HIGH PRODUCTIVITY OPERATION OF SHAFT-TYPE Fe-Mn SMELTING FURNACE

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ABSTRACT

The shaft-type ferromanganese smelting furnace (SF) at Mizushima Ferroalloy Co., Ltd. has been in operation since startup in 1985 and is continuing to perform smoothly. Production has been increased from the original design capacity of 270t/d to 350t/d by various operational improvements. As a productivity index of the shaft-type furnace, production of 350t/d is equivalent to productivity of 0.9t/m3/d (daily production/cubic capacity of furnace).

Recently, various operational improvements were implemented to achieve productivity of 1.0t/m3/d or higher, including oxygen enrichment operation, increased tapping frequency, maintenance of the throat profile, and operation with small lump coke. The target productivity of 1.0 t/m3/d was achieved in January 2005. This report describes the improvements introduced as part of this high productivity technology.

1. INTRODUCTION

The shaft-type ferromanganese smelting furnace (SF) at Mizushima Ferroalloy Co., Ltd. has performed smoothly since startup in 1985. Although the original specifications of the SF were a design capacity of 270t/d and productivity coefficient of 0.68t/m3/d, it was possible to increase production to 350t/d with productivity of 0.9t/m3/d by various operational improvements. Here, "productivity" means daily production/cubic capacity of the furnace and is an index of SF productivity.

To further increase production and achieve productivity of 1.0 or higher, the company implemented various operational improvements, including oxygen enrichment operation, increased tapping frequency, maintenance of the furnace throat profile, and operation with small lump coke, and as a result, achieved high productivity operation with productivity exceeding 1.05. Details are reported in this paper.

2. SHAFT-TYPE FERROMANGANESE SMELTING FURNACE (SF)

2.1 Outline of SF Equipment

The SF operated by Mizushima Ferroalloy Co., Ltd. is a smelting furnace for direct reduction of manganese (Mn) ore by coke. Although it is a small-scale furnace with an inner volume of 398m^3, the equipment is basically the same as that of the ironmaking blast furnace. A view of the SF is shown in Figure 1.

Mn ore and coke are charged into the furnace top in layers by a bell-less top charging system, and smelting is performed by blowing hot blast (800°C) from the tuyeres at a blast volume of 610Nm^3/min. The metal and slag formed by smelting in the furnace are tapped at set time intervals and separated by specific gravity. The gas formed in the furnace is purified and used as fuel gas. An outline of the equipment is given in Table 1.

Table 1: Outline of SF equipment

Item		Specification
Furnace proper	Inner volume	398 m^3
	No. of tuyeres	13
	No. of tap holes	1 (10°)
Charging system		Cardin-type new bell-less top
Blast system	Recuperator	
	Blast temperature	860°C (max.)
Gas purification system	Dust catcher	Gravitational settling type
	Cyclone	Centrifugal separation type
	Venturi scrubber	Wet dust scrubber type
	Electric precipitator	Wet type

2.2 Equipment Specification

Table 2: Design specification of SF

Item	Normal specification	Maximum specification
Inner volume	398 m^3	398 m^3
Production	230 t/d	270 t/d
Productivity	0.58 $t/m^3/d$	0.68 $t/m^3/d$
Blast volume	500 Nm^3/min	570Nm^3/min
Oxygen enrichment	7%	10%
Blast temperature	800°C	860°C

Figure 1: View of the SF at Mizushima Ferroalloy Co., Ltd.

