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OPTIMISATION OF SPECIFIC POWER CONSUMPTION IN THE PRODUCTION OF FERRO ALLOYS THROUGH RATIONALISATION OF CHARGE DISTRIBUTION

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ABSTRACT

Production of ferro-chromium in the submerged-arc furnace is highly energy-intensive. Several process rates have been attempted to reduce the specific energy consumption in the production of this alloy. An exhaustive understanding of the thermo-chemical features of the production process can be used to reduce the specific power consumption significantly. The knowledge can be used to reduce the energy drain through undesired reactions in the process can be minimised. Plant trials have shown that specific energy consumption upto 100 kWh/tonne of hot metal can be obtained by adopting this strategy. The process requires modification in operation practice and does not require any capital investment unlike other processes adopted for reducing power consumption. The principle of thermo-chemistry involved in this process development and results of plant trials are discussed in detail.

1. INTRODUCTION

The specific power consumption in the production of ferro-chromium can be as high as 3.8 MWh/tonne of hot metal and sometimes exceeds 4.0 MWh/tonne. Considerable efforts are made in industries to reduce the specific power consumption by adopting novel processes and practices. A thorough analysis of the thermo-chemistry of the process shows that there is considerable scope to exploit the energy distribution and optimise the specific power consumption. The hot metal produced in the process contains chromium and iron as the major constituents. Apart from these, it contains significant levels of silicon. Though silicon is desirable in the hot metal at certain levels to improve its fluidity, at higher levels it is not only undesirable being a major impurity, it also leads to considerable drain of energy. If the silicon level in the hot metal can be brought down by one percentage point (say, from 3.5% - 2.5%) this can result in a saving of 3750 MWh of energy per annum for a plant producing 50,000 tonnes of ferro-chromium every year. The thermo-chemical nature of the process and the thermal profile prevailing in the furnace can easily facilitate a reduction in the specific energy consumption through minor modifications in the operation procedure.

2. REDUCTION REACTION

Table 1 gives a typical analysis of the charge material used in the production of ferro-chromium[1]. The charge consists of a mixture of chromate ore, coke and quartz as flux. A typical temperature profile in the submerged-arc furnace(S.A.F). has been derived through mathematical modelling[2]. The temperature varies from about 2000^{o}C at the top of the electrode to about 250^{o}C at the top of the charge bed. Investigations on the reducibility of the chromate ores show that iron starts getting reduced at 900^{o}C. The reaction is usually complete at 1000^{o}C. The reduction of chromium commences at 1200^{o}C and is completed by the time the charge reaches[3-16] 1400^{o}C. The rate of reduction of chromium is enhanced by the reduction of iron due to the formation of alloy of iron and chromium. Therefore, as the charge descends through the various temperature zone of the S.A.F, its composition changes due to the various reduction reactions occurring to various extents in the different zones. It is observed in laboratory experiments that reduction of silicon (present in the ore, in quartzite and the ash of coke) can get reduced at temperature as low as 1400°C supplied by the formation of the FeCrSi alloy.

Table 1: Charge used in the production of ferro-chromium (tones/day) [1]

H.L.	*F.L.*	*S.P.*	*Coke*	*Quartzite*
168.4	66.973	135.770	86.094	25.297

Note : H.L. - hard lumpy ore; F.L. - friable ore: S.P. - sinter pellet

3. SLAG-METAL EQUILIBRIUM

As the charge descends through higher temperature zones, above 1600°C, liquid slag is formed. The interaction between the slag and metals is rapid and equilibrium is reached. Therefore, the composition of the metal is determined by the equilibrium between the two phases above this temperature. The composition of the metal in equilibrium with the slag at different temperatures is given[17] in table 2. A striking feature of the equilibrium compositions of the metal is that silicon is not present in the hot metal at temperatures less that 2000°C. The zone where temperature is equal to or above 2000°C is close to the electrode.

