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The Heat-recovery System at Minami–Iwate Works

K. KOSAKA, H. OTA, and Y. TAMURA

Japan Metals & Chemicals Co. Ltd, Tokyo, Japan

A heat-recovery system for the generation of electricity in a ferrosilicon semi-closed furnace (32 MVA) has been operating satisfactorily in Japan since it was developed in 1979. This paper gives details of the operation on this new technology for the past 11 years.

(1) The average recovery ratio of generated power against electric furnace load has been 19,3 per cent, but is currently 20 per cent or more.

(2) The average operating rate of the system related to both recovery and generation is 99,3 per cent. It has been nearly in full operation during the past few years.

(3) Such a high level of performance could not have been maintained for any extended period of time unless it had been founded on sound, stable technology.

History

The heat-recovery technology[1] described in this paper was introduced at INFACON 83 and in the magazine *Sho-Energi* (which means 'Energy conservation') in January 1982. The technology had just been developed by Japan Metals & Chemicals Co. Ltd (JMC), and not enough data had been accumulated. After 11 years of operation, the operating results can be reported.

During 1975 and 1978 of this technology-development period, the Japanese ferroalloy industry went through a severe depression. FeSi, which needs an excessive amount of electrical energy for smelting, lost its international competitiveness owing to a sharp increase in power costs, an increase in imports, and a slump in domestic demand. As a result of this, a law entitled the 'Extraordinary Measures Law for the Stabilization of Specific Depression-ridden Industries' was promulgated in 1978. This law enforced the dismantling or cessation of 20 per cent of the domestic production capacity of FeSi.

In order to improve the consumption of energy in the smelting of FeSi, preliminary tests had been carried out since 1976 in a small-scale electric furnace. In 1976, a large-scale furnace, No. 11EF (32 MVA), which could operate on this technology, was installed. At first the furnace was operated in an open condition but, after the equipment had been improved and a high-temperature smelting test had been carried out (1977–1978), full high-temperature operation with the recovery of exhaust gas was started (1979).

Furnace Operation

In this technology, use is made of a semi-closed type of furnace. By controlling the volume of atmospheric inlet air to combust the exhaust CO gas generated inside the furnace, high-temperature operation and improved FeSi smelting became possible. Electrical energy is concurrently recovered by circulation of the high-temperature exhaust gas to a power-generation plant.

In the past, FeSi was usually smelted in an open electric furnace, as shown in Figure 1. Air flows into the furnace, diluting the furnace gas by 50 times. The temperature inside the furnace is 300 to 400 °C, and the exhaust gas, cooled by a cooling tower of the wet-walled type, is led into a dust collector.

In the present technology, as shown in Figure 2, a semi-closed furnace is used. The inlet air is controlled to be diluted 15 times, and the inside furnace temperature is raised to between 750 and 800 °C. This high-temperature gas flows to a heat exchanger for the generation of steam, which is led to a turbine generator.

Problems and Solutions

Various problems, which required a considerable effort to solve, occurred during the initial high-temperature operation.

Blockage of the Exhaust-gas Duct

After the furnace had been operated at high temperature, dusts (silica fume) started to build up inside the exhaust-gas duct and, in extreme cases, completely blocked it in a few hours. In the early stage, power to the furnace had to be shut off almost every day so that the dust could be raked out. This phenomenon is related to the composition of the dust and the inside temperature of the furnace. Dust attached to the duct is softened and becomes sintered under high temperature, being of a substantially different composition from the ordinary dust collected at a baghouse.

Once these dusts become attached to the inner wall of a duct, the open area of the duct narrows, the suction volume of the exhaust gas decreases, and the furnace temperature rises. These factors accelerate the formation of blockages in the duct. Possible solutions include

(1) the installation of soot blowers, and doors for inspection of the duct

(2) stricter adjustment of the inside furnace temperature

(3) better selection of raw materials.

