CONSIDERATION OF ELECTRIC FURNACE DIMENSION & DYNAMIC OPERATION BASED ON RESEARCH OF REDUCTION BURDEN IN A MODEL FURNACE

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SYNOPSIS

In Japan, since 1970, the electric furnaces for producing the ferro-manganese have been replaced one after another with large closed modernized furnaces having capacities of 36,000 to 51,000 KVA. Since the production capacity for these furnaces is very big, the stoppage of these large furnaces gives enormous damages to the supply and demand. Therefore, technology which enables the equipment to operate for a period of more than 10 years is necessary.

We have investigated the distribution of the inner furnace reaction zone using 2,500 KW (4,000 KVA) model furnace and have found out that the vertical dimension of the electric furnace was one of the most important factors for designing electric furnace. We have also found out the formula for obtaining adequate thickness of metal zone (Hm), tip position of electrode (He) and thickness of raw material zone (Ho).

$$Hm = H_p + \frac{Sg_1 \times H_1 + Sg_2 \times H_2}{Sg_4}$$

$$He = \alpha \times \frac{Sg_1}{Sg_2} \times H_1 + C \times \frac{(KW) \times 10^{-3}}{A} + H_3$$

$$Ho = H_1 + C \times \frac{(KW) \times 10^{-3}}{A} + H_3$$

As a result of modification of two large furnaces on the basis of these formulas, we were able to get good results as follows :

(1) Prevented furnace bottom carbon lining from erosion.

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(2) Increased thermal efficiency of the electric furnace and decreased power consumption per ton of alloy to 2,000 KWH/t.

(3) The long term continuous furnace operation of more than 8 years became practicable.

1. Summary

In Japan, 1,510,000 t of ferro-alloy was produced in 1978, using 95 electric furnaces having a capacity of more than 5,000 KVA. As to electric furnace for producing ferro-manganese and silico-manganese, since 1970, these furnaces have been replaced one after another with large closed automated electric furnace having capacities of 36,000 to 51,000 KVA.

At present, these 10 large closed furnaces are producing ferro-manganese and silico-manganese and have enough capacity to supply those, which is required for 120 million tons per year of steel production in Japan (refer to Table 1). For the operation of large closed furnaces, there are the following two targets :

(1) Safety furnace operation for more than 10 years without trouble to furnace lining.

(2) Getting good result of the continuous furnace operation.

When there occurs the trouble to furnace lining, two or three months, stoppage of furnace operation will be forced and enormous expense will be required to repair the electric furnace. Furthermore, in these stoppage terms, there will occur the shortage of product supply. The bigger the furnace capacity, the bigger the damage from the stoppage of furnace.

In order to keep the production cost low, it is most important that the electric power consumption per ton of alloy (KWH/t) be kept low. In other words, the electric energy supplied into the furnace should be most efficiently used.

Until now, in order to operate electric furnace in optimal condition, many researches concerning the conditions of raw material, electric supplying device, chemical and metallurgical reaction, electric furnace dimension and so on have been actively investigated and reported in the paper.

In spite of the metallurgical reaction process in the electric furnace and the vertical dimension of the electric furnace body being most important factors, little research about these factors have been made. Since it is very difficult to make investigation of inner furnace, we have made investigations of reaction process of material zone, raw material melting zone, reaction zone, slag zone and metal zone with 2,500 KW model furnace and were able to obtain some index of the vertical dimension being important for designing the electric furnace.

Applying the index to the large closed furnace of 38,500 KVA, the steady operation of more than 8 years have been obtained without stoppage. Furthermore, the electric consumption decreased to 2,000 KWH/t.

Table 1. Large Furnaces in Japan (FeMn)

