Automation and Reduction of Labor in the Operation of Electric Arc Furnace for HCFeMn Production

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Summary

In our Kashima Works, we are operating the two furnaces, one is a 40 MVA for HCFeMn and the other is a 50 MVA for SiMn.

In order to reduce the total production costs for HCFeMn and SiMn, we are utilizing the entire HCFeMn slag for producing SiMn as a raw material. In addition, we have endeavored to reduce the power cost by the optimum different load operation and improve the labor productivity by automation and improvement of the operation.

Introduction

The characteristic of our HCFeMn operation is to charge raw materials with heat and such raw materials are treated with heat for pre-deoxidization and evaporation of moisture in a rotary kiln in advance.

In Japan ferro-alloy production, labor cost and power cost are comparatively high and these costs as a proportion of the production cost is accordingly high. Besides, in recent years, due to the sharp appreciation of Japanese yen, imports of ferro-alloys have been increasing and domestic prices have been decreasing, which has adversely affected our business results.

Under such circumstances, in order to strengthen the market competitiveness of our products, we have tried to automate and improve our operation. Our targets were to decrease unit power cost by half and double labor productivity. We have succeeded in attaining these targets and would like to report on the contents of the improvement.

Improvement of Rotary Kiln Operation and Automation

In the rotary kiln, as you can see in Fig. 1, EAF gas and kerosene charged from the surge hopper side and coal charged from the top of the rotary kiln was used as heat sources.

In the operation of the rotary kiln, the big difference of load between flat and high level had made it very difficult to control the temperature of the rotary kiln. Besides, we were faced with low utilization of the furnace, increased energy cost in the low load operation and the difficulty of the manual temperature control. (See Table 1)