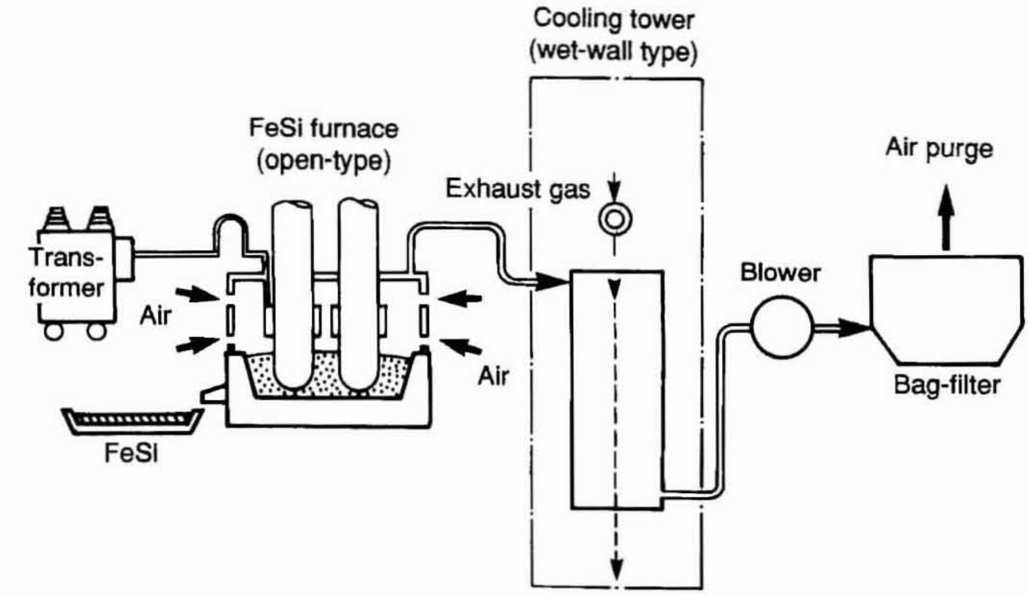

FIGURE 1. Flowsheet of a conventional open type of FeSi furnace

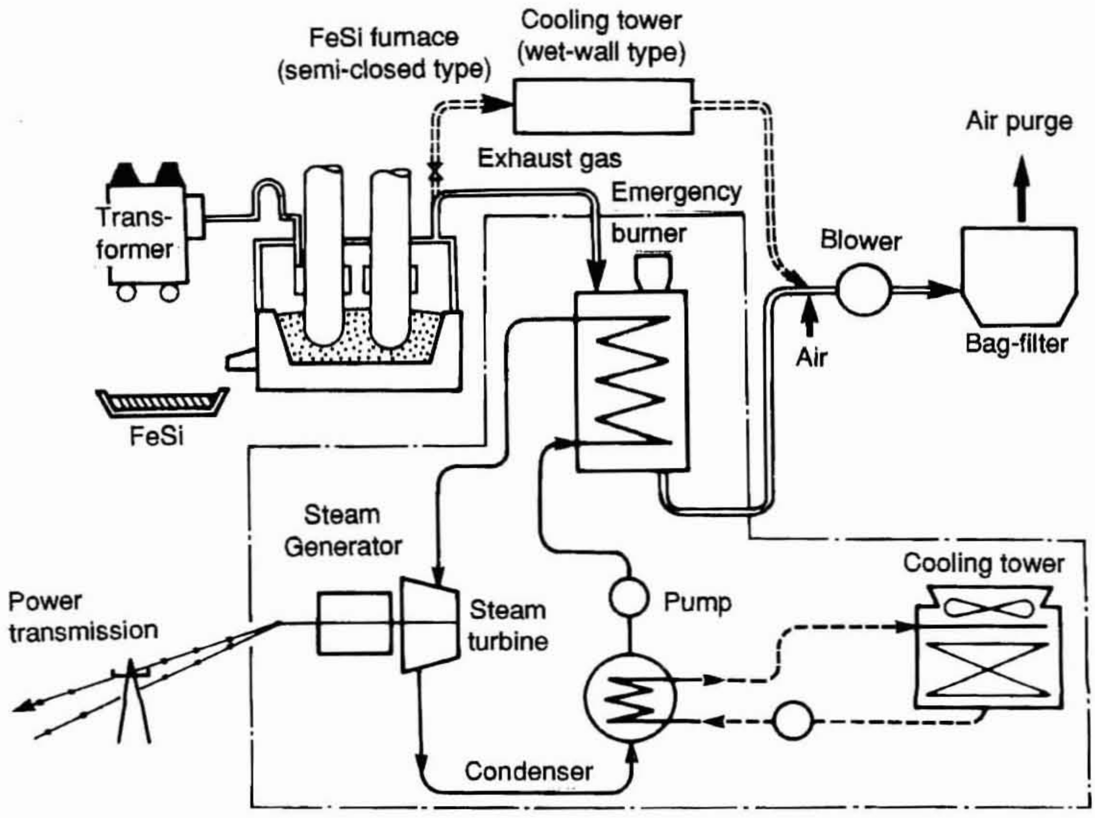

FIGURE 2. The recovery of heat from a semi-closed type of FeSi furnace

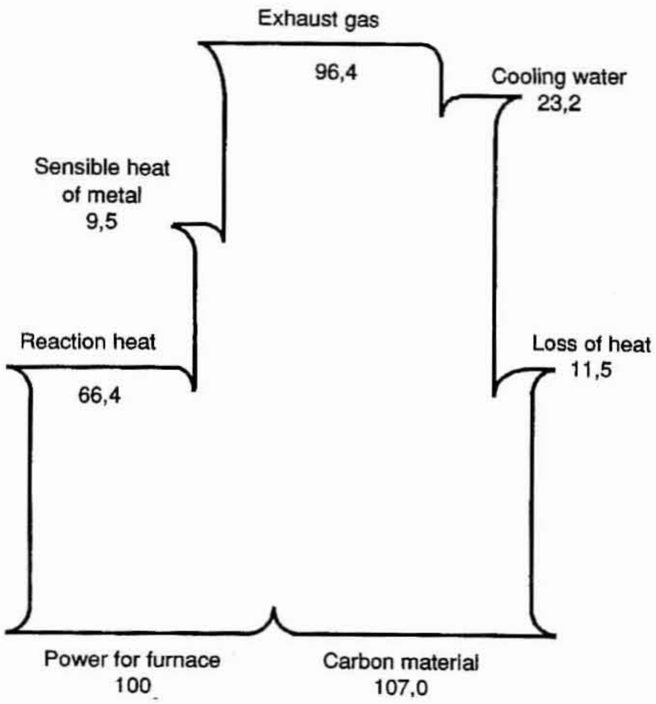

FIGURE 3. Typical heat balance

These measures are being taken at present and have reduced the blockages. Only a few hours of cleaning are now required every one to two months under the reduced electric load, and a shut-down has not been necessary.

Electrode Control

High-temperature operation directly affects electrodes. At first, the same electrode paste was used after the change from the previous operation to the present high-temperature operation. However, it was found that, as the temperature inside the furnace rose, the baking of the electrode paste accelerated, and cracks and breakages at the tip of the electrode occurred frequently. Therefore, the paste was changed to one that does not bake so easily, but this change of paste, together with the strong water cooling of the equipment around the electrode under high-temperature operation, resulted in less calcination of the paste and caused sparking of the electrode holder and snapping of the electrode.

Such problems meant that the electric load had to be restricted for about a week before normal operation could be resumed. The following measures were therefore taken:

(i) the characteristics (electric resistance, etc.) of the paste were adjusted
(ii) the standards of slipping were changed
(iii) the specifications for the electrode casing were altered.

It took a substantial time before a final solution was reached. There have been no major electrode accidents since 1980.

Heat-resistant Equipment

At the first stage of the high-temperature operation, cracks appeared in most of the raw-material feeding chutes, which were exposed to the most severe conditions, and water leaked from the cracks. The following measures were taken:

(a) the material of the raw-material feeding chute was changed
(b) the volume of cooling water for each piece of equipment was checked and adjusted
(c) the raw-material feeding chutes were lined.

Since the above measures were taken, no accidents have occurred.

Operational Records

