RESEARCH NOTE

Effect of Impurities on Energy Requirements in Electric Steelmaking with DRI

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Utilization of low-quality raw materials introduces considerable constraints to the development of continuous steelmaking systems. The additional heat requirements, due to the enhancement of gangue and impurity elements, influence the length of refining and the economics of the process. Optimization of the refining process through adaptation of innovative designs for charge materials, feeding method, heating system and operational procedures can help in reduction of the energy requirements, the total melting/refining times and the volume of the fluxes generally required. These improvements can help the steelmaker to customize the post-steelmaking operations.

INTRODUCTION

Recent increases in the content of impurity elements in the iron ore deposits of the world have caused great concern regarding the economics of the alternative iron and steel manufacturing processes. Electic arc steelmaking with direct reduced iron and the in-bath steelmaking processes are two familiar examples [1.2]. The former is traditionally used to convert mixtures of scrap and DRI into steel while the latter incorporates a pre-reduction unit which produces partially reduced materials and a melting unit which produces liquid iron.

The final refining of liquid iron to steel can be done in a separate steelmaking unit or (after modification) in the same smelting unit. During the pre-reduction process, the percentage of oxygen (and to a lower extent sulfur) is drastically reduced while that of the phosphorus is slightly increased due to the reduction of the oxygen content of the ore.

The overcharge into the furnance of phosphorus contained in the ore has substantial effects on the electric furnace performance. The inevitable rise in the quantity of the reagents charged into the molten bath, not only imposes a decrease on the productivity of the furnace by enhancing the volume of the slag, but also results in an increase in the consumption of energy. A detailed calculation of these effects is necessary in order to develop a quantitative understanding of the subject.

The phosphorus carried with DRI to the electric arc bath must be removed from the metallic phase through a dephosphorization treatment. An extensive dephosphorization treatment can dramatically affect the steel refining process. Some of the changes imposed are: prolonged heating times, increased quantities of the basic oxides utilized as reagent materials and additional energy consumption for melting the excess gangue minerals and compensation of heat loss.

How quantities of phosphorus and gangue influence the economic evaluation of an ore

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deposit is a question to be answered before deciding to utilize any poor quality raw material for a specified technical route. It is of considerable interest to quantitatively aquire the influence of impurities on the economics of the system when faced with the choice of alternative strategies [3,4].

Optimization of the melting process can result in a set of design-variables that, if employed properly, may cause a substantial saving in the high temperature performance of a specific melting/refining system. Detailed information on the physical chemistry of the refining reactions and the heating and melting processes taking place in the hot liquid bath are required for running an optimization procedure.

A comprehensive calculation is carried out on the material consumption and the heat requirements in order to achieve the desirable values for the influential parameters. A relatively detailed quantitative study is presented in this article on the effects of the chemical content of gangue minerals and phosphorus which are carried with the continuously charged iron ore into the steelmaking bath. Essential use is made of the thermochemical information available in the literature [5,6].

ASSUMPTIONS

The chemical composition of the ore samples used in this study are given in Table 1. The quantity of gangue minerals in the ore remains nearly the same during the pre-reduction process but, because of the removal of a substantial quantity of oxygen and the deposition of carbon inside the pre-reduced pellets, the weight fractions of the components will change.

Table 1. Chemical composition of gangue in the ore samples.

Material	Weight Percent					
	1	2	3	4	5	6
SiO_2	1.23	1.44	1.62	1.92	2.36	3.08
Al_2O_3	0.77	0.90	1.01	1.20	1.48	1.92
CaO	1.84	1.63	1.45	1.15	0.71	0.00
MgO	1.16	1.03	0.92	0.73	0.45	0.00
Total	5.00					
$\frac{CaO + MgO}{SiO_2 + Al_2O_3}$	1.50	1.14	0.90	0.60	0.60	0.00

The gangue is assumed to be composed of chemical compounds specified in Table 2, where the total quantities of heat required for heating and melting of the gangue is given. These are calculated from the data presented in Table 3.

The fusion of gangue in the smelting furnace results in the formation of the slag that is assumed to contain 22 percent FeO. This percentage is suitable for extensive removal of phosphorus. The temperature of the liquid slag and that of the hot metal are assumed to be the same as and equal to 1873 K.

The enthalpy increments for heating and melting FeO are added to the total heat requirements for heating and melting the gangue, in

Table 2. Chemical compositions and enthalpy increments for heating and melting the gangue contained in the ore samples [3,5].

