do with the issue of product flexibility with open and sealed ferroalloy furnaces.

A furnace-design feature which does have direct bearing on the flexibility issue is the need for and incorporation of auxiliary means of controlling charge descent and flow into the reaction zones. One means of affecting the descent of charge material into the reaction zones is by stoking (i.e., rabbling the charge). Another is by rotating the furnace shell. With many ferroalloys (e.g., FeMn, SiMn, FeCr, 50% FeSi), the use of sized and controlled-property mix components is adequate to insure that the charge materials will descend uniformly under reasonably controlled smelting conditions. However, this is not the case with high-silicon ferroalloys. As the silicon content of the alloy increases, the extent to which silicon monoxide (SiO) vapor is generated also increases. This SiO vapor condenses throughout the descending portion of the charge and can form an impervious crust or "bridge" in the mix. This crusting in turn causes a buildup of the hot by-product gases beneath the crust. When sufficient internal pressure

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* These smelting processes in which no slag by-product occurs are frequently referred to as "dry" processes.

has developed, the gases either flow along the electrode sides (by-passing the crust) or erupt through the charge. Eruption can throw hot mix for distances of tens of feet*. The jetting of gases along the electrodes represents a significant loss of energy (as contrasted to uniform gas flow up through the charge) and a significant increase in both silicon loss and dust generation. The loss of hot SiO vapor along the electrodes results in the release of large quantities of super-fine fume; i.e., this SiO is not condensed on the charge and is not returned to the reaction zone. Stoking is the primary measure used to break up the crusts once they are formed, or as a preventive practice to keep them from forming initially.

Rotating the furnace shell is another means utilized to provide more uniform control of the mix descent and to minimize crust formation and "blowing"(7).

While stoking can be and has been incorporated in sealed-furnace operations, stoking is more easily practiced with open furnaces where a furnace operator has access to and a complete view of the mix surface. Likewise, while a rotating shell can be designed with a totally closed cover, the rotation of the shell with an open top is simpler and more amenable to engineering design and operation. As previously stated, the need for stoking and/or shell rotation is related to the silicon content and/or the content of other chemical species which are volatile at high temperatures but which condense out in the descending charge, forming viscous and impervious crusts. The tendency for bridging and crusting and, in turn, the need to stoke the charge, coupled with the extremely high temperatures of the offgas, are the reasons why such ferroalloys as silicon and FeSi with silicon content greater than 75 percent have not to date been produced in sealed furnaces. This is also true for the rare-earth silicides. Those alloys for which the uniform flow of charge can be controlled by sizing and preparation of the mix components (without the need for extensive stoking and/or shell rotation) are amenable

* The eruption of the gas from the mix is appropriately called a "blow".

to either open or sealed furnace production. Thus, standard FeMn, SiMn, FeCr, and 50 percent FeSi can be produced with only minor stoking if the charge materials are properly sized and prepared prior to charging. These ferroalloys are presently made in both open and sealed furnaces.

Another particular furnace-design feature associated with sealed furnaces producing ferromanganese is the use of drying and pre-reducing procedures to prepare the manganese mix prior to smelting. It should be noted in this instance that the emphasis is shifted to the complete mix drying and prereduction system rather than only a smelting-furnace operation. Drying and prereduction of the manganese-bearing mix lowers the probability of a furnace blow resulting from mix cave-ins and rapid reduction of the large quantities of the high-manganese oxide contained in the untreated ore. While drying and pre-reduction are not an absolute requirement for smelting ferromanganese in sealed furnaces, utilization of this practice significantly increases the operator's confidence that the sealed-furnace operation will be smooth. In turn, a smooth operation is less prone to dangerous furnace explosions and requires less stoking. The use of drying and prereduction of manganese charge materials could be (and sometimes is) used as part of an open ferromanganese furnace operation, and should contribute the same improvement in operating conditions on the open furnaces as with sealed furnaces. However, this more complex mix preparation is less needed on the open furnaces, because furnace blows are generally less harmful on open furnaces and the open-furnace operation can counteract to a greater extent the occurence of blows by stoking and rabbling the mix

In summary, there are notable minor variations in furnace design throughout the industry. Here the word "design" is used in a general sense. Specific parameters of "design" that pertain to particular ferro-alloys are discussed in the following subtasks.

In the general sense of the word design, the stoking requirement is a major factor in assessing the ease with which an open furnace operation can be converted to a sealed operation. The other general furnace

design variations have little direct effect on the issue of open versus sealed furnaces and furnace flexibility.

Furnace size is an element of significance with regard to the flexibility issue. This issue will be addressed in Subtasks 2 and 4.

Subtask 2: Define The Parameters Which Must Be Considered When Switching Products in Both Open and Sealed Ferroalloy Furnaces

The parameters which affect the successful smelting of the various ferroalloys are described in texts on electric-arc furnace operations[6-8]. As presented by Robiette[6], the boundaries within which a given electric-arc furnace can be utilized are established by

(1) the maximum electrode current (and/or current density),

(2) the range of transformer secondary voltage taps,

(3) the transformer capacity,

(4) the acceptable natural power factor,

and (5) the maximum operating resistance.

The operating resistance is, to a large extent, determined by the specific resistivity of the mix materials. The interrelations between the charge resistance and the other electrical and geometrical parameters of the furnace (i.e., electrode-to-hearth potential, electrode current, and diameter) were empirically established and set forth as K-factor versus Electrode Power Density curves by Andreas[11] and Kelly[12]. The K-factor, or peripheral resistance of the charge, is defined as:

$$K = (E/I)\ \pi D, \qquad [1]$$

where E = electrode to hearth voltage (volts)

I = electrode current (amperes)

and D = electrode diameter (cm).

Curves for K-factor versus electrode power density* for selected ferroalloys are shown in Figure 2**.

As indicated in Figure 2, a characteristic K-factor - electrode power density relation is associated with the smelting of a given ferroalloy***. By combining the K-factor - electrode power density curves with the electrical formulations for the furnace circuit (i.e., the electrode critical current as a function of the electrode diameter); the

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* The electrode power density is the electrical power carried in each electrode (kw), divided by the electrode cross-sectional area (cm^2).

** In metric units.

*** Persson[13] indicates that the electrode-to hearth potential divided by the square root of the electrode diameter (i.e., $E/\sqrt{D}$) is another equivalent unique characterizing parameter for each ferroalloy.

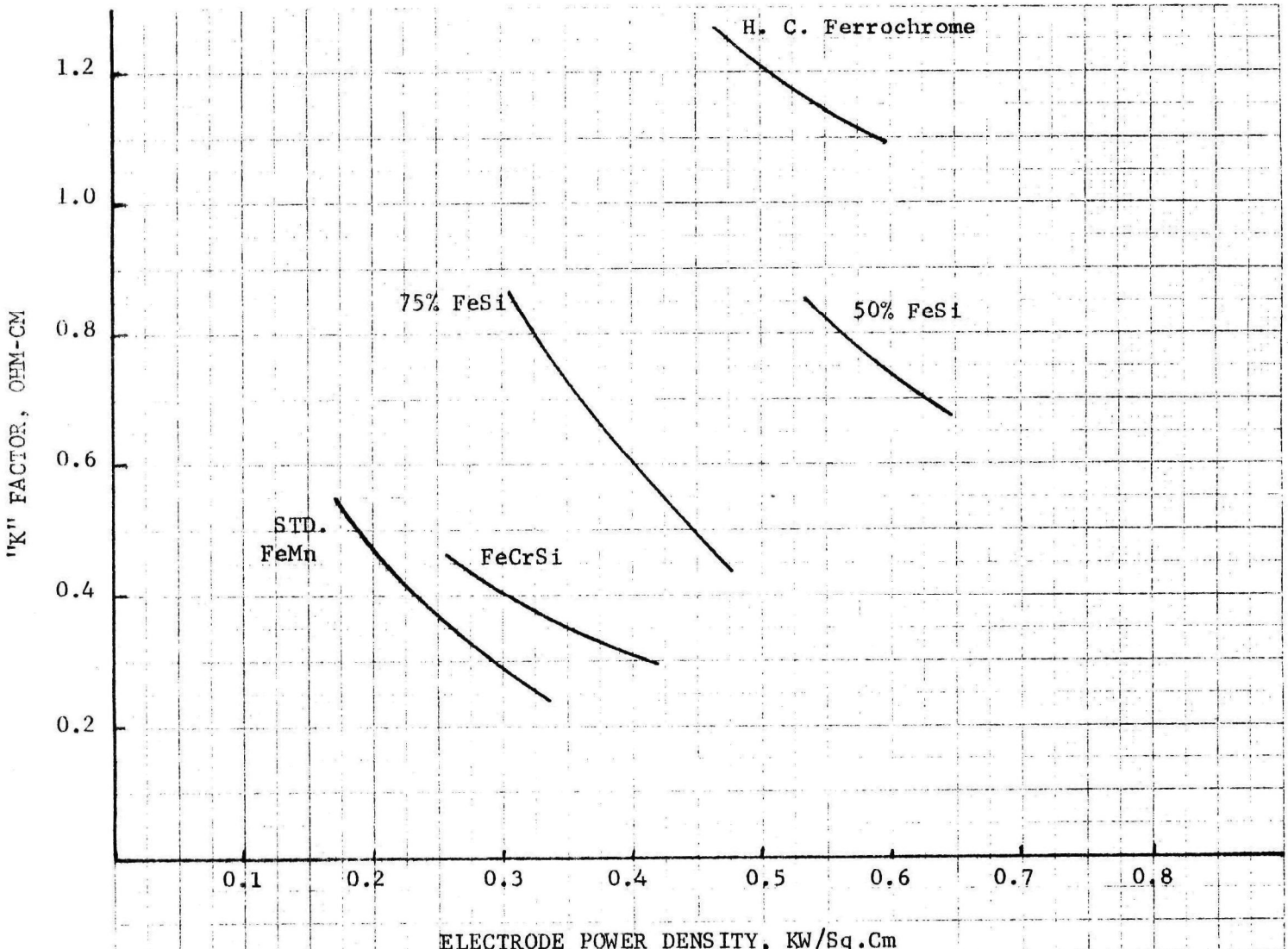

FIGURE 2. K-FACTOR VERSUS ELECTRODE POWER DENSITY FOR SELECTED FERROALLOYS

furnace power as a function of electrode current, tap voltage, and power factor), a set of technically acceptable electric smelting conditions can be established for a given ferroalloy. Curves of the type shown in Figure 3, relating furnace load, voltages, K-factors, and electrode currents may be used as furnace-operating charts[14] for smelting a given alloy. Knowledge and control of the mix conductivity and its K-factor, and the maximum allowable electrode current allows one to establish the maximum furnace load for given available tap voltages*. For example, referring to Figure 3, if the electrode current must not exceed 60,000 amperes and the smelting of the alloy is recommended over a range of 0.50 to 0.55 ohm-cm, then the maximum furnace load will range from about 14.2 to 15.9 MW, with voltages between 161 and 175.

To obtain maximum transformer utilization at a given voltage, the furnace is generally operated with the greatest allowable current that will also satisfy the other conditions of charge resistance and power factor. It is desirable to have the current-conduction paths restricted to the "reaction" zones between the tips of the electrodes and the hearth. To achieve this design condition, the voltage is adjusted or prescribed such that there is little or no current flow through the charge between the electrodes. If a maximum voltage is exceeded in smelting a given ferroalloy, the current flow between the electrodes increases and becomes more difficult to regulate. Greater electrode motion is required when there is excessive current flow between the electrodes than when the predominate current flow is between the electrode tips and the hearth. Under extremely high-voltage-input conditions, the electrode penetration is shallow (i.e., the electrodes are high in the mix) and there may be large open areas or zones under each electrode.

In the 3-electrode furnaces there are three interconnected reaction zones near the hearth level. These reaction zones are essentially fixed relative to the furnace structure, but have a continual flow-through of materials. The material in the reaction zones is continuously undergoing reduction and melting. While the concept of "reaction" zones has

* There is more art and empirical know-how behind this statement than science. Science, however, is making inroads in this area.