Heat balance in high-temperature operation

Figure 3 shows an example of the recent heat balance in a high-temperature operation. The data are based on 100 points to represent the electrical power for the furnace. The figures show about 66 for the reduction, formation, and vaporization of heat; 10 for the metal sensible heat; 12 for the loss from the electrical equipment and from the furnace body; 23 for the heat removed by the cooling water; and 96 for the heat taken by the exhaust gas. As can be seen, the amount of heat removed by the exhaust gas from the furnace is enormous, being almost equivalent to the electrical power for the operation of the furnace.

The heat balance varies according to the raw materials used. For example, if only charcoal is used as the reducing agent, the heat removed by the exhaust gas from the furnace is estimated as being responsible for about 80 points of the electrical power for the furnace.

Generation of electrical power

Figure 4 shows a typical recent record of power generation in one day. The maximum is 4600 kW and the minimum is 4100 kW, the average being 4354 kW and the recovery ratio (power generation/furnace load) 19,5 per cent. The arrows in Figure 4 show tappings, which took place six times in that day.

The amount of power generated decreases as the smelting reactions inside the furnace subside before tapping. After tapping, the power generation increases since the feeding of a large quantity of new raw materials into the furnace activates the reactions.

Table I shows operational records of the power generation for one month. The monthly average is 4363 kW, the average furnace load is 21 865 kW, and the recovery ratio is 20 per cent. Table II shows the power generation from the start-up on 1st October, 1979, to 31st December, 1990. Power generation in this context means the output of the generator. However, since about 400 kW are used as power for the generation plant itself to generate power, this figure must be deducted from the power generation to obtain the final usable power. The power used for the generation plant (400 kW) includes about 200 kW for a supply pump for the boiler and a circulating pump for cooling water, the remainder of about 200 kW being used by other pumps and fans, etc.

