Improvement of energy efficiency by process computer for ferroalloy electric furnace, and production of medium or low carbon ferromanganese by direct decarbonization of FMnH melt.

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1. INTRODUCTION

The ferroalloy plant at Kakogawa Works in Kobe Steel, Ltd. produces both high-carbon ferromanganese (FMnH) and silicomanganese (SiMn) by two, closed-type furnaces, both which have capacities of 20MVA.

The ferroalloy plant is conveniently located in our steel works, so its advantages and distinctive features are listed as follows:

(1) Raw materials can be delivered by ship directly to the ore and coal-wharf equipment, which reduces freight costs.

(2) By-products can be used in other processes, for example:

Silicomanganese slag is used in the blast furnace.

Dust from the blast furnace is used in the production of manganese-sintered ore.

(3) Several plants can use electric power from a single power plant in Kakogawa, which, in turn, utilizes gas from the electric furnace.

(4) The ferroalloy plant can use a constant load of electric power, while on the other hand, the load can also be adjusted more easily than that of other plants. Therefore, the power consumption of the entire Kakogawa Works can be adjusted to that of the ferroalloy plant.

(5) The cost of transportation can be reduced because products are used in the neighboring steel-making plants.

(6) Labor and production costs can be reduced, since the maintenance of equipment, analytical work, and administration duties can be performed together.

(7) Electrode tip positions can be controlled by computer.

(8) "The Best Economical Load Operation" can be excuted. During low cost electric charge, the furnace can operate at maximum power capacity, and during high cost electric charge, the furnace can operate at minimum power capacity or at power stoppage.

(9) Hot-sintered ore can be charged in the electric furnace.

In Japan, the cost of electric power rose sharply due to the oil crisis in 1979, and consequently, the production of ferroalloy met with severe competition with foreign products. The ferroalloy industry consumes large quantities of electric power, which occupied 39.3% of the cost of production for high-carbon ferromanganese, and 56.2% for silicomanganese in 1980. Therefore, the authors have developed cost-cutting techniques for electric power consumption in order to maintain our competitive edge.

[Electric Power Cost (YEN/T)] = [Unit Electric Power Consumption (kwh/T)] X [Unit Electric Power Cost (YEN/kwh)]

A decrease in the electric power cost must be achieved by reduced electric power consumption or the unit electric power cost from the above formula.

Various methods of reducing the unit electric power consumption have been carried out, and the authors have found that in reducing energy consumption, it is essential to maintain optimal electrode tip positions in the furnace. Therefore, the authors have developed the computerized "Electrode Tip Position Control System."

As a method to reduce the unit electric power cost, it achieves maximum effectiveness if used in conjunction with "The Best Economical Load Operation".

Fig. 1 shows the changes in the unit electric power consumption of silicomanganese at the Kakogawa plant.

In addition, the conventional method for production of medium or low-carbon ferromanganese (FMnH or FMnL) has been by silico-thermic reduction of manganese ore. However, not only is the silico-thermic process not very productive, but it uses large amounts of electric power, which comprises a large portion of the production cost.

Therefore, in countries where electric power is expensive, the production of FMnM or FMnL by a process which conserves energy is highly beneficial.

In this report, the investigation of production of FMnM or FMnL by means of direct decarbonization of FMnH melt using oxygen gas, the production cost of which is relatively low, is also described.

2. ELECTRODE TIP POSITION CONTROL SYSTEM

Fig. 2 shows an outline of the electric furnace.

The different kinds of heat energy required to operate a ferroalloy electric furnace are as follows:

(1) The heat required to melt raw materials.

(2) The heat required to reduce an oxide of Mn, Si, Fe, etc.

(3) The heat required to give fluidity to metal and slag.

These kinds of heat energy are supplied by electric resistance heat, which is produced at electrode tips and its surrounding area. And so, if the electrode tips are positioned optimally in accordance with the actual operational condition of the furnace at that time, the heat which is required for these various purposes will be distributed evenly, and the electric power will be supplied efficiently and economically.

Furthermore, the electric furnace will acquire a stable furnace operational condition. However, the inside of the furnace can't be viewed externally, so it is very difficult to control the electrodes' position accurately. Moreover, it is a fact that, to date, electrodes have not been accurately or effectively controlled.

Therefore, to improve electrode tip accuracy, the authors have developed the "Electrode Tip Position Control System" for a ferroalloy electric furnace, which enables operations to be carried out using a minimum of unit electric power consumption. This system is based on the following principles: (An electronic computer has been adopted for the fastest and the most accurate control.)

(1) To maintain constant and optimal electrode tip position to suit the supplied electric power calculated from the analysis of the actual operational data.

(2) To calculate a specific index from various actual operational data, in order to quickly recover the optimal electrode tip positions at the time when the index is found to vary over the given range. If the calculated index remains within a given range, the electrode tips prove to remain within the optimal positions.

(3) To recover the electrode tip positions concerning the above ((1) and (2)) to establish procedures for calculating the electrode tip positions.