	Firm / Unit	JMC	JMC	NDK	NDK	NKK	NKK	CDK	CDK	MGK	MGK
EF No.		31	32	1	2	16	17	1	2	3	4
Product		FeMnH	SiMn	FeMnH	SiMn	FeMnH	SiMn	FeMnH	SiMn	FeMnH	SiMn
Transformer	KVA	38,500	51,000	36,400	40,500	40,000	40,000	40,000	50,000	40,000	40,000
Load	KW	25,000	33,000	25,000	25,000	26,000	26,000	25,000	28,000	26,000	26,000
Product Capacity	t/y	85,000	67,000	88,400	57,100	88,400	53,000	85,000	57,100	88,400	53,000
Elec. Dia.	m	1.70	1.70	1.70	1.70	1.75	1.75	1.70	1.70	1.70	1.70
Hearth Area	m^2	88.0	95.0	96.0	103.0	99.3	95.0	100.2	113.1	106.7	100.0
Hearth Depth	m	5.54	5.89	4.50	5.50	6.00	5.60	4.63	4.70	5.90	4.60
2ry Voltage (R)	V	218	225	218	190	260	260	218	230	210	185
2ry Ampere (mx)	A	102,000	130,000	97,000	123,000	89,000	89,000	106,000	100,000	110,000	125,000
Metal Hole	m	0.7	0.7	0.5	0.5	0.5	0.5	0	-	0.9	-
Slag Hole	m	1.8	1.8	1.15	1.6	1.5	1.5	1.0	-	1.2	-

2. Ferro-manganese operation and investigation of the model furnace

1) Outline of Model Furnace

The 4,000 KVA ferro-manganese electric furnace in Takaoka Plant was used for the model furnace. This model furnace had been operating with best condition since January to December, 1971. Just before the last tapping in December, 1971, the electric power had been cut off. After this model furnace had been cooled, this furnace body was cut out vertically. The burden of this furnace was carefully dug out from the furnace so that the shape of each layer, raw material zone, reaction zone, slag zone and metal zone may be accurately observed and investigated.

2) Dimension and Results of the Model Furnace

Dimension of the model furnace is as follows :

Item		
Capacity of transformer	KVA	4,000
Average operating load	KW	2,500
Electrode diameter	mmϕ	610
Secondary current	A	19,000
Current density of electrode	A/cm^2	6.5
Distance between electrode	mm	1,400
Furnace depth	mm	1,930
Area of furnace bottom	m^2	8.62
Volume of inner furnace	m^3	16.6
Metal tapping hole level from furnace bottom	mm	300

Fig. 1 shows the section of the model furnace.

Operation results of the model furnace during December, 1971 are as follows :

Average electric load		KW	2,500
Power consumption		KWH/t	1,982
Manganese yield		%	80.8
Mn ore consumption		Kg/t	1,995
Coke consumption		Kg/t	345
Electrode consumption		Kg/t	10
Metal composition	Mn	%	74.2
	Si	%	0.3
	C	%	6.8

3) Investigation and Analytical Research of the Model Furnace

The burden distribution inside the model furnace is shown in Fig. 2.

As shown in Fig. 2, the burden is divided into metal zone, slag zone, melting reaction zone and raw material zone. The distribution seems to be found based on the physical law. The investigation about each zone is as follows :

(1) Metal Zone

The metal composition is : Mn 77.3 %, Si 0.01 %, Fe 14.7 % and C 7.6 %; namely, [Si] % in this metal is rather lower than the standard HCFeMn, and [C] % is saturated and this metal is horizontally distributed all over the furnace bottom.

The carbon lining of the furnace bottom was eroded to 840 mm from the tapping hole level and the metal with thickness of 240 mm piled on the eroded surface of the carbon bed. It was found out that the metal level was rather lower from the tap hole than expected. Owing to this fact, it was assumed that in tapping time the metal in the furnace was forced out from the furnace by the burden pressure on the metal inside the furnace, and was stopped at balanced point between the burden pressure and the metal pressure from the tapping hole.

(2) Slag Zone

Chemical composition of the slag (Mn 29.8 %, SiO_2 23.6 %, Fe 0.9 %, CaO 12.8 %, T-C 0.065 %) was similar to the standard of H-C FeMn slag.

The slag was overspread on the metal zone. The upper surface of the slag zone was located under three electrodes and near the side wall of the furnace, especially near the tap hole, and the three slag zones under the electrodes were connected with the narrow passage ways. As the volume of this slag was 1 m^3, and same as one tapping volume, almost all the slag produced during one cycle seemed to have been forced out from the furnace. In the center of the furnace, hardly any slag was observed and the melting reaction zone with the high MnO dense slag was directly contacted with the metal zone.

Still more, this high MnO dense slag has a chance to directly contact with the bed carbon lining of the furnace bottom, especially after tapping of the metal.