Compound	mol/kg					
	1	2	3	4	5	6
$CaO \cdot 2Al_2O_3$	0.7552	0.8827	0.9906	1.1770	1.4516	0.0000
$3CaO \cdot SiO_2$	0.1731	0.4539	0.9603	0.7645	0.2028	0.0000
$2CaO \cdot SiO_2$	0.1668	1.2298	0.3681	0.0049	0.1200	0.0000
$CaO \cdot MgO \cdot SiO_2$	1.7540	1.1091	0.5635	0.6210	0.2321	0.0000
$2MgO \cdot SiO_2$	2.0000	2.0000	2.0000	1.5000	1.0000	0.0000
$Al_2O_3 \cdot SiO_2$	0.0000	0.0000	0.0000	0.0000	0.0000	3.7662
SiO_2	0.0000	0.0000	1.5000	3.5000	6.3000	6.4851
CaO	3.2000	0.0000	0.0000	0.0000	0.0000	0.0000
$H^{\circ}_{1873} - H^{\circ}_{298}$, cal/g	678.73	668.16	647.16	627.23	594.90	489.52

Table 3. Enthalpy increments of materials [3,5].

Substance	$\Delta H^{\circ}_{1873-298}$ cal/g.mol	ΔH_m cal/g.mol	$\Delta H^{\circ}_{1873-298} + \Delta H_m$ cal/g.mol
$CaO \cdot 2Al_2O_3$	108000	-	(179000)
$3CaO \cdot SiO_2$	91000	-	(150000)
$2CaO \cdot SiO_2$	73000	-	(113040)
$CaO \cdot MgO \cdot SiO_2$	71700	-	(111158)
$2MgO \cdot SiO_2$	51000	-	(89876)
$Al_2O_3 \cdot SiO_2$	54000	-	(82040)
SiO_2	25800	2040	27840
Al_2O_3	46000	26000	72000
CaO	19750	19000	38750
MgO	18550	18418	36968
$Fe_{0.947}O$	29300	7490	29300
Fe	18500	3700	18500

() Calculated from other data.

order to determine the enthalpies that are necessary for formation of the slag phase. Proper corrections are made for transfer of iron from the liquid metal to the slag.

EFFECT OF GANGUE ON HEAT CONSUMPTION

The total quantity of heat required for melting both gangue and FeO is plotted in Figure 1 against the content of gangue in the ore. It is observed that the heat requirements increase slightly faster than gangue content. For a hypothetical gangue content of about 21% with basicity of 1.5, the heat required for production of the slag is the same as the heat required for melting one ton of pure iron pellets.

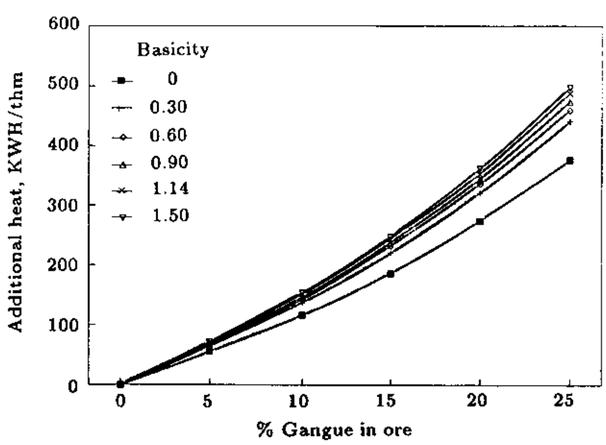

Figure 1. Additional heat requirements for formation of liquid slags with basicities specified on the curves.

In Figure 2, the quantities of lime that must be added to the furnace in order to modify the chemical character of the liquid slag by rising the basicity to 1.5, as well as the additional heat requirements for this rise, are plotted against the basicity of gangue in the pellets. In Figure 3, the total quantities of heat necessary for formation of such slags are plotted against gangue content of the pellets. It can be seen that the addition of lime to the furnace increases the slope of the curves. The

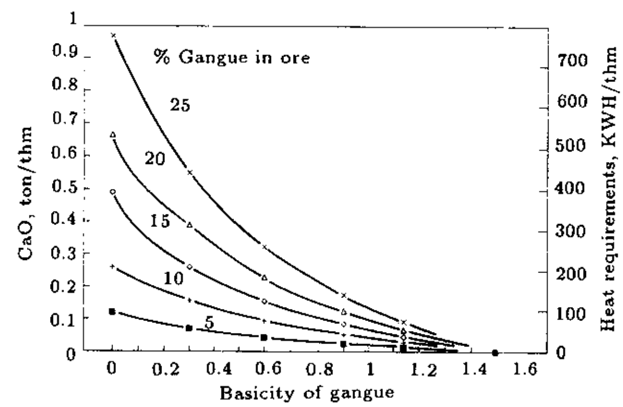

Figure 2. Quantities of lime and heat needed for production of modified slags with basicity of 1.5.

