

# Manganese ore pre-reduction using a rotary kiln to manufacture super-low-phosphorus ferromanganese

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**Abstract** - Nippon Denko Co. Ltd's Tokushima plant produces low-phosphorus ( $\leq 0.050\%$ ), low-carbon ( $\leq 0.20\%$ ) ferromanganese (SLPFeMn) using a silicothermic process in a three-phase Heroult electric arc furnace.

In the past, sintered manganese ore was used as the raw material to produce SLPFeMn, but it has become necessary to use manganese ore containing carbonates instead. With this as an opportunity, the Tokushima plant has constructed a new manganese ore pretreatment process by utilizing an idle rotary kiln, which can carry out not only de-carbonation but also pre-reduction of the ore by using coke. In this study, optimal operating conditions were found that would allow pre-reduction without leaving residual coke, which increases the carbon content of the products, consequently reducing silicomanganese consumption, a reducing agent, in the SLPFeMn production process. This new process also saved energy by utilizing the excess gas from the electric furnace, used in the production of high-carbon ferromanganese, as its energy source.

*Keywords:* manganese ore, pre-reduction, rotary kiln, ferromanganese

## INTRODUCTION

### Regarding SLPFeMn

Nippon Denko Co. Ltd's Tokushima plant produces super-low-phosphorus ferromanganese (SLPFeMn) using a silicothermic process in a three-phase Heroult electric arc furnace. The silicothermic process is a widely used method of producing medium- and low-carbon ferromanganese (MC/LCFeMn) (Olsen, Tangstad, & Lindstad, 2007). In a silicothermic process, first, low-carbon silicomanganese is produced as the intermediate product. Next, this silicomanganese is charged into an electric furnace along with manganese ore to be refined. Then, the manganese oxide in the manganese ore is reduced by the silicon in silicomanganese, thus obtaining MC/LCFeMn.

In our company, we produce a low-phosphorus, low-carbon SLPFeMn using our proprietary technology that was developed by advancing and applying the silicothermic process.

Table I shows the SLPFeMn and other typical MC/LCFeMn specifications.

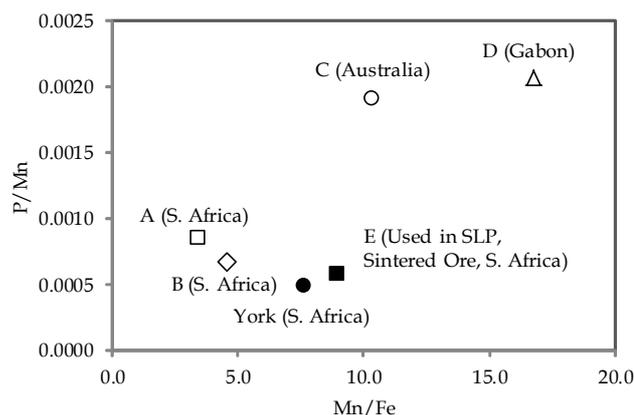
**Table I:** SLPFeMn specifications

		(wt.%)				
		Mn	C	Si	P	S
SLPFeMn	Specification	87.2-95	$\leq 0.2$	$\leq 1.2$	$\leq 0.05$	$\leq 0.02$
SLPFeMn	Typical	88	0.15	1.0	0.04	0.003
MCFeMn	Specification	75-85	1.5-2.0	$\leq 2.0$	$\leq 0.35$	$\leq 0.030$
LCFeMn	Specification	75-80	$\leq 1.0$	$\leq 2.0$	$\leq 0.30$	$\leq 0.030$

## Manganese ore for SLPFeMn

At the Tokushima plant, we had been purchasing sintered manganese ore with a low phosphorus content, from external sources, to produce SLPFeMn. However, we were faced with a situation where we could no longer buy the said sintered manganese ore. We decided to use a manganese ore called York ore – which is mined at the site of a manganese mining project (the current Kudumane Manganese Resources Ltd) in which we had been considering participating – to produce SLPFeMn.

Figure 1 shows the relationship between the most common manganese ores and York ore in relation to Mn, Fe, and P. The composition and size distribution of York ore is shown in Table II.



**Figure 1:** The relationship between common manganese ores and York ore in relation to Mn, Fe, and P

**Table II:** York ore composition and size distribution

Mn	Fe	SiO <sub>2</sub>	MgO	CaO	P	Ig.loss	(wt.%)		
							+75 mm	+6 mm	-6 mm
36.9	4.8	5.4	2.8	14.5	0.018	15.7	2	93	5

York ore is both low in phosphorus and high in Mn/Fe, just like the sintered manganese ore ("E" in figure 1) that we had been using. However, because York ore contains a lot of carbonates, it is difficult to charge York ore directly into the furnace. The MnCO<sub>3</sub> and CaCO<sub>3</sub> existing in the York ore generate CO<sub>2</sub> gas, which makes furnace operation dangerous as it boils the molten metal during refining. Thus, a pretreatment facility for removing CO<sub>2</sub> gas is necessary to use York ore as the raw material to produce SLPFeMn.