2.1 Electrode Tip Position Control

Fig. 3 shows an example of the Electrode Tip Position Control. The silicomanganese manufacturing process depends on this method. This figure shows the changes of the specific index and the electric tip positions. In this example, the controllable range of the specific index is from 0.30 to 0.50. The specific index of electrodes before control for each electrode begins, is adjusted within a given range. The rise of each electrode after control begins is usually activated by the electrode tip position pattern. Then, the specific index of each electrode is calculated continuously from actual operational data. When the calculated index exceeds the upper limit, the upward speed of the electrode is decreased, and when the calculated index goes below the lower limit, the downward speed of the electrode is increased.

Accordingly, the electric resistance heat at each electrode tip area is kept within a fixed range, and is being consumed at a constant rate. Each electrode tip position is adjusted at about the same level, and is increased at a constant speed. As a result, any one electrode seldom rises or falls excessively, and therefore, the operator is able to continue the operation, maintaining a stable melt zone and reduction zone. Moreover, the supplying electric power is utilized at maximum efficiency by means of automatic control of the specific index of each electrode within the fixed range. (The fixed range of a specific index is decided beforehand to achieve the most effective operation.)

2.2 Procedure for Calculation of the Electrode Tip Positions

This system operates accurately and efficiently without interrupting furnace operation, electricity flow, or production of EFG. To calculate the electrode tip position, temperature (T) and CO content (P) in EFG are measured, and an electrode tip position index (X) is calculated by the following formula:

$$X = \alpha \times T + \beta \times P + \gamma \quad (1)$$

note: α, β, and γ are a constant value which are decided by furnace type, operation condition, raw materials, etc.

The electrode tip position (L) is calculated by the following formula:

$$L = a \times X + b + c \quad (2)$$

note: a, b, and c are constant value which are calculated by an electric resistance value, an electrode, etc.

However, the distance between the electrode tip and hearth should not be calculated at tapping time, furnace-blowing time, and during emergency electrode operation time. For example, Fig. 4 shows the relation between an electrode tip position and its index. The correlative coefficient was 0.85, but increased to more than 0.95 during "no tapping" time.

2.3 Attained Effects

(1) Reduction of the Unit Electric Power Consumption
The attained rates of reduction of the unit electric power consumption are listed in the table 1.

(2) Productivity Improvement due to Stabilization of the Below-Mentioned Furnace Operational Condition.
Reduction of the number of power stoppages and their length of time due to the reduction of furnace-blowings, slippings and trips caused by overcurrent, lead to an improvement in productivity.

(3) Reduction of Labor Load on Workers and Hazardous Working Conditions

(4) Standardization and Automation of Operations
The company computerized the electrode operation and standardized of the coordinating control of the quantity of coke charged, and this has been operating smoothly and efficiently.

3. THE BEST ECONOMICAL LOAD OPERATION

"The Best Economical Load Operation" means the operation which reduces the average unit electric power cost. For example, an electric furnace operates at full capacity during low cost consumption time, and conversely, operates at lowest capacity, or not at all, during high cost power consumption time.

Fig. 5 shows an hourly unit electric power cost (YEN/kwh) index at the company. The highest electric charge is about three times the lowest electric charge. Therefore, the operation objective to use maximum electric power at night, and to stop operation during the day, reduces energy costs considerably. In the past, the electric furnace has been operating continuously for a long period of time in order to prevent the breaking of electrodes. Therefore, no precedent, as yet, has been established for long (8 hours) periods of electricity stoppage per day. Accordingly, the authors have established the following steps to prevent operational problems:

(1) Prevention of electrode breakage
The authors have developed a method of applying "no heat" shock treatment to the electrode.

(2) Prevention of furnace operational condition malfunction
The authors state that heat loss of the electric furnace can be prevented by the improvement of the "Electrode Tip Position Control System" and development of the "Furnace Operational Condition Diagnosis System".

Fig. 6 shows an example of the electric load pattern which takes into consideration planning output and equipment capacity, the heat guarantee of a furnace, the electrodes' protection, etc, as in the case of the silicomanganese manufacturing process. By this method of operation, the average unit electric power cost (YEN/kwh) was reduced from 100 to 75, resulting in a significant reduction in energy costs.

4. ADOPTION OF AN ELECTRONIC COMPUTER

In 1981, the company installed an electronic computer in order to meet increased production demands.

4.1 Hardware Structure

The hardware structure of this system is shown in Fig. 7. This system's central processor unit (CPU, 256KB) is an IBM Series/1, which is connected to a data gathering and control unit, a disk storage unit (9.3MB), a magnetic tape unit, a display station (CRT), a line printer, a semi graphic CRT, and an operator console. Collective data numbers include: 128 Analog Inputs, 16 Interrupt Inputs, 64 Counter Inputs, 128 Ditital Inputs.