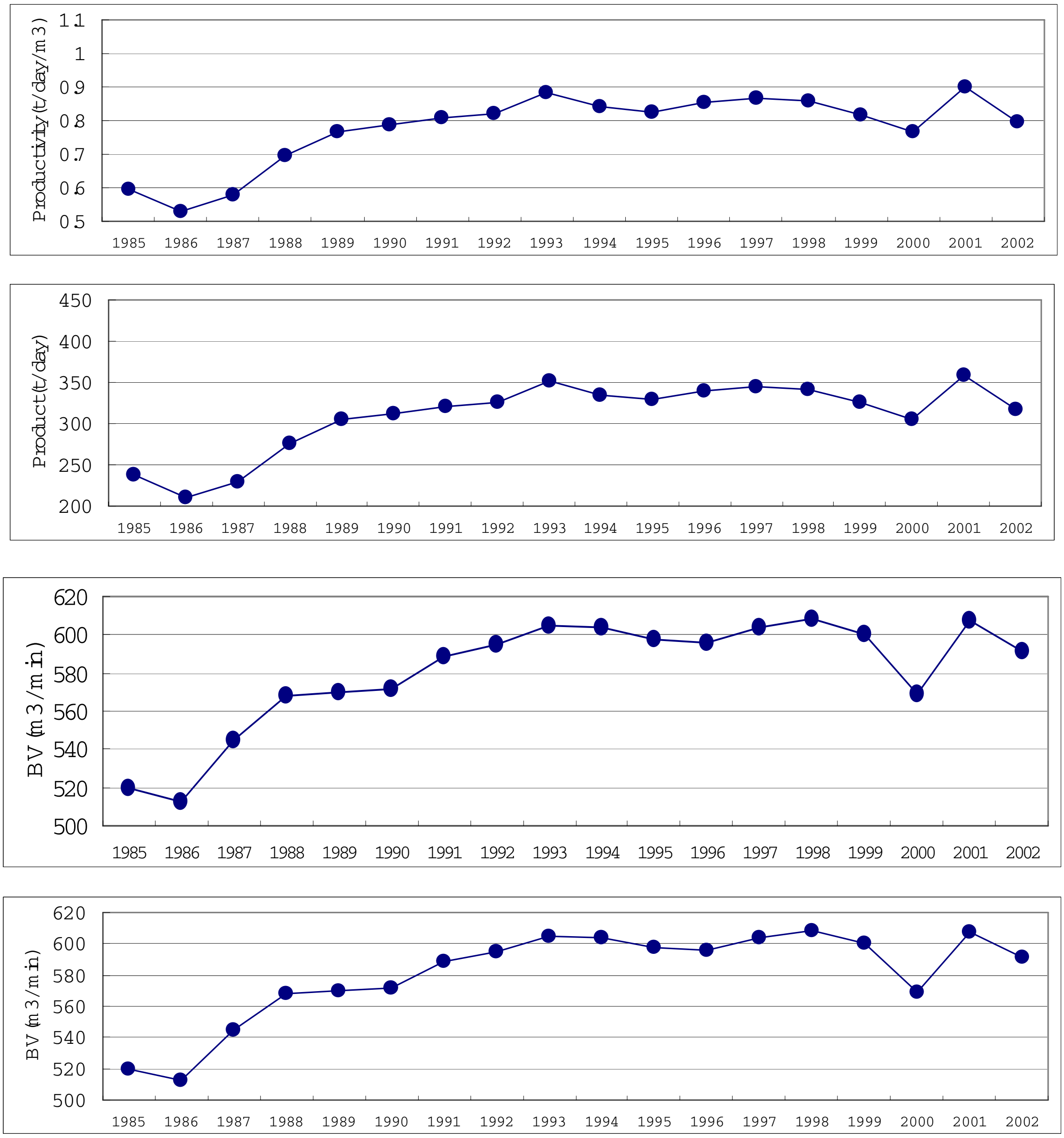


Figure 2: Transition of operational parameters before production increase

3. SF OPERATING CONDITIONS BEFORE PRODUCTION INCREASE

Table 3: Operating conditions before production increase (2002)

Item	*Unit*	*Value before increase*
Blast volume	Nm^3/min	600
Oxygen enrichment	%	11.5
Theoretical flame temperature (TFT)	°C	2550
Coke rate (CR)	Kg-coke/t	1280

Table 3: Operating conditions before production increase (2002) (Continued)

Reducing agent rate (RAR)	Kg/t	1380
Slag to metal ratio	Kg/t	500
Top gas temperature	°C	390
Production	t/d	350
Productivity	$t/m^3/d$	0.88

Typical Chemical analysis	Mn	Si	C	P	S	Fe
FeMn metal	74	0.2	7	0.1	0.01	18.7
	Mn	SiO2	CaO	MgO	Al2O3	Fe
Manganeze ore	48	3.5	7	0.4	0.3	9.5
Slag	7	28	38	9	9	Å|

4. MEASURES FOR ACHIEVING HIGH PRODUCTIVITY (>1.0)

4.1 Oxygen Enrichment

The following three methods of increasing SF production were considered:

<1> Increasing blast volume

<2> Increasing oxygen enrichment

<3> Reducing RAR (reducing agent rate)

Of these, <1> was not realistic, as it would have been necessary to increase the capacities of the blower and the recuperator, requiring a large capital investment with a long period required for return on investment. On the other hand, RAR in <3> was near its limit due to the decrease in top gas sensible heat loss resulting from previous improvements achieved by burden control, etc. Where <2>oxygen enrichment was concerned, although the equipment was currently operating at maximum capacity, the possibility of an increase in the capacity of the oxygen system was studied.