### Pretreatment facility

At the Tokushima plant, there were two potential pretreatment methods that could be used for removing CO<sub>2</sub>. One is to utilize an idle internal-heating-type rotary kiln, and the other is to use a Dwight Lloyd sintering machine (Rowen, 1956) that is used to produce sintered manganese ore for high-carbon ferromanganese (HCFeMn). We examined which method would work better as a pretreatment.

Based on the two reasons mentioned below, we decided to utilize the idle rotary kiln for the pretreatment, and, to this end, we modified equipment and conducted maintenance work. We also decided to charge coke fines along with the York ore into the rotary kiln for pre-reduction. The purpose of pre-reduction is explained below.

### 1) *Effective use of the excess electrical furnace gas*

At the Tokushima plant, HCFeMn is produced in a closed-type electrical furnace, and the electric furnace gas (70% CO, 25% CO<sub>2</sub>, 5% H<sub>2</sub>) generated from this electric furnace is used effectively as the fuel for our own power generators and ladle dryers. However, a portion of this electric furnace gas was in excess and therefore disposed of. At the Tokushima plant, this excess electric furnace gas could be used as the energy source for the rotary kiln.

In contrast, the sintering machine used at the Tokushima plant uses as its fuel coke fines purchased from external sources. For this reason, if we were to pretreat manganese ore for SLPF<sub>2</sub>Mn in a sintering machine, we would need to purchase and use new coke fines. Newly purchasing and using coke fines is not ideal from the perspective of energy conservation and reduction, as well as from the standpoint of cost. In addition, because it leads to an increase in CO<sub>2</sub> emissions, it is not ideal from an environmental stance either. If the sintering machine were to be used, the energy consumption would increase by an approximate equivalent of 3000 kL of crude oil annually, and CO<sub>2</sub> emissions would increase by about 13 000 tons per year. From the viewpoint of available energy sources, as described above, it was seen to be advantageous to use the rotary kiln rather than the sintering machine in the Tokushima plant.

### 2) *The pre-reduction of manganese ore*

If carbonaceous reducing agents could be used in the pretreatment facility for pre-reduction, it would be possible to reduce the amount of silicomanganese used as a reducing agent in the production of SLPF<sub>2</sub>Mn. This would mean the replacement of silicomanganese, which is an expensive reducing agent, with a cheap carbonaceous reducing agent, which would reduce the production cost of SLPF<sub>2</sub>Mn. Of course, if greater reduction is possible during pre-reduction, the impact on cost reduction would be greater. Generally, a sintering machine is designed for the agglomeration of ore fines. Although it is possible to achieve reduction as a secondary effect, such reduction is limited. In contrast, a rotary kiln is able to obtain greater reduction than a sintering machine, with the addition of a reducing agent. In other words, using the rotary kiln for pre-reduction would enable greater cost reduction.

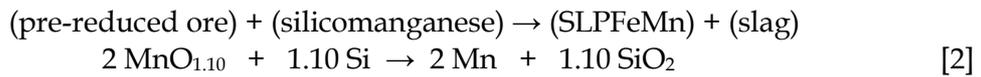
It should be noted that using carbonaceous reducing agents for pre-reduction in a rotary kiln is not unique to ferro-alloy manufacturing processes (Abdel Halim *et al.*, 2011). However, they are most typically used with products that are allowed a certain amount of residue, *i.e.*, C contaminants, left from the reducing agent used in pre-reduction, and they are hardly ever used in products that do not tolerate C contamination such as with SLPF<sub>2</sub>Mn. This is because it is difficult to conduct pre-reduction without leaving residual C.

#### **Pre-reduction target**

At the Tokushima plant, we call ore with its CO<sub>2</sub> removed “de-carbonated ore,” and ore after pre-reduction is called “pre-reduced ore”.

The progress of the preliminary reduction is evaluated by O/Mn molar ratio. The O/Mn molar ratio is derived from the chemical analysis of oxygen in manganese oxide (ISO 312). York ore and de-carbonated York ore’s O/Mn molar ratio is 1.45. We set the pre-reduction target to reduce this ratio to 1.10.





At the Tokushima plant, after the pretreatment facility was completed, we first began with the commercial production of de-carbonated ore. After that, we conducted tests for the pre-reduced ore.

## PRODUCTION FACILITY

### Production flow

The production flow is represented in Figure 2. The manganese ore and coke fines are transported from the raw material yard, and fed into the storage tank by a belt conveyor and a bucket elevator, respectively. Then, the manganese ore and coke fines are weighed with a constant-feed weigher, and conveyed to the rotary kiln via a belt conveyor, bucket elevator, and screw conveyor. The maximum charge rate of the manganese ore to the rotary kiln is 12 t/h. The rotary kiln has a burner capable of mixed combustion with kerosene and electric furnace gas, and its length and the refractory inner diameter are 45 m and 3 m, respectively. The slant angle is 35/1000, the maximum rotation speed is 0.3 rpm, and the raw material residence time is at most 9 h. The pre-reduced ore that comes out of the rotary kiln is quickly cooled to 300°C in the quenching hopper, and then further cooled in a rotary cooler and carried to the product warehouse via a belt conveyor. From the product warehouse, a dump truck is used to carry it to the SLPFeMn production electrical furnace.