Table 2: Chemistry of metal in equilibrium with slag[17] (mass%)

Temperature, ℃	*%Cr.*	*%Fe*	*%C*	*%Si*
1600	64.24	24.03	11.77	0.0
1700	64.24	24.03	11.77	0.0
1800	64.24	24.03	11.77	0.0
2000	64.95	17.69	3.604	13.76
2100	65.53	16.73	3.069	14.67
2200	65.82	16.45	2.650	15.08

The charge can be assumed to move uniformly through the cross-section of the S.A.F. Since silicon is produced excessively in the light temperature zone where the temperature is 2000°C or above, it is possible to predict the size of the zone from mass balance for silicon between the charge and the metal and slag produced. The level of silicon in the hot metal produced can be shown to be a linear function of the high temperature zone of the form:

$$(\%\mathrm{Si})_{\mathrm{hm}} = X^{*}(\mathrm{Si})_{\mathrm{B}} \tag{1}$$

where $(\%\mathrm{Si})_{\mathrm{hm}}$ is the percentage of silicon in the hot metal, $(\%\mathrm{Si})_{\mathrm{B}}$ is the equilibrium level of silicon in the hot metal in the high temperature zone expressed as a mass percentage. ‘X’ is the relative size of the high temperature zone. As indicated above, the size of the high temperature zone can be predicted from a mass balance for silicon. The size of this zone predicted through this model was in good agreement with that predicted based on the model of thermal profile in the SAF[18]. Good agreement between results obtained using the two different models enhances the applicability of the model.

Data were collected from different industrial plants producing ferro-chromium. The size of the high temperature zone was correlated with the level of silicon in the hot metal, in each case. The following expressions were obtained in the four cases studied:

$$(\%\mathrm{Si})_{\mathrm{hm}} = -0.04 + 14\,X \tag{2}$$

$$(\%\mathrm{Si})_{\mathrm{hm}} = 0.24 + 12\,X \tag{3}$$

$$(\%\mathrm{Si})_{\mathrm{hm}} = -0.43 + 14X \tag{4}$$

$$(\%\mathrm{Si})_{\mathrm{hm}} = -0.32 + 15\,X \tag{5}$$

Two of the cases above are illustrated in figures 1 and 2. It is obvious that there is a linear relation between the size of the high temperature zone and the level of silicon in the hot metal. The intercepts in the expressions are negligible and close to zero. Hence, the expressions are consistent with that derived theoretically in expression (2). Such an excellent agreement between the model and plant observations enhances the utility of the thermo-chemical model and its role in devising appropriate operation practice to maximise the process-efficiency.