At Mizushima Ferroalloy, high carbon ferromanganese (HC/Fe-Mn) which has been smelted in the SF is decarburized by oxygen blowing in an Shaking ladle furnace (SL). Mizushima Ferroalloy is located within the site of JFE Steel Corporation's West Japan Works (Kurashiki District), and the oxygen used by the SF and SL is supplied by a JFE Steel oxygen plant via a pipeline. As part of a plant debottlenecking project, a dedicated pipeline serving the SL was newly constructed in parallel with the pipeline shared by the SF and SL, and the existing pipeline is now used exclusively by the SF. The construction of this system made it possible to increase oxygen enrichment at the SF freely, without affecting the operation of the SL. (Figure 3). This improvement enabled an increase in the oxygen supply capacity to the SF (oxygen enrichment capacity) from 11.5% to 14%. (Table 4)

Table 4: Oxygen supply capacity

	Before expansion	After expansion
SF oxygen supply capacity (Nm3/hr)	5300	6500
Oxygen enrichment (%) (BV = 610)	11.5	14

However, if the oxygen enrichment ratio is simply increased without other adjustments, the theoretical flame temperature (TFT) in front of the tuyeres will increase, accelerating evaporation of Mn in the raceway

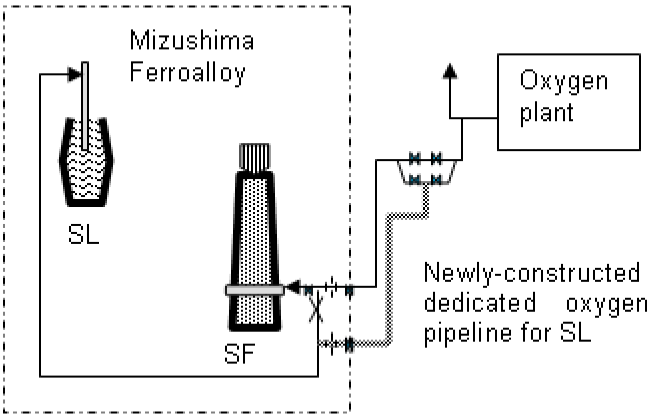


Figure 3: Newly-constructed oxygen piping route

(with a negative impact on yield) and causing a rapid increase in the amount of fine dust generated. To prevent these problems, the company developed a high oxygen enrichment operation technique in which TFT is controlled to a constant value by increasing the amount of heavy oil injection through the tuyeres as required by the level of oxygen enrichment.

TFT is generally calculated using Equation (1), but under the operating conditions at the SF, TFT can be approximated using Equation (2).

TFT (°C) = (Heat generated in front of tuyeres + sensible heat of blast)/(Heat capacity of bosh gas <corrected>) (1)

TFT (°C) = 60 EO2(5) - 7.4 BM(g/Nm3) + 0.94 BT(°C) - 6.2 OIL(kl/d) + 1430 (2)

EO2:Oxygen enrichment (%)

BM:Blast moisture (g/Nm3)

BT:Blast temperature (°C)

OIL:Oil injection rate (kl/d)

According to this equation, TFT can be controlled to a constant value if the amount of heavy oil injection is increased by 10t/d for each 1% increase in oxygen enrichment. Table 5 shows a comparison of the operating conditions before and after implementation of oxygen enriched operation.

Table 5: Comparison of operating conditions before/after high oxygen enriched operation

Item	*Unit*	*Before O2 enrichment*	*After O2 enrichment*
Blast volume	Nm3/min	600	630
Oxygen enrichment	%	11.5	14
TFT	°C	2580	2600
Coke rate	Kg-coke/t	1280	1180
Oil rate	Kg/t	100	130
RAR	Kg/t	1380	1310
Top gas temperature	°C	390	330
Production	t/d	350	420
Productivity	t/ m3/d	0.88	1.05

After expansion of the oxygen piping system, the conventional oxygen enrichment level of 11.5% was gradually increased, and could be raised to the present 14%. This corresponds to a production increase of approximately 30t/d. Furthermore, because the increase in oxygen enrichment resulted in some excess blower capacity, it was also possible to increase the blast volume by 30Nm3, corresponding to an additional 20t/d increase in production.