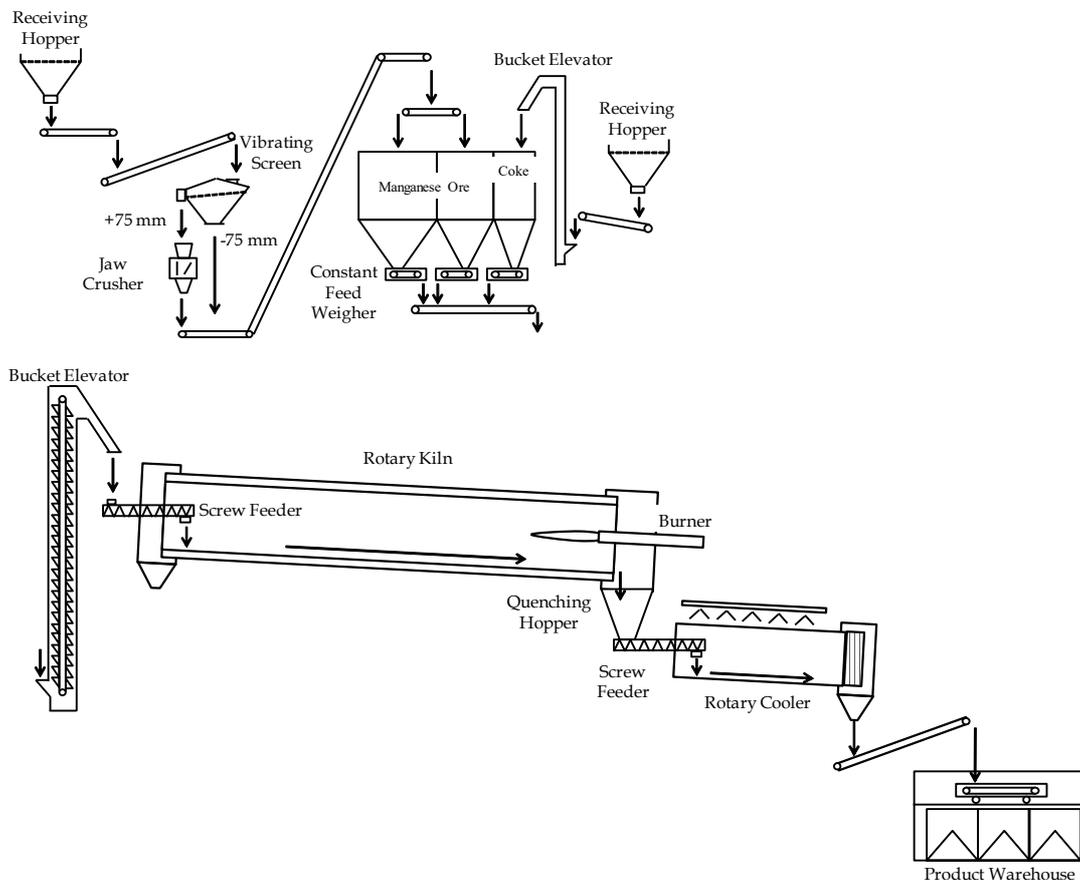


Figure 2: Production flow

### Reoxidation and the quenching hopper

When pre-reduced ore is cooled in air, it will reoxidize to a certain extent. In order to investigate to what extent it undergoes reoxidation, we conducted laboratory experiments in advance. The apparatus for the experiments is shown in Figure 3.

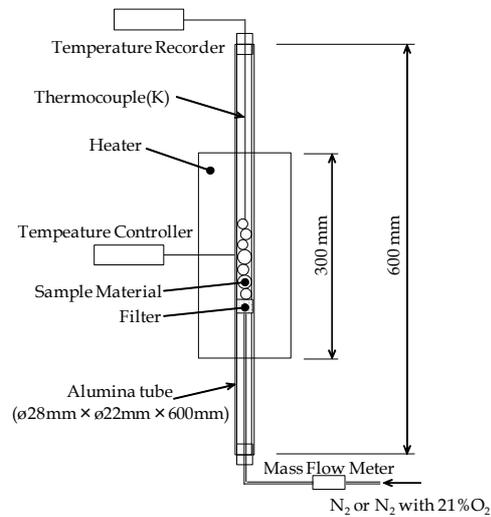


Figure 3: Experimental apparatus

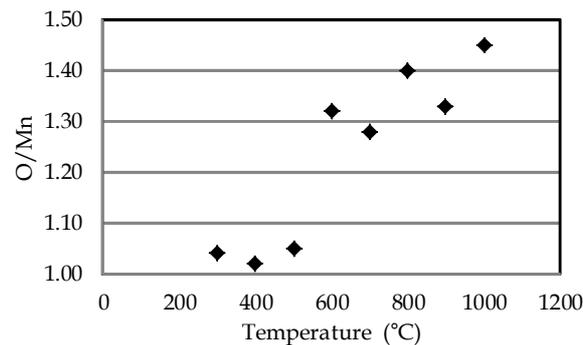


Figure 4: Relation between temperature and isothermal reoxidation for 30 minutes in air, of pre-reduced ore with an initial O/Mn ratio of 1.0

