HIGH-EFFICIENCY FERROSILICON SMELTING TECHNOLOGY WITH HEAT RECOVERY SYSTEM

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ABSTRACT

In order to develop ferrosilicon smelting technology in a high temperature atmosphere, we have carried out tests using a small capacity furnace in 1975 and the following years. The obtained test results were applied to the 32,000 KVA electric furnace in 1978. Then, after approx. two years' period of development, have established the "High-Efficiency Ferrosilicon Smelting Technology".

The aim of this technology was to improve smelting system by increasing an atmospheric temperature to 800 - 900 °C through the controlling of an air inflow into the furnace hood at the time of manufacturing ferrosilicon product (JIS Grade #2, Si 75 - 80%) so that an oxygen content of exhaust gas may be kept at 12 - 17%. Simultaneously, this high temperature exaust gas was utilized for electric power generation.

As concrete targets, the reduction of a unit electric power consumption, improvement of Si yield and high efficiency recovery of exhaust heat were made. Then, we tackled the development work and as a result, obtained satisfactory results. Compared with smelting in a conventional open-type furnace, the newly developed technology showed an energy saving of upto approx. 30%.

We herein report on the progress of developing "High-Efficiency Ferrosilicon Smelting Technology", the outline of equipment, results, etc.

1. INTRODUCTION

Since the oil crisis in 1973, Japan experienced a sharp electric power charge hike in 1978 and 1981 respectively. As a result, the ferrosilicon (hereinafter called "FeSi") industry in Japan which consumed a large amount of electric power was hardest hit by its impact.

Especially the FeSi manufacturers who used to consume electric power at a high consumption rate were compelled to carry out a series of production reduction under the pressure of an increaseing volume of imported products following a soaring manufacturing cost and further a slow domestic demand. They have been under this state upto now.

In the meantime, however, the Japanese FeSi manufacturers did not necessarily simply leave themselves to developments but took many constructive steps to tide over this crisis.

One of the steps taken under the assumption of orderly imports was to restrain domestic FeSi production to the extent that they only fulfill their social responsibilities through a stable supply of high-quality FeSi to the users in Japan and establish a production system based on a collaboration with foreign manufacturers.

To realize this step, 16 FeSi manufacturers, in September 1978, handed an application to the MITI (Minister of International Trade and Industry) for an approval of their steps to scrap or freeze electric furnaces worth 100,000 tons/year of FeSi which is equivalent to 20% of the existing total FeSi manufacturing capacity of approx. 500,000 tons/year based on "Extraordinary Measures Law for the Stabilization of Specific Depression-Ridden Industries". And the steps were put in practice in December of the same year.

The number of electric furnaces for FeSi manufacturing which were subjected to the said steps at that time was 17 out of the total 46.

In the meantime, we pushed research and development activities on smelting technology and carried out all available energy-saving measures one after another. At the same time, efforts were made to enhance labor productivity.

Technology we introduce this time in this report is "High-Efficiency Ferrosilicon Smelting Technology" (hereinafter called "New Technology") developed by Japan Metals & Chemicals Co., Ltd. (hereinafter called "JMC"), which has been quite successfully applied to actual operations upto now. Thus the targets originally set for the utilization of New Technology have fully been attained.

HISTORY OF ESTABLISHING ENERGY-SAVING TYPE FeSi PRODUCTION METHOD

In order to improve productivity and significantly reduce a unit energy consumption in the production of FeSi, JMC has been endeavoring for the development of the production technology. When the soaring of electric power price was seen following the generation of the first oil crisis, JMC began basic tests, in 1975, on the development of New Technology using small-size electric furnace for FeSi manufacture (4,000 KVA and 12,500 KVA).

Meanwhile, an FeSi manufacturing project using electric power generated by the Matsukawa Geothermal Power Plant, Iwate prefecture, developed and operated by JMC, was promoted. That is, a 32,000 KVA electric furnace was constructed at the Wakagawa Factory in October 1976 and was started in the same month.