The coke rate was reduced corresponding to the increase in the oil injection rate which was implemented to control TFT to a constant value. This made it possible to increase the Ore/Coke rate, which improved heat efficiency by accelerating heat exchange in the furnace shaft, thereby enabling an approximate 60°C reduction of the top gas temperature. As a result, the total reducing agent rate (RAR) could be reduced by 70kg/t. A further production increase of approximately 20t/d was achieved by this means.

As a total result of the above-mentioned changes, it was possible to increase production by 70t/d and achieve productivity exceeding 1.0 t/m3/d.

4.2 Increased Tapping Frequency

Each time metal and slag are discharged from the SF by tapping, a runner is prepared in anticipation of the next tapping operation. During this interval, metal and slag accumulate in the furnace. Because there is an upper limit to the capacity of the hearth where these materials accumulate, when production is increased, it is also necessary to shorten the time during which these materials accumulate, by increasing the tapping frequency. Beginning in 2004, efforts were made to shorten the setup time between taps. Various improvements were made, including equipment-related improvements such as increasing the crane capacity and adoption of a ladle for recovery of metal running out of the dry pit, and operational improvements such as a review of the work procedure and reduction of the work load, etc. As a result, it was possible to shorten the tapping interval from 175 minutes to 150 minutes, and by the end of the same year, the tapping frequency had been increased from 6 to 7 taps/day. This created a system for increasing production corresponding to the increase in the oxygen supply capacity. The SF tapping cycle is illustrated in Figure 4.

4.3 Reduction of RAR by Stabilization of Burden Descent

The basis of stable blast furnace operation is stable descent of the burden (raw materials) in the furnace. Reduction of RAR was achieved by improvement/maintenance of the furnace throat profile and use of small lump coke, contributing to increased production.

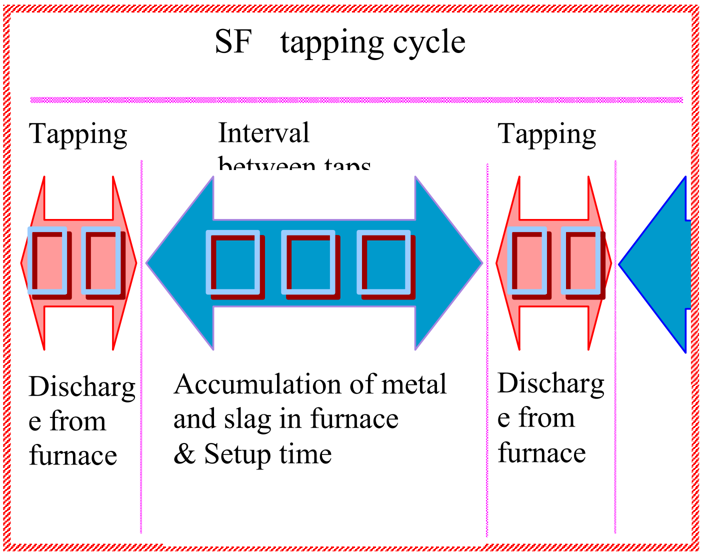


Figure 4: SF tapping cycle

4.3.1 Maintenance of throat profile

The brickwork in the SF furnace, which has been in service for more than 20 years, has worn and peeled off, exposing the cooling panels, and the furnace wall had a rough profile. (Figure 5) In particular, in the furnace throat, a smooth gas flow was impeded by stagnation of the burden, and burden descent was disrupted by permeability fluctuations and blast pressure rise, among other factors. Thus, deterioration of the furnace lining in the furnace throat, had become a factor in reduced blast/reduced production and furnace heat drop due to slip and similar problems.

In order to improve this situation, refractory gunning repair of the throat section is performed periodically. Stabilization of smooth burden descent has been realized by maintaining a sound throat profile at all times. Refractory gunning work is shown in Figure 6.