These data are gathered from various sources, for example, raw material equipment, the sintering machine, and the electric furnaces of No. 1 and No. 2. This system has 32 Digital Outputs and 16 Timer Digital Outputs for the Electrode Tip Position Control and the operator console output.
Furthermore, there is a display station connected to the host computer (IBM 3033) for analysis in the office. The specifications of the apparatus for this system are shown in Table 2.

4.2 Software Structure

This system uses a realtime system of 24 hour operation, and furthermore, a multi-operation is executed at six partitions. Fig. 8 shows the structure of a program module and procedure of control and data management. Functions of the system are as follows:

(1) Data logging
(2) Control of the electrode tip positions
(3) Presumption of the electrode tip positions
(4) Operator guidance
(5) Writing of daily operation reports
(6) Operation management
(7) Calculation of the mixing ratio of raw materials

4.3 Effects of the Adoption of the Computer System

Due to the adoption of the ferroalloy electric furnace computer system, electrode tip position and furnace operational condition are now controlled by gathered data of the computer, where as they had previously been controlled conventionally by the operator's experience and intuition.
Labor reduction was made possible by the writing of daily operation reports, the suggestions put forth by operators, automation of an electrode operation, etc.
It was also possible to achieve many benefits and a stable furnace operational condition by the ability to calculate vast quantities of data quickly and accurately.

5. OUTLINE OF DECARBONIZATION PROCESS OF FMnH MELT

The experiment was carried out by the use of 500kg FMn per charge capacity top and bottom blowing converter as a reactor, which is lined with magnesia-carbon refractory and is equipped with sub-lance for sampling of metal and slag and temperature measurement.
Schematic diagram of the converter is shown in Fig. 8.
500kg or 400kg of FMnH melt is charged from the ladle into the converter, and oxygen is blown from the water-cooled top lance and the argon gas-cooled bottom tuyere. During the blowing operation, burnt lime and sintered manganese ore are charged into the converter, and metal and slag are sampled and the temperature is measured by the use of sub-lance probe.

After the blowing operation, Ferrosilicon (containing 75% Si) and burnt lime is charged in order to recover the manganese in the slag.

The typical behavior of carbon, manganese and temperature is shown in Fig. 9.

Carbon content is reduced and temperature is raised as oxygen is blown in. Manganese content is hardly reduced during the primary and middle stages of the blowing operation, but is remarkably reduced in the last stage.

After the blowing operation, the increase of manganese content is caused by reduction treatment of manganese slag using ferro silicon.

The chemical composition of the product which is obtained in this experiment is shown in Table 3, and is satisfied the specification of the Japan Industrial Standard.

The average yield of manganese in this process is 78% and the results of comparison of production cost based on the average manganese yield is shown in Table 4.

Production cost can be successfully reduced by $50000 per month in the plants producing 5000 tons of FMnL per month.

6. CONCLUSION

Kobe Steel now has the most advanced technology for its ferroalloy electric furnace operation. The authors have achieved significant cost reductions as a result of these technology, and our steel has maintained its competitive position against its foreign imports.

In the future, the authors intend to develop the following technology.

(1) Operation in Absence of Electric Power
Conversion to alternative sources of energy, as opposed to the use of electric power

(2) Further Labor Reduction
Promotion of a more automated and standardized operation

Furthermore, the improvement of the decarbonization operation of FMnH has been examined and will soon be implemented.

Table 1. Attained Effects

	Silicomanganese Production	High-Carbon Ferromanganese Production
The effect of "Electrode Tip Position Control System"	Δ 5.4%	Δ 1.8%
The effect of "Electrode Tip Position Control System" containing calculation of the electrode tip positions	Δ 6.0%	Δ 2.2%

Table 3 Chemical composition of product (wt %)

	Mn	C	Si	P	S
Product	75.8	0.95	0.25	0.128	0.006
JIS (L-1)	75/80	< 1.0	< 1.5	< 0.4	< 0.02

Table 2 Specifications of the Apparatus

CPU		IBM Series/I Storage Size 256 K bytes
Peripheral Equipment	Disk Storage Unit	Storage Size 9.3 M bytes
	Diskkette Unit	Storage Size 606 K bytes
	Display Station	14 inches 80 lines x 24 characters
	Semi Graphic CRT	20 inches 80 lines x 24 characters
	Line Printer	Lines per minute : 155 lines per minute
	Magnetic Tape Unit	Recording density 1600 BPI Tape 2400 feet
I/O Device		Data Gathering and Control Unit o Series/I Interface o Digital Output o Timer Digital Output o Interrupt Input o Digital Input o Analog Input o Counter Input
Language		EDL

Table 4. Comparison of production costs ('86.4) yen/Ton FMnL

	Silicothermic reduction (A)	This process (B)	Difference of price (A−B)
FMnH	—	1285 kg/T	△11,000yen/T
SiMn-L	776 kg/T	—	
Mn ore	1.174 〃	180 kg/T	20,685 yen/T
Burnt lime	517 〃	200 〃	2,853 〃
Ferrosilicon	—	75 〃	△9,495 〃
Electrode	6 kg/T	—	3,360 〃
Power	783 Kwh/T	—	8535 〃
Refractory	Equivalent		0 〃
Argon	—	22 m^3/T	△ 869 〃
Oxygen	—	128 〃	△ 654 〃
Total	—	—	13,415 〃