In constructing the above electric furnace, a semi-closed type furnace, which enable high temperature operation and exhaust heat recovery in furnace, was adopted parallel with the aforementioned New Technology then under development. In addition, various considerations were put into the other equipments.

The reason why we selected the semi-closed type furnace to achieve this project's purposes are as follows:

1) For the improvement of smelting efficiency, it is necessary to realize a furnace condition where a material mixture charged through such operation as not requiring manual or mechanical poking, etc. descends continuously and smoothly on the entire furnace surface. As one of its techniques, a method to maintain an atmospheric temperature inside the hood at a required high temperature, was adopted.
2) The closed-type furnace has to adopt a wet type dust collector for trapping dust in exhaust gas. In this case, equipment and treatment for waste water drainage from gas cleaning system would be costly.
3) It was assumed that compared with the semi-closed type furnace, the closed-type furnace would lose approximately 15 - 20% of energy due to the losses such as sensible heat in exhaust gas, unburnt fine coke entrained in slurry, etc.

During the period from April 1977, when subject furnace was started normal condition up through January 1978, JMC performed high-temperature smelting tests with the furnace to obtain additional requred data.

The high-temperature operation was quite a new technology and its success would lead to an improvement of smelting efficiency (unit electric power consumption, silicon yield, etc.) and to the recovery of high-temperature exhaust gas generated from smelting in the form of steam through a heat exchanger furthermore in the form of electric power by feeding the steam into a turbine.

Thus, New Technology will contribute toward energy saving and at the same time, be one step in establishing an internationally competitive FeSi production system.

Under the above-mentioned circumstances, the development of the New Technology drew attention from "New Technology Development Association (governmental agency)". JMC was entrusted by the association with the job to develop it.

After two years and three months' period of development from December 1978 through March 1981, the development of New Technology was recognized as success.

OUTLINE OF NEW TECHNOLOGY

1. Conventional Method and Post-Development Method

New Technology is aimed at the establishment of FeSi (JIS Grade #2, Si 75 - 80%) smelting technology to atain the follow-

ing three purposes simultaneously:
1) To reduce a unit electric power consumption for smelting.
2) To improve silicon yield during smelting operation.
3) To recover heat from high-temperature exhaust gas in the form of electric power.

We named this technology "High-Efficiency Ferrosilicon Smelting Technology". The reason why we developed the technology to turn the recovered energy 100% to electric power was that users of process steam, etc. were not in the vicinity of the factory.

Here we emphasize that our primary purpose is to make electric smelting highly efficient and make the best use of high-temperature exhaust gas generated resultantly.

So far, FeSi smelting was carried out by carbon reducing quartzite, mill scale, etc. using an open-type furnace.

However, because of an air flowing into the furnace from atmosphere, the inner-furnace atmospheric temperature was approximately 300 °C.

The reaction in FeSi smelting is represented by the formula

$$SiO_2 + 2C = Si + 2CO \quad \text{(1)}$$

However, it is considered that actual smelting in the furnace would be under a combination of mainly the following reactions:

$$2SiO \rightarrow (Si + SiO_2) \quad \text{(2)}$$

$$2SiO + 4C \rightarrow 2SiC + 2CO \quad \text{(3)}$$

$$2SiC + 3SiO_2 \rightarrow Si + 4SiO + 2CO \quad \text{(4)}$$

Of the above, the formula (2) represents a reaction which mostly takes place near the material mixture surface in smelting furnace. When the area near the furnace surface is cooled off, a vapor of silicon mono-oxide (SiO) which is produced in the furnace and ascends through a reaction zone condensates and solidifies in the low temperature part of the material mixture layer, thus forming "crust". Once the crust has been formed, the uniform release of carbon monoxide (CO), produced simultaneously through the reaction from the furnace surface, is blocked and the smooth descending of material mixture to the reaction zone is prevented. Consequently, a local blow occurs and the reaction becomes sporadic resulting in the deterioration of silicon yield and the increasing of a unit electric power consumption during smelting operation. We often experience this fact.

