THE BUILD UP OF ADDITIONAL HCFeMn PRODUCTION CAPACITY BY THE DEEPENING OF A FURNACE

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ABSTRACT

In recent years the requirement for high carbon ferro-manganese (HCFeMn), which is the key product of our company, has increased due to bullish demand for steel products.

In our Tokushima works, we have 2 closed types of electric furnaces (1F and 2F), with which we are manufacturing HCFeMn. In order to meet the increase in demand, we made various modifications to these furnaces and we tried to increase the furnace operating loads. Especially for 1F, we deepened the furnace. In this paper, we report the results of this modification.

The operational situations of the above-mentioned two furnaces are different because they have different individual profiles. As for 1F prior to modification, the depth of the furnace was one meter shallower than 2F, because 1F was designed for the manufacturing of SiMn. On the other hand, our Tokushima works specialized in HCFeMn 14 years ago. However, the profile of 1F was not optimized for HCFeMn. In comparison to 2F, 1F was more difficult to stabilize due to the smaller tolerance for the adjustment of the electrode length, the metal / slag level, and the coke-mixing ratio.

We deepened 1F by 770mm by disposing of the furnace rolling mechanism.

We consequently achieved a 10% increase in production capacity. This meant the operating load was enhanced from 24.5MW to 27MW, the furnace became more stable and the tapping speed of both metal and slag increased, all which made the tapping easier than before.

1. INTRODUCTION

Since the year 2000, the market requirement for HCFeMn, which is the key product of our company, has grown due to bullish demand for steel products. In order to meet the increase in demand for HCFeMn, we carried out work to further stabilize 2F at an annual production capacity level of 170,000mt (180,000mt tapped base). However it was expected that demand by the end of 2003 would exceed 190,000mt (200,000mt tapped base), so we realized that we urgently needed to further increase our production capacity. Sales of HCFeMn are shown in Figure 1.

2. PLAN FOR INCREASING PRODUCTION

It was necessary to increase production by 20,000mt, so that we could achieve the required capacity level of 200,000mt / year (tapped base). We set up the the objectives, as stipulated in Table 1, showing individual target figures with availability (%) improvements and operating-load (MW) increases.

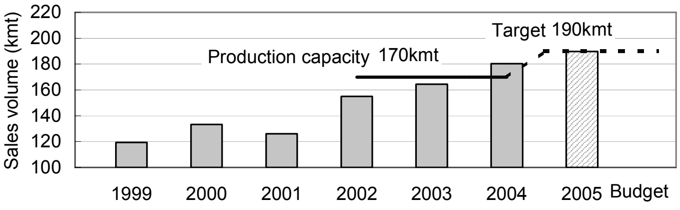

Figure 1: HCFeMn / Sales Volume

Table 1: Plan for Increasing Production

		Present	Objective	Objective/Prst	Increase (Tapped kmt)
Operating Load (MW)	1F	24.5	27.0	1.10	
	2F	28.5	30.0	1.05	
	Total	53.0	57.0	1.08	14
Availability (%)	1F & 2F	96.1	99.0	1.03	6
Total					20

Availability (%) = Hours operated / (Hours operated + Hours down) x 100

2.1 Increasing the Operating Load

Each of the operating loads to be targeted in 1F and 2F were 74% of the capacities of the transformers, which were 36.4MVA for 1F and 40.5MVA for 2F. 2F was relatively stable, therefore it was supposed that the targeted load could be achieved by enhancing control over the power sources and transformers.

However, 1F was unstable, so it was presumed that drastic stabilization measures would need to be taken in order to achieve a 10% higher load than now.

2.2 Improvement of Availability

The exhaust gas dust from 1F and 2F was dealt with by using exhaust gas cleaning equipment such as a spray tower and venturi scrubbers. We had to remove the scale caused by the dust, attached inside of the ducts in the spray tower and the venturi scrubbers and we were forced to stop the operation for 8 hours once a month. In order to achieve the 99% availability that was targeted, it was indispensable to remove the scale in a shorter time period, or without stopping the operation.