In refractory gunning repairs, a repair method using an in-furnace rotary-type automatic gunning machine was introduced in order to obtain a smooth, strong furnace wall. Although it was originally necessary to stop the blast (shut down the furnace) for 36 hours when performing repair work, it was possible to shorten this to 24 hours by repeated improvements in the method of moving the gunning machine into and out of the furnace, which are particularly time-consuming operations. At present, a sound throat profile is maintained by periodic gunning repair once a year. The temperature of the furnace body bricks in the part where gunning repair is performed has been reduced from approximately 300°C to around 120°C and stabilized. In addition, stabilization of burden descent has also made it possible to perform furnace operation with an orientation toward the burden distribution control with the highest thermal efficiency.

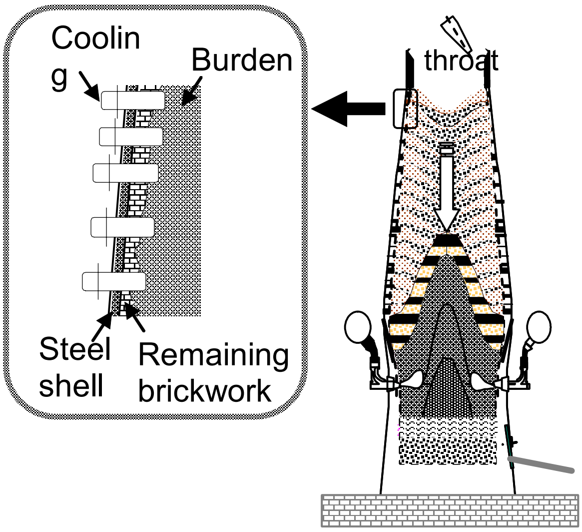


Figure 5: Condition of wear in SF throat

In the past, when burden descent was unstable due to the roughness of the throat wall, it was unavoidably necessary to strengthen the central gas flow in order to avoid slip and hanging of the raw materials.

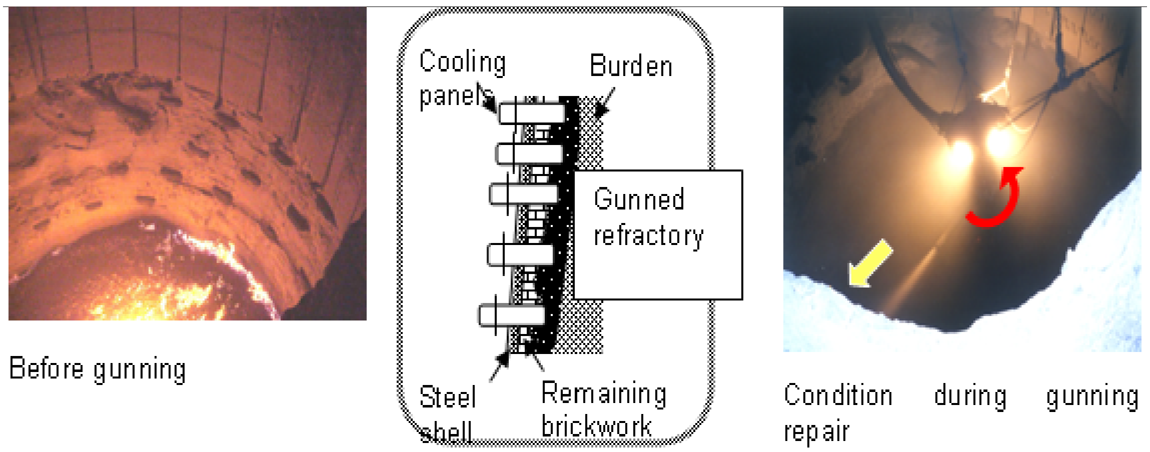


Figure 6: Refractory gunning in furnace throat

The gas temperature distribution in this case is shown in Figure 7. However, this reduced gas utilization efficiency and resulted in a loss of thermal energy as sensible heat of the top gas. After measures to maintain a sound throat profile, burden descent has stabilized, even when the furnace gas flow is controlled to a flat pattern (Figure 8), making it possible to aim at burden distribution control with the highest energy efficiency. This has enabled a large reduction in heat loss to the top gas, and has made an important contribution to increasing gas utilization efficiency and reducing RAR.