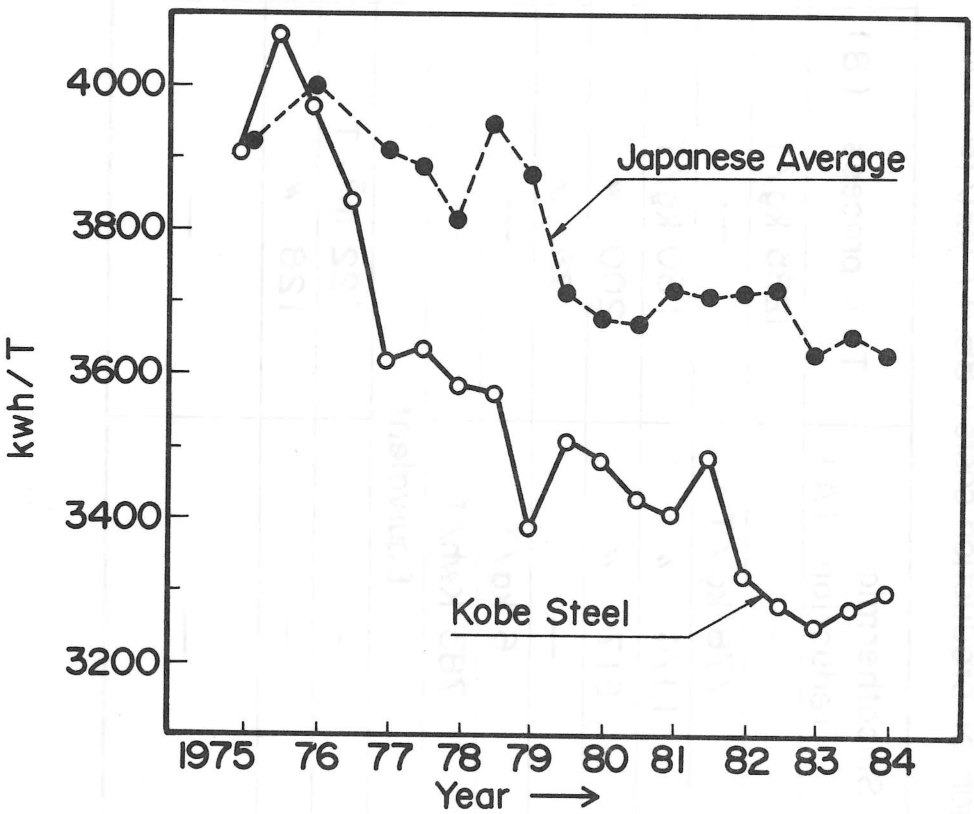

Fig. 1 Change of Unit Electric Power Consumption

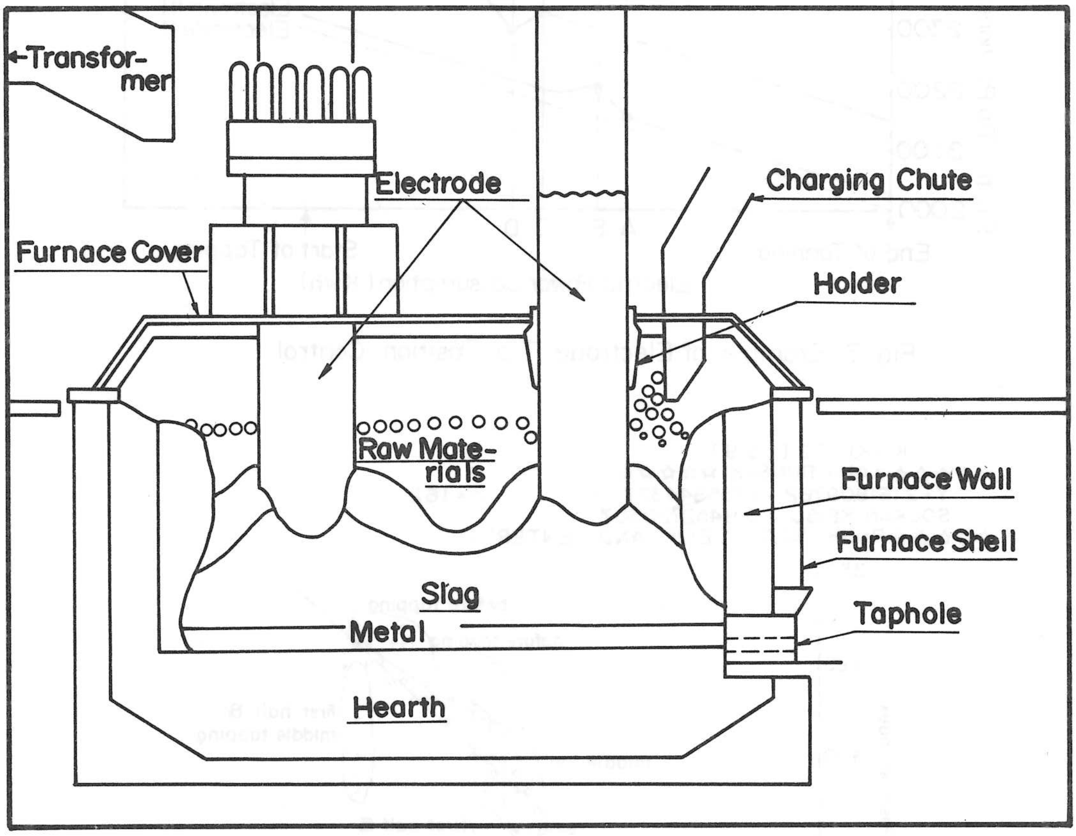

Fig. 2 Outline of Electric Furnace

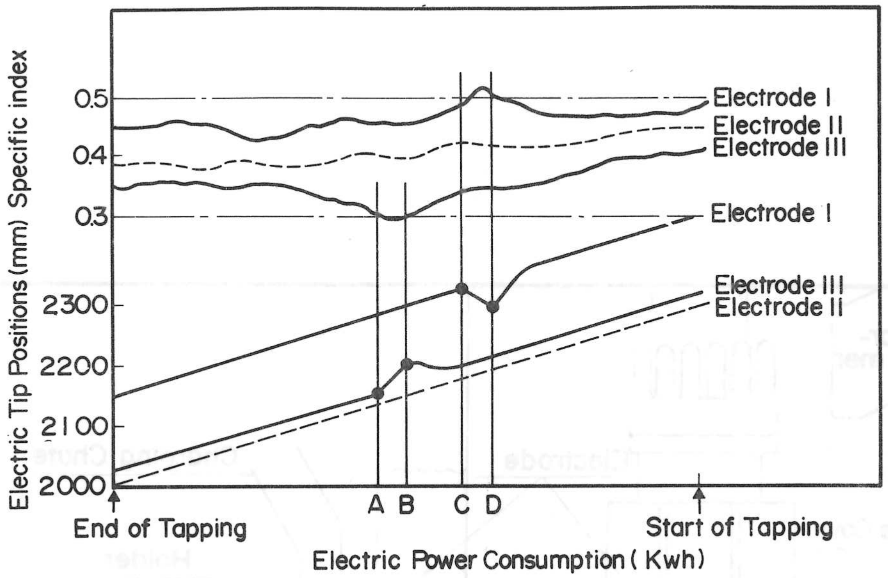

Fig. 3 Example of Electrode Tip Position Control