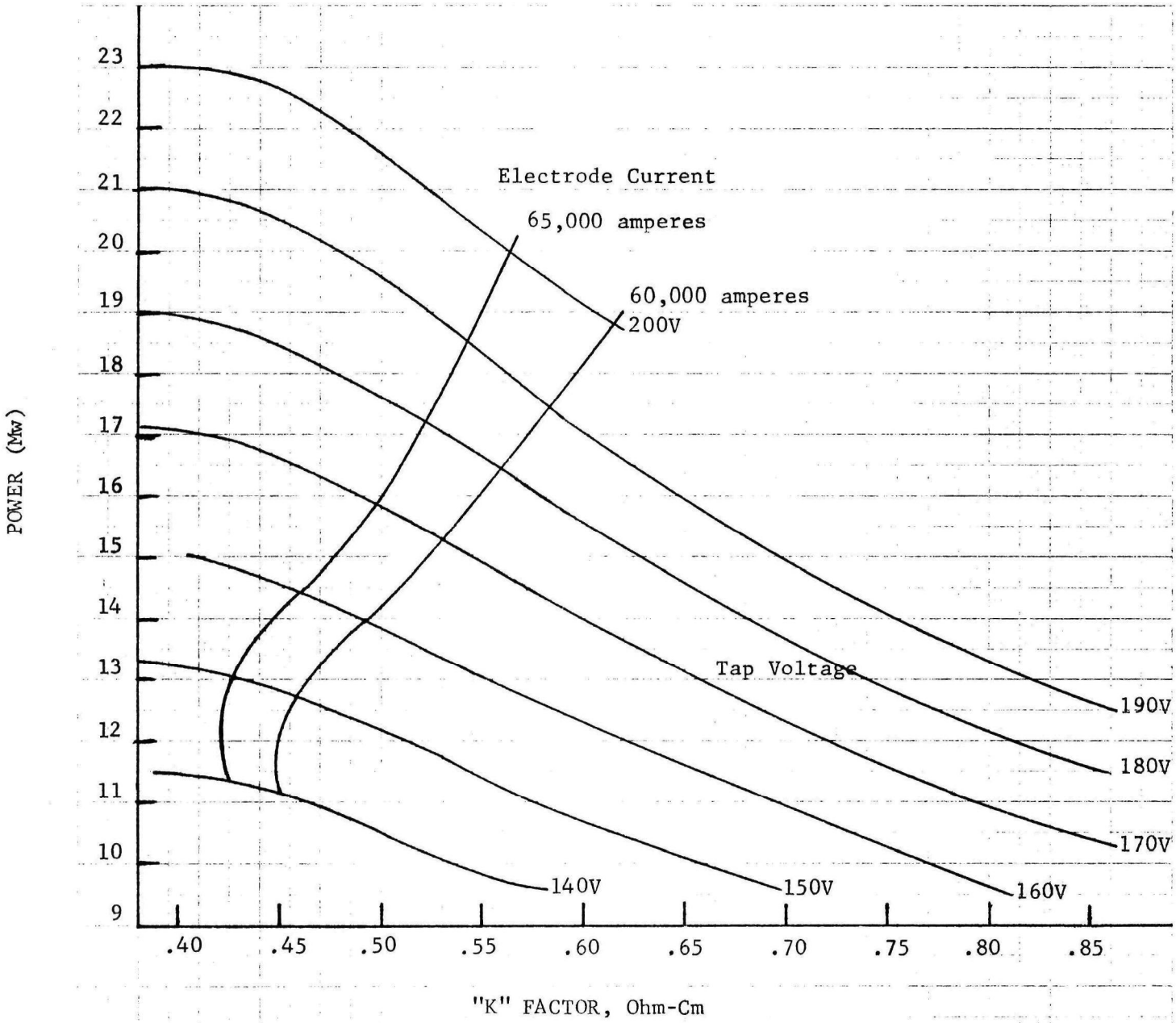

FIGURE 3. CURVES RELATING FURNACE LOADS, VOLTAGES, "K" FACTORS, AND ELECTRODE CURRENTS (14)

been successfully applied to furnace design and operation, the current-flow patterns and the precise size and shape of the zones have not been experimentally determined.

The current-carrying capacity of particular diameters of electrodes is an intrinsic furnace-design limitation. As the electrode-current density (and, in turn, the electrode-power density) increases, the surface temperature of the electrode increases. The temperature of the electrode portion immersed within the charge is relatively unimportant , because the heat developed in that section is dissipated directly to the charge. However, the exposed electrode surface (i.e., the portion above the charge) is critical, because it oxidizes and/or deteriorates rapidly as its surface temperaature rises. Thus, the limiting electrode-current density is determined by the physical properties of the electrode material and the amount of exposed surface area. The maximum allowable electrode current is a principal design feature, in conjunction with the K-factor - electrode power density relations.

Thus, the electrical-design parameters for the ferroalloy furnaces are essentially contained within the K-factor - electrode power density and the electrode diameter - critical current relations. However, there are also geometrical parameters to be considered in designing and operating the furnace. The electrode diameter is a design parameter of extreme significance as will be discussed later in this section. Practically all of the geometrical features of the furnace are derived from or scaled to the electrode diameter. The electrode diameter is inherent in the K-factor - electrode power density relation and in considerations of the critical current density for available electrode sizes.

Other geometrical factors of importance for smelting a particular ferroalloy are the electrode spacing (herein specified as the distance between electrode centers) and the crucible and shell dimensions. The preferred electrode spacing for smelting a given ferroalloy is based primarily on experience. The ratio of electrode spacing to electrode diameter (ES/D) varies from slightly less than 2 to somewhat less than 3 for most of the common ferroalloys. Generally, the higher the silicon content of the alloy, the closer the electrodes are grouped. Thus,

silicon metal is smelted in furnaces with electrode-spacing-to-diameter ratios of 1.9 to 2.1, while 50 percent ferrosilicon operations utilize ratios of 2.2 to 2.7.

Kelly[12] suggests that the crucible and shell diameters should scale with the electrode spacing. Data taken from the literature indicate that the ratio of shell diameter to electrode diameter (S/D) falls within the range of 6 to 8 for the common ferroalloys.

Furnace depth is one of the more difficult design parameters to reduce to a formal relation with the other design parameters. It has been suggested[12] that the ratio of electrode penetration (i.e., the distance the electrode is submerged in the mix) to the distance between the electrode tips and the hearth could provide a design parameter for predicting desirable furnace depths. Typically, this ratio varies from 3.0 to 0.3 for the standard ferroalloys.

Furnace designers have developed today's ferroalloy furnaces for particular alloys by collecting design and performance data from previous furnaces and attempting to improve upon earlier designs. Ferroalloy-furnace designers point out that this is an ongoing process, and that the "optimum" furnace remains to be defined for many ferroalloys.

To more fully develop the interrelation of the design variables of ferroalloy furnaces for given products, ferroalloy-furnace design and operating data were collected and tabulated from the open literature and from field-trip data. These data are presented in Table 1. The data entries include furnace rating, furnace load, electrode diameter, ratio of electrode spacing to electrode diameter, ratio of shell diameter to electrode diameter, crucible depth, electrode penetration, K-factor, electrode-power density, Persson's parameter[13], tap voltage, electrode-current density, electrical energy consumed (kwhr) per tonne of product, the percent operating time, the recovery percentage for the element, and the furnace type (i.e., open or sealed), and reference numbers identifying the source of the data. Entries are grouped according to the ferroalloy product.

The ranges of K-factors and electrode-power densities, as well as Persson's electrode-to-nearth potential factor presented in the table are in keeping with the values depicted in Figure 2. Other Table 1 design and operating

TABLE 1. FURNACE DESIGN AND OPERATION DATA FOR SELECTED FERROALLOYS

Alloy	Furnace Rating, MVA	Furnace Load, MW	Electrode Diameter, cm	ES/D[1]	S/D[2]	Crucible Depth, m	Electrode Penetration, m	"K"[3], ohm-cm	Electrode Power Density, KW/cm^2
Silicon								0.58-0.31	
	7	7	89	1.77-1.94	7.4	1.8	-	-	0.375
	12	9	89	2.42	8.9	2.13	~1.37	-	0.48
	12	10.5	89	2.23	8.9	2.05	~2.59	-	0.56
	29	17	127	2.0	6.7	-	2.3-2.4	-	0.45
	36	20	140	2.0	-	-	2.3-2.4	-	0.43
75% FeSi								0.51-0.41	0.31-0.465
	8	7	89	1.91	7.4	~1.8	1.07	0.48	0.375
	-	8.5	89	2.23	7.54	1.88	~1.2*	0.41-0.51	0.46
	8.5	-	95	2.26	-	1.98	-	-	-
	15	11	105	2.52	~7.7	2.4	-	-	-
	21.3	12.5	101.6	2.225	7.35	~2.2	1.52	0.58	0.51
	-	15	114.3	2.57	6.53	2.21	~1.5*	0.56-0.70	0.50
	16.5	-	115	2.18	-	2.35	1.2	0.55	-
	21	16.1	120	-	-	-	-	0.49	0.47
	-	17	127	2.40	7.54	2.92	2.2*	0.64-0.83	0.45
	75	45	180	2.16	6.55	-	-	-	0.59
50% FeSi								0.86-0.61	0.51-0.635
		8.8	89	2.23	7.54	1.88	1.2	0.37-0.46	0.47
		10.9	101.5	2.35	7.50	2.41	1.7	0.57-0.73	0.45
		12.8	114	2.57	6.53	2.21	1.5	0.64-0.83	0.42
		17.1	127	2.40	7.54	2.92	2.2	0.57-0.73	0.45
50.6% Si	45	27.7	140	-	7.50	-	-	0.60	0.60
	60	42	175	-	8.74	-	-	0.71	0.58
	60	45-50	140	2.73	8.0	2.49	2.3	0.43-0.58	1.03
Standard FeMn								0.33-0.20	0.17-0.33
74.5% Mn	-	7.5	105.4	2.55	6.65	2.18	1.4		0.29
	-	8.5	101.6	2.2	8.4	2.23	-		0.35
78% Mn	16	13	142	-	7.07	3.35	-		0.27
74.5% Mn	40	25	170	2.47	7.94	4.95	-		0.37
	30	27-30	190	2.32	6.58	5.1	0.9-1.5		0.335
75.5% Mn	36	29	190	2.31	6.58	4.0	-		0.34
78-82% Mn	72	30	190	2.5	8.0	6.3	1.5-2.5		0.35
Si-Mn								0.38-0.25	0.37-0.54
	-	10	89	2.74	8.9	-	-		0.535
	-	25-27	170	2.35	9.8	4.7	0.9-1.5		0.38
	-	26	150	2.5	-	-	-		0.49
	45	30	165	2 31	6.46	~3	~1.7		0.47
	72	33	190	2.5	8.0	6.3	1.5-2.5	0.26	0.39
High Carbon FeCr								High Si 0.76-0.40	0.50-0.83
	11.25	8.9	89	2.43	>7.88	2.36	1.3-1.5		0.48
	43	35	165	1.92	6.25	3.3	-		0.545
FeCrSi								0 43-0.30	0.62-0.83
41% Cr, 41% Si	13.5	10	89	2.57	>7.9	2.33	1.37		0.54
37% Cr, 47% Si	13.5	10	89	2.57	>7.9	2 33	1.37		0.54
36% Cr, 40% Si	25	23.5-25	145	2.1	6.93	3.1	~1.73		0.49
36% Cr, 42.3% Si	40	24	150	2.365	7.67	3.9	-		0.45

(1) ES/D = Electrode Spacing (center-to-center)/Electrode Diameter

(2) S/D = Shell Diameter/Electrode Diameter.

(3) "K" = K Factor = Peripheral Resistance.

*Estimated Values.

TABLE 1. (Continued)

$E/\sqrt{D}$[4], volts/$\sqrt{cm}$	Top Voltage, volts	Electrode Current Density, amp/cm^2	Energy Consumption per Tonne, KWHr/t	Operating Time, percent	Element Recovery, percent	Electrode Type[5]	Furnace Type[6]	Reference Number
8.6			15,400					1, 2, 3
	120-130	6.5	13,780	-	71.3 Si	P	O	4
	150	6.98	19,400	89.9	58.4 Si	P	O	5
	155-160	7.78	12,400	92	77-81 Si	P	O	5
	220	5.5	-	-	-	-	O	6
	230	5.2	-	-	-	-	O	Field Data
8.625		5.0-5.5	9,680					1, 2, 3, 7
	120	6.78	-		-	P	O	8
	140	7.17	9,570		85.1 Si	P	O	9
	140	5.0	-		-		O	10
	-	-	8,100		-		S	11
	170	-	9,450		84 Si	P	O-R	8
	190	5.5	9,194		86.8 Si	S	O	9
8.4-8.8	200	5.8	-		-		O	10
	182	5.3	9,213		86.2 Si		O	12
	210	4.65	9,018		85.1 Si	S	O	9
	-	~5.5	8,680-8,820		-		O	13
10.6			5,500					1, 2, 3
	135	7.56	5,710		93.2 Si	P	O	9
	170	5.72	5,512		93 Si	S	O	9
	190	4.77	5,446		96.3 Si	S	O	9
	195	4.99	5,203		93.5 Si	S	O	9
9.9	~233	5.6	5,600-6,000		-	S	S	14
10.9	~298	4.6	5,600-6,000		-	S	S	14
	300-320	7.0-7.75	~4,500	~95	97-99 Si	S	Semi-C	15
5.5			2,600					1, 2, 3
	115-120	4.1	3,000-3,200	-	78-80 Mn	S		16
	120-140	-	-					17
	-	3.7	2,680			S		18
	204	4.4	1,960**	95	73 Mn		S	19
	-	-	2,650	-	-		S	Field Data
	-	3.7(4.4 Max)	2,645	93.5	71 Mn	S	S	20
	285	4.7	2,200	98+	-	S	S	Field Data
7.38			4,840					1, 2, 3
			-					21
			4,850				S	Field Data
	125-150	~5.1	4,410-4,740	<93	-		S	Field Data
	-	<5.0	4,850	94	85 Mn	S		22
	300	4.7	~4,000	98+	-	S	S	Field Data
9.1			4,620					1, 2, 3
	177	5.8	3,932	92.9	85.8 Cr	P		23
	-	4.2	~4,400	-	-	S		24
6.62			8,140					1, 2, 3
	~168	6.9	7,358	93-95	88-90 Cr	P		25
	~168	6.9	8,846	90-96	82-91 Cr	P		25
	160-180	~6.4	7,500-8,600	93	84-92 Cr			Field Data
	-	-	7,050	-	90.6 Cr	S	C-R	26

(4) $E/\sqrt{D}$ = Person Electrode to Hearth Potential Factor

(5) Electrode Type Code
P = Prebake
S = Soderburg.

(6) Furnace Type Code
O = Open
S = Sealed (totally closed)
Semi-C = Semi-Covered
R = Rotating.

**Prereduced Charge Materials.

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data of particular interest include (1) ranges of electrode spacing used with each alloy, (2) use of prebaked versus Soderberg electrodes, and (3) the electrode diameter versus furnace load for the various alloys.