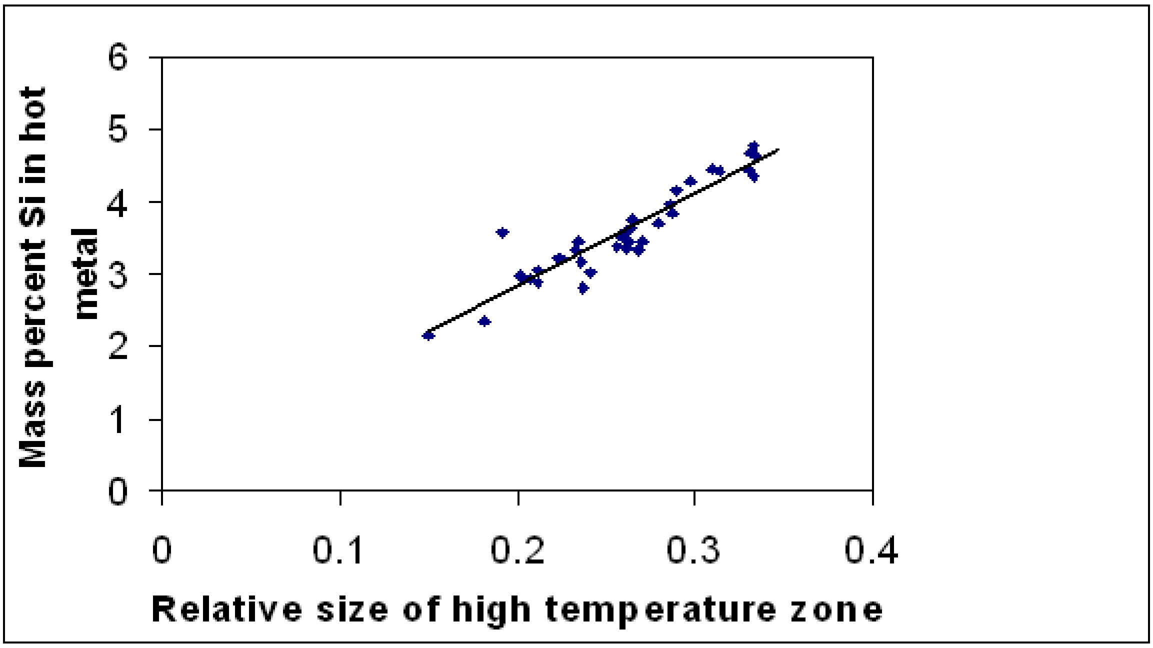

Figure 1: Silicon level in hot metal as a function of the size of the high-temperature zone (case 1)

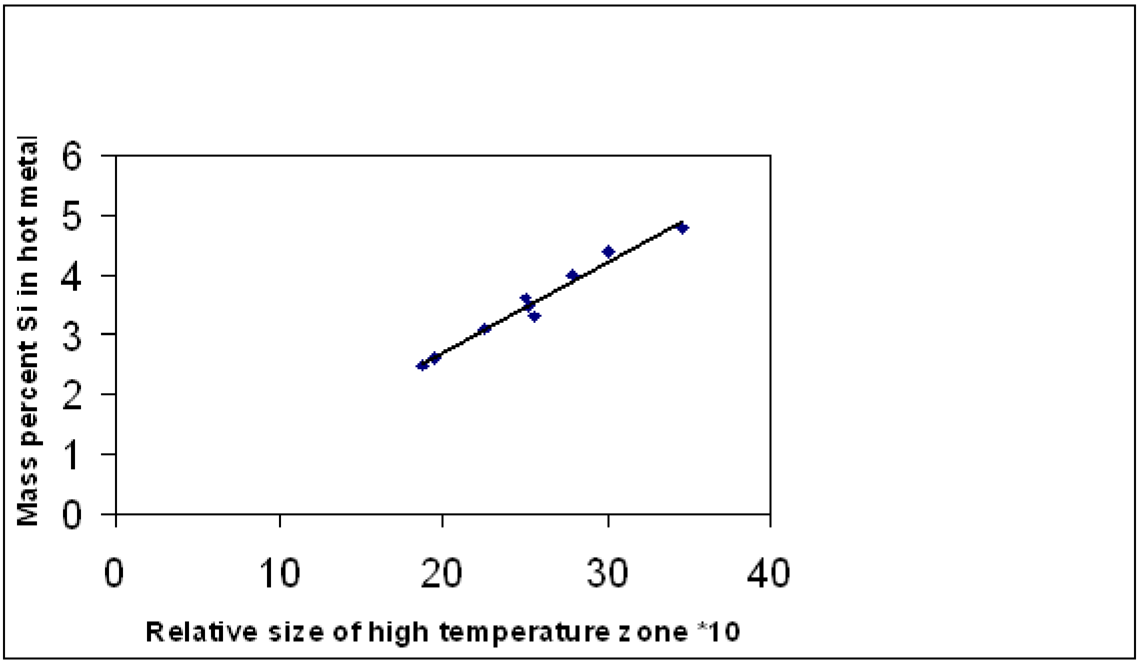

Figure 2: Silicon level in hot metal as a function of the size of the high temperature zone (case 2)

4. CONTROL OF ENERGY CONSUMPTION

If the extent of reduction of silicone in the charge can be decreased utilising the energy and coke available for the reduction in the charge, the specific energy consumption can be decreased. From expression (2)–(6) above, it can be seen that this objective can be achieved if the amount of silica passing through the high temperature zone can be reduced. The thermo-chemical model and the mathematical expressions derived above retaining the spatial dimensions of the furnace to the extent of silicon recovery provide an excellent tool to achieve this. Silica in the charge comes from quartzite ore and coke. About 50% of the silica charged is in the form of quartzite. The conventional procedure of ferro-chrome production mixes all the low materials and charges them uniformly across the cross-section of the furnace. If the quartzite present in the burden is segregated and distributed selectively, it can be ensured that the energy and coke would automatically be utilised in greater recovery of chromium resulting in a reduction in specific power consumption.