In order to improve this phenomenon, the ordinary techniques would be to carry out poking sometimes, provide a rotating furnace, etc. Neverthless, satisfactory results can not be obtained and much labor be involved.

Further in the open type furnace, exhaust gas at around 300 °C collected in the hood located upward of the electric furnace used to be put through a cooler for thermal radiation, then the gas would have dust eliminated by a bag type dust collector so that it might avoid air pollution and be released into the atmosphere. A large quantity of energy for operating dust collector was spent for gas treatment and gas contained energy dumped uselessly.

The technology developed by JMC this time is an operation with a semi-closed type hood, high temperature which is obtained by burning the generated carbon mono-oxide with appropriately controlled quantity of air. Thus it is meant for the establishment of a new reaction equilibrium system including a mixture layer which prevents the formation of the afore-mentioned crust and allows the smooth descending of material mixture.

Through the development work, we intended to pursue the maximum effect of the tripartite collaboration of such factors as "high-temperature smelting technology" realizing the improvement of silicon yield and the reduction of a unit electric power consumption at the time of smelting, technology to recover heat from exhaust heat and electric power generation through turbine operation using the exhausted heat.

The flow sheets of the conventional open type furnace and technology developed by JMC this time are shown in Figs. 1 and 2.

2. Targets and History of Development

In developing New Technology, we established the following three concrete targets:

1) The unit electric power consumption for the manufacture of FeSi (JIS Grade #2, Si 75 - 80%) is approx. 9,500 KWH/ton an average value in Japan then. However, this value shall be less than 8,600 KWH/ton representing approx. 10% decrease.
2) Silicon yield at the time of smelting shall be improved from 85% to higher than 92%.
3) More than 20% of energy contained in exhaust gas shall be recovered in the form of electric power.

The development stage was divided in the following 4 stages:

1) <u>First stage</u>: Basic tests (June 1975 through December 1977)

In June 1975, we examined the change of furnace condition and an influence on the unit electric power consumption resulting from the redesigning of 4,000 KVA furnace into a semi-closed type and at the same time, made clear points of issue in equipment.

From 1976 through 1977, the test was continued by using 12,500 KVA furnace, whose exhaust gas was led to a test-size boiler to obtain basic data for the design of New Technology such as heat exchange efficiency, characteristic and condition of the dust, the dust-off method, etc. (performed at JMC Date Factory).

2) <u>Second stage</u>: Remodeling work for the furnace (October through December 1978)

We remodeled the 32,000 KVA furnace so that the construction may meet its target.

At that time, we paid special attention to the designing of a construction which enabled stable operation of furnace for a long period of time. In order to increase the inner-furnace atmospheric temperature from 300 - 350 °C to a high level of 800 - 900 °C, we made sufficient consideration to the provision of a heat resistant structure to each equipment/devices and cooling system, sealing method on various parts, air volume control, heat insulation method, etc.

3) <u>Third stage</u>: Preliminary tests for high-temperature operation (January through July 1979)

We started up the furnace after remodeling for high-temperature operation, gradually increased the inner-furnace atmospheric temperature and changed operating conditions to meet high-temperatures.

During this period, smelting conditions at 800 - 900 °C, which was the target atmospheric temperature, were established, an impact on the quality of finished product, specification of equipment/machinery, and the performance were confirmed, point of issue were picked up and remedies for such points were taken. Especially, development of the quality of electrode paste to high-temperature operation was continued even in the fourth stage.

In the meantime, construction of the boiler for exhaust heat recovery, turbin for electric power generation, etc. went on along with the above jobs.