As indicated in Table 1, the electrode spacing (center to center) typically is 2.2 to 2.6 times the electrode diameter for all the ferroalloys considered, with the exception of silicon metal. Silicon-metal operations utilize electrode spacings of about 2.0 times the electrode diameter*. It appears that with the exception of silicon, each and all of the ferroalloys considered can be successfully produced with electrode spacings in the above-cited range (i.e., 2.2 to 2.6 times electrode diameter). While individual companies and particular furnace operators have defined the optimum or preferred electrode spacing for smelting particular alloys, it does not appear that the electrode spacing in itself is a restricting parameter to furnace flexibility. That is, in general, the electrode spacing need not be changed in carrying out a product change. However, some furnace operators do adjust electrode spacing (on some open furnaces) when making a product change.

Prebaked electrodes, which are capable of carrying a greater current density than the Soderberg (or self-baking) type of electrode are used predominately in the smelting of the high-silicon-content alloys (e.g., silicon metal and 75% FeSi). However, Soderberg electrodes are available in larger diameters than the prebaked types and are, therefore, used predominately in today's larger ferroalloy furnaces. As presented in Table 1, Soderberg electrodes are widely used in smelting of standard FeMn and silicomanganese. While a given type of electrode may be preferred for smelting any of the given ferroalloys, furnace flexibility is affected primarily through considerations of the power and current-carrying capacity associated with the particular electrode used.

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* The one silicon furnace entry in Table 1 wherein an ES/D ratio of 2.43 was used was an inefficient operation and was corrected, in part, by reducing the ES/D ratio to 2.23.

As indicated in Table 1, the electrode diameters (and, in turn, all the parameters which scale with electrode diameter, such as electrode spacing and shell diameter, etc.) increase with the furnace load. The furnace load - electrode diameter data for the silicon alloys (i.e., silicon metal, 75% and 50% ferrosilicon), silicomanganese, and ferromanganese are plotted in Figure 4. As shown in Figure 4, most of the furnace load - electrode diameter data for the given ferroalloys indicate that the furnace load is proportional to the square of the electrode diameter (i.e., $W \alpha D^2$). Such a load - electrode diameter dependence is anticipated if the maximum electrode current-carrying capacity (i.e., current density) is proportional to the reciprocal of the square root of the electrode diameter.

The specific point of interest to be derived from Figure 4 is that the furnace load - electrode diameter relations not only differ for the ferrosilicon alloys and for ferromanganese furnaces, but that the extent of difference increases with increasing furnace load and/or electrode diameter (i.e., with furnace size).

Thus, as indicated by Figure 4, a furnace with 90 cm-diameter electrodes (specifically Soderberg electrodes) would probably operate at a load of about 10 megawatts for smelting 50 and 75% ferrosilicon and about 6 megawatts for smelting ferromanganese. Such a difference in furnace load (i.e., 6 to 10 megawatts) is not particularly difficult to obtain or achieve with a variable-tap transformer with an acceptable power rating and operating power factor. However, a furnace which utilized 180-cm-diameter electrodes would probably be designed to operate at a load of 37 or more megawatts for smelting the ferrosilicon alloys and 25 megawatts for the ferromanganese operation. While a transformer and associated electrical system with a variable power output over the above range (i.e., 25 to 37 megawatts) is certainly possible, the cost of such a system is quite high. In general, the voltage range of the transformer and the total range of allowable power input, are determined by capital-cost considerations. The transformer costs increase rapidly with both the number of voltage taps and the size (i.e., power

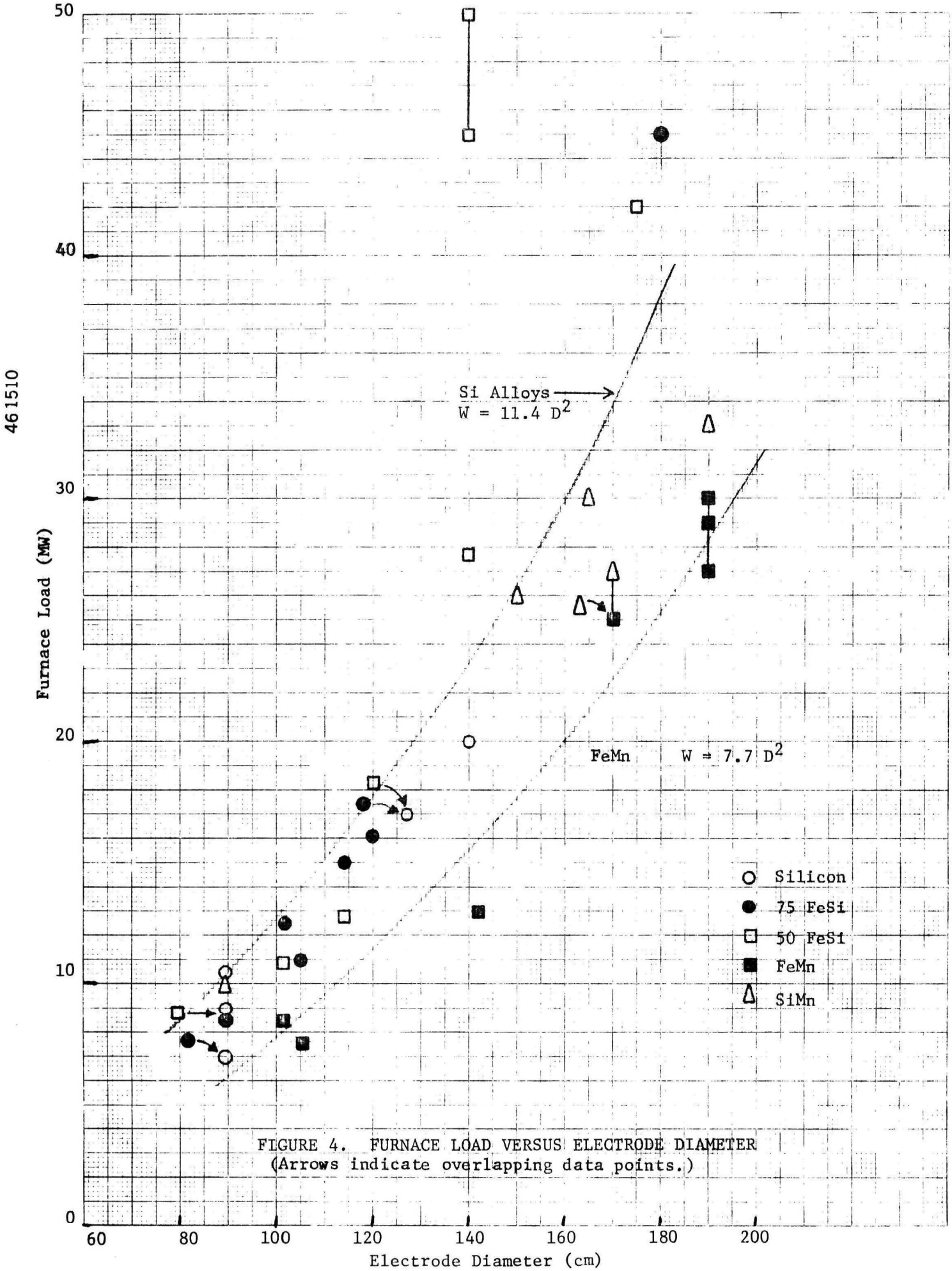

FIGURE 4. FURNACE LOAD VERSUS ELECTRODE DIAMETER
(Arrows indicate overlapping data points.)

rating) of the transformer. In addition, terms of the ferroalloy company's contract with the electric power company regarding firm, interrupted and dump power also influence the design versatility of any installed transformer system.

As a result of capital and operating cost considerations, large ferroalloy furnaces and, in turn, the required large transformer systems and electrode columns are generally designed specifically for the production of one ferroalloy or a limited group of ferroalloys requiring similar smelting conditions. Based on the Figure 4 data and economic considerations, it appears that furnace size is a major parameter relative to the issue of furnace flexibility.

Based upon this review of the theory and practice for ferroalloy furnace design and operation, the major operating parameters which must be adjusted to effect any product change in a given furnace are

(1) the mix composition

and (2) the voltage and power to secure proper smelting conditions.

As will be discussed in Subtask 3, many of today's ferroalloy furnaces are equipped with on-line voltage changers which allow the furnace operator to stepwise change the transformer tap voltage without a major interruption of the power supplied to the furnace and charge. The ability to change tap voltage (and, in turn, input power) as the charge resistance changes in conjunction with the change in mix composition, allows the furnace operator to effect a continuous, gradual product change in a given furnace.

While generally not a major prerequisite to achieving a product change, some furnace operators also adjust electrode spacings when carrying out a product change. It is the opinion of the Battelle researchers that, in general, the electrode spacing need not be changed in carrying out most product changes.

BCL personnel realize that the foregoing presentation of operation parameter relations are not simple or even "straight forward". The relationships required to understand and parameterize a total furnace operation are couched in mathematical terms. A mathematical formulation was not presented herein, but rather a simplified overview of each parameter and the effects of parameter changes.

Subtask 3: Identify and Compare General Procedures for Changing From One Product Family to Another in Open and Sealed Ferroalloy Furnaces

Prior to describing the general procedures involved in carrying out a change of product in a given furnace, it is advantageous to describe what is meant by a given furnace. In this report, a given furnace is taken to indicate that the following furnace components or parameters are prescribed and fixed (i.e., they are not subject to change):

(1) the installed transformer and associated electrical system (e.g., the bus bars),

(2) the electrode diameter,

and (3) the furnace crucible and shell.

To change any of the above furnace components (or parameters) requires major alteration to the unit. The above components are generally only changed in a complete retrofit and/or overhaul situation*, resulting essentially in a new "given" furnace. While the above components can be changed (i.e., essentially a new furnace can be constructed in place of a previous one), such major alterations are long-term events and do not affect short-term furnace flexibility.

Now, let us turn our attention to those procedures and/or conditions which are involved in carrying out a change of product in a given ferroalloy furnace.

In effecting a change of product in a furnace, several basic operating conditions must be adjusted or changed. These basic or fundamental changes include:

(1) the change of mix composition

and (2) adjustment of voltage and power for proper smelting conditions.

That the mix composition must be changed to effect a change in product is obvious. For example, in changing from a 50% ferrosilicon to a 75% ferrosilicon operation, less scrap and more silica and reductant (e.g. coke) are charged per unit of mix fed to the furnace. Mix compositions for smelting the various ferroalloys are available in in the literature[6, 9, 16].

* Interlake[15] has reported on the use of interchangeable crucible and shell units for increasing the flexibility of one of their furnaces.

As described in the Subtask 2 section on parameters which must be considered in performing a product change, the voltage and, in turn, the furnace load are adjusted (using the K-factor-electrode power density data) in any change of product. The particular adjustment of tap voltage and furnace load will depend on both the product change and the allowable range of voltage (and power) for the given transformer.

Most of today's transformer-furnace systems are equipped with on-line voltage-changing facilities which enable the furnace operator to incrementally raise or lower the tap voltage with a simple switch (a tap-voltage selector). As the composition of the mix charged to the furnace is altered to secure a product change, the charge resistance is also altered. For a fixed voltage, the current flow through the electrodes will change with the change in mix resistance.

The furnace operator may monitor both furnace voltage and current and can adjust the working voltage via the on-line voltage selector to maintain the current at a prescribed value within the allowed working range. The maximum current allowed is determined by the current-carrying capacity of the electrical system components (e.g., transformer, and electrodes). In general, the furnace operator will attempt to utilize a current slightly less than the allowed maximum, in order to obtain a near-maximum total power input under all smelting conditions.

The above changes are required in any product change, independent of the furnace being open or sealed.

There are two basic methods for securing a change of product; (1) a gradual change of product by continuing to feed the new mix composition to the operating furnace; and (2) to shut down the furnace, dig out and remove the old product mix from the furnace, and recharge and start again with the new product. The decision to utilize one or the other of these approaches to a product change depends on a number of factors, such as (1) feasibility of a continuous (i.e., furnace-on) product change, (2) the time required to effect the product change from Alloy No. 1 to on-grade Alloy No. 2, and (3) the marketability of the off-grade product(s) produced during the product-change period.

The gradual and continuous change of product is the most frequently utilized procedure. Ferroalloy-company representatives estimated

that better than 95 percent of the U. S. industry's product changes were performed as continuous operations, without shutdown of the furnaces. Those product changes wherein the furnace is shut down and subsequently restarted on a new product are only used when the product changeover can be concurrent with a shutdown of the furnace for major repairs and overhaul.

During a gradual product changeover period in the switching of products with significantly different smelting conditions, the furnace operation may not be so "smooth" nor so well controlled as during "steady-state" operations. In the anticipation of trouble, sealed furnaces may be opened during changeover to observe closely the furnace top and to be in a position to stoke, if necessary. In these instances, the emission-control equipment would have difficulty handling the increased flow of gases and the offgases may be released without cleaning. If this "safety" practice were followed (i.e., sealed furnaces were operated in an open mode during product transition), the air-pollution control and energy advantages of sealed furnaces might be lowered.

Some furnace operators also adjust electrode spacings when carrying out a product change in a given furnace. An adjustment of electrode spacing is relatively easy on some open furnaces. However, with a sealed furnace, the furnace cover is designed to seal against the electrodes at a particular design spacing. Thus, the electrode spacing on a sealed furnace is essentially fixed and constant. While the data in Table 1 indicate that most of the ferroalloys can be smelted with an electrode-spacing-to-diameter ratio between 2.2 and 2.6, the ability to adjust the electrode spacing in conjunction with a product change gives the furnace operator additional freedom to improve the smelting operation.

The general procedures for changing from one ferroalloy product to another in open or sealed furnaces should be quite similar (i.e., change in mix composition, voltage, etc.). However, because of the accessibility of the charge in an open furnace (and, in turn, the ability to stoke and rabble the charge), an open furnace is inherently more flexible (i.e., more product changes can be carried out) than a sealed furnace.