3. UNSTABLE OPERATION OF 1F

3.1 Up and Down Movement of Electrodes

The electrodes move up and down so as to keep a certain level of electrical resistance. In general, since the molten materials in the furnace increase, the electrodes move up in order to maintain electrical resistance until the time of tapping. During the tapping, the electrodes move down in order to keep the electrical resistance since metal and slag are discharging. The operation of the electrodes is restricted within the upper and lower limits of the equipments, which have the limits in the movement of the electrodes. In case of too much molten material and / or too little electrical resistance in the furnace, it will be impossible to keep a certain level of electrical resistance even after the electrodes reach the top position and the operating load consequently drops down. In the case where the discharging volume of the slag in the tap is much less than planned and with a set electrical load, the same result can be expected, since the electrodes reach to the top before the next tapping. In the opposite case of too much resistance in the furnace, it will be impossible to keep a certain level of electrical resistance even after the electrodes reach the bottom position and the operating load drops down.

Figure 2 shows the distance moved downwards by the electrodes before and after tapping in 1F and 2F. The figure in a cross axle is not the position of the electrodes, but it shows the distance moved downwards by the electrodes. It varied widely in 1F and had a higher average than 2F. The electrodes sometimes didn't move down due to non-discharging of the slag during tapping, but on occasion they slipped down from top to bottom. We were worried that this tendency would further develop with a higher operating load and it was assumed that the 10% increase of the operating load would not be achievable.

3.2 Tapping Speed of Metal and Slag

Table 2 shows the average tapping speed of metal and slag in 1F and 2F. The speed of 1F in metal and slag was about 60% of 2F.

The tapping of 1F occasionally had to be stopped due to the solidifying of the metal in the gutter, which was caused by the slow speed of the tapping.

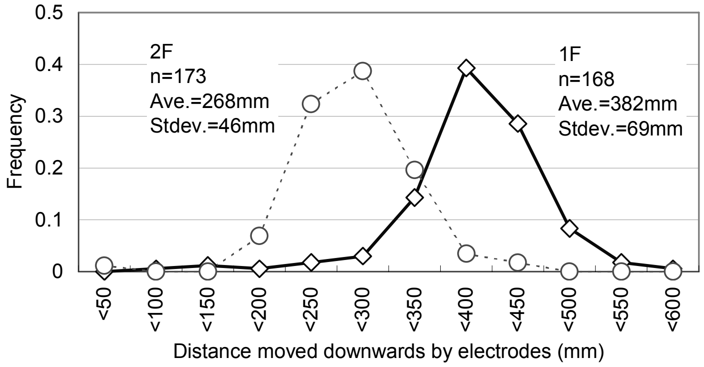

Figure 2: Frequency and variance of distance moved by electrodes of 1F and 2F

Table 2: Tapping Speed of Metal and Slag

	Unit	1F	2F	1F/2F
Velocity of Tapping Metal	t/min	1.36	2.17	0.63
Velocity of Tapping Slag	t/min	2.13	3.35	0.64

The slower was the tapping of the slag, the harder was the discharging of the cokes remaining in the furnace. When the electrodes were automatically moving upwards due to some reason, we found ourselves in a vicious circle where a little discharge of slag with the increase in cokes remaining in the furnace frequently forced us to reduce the operating load.

If we could discharge both slag and cokes more easily before getting into this vicious circle, we could take necessary action so as to return the furnace to its normal operating state and avoid making things worse.

3.3 Electrical Resistance of In-furnace burden

The electrical resistance of in-furnace burden of 1F and 2F was well controlled by an optimal batch of a mix of several ore types. The electrical conductivity varied depending on ore types. It was proven that the electrodes lifted up and reliable operation was not assured when an ore body was used in large volumes at high temperatures thus giving high electrical conductivity 1.

On the other hand, it was assumed that the electrical resistance of in-furnace burden increased, or decreased depending on the volume of the coke-bed.

It is indispensable to properly control the quality of the cokes in terms of size and reactivity and the ratio of the cokes against manganese ores, because the cokes function in the reduction role and help both gas penetration and electrical resistance.

It was difficult for 1F to keep a good-sized coke bed due to the uneven volume of discharged slag, and the volume of cokes remaining in the furnace fluctuated much. The electrodes were lifted up and the operating load was adjusted down because of lower electrical resistance of in-furnace burden, caused by richer cokes remaining in the furnace.

3.4 Dimensions

Table 3 shows the dimensions of 1F and 2F.

The depth of 1F was shallower than 2F and the space between the electrodes of 1F was narrower than 2F. The reason for this is that 1F was designed for the production of SiMn, which was refined at a higher temperature than HCFeMn. The narrower space between the electrodes helped to concentrate the heats easier.

At Tokushima works, the production of SiMn in 1F was stopped in the latter half of 1990 and HCFeMn was substituted for it, for which demand had increased. Since then, both 1F and 2F are dedicated for the production of HCFeMn. Therefore the dimensions of 1F, originally designed for SiMn production, were no longer required to be maintained.