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KAIKI  T2 [; 6 9]
☆☆☆☆☆ KAIKI BUNSEKI ☆☆☆☆☆
Y = 2.161809762 + 1.355844337  X          n = 162
SOUKAN KEISU = 0.8452120507
☆☆☆☆☆ PUSH 'ALT/CLEAR' AND 'ENTER' :
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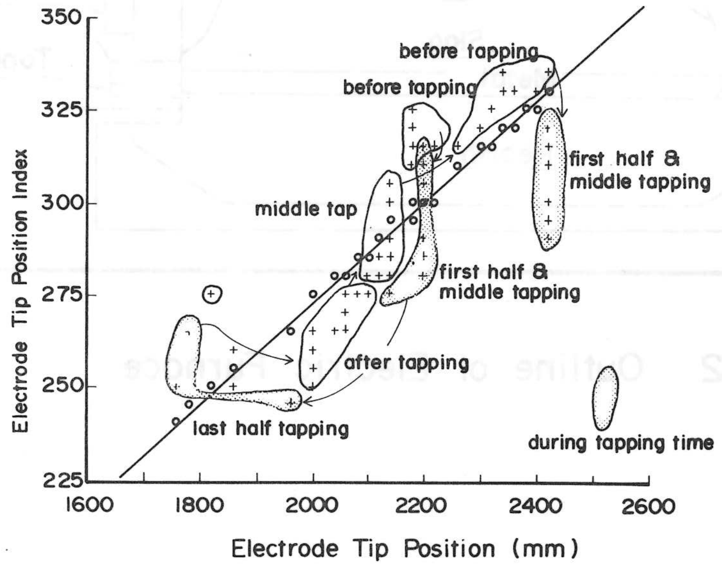