Subtask 4: Identify Deviations from Optimum Conditions and Other Penalties (Including Economics) Which are Involved in Switching Products in Open and Sealed Furnaces

The incentive for changing the ferroalloy produced in a given furnace is purely one of economics. In general, a product change has been made for one of two basic reasons--(1) the raw materials which were used are no longer available at an acceptable price level or (2) the market demand and/or profitability associated with a new product sufficiently exceeds that of the old product to warrant a furnace changeover. U. S. ferroalloy companies have practiced furnace flexibility for both of the above-stated reasons and have indicated that long-term furnace flexibility is a desirable consideration in any new furnace designs, because of the possible reduced availability of manganese and chromium ores to U. S. smelters. As noted in the Introduction, many speciality ferroalloy producers use small (~10 MW) furnaces to produce several ferroalloys per year in a given furnace. In this case, the market demand is limited and the output of a year-long campaign on one of these specialty ferroalloys would exceed the total marketable quantity several times over. These companies practice short-term furnace flexibility to remain profitable and competitive.

Thus, while there may be operating "penalties" associated with a product change in a given furnace, there should be no economic penalty, assuming that the company management has adequately and accurately analyzed the business market. That is, even though the furnace operation may be "rough" and require greater operating attention, the product switch is designed to be profitable.

When a product change is made in a given furnace, be it open or sealed, there are several factors which influence the overall profitability of the change. Several of these factors to be considered are:

(1) The required down-time to achieve the product switch and/or the loss associated with the production of off-grade or nonsalable alloys,

(2) the required power consumption per ton product,

and (3) the change in furnace productivity (i.e., tons of ferroalloy produced per month).

The time required to achieve a product change is, in part, a function of the specific alloys involved, the size of the furnace, and the furnace design (e.g., whether the furnace is open or sealed). A minimum conversion time is associated with a gradual product change between ferroalloys of similar smelting conditions (i.e., 50% $\rightleftarrows$ 75% ferrosilicon) in small open furnaces (of the order of 10 megawatt load). A conversion time of about several days to a week is anticipated for the above case and, also, the product associated with the conversion period is often salable as off-grade material. As the furnace size increases and smelting conditions differ, the time required for conversion increases. Typically, 4 to 8 weeks may be required to convert a reasonably large (about 30 MW) open furnace from one product to another. In some cases, this time period is downtime during which no ferroalloy is produced.

There is very little field experience to date to define precisely the time required for a product change in a large sealed furnace. However, for products with a major change in smelting conditions, the conversion time is expected to exceed that of a compariable open furnace because of the additional time required to adjust and stabilize the operation prior to the replacement of the cover seal. It is anticipated that the conversion time required for a large sealed furnace could exceed that of an open furnace by several weeks.

To date, the procedures for carrying out a product change between ferroalloys requiring significantly different smelting conditions in a large sealed furnace have not been presented in the open literature. Based on the MRI study (see the Appendix) and discussions with the U. S. ferroalloy companies, the large sealed furnaces operated to date are essentially single-product furnaces and are likely to remain single-product operations for the life of the furnace. Because there are no field data as to how a product change would be performed within a large sealed furnace, our presentation is based upon our best estimate of this technology. We

anticipate that a large sealed furnace may be operated in the open mode (i.e, without the sealed cover) during any major product change. Thus, whereas a product change with an open furnace would essentially utilize the same air-pollution-control devices as during its steady-state operation, additional air-pollution-control systems and/or permission to operate the furnace with increased emissions may be required in the changeover of a sealed furnace. This premise is based on the belief that the successful sealed-furnace operation requires greater control of the process than the corresponding open-furnace operation. The product change with a sealed furnace is anticipated to involve (1) opening the furnace (bypassing the air-pollution-control system) and (2) stabilizing the operation on the new product prior to resealing. Such a procedure may have a direct bearing on the overall air cleanliness rating of the operation.

As stated in the Subtask 2 and 3 sections, the voltage and furnace load are generally changed when carrying out a product change in a given furnace. These changes, in turn, may cause an electrical energy consumption penalty. For example, if the furnace and transformer system were designed for optimum power input for smelting one ferroalloy, a shift from that alloy to another may cause a change in power factor and in energy usage. Thus, the operator may have to pay for more electrical energy than would be required in a system specifically designed (and optimized) for smelting the new product.

There is an anticipated change in furnace productivity with any change in furnace product. As indicated in Table 1, the electrical energy consumption per tonne of product (Kwhr/tonne) varies with the particular ferroalloys. For example, approximately 15,000 Kwhr are consumed to produce a tonne of silicon metal in the U. S. practice, while a tonne of standard ferromanganese requires about 2600 Kwhr. The anticipated productivity of a furnace is the furnace load divided by the specific energy consumption per tonne of alloy times the operating time factor. This is:

$$Q = (P/EC) \times \text{Operating Time Factor}, \qquad [2]$$

where Q = quantity (tonne) of ferroalloy produced per hour,

P = furnace load in kilowatts

and EC = required energy consumption in kilowatt-hour per tonne of alloy.

Based on the estimated furnace output (i.e., tonnes of product per unit time), the market demand and the profit margin (i.e., the sales price minus the production cost), the ferroalloy company management can formulate their policies and decisions regarding furnace flexibility.

Throughout this discussion of the penalties (and gains) associated with product changes in a given furnace, it has been assumed that the product change is feasible and possible within the particular furnace. There have been cases where a product change was initiated and the ultimate penalty of zero production occurred; that is, the furnace could not be tapped under the prescribed smelting conditions. While this condition of an untappable furnace has occurred, it is rare in today's operations.

Subtask 5: Do Case Studies of the Product Families Which are Most Frequently Interchanged Based on Typical Open and Sealed Furnaces

The examples of product changes cited in this section are based on open literature data and information provided by individual U. S. ferroalloy companies. Because of the longer history of usage and the inherent greater product flexibility associated with open furnaces, there are significantly more examples of product changes with the open-type furnaces than with sealed furnaces.

The most frequent and/or common changes of product within given open furnaces are those involving similar smelting conditions. For example, product changes of silicomanganese to standard ferromanganese or vice versa (hereafter represented as SiMn $\rightleftarrows$ FeMn) or 50% ferrosilicon to 75% FeSi to silicon metal or vice versa (i.e., 50 FeSi $\rightleftarrows$ 75 FeSi $\rightleftarrows$ Si) are fairly common. Other reasonably frequent product changes in open furnace include the sequence 50% ferrosilicon to ferrochrome-silicon and then to ferrochrome (i.e., 50 FeSi $\rightleftarrows$ FeCrSi $\rightleftarrows$ FeCr). Changes of alloy grade within a family are also common (e.g., FeCr $\rightleftarrows$ blocking chrome $\rightleftarrows$ charging chrome). The product switch between ferrosilicon alloys and ferromanganese is less frequent, but this change has been performed. As a generalization, one can state that all the permutations of product changes have been carried out with small open furnaces. The time required for a particular product change has typically been 1 to 2 weeks, depending on the extent of difference in required smelting conditions for the particular ferroalloys involved.

The versatility of a small open ferroalloy furnace is evidenced by the operation of what may be termed the "universal" furnace, in which essentially all the common ferroalloys have been successfully smelted. The basic "universal" furnace consisted of three 89-cm-diameter electrodes, with a 2.44-meter center-to-center-electrode spacing (i.e., $^{ES}/_{D} = 2.74$) and a 7.92-meter diameter shell (i.e., $^{SD}/_{D} = 8.9$). The open furnace was equipped with a variable-tap transformer to allow the smelting of <u>all</u> the common ferroalloys in one furnace. These basic furnaces were used for many years to smelt all the common ferroalloys. The only major parameters

changed (besides mix composition) in performing a product charge were voltage and furnace load. For example, ferromanganese was smelted with a furnace load of 6 to 7 megawatts, silicomanganese with about 8 megawatts, ferrochromium with about 10 megawatts and 50% ferrosilicon with 12 to 14 megawatts. Stoking was practiced with all these operations.

The examples of short-term furnace flexibility, wherein up to ten specialty ferroalloys (including the rare-earth silicides, calcium silicon, and the ferrosilicons) are produced per year in a single ferroalloy furnace are also achieved with relatively small (up to about 10-megawatt) open furnaces.

Some longer term product flexibility is also associated with larger (about 30-megawatt) open furnaces. U. S. ferroalloy companies cited numerous examples of product changes (e.g., FeSi $\rightleftarrows$ FeCr) carried out on large open ferroalloy furnaces. These product changes typically required several weeks for completion and were dictated by a major shift in market demands.

To date, sealed furnaces are designed and operated essentially as single-product furnaces. Because the majority of the world's sealed ferroalloy furnaces are located in Japan, a subcontracted study through Mitsubishi Research Institute, Inc. was made of the Japanese ferroalloy industry. The full text of the MRI study of the Japanese ferroalloy sealed furnace operations is presented in the Appendix. The MRI study supports the previous statement that the Japanese sealed furnaces are currently designed and operated as one-product furnaces. The greatest number of sealed ferroalloy furnaces is producing standard ferromanganese. The ferromanganese sealed-furnace operation can and has been converted to the production of silicomanganese and vice versa; however, no other product changes are known of in sealed furnaces. The lack of demonstrated flexibility for sealed furnaces may be due in part to (1) the relatively large size of most of the new sealed furnaces and (2) the lack of operating experience associated with the sealed-furnace operations. In either case, no case histories based on foreign or domestic field experience is available relating to product changes (other than FeMn $\rightleftarrows$ SiMn) in sealed ferroalloy furnaces.

Subtask 6: Draw Conclusions, Where Possible, on the Limitations to Flexibility Which Would Be Encountered in the Domestic Ferroalloys Industry if All Future Capacity Expansion Were to Consist of Sealed Furnaces

Recognizing that sealed-furnace operations have not been demonstrated feasible for smelting some ferroalloys, the installation of only sealed furnaces in the future would limit the production of the new furnaces (by comparison with open furnaces) to only those products amenable to sealed-furnace production. The literature and field data indicate that the current sealed-furnace product capability is as shown below:

Demonstrated Operational	Marginal	Not Feasible
FeMn	75 FeSi	Si
SiMn	FeCrSi (1 stage)	CaSi
FeCr		Rare-Earth Silicides
50 FeSi		

FeMn, SiMn, and FeCr are currently smelted in large sealed furnaces throughout the world. Fifty percent FeSi is smelted in relatively large sealed furnaces in Japan. However, the large U. S. 50% FeSi furnaces are all open.

Japanese sealed-furnace smelting of 50 percent ferrosilicon differs from the U. S. open furnace practice in that the Japanese use siliceous ore as their source of iron. Steel scrap is the iron-bearing charge material used throughout the U. S. industry to produce ferrosilicon. While a greater electrical energy should be required per tonne of ferrosilicon product with the ore practice relative to the scrap method, the Japanese ferroalloy representatives indicate the ore usage is justified in terms of allowing better mix sizing and feed control and yielding a smoother smelting operation (Refer to Yakagi Interview, pages A5.1 and 5.2 of the Appendix). U. S. ferroalloy industry representatives have indicated that, while the sealed furnace smelting of 50 FeSi is clearly demonstrated with the use of ore, the sealed furnace production of ferrosilicon with a steel scrap charge has not yet been proven feasible.

The smelting of 75 FeSi and single-stage FeCrSi in large sealed furnaces is presented herein as marginal; that is, these alloys have been smelted in relatively small (by today's standards) sealed furnaces, but further development is required before large sealed-furnace operations are proven. From both the theoretical and practical views, the smelting of silicon metal and the rare earth silicides in sealed furnaces is not yet feasible.

As previously stated, the average size of the new installed furnaces has shown a steady increase over the last several decades[17]. Thus, the significance of furnace size relative to the ability to seal the furnace on a given product is extremely important. In general, a large open furnace is more difficult to operate smoothly than a small open furnace, particularly if stoking is required. This is, in part, the reason that U. S. ferroalloy producers do not accept the operation of a 11 MW sealed-furnace operation with 75 FeSi as confirmation or demonstration of feasibility for smelting 75 FeSi in a large (e.g., 45 MW) furnace.

As implied in the Mitsubishi Research Institute report on the Japanese sealed-furnace operations, a sealed ferroalloy furnace is less flexible than an open furnace. The Japanese essentially present the sealed furnace as a single- product furnace. However, product flexibility, particularly long-term flexibility, is a matter of definition and degree.

It is of some interest to herein speculate on the differing need for furnace-product flexibility in foreign countries relative to the United States. As noted in the Introduction, most of the world's sealed ferroalloy furnaces are in Japan. Japan currently has 39 totally sealed ferroalloy furnace operations (Refer to Page A.2.1. of the Appendix). There is only one sealed furnace currently producing a major ferroalloy product (silicomanganese) in the United States*.

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* The particular U. S. sealed furnace was originally designed and operated for the production of pig iron. Operational difficulties were encountered in converting this sealed furnace to the production of ferrosilicon and ferromanganese. The furnace is currently utilized to produce silicomanganese. Because this particular furnace was not specifically designed for the smelting of ferroalloys, it is the position of BCL personnel that this particular sealed furnace should not be cited as a pro or con in judging the attributes of sealed-furnace technology.

In the United States, producers of ferroalloys are concerned that the ability of sealed furnaces to switch from product to product is or may be less than the ability of open furnaces to make such switches. In Japan, the ferroalloy producers generally do not have the same concern about furnace "flexibility". Thus, sealed furnaces generally face a more receptive attitude in Japan than in the United States. One can question the reason for this difference in attitude. The answer involves some speculation, but basically appears to the present BCL investigators to be the result of (1) differences in the relationships between the Government and the ferroalloy producers and (2) differences in the relationships between competing producers of ferroalloys.