First, the York ore was reduced with coke in the test furnace and pre-reduced ore with an O/Mn molar ratio of 1.0 was created. Then, the ore was sieved to 16–20 mm, and 50 g of it was charged into a heating furnace. Then,  $\text{N}_2$  (500 mL/min) was injected into the furnace, the temperature was raised to a preset value, and  $\text{N}_2$  was switched to  $\text{N}_2$  with 21%  $\text{O}_2$ . The temperature was maintained for 30 minutes. Finally,  $\text{N}_2$  with 21%  $\text{O}_2$  was switched back to  $\text{N}_2$  and cooled. The samples were taken out to measure their O/Mn molar ratios. The results of the experiment are shown in Figure 4.

Based on this experiment, we learned that reoxidation occurs quite rapidly at temperatures above 600°C. In order to control reoxidation, it is necessary to reduce the temperature rapidly to below 600°C. However, because the rotary cooler in the equipment that sat idle did not seem to have the cooling speed needed, we installed a quenching hopper to cool the pre-reduced ore rapidly. A schematic diagram of the quenching hopper is shown in Figure 5.

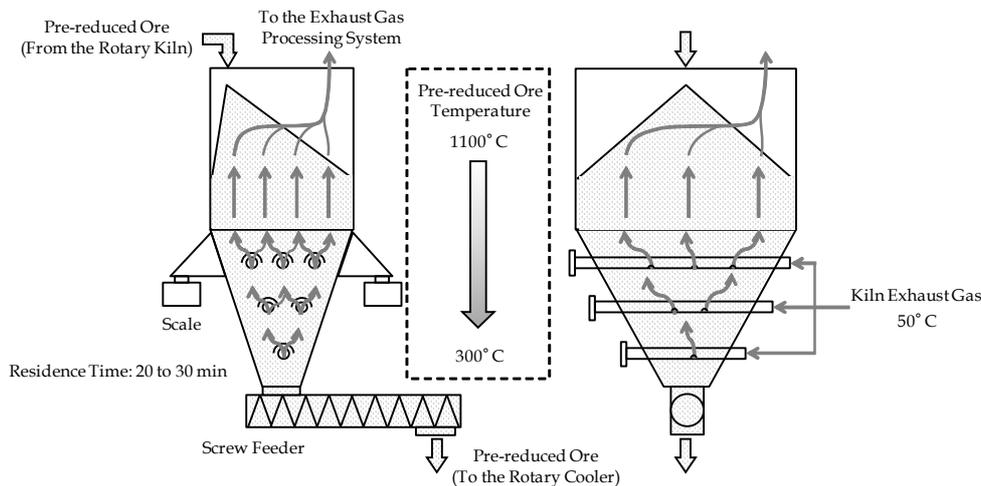


Figure 5: Quenching hopper

The pre-reduced ore discharged from the rotary kiln is temporarily held in this quenching hopper. The amount of pre-reduced ore in the quenching hopper is managed using an installed scale, and the amount is controlled by the screw feeder's cutout speed. The pre-reduced ore is then rapidly cooled by blowing the rotary kiln's low-O<sub>2</sub> exhaust gas cooled down to 50°C. It takes 1.5–2 h for the rotary cooler to reduce the pre-reduced ore's temperature by itself down to 300°C. In contrast, this can be reduced to 20 to 30 minutes when a quenching hopper is used.

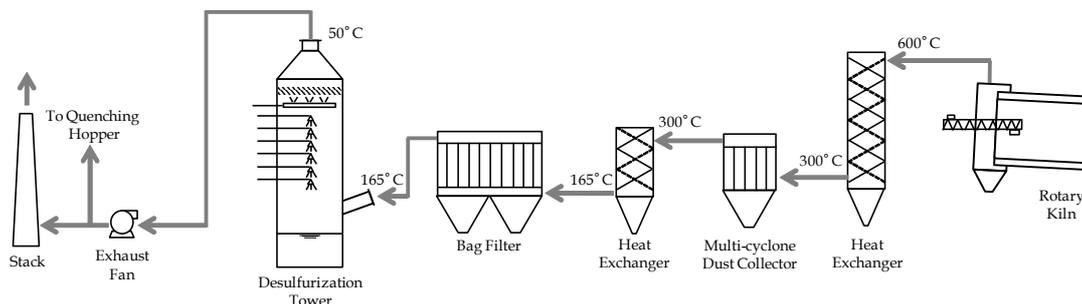


Figure 6: Exhaust gas process flow

The exhaust gas from the rotary kiln is taken from the raw material feed end, and, after reducing the temperature with the heat exchanger, dust is removed using the multi-cyclone and the bag filter. The exhaust gas then goes through the desulfurization process at the desulfurization tower, and a portion is used as the cooling gas in the quenching hopper; the rest is discharged from the stack.