Table 3: Furnace dimensions of 1F and 2F

	Unit	1F	2F	1F/2F
Trance Capacity	MVA	36.4	40.5	0.90
Electrode Diameter	m	1.70 (D)	1.70 (D)	1.00
Crucible Diameter	m	10.94 (6.4D)	11.52 (6.8D)	0.95
Pitch Circle Diameter	m	5.10 (3.0D)	5.30 (3.1D)	0.96
Crucible Depth	m	4.72 (2.8D)	5.82 (3.4D)	0.81
Height of Metal Tap Hole	m	0.90	1.12	0.80
Height from Metal Tap Hole to Slag Tap Hole	m	0.65	0.80	0.81
Height from Slag Tap Hole to Crucible Top	m	3.15	3.90	0.81
Limit of Electrode Stroke	m	0.90	1.00	0.90

The main reason mentioned above for the instability in the operation of 1F might have been the difference in dimensions taking into consideration that the raw materials used for 1F were more, or less the same as for 2F, or better mixing between smaller sizes of coke and a higher ratio of sintered Mn-ore.

Horizontal dimensions such as crucible diameter and pitch circle diameter of 1F were only 5% smaller than those of 2F, but vertical dimensions like crucible depth, height of metal tap hole, height from metal tap hole to slag tap hole and height from slag tap hole to the top of the furnace were about 20% smaller than those of 2F.

4. THE DEEPENING OF 1F

The pool of metal and slag in 1F became bigger after deepening 1F to the level of 2F. It is believed to have helped to get a higher tapping speed for metal and slag.

We could extract ourselves from the vicious circle when the furnace becomes unstable, and would not need to reduce the operating load, if we could achieve a higher tapping speed for metal and slag.

4.1 Decision Regarding Furnace Depth

1F was enlarged upwards by removing the rotator, attached under the bottom of the furnace, which was rarely used in the past.

We deepened 1F to 5.53meters based on the same ratio of Depth / Diameter = 0.505 as an ideal furnace such as 2F, although it could be deepened by 1.0meter to the same depth as 2F physically.

2F: Crucible Depth / Crucible Diameter = 5.82m / 11.52m = 0.505

1F: Crucible Depth = 0.505 x 10.94m = 5.53m

4.2 Decision Regarding the Height of the Slag Tap Hole

The molten slag discharged from 1F and 2F was poured into the ladle for the production of refined SiMn with low carbon and low phosphorus (hereafter LCLPSiMn). The height of the slag tap hole was carefully fixed so that the molten metal could never be mixed and discharged from the slag tap hole. This was because the metal, if it was mixed into the ladle, would push up the carbon content remarkably. The height of the slag tap hole theoretically could be calculated as shown below under the conditions of preserving the balance between the pressure on the surface of the metal and the pressure pushing the metal up to the slag tap hole.

$$\rho_1 \times (H - H_M) = \rho_M \times (H_{SH} - H_M)$$

$$\therefore H_{SH} = H_M + (H - H_M) \times \rho_1 / \rho_M \tag{1}$$

where: ρ_1; Average bulky specific gravity of raw material and or slag, located above of metal (kg/m^3)

ρ_M; Bulky specific gravity of metal (kg/m^3)
H; Crucible depth (m)
H_M; Height from bottom to surface of metal (m)
H_{SH}; Height from bottom to slag tap hole (m)

Under the above equation (1): height of slag of 1F could be calculated as 1.84m with its metal surface height, which was assumed to be the same as the height in the case of 2F, whose metal surface height was calculated as 0.44m.

$$H_{SH} = 0.44\text{m} + (5.53\text{m} - 0.44\text{m}) \text{ x } 1650 / 6000 = 1.84\text{m}$$

So in order to achieve similar tapping speed in 1F as in 2F, we fixed the same ratio in 1F as those in 2F. The metal tap hole height in 1F was calculated based on the same ratio of 0.126 with (2) and (3) below in 2F.

$$\text{2F: } H_{MH} - H_M = 1.12\text{m} - 0.44\text{m} = 0.68\text{m} \tag{2}$$

where: H_{MH}; Height from bottom to metal tap hole (m)

$$\text{2F: } H - H_M = 5.82\text{m} - 0.44\text{m} = 5.38\text{m} \tag{3}$$

$$(2) / (3) = 0.68\text{m} / 5.38\text{m} = 0.126$$

$$\text{1F: } H - H_M = 5.53\text{m} - 0.44\text{m} = 5.09\text{m} \tag{4}$$

$$\text{1F: } H_{MH} - H_M = (4) \text{ x } (2) / (3) = 5.09\text{m x } 0.126 = 0.64\text{m}$$

$$H_{MH} = 0.64\text{m} + 0.44\text{m} = 1.08\text{m}$$

Table 4 shows the dimensions after deepening 1F. A bigger slag volume was achieved since the gap between the metal and the slag tap hole was 100mm wider than before. The electrode stroke limit was widened from 0.90m to 0.95m.