As indicated in a previous EPA-prepared document[1], differences do exist between Japan and the United States with respect to Government involvement and interactions with industry with regard to taxation, subsidy payments for promotion of industrial growth, export policies, and other aspects. Although the specific mechanisms are obscure when viewed by outsiders, it is a fact that Government - industry relationships in Japan are such that the Government is in a strong position to influence the output and operating practices of even private-sector manufacturers. The Japanese government has at its disposal methods for applying pressure on industrial manufacturers to a degree not practiced in the United States. One form of this pressure appears to be as follows.

> A Government planning group (frequently MITI, The Ministry of International Trade and Industry) devises a national plan for the production of some commodity, say, for example, ferroalloys. The plan takes into account existing facilities, domestic demand, export and import potentials, costs of production, availability of raw materials, and even social factors. One possible conclusion from such an analysis is that it would be better overall for the national economy for Plant 1 to specialize in Product A, Plant 2 to specialize in Product B, etc.

Although the organization of the Government-industry relationship does not necessarily permit "control" of the manufacturers to follow the plan, in

practice the types of pressure available to the Government generally result in acceptance of the plan by the individual manufacturers.

The Japanese system, therefore, in essence evolves to a type of allocation of tonnage and products among various manufacturers. The tendency is for each manufacturer to be responsible for the production of a narrower range of products, but at a higher rate of output than if a larger number of his competitors were also making the same products. To the degree that sealed ferroalloy furnaces have limited flexibility relative to open furnaces, this Government-industry relationship makes sealed furnaces more attractive to the limited-product companies that tend to evolve more extensively in Japan than in the United States.

The Government-industry relationships in Japan also has an influence on the relationships that develop between competing ferroalloy companies in the private sector. Somewhat assured of a large market for their specific products, and somewhat insulated from the threat of unexpected foreign intrusion of another producer into their prime market, individual ferroalloy companies operate in an environment that encourges them to exchange technical and research information through industrial associations.

Less there be misunderstanding, the Japanese system as described here according to our understanding of the system, involves little in the form of formal "controls". An individual manufacturer can on his own initiative deviate from the plan and take his chances in open competition. This has been done from time to time, but the resulting experiences have been such that such deviations involve more risks than does compliance with the plan. Furthermore, it should be recognized that the Japanese system of "planning and pressure" is not limited to the ferroalloy industry, but extends also into other industries, of which the steel industry is another example.

In the United States, there is no equivalent of the Japanese national plans, and the pressures available to the Government to influence the tonnage or type of product made by any manufacturer usually are insignificant. The result is that U. S. producers of ferroalloys compete

vigorously with each other over a wide range of products, often changing product mix or tonnage based on each producer's evaluation of the total market, sources of raw materials, import and export situations, actions of his competitors, and relative profitability of various products. In this environment, flexibility of ferroalloy furnaces takes on great importance. Large sealed furnaces, especially in their present stage of development are not so acceptable in the U. S. system as in the Japanese system and, in the final analysis, this difference arises from difference in business modes between the United States and Japanese ferroalloy companies.

The U. S. producers are concerned about the availability of chromium and manganese ores to the U. S. for the future smelting of ferrochrome, ferromanganese, and related products. Because of this long-range concern, U. S. producers would prefer the installation of large open furnaces. Thus if a forced product switch were made (i.e., manganese and/or chrome products to silicon products), the adjustment could be carried out more easily in existing furnaces.

In conclusion, if all new furnace installations were sealed furnaces, flexibility would be curtailed. Short-term product flexibility, which is essentially associated with the smelting of specialty products in small furnaces, would be severely affected, if not eliminated. Long-term flexibility would be possible. However, the difficulty, as measured by the time and cost, associated with a product change in a large sealed furnace would be greater than the corresponding product change in a large open furnace.

Subtask 7: Make Recommendations for Additional Research, Development, and Possible Demonstration Programs Which Could be Undertaken by EPA to Aid in the Solution of the Product Flexibility Problem Identified in Subtask 6

As has been shown, a movement towards large, sealed ferroalloy furnaces is a movement towards furnace inflexibility. The development and acceptance of sealed ferroalloy furnace operations is in its early stages*. As the state of the art evolves, it is considered probable that large ferroalloy companies in the United States having large resources (capital and technology), and an assured market, will in the future install sealed furnaces dedicated to one product. Battelle has no recommendations for research and development that could make a sealed furnace more flexible in terms of product shifts.

As indicated in this report, some ferroalloys cannot as yet be produced in sealed furnaces. Also, to retain some elements of product flexibility, some ferroalloy producers want to install only open furnaces in the future. On large furnaces this flexibility aspect may be more theoretical than practical, but the flexibility aspect is more available with open furnaces than with sealed furnaces. It is judged, therefore, that there will continue to be many open furnaces even in the future. Battelle has, therefore, included recommendations for (1) reassessment and comparison of the relative environmental impact of open and sealed furnaces via a cross media impact type study, and (2) approaches to be considered for the improvement of the air-pollution control of open furnaces.

The EPA is interested in aiding a movement towards sealed ferroalloy furnaces for new installations in the United States. As stated by Japanese ferroalloy company representatives, the normal development of sealed furnace operations is to improve the smelting performance in open furnaces to the point where sealing of the operation can be technically justified. Battelle researchers have, therefore, included in this Subtask some suggestions for possible research projects that could improve smelting operations in general.

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* Semiclosed (i.e., mix seal) ferroalloy furnaces and totally sealed pig iron and calcium carbide furnace operations predate the introduction of sealed ferroalloy furnaces. Sealed ferroalloy furnaces came into use in the mid to late 1960's.

Battelle's Recommendations Relative to Open and Sealed Ferroalloy Furnaces

(A) It is recommended that the EPA study and evaluate the comparative environmental-impact level of both sealed and open furnaces using the criteria of all of the expected environmental guidelines of the future. These criteria should include water- and air-pollution guidelines and waste-control standards, and energy considerations. Also included in this evaluation should be the expected improvements in baghouse performance (if any) and expected improvements in water-treatment methods to achieve zero-discharge standards.

It is appreciated that EPA has stated that "sealed" furnaces are inherently superior from an air-pollution-control aspect [1]. While this superiority in one environmental area is significant, the need exists to define that furnace system which is best from the viewpoint of total environmental impact. To quote a recent paper entitled "Assessing Cross-Media Impacts"[18],

> "Certain control technologies aimed at achieving specific limits generate new waste streams which, in turn, require controls. Without a systematic assessment of these impacts, there is a substantial risk that pollution control strategies for controlling pollution in one medium will exacerbate problems in another medium".

Such may be the case with sealed ferroalloy furnaces.

In sealed ferroalloy furnaces coupled to wet-scrubber systems, there is no combustion of the organics released from the operation prior to the delivery of these gases to the wet-scrubber system. All of the volatiles from the coal, coke, electrodes, and wood chips then enter the scrubbers. Under these conditions it is probable that some of these organics report both to the cleaned carbon monoxide gas (which is later combusted under varying conditions) and to the recycled scrubber water. This point is recognized in the EPA waste-water-treatment guidelines for the ferroalloy industry. In these guidelines, cyanide and phenols are

expected in the waste water from wet air-pollution-control devices on sealed ferroalloy furnaces. These pollutants are not encountered in the waste water from open ferroalloy furnaces.

There is also concern over the buildup (and elimination) of soluble elements and compounds (organic and inorganic) in totally recycled scrubber water (from sealed furnaces) over time. There is a need to evaluate ferroalloy furnaces of the sealed and open variety from a viewpoint of total environment impact.

These potential water problems have already been evaluated in part by the water-pollution-control sections of EPA. From one viewpoint, a sealed ferroalloy furnace can be regarded as a coal gasifier. The overall environmental impact of coal gasification projects is being evaluated and the knowledge developed on these projects can be used to evaluate the air- and water-pollution control aspects of both sealed and closed furnaces.

Battelle researchers also recommend that the air-pollution-control aspects of sealed ferroalloy furnaces be reviewed taking into consideration the emissions from sintering and drying operations often associated with the use of upgraded material in sealed furnaces. Sintering and drying operations are often difficult to control adequately from an air-pollution point of view and, if required as part of the ferroalloy-furnace operation, those sources of air pollution should be examined in any evaluation of the total system.

(B) It is recommended that EPA evaluate the designs, operation, and performance of the baghouses associated with ferroalloy operations. This evaluation should be from the viewpoint of aiding in decreasing the annual average emission weight (per ton of a particular alloy) in future baghouse installations for both old and new furnaces. At this time, it is not technically possible to produce silicon metal (and several other ferroalloys) in sealed furnaces. There is, therefore, a need to improve baghouse performance with open furnaces to lower the overall emission rate and to approach the particulate emission rate of sealed furnaces.

It appears that there will be a need to operate some new and old ferroalloy furnaces in the open mode with dry dust collection. Ferroalloy producers are, in part, dissatisfied with the efficiency and operating-time performance of baghouses. It is recommended that EPA sponsor research and evaluation studies to improve the performance of baghouses on ferroalloy furnaces. This study should take into consideration the special or different characteristics of the ferroalloy furnace dust and develop new approaches to improving baghouse performance collecting these materials. The possibility exists that the industry may lend support (possibly as a joint sponsor) to such a program.

In the evaluation portion of this baghouse study, information should be obtained on the factors influencing the operating-time performance of existing baghouses. Some baghouse designs or equipment require considerable "down-time" for maintenance and repairs. Some of the problems are (1) difficulty in locating and eliminating individual broken or torn bags and (2) maintenance of the fans and blowers required to operate these units. Baghouses are most often purchased on a competitive-bidding basis and only some purchasers are in the technical position to specify desired design improvements that relate to their type of particulate dust. These design improvements either remain proprietary or they become incorporated into units sold to other companies, provided that the price remains competitive. There is thus only a slow improvement in baghouse performance, most of which (say the buyers) indirectly results from efforts by individual ferroalloy companies. There is a need for an overall evaluation from the user's viewpoint and an acceleration in the improvement of baghouse performance as the result of a concentrated and innovative technical input.

Battelle's Suggestions for Possible Research Projects

Because of EPA's interest in sealed furnaces, Battelle researchers have considered research and development projects that would promote the development (and acceptance) of sealed furnaces.

Overall, it is judged that additional conferences and discussions will be required between EPA and ferroalloy-industry executives before specific research programs are formulated. A problem to be resolved is to avoid duplication of confidential in-house research and development projects being carried out at competing ferroalloy companies. As an example, Battelle researchers until recently were expecting to suggest research in the fields of (1) development of computer controls on electric smelting furnaces to smooth the operations in preparation for eventual operation in sealed furnaces and (2) salvaging the heat generated from combustion in open furnaces (using close-coupled waste-heat boilers). Further consideration of these suggestions was abandoned when two papers on these subjects were given at a recent meeting of the AIME Electric Furnace Conference (December 11 and 12, 1974)[19, 20]. It is possible that some or even all of the following research projects may already be underway at individual ferroalloy companies.

Battelle's suggested research programs relate mainly to improving the technology of smelting operations for 75% ferrosilicon. This particular alloy is selected as a target for production improvement because (1) it is expected that there may be a future emphasis on silicon alloys in the United States, (2) this is probably the next major ferroalloy to be "tamed" by advancing sealed-furnace technology, and (3) improvements in the production technology of this alloy can be transferred to other alloys (including Si metal).

Possible Research Projects

(A) Determine whether the substitution of iron-ore pellets for ferrous scrap in the production of 50 and 75% ferrosilicon alloys decreases the need for stoking these operations and results in a smoother operation.

U. S. producers of ferrosilicon alloys use ferrous scrap in the charge to supply the ferrous component of the alloy. Japanese manufacturers, on the other hand, use iron ore or siliceous iron ores to provide the ferrous component of the alloy. U. S. producers prefer the use of scrap because, in their evaluation, it is a more economical source of iron. A Japanese producer (see Yahagi Iron Company information in the Appendix)

claims that (1) the use of ore permits a "low refining temperature (1220 C) to be used that makes it convenient to totally seal 50% FeSi furnaces"; (2) the use of ore permits proper charge sizing, minimizes segregation, and promotes a smooth operation, and (3) the use of ore prevents the contact of quartzite and improves the movement of the charge because it avoids "the softening and sticking to each other" of the quartzite pieces.

The subject of iron ore usage versus scrap usage in ferrosilicon production is controversial in the United States with most (if not all) of the producers having negative opinions on the use of iron ores in this application. However, Battelle researchers suggest that this subject be studied in a demonstration program. It is suggested that this topic be studied in some small experimental electric-smelting furnace even though there are some negative sentiments in the industry relevant to the validity of the conclusions that can be drawn from small-scale tests.

As part of the above experimental program it is also suggested that lumps of coal char incorporating silica fines be used as part of the charge to the test furnaces. The intimate mixture of the major raw materials to a ferrosilicon operation may improve the operation of these furnaces. The Russians are experimenting with the approach[21]. It is suggested that this coal-char-plus-silica-fines agglomerate could be produced in the United States with traveling-grate coker units*

Overall, all ferroalloy companies are interested in upgrading their reducing agents. Further study and/or information from the industry is required before it is possible to judge whether improved reductants could significantly improve the smoothness of ferrosilicon (and other) operations.

(B) At one time, the EPA was considering a requirement that the U. S. ferroalloy industry construct only sealed furnaces for those ferroalloy products that can be produced in sealed furnaces, as a requisite part of the best-demonstrated air-pollution-control technology[2]. If this requirement may develop in the future, it is suggested that EPA sponsor research directed at insuring that sealed furnaces are safe operations.