## PRE-REDUCED ORE PRODUCTION TEST

### Pre-reduced ore production test (1<sup>st</sup> round)

#### *Test condition*

The first round of the experiments was conducted in order to determine the issues relating to the production of the pre-reduced ore and the necessary operating conditions for its production. Table III shows the pre-reduced ore production test conditions.

**Table III:** Pre-reduced ore production test conditions (1<sup>st</sup> round)

Coke addition rate	Theoretical coke addition rate (O/Mn = 1.10) × 1.5
Raw material temperature inside the kiln	1000 to 1150°C
Kiln fuel	Electric furnace gas
Kiln rotation speed	0.30 rpm , 0.15 rpm
Static pressure in the kiln	-3 to -5 Pa, -2 to -4 Pa
Quenching hopper	Not used

As to the coke, we considered the combustion loss in the rotary kiln, and increased the theoretical coke by 1.5 times, in an attempt to reduce the O/Mn molar ratio to 1.10. The theoretical coke addition rate was calculated assuming that the reduction of the manganese oxides proceed theoretically according to the following equations.



The raw material temperature inside the kiln was increased from 1000°C, which is the temperature used when the de-carbonated ore is being produced, in 50°C increments until it reached 1150°C. The raw material temperature inside the kiln was controlled by the combustion level of the electric furnace gas, and the temperature was measured using a radiation thermometer at the raw material discharge end of the rotary kiln. The temperature measuring point of the raw material was located 7 m from the discharge end of the kiln, which is at a location with the highest temperature inside the kiln.

For the test, the rotary kiln's rotation speed was changed, and the raw material residence time, as well as the raw material occupancy rate, was changed. The rotation speed was set to two standard values, *i.e.*, 0.30 rpm and 0.15 rpm; the raw material residence time was set at 4.5 h and 9.0 h, and the raw material occupancy rate was set at 8% and 16%.

The temperature distribution and the level of oxygen in the atmosphere in the rotary kiln were controlled by changing the amount of air suction from outside the rotary kiln at the raw material discharge end. The amount of suction of outside air was controlled by the static pressure on the feed end of the rotary kiln raw material, and the static pressure was set at two levels, one at -3 to -5 Pa and the other at -2 to -4 Pa. It should also be noted that the static pressure was adjusted using the main exhaust vent damper opening.

During the test, in order to evaluate the reoxidation level when the rotary cooler alone was used for cooling, the ore storage in the quenching hopper and cooling gas were not used.

The product sample was collected from the discharge ends of the rotary kiln and the rotary cooler. The purpose of collecting the samples from these two locations was to verify the change in the composition during the cooling process at the rotary cooler, particularly in terms of the extent of reoxidation.

The proximate analysis and size distribution of used coke fines are shown in Table IV.

**Table IV:** Coke fines proximate analysis and size distribution

	Fixed carbon	Volatile matter	Ashes	+5 mm	+3 mm	-3 mm
Coke fines	87	1	12	2	10	88

(wt.%)

Over 90% of the coke fines had particle sizes of up to 5 mm. These sizes are substantially smaller than those of York ore. For this reason, in case coke residue remains in the pre-reduced ore, it can be removed by sieving. To test if residue coke could be removed by sieving, the samples collected at the discharge end of the rotary cooler were sieved and separated at 4.75 mm, and the C content was analysed according to its particle size. At the same time, we also investigated how much was sieved down and how much was left in the sieve.

#### *C content of the pre-reduced ore*

The C content of the pre-reduced ore, obtained in the chemical analysis, was derived from the CO<sub>2</sub> existing in the form of MnCO<sub>3</sub> or CaCO<sub>3</sub> within the ore, as well as from the solid C mixed in the ore. From the values obtained in the analysis, it was not possible to determine from where the C content was derived. Table V shows an example of the composition of de-carbonated York ore.

**Table V:** De-carbonated ore (at 1000°C, 9 h) composition

	Mn	Fe	SiO <sub>2</sub>	MgO	CaO	P	C	O/Mn
De-carbonated ore	44.7	6.1	6.1	3.6	17.6	0.023	0.020	1.46

(wt.%)

The C content of the de-carbonated ore was 0.020% on average. This is likely due to the CO<sub>2</sub> that could not be removed in the heating process. However, most of it is let out of the furnace as CO<sub>2</sub> gas, and as long as it is not introduced in abundance, there is no issue. In contrast, C introduced into the electric furnace in the production of SLPFeMn as C solids, such as coke, practically 100% yield to SLPFeMn and significantly increases the C content of SLPFeMn. Therefore, the introduction of even a small amount of solid C could be an issue. Based on this, it is necessary to consider the C percent derived from CO<sub>2</sub> and the C percent derived from solid C separately.