4.3.2 Reduction of furnace permeability fluctuations

With progress toward higher production, variations in the charged raw materials began to have a large effect on fluctuations in permeability in the furnace. In the SF, depending on the Mn grade, it is also necessary to increase the coke rate (CR) from 80kg to 100kg in a short time in order to supply mother materials matching the product being blown at the SL. When CR is increased, permeability decreases, but when CR is decreased, permeability resistance in the furnace increases rapidly due to the large change in the Ore/Coke rate, from 1.3 to 1.5, and this induces a deterioration of burden descent and a poor furnace condition. Because the amount of ore relative to the amount of coke in the furnace increases greatly in a short period of time, it was impossible to follow these changes with burden control, and instability of the burden descent due to sudden rises in permeability resistance were a frequent occurrence. To cope with this, when a large reduction was made in CR, it was possible to alleviate these sudden changes in permeability and reduce CR without negatively affecting burden descent by returning to a higher CR level based on from 2 to 3 steps. In spite of the basically higher level of production, by adopting the above-mentioned measures to stabilize the furnace condition, it was possible to suppress rises in permeability resistance while also greatly reducing RAR by improving gas utilization efficiency.

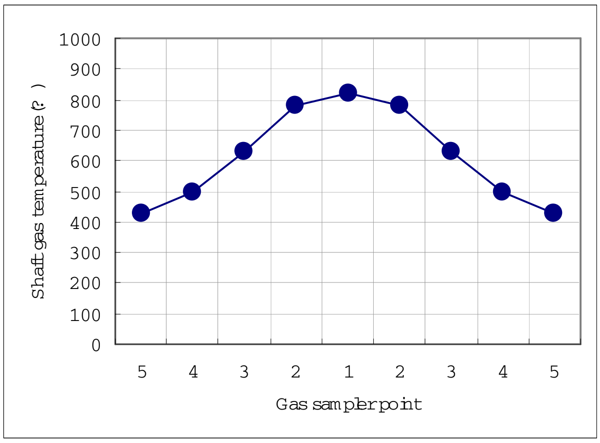


Figure 7: Gas temperature distribution before improveme

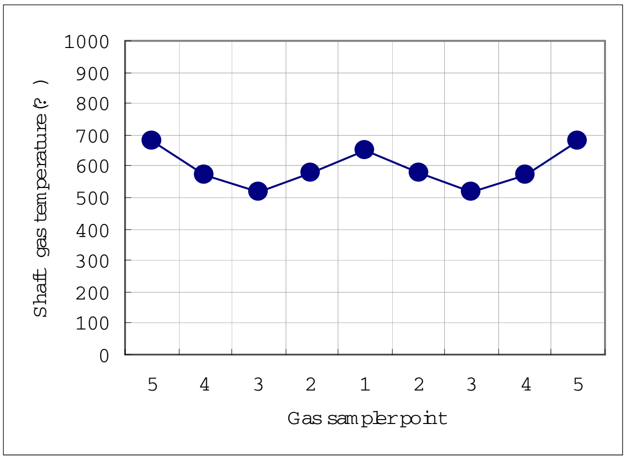


Figure 8: Gas temperature distribution after improvement

4.3.3 Reduction of RAR by utilization of small lump coke

Although the SF had been operated with all lump coke, there was concern that a reduction in production might be unavoidable due to the tight supply of lump coke. Because small lump coke is comparatively easy to obtain and is lower in cost than lump coke, a replacement test with small lump coke was carried out beginning in August 2003. The small lump coke in this test was material with a size distribution comprising mainly 20-40mm. A comparison of the coke size distribution is shown in Table 6.

Table 6: Comparison of coke size distribution

Particle size (mm)	>50	50-40	40-30	30-20	20-10	<10
Lump coke (%)	41	24	21	9	2	3
Small lump coke (%)	1	4	48	36	8	3

In the SF, coke and Mn ore + coke are charged alternately in 2 batches by the bell-less top. Thus, in charging, the coke is divided between the 1st batch and 2nd batch. Only coke is charged in the 1st batch. This coke is used to maintain furnace permeability. In the 2nd batch, 24% of the total coke is mixed with approximately 6t of Mn ore. The main function of this coke is direct reduction of the ore. A schematic diagram of the SF burden is show in Figure 9. The procedure of the small lump coke replacement test is presented below.

Step 1: The lump coke in the 2nd batch was replaced with small lump coke. By adjusting the burden distribution in line with the increased small lump ratio so as to secure permeability at the furnace wall, it was possible to replace all 24% of the lump coke in the 2nd batch with small lump coke.