By the above mentioned phenomenon, the bed carbon lining of furnace bottom is attacked quickly during the early operation term.

(3) Melting Reaction Zone

The melting reaction zone with a high MnO dense slag (Mn 30.1 %, SiO_2 15.2 %, CaO 7.4 %, Fe 6.3 % and T-C 15.6 %) has concaves in the center of the furnace, in the parts between electrodes and near the furnace side wall, and has convexes under electrodes. Its volume is about 4.8 m^3 and its thickness about 75 cm.

In this zone, the coke was uniformly scattered. The size of coke becomes smaller as the coke falls down to lower part of this zone, and turns to fine graphite in the boundary surface of the slag zone. The innumerable granular metals are found out in this zone. Namely, in this zone, HCFeMn metal are produced by reduction process and then stored in the metal zone.

As there are many cokes in this zone, the electric resistance of this zone is very small. The penetration of the tip of electrode from the surface of the raw material is especially concerned with this small resistance.

(4) Unmelted Raw Material Zone

The unmelted raw material zone consists of Mn ore, lime and coke which have not yet melted and reacted. But these raw materials are reduced, for instance, as follows :

$$MnO + C(CO) \longrightarrow MnO$$

$$Fe_2O_3 + C(CO) \longrightarrow FeO$$

This unmelted raw material zone piles up above the melting reaction zone and falls down to rather lower level in the center of the furnace and in the part between electrodes and forms complicated shape. The height and weight of this zone influence upon the shape of the melting reaction zone and the electrode penetration.

3. Dynamic consideration about the reaction zone

Owing to the investigation of the model furnace, the vertical dimension is shown as follows :

$$H_1 = 160 \text{ cm} = H_1$$

$$h = 55 \text{ cm} = \alpha \cdot \frac{Sg_1}{Sg_2} \cdot H_1 \qquad \alpha = 0.60$$

$$H_2 = 75 \text{ cm} = c \cdot \frac{(KW) \cdot 10^{-3}}{A} \qquad c = 1.92 \text{ m}^3/1{,}000 \text{ KW}$$

$$H_3 = 10.7 \text{ cm}$$

$$H_4 = 73.3 \text{ cm} = \frac{Sg_1 \cdot H_1 + Sg_2 \cdot H_2}{Sg_4}$$

where,

H_1 : Thickness of the unmelted raw material zone (cm)

Sg_1 : Bulk density of the unmelted raw material zone (1.4)

H_2 : Thickness of the melting reaction zone (cm)

Sg_2 : Bulk density of the melting reaction zone (2.45)

H_3 : Thickness of the metal zone

H_4 : Distance between the tap hole and the surface of the metal (cm)

Sg_4 : Bulk density of the metal

h : Depth of the concaves in the melting reaction zone (cm)

α : Floatation coefficient

Near the center, 0.60;
Area between electrodes, 0.459;
Near the side wall, 0.294.

$$\alpha = \frac{Sg_2 \cdot h}{Sg_1 \cdot H_1}$$

A : Effective reaction area of the furnace

$$A = \left(\frac{D}{2} + \beta D \right)^2 + 3 \times \left(\frac{D}{2} + \beta D \right) \times l \cdot D + \frac{\sqrt{3} \cdot l^2 \cdot D^2}{4}$$

where,

D : Diameter of the electrode

$\beta \cdot D$: Melting zone ratio around electrode (0.7 D)

l : Electrode distance ratio between the centers of the electrodes (2.5)

c : Volume coefficient of the melting reaction zone ($1.92\ m^3$ / 1,000 KW)

From the result mentioned above, the vertical dimension is obtained as follows :

(1) Optimal furnace depth (Ho)

$$Ho = H_1 + H_2 + H_3$$

(2) Optimal electrode tip position from the furnace bottom (He)

$$He = h + H_2 + H_3$$

(3) Optimal metal hole level from the furnace bottom (Hm)

$$Hm = H_p + H_4$$

Namely,

$$Ho = H_1 + C \cdot \frac{(KW) \times 10^{-3}}{A} + H3$$

$$He = \alpha \cdot \frac{Sg_1}{Sg_2} \cdot H_1 + C \cdot \frac{(KW) \times 10^{-3}}{A} + H_3$$

$$Hm = H_p + \frac{Sg_1 \cdot H_1 + Sg_2 \cdot H_2}{Sg_4}$$

Hp : permanent metal thickness.