4) Fourth stage: Final test on high-temperature operation, heat exchanger with corrected operation of turbin generator (October 1979 through March 1981)

In August 1979, exhaust gas ducts were connected to the heat exchanger and steam supplying, performance tests on the turbine generator were conducted successively. In September, governmental inspections were made on the boiler and turbine, thus an officially being approved. Final test on the combinational performance of the three units, i.e. furnace high-temperature operation, heat exchanger operation and turbine generator operation, were started in October.

During this period, computerized control was introduced into the areas of electrode control, electrode slip, exhaust gas control and raw materials feeding control. This introduction contributed significantly toward the obtaining of fruitful results. The final tests were completed in March 1981. They lasted 18 months and the first periodical inspection was conducted one year later to find that each requirement was not faulty. After the final tests, the high-temperature operation was placed under regular operation and it has continued upto now. The furnace equipment is shown in Photo. 1.

3. Specification and Conditions of Main Equipment/Machinery

1) Electric furnace facility

Comparison of furnace specification before and after remodeling is shown in Table 1:

2) Heat exchanger (jointly developed with Takuma)

Type	: WF-1400S, Forced circulation type boiler
Unit	: One unit
Steam pressure	: 59.0 Kg/cm^{2}g at normal condition (superheater outlet)
Steam temperature	: 450 °C (superheater outlet)
Steam generation	: 22,200 Kg/hr.
Dust removal method	: Shot cleaning
Emergency oil combustion system	: One unit
Pure water treatment device	: One unit

3) Steam turbine (made by Fuji Electric Mfg.)

Type	: Condensation type
Unit	: One unit
Rated output	: 5,000 KW
No. of rotation	: 7,200 rpm

4) Generator

Type : 3-phase AC synchronous type
Unit : One unit
Rated output : 5,883 KVA

Table 1
Comparison Table for Furnace Specification and Condition

Item	Before Remodeling	After Remodeling
Transformer capacity (KVA)	32,000	32,000
Furnace load (KW)	21,000	23,000
Electrode diameter (cm)	135	135
Furnace hearth area (m^2)	44	44
Hearth depth (m)	2.8	2.8
Exhaust gas volume (Nm^3/hr)	150,000 - 230,000	60,000 - 70,000
Exhaust gas temperature (°C)	280 - 400	800 - 900
Exhaust gas cooling tower	Operated	Shut-down
Blower for dust collector	2 units	1 unit*
Dust collector	2 lines	1 line
Computer process control	Raw materials mixing and coke control	Addition to Electrode slip, Raw materials feeding and Gas volume control

Note: *Change to small capacity

RESULTS OF DEVELOPMENT

It is considered that New Technology which we had been developing has shown satisfactory results with regard to three items which were initially set as targets.

In addition, power for dust collecting was saved to an extent beyond the level originally estimated.

Points to which we paid very special attention in the development work were to improve smelting efficiency and assure stable continuous operation of the furnace. In these purposes, the analysis of the under-mentioned points was the most important subjects for study:

1) Design and construction of equipment/machinery which fit the case of high-temperature smelting.
2) Grasp of high-temperature smelting conditions including quality of electrode paste.

3) Remidies for dust in the duct and heat exchanger.
4) Establishment of detection method of oxygen content in the exhaust gas and of control method of gas volume and temperature (including computer control).
5) Determination of optimal conditions for operation of three units which are furnace, heat exchanger and turbine generator.

A list of results of New Technology is shown in Table 2.

Table 2
List of Development Results

	Level of Conventional Technology	Target Value of New Tech.	Attainment Value
Silicon yield (%)	85	92 min.	92.6
Unit electric power consumption (KWH/ton)	9,500	8,600 max.	8,595
Exhaust gas energy recovery rate (%)	-	20 min. (1,700 KWH/t)	20.2 (1,700 KWH/t)
Power for dust collecting (KWH/ton)	350	180	140
Power consumption balance before/after energy recovery (KWH/FeSi ton)	9,850 → 7,037 KWH/ton (= 71%)		

The operating rate of the open-type furnace for 23 months from October 1976 through October 1978 was 99.1%. However, the rate at the time of high-temperature operation for 32 months from December 1978 through July 1981 was 98.3%. The operation rate referred to here is the ratio of an actual operating period against an operable period. The shut down period during high-temperature operation includes time required for actual measurement of electrodes length and improvement of minor problem during the early stage of development. The operating rate of the regular operation was 99.4%.