5. PLANT TRIALS

Plant trials were conducted at an industrial furnace to validate the model. This furnace had six chutes feeding the raw materials. Three of the chutes were located such that each pair of electrode had a chute in between them. The other chutes were on an outer circle such that the centre of the chute, that of one of the electrodes and the centre of the furnace were co-linear. From the geometry and dimension of the furnace and chutes, it was estimated that about 61% of the material charged through the inner chutes passed through the high temperature zone and 29% of the material charged through the outer chutes passed through the high temperature zone where the temperature was 2000^{o}C or above.

A typical charge contained about 72-78% chromate ore, 15-22wt.% coke and 4-7wt.% quartzite. The charge was divided into two portions. The first portion had the same proportion of ore and coke as above but the proportion of quartzite was reduced. This was balanced by adding the same quantity of quartzite to the second portion of the charge. Thus, the second portion had the same proportion of ore and coke as the first portion but a higher level of quartzite. The first portion of the burden was charged through the inner chutes and the second portion through the outer chutes during the production operation. Data were collected on the chemistry of the raw materials; that of hot metal and slag and on power consumption during the trials.

6. RESULTS AND DISCUSSION

To evaluate the performance of the process during the trial period, the average power consumption for a period of one week preceding the trial period was taken as a reference. The other operation parameters of the process, such as the nature and quantities of raw materials charged, the power supply characteristics etc. were maintained constant during the trial and reference periods. The average specific energy consumption during the trial period was compared with the average for the preceding week. During trial-1, the average energy consumption was 3.317 MWh/THM. The average for the preceding week was 3.439 MWh/THM. During the second and third phase of the trials, the average specific energy consumption was 3.362 MWh/THM. The average specific energy consumption for the preceding week was 3.466 MWh/THM. Table 3 shows[1] the level of silicon in the hot metal during the trial period compared with that obtained during the reference period. It is obvious that the modified operation practice decreased the level of silicon considerably. Table 4 gives[1] the fraction of the total carbon charged that was used in the reduction of SiO_2 to Si. This table also gives the fraction of silicon recovered out of the total charged. It is demonstrated that the recovery of silicon decreased considerably during the trial period. This also released significant amounts of carbon for other reduction reactions. Hence, the specific power consumption decreased during the trial period.

Table 3 : Silicon level in hot metal during the trial period

Trial No	*Tap. No.*	*Ref.*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
1	%Si	3.4	3.63	3.55	3.15	2.76	2.48	2.45	2.63	2.60	2.68	2.86	2.76	3.23
2	%Si	4.14	3.27	3.79	3.39	4.22	3.00	3.08	2.45	2.56	2.96	3.11	3.19	3.25

Note : The silicon level against the column marked ‘Ref.’, represents the silicon at the beginning of the trial period.

Table 4 : Fraction of carbon consumed in recovery of silicon

Trial	$(\%Si)_R$		$(\%C)_{Si}$	
	Tri.	*Ref.*	*Tri.*	*Ref.*
1	15.35	20.83	5	5.66
2	25.83	22.62	7.45	7.87
3	17.55	22.62	6.04	7.87
4	17.99	22.62	5.98	7.87
5	22.61	22.62	7.17	7.87
6	18.71	22.62	5.97	7.87

Note: (%Si)R – percentage of silicon recovered
(%C)Si – percentage of carbon consumed in the reduction of silica
Tri. – trial period
Ref. – reference period

The same principle can be applied to the optimisation of specific power consumption in the production of ferro alloys. A case which is very similar to the above is the control of the reduction of Al_2O_3 in the production of ferro-silicon. Adopting the process illustrated above, the specific power consumption can be lowered here, also. Other similar cases in the production of ferro alloys can be explored.

7. CONCLUSION

Modelling of the thermo-chemistry of the production of ferro-chromium in the submerged-arc furnace showed that it would be possible to reduce the specific energy consumption in the production of the alloy by rationalising the distribution of charge. Plant trials were carried out to validate the model. The trials showed that it was possible to reduce the specific energy consumption by about 100 kWh per tonne of hot metal produced by adopting this strategy. A similar process can be adopted to optimise the specific power consumption in the production of other ferro alloys also.

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