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* One such unit is the Peabody Coal Company's traveling-grate coker in Tennessee.

For a ferroalloy company which has learned to produce 50% and 75% ferrosilicon quietly and smoothly in open furnaces (probably with computer controls), without a need for excessive stoking, it is not difficult to foresee a future safe operation in sealed furnaces. However, if all future ferrosilicon operations are to be conducted in sealed furnaces, it is suggested that EPA should be interested in aiding the development of controls that will improve the safety of operation of all sealed ferrosilicon operations.

Japanese producers of ferroalloys in sealed furnaces maintain that operations in sealed furnaces are safe provided that the procedures are developed on open furnaces and provided that there are sufficient controls on the follow-on sealed furnaces (see Appendix: MRI Study on Sealed Ferroalloy Furnace Operations in Japan).

A serious problem is the development of pressure in the high-temperature cavity(s) deep in the charge resulting from crusting or sealing of the top mix. At the present time there is no direct signal or indication of the contained pressure inside ferrosilicon or silicon-metal operations. Excessive pressure can result either in excessive "blowing" (with attendent overheating of the furnace roof and high loss of silica fume) or in heaving of mix out of the crucible and, in extreme cases, furnace explosions. All present control methods are indirect or secondary in nature and there is no direct method of knowing or anticipating when a furnace will erupt. It is to be expected that some U. S. furnace operators will, in the interest of lowering costs, be using low-grade local charge materials. In these instances, it would be particularly important that improved controls be developed for sealed-furnace operations.

No attempt has been made on this project to develop concepts for the improved control of silicon smelting operations. On first evaluation, it would appear that the internal pressure could be monitored by the use of hollow electrodes and pressure measuring equipment. However, one company which has pioneered the use of hollow electrodes for feeding fines to electric furnaces is not enthusiastic about this approach to improve controls. Here again, if EPA is interested in improved furnace controls, it is suggested that conferences be held with representatives of the U. S. ferroalloy companies. It is considered probable by the Battelle personnel that research on this subject may be in progress at some companies.

SUMMARY AND CONCLUSIONS

The major topic of this study is ferroalloy furnace flexibility. Flexibility is a relative term which has been discussed, in this report, in terms of (1) open versus sealed furnaces, (2) small versus large furnaces, and (3) by ferroalloy type. The subject is both complex and controversial and it can be misleading to summarize via generalizations. However, six general conclusions are presented here as a summary concerning the flexibility issue.

(1) The U. S. ferroalloy industry has used and will probably continue to use furnace flexibility (on both a short-term and long-term basis) to remain competitive in a changing product-demand market in the United States.

(2) Sealed furnaces are less flexible (i.e., it would be more difficult, time consuming, and costly to effect a product change) than comparable, open-hooded furnaces.

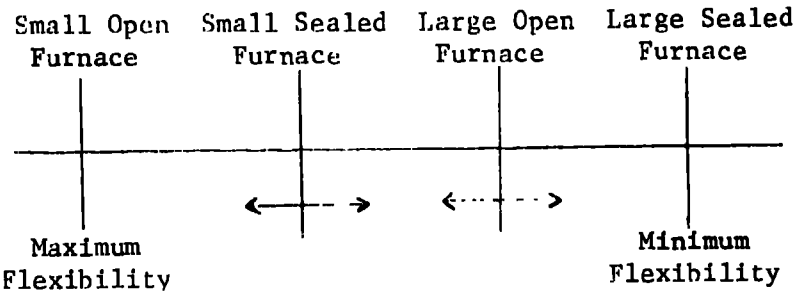
(3) It has not yet been demonstrated feasible to smelt all the common ferroalloys in sealed furnaces. Sealed furnaces have been successfully used (mainly in Japan) to produce ferromanganese, silicomanganese, ferrochrome, ferrochromesilicon and the ferrosilicon alloys with silicon contents of 75% or less. The high-silicon-content (75 Si) ferrosilicons, silicon metal, and the rare-earth silicides have not been commercially prepared under sealed-furnace conditions.
A sealed-furnace operation requires greater charge preparation and attention to operating details than a comparable open-hooded furnace on the same product. However, a sealed furnace often exhibits a greater operating time percentage and a good efficiency rating (e.g., kwhr/tonne, element recovery percentage, etc.) as a result of the additional attention given to the operating practice (see Table 1).

(4) In general, the newer and, in turn, larger ferroalloy furnaces are currently used to produce one product (or, as with FeMn and SiMn, to make very similar products). However, U. S. companies desire the ability to change products (even in the newer furnaces) if market conditions require or warrant such a change.

(5) A large (open or sealed) furnace is less flexible than a small furnace. The time and cost associated

with a product change in a large furnace is significantly greater than for the corresponding change in a small furnace.

(5) Combining Conclusions (2) and (5) above, a graphic presentation of the degree of flexibility associated with ferroalloy furnaces is as follows:



(6) A meaningful comparison between open and sealed ferroalloy furnaces in carrying out a product change is extremely difficult to formulate, as there are multiple differences in furnace designs and operating procedures from plant to plant. Based upon the furnace design and operating data presented in Table 1, it appears that a given ferroalloy product can be successfully made with a range of operating conditions (such as electrode spacing to electrode diameter ratio, electrode penetration, etc.).

While the ranges of operating conditions for various products overlap, the ability to switch products is presently dependent on the operator's ability to stoke and observe the electrode penetration and the charge-level condition. Thus, it may be that to change products in a sealed furnace, the furnace would have to be opened, the product change carried out, and then the furnace returned to operation in the sealed condition. As sealed ferroalloy furnace operations are a relatively recent development, the data base for carrying out a product change (e.g., from standard ferromanganese (FeMn) to silicomanganese

(SiMn) or vice versa), is not simply a matter of changing the charge materials. A product change requiring a major adjustment of smelting conditions may require that the furnace be opened to make the product changeover.

These conclusions are essentially in accord with the statements concerning ferroalloy furnace flexibility presented in a recent EPA report on Standards of Performance for Electric Arc Furnace for the Production of Ferroalloys(2).

Relative to the second specific objective of this study, BCL personnel could not identify any existing technology and applied engineering practices which could be applied simply to existing furnace facilities to allow the achievement of additional furnace flexibility in sealed furnaces without further long-term research and development efforts.

However, BCL personnel recommend that EPA (1) study and evaluate the overall (i.e., air, water, solid waste, etc.) environmental characteristics of open-hooded and sealed ferroalloy furnaces to establish future policy statements, and (2) evaluate the design and operation and performance of baghouse associated with ferroalloy furnaces with the objective of defining methods of decreasing the annual total emissions from existing and future furnaces.

The BCL-formulated suggestions for additional programs which could be undertaken by EPA (possibly jointly with the U. S. ferroalloy industry) to enhance the utilization of sealed furnaces and/or lower furnace emission from U. S. furnaces include:

(A) Determine whether the substitution of iron-ore pellets (as used in Japan) for ferrous scrap (as used in the U. S.) decreases the need for stoking and improves the ease of operation in the smelting of 50 and 75 percent ferrosilicon alloys.

and (B) Sponsor research directed at insuring that sealed furnaces are safe operations through the development of improved furnace-monitoring techniques and devices.

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APPENDIX

MITSUBISHI RESEARCH INSTITUTE REPORT ON SEALED FERROALLOY FURNACE OPERATIONS IN JAPAN

TABLE OF CONTENTS

		Page
A-1.	MRI REPORT COVER LETTER.....	A-1.1
A-2.	MRI INTERVIEW WITH JAPANESE FERROALLOY ASSOCIATION.....	A-2.1-A-2.7
A-3.	MRI INTERVIEW WITH JOETSU DENRO KOZYO COMPANY.....	A-3.1-A-3.3
A-4.	COMMENTS AND OBSERVATIONS BY MITSUBISHI RESEARCH INSTITUTE, INC., BASED ON JOETSU STUDY.....	A-4.1-A-4.2
A-5.	MRI INTERVIEW WITH YAHAGI IRON COMPANY.....	A-5.1-A-5.4
A-6.	MRI INTERVIEW WITH TANABE KAKOKI COMPANY.....	A-6.1-A-6.3

MRI REPORT COVER LETTER

MRI MITSUBISHI RESEARCH INSTITUTE, INC.

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HIBIYA PARK BUILDING
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December 27, 1974

Dr. C. E. Mobley
Primary Operations Section
Battelle Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201
U.S.A.

Dear Dr. Mobley:

I am sending under the separate cover the report on sealed ferro-alloy furnace operations in Japan requested by your purchase order No. J-8275.

Our conclusions for this research are as follows.

1. It is not technically feasible at present for every company to convert the production of 75% FeSi to totally sealed furnace. Judging from experiences in Japan, introduction of sealed furnaces should be in paralled with the operation of open furnaces, through which technical development be achieved and experiences be accumulated.

2. 50% FeSi can be safely produced with sealed furnaces without any pollution problems. Especially, the process using ore as raw material has been technically established.

3. Those interviewees in Japan are ready to sell their know-hows to foreign companies.

4. A sealed furnace builder in Japan has actual experiences in supplying furnaces to foreign companies overseas except for the U.S. The company considers that the export directly to the U.S. ferro-alloy producers is rather difficult, since they seem to have their own accumulation of technology. Therefore, the company wishes to find an appropriate furnace builder as the partner in the U.S. to make its know-hows available in the U.S.

Very truly yours,

Yoshio SATO
Research Director

YS:sm

A-2. MRI INTERVIEW WITH JAPANESE FERROALLOY ASSOCIATION

Q. 1. How many totally sealed ferroalloy furnaces are there in operation in Japan? What percentage of the total Japanese furnace capacity? Is it possible to obtain the total number (of sealed furnaces), the alloy type per furnace, and the rated and actual average power input and ton of product per year per furnace and age of furnace?

A. 1-1 At the present time, 39 units of totally sealed ferroalloy furnaces are in operation in Japan.

A. 1-2 We refrain from revealing the production capacity. However, the following table shows the production during the period from April 1 to June 30:

(Ton)	Insiders*	Outsiders*
Fe-Mn	163,000	2,900
Si-Mn	150,000	5,400
Fe-Si	63,000	33,900
Fe-Cr	150,000	2,300
Others	29,000	66,700
	555,000	111,500
Total	666,500 Ton	

The above figures show the highest record in the past history.

A. 1-3 Power rating of furnaces in June, 1973

	Total furnaces		Sealed furnaces	
	Unit	Rating (KVA)	Unit	Rating (KVA)
Hc Fe-Mn	11	248,200	9	239,400
Si-Mn	36	479,700	15	304,000
Fe-Si	43	692,500	3	120,000
Hc Fe-Cr	32	336,000	4	91,000
Si-Cr	8	101,000	1	40,000
M & LC Fe-Mn	16	55,200	7	-

A. 1-4 We are unable to give answers to other questions. It is necessary for MRI to conduct an additional market research to obtain proper answers.

Q. 2. Of the sealed furnaces, what is the listing of gas cleaning equipment? (bag house, scrubbers, scrubbers plus wet electrostatic)

A. 2. We can not reply to this question. An additional market research is required. However, the characteristics in Japan are;

1. Baghouses are used for open type furnaces.
2. Scrubbers or scrubber + Wet electrostatic facilities are used for sealed furnaces.

---

* We believe that these terms are used to designate members and nonmembers of the Japanese Ferroalloy Association, respectively.

Q. 3. As of 1973 it was understood that there was one sealed furnace (Joethu Electric Furnace Industry Company) in operation in Japan making 75 percent FeSi. This we understand is a small furnace. Is this furnace still in operation? Are there other sealed furnaces making 75 percent FeSi now? Are there larger furnaces in operation or going to be put into operation on this difficult alloy?

A. 3-1 Yes, the furnace is in operation at the present time.

A. 3-2 Only 75%-Fe-Si is produced.

A. 3-3 No larger furnaces are scheduled to be put in operation.

Q. 4. Is the small furnace (making 75 percent FeSi) kept on this product or is it necessary to switch to 50 percent FeSi (or other products) for periods to clean out the silicon carbide that may have formed in the furnace?

A. 4. Only 75%-Fe-Si is produced.

Q. 5. In all ferrosilicon and silicon operations there is an input quartzite to reductant ratio with a variable loss of silicon monoxide. Are there any attempts being made to measure the rate of loss of silicon (as a compound) in order to adjust the input quartzite to reductant ratio? Is it possible to control a ferrosilicon or silicon furnace accurately without knowing the silicon losses hour by hour? (This question is asked because in the U. S. high-silicon alloys represent a problem in manufacture because of bridging, high-temperature blows, and serious control problems. On the other hand, EPA descriptions of high-silicon alloy production in sealed furnaces in Japan indicate that there are no particular problems, difficulties, or system "upsets".)

A. 5. There are no particular problems, difficulties or system "upsets", associated with quartzite addition. As you pointed out, the input is adjusted by the weight and no other ways are used.

Q. 6. The U. S. EPA visitors to Japan were impressed by the dust-collection efficiency of various scrubber and wet electrostatic precipitator arrangements on sealed furnaces in Japan. The use of a wet electrostatic precipitator following two scrubbers in series represents a new approach to collection equipment to Battelle researchers. In this regard we have the following questions:

(a) In the series arrangement of: scrubber-scrubber-wet electrostatic precipitator, what percent of dust collection (of the total) occurs at the wet electrostatic precipitator?

(b) Does this arrangement control and collect superfine silica (SiO_2) fume?

(c) Is this arrangement more efficient than a well-maintained bag house on a sealed furnace? Why?