4. Importance of vertical dimension of ferromanganese furnace

In view of the results from the investigation and consideration in §2 and §3, the vertical distribution of the burden in the furnace, which had been scarcely reported up to now, was found out.

This paper indicates that the decision of the adequate dimension is very important to keep the good operation for a long period.

1) Distribution of the Burden

Each zone is distributed horizontally not as flat layer but as complicated wavy shape influenced by the physical dynamic pressure of the upper zone.

2) Height of the Metal Zone and Level of the Tapping Hole from the Furnace Bottom

In order to prevent the furnace bottom from erosion, the adequate thickness of the metal zone should be kept. In other words, if the height of the tapping hole from the surface of the furnace bottom lining is not enough, all the metal will be forced out from the furnace and the melting reaction zone will be contacted with the furnace bottom carbon lining.

If the high MnO dense slag of the melting reaction zone contacts with the bed carbon lining, the carbon lining will be actively reacted with the high MnO dense slag and eroded in the center of the furnace, especially. Furthermore, the lack of the thickness of the metal zone will prevent the slag from being forced out from the furnace, because the sticky slag and coke of the reaction zone will fall down to the furnace bottom and plug the passage way between the slag zones under the electrodes.

As much slag and coke will remain in the furnace, the tip of the electrode will rise even after tapping.

According to the above mentioned reason, the position of the tap hole should be set at adequate level.

3) Electrode Penetration into the Raw Material Zone

In order to get the good energy consumption, high temperature CO and CO_2 gas energy which occurs from the reaction zone should be efficiently exchanged in the raw material zone. If the thickness of this raw material zone is too much, not only the tip of the electrode will rise but also the stationary gas flow through the raw material zone will be disturbed and the gas blowing will occur because of the differential pressure of the raw material zone becoming high.

This phenomenon makes the thermal efficiency in the furnace lower. On the contrary, if the thickness of this raw material zone is too thin, the energy of the gas will not be used for the thermal exchange and will be exhausted out of the furnace.

The thermal efficiency of this condition is not effective. The adequate thickness of the raw material zone was found out to be 150 cm owing to investigations from the model furnace, and this figure is almost the same with the small furnace and the large one.

Conditions :

- Gas temperature	:	$1{,}800^{\circ}$ C (at the inlet)
		200° C (at the outlet)
- Gas velocity	:	0.4 m/sec.
- Gas specific heat	:	0.39 cal/$Nm^3 \cdot {}^{\circ}C$
- Raw material specific heat	:	0.2 cal/gr$\cdot{}^{\circ}$C
- Raw material temperature	:	50° C (at the inlet)
		$1{,}200^{\circ}$ C (at the outlet)
		500° C (average)

4) Tip Position of Electrode

It is very important to keep the tip of the electrode in an adequate position especially for the large furnace. The electrode tip position is a good index for controlling the furnace operation and for getting high furnace efficiency. The electrode tip position will go up and down depending on the electric resistance of the burden in the furnace. Too much coke will make the electrode tip position go up and the thermal efficiency down, because of enrichment of coke in the melting reaction zone under the electrodes making the electric resistance low.

The adequate electrode tip position can be obtained using the next formula as a function of the furnace load (KW)

$$He = \alpha \cdot \frac{Sg_1}{Sg_2} \cdot H_1 + C \cdot \frac{(KW) \times 10^{-3}}{A} + H_3$$

5. Instance of application for large furnace

1) 11,000 KW (22,000 KVA) Closed Ferro-manganese Furnace

This furnace having obtained good result in ferro-manganese operation has been periodically repaired every two years because of the erosion of the furnace bottom. After the consideration to prevent the furnace bottom lining from being eroded, the level of the tapping hole was re-designed at higher position of 120 cm, from the surface of the bottom lining than before, with the formula mentioned before. The height of the tapping hole calculated was H_4 = 104 cm.

The furnace bottom lining after being re-designed is scarcely eroded and this furnace has been continuously operated.

2) 22,000 KW (38,500 KVA) Closed Furnace

This furnace had the problems for the operation as follows :

(1) The electrode tip position was too high (380 to 400 cm).