Based on the average and deviations of the C content of the current SLPFeMn, the increase allowed in the C content derived from solid C in the pre-reduced ore used in the SLPFeMn manufacturing process is limited to 0.020%. In other words, the allowable upper limit of the C content of the pre-reduced ore is 0.040%, which is the upper limit of the allowable increase in the C content derived from the introduction of solid C, 0.020%, added to the 0.020% C content derived from CO<sub>2</sub>.

#### *Test results*

The test results are shown in Table VI.

**Table VI:** Results of the pre-reduced ore manufacturing test (1<sup>st</sup> round)

		Test 1	Test 2	Test 3	Test 4
Kiln fuel		Electric furnace gas			
Static pressure in the kiln		- 3 to - 5 Pa		- 2 to - 4 Pa	
Coke addition rate		Theoretical coke addition ratio (O/Mn = 1.10) × 1.5			
kiln rotation speed		0.30 rpm			0.15 rpm
Material residence time		4.5 h			9.0 h
Raw material temperature inside the kiln		1000°C		1100°C	1150°C
O/Mn molar ratio	Kiln discharge end	1.43	1.42	1.27	1.09
	Cooler discharge end	1.41	1.41	1.31	1.14
C content (Cooler discharge end)	+ 4.75 mm	0.151%	0.173%	0.071%	0.024%
	- 4.75 mm	0.771%	2.279%	4.010%	1.439%
	Total	0.380%	0.852%	1.288%	0.494%
- 4.75 mm rate (Cooler discharge end)		36.9%	32.2%	30.9%	33.2%

The oxidation level was reduced to 1.14 under the conditions of test 4, which is close to the targeted value of 1.10.

In contrast, the product's C content when not sieved was over 0.040% under each condition. If it remains so, the product cannot be used as the raw material for SLPF<sub>2</sub>Mn. As stated earlier, in order to use it in the production of SLPF<sub>2</sub>Mn, it is necessary to have C ≤ 0.040%. After sieving, all except in test 4, the C content was higher than 0.040%. Based on this, in order to remove coke, it is clear that it is necessary to enlarge the sieve openings. However, even at an opening of 4.75 mm, the fraction of pre-reduced ore in the underflow of the sieve was over 30%. With increasing sieve openings, the amount that passes through the sieve will increase. To remove the residual coke in this way is not economically feasible and thus not practical. Also, in the test, we did not carry out the storage in the quenching hopper nor did we inject the cooling exhaust gas in order to suppress reoxidation. Despite this, the reoxidation of the pre-reduced ore in the rotary cooler was at a maximum of 0.05. This indicates that rapid cooling in the rotary cooler alone can suppress reoxidation sufficiently.

One of the reasons that reoxidation did not occur at the same rate as in the laboratory experiment is most likely the amount of time the pre-reduced ore came into contact with the oxygen in the air. In the rotary cooler, the pre-reduced ore is rotated at a thickness of approximately 20 cm. While being agitated by rotary cooler rotation, the pre-reduced ore on the surface comes into contact with the air that flows through the rotary cooler and reoxidizes. However, some of the pre-reduced ore at the bottom does not come into contact with air, and thus, reoxidation does not occur at the same rate. Just as in the laboratory experiment, the pre-reduced ore was vulnerable to reoxidation at temperatures above 600°C. It is thought that the pre-reduced ore in the rotary cooler remained at this temperature range for over 30 minutes. However, reoxidation may not have occurred as expected as the pre-reduced ore was not constantly exposed to air as in the case of the laboratory experiment.

Another possibility is the influence of the O/Mn molar ratio of the pre-reduced ore that was discharged from the rotary kiln. In the actual equipment, the lowest O/Mn molar ratio of the pre-reduced ore at the discharge end of the rotary kiln was 1.09, which was higher than that of 1.00 during the laboratory experiment. Therefore, the pre-reduced ore in the actual machinery had a lower activity than that during the laboratory experiment. This is thought to be one of the reasons why reoxidation did not progress.

## Pre-reduced ore production test (2nd round)

### Test condition

As stated above, sieving to remove the residue coke was not a realistic solution. It would be more practical to produce pre-reduced ore without any coke residue. Therefore, a second pre-reduced ore production test was conducted to determine if it was possible to produce pre-reduced ore without coke residue. Table VII shows the conditions for the second pre-reduced ore manufacturing test.