Table II shows that the power generation is 26 to 32 million kWh per year or 344 million kW for 11 years. The usable power is 24 to 30 million kWh per year, or 312 million kWh for 11 years without large fluctuations.

The electric furnace load in this table does not include the power that is consumed during the start-up of the furnace, for example, after operations have been stopped for maintenance purposes.

The recovery ratio has averaged 19,3 per cent over 11 years. From 1979 to 1981, just after operation began, this ratio was 20 per cent or even higher; it then fell to 18 per cent before again rising to about 20 per cent in the past few

(Average 4 354 kW)

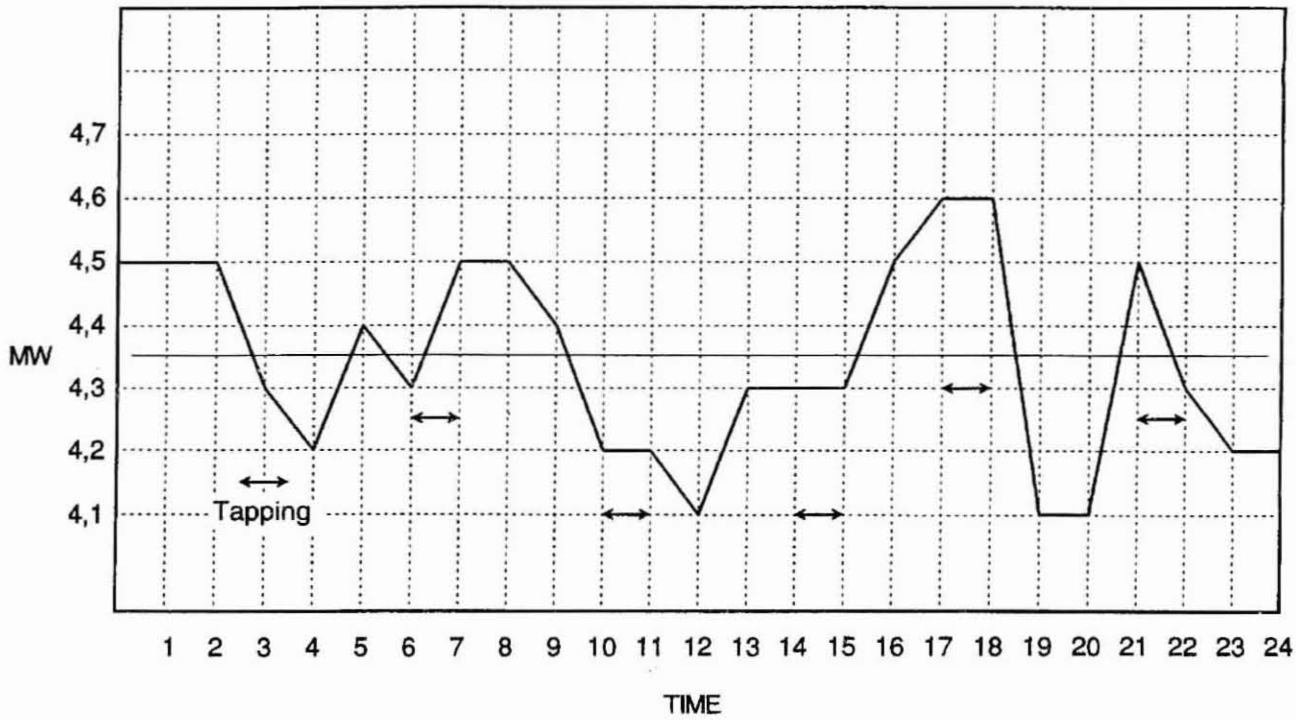

FIGURE 3. Typical pattern of power generation during one day

TABLE I
DAILY POWER GENERATION

Day	Power generation			Recovery ratio
	kW	Max. MW	Min. MW	%
1	4 688	5,0	4,1	20,9
2	4 638	4,9	4,5	20,7
3	4 496	4,8	4,3	20,0
4	4 550	4,9	4,3	20,2
5	4 492	4,8	4,2	20,0
6	4 625	5,0	4,2	20,5
7	4 542	4,8	4,3	20,2
8	4 642	5,0	4,3	20,8
9	4 433	4,6	4,2	20,3
10	4 404	4,7	4,2	20,2
11	4 404	4,7	4,2	20,1
12	4 304	4,5	4,0	19,7
13	4 221	4,6	4,0	19,4
14	4 233	4,5	3,9	19,2
15	4 296	4,6	4,0	19,3
16	4 350	4,6	4,1	19,6
17	3 988	4,6	2,5	18,9
18*	3 296	4,4	0,0	17,4
19	4 217	4,7	3,8	18,8
20	4 458	4,8	4,2	20,0
21	4 488	4,8	4,0	20,0
22	4 533	4,8	4,1	20,1
23	4 446	4,7	4,1	20,1
24	4 483	4,8	4,0	20,4
25	4 417	4,6	3,5	20,3
26	4 392	4,7	4,0	20,5
27	4 083	4,5	2,1	19,3
28	4 254	4,5	4,1	19,8
29	4 329	4,9	4,0	20,4
30	4 279	4,5	4,0	20,4
31	4 267	4,5	4,0	20,4
1–31	4 363			20,0†

* The length of the electrode was measured
† At an average monthly furnace load of 21 865 kW

years. The measures taken to make the equipment more heat-resistant were responsible for these successful results.

Table II also shows the working rate of the power-generation system. The periods during which the furnace was shut down for maintenance, or for the legally required inspections of boilers and turbines, were ignored in the calculation of the working rate. The average working rate in the past 11 years was as high as 99,4 per cent. It was 99 per cent in 1989 because of trouble in a boiler valve, but 100 per cent was achieved from 1984 to 1988 and in 1990.

The noticeable decrease in the working rate in 1980 and 1983 was the result of the abrasion of boiler tubes, etc., due to shot-cleaning in a boiler. The subsequent adoption of appropriate measures, such as a change in the tube material and an improvement in the method of shot-cleaning, resulted in higher working rates. The system has proved to be quite stable and satisfactory.