. Fig. 4 Regression Figure of Electrode Tip Position and its Index

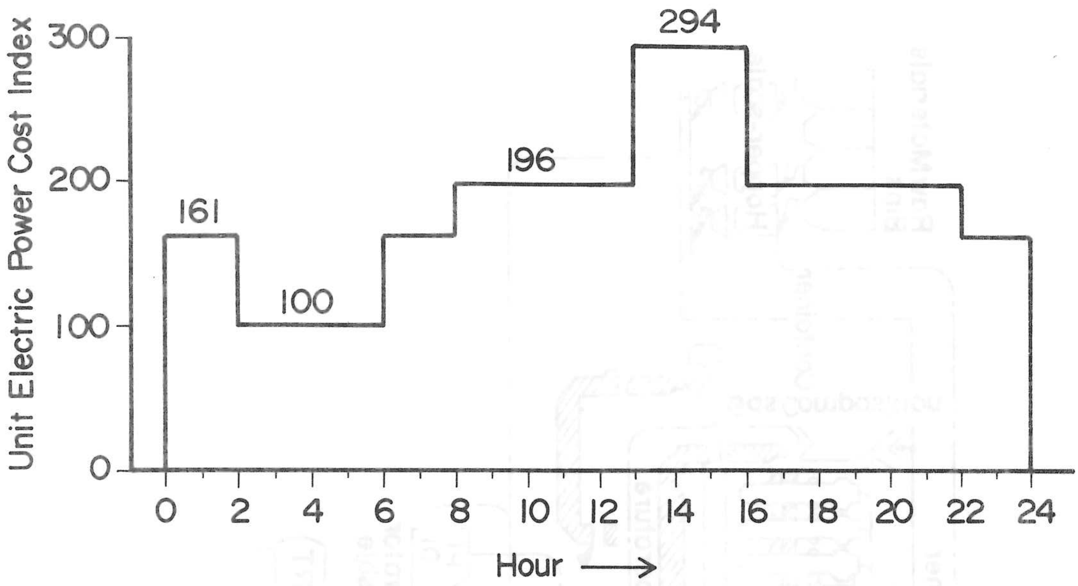

Fig. 5 Hourly Unit Electric Power Cost Index

