Lecture 17 Alternative Charge Materials in EAF

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Key words: Sponge iron, DRI, electric arc furnace, UHP furnaces

Introduction

Raw materials and operating practices affect EAF efficiency and yield. The traditional EAF charge has been 100% cold scrap. The charge materials saturation is critical for several reasons:

- The product mix served by EAFs is moving more towards value-added steels, which are specified with low metallic residuals and low nitrogen levels (automotive flat rolled, cold heading- rolled and wire).
- The availability of scrap needed to meet the requirements of value added products is limited. The availability of scrap is decreasing as more and more near-net-shape metalworking operations appear.
- Yield and energy consumption are both strongly dependent on the quality and physical characteristics of the charge materials availability.

Type of metallic charge materials

- Pig iron/hot metal
- Directly reduce iron (DRI)
- Iron carbide (Fe_3C)

Pig iron

Pig iron is a good charge material because of its

- High density
- Low melting point
- Carbon contribution
- No tramp elements

It must be known that EAF is designed exclusively to use electrical energy. Pig iron contains $3-4\ \%C, 0.1-0.2\%\ P, 0.6-0.8\%\ Mn$ and $0.6-0.8\%\ Si$. Charging of pig iron means refining is to be done in EAF. For example if we make a charge mix containing 20% hot metal with 3.5%C and 80% scrap with 0.1%C to produce100 ton steel with 0.1% carbon. We need to remove around 640kgC. To remove this amount of carbon we would be needing $\approx 630\ \mathrm{m}^3$ oxygen on the assumption that oxygen utilization is 100% and is used for removal of carbon only. Under actual conditions we would be needing more oxygen to remove carbon if we take into account oxidation of $\mathrm{Fe} \rightarrow \mathrm{FeO}, \mathrm{Si} \rightarrow \mathrm{SiO_2}, \mathrm{Mn} \rightarrow \mathrm{MnO}$ and $\mathrm{P} \rightarrow \mathrm{P_2O_5}$. More proportion of pig iron in charge mix will increase oxygen requirement. What we learn from this simple calculation is that one has to supply oxygen under EAF condition and has to handle large amount of CO as well. Extra decarburization will increase tap to tap time and may decrease productivity. Under practical condition 30%hot metal is suggested to give optimum results with regard to productivity, electric consumption etc. The source of hot metal is either blast furnace or smelting reduction process. Hot metal can only be used when EAF plant is in close proximity of the blast furnace or smelting reduction units, otherwise one has to use pig iron and extra energy would be required to melt the pig iron

Direct reduced iron

Direct reduced iron (DRI) or hot briquetted iron (HBI) has emerged as an important substitute of the scrap. DRI does not contain any tramp element; hence substituting DRI for scrap leads to dilution of tramp elements in steel.

DRI is produced by reduction of iron ore with carbon or gaseous reducing agent. The product of gaseous reductant is HBI.

DRI contains: Free iron +oxygen combined with iron+ free carbon+ gangue minerals ($\mathrm{SiO_2}, \mathrm{Al_2O_3}, \mathrm{P_2O_5}$ etc).

Quality of DRI is important. Quality of DRI can be judged in terms of metallization and oxygen remaining. Metallization (M) is defined as

$$\mathrm{M} = \frac{\text{Free Iron} \times 100}{\text{Total Iron}} \qquad (1)$$

Higher is the metallization, less oxygen would be required to remove oxygen from iron oxide of DRI during steelmaking.

Consider 1000kg iron ore of composition $80\%\ \mathrm{Fe_2O_3}$ and 20% gangue minerals. Reduction of iron ore produces DRI in which oxygen is present as FeO.

Metallization (%)	Free iron (kg)	Fe-FeO (kg)	Gangue (kg)	Oxygen with FeO(kg)	Total gangue (kg)
80	450	110	200	31.00	310
85	480	80	200	18.00	280
90	500	60	200	10.00	260
95	530	30	200	3.00	230

We note from the table the following:

a) Increase in metallization increases free iron in DRI which is good.
b) Increase in metallization decreases iron which is combined with FeO. Lower amount of heat and reductant would be required to recover iron of FeO from DRI. Reduction of FeO with C is endothermic. Energy is required to compensate for the endothermic reaction.
c) Increase in metallization decreases the gangue minerals in DRI. Gangue minerals would be recovered as slag; decrease in gangue minerals will decrease slag volume during production of steel using high metalized DRI as a charge material.
d) Because of b) and c), the overall effect would be decrease in electric consumption and reduced electrode wear.