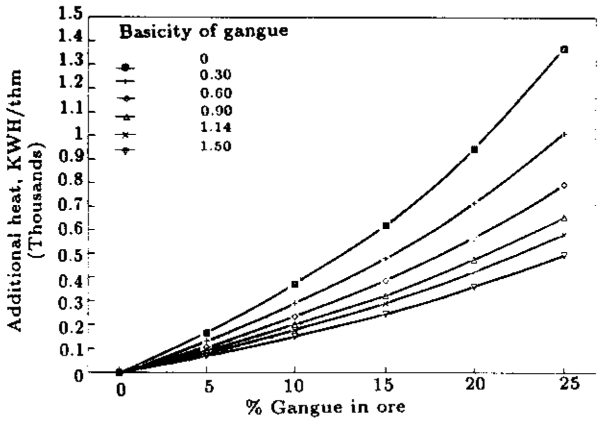

Figure 3. Quantities of heat required for heating and melting of gangue and lime for formation of liquid slags with basicity of 1.5.

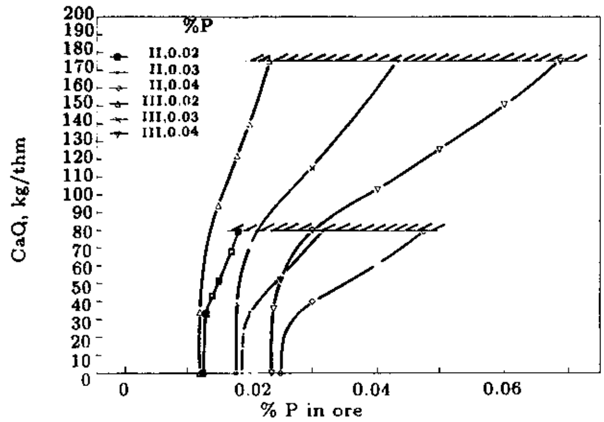

Figure 4. Quantities of lime required for controlling the P content of the bath to the specified levels.

data plotted in Figures 2 and 3 indicate that the basicity of gangue in the ore has a substantial impact on the heat requirements of the smelting furnace.

EFFECT OF PHOSPHORUS

Figure 4 illustrates the quantities of lime that must be added to the steelmaking slag in order to maintain the phosphorus content of the liquid metal at the levels specified in the figure. The specifications of the pellets, before and after the direct reduction, are given in Table 4. Calculations are made for smelting with 100 percent DRI pellets through a single-slag practice. The content of ferrous oxide in the slag is assumed to be maintained at 22 weight percent. The hatched lines show the maximum permissible levels of phosphorus in the ore. When the content of the phosphorus in the ore exceeds the contents shown on the hatched lines, bringing the phosphorus content to the specified levels will become impossible.

The dramatic changes in the slope of the curves when the phosphorus content is relatively low, indicates that the phosphorus scavenging power of the lime increases appreciably as the phosphorus content of the ore exceeds a break-through point at about 20 percent above the minimum phosphorus content required for production of the specified liquid melt.

Increasing the content of gangue loosens the constraint on the maximum permissible content of phosphorus in the ore but increases the quantity of the heat that is required for producing a certain amount of liquid metal. For simplicity, the additional heat requirements for production of one ton of hot metal is calculated

Table 4. Specifications of the ore and the DRI pellets.

Substance	Pellet II		Pellet III		Pellet IV	
	In Ore	in DRI	In Ore	In DRI	In Ore	In DRI
Iron	66.45	86.64	62.95	80.66	59.45	74.90
Oxygen	28.55	4.63	27.05	4.32	25.55	4.01
Carbon	–	2.20	–	2.20	–	2.20
Gangue	5.00	6.52	10.00	12.81	15.00	18.90
Total	100	100	100	100	100	100
Metallization Degree	0	86	0	86	0	86

by summing the heat that is necessary for production of the required volumes of the liquid slag for removal of the phosphorus up to the specified levels. It is assumed that the content of ferrous oxide in the slag remains the same (i.e. 22%). The contributions of the following items are considered in the calculations:

a) Heating and melting of gangue.

b) Heating and melting of the lime that is added to the furnace for removal of the phosphorus from the melt.

c) Heating and melting of the ferrous oxide contained in the slag phase.