Step 2: The small lump coke in the 2nd batch was further increased to 30%. In this case, 1st batch lump coke was replaced with 2nd batch small lump coke. However, a phenomenon was observed in which the ore batch charged at the wall flowed in toward the furnace center, remarkably impeding permeability. For this reason, an upper limit of 1.1t/ch was set on the mixed small lump coke in the 2nd batch.

Step 3: 1st batch lump coke was replaced with small lump coke. When small lump coke is mixed in the 1st batch lump coke layer, the average particle size decreases, resulting in an increase in permeability resistance, but the laying profile of the coke layer as a spacer remains stable. At present, 10% of the 1st batch lump coke can be replaced with small lump coke. However, replacement with small lump coke is possible so long as permeability resistance permits.

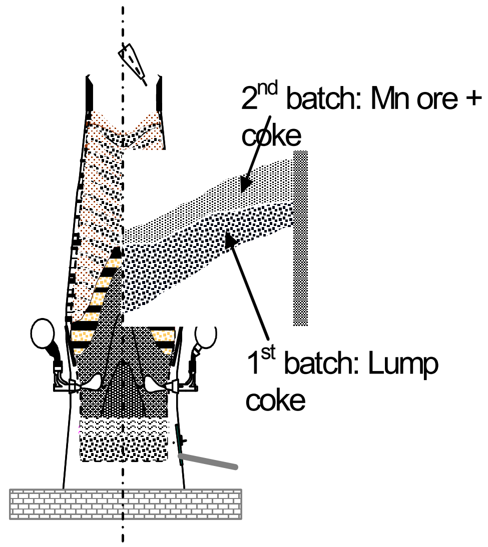


Figure 9: SF burden

Table 7: Small lump coke ratio and average size in test

	Small lump coke use ratio (%)	Average size (mm)
Step 1	24%	43
Step 2	27%	41
Step 3	34%	39

The results of this replacement test showed that replacement of 34% of total coke with small lump coke reduces consumption of lump coke, and at the same time, heightens permeability resistance, which encourages heat exchange of the sensible heat of the furnace gas to the raw material. This makes it possible to reduce the top gas temperature, thereby contributing to a reduction of RAR.

5. TRANSITION TO HIGH PRODUCTIVITY OPERATION (>1.0t/m^3/d)

As a result of various measures implemented over an extended period of time, high productivity, as shown by a productivity coefficient of 1.05 t/m3/d, was achieved in January 2006. Since that time, the SF has remained

