Lecture 16 Developments in EAF steelmaking

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Key words: Electric steelmaking, bottom stirring, scraps preheating, foamy slag, chemical energy

Introduction

The growth of electric steel production around the world has been driven by lower investment, higher operational flexibility and easy adoptability to market demand on long or flat products of either plain carbon or alloy steels. Growth has been supported by updating installations and technologies to reduce the electric energy, electrode consumption and tap to tap time. Figure16. 1 shows the developments in
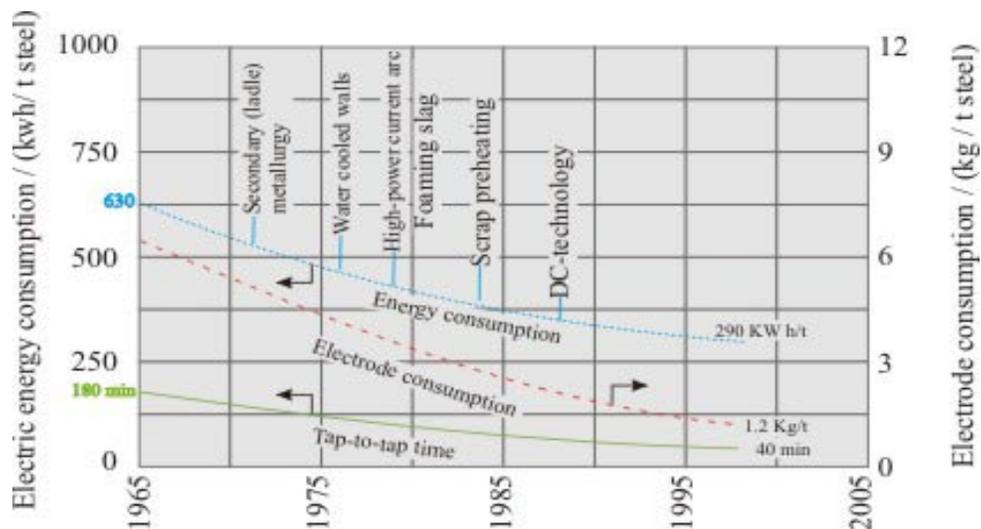

Figure 16.1: Trends in EAF steelmaking technologies developments in EAF steelmaking

electric steelmaking technologies. Developments in EAF technologies are strongly supported by secondary steelmaking. One can note in the figure that the power consumption has decreased from 630

Kwh/ton of steel to 290kWh/ton. Similarly tap tp tap time has decreased from 180 minutes to 40 minutes and electrode consumption has decreased from arounf 6.2 kg/ton to as low as 1.2 kg/ton within the periods of representation in the figure. This became possible with the several simultaneous developments in the secondary steel-making method. Table shows the various developments

Developments in EAF steelmaking

Furnace design	Process operating technologies	Chemical energy	Charge materials
Split shell design	Bottom stirring	Oxidation reaction	Directly reduced iron, hot metal
Transformer power	Foamy slag practice	Post combustion oxy fuel burner	
DC arc furnace	Scrap preheating	Carbon injection	

Furnace design:

i) Construction of hearth and lower side section of the shell of larger diameter than the top opening. This leads to increase in shell volume which results in larger tonnage charge, lower heat losses and improved thermal efficiency.

ii) In the split shell design, shell structure is constructed in two sections: lower section which contains hearth and free board allowance for slag, and upper section containing side wall and roof. The two sections are coupled such that the upper section can be repaired easily. This reduces the downtime and increases furnace availability.

iii) High powered transformers are the current trends. Most modern furnaces operate at $500 \, \mathrm{k \, VA/ton}$ and the trend is towards ultra high power ranging in between $700 \, \mathrm{k \, VA/ton}$ to $1000 \, \mathrm{k \, VA/ton}$. Developments are in progress to install transformer with $1500 \, \mathrm{k \, VA/ton}$ capacity. It is claimed that a 120 tons operating at $180 \, \mathrm{MVA}$ transformer capacity and by using refining combined burner technology through oxygen gas and carbon injection, it is possible to increase capacity by up to 50%. The largest transformer in AC EAF corresponds to a rated power 0f $240 \, \mathrm{MVA}$ for 300 ton furnace.

iv) Eccentric bottom taping reduces tap times, temperature losses and slag carry over into ladle. The strip producing plants are equipped with eccentric bottom tapping in electric arc furnaces