Reportedly, several similar heat-recovery systems have been implemented in FeSi electric furnaces in other countries, but their long-term performance does not seem to have been satisfactory.

The operation at JMC would not have been successful without the prior establishment of high-temperature FeSi-smelting technology, and the use of superior equipment. Efficient coordination of the software and the hardware was the source of the success.

The improvement in FeSi-smelting conditions by raising the furnace temperature was one of the targets in the development of this technology. Before the application of this technology, raising the temperature of the raw-material mixture at the top of the furnace was expected to decrease the furnace resistance and entail the risk of so-called top-heat operation. However, by suitable operation and the use of the most suitable raw material, it proved possible to prevent the formation of crust and to enlarge the reaction zone

TABLE II
POWER-GENERATION RECORD

Year	Power generation MWh x 10^3		Electric furnace load	Recovery ratio against No. 11 EF, %		Working rate
	Generation	Transmission	MWh x 10^3	Generation	Transmission	%
1979	8,5	7,8	42,2	20,1	18,5	99,6
1980	33,2	30,4	162,8	20,4	18,7	97,1
1981	31,8	29,2	160,6	19,8	18,2	99,9
1982	32,6	29,8	167,2	19,5	17,8	99,8
1983	31,0	28,0	171,0	18,1	16,4	97,1
1984	28,9	26,0	156,0	18,5	16,7	100,0
1985	28,5	25,6	155,9	18,3	16,4	100,0
1986	27,0	24,3	146,7	18,4	16,6	100,0
1987	31,9	28,9	164,4	19,4	17,6	100,0
1988	32,6	29,6	162,9	20,0	18,2	100,0
1989	32,5	29,1	162,5	20,0	17,9	99,3
1990	25,6	23,7	134,0	19,1	17,7	100,0
	344,1	312,4	1 786,2	19,3	17,5	99,4

inside the furnace. This resulted in increased electric-furnace load, increased performance, and higher productivity.

Summary

The work done in the past 11 years on furnace No. 11EF in the Minami–Iwate Works of JMC can be summarized as follows.

(1) It took a long time before the problems relating to the new technology could be solved, but stable operation has now been achieved.
(2) The average recovery ratio (ratio of generated electrical power to the electrical power used in the furnace) over the past 11 years has been 19,3 per cent, but 20 per cent was achieved recently.
(3) The average net working rate of the equipment for the generation of power for top-furnace heat is 99,3 per cent and, in recent years, has been as high as 100 per cent.
(4) Such a satisfactory recovery ratio and the net operation rate could not have been achieved without the prior establishment of stable FeSi-smelting technology at high temperature.

Reference

Senga, T., *et al.* (1978). Method and apparatus for refining ferrosilicon. *Jap. pat.* 1, 137, 040, appl. 18 Jul., 1978, reg. 28 Feb., 1983.