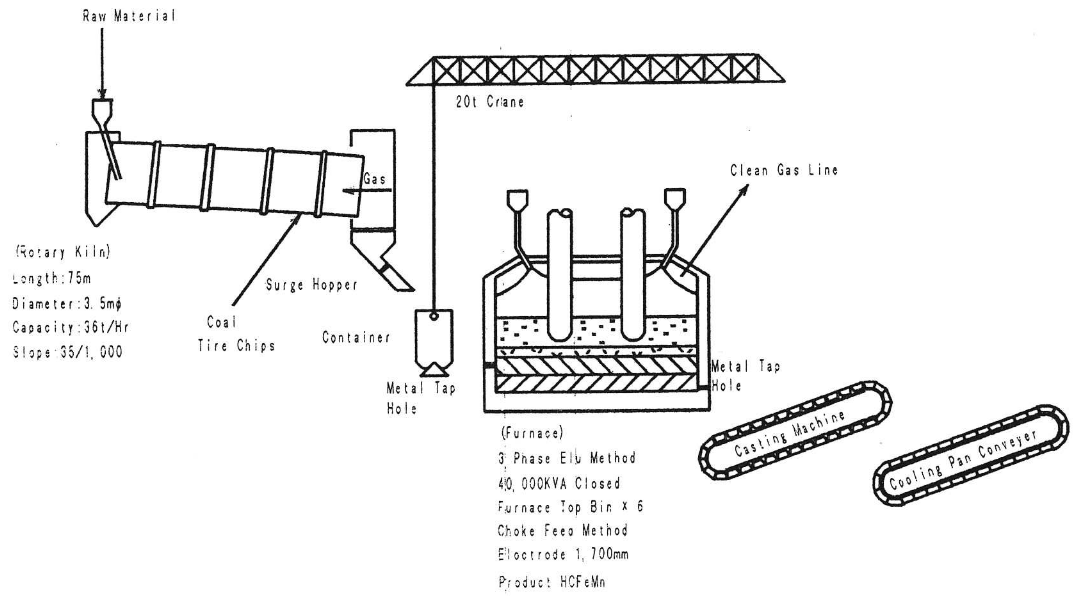

Fig. 1. Furnace Flow Sheet

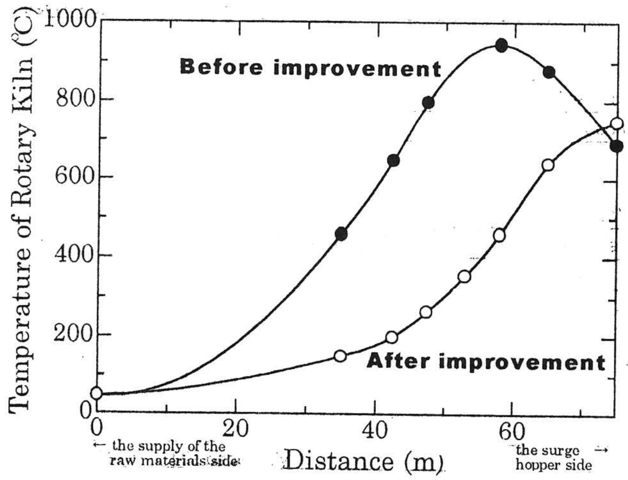

Fig.2. Heat Patterns of Rotary Kiln

Thus, we had studied improvement of the rotary kiln operation and the effects on the EAF production factors by running a simulation model and put the plan for the operational improvement into practice. The heat patterns of the rotary kiln before and after the operational improvement are described in Fig. 2 and the energy consumption situation is described in Table 2. Before the improvement, 61%, 36% and 3% of the total required energy had been covered by the EAF gas, coal and kerosene respectively. After the improvement, the total consumption of energy was reduced by lowering the temperature from 950℃ to 700℃. Further, the consumption of the relatively costly energy sources (kerosene, EAF gas) was reduced and the consumption of the cheap sources was increased and 8% and 79% of the total required energy was covered by tire chips and coal respectively.

In Table 3, the effect on unit power consumption in the EAF, subject to the change of the temperature in the rotary kiln is described. As you can see, within the range between 500℃ and 650℃, little difference can be seen. However, the deoxidization by gas decreases significantly and unit power consumption deteriorates.

Consequently, it should be optimum to operate the rotary kiln at 700℃ where the combustion of coal and tire chips is stable and unit power consumption doesn't deteriorate. Further, the coal consumption was determined so that the adjustment of the temperature in the rotary kiln can be done within the range of the EAF gas consumption between 1,600 ± 800 Mcal/h, even if the quantity of raw materials varies. Thus, the temperature in the rotary kiln can be automatically controlled by the adjustment of the EAF gas regardless of the raw materials quantity. Consequently, we were able successfully to reduce energy consumption by 25 % and labor from 3 persons to 1 person.

Table 1. Problems in the Rotary Kiln Operation and Counter Measures

PROBLEMS BEFORE IMPROVEMENT	COUNTER MEASURES
1. Clinging of raw materials occurs easily due to the high temperature, 950℃. 1) Much difficulty in disposing cling-on material 2) Deterioration of furnace utilization due to frequent clogging with raw materials	1. The optimum operation has been searched by running the simulation model and the temperature has been reduced to 700℃.
2. Energy cost increases in the low load operation. 1) Increase of kerosene consumption 2) Decrease of salable EAF gas	2. Review of the temperature and the change of energy source mix 1) Increase of coal consumption 2) Utilization of tire chips
3. Processing quantity of raw materials varies in the low load operation 1) Unstable temperature in the rotary kiln 2) Unstable oxidization of raw materials and quantity of carboneous materials	3. Standardization of raw material process to five patterns
4. Manual temperature control in the rotary kiln leading to : 1) Unstable temperature 2) Much loss of energy	4. Automatic control 1) 87% of the required energy is covered by coal and tire chips 2) Adjustment of temperature by the automatic control of EAF gas

Table 2. Energy Consumption

RAW MATERIALS	ENERGY CONSUMPTION BEFORE IMPROVEMENT(Mcal/h)				
QUANTITY(T/h)	COAL	EAF GAS	TIRE CHIPS	KEROSENE	TOTAL
20	4,390	8,060		400	12,850
25	5,490	9,200		430	15,120
30	6,590	10,340		460	17,390
RAW MATERIALS	CALORIE CONSUMPTION AFTER IMPROVEMENT(Mcal/h)				
QUANTITY(T/h)	COAL	EAF GAS	TIRE CHIPS	KEROSENE	TOTAL
10	4,080	1,600	1,020	140	6,840
15	5,630	1,600	1,020	140	8,390
20	7,180	1,600	1,020	140	9,940
25	8,730	1,600	1,020	140	11,490
30	10,280	1,600	1,020	140	13,040