The benefits arising due to the use of high metalized DRI in charge materials must be considered along with the production cost of metalized burden. Overall economics of metalized DRI in electric steelmaking is important while deciding % metallization in the feed.

Another important issue in case of DRI is the proportion of DRI in the charge. For this purpose 1000 kg sponge iron of 90% metallization is to be used in different proportions. We consider charge mix is scrap and DRI. Calculations show that 1300 kg iron ore would be needed to produce 1000 Kg DRI with 90% metallization. The following table illustrates the influence of proportion of DRI on the free iron and other variables of DRI:

DRI (%)	Free iron (kg)	Fe-FeO(kg)	Gangue (kg)	Total gangue (kg)
10	66	7	27	36
30	198	22.4	81	110
40	264	29.2	108	146
50	330	36.0	135	181

We note the following:

i) Increase in proportion of DRI increases the free iron in the charge.
ii) Fe which is combined with oxygen as FeO increases with increase in the proportion of DRI. This would require extra amount of heat energy both chemical and thermal to reduce FeO to Fe and to raise the temperature of reactants to $1500-1600°C$.
iii) Gangue content of the DRI increases with the increase in proportion of DRI. This would lead to increase in slag volume and heat load.

What is the consequence?

A) Tap to tap time may decrease with the increase in DRI but more proportion of DRI may increase tap to tap time for two reasons, namely more time is required to reduce $FeO \rightarrow Fe$ and, to handle increase volume of slag.

B) Increased proportion of DRI beyond a limit may increase electrode consumption and refractory wear.

Carbon content in DRI

Carbon content in DRI helps reducing FeO to Fe. Excess carbon than required to reduce FeO would require oxygen injection. Oxygen in DRI is $0.286 \times \mathrm{FeO}$. Reduction of FeO is

$$\mathrm{FeO} + \mathrm{C} = \mathrm{Fe} + \mathrm{CO}. \qquad (2)$$

According to reaction 2 carbon requirement is $0.17\ \mathrm{kg/kg\ FeO}$.Carbon content in excess of $0.17\mathrm{kg/kg\ FeO}$ would require oxygen injection and CO will be generated. Excess carbon aids chemical energy which reduces electrical energy requirement. While producing DRI from carbononaceous reductant, excess carbon than reduction for FeO requirement is to be maintained. In DRI produced from gaseous reductant, extra carbon can be mixed with DRI or otherwise carbon injection is to be done.

Iron carbide

Other charging material is iron carbide which contains 6% carbon. It is prepared by heating iron oxide fines in a mixture of CO, CO_2, methane, H_2 and water vapour at temperatures between 550^{o}C and 650^{o}C and pressure 1.8 bar. Iron carbide is lighter than steel and is introduced pneumatically below the slag layer through a lance. Iron carbide has a melting point (2110 K) greater than molten steel and it dissolves in steel. On dissolution carbon of iron carbide is released, reacts with oxygen and releases heat which leads to saving in electric energy. Also CO produced foams the slag and brings advantages of slag foaming on the electric arc furnace operation. Iron carbide does not contain gangue and tramp elements. Use of iron carbide increases yield. However the benefits of iron carbide addition must be considered in relation to its cost of production and method of addition into electric arc furnace.

Charging methods for DRI

In small furnaces (lower than 5T) batch charging is preferred.

Continuous charging brings advantages like

- Less power off-time.
- Heat losses resulting from delays are eliminated.
- Lower electrical losses.
- Reaction between carbon and FeO of DRI produces strong carbon boil during charging which improves heat transfer and slag/metal mixing.
- Charging and refining take place simultaneously which reduces tap to tap time.

Continuous charging is preferred when the sponge iron or DRI is around 60%; the limitation is due to the small furnace capacity. However, ultra high powered furnaces can operate with 100% sponge iron.

References

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