(2) The electrode penetration into the raw material was shallow. The gas temperature in the furnace was high (between 360 and 400° C) and the thermal exchange in this term was not so effective.

(3) The metal came from the slag tap hole at the end of the slag tapping time, the slag could not be sufficiently taken out from the furnace.

(4) As the result of the phenomena of (3), much slag remained in the furnace and tips of the electrodes did not go down even after the slag tapping. The coke for reduction, therefore, should be forced to decrease and the Mn yield fell down owing to the lack of coke in the furnace.

In order to solve these problems, the following actions were carried out, as it was concluded that the cause of these problems was due to the big burden pressure of the raw material using this investigation of the model furnace.

(1) Thirteen (13) spouts of the raw material charging chutes were descended 60 cm in order to decrease the thickness of the raw material zone.

(2) The center spout was divided to three spouts to decrease the burden pressure in the center part of the furnace.

(3) The sintered ore was increased from 25 % to 40 % in order to decrease the bulk density of the raw material, to improve the furnace gas flow through the raw material zone and to increase the electric resistance.

After that, the electrode tip positions were kept between 330 and 340 cm and the furnace gas temperature was controlled between 200 and 250° C. This furnace has been continuously operated for a long period and runs still in good condition.

Table 2. Operating Results of this 38,500 KVA Furnace

	1979			
	October	August	June	May
Average load (KW)	21,341	21,054	20,556	21,930
Operating Rate (%)	99.3	99.1	98.5	98.6
Power consumption				
KWH/t	2,102	2,089	2,086	2,062
Mn yield	81.8	82.1	81.2	81.5
Raw material				
Mn ore	1,880	1,944	1,844	1,808
Metal for remelt	86	70	73	101
Coke	362	362	354	349
Lime stone	13	-	56	47
Electrode	7	8	7	6
Metal composition				
Mn %	74.1	74.0	73.8	73.9
Si %	0.1	0.1	0.1	0.1
C %	6.95	6.81	6.87	6.87
Slag ratio (Kg)	572	607	584	590
Slag component				
Mn %	27.5	27.8	29.5	29.4
SiO_2 %	22.7	23.2	21.5	21.7
CaO %	20.2	21.0	18.9	18.3
Al_2O_3 %	8.9	9.8	10.0	10.3
MgO %	4.5	5.0	3.0	3.3

Mn slag to be used as the raw material for Si-Mn.

6. Conclusion

A large furnace increases the production capacity and the labour productivity. But, if there occurs some trouble on a large furnace, high expense for repairing should be accommodated, also shortage of the product will make the Supply-Demand relation abnormal not only in domestic market but also in foreign one. From this point of view, the large electric furnace should always be operated continuously and in safety.

The fundamental vertical dimensions were found out from the investigation of the Model Furnace. The already constructed large one which was applied and improved on the basis of these vertical dimensions could obtain a good result.

In future, the vertical dimensions will be found out more exactly by investigating the large furnace itself.

Another important factor for operating the electric furnace is the electrical condition. It is necessary to increase the electric resistance of the raw material for operating furnace. The electric resistance of the raw material mixture depends on coke volume rather than on ore volume in the mixture. The sintered ore makes the electric resistance higher by its porosity and by less coke needed than normal Mn ore.

In the case of the electric resistance of the mixture being high, the tip of the electrode will be kept in lower position of the furnace and the good thermal efficiency will be obtained.

When the dynamic condition mentioned in this paper will be combined with the electrical condition, the more improved theory could be established. We will try to make this point clear in the future.