Table 3. The Effect on Unit Power Consumption in the EAF,
Subject to the Charge of the Temperature in the Rotary Kiln

Quantity of Heat	Temperature of Discharged Materials (℃)					
(×Mcal/t)	500	600	650	700	800	900
Sensible Heat of Exhaust Gas	57	62	62	64	64	73
Sensible Heat of Raw Materials	-233	-287	-315	-342	-397	-452
$MnO_2 \rightarrow MnO$	352	326	282	254	118	72
$C \rightarrow CO, CO_2$	-1,212	-1,141	-1,065	-1,005	-748	-641
H_2O(C.W.) $\rightarrow H_2O$	20	15	10	8	2	0
$CaCO_3, MgCO_3 \rightarrow CaO, MgO$	13	9	3	1	0	0
Heat Loss	561	575	583	591	608	636
Other	2,147	2,143	2,143	2,143	2,142	2,,142
Total	1,705	1,702	1,703	1,714	1,798	1,830
Power Consumption (kWh/t)	1,985	1,981	1,983	1,995	2,083	2,130

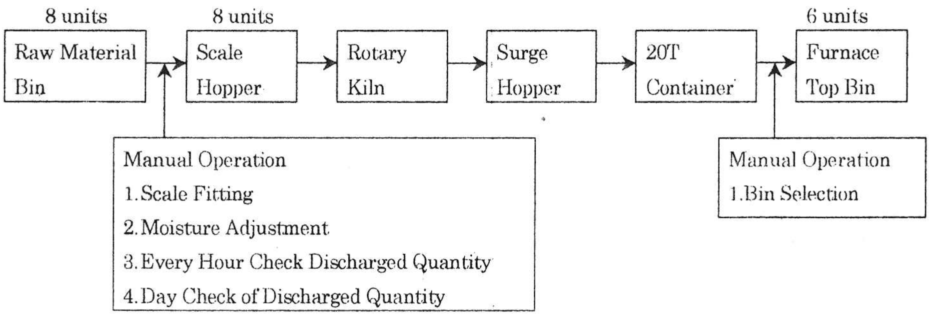

Fig.3. Flow Chart of Raw Materials Mixing

Automation of Raw Materials Mixing

As you can see in Fig. 3, there used to be two points where the raw manuals mixing process had been performed manually. Also, one person per shift had been required for raw materials mixing to meet the frequent change of the quantity of raw material required by different operative loads. The required number of such person has been reduced by automation of the manual operations.

Automatic Control of EAF

In the EAF operations, the following automation has been carried out.

① Slipping of electrode
② Raising and lowering of electrode
③ Control of power load

Excluding these operations, for instance, the gas exhausting system can be controlled by sequencer to some extent, therefore, it has been excluded from the operations to be automated. While, with regard to control of power load (③ above), the controller was designed so that it can control :

a) The target power load in the normal operation (the different load operation is done in order to make use of the cheap power during night time and the target load is different between day and night time.)

b) The power load in the irregular operation (the target load is lowered while the furnace condition is getting worse and it can be reduced.)

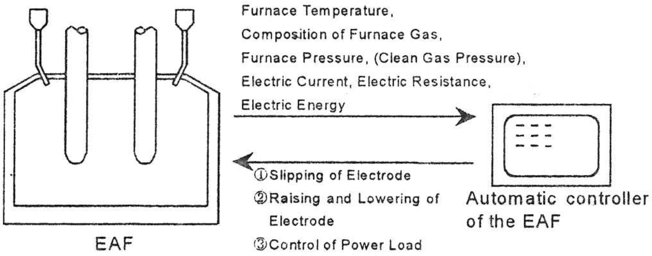

Fig.4. The Outline of the Automatic Control of EAF.