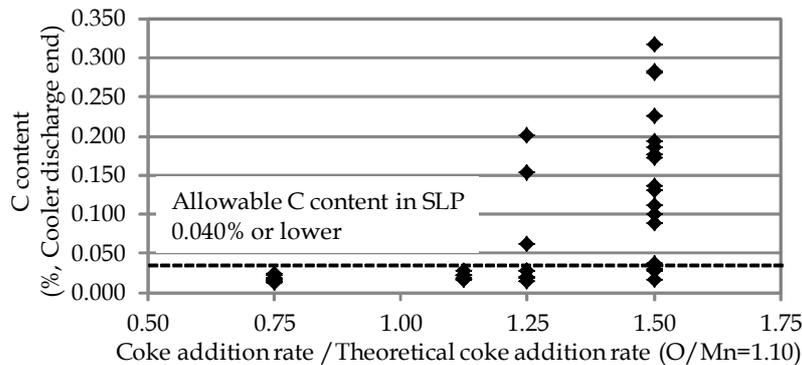
**Table VII:** Pre-reduced ore production test conditions (2<sup>nd</sup> round)

Coke addition rate	Theoretical coke addition rate (O/Mn = 1.10) × 0.75 to 1.5
Raw material temperature inside the kiln	1250°C
Kiln fuel	Electric furnace gas
Kiln rotation speed	0.15 rpm
Static pressure in the kiln	- 2 to - 4 Pa
Quenching hopper	Not used

Aside from the temperature and the coke addition rate, the conditions were the same as those in Test 4 of the first round of tests, where an O/Mn molar ratio of 1.14 was obtained. The temperature was set 100°C higher than that in the first test. The temperature is the highest temperature at which York ore and ash of coke fines does not melt. The coke addition rate was adjusted to be 0.75 to 1.5 times that of the theoretical coke addition rate to reach the condition in which an O/Mn molar ratio of 1.10 should be achieved, and the rate at which no coke residue was formed was investigated. It should also be mentioned that it was again decided to not use the quenching hopper based on the results of the first test.

### Test results

The relation between the coke addition rate and residual carbon from the second test is shown in Figure 7.



**Figure 7:** Coke addition rate and residual C

We can see from the figure that if the coke addition rate was 1.1 times the theoretical coke addition rate, then it is possible to produce pre-reduced ore without residual C.

Next, the relationship between the coke addition rate and the O/Mn molar ratio is shown in Figure 8.

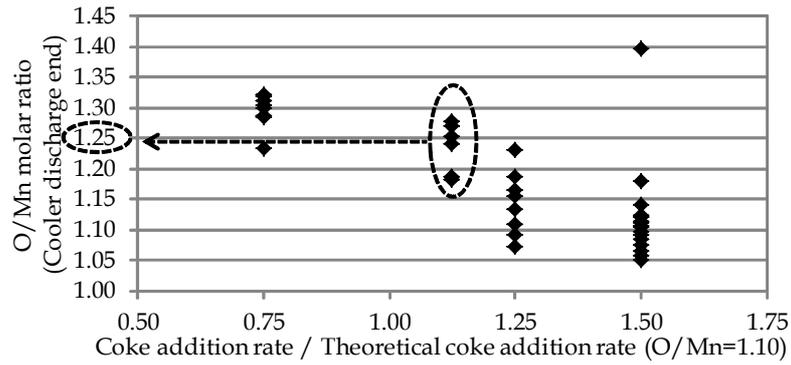


Figure 8: Coke addition rate and O/Mn molar ratio

We can see a molar ratio of approximately 1.25 when there is no coke residue, that is to say, when the actual addition rate of coke was 1.1 times that of the theoretical coke addition rate.

Figure 9 shows the relation between the O/Mn molar ratio and C residue.

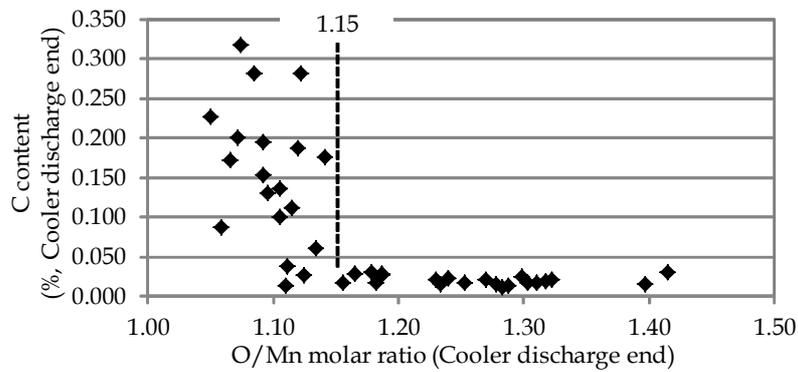


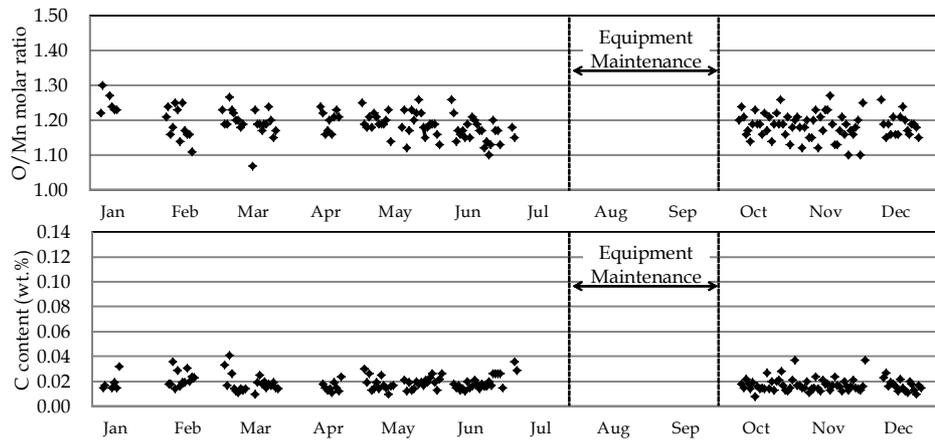
Figure 9: O/Mn molar ratio and C residue

These results show that if the molar ratio is up to 1.15, it is possible to operate without having any residual coke.