(d) On ferrosilicon operations is there any official data on dust release to the atmosphere by (1) type of collection system, (2) type of alloy, (3) weight per MW-hour?

(e) Are there any bag house installations in Japan connected to ferrosilicon operations both on sealed and open furnaces. If the answer is yes, what is the relative performance (in terms of emissions to the atmosphere in grams per MW-hr)?

A. 6. Since the manufacturers concerned have directly submitted the data to EPA, this Association knows nothing about the contents of data.

Q. 7. Do the safety records (or injury data) of the Japanese Ferroalloy Association indicate that sealed furnaces are as safe as open furnaces?

A. 7. No accidents have been recorded. (Refer Yahagi's counter opinion.)

Q. 8. Are there any sealed ferrosilicon furnaces connected to suction bag houses? If yes, what is the reported emissions rate to the atmosphere?

A. 8. There is one (1) unit at Showa Denko. N_2 is used. No data available.

Q. 9. Is there any information on the emissions of organic volatile compounds (by weight and by compounds) from sealed furnaces? It is appreciated that all the gas from sealed furnaces is completely burned either as fuel or in flaring, but what amount of the volatile organics end up as input to the water-control system? U. S. ferroalloy companies are concerned about using scrubbers on sealed furnaces because they occasionally use a rather high percentage of coal and/or wood chips in the charge both for economic and operational considerations. The probable condensation of coal and wood volatiles would appear to have many problems in common with coal coking and tar processing. Does the Japanese Ferroalloy Association have any information on the amount of organics that may appear in the scrubber water on sealed furnaces? Does the industry have a position or preference for wet versus dry collection techniques? To what extent are water effluents considered a pollution problem and how is the industry dealing with the water effluents?

A. 9. No data available.

Q. 10. It is appreciated that of the many advances made in ferroalloy operations in Japan, two improvements concern themselves with (a) well distributed unsegregated feed to each electrode, and (b) monitoring the charge consumed at each electrode. Given that the operator has information of when bridging starts at one electrode in a sealed furnace, what action does he take to return the consumption of charge material to steady flow conditions?

A. 10. Since the quality of electrode is excellent and the facilities used for charging materials into the furnace are superior, no troubles have been experienced.

Q. 11. In general, what actions are taken (and what actions are possible) in a sealed furnace to improve any "rough" operation that may develop? It is appreciated that drying the mix, sizing the mix, and preventing segregation on charging improves the operation of any ferroalloy furnace. However, in the judgment of many, no ferroalloy furnace is actually in close hour-by-hour control. An erroneous mix change, for example, can result in furnace difficulties 2 to 4 hours later. In instances when this does happen, what corrective actions are possible?

A. 11. No particular mix-preparation is made for the materials. The operations used for the closed furnaces are equal to those used for the open furnaces. (Refer Yahagi's counter opinion.)

Q. 12. In sealed furnaces, are electrodes ever raised to determine the length submerged in the charge? If this is not possible, what method aside from estimated electrode consumption is used to estimate electrode length?

A. 12. We depend on experiment.

Q. 13. In selecting quartzite for use in the production of silicon-bearing alloys is there any qualification other than chemical analysis? Is the resistance to thermal shattering determined? What is the source of quartzite in Japan and are there any local quartzites that are not used because of the problems of bridging that may be related to this particular quartzite?

A. 13-1 Chemical analysis is used for qualification.

A. 13-2 Since the specifications of supplyers are trusted, no special testing is carried out and there has been no troubles.

A. 13-3 In Japan, quartzites is produced in Fukushima, Mikawa, Fukui, etc. As a matter of fact, quartzites is abundantly produced elsewhere in Japan. In order to save the transportation cost, the locally produced quartzites is selected by each suitable ferro alloy manufacturer who is located at different area.

A. 13-4 There has been no problems of bridging related to any particular quartzites. (Refer Yahagi's answer.)

Q. 14. It is judged, by Battelle-Columbus, that the operation of a sealed furnace requires more knowledge, expertise, and understanding than the operation of an "open" furnace making the same alloy. Is this correct? If this is indeed correct, it is difficult to convert an operator used to working an "open" furnace to operating a closed furnace, making the same alloy? Is special training required to operate a totally sealed furnace over and above that given for open furnace operation? In the United States, many operators are very reluctant to "give up" their control of the operation based on the visual observation of the top of the charge. Is this also true in Japan?

A. 14-1 Yes.

A. 14-2 It is easy to convert an operator used to working an "open" furnace to operating a close furnace, making the same alloy.

A. 14-3 Special training is required to operate closed furnaces.

A. 14-4 Most of operations and actions are controlled by instruments which are observed in the control room, but the furnace operating conditions are determined through the inspection shutter by visual observation, if necessary.

Q. 15. Has any method been developed to measure or obtain direct warning of either (a) deep bridging down in the mix and/or (b) pressure build-up in the sealed furnace. Again it is appreciated that a sealed furnace may require extensive mxi preparation (like a modern Japanese blast furnace) and mix preparation improves operations in general. However, in a ferroalloy furnace there is no indirect indication of internal pressure, or has this been developed? If not, would this be a worthwhile topic of research?

A. 15-1 The pressure within the cover of sealed furnace is measured.

A. 15-2 Since the relative position of the electrode and the material charge chute is designed excellently, there has been no trouble.

A. 15-3 The method of removing furnace gases and dust is very excellent--this is another reason which contributes to eliminating troubles.

Q. 16. Mix preparation in blast furnace operation had the effect of increasing productivity. It is appreciated that ferroalloy furnaces do not work on the same principle (blowing air into carbon to produce heat and reducing agent) but are there any indications that mix preparation improves the productivity of ferroalloy furnaces? We would be interested in the productivity figures on two furnaces (open and sealed, ordinary mix and prepared mix) having about the same transformer rating. Is information of this type available in Japan?

A. 16. We do not think productivity can be improved, but the working conditions can be improved and pollution can be reduced.

Q. 17. Is the collection and effective utilization of the carbon monoxide off-gas from sealed furnaces the economic justification for sealing ferroalloy furnaces and preparing the mix for these furnaces? If this is correct, would it be possible to elaborate on the gains?

[In this instance, the Battelle researchers appreciate the gains made by the Japanese in installing the OG system on Japanese LD vessels.]

A. 17. With most of sealed furnaces, gases from the furnaces are collected and used for boilers. Some plants sell such gases to outsiders. Nippon Kokan plans to use this off-gas from sealed furnace for pre-reduction of raw materials or chemical industry.

Q. 18. If absolutely necessary, at what cost and at what time loss can a sealed ferromanganese furnace be converted to a furnace for producing 75 percent ferrosilicon? Here the Battelle investigators appreciate that this is not an efficient procedure, but for the moment if this had to be done, how flexible are sealed furnaces? Please elaborate. (In this question we are assuming that the off-grade product made during the switchover can be sold somewhere at a discount). Our interest is mainly in the expense involved in adjusting electrode diameter and electrode working diameter with a sealed furnace.)

A. 18-1 Fe-Mn furnaces cannot be converted to Fe-Si furnaces. This kind of conversion is not practiced in Japan, because each furnace is highly specialized. Even if converted, the depth of furnace is different (technically speaking). A large amount of slag is formed in case of Mn operation.

A. 18-2 For the data of electrode, refer to MRI note on Electrode Diameter Calculation.

MRI NOTE ON ELECTRODE DIAMETER CALCULATIONS

Ferro Alloy	Furnace Designation	Furnace Load, Kilowatts	Electrode Diameter, cm Calculations		
			Kelley	Aono	Actual
Std. Ferromanganese	A	25.0	200	160	170
"	B	14.1	150	130	143
"	C	15.0	151	132	145
"	D	26.0	207	163	170
Silicomanganese	E	25.0	195	161	170
"	F	15.0	150	137	135
"	G	18.4	166	145	147
"	H	30.0	210	173	170
75 Percent Ferrosilicon	I	16.0	137	125	125
	J	12.6	124	120	110
"	K	14.0	127	120	105
"	L	24.0	168	145	135
"	M	30.0	190	160	140
"	N	26.0	173	150	140

A-3. MRI INTERVIEW WITH JOETSU DENRO KOZYO COMPANY

Q. 1. The EPA representatives have reported that this company is operating a 12 MW furnace to produce 75 percent FeSi, without special mix preparation. It is also reported that this company has determined that the silica fume collected at this furnace is an order of magnitude larger in size than similar fume from open furnaces. Our general questions are as follows:

(a) Is this small furnace still producing 75% FeSi?

(b) To establish operating reliability, will this company report for one year:

(1) The tons of various alloys made in this sealed furnace?

(2) Average MW-hrs per ton of each product.

(3) Number of operating hours per one year (power on time).

(4) Average MW hour input per ton of product.

(5) Range of MW input (high and low).

(6) Average number of repair or maintenance hours per week.

It is appreciated that Joetsu may be varying the power input to this sealed furnace depending on power availability. If this is the case, we would appreciate knowing the power availability schedule.

A. 1. (a) Yes, as of now, this furnace produces 75% FeSi.

(b)-1 Only 75% FeSi was produced.

(b)-2 8100 kWh/tapped metal ton.

(b)-3 We refrain from answering.

(b)-4 Refer to (b)-2.

(b)-5 6000 - 12,000 kw.

(b)-6 The furnace has not been repaired since 1971. It is, however, scheduled to repair it in 1975.

Note: The charging chutes and contact chutes are maintained at all times to prevent abrasion caused by raw material.

(b)-7 Electric power availability.

10,000 - 11,000 kw load is the target value. However, it drops down to 6000 kw in the dry seasons in winter and summer.

Q. 2. Several countries have reported difficulties with attempting to produce 75 percent FeSi in sealed furnaces. Besides the expected dust build-up problems, the major operating problem was the crusting of the mix. In some instances special cokes were used in an attempt to correct this problem. What action is taken at this company to overcome or prevent the typical bridging problems with 75 percent FeSi production?

A. 2-1 No special cokes are used.

A. 2-2 The problem has been solved by improving the facilities concerned. That means that the sealed furnace is provided with the fixed and the mobile poking devices and, therefore, there is no trouble of "dust build-up".

Q. 3. Does this company plan a larger furnace? If they do not plan to utilize a large furnace due to current economic or market reasons, do they consider a larger 75 FeSi furnace feasible?

A. 3. Yes, this company plans to build a sealed furnace of 26,000 - 30,000 kva, but as of now, this plan is pending due to the increasing power rate and the problems in the FeSi market. Technically speaking, however, there is no problem to build a large scale sealed furnace.

Q. 4. Japanese technical descriptions of this 75% FeSi operation have not indicated any special technological factors that would appear to have solved the production problems with this alloy whether using an open or a closed furnace. Are there special considerations? (A satisfactory answer would be that there is proprietary technical information other than engineering modifications.)

A. 4. There is a difference between the closed furnace and the open furnace in regard to the engineering of design itself. Especially, with the experience to operate open furnaces, a highly efficient operation of closed furnaces is possible. However, in order to learn the operating procedure in a short period of time, a "know-how" should be used for the operation.

Q. 5. Of particular interest (to the world) is the reported growth in size of the fume from this furnace making collection a relatively simple matter. It would be interesting to know if this fume-growth factor has been <u>confirmed</u> particularly in the fume collected routinely at the dust collector? It is possible to visualize growth in particle size of deposits in and on the furnace structure. Growth in transit or flight to the collector could, however, represent new technical information that would rapidly encourage the use of sealed furnaces on 75% FeSi with Japanese know-how.

A. 5. The characteristics of sealed furnace is such that the size and shape of dust are fundamentally different. The fact that the size of dust is large makes the closed furnace fundametally different from the open furnace in regard to the know-how of operation, structure and mechanism of furnace, etc.

A. 5-1 For the shape and size of dust, refer to Joetsu Report.
Note: This report was made by checking the dry dust (before soaked in water).

A. 5-2 Can be seen with naked eyes.

Q. 6. Most high-silicon operations build up a deposit of silicon carbide in the bottom of the furnace after some period forcing switching to 50% silicon operation for a period. Others keep operating by rotating the furnace. What is the practice of Joetsu Electric?

A. 6. The furnace has not been repaired. The 50% FeSi will not be produced.

Q. 7. What is the electrode spacing to electrode diameter ratio for the sealed 75 FeSi furnace?

A. 7. Electrode ratio is 1.52 which is used formally for producing carbide.

A-4. COMMENTS AND OBSERVATIONS BY MITSUBISHI RESEARCH INSTITUTE, INC., BASED ON JOETSU STUDY

(1) U.S.S.R. is using closed furnaces to produce 75% FeSi. Please refer to the book; "Steel in USSR", November, 1972, page 881. Closed furnace melting 75% FeSi in USSR.

(2) The know-how possessed by Joetsu is "How to dispose of the dust peculiar to the closed furnace operation".

(a) How to prevent the dust from being accumulated in the furnace cover, i.e., how effectively ventilate the gas in the furnace cover.

(b) To ensure a stabilized operation by detecting a signal from the furnace (related to the proper operation).

(3) The closed furnace of Joetsu is manufactured by Tanabe Kakoki Co. (refer visiting report of Tanabe Kakoki Co.). Tanabe and Joetsu are under a special agreement for their closed furnaces. Whenever Tanabe sells a furnace to other company, Joetsu receives a "fee". from Tanabe. Tanabe has already supplied a FeMn furnace to UCC in USA and, as of now, received about 25 inquiries from companies of different countries in the world.*

(4) A dry type baghouse is used for the dust collector of closed furnace of Showa Denko (Toyama Works).

(5) With closed furnaces, gases are not released into the atmosphere and, therefore, the environment is kept clean, but special care is required in operation because incompletely combusted gases and CO gas are handled.