In the Fig. 4, the outline of the automatic control of the EAF is described. From the EAF, the data on the furnace condition such as furnace temperature, composition of furnace gas and furnace pressure and on the electrode condition such as electric current and electric resistance are measured and transferred to the controller. Then, such data is analyzed and the data on the control of slipping of electrode etc. is output based on the result of the analysis. (See Fig. 5)

Control of Electrode Slipping

Electrodes are baked by the heat from hot charged raw materials and the change of the temperature inside of the electrode is small, therefore, break down of the electrode doesn't occur relatively. In this connection, the strict and special control of electrode isn't required. Therefore, the simple method that each electrode is automatically slipped when the electric current of it reaches a certain level is employed. If the electrode slipping value is set to the point where the values of the electrode slipping and the consumption are balanced, the length of the electrode is always in the same position. However, the value of the electrode slipping is determined by the controller.

Control of Electrode Raising and Lowering

The operation is controlled in order for the resistance, R to be stable and the electrode is raised and lowered so that the resistance of each electrode can be at the target level. Further, the operation that the electrode is raised and lowered per a certain time and mix the raw materials is done in order to prevent the raw materials in the raw material feeding chute from being sintered.

Control of Power Load

In the normal operation, power load is controlled by increasing and decreasing the tap voltage so that it reaches close to the target level within the range up to the limited electric current restricted by the capacity of the equipment.

The power load is controlled based on the following three parameters :

a) Gas pressure inside the furnace and clean gas pressure

b) Temperature inside the furnace and its variation

c) Furnace gas CO% and its variation

Here, the variations are calculated by multiplying the sum of the square of the variations during unit time in 60 samples by a coefficient. (See Fig. 6) Further, the two different unit times, long time and short time are set up, therefore, the two parameters for the different unit times are calculated.