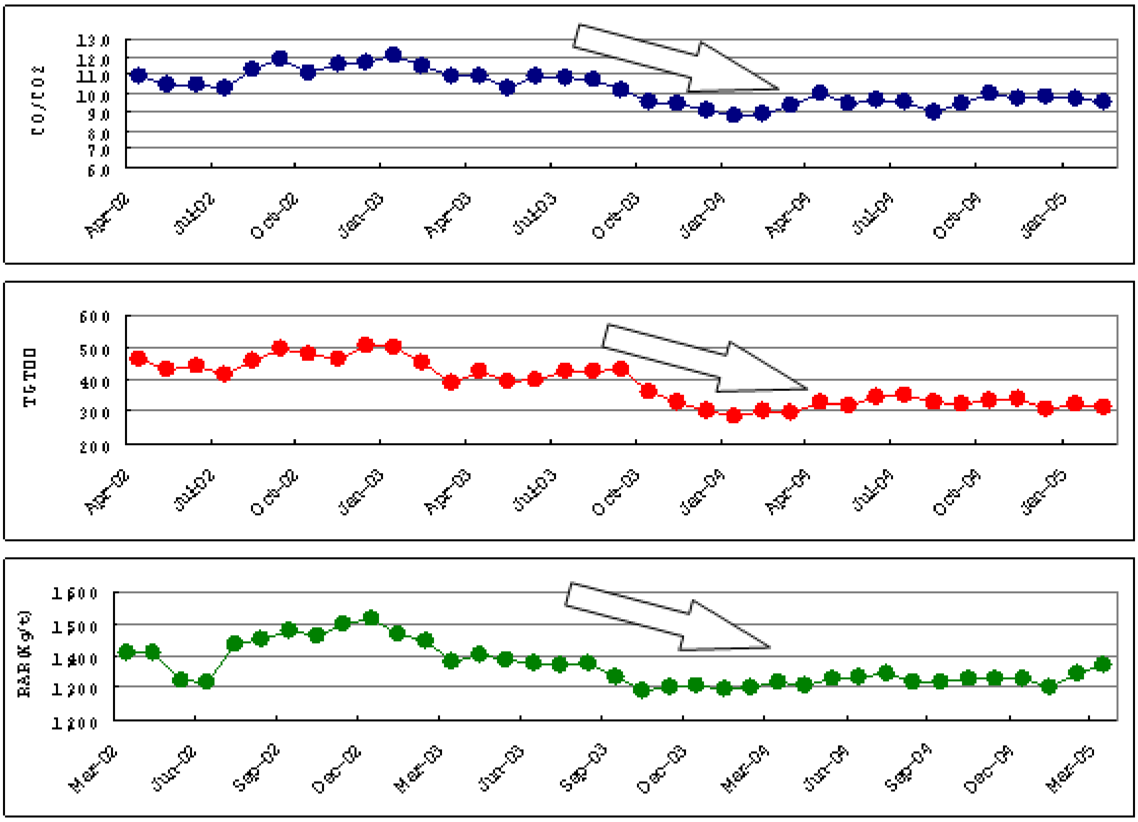
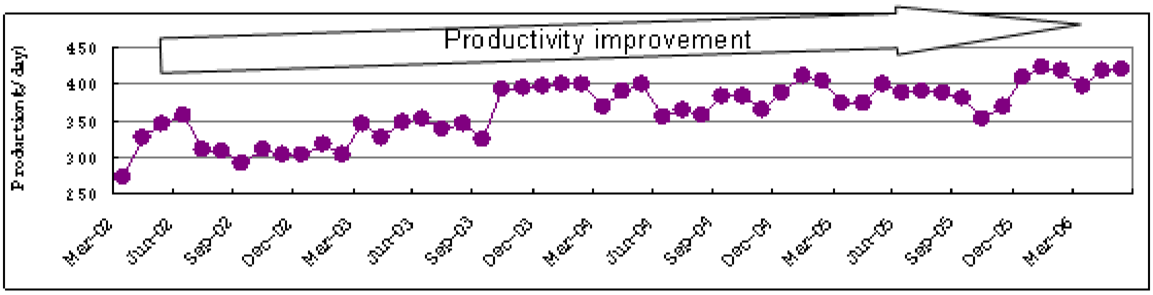


Figure 10: Transition of top gas temperature (TGT) and reduction of RAR

in stable high productivity operation. When compared with past data for Mn blast furnaces worldwide, productivity of 1.0 t/m3/d is an extremely high level.

6. CONCLUSIONS

In order to realize target productivity of 1.0 t/m3/d or higher with its shaft-type ferromanganese smelting furnace (SF), Mizushima Ferroalloy Co., Ltd. solved a number of technical problems and achieved production of 421 t/d and productivity of 1.05 t/m3/d in January 2006. A technology for stable high productivity operation was also established. Aiming at a furnace life of 30 years with this SF, which has been in operation since 1985, the company plans to implement furnace life extension measures based on stable operation realized through operational improvements, while continuing stable high productivity operation.



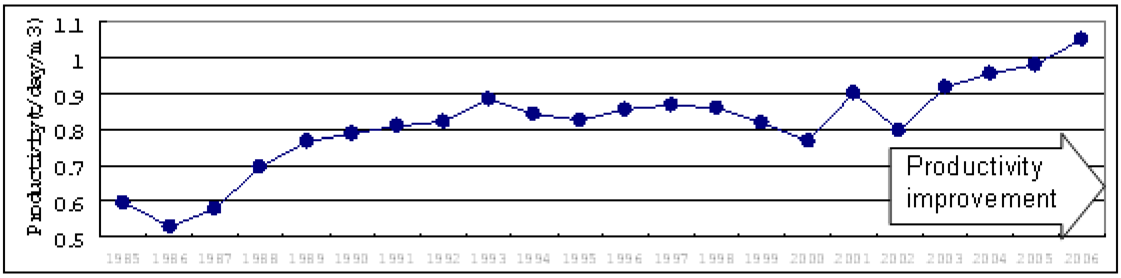


Figure 11: Transition of SF productivity (t/m^3/d)

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