Assuming that the phosphorus both in the ore and in the slag is in the same oxide form, the enthalpies of reduction and oxidation of the phosphorus are neglected. Since the phosphorus content of the ore is small, the enthalpy changes for heating, melting and dissolution of the elemental phosphorus are also neglected. The calculations are made for dissolved phosphorus contents of 0.02, 0.03 and 0.04 percent in the hot metal.

The results are illustrated in Figures 5 and 6, in which the total additional heat requirements for removal of the phosphorus is plotted against the phosphorus content of the ore. As can be seen from the data given in Table 3 and Figure 5, the additional heat that is essential for

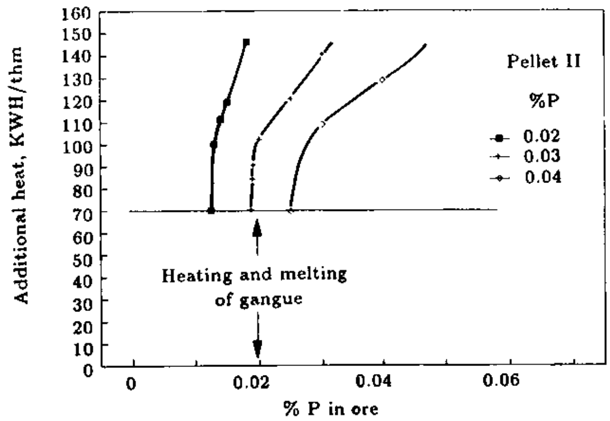

Figure 5. Quantities of heat required for formation of slag and removal of phosphorus from initial levels in steelmaking with DRI pellet no. II.

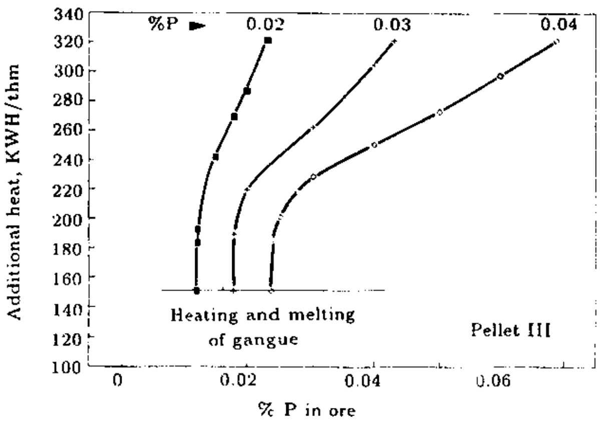

Figure 6. Quantities of heat required for formation of slag and removal of phosphorus from initial levels in steelmaking with DRI pellet no. III.

removal of the maximum permissible amount of phosphorus contained in the type II pellets is about 40 percent of the total heat necessary for melting 100 percent pure iron pellets. As can be seen from Figure 6, these requirements are doubled for type III pellets. This means that the additional heat necessary for removal of the phosphorus content of such pellets is more than 80 percent of the heat needed for melting pure iron pellets.

The total metallic losses which occur due to the transfer of iron into the slag, are plotted against the phosphorus content of the ore and the hot metal in Figure 7. As is shown, the rate at which the metallic losses increase against the phosphorus content of the ore is considerably less at relatively higher phosphorus contents.

The influence of the gangue content of the ore pellets on additional heat requirements, iron losses and the total weight of the slag produced per ton of hot metal for maximum permissible dephosphorization of the hot metal is illustrated in Figure 8. As is shown, the heat requirements and the metallic losses increase faster than the gangue content of the pellets. At a gangue content of about 11 percent, the additional heat that is required for maximum removel of phosphorus from the melt is equal to the heat that is consumed for melting one ton of pure iron pellets. At 20 percent, this amount exceeds twice as much.

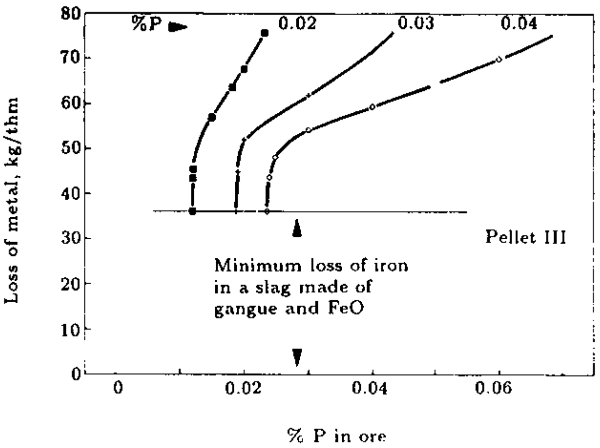

Figure 7. Effect of the phosphorus content of the ore and hot metal on the total losses of metal in steelmaking with DRI pellets II and III.