From an energy saving point of view, the results obtained this time are summarized in the following way. The annual production of FeSi (JIS Grade #2, Si 75 - 80%) is approx.20,000 tons, on which the following calculation was based:

1) Energy saved by the improvement of unit electric power consumption:
   (9,500 - 8,600) KWH/ton x 20,000 ton = 18,000 x 10^3 KWH/yr ..(1)
2) Energy saved by the reduction of power for dust collection:
   (350 - 140) KWH/ton x 20,000 ton = 4,200 x 10^3 KWH/yr ....(2)
3) Energy saved by the recovery of electric power from exhaust gas:
   1,700 KW/ton x 20,000 ton = 34,000 x 10^3 KWH/yr ....(3)

Therefore, (1) + (2) + (3) = 56,200 x 10^3 KWH/yr.

If the amount of an annually saved energy is converted in terms of one ton of FeSi, the equivalent value will be approx. 2,800 KWH/ton.

For reference, one example of a total heat balance diagram of the systematic operation of the furnace, heat exchanger and turbine generator is shown in Fig. 3.

Through this data, it is realized that an enormous amount of energy, equivalent to an input electric power at the conventional open-type furnace would be uselessly lost with exhaust gas. If this lost energy is converted to heavy oil, it will be equivalent to approx. 15,000 Kℓ/yr (based on an estimate of 2,450 Kcaℓ/1 KWH generated power).

CONCLUSION

It is already 4 years since the New Technology was applied to actual operation and is approximately three years since New Technology was ever operated along with heat recovery facility, the system is being performed quite smoothly until today.

From an energy saving point of view, it is considered that the development of New Technology is highly significant.