Based on the above findings, the operational target was set to a molar ratio of 1.25, at which no coke residue was obtained, and we went into the production of the pre-reduced ore.

### COMMERCIAL PRODUCTION OF PRE-REDUCED ORE

The relationship between the transition of the molar ratio and of the C content after entering commercial production is shown in Figure 10.



**Figure 10:** Transition of O/Mn molar ratio and of the C content (2016)

The charge rate of the manganese ore to the rotary kiln during this period was approximately 10 t/h. The average molar ratio during this period was 1.19, and we were able to clear the initial target of 1.25. The average C content was 0.018%, and none of the pre-reduced ore was unsuitable for manufacturing SLPFeMn due to a high C content.

Additionally, throughout this period, by the use of mono-fuel combustion with the electric furnace gas, we were able to save an equivalent of 5000 kL of crude oil annually by using energy effectively.

Table VIII shows an example of the pre-reduced ore composition manufactured after we went into full production.

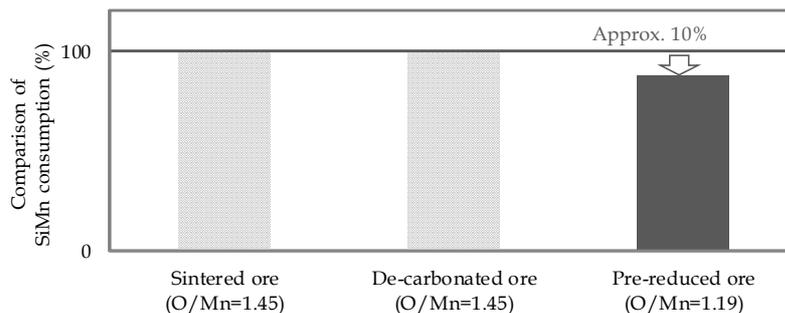
**Table VIII:** York ore pre-reduced ore composition

	(wt.%)							
	Mn	Fe	SiO <sub>2</sub>	MgO	CaO	P	C	O/Mn
Pre-reduced ore	46.1	6.3	6.5	3.7	18.2	0.025	0.018	1.20

Although the ore lost oxygen during the pre-reduction, when compared with the de-carbonated ore, the concentration of each chemical component increased proportionally.

### SILICOMANGANESE CONSUMPTION

The silicomanganese consumption per ton of SLPFeMn is shown in Figure 11.



**Figure 11:** Comparison of silicomanganese consumption in SLPFeMn production

Based on the silicomanganese consumption when using the sintered ore, the silicomanganese consumption when the de-carbonated ore is used and when the pre-reduced ore used are compared. It can be seen here that using pre-reduced ore with a molar ratio of 1.19 reduces the use of silicomanganese by approximately 10%.

More than half of the production cost of SLPFeMn is the cost of silicomanganese, and so there is a great impact on cost reduction.

## CONCLUSIONS

At the Tokushima plant, originally sintered manganese ore was used as the raw material for the production of SLPFeMn. However, it became necessary to use a manganese ore that contains carbonates. At the Tokushima plant, we utilized an idle rotary kiln and constructed a new manganese ore pretreatment process, where we would not only de-carbonate the ore but also conduct pre-reduction with the use of coke. Based on this, we accomplished the following:

- 1) A pre-reduced ore production test was carried out, and the appropriate operating conditions and coke addition amount that would allow for pre-reduction while satisfying the  $C \leq 0.040\%$  requirement for manganese ore used in SLPFeMn production were determined. Also, we found that the achievable molar ratio under these conditions was 1.15. Additionally, we succeeded in stable pre-reduction over a long period of time and achieved an annual average O/Mn molar ratio of 1.19 by applying the operating conditions and coke addition amount obtained during our tests.
- 2) By using the excess electric furnace gas effectively, we managed to save energy equivalent to approximately 5000 kL of crude oil per year. In addition, by using the rotary kiln for pre-reduction, we reduced usage of energy equivalent to 3000 kL of crude oil, and reduced CO<sub>2</sub> emissions by approximately 13 000 tons per year compared to when manganese ore went through pretreatment in the sintering machine.
- 3) By reducing the O/Mn molar ratio to 1.19, it was possible to reduce the silicomanganese consumption in SLPFeMn production by approximately 10%.

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