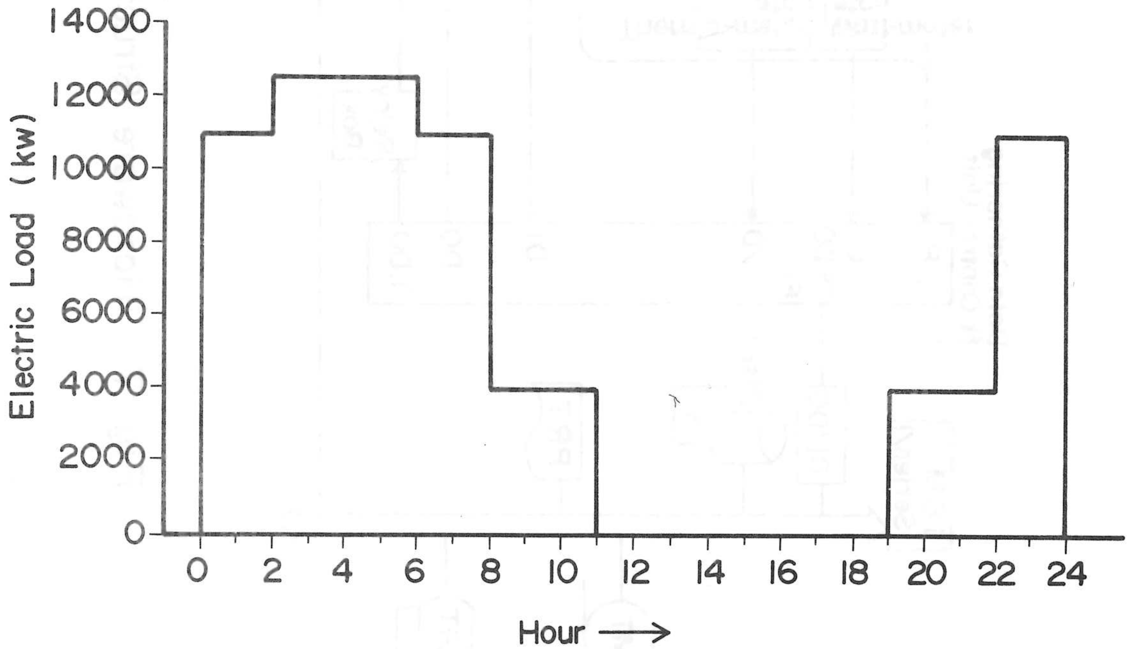

Fig. 6 Example of the Electric Load Pattern

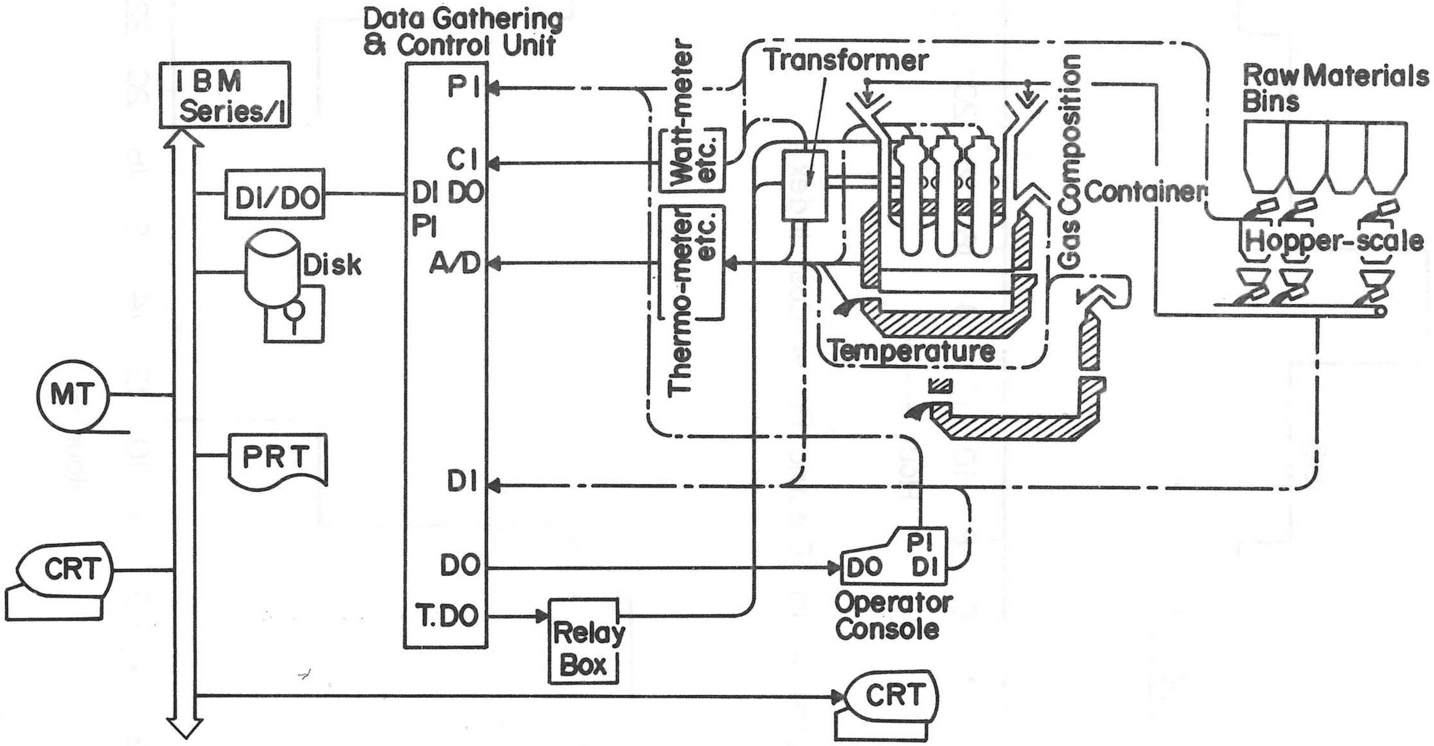

Fig. 7 Hardware Structure