FIG. 1 DIMENSION OF MODEL FURNACE

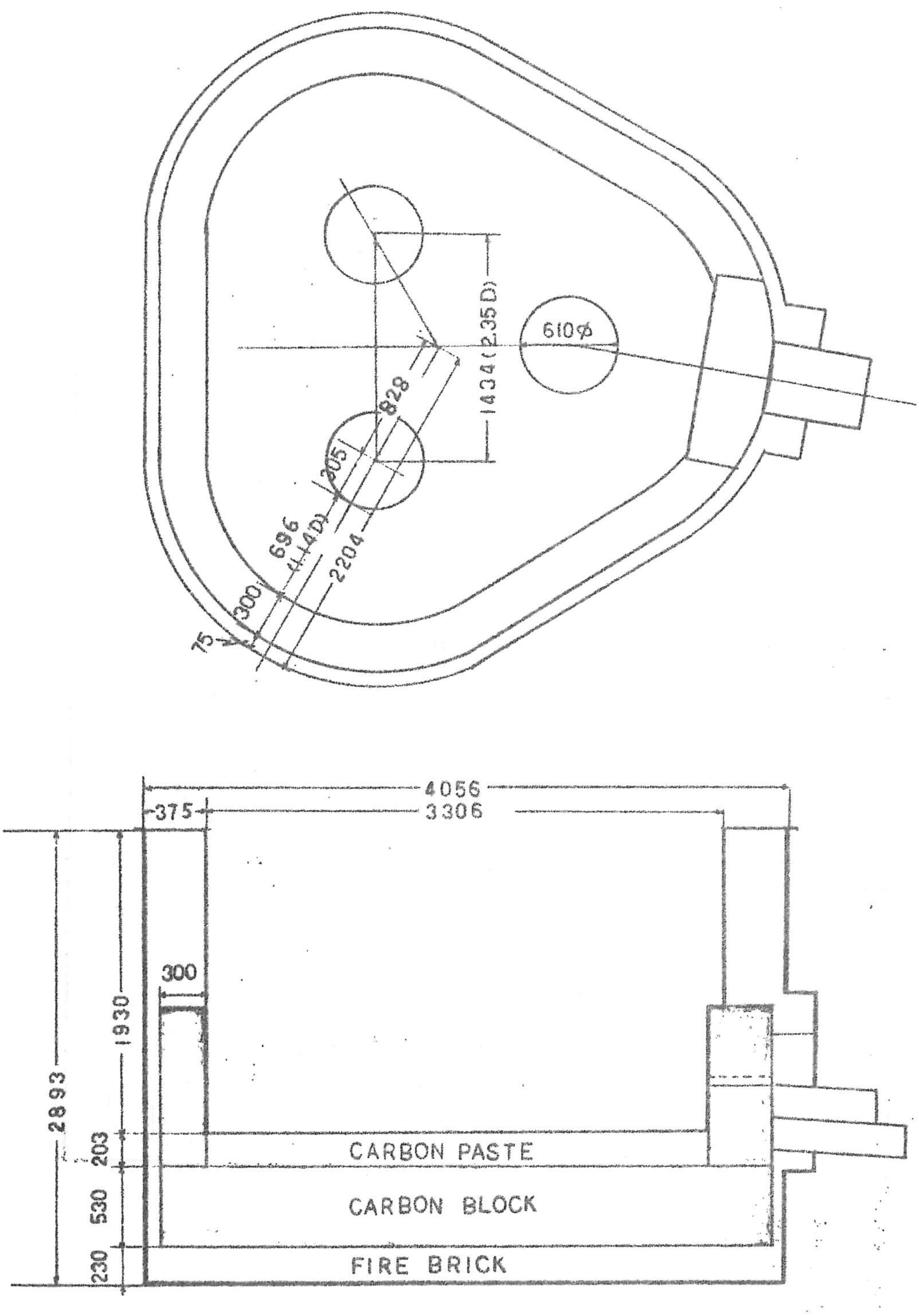


FIG. 2 SECTION OF MODEL FURNACE

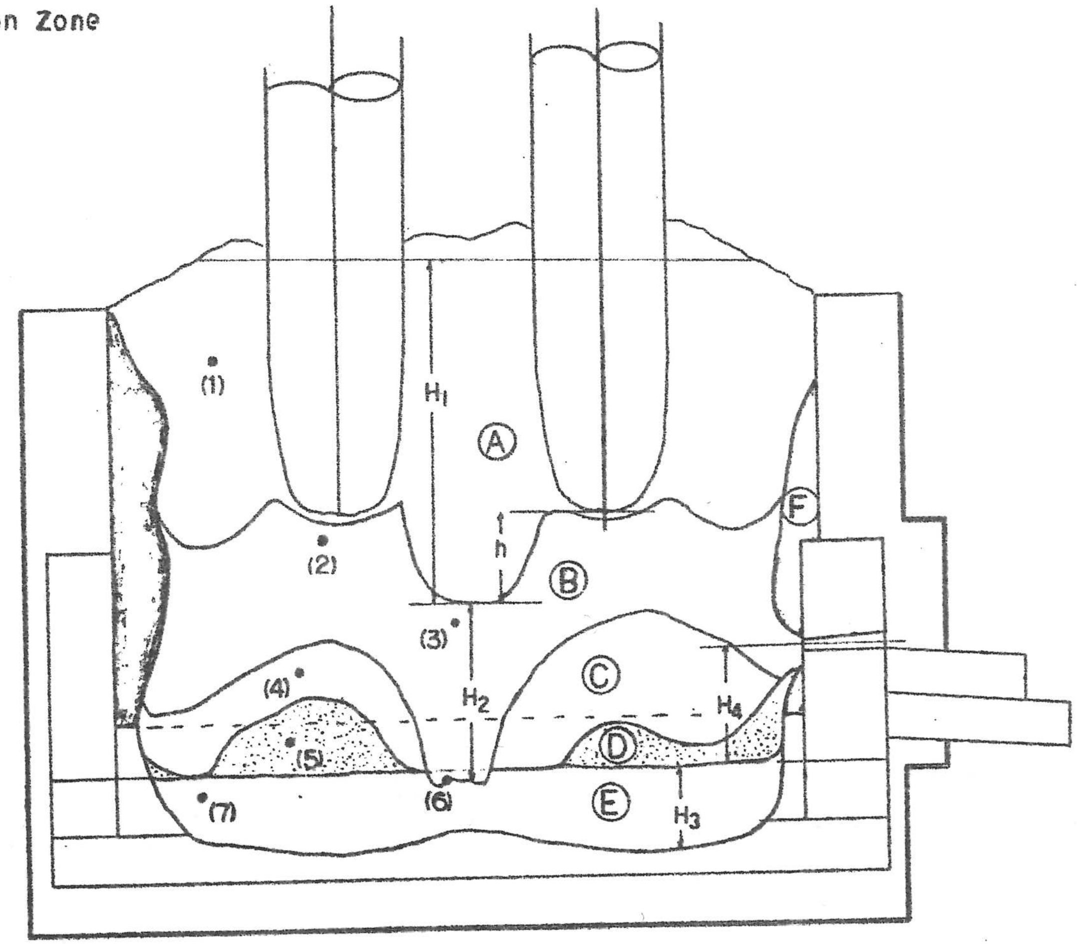
Ⓐ--- Raw Material Zone

Ⓑ Ⓒ --- Melting Reaction Zone

Ⓓ--- Slag Zone

Ⓔ--- Metal Zone

Ⓕ--- Self Lining



COMPOSITION

	Mn	SiO_2	Fe	CaO	C
(1)	37.5	5.0	5.9	6.6	11.6
(2)	30.1	15.2	6.3	7.4	15.6
(3)	37.6 / 47.1	15.0 / 10.3	2.9 / 7.2	11.4 / 5.3	7.7 / 2.1
(4)	39.7	14.3	3.1	8.4	12.9
(5)	29.7	23.6	0.9	12.9	0.065
		Si			
(6)	77.3	0.01	14.7	–	7.6
(7)	68.4	1.23	13.5	–	11.1

DISCUSSION

Dr. C. Finn*

I would like to ask two questions: The first one concerns Figure 1 from the paper. In Figure 1, you show a triangular shape for the furnace. Is this typical in Japanese ferro-manganese production and if so why? And the second question: The National Institute for Metallurgy in South Africa has reported on a dig out of a 48 MVA ferro-manganese furnace. Very different patterns or reaction zones, in particular, were found. Do you think that a scale up from 4 MVA to 30 MVA is valid?

Mr. S. Yoneka:

To your first question: Triangular shape is very typical in our case. In former days, to have economical usage of heat we had to introduce our triangular form but recently, we are working toward round ones. To your second question: We have never experienced digging out such a big furnace as 48, so this will be our future study.

Mr. A.T. Manara**

I would like to know whether with the experimental furnace to which Mr. Yoneka's conference refers, they have ever run a test upon the slag retained methods? If so, what are the comparative results one to the other: the traditional and the retained slag method?

Mr. S. Yoneka:

Our experience with retaining slags is that we get a wider melting zone and a very stable operation.

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