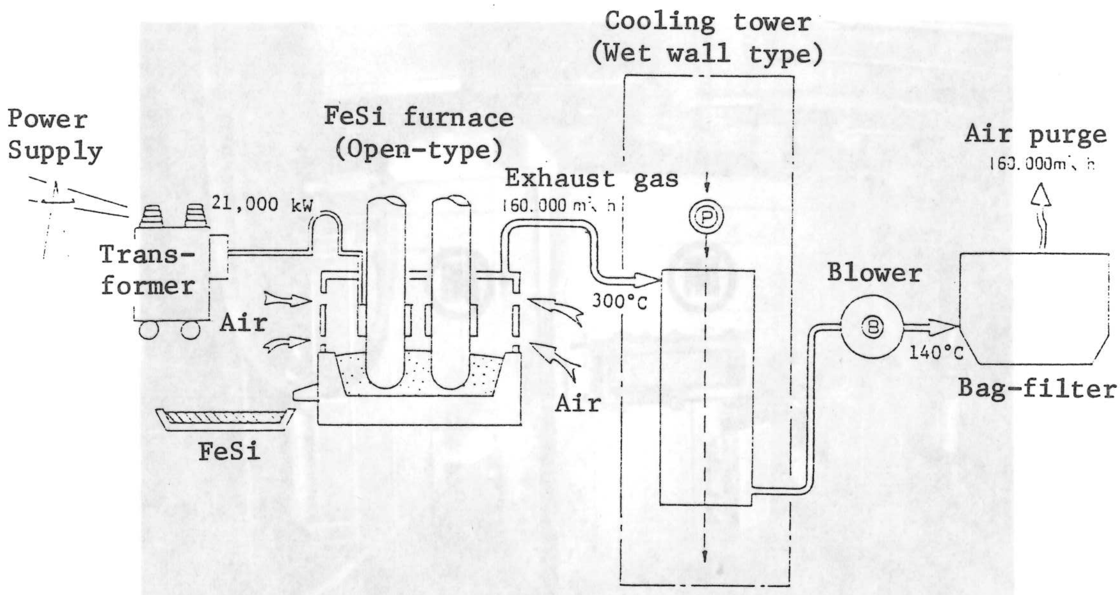


Fig. 1 - Flow of Conventional Open-Type FeSi Furnace

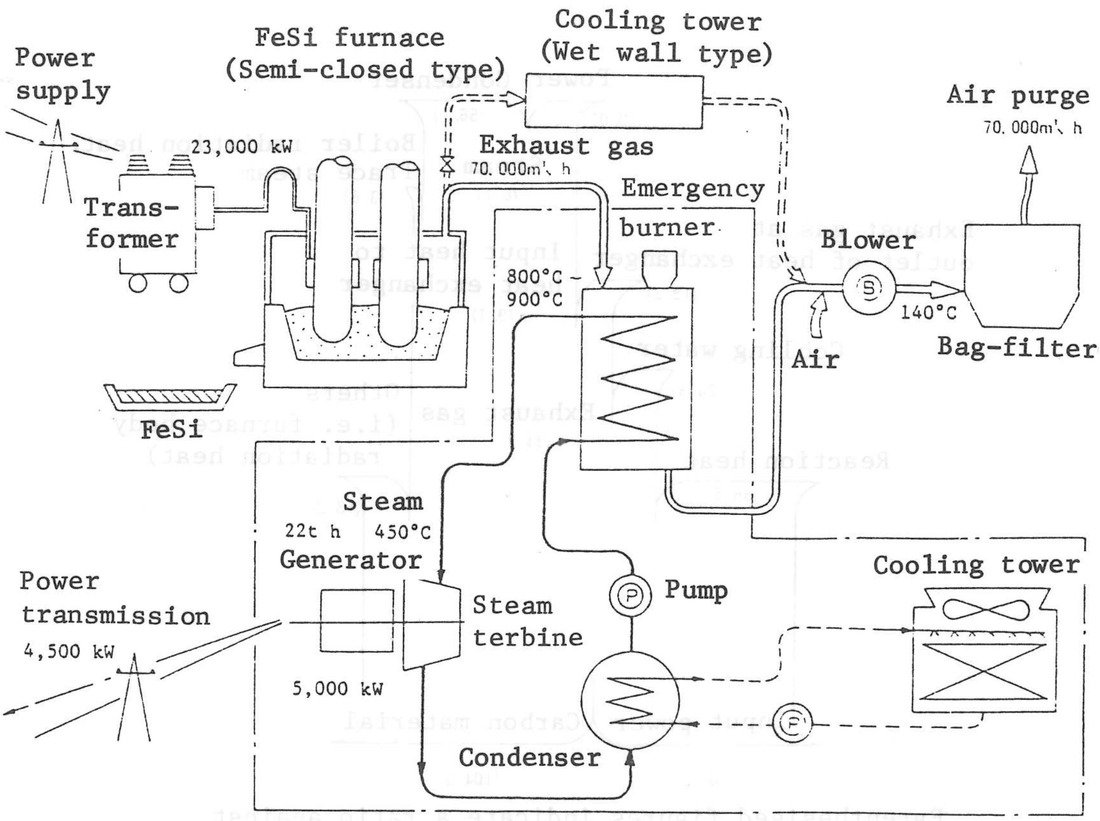


Fig. 2 - Flow of New Technology Semi-Closed Type FeSi Furnace

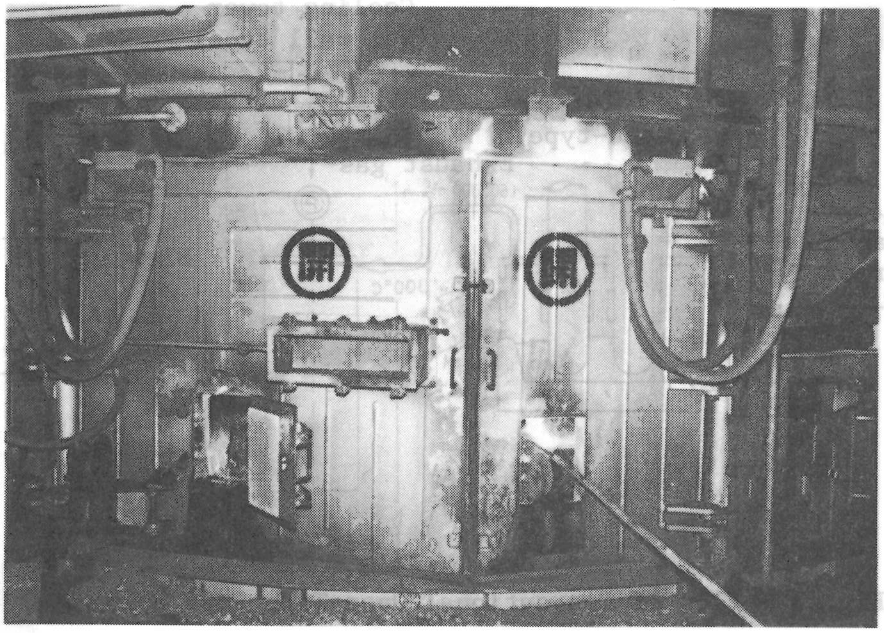