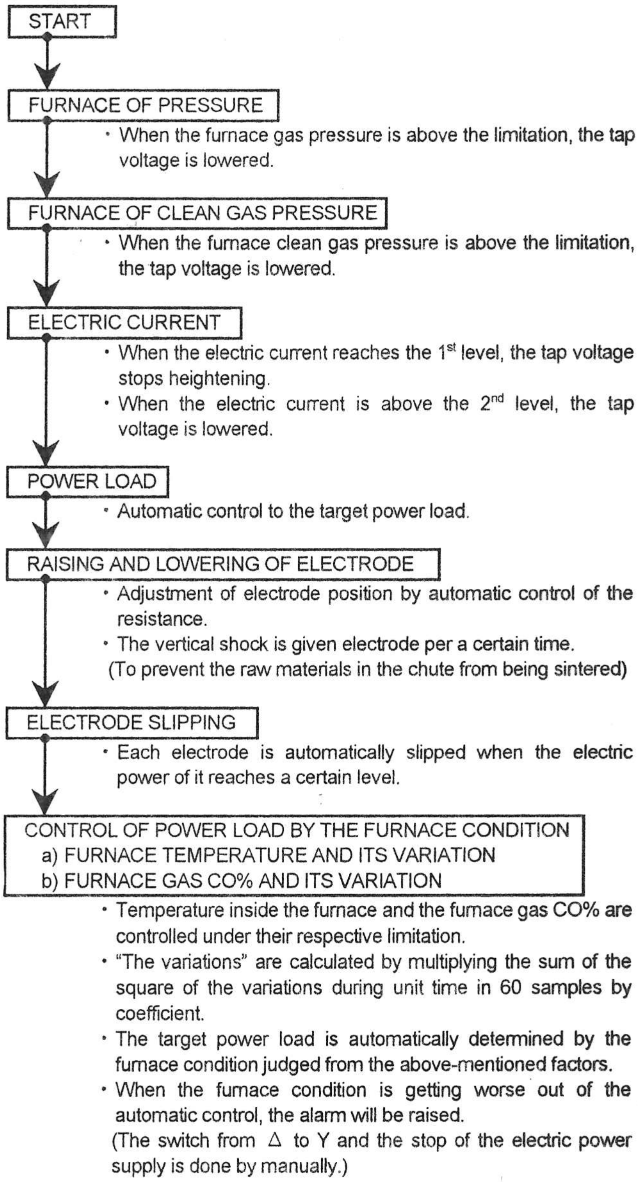

Fig.5. Flow of Automatic Control of EAF

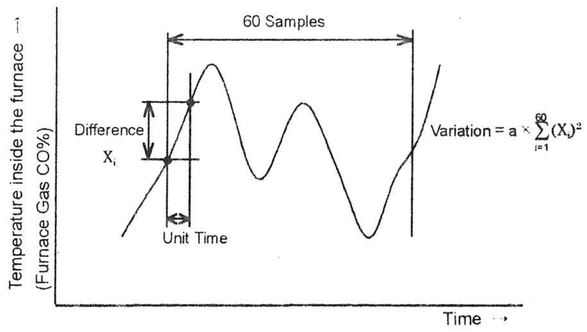

Fig.6. Image og Vatiation

When the automatic operation was introduced, any other special parameters weren t added and the above parameters as the indications of the furnace condition had been referred by the furnace operator in the previous manual operation.

If the operator judged that the furnace was in an unsustainable condition, the deterioration of the furnace condition should be avoided by lowering the target power load as necessary as per the following procedures.

a) The gas pressure inside the furnace and clean gas pressure have their limitations and if actual figures go beyond such limitations, the tap voltage will be lowered in order to lower the power load.
b) The temperature inside the furnace is controlled at the three levels and if the actual figure goes beyond each level, the power load will be lowered from the first level to the third level.
   If the third level continues for more than a certain time, the alarm will be raised.
c) The variation of the temperature inside the furnace is controlled at the four levels which are determined by the combination of the long time variation, the short time variation and the continuous time.
   If the forth level continues, the alarm will be raised.
d) The furnace CO% is controlled at the three levels and if actual figure goes beyond each level, the target power load will be lowered from the first level to the third level.
e) The variation of the furnace CO% are controlled at the four levels which are determined by the combination of the long time variation, the short time variation, the continuous time and the furnace CO%.
   At the each level, the power load will be lowered and if the fourth level continues during a certain time, the alarm will be raised.

The alarm indicates that the furnace isn't in the condition where it can be controlled automatically and such being the case, the furnace operator should operate the furnace manually as per the standards of emergency and as the case may be, the operator should take the necessary counter measure such as to stop off the electric power supply. (The switch from Δ to Y and the stop of the electric power supply should be done by manually instead of automatically.)

In the case that the above a) to e) occur at the same time, the biggest one is selected. However, in many cases, judgement of the furnace condition is made based on the variation of the furnace gas CO% and other parameters work as subsidiary factors.

Different Load Operation

As described in Fig. 7, in Japan, the unit power price during day time is much higher than that during night time by five times. Therefore, the operation is done at the maximum load during night time when the unit price is cheap and the power load is at minimum as much as possible during day time when the unit price is expensive.

As described in Fig. 8, the different load operation is carried out and the load during night time and day time is 23 MW and 3 MW respectively.

In the different load operation, the points of operation are :

① Break down of electrode
② Decrease of metal temperature
③ Adjustment of the quantity of coke

In the different load operation, in the low load operation, the biggest point is counter measures against the break down of electrode. In general, such counter measures are taken by changing the load generally and controlling the temperature inside of the electrode. However, in our operation, the electrodes are baked well by heat from hot charged raw materials. Therefore, as described in Fig. 5, the change of load is done instantly. Besides, as the counter measures against the decrease of the metal temperature, the same quantity as that during night time are mixed during day time.

Due to the different load operation mentioned in the above, unit power price has been reduced by half. compared with that in the flat load operation.