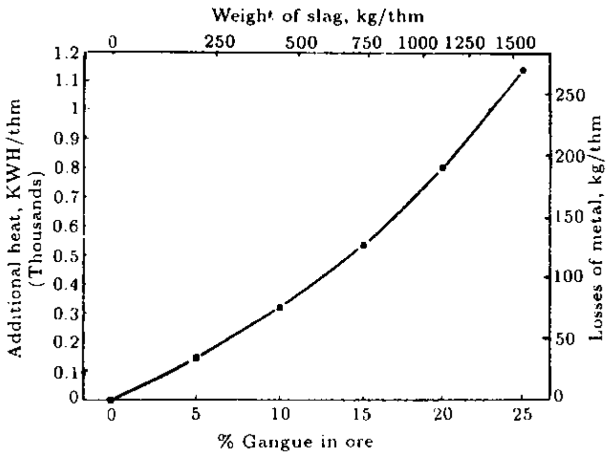

Figure 8. Effect of the gangue content of the ore on heat requirements, the iron losses and the quantity of the slag produced during the maximum permissible dephosphorization of the hot metal.

SUMMARY

Recent developments in alternative steelmaking technologies have increased the general need for high quality raw materials in production of iron and steel.

The addition of low grade materials with high phosphorus content into the smelting bath has the disadvantage of an increase in the time for refining, consumption of basic oxides and fluxes. quantity of metal that migrates into the slag and the amount of heat that is required for production of the same quantity of steel.

These increases are calculated based on the thermochemical information available in the literature. The results show that the production of ore agglomerate with a ballanced gangue basicity can lower the consumption of heat and improve the steel refining process. The chemical composition of the ore is obtained for an optimum refining operation.

The data given in Table 5 are recommended for achievement of maximum saving in energy consumption for elimination of phosphorus from the molten metal, produced by melting 100 percent DRI pellets in a smelting furnace.

ACKNOWLEDGMENT

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Table 5. Optimum phosphorus content of ore for maximum savings in the consumption of energy in electric steelmaking with DRI pellets.

Pellet	% Gangue		% Phosphorus	% Phosphorus	Iron Loss	Additional Requriements	
	In Ore	In DRI	In Metal	In Ore	kg/thm	Lime, kg/thm	Heat, 10^6cal/thm
	5	6.52	0.02	0.013 0.018	24.0 - 34.5	35 - 80	88 - 125
II	5	6.52	0.03	0.021 0.032	24.0 - 34.5	35 - 80	88 - 125
	5	6.52	0.04	0.029 0.048	24.0 - 34.5	35 - 80	88 - 125
	10	12.81	0.02	0.014 0.023	55.0 - 75.8	80 - 175	198 - 276
III	10	12.81	0.03	0.022 0.043	55.0 - 75.8	80 - 175	198 - 276
	10	12.81	0.04	0.031 0.069	55.0 - 75.8	80 - 175	198 - 276
	15	18.90	0.02	0.015 0.028	91.0 - 126.0	140 - 291	384 - 460
IV	15	18.90	0.03	0.025 0.055	91.0 - 126.0	140 - 291	384 - 460
	15	18.90	0.04	0.036 0.090	91.0 - 126.0	140 - 291	384 - 460

REFERENCES

1. Sadrnezhaad, K. "Continuous melting of metallised ore pellets", *Iron and Steel International*, **54**(6), pp 309-314 (1981).

2. Agrawal, J.C. "Strategic considerations in direct steelmaking", *Iron and Steelmaker*, **18**(3), pp 69-72 (1991).

3. Sadrnezhaad, K. "Direct reduced iron: An advantageous charge material for induction furnace", *Journal of Engineering*, I.R. of Iran, **3**(1–2), pp 37-47 (1990).

4. Hirsch, M., Fischer, P. and Serbent, H. "Continuous process of melting sponge iron", *U.S. Patent 4540432* (1985).

5. Elliott, J.F., Gleiser. M. and Ramakrishna, V. *Thermochemistry for Steelmaking*, **2**, Addison-Wesley (1965).

6. Young, R.W., Dufty, J.A., Hassal, G.J. and Xu, Z. "Use of optical basicity concept for determining phosphorous and sulphur slag-metal partition", *Ironmaking and Steelmaking*, **19**(3), pp 201-219 (1992).