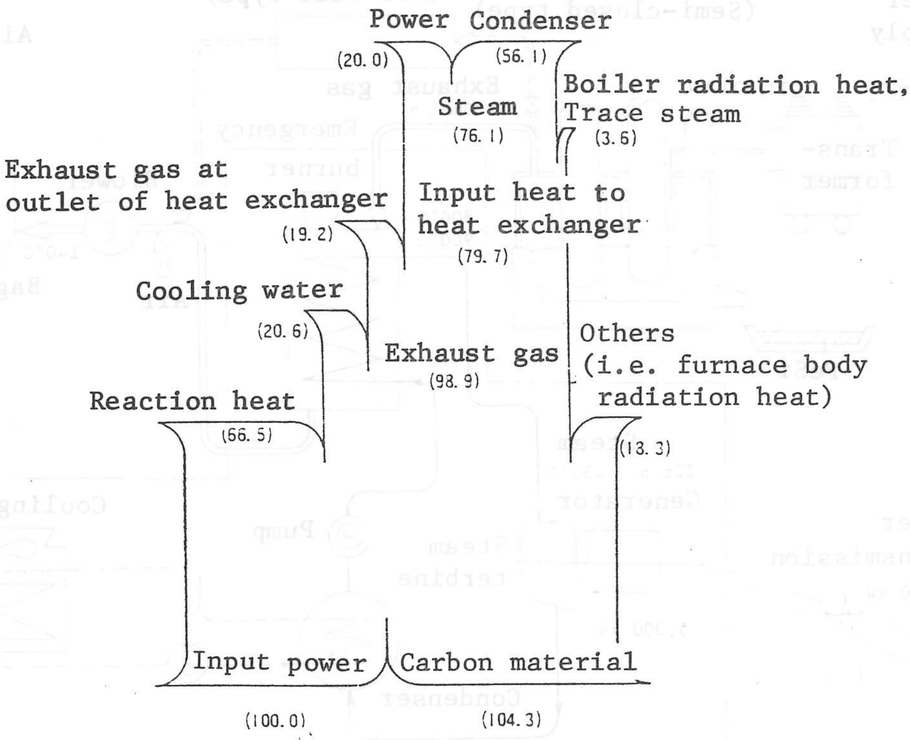


Photo. 1 - Furnace to be used Development of New Technology



Parenthesised figures indicate a ratio against
input electric power (furnace load)

Fig. 3 - Example of Total Heat Balance