5. OPERATING RESULTS AFTER DEEPENING FURNACE

5.1 Difference of the distance moved downwards by the electrodes before and after tapping: Before and After Deepening Furnace

Figure 3 shows the distance moved downwards by the electrodes before and after tapping. The average was 73mm less than before while the standard deviation was 7mm less. These were the results of the stabilized electrode, which rarely was shifted up, or rarely slipped down from the top to the bottom of the limit. It proves that the tapping somewhat stabilized.

Table 4: Furnace Dimensions of 1F (after) and 2F

	Unit	**1F After**	2F	**1F After**/2F
Transformer Capacity	MVA	36.4	40.5	0.90
Electrode Diameter	m	1.70 (D)	1.70 (D)	1.00
Crucible Diameter	m	10.94 (6.4D)	11.52 (6.8D)	0.95
Pitch Circle Diameter	m	5.10 (3.0D)	5.30 (3.1D)	0.96
Crucible Depth	m	**5.49 (3.2D)**	5.82 (3.4D)	**0.94**
Height of Metal Tap Hole	m	**1.07**	1.12	**0.96**
Height from Metal Tap Hole to Slag Tap Hole	m	**0.75**	0.80	**0.94**
Height from Slag Tap Hole to Crucible Top	m	**3.67**	3.90	**0.94**
Limit of Electrode Stroke	m	**0.95**	1.00	**0.95**

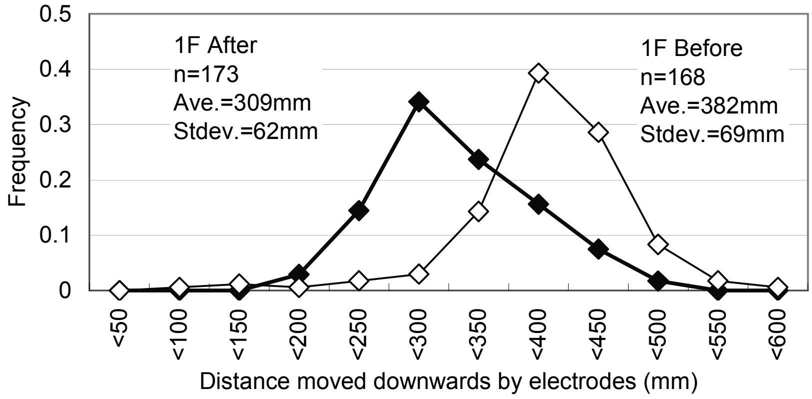

Figure 3: Frequency and variance of distance moved by electrodes before and after deepening furnace

5.2 Tapping Speed

Table 5 shows the tapping speed of metal and slag. It improved by 10% for both metal and slag after execution, but was still about 70% of the 2F speed, as mentioned above. This might be due to the molten slag volume in 1F being smaller than in 2F, although the tapping of 1F was stabilized after execution. A case occurred where the electrode lifted up due to a lack of slag discharge because not enough slag volume could be achieved. It was proved that the standard deviation of 1F for the distance moved downwards by the electrodes before and after tapping was 62mm, which was still 16mm bigger than that of the 46mm in the case of 2F.

Table 5: Tapping speed of metal and slag before and after execution

	Unit	1F Before	**1F After**	**1F After**/ 1F Before
Velocity of Tapping Metal	t/min	1.36	**1.50**	1.10
Velocity of Tapping Slag	t/min	2.13	**2.35**	1.10

5.3 Operating Results

Table 6 shows the operating results of 1F before and after execution. The planned operating load objective was achieved. The furnace condition was stabilized, supported by the improvement in the smaller distance moved downwards by the electrodes before and after tapping and higher tapping speed. The furnace gas temperature did not change in spite of having an increased operating load.