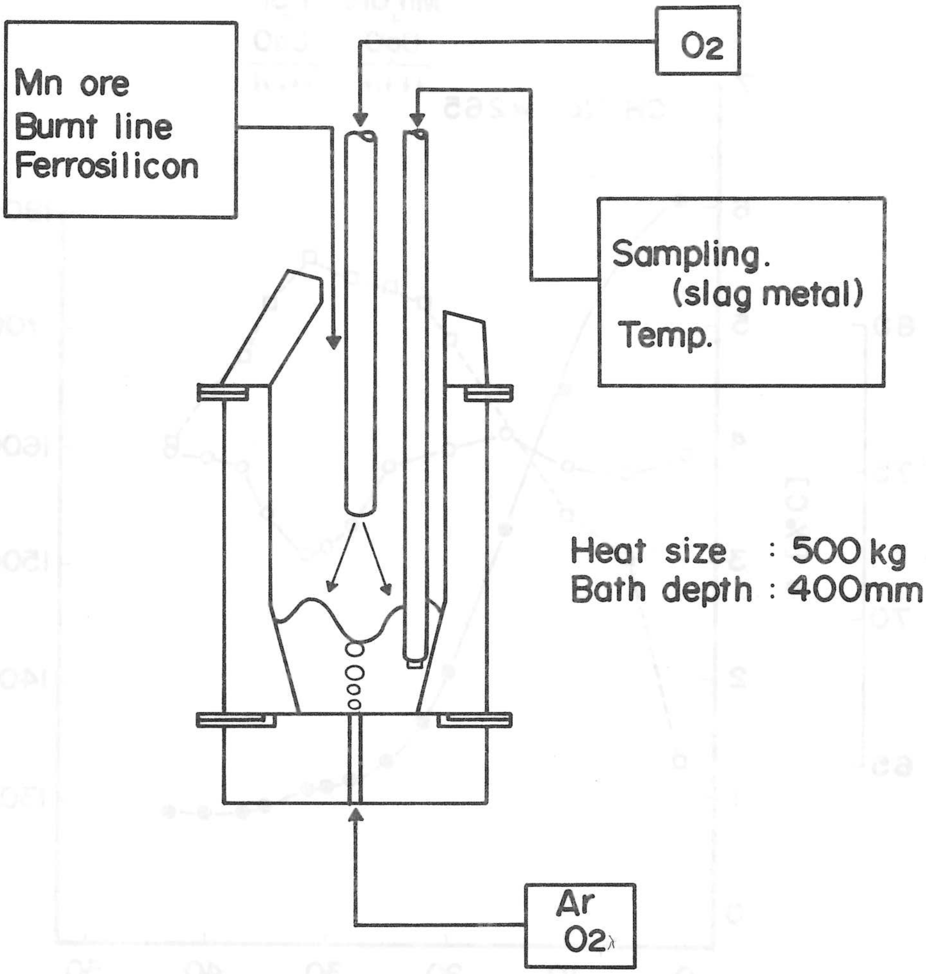

Fig. 8 Schematic diagram of 0.5t BOF

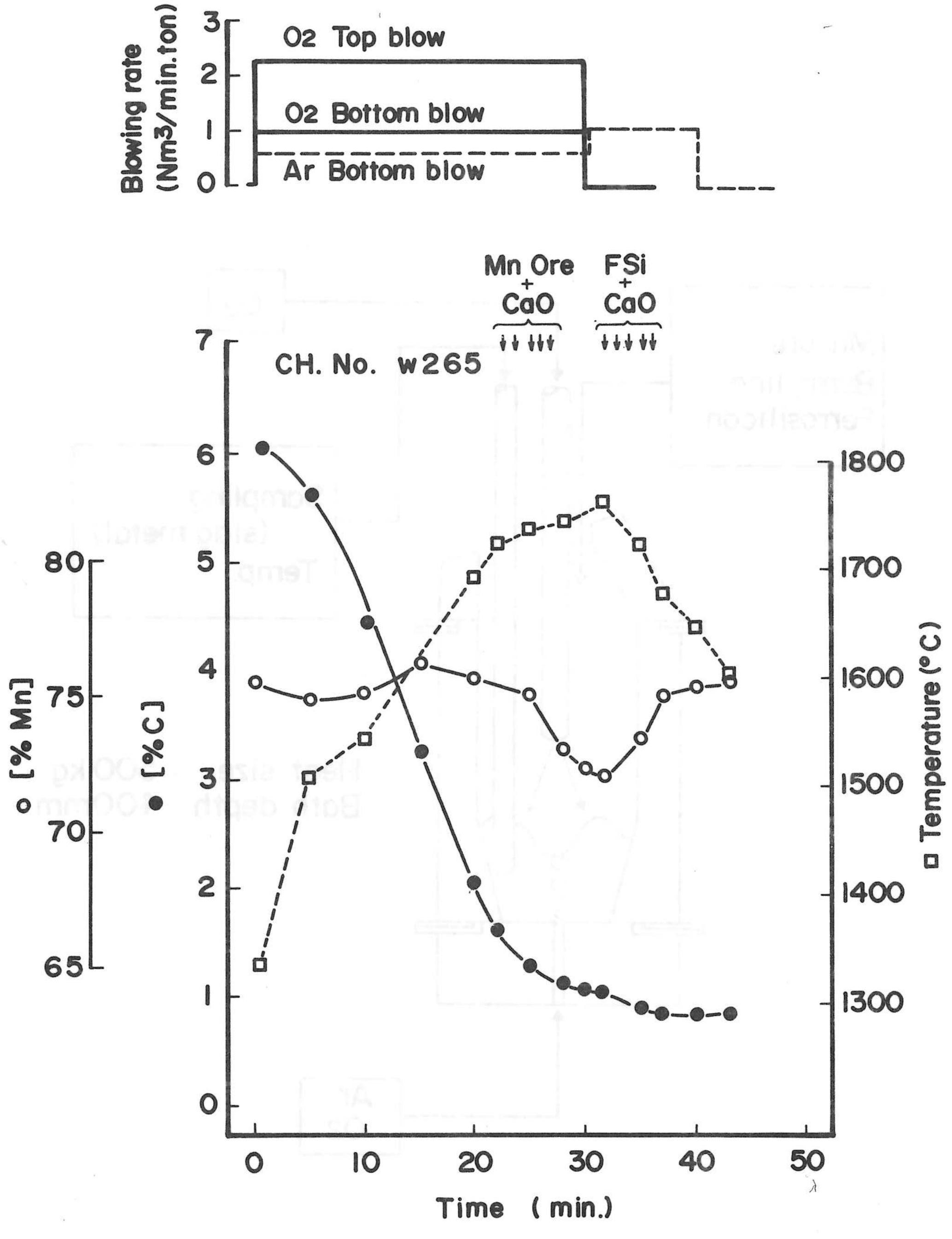

Fig.9 Behaviour of carbon, manganese and Temperature of melt.