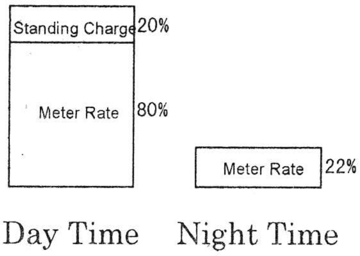

Fig.7. The Unite Power Price of Day Time and Night Time

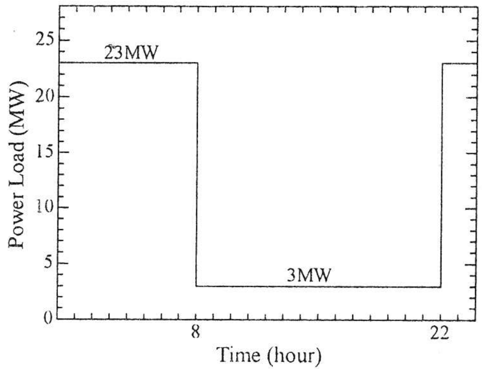

Fig.8. Different Load Operation

Decrease of the Number of Tapping

In the flat load operation, the number of tapping was eight/day (four times for metal and four times for slag) and the tapped quantity was 60 MT.

In order to reduce the labor cost, the tapping material cost and the mid night work, the number of tapping has been decreased. As described in Table 4, the counter measures against the three points were taken. Consequently. the tapped quantity has been able to be increased to 150 MT, though the load during night time hasn't been lowered and the furnace condition hasn't deteriorated.

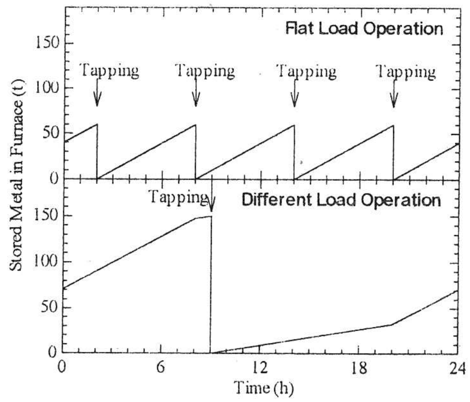

Fig.9. Tap Interval

Table 4. The Problems Caused by the Decrease of the Number of Tapping and the Counter Measures

PROBLEMS	COUNTER MEASURES
1.The furnace wall is relatively low for the increase of the molten metal quantity.	1.The height of furnace wall lining is Increased from 2.5 m to 3.2 m.
2.The electric resistance inside the furnace decreases. 1)The furnace is over heated. 2)The load is difficult to be conducted during night time. 3)The furnace condition deteriorates.	2.Unit coke consumption is reduced from 346 kg/MT to 325 kg/MT by improving the rotary kiln operation. The deterioration of the furnace condition is prevented by the automation of the control of the furnace.
3.The tapping pressure increases.	3.The cooling is strengthened by changing the lining to all carbonized materials.

Table 5 Labor Reduction Effect

ITEM	BEFORE	1ST STEP	2ND STEP	3RD STEP
ROTARY KILN OPERATION	3×3	3×3	2×3	2×3
MIXTURE OF RAW MATERIALS	1×3			
GAS CLEANING OPERATION	1×3			
CONTROL ROOM	1×3			
TAPPING OPERATION	4×3	4×3	3×3	1.5×3
MANAGER	1×3	1×3	1×3	0.5×3
EAF OPERATION	33/D	24/D	18/D	12/D
LABOR PRODUCTIVITY	2,580MT/P/Y	3,120MT/P/Y	3,890MT/P/Y	4,920MT/P/Y

NOTE:

1. 3×3: 3 Person/Shift × 3Shift
2. 1ST STEP: 1) The different load operation started.
   2) The rotary kiln operation was automated.
3. 2ND STEP: 1) The mixture if raw materials was automated.
   2) Control rooms was restructured.
4. 3RD STEP: 1) The EAF operation was automated.
   2) The number of Tapping was decreased.

Labor Reduction Effect

The total production per year was to be decreased to 60 % of the previous year by carrying out the different load operation, consequently, we anticipated that the labor productivity would deteriorate significantly. However, due to the various automations and improvements of the operation, as described in Table 5, the labor productivity has significantly increased from 2,580 MT/person to 4,920 MT/person.

Conclusion

Due to the automation and improvements of the operation, the labor productivity has increased by 1.9 times. Besides, the unit power price has decreased by half through the different load operation. Consequently, the production cost has been successfully reduced by 25 %.

However, our labor cost is still higher than those of overseas producers, therefore, we should make our utmost effort to continue to reduce our costs further.