Table 6: Operating results before and after deepening the furnace

	Unit	1F Before	**1F After**	**1F After**/ 1F Before
Operating Load	MW	24.7	**27.4**	1.11
Electrical Resistance	mΩ	0.74	**0.75**	1.01
Fce. Gas Temperature	K	432	**430**	1.00
Fce. Gas $CO/(CO+CO_2)$	%	74.7	**75.9**	1.02
Ore Mn^{4+}	%	23.3	**22.8**	0.98
Coke/Ore		0.208	**0.205**	0.99
Slag Mn	%	26.6	**28.7**	1.08
Slag CaO/SiO_2		0.87	**0.83**	0.95

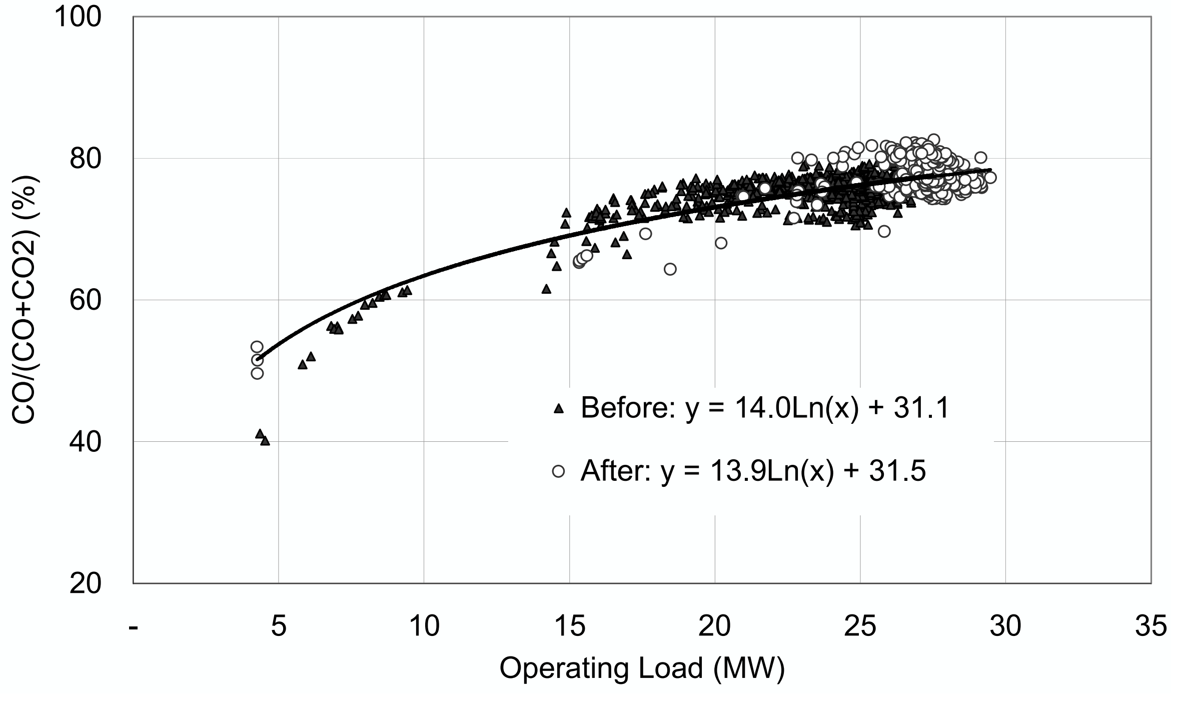

Figure 4: Correlation between operating load and CO ratio before and after execution

Figure 4 shows the correlation between operating load and CO ratio. It proves that no remarkable increase occurred in the difference between the reduction efficiency and CO ratio by the increase in the operating load.

6. CONCLUSION

Table 7 shows the results in CY2005 vs. objectives. After deepening 1F we improved its stability and the targeted operating load of 27MW was achieved. Our operating load objective of 30MW for 2F was also achieved due to the various measures taken. Regarding our objective to increase availability, we were able to increase our availability time from 96.1% to 97.4% by utilizing new automatic de-scaling equipment. Consequently our plant set an annual production record of 200,227mt in total from both furnaces CY2005 and established a new production level of 200,000mt (tapped annual base), which was the most important objective.

Table 7: Objective and result

		Objective	Result	Objective/Result
Operating Load (MW)	1F	27.0	27.4	1.01
	2F	30.0	30.2	1.01
	Total	57.0	57.6	1.01
Availability (%)	1F & 2F	99.0	97.4	0.98

REFERENCES

[1] Miyauchi, Y., High Thermal Electrical Property of Manganese Ore in Production of High Carbon Ferromanganese, INFACON9, 2001, pp. 236-243.