(6) In case of Joetsu, The speed of scrubber is so slow that it should rather be called "washer".

(7) Since the electric resistance of Japanese cokes is low at a high temperature, coal is used partially. By doing so, tar from coal is a problem for the water system.

(8) Joetsu makes electrodes at their own factory. No bridging is caused by the paste of electrode by controlling the quality and temperature of electrodes as well as the quality of paste.

(9) The raw material is charged to the surrounding area of one (1) electrode through four (4) charging chutes. Also, there is one chute common at the center. Furthermore, since there is a fixed and mobile poking device, no abnormal condition occurs in the furnace.

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* This is somewhat incorrect as the sealed ferromanganese furnace supplied to Union Carbide Corporation by Tanabe is part of a Canadian ferroalloy plant operated by Union Carbide, Canada.

(10) We understand that, in the USA, the electrode consumption is measured by means of the load cell, but we are doubtful of the effects of this method. In Japan, we rely on the operator's experience and, so far, have no troubles.

(11) Joetsu buys quartzites from Fukui and Ashikaga.

(12) When the melting point of quartzities is low, banking occurs. However, there has been no operational accident or trouble by using the purchased quartzites.

(13) In case of Joetsu, the exhaust gas is used for boilers. 1500 m^3/FeSi ton is produced.

(14) Some companies in Japan are using wood chips. Rate of wood chips consumed; 350 kg/ton.

A-5. MRI INTERVIEW WITH YAHAGI IRON COMPANY

The production results on 50% FeSi on a large sealed furnace are impressive. Possible questions for this company are as follows.

Q. 1. Is this company considering making 75% FeSi in their furnace?

A. 1. Yes. The company is considering making 75% FeSi in the closed furnace.

Reasons: Since the FeSi of this company is produced by the ore method in this company, the amount of gases (O_2, H_2) generated from the product is less than those generated by scrap process. Since the FeSi of this company has excellent quality, it has been enjoying a good reputation.

Furthermore, in case of the closed furnace operation, a low refining temperature (1,220 C) is used in the ore method of this company and, therefore, it is very convenient to totally seal the furnace.

Q. 2. If not, what are the problems to be overcome?

A. 2. _____

Q. 3. It is understood that this operation (50% FeSi) is carried out using siliceous iron ore which keeps the fraction of quartzite charged from touching and fusing. Could this company produce 50% FeSi routinely using only quartzite and coke?

A. 3. This company uses special coal.

Reasons: If special coal is not used, proper reducing reaction can not be ensured.

Q. 4. Are there any indications of large sized silica fume in the off-takes of this furnace?

A. 4. Only very fine dry SiO_2 is obtained.

Reasons: Differences from other types of closed furnace in obtaining SiO_2 are (a) refining method, (b) raw materials, and (c) temperature.

The offtakes are not clogged with the SiO_2.

Q. 5. Would this company consider an operation using quartzite, coke, coal, and iron scrap? We would be particularly interested in any information on the effect on the smoothness of operation using iron or steel scrap.

A. 5-1 Iron scrap has never been used.

A. 5-2 Even if the price of the iron scrap becomes low, we are most certain that the low temperature refining of FeSi would continue to be more attractive and beneficial.

A. 5-3 In order to ensure the smoothness of operation, the "preparation of material mix" is very important. In the operation using the scrap, the "mix preparation" is made for the sizes of raw materials such as scale, chips, etc, and the size of the quartzite, beforehand, but a segregation is unavoidable when the materials are charged, thus the smooth operation being impaired. This is the reason why this company uses "Ore". In case of "Ore", sizing can be done properly against the size of quartzite and other charging materials.

Q. 6. It is probable that hanging is encountered in the smelting zones at times. What action is taken when this occurs. What danger exists if a hanging condition is not corrected?

A. 6-1 If the experience, controlling, etc are not enough and "hanging" is encountered, the operation of closed furnace can not be performed. Therefore, a company (operators, workers, etc) must obtain enough experience and acquire the know-hows by operating open furnaces and learn how to prevent hanging before proceeding into operating closed furnaces.

MRI Note: A large amount of SiO_2 fume is especially produced in a high temperature operation for which scrap, quartzite and coke are used as raw material.

Rate of fume produced is; 300 g/M^3 gas x 1500 M^3/ton FeSi = 450 Kg/ton FeSi.

A. 6-2 Around the year of 1970, there was an accident caused by hanging of closed furnace (not in Yahagi). In this accident, a furnace cover was blown up and two operators in the control room were killed by the explosion

Q. 7. Is the silica fume collected at the collection equipment monitored to serve as an adjustment on the silica to carbon ratio of the mix?

A. 7. The operation cannot be performed only by changing the carbon ratio by monitoring the fume generating rate. The following matters should be taken into consideration.

(a) Temperature of gas (in offtakes and furnace cover).

(b) Tapping temperature.

A. 7. (Continued)

(c) Analyzed values of CO, CO_2, and H_2 in the gas.

(d) Contents of Al and Ca in the metal.

Also, the problems should be solved from the standpoint of facilities concerned, because the electric unbalance should be prevented by checking the balance of consumption of raw material with reference to each electrode.

(Patent No. US 3,499,970)

Q. 8. If this company uses coal as part of the charge material, what effect is noted in the water treatment system, if any?

A. 8. Cyanogen and heavy metals are contained in water and, even when the water is passed through a thickener and a pre-filter, it cannot be reconverted to pure (fresh) water.

At the present time there is no problem, because a perfectly closed cycle is used for the water system. There is, however, a minor problem which stems from excessive bubbles produced in the water system due to the effects of tar from coal.

Q. 9. If possible, please ask this company for performance figures (particularly for the sealed 45 and 60 kva furnaces) over an entire year as follows:

(a) Number of operating hours per year

(b) Tonnage of alloys (by type produced)

(c) Average MW hours per ton of product

(d) Average MW during operating period

(e) Range in MW (high and low)

(f) Electrical energy supply conditions?

A. 9. Please refer to the Yahagi Report.

The closed furnace should not be evaluated on the basis of the operating hours, because there is a restriction in the electric power supply.

Reasons:

(1) The restriction in electric power supply at the peak time of day.

(2) Restriction in the power consumption in winter and summer.

(3) Night factor (38% of total consumption should be alloted during 8 hours at night); 12 hours/month is always used for periodical maintenance of closed furnaces.

Q. 10. What is electrode spacing to electrode diameter ratio for the two sealed 50 FeSi furnaces?

A. 10. This is the specific "know-how", and the answer to this question cannot be obtained.

Q. 11. Is this company, or the equipment supplier, ready to export the know-how and furnace design for producing 50% FeSi under other operating conditions? What are the restrictions? What are the requirements?

A. 11. Yes, this company is ready to export the know-how, patent, and furnace design. However, the decision shall be made according to the possibility of territorial conflict with the would be licensee in marketing the product. That is, the decision shall be made on the case-by-case basis.

Q. 12. Is the quartzite given any qualification other than chemical analysis? Is spalling resistance determined?

A. 12-1 The softening point of quartzite within the range of 1,600 C - 1700 C is measured.

Any quartzite which is softened quickly can not be used for Si refining.

A. 12-2 Thermal shocks are also tested.

Other comments:

(1) It is said that, in general, furnaces for FeSi and for FeMn cannot be substituted for each other.

(2) The (electric) power density of refining zone for FeMn is $35W/cm^2$, and $85W/cm^2$ for FeSi.

We believe that if the furnace capacity and structure are appropriately designed, a mutually substitutable furnace can be constructed, but not economical.

A-6. MRI INTERVIEW WITH TANABE KAKOKI COMPANY

General Consideration design for Closed Furnace

When a closed furnace is used, a technical bottle neck is how to handle CO gas produced from the carbon contained in the raw material. On the other hand, since the air flow-in rate is low, the absolute amount of disposed gas is small and the amount of produced gas is only a few times more than that of the theoretically estimated gases. Because of these reasons, the dust collecting system is much smaller when compared with that of the open electric furnaces. However, since the concentration of CO gas is 50 - 70 percent, it is unavoidable to use a wet type dust collector as long as the technical level remains in the present condition. The reasons why the wet type is used are: When a dry or an electric method is used, air may flow-in, air lock may occur when dust is taken out, the rotating units may be overheated, mechanical shock may occur, gas explosion may be caused by an arc, etc. Now, the matters concerning the plan, operation and maintenance of dust collecting system shall be discussed with reference to the above matters. First, "dust" is produced as follows: the raw material is sent from the mixing tank to the plural number of raw material throwing tanks installed on the top of furnaces. Then, a fixed quantity of raw material is alternately thrown into the furnace through the air locked gate provided on the lower part of the above tanks. Generally speaking, the raw material in the furnace consists of (from the top to the bottom) the layer drying, preheated layer, the slag and molten metal on the bottom.

The exhaust gas rises in the reverse direction of the above described sequence of layers and the heat of heat-gas is exchanged with that of the layers of raw materials and the lower raw material in the raw material throwing-tanks. Then, it filters the coarse grains of dust in the raw material layer and sends the gas and fine grains to the dust collecting system provided outside. In this case, if the pretreatment of raw material is insufficient, the water content in the raw material moves into the gas, condenses on the inner walls of pipes and may cause a clogging in piping. In order to prevent this trouble, the temperature of inner wall of pipe and dew point of gas should be calculated with reference to the gas temperature, gas calories, ambient temperature, etc and necessary measures such as heat-insulation, heating, etc of external walls of piping should be taken.

Besides the above matters, there is another effective method. Let water flow through the piping to protect the inner wall of pipe with a film of water, preventing the dust from sticking.

In order to ensure reliability and effects of operation of the wet type dust collecting system, it is necessary to combine different types of dust collectors of different functions, thus making it possible to cope with troubles of every possible cause. For example, a combination of Taizen washer, Venturi scrubber, mist catcher, etc or a combination of a low pressure Venturi and a high pressure Venturi-cyclone scrubber.

When combining a low pressure Venturi, Taizen washer, filling tower, etc, it is necessary to take into consideration the characteristics of each element referring to the limitation of the amount of water used by the factory, the capacity of waste water treatment, etc. When designing a system and if water and dust should be removed from each dust collector, the diameter of grain, physical properties of dust at each dust collecting stage, etc should be predicted properly and the system should be provided with such a function which can fully cope with the sinking speed, condensing property, PH values of drained water, etc. Generally, in case of the wet type dust collector, the ferroalloy dust is often hardened while sinking and cannot be discharged to the outside and, when water is used for recycling, the substances dissolved in the liquid are educed by the change in the density and humidity, thus often resulting in clogging the system. From this point of view, the amount of water to be added should be decided by taking into consideration the economy of factory water as well as the safety in operation. Another important matter is that each dust collector should be provided with a bypass route so that, when repairing or replacing the equipment, it is not necessary to stop the entire system. It is quite natural that the density of discharged "dust" should be kept lower than the value prescribed by laws concerned. In case of a closed furnace, CO gas is combusted in the flare-stack before it is released into the atmosphere. It is possible that the aforementioned heavy metals, other solid substances, dissolved substances, harmful substances such as cyanogen may be mixed in the drained water and, therefore, this is another problem that should be taken into consideration when designing the drained water disposing facilities.

Cyanogen was detected by a public research organization a few years ago. Cyanogen gas is produced as the carbonic substance reacts by heat in the closed furnace. This phenomenon is not observed in open furnaces. When designing a wet type dust collecting system, it is inevitable to take necessary measures that can remove smoothly the drops of liquid from the inside of equipment. This is because the driving source is a gaseous body of small density which is the characteristics of this system.

Characteristics of Dust and System for Ferro-Cr and Ferro-SiCr Open Furnace

In case of Cr, the temperature is at an intermediate level of FeSi and FeSi and FeSiMn but the dust is comparatively coarse and large -- for example, with the centrifugal circulation type multi-cyclone with Z = > 150, the exhaust gas density was 0.1 - 0.1 G/Nm^3. In case of an open electric furnace, damage on electrodes, calcination of paste, condensation point of carbon, tar volatilization, etc are taken into consideration and in case of the actual example, the load of electrode calcination (approximately 1/3 of power consumption required for melting) and a back-filter used for filtering only the amount of occasionally produced disposed gas should be provided. In case of Cr, there are many large coarse particles at the preduster and when Z = > 150, it is just as described above, but with silicon steel plate multicyclone, the conical section was damaged in approximately 6 months.

As a general theory, Z = 30 of the common idea is to use a gravity settling type preduster and provide a back-filter on the rear stage. For the dust discharging system of the first stage dust collection, it is better to use a double damper type air lock method rather than using a rotary type. However, if the effects of preduster is insufficient, the runners of blower will wear excessively, thus unabling to perform operation and, therefore, it is necessary to keep spare runners at all times. Depending upon the temperature at the inlet of preduster, it may be better to use a multicyclone and apply a rubber lining is force-fitted into the back-filter. When FeSiCr is compared with FeCr, FeSiCr has finer particles. In case of a wet type, the filtering thickness is approximately < 2m/m by Oliver Test, thus making it difficult to apply it for industrial use. Water can be separated from dust very quickly but is condensed and becomes very hard. It was, therefore, difficult to dispose of it mechanically.

From the above point of view, the dry method is the best way to dispose of FeCr and FeSiCr.

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The report gives results of a study of ferroalloy furnace flexibility, in terms of open versus sealed furnaces, small versus large furnaces, and ferroalloy type. It identifies operational parameters that must be adjusted when changing products in a ferroalloy furnace and compares domestic furnaces and operating practices to those in parts of Europe and Japan. The report suggests additional research and development programs that could be undertaken by EPA to enhance the utilization of sealed furnaces and/or reduce furnace emissions in the U.S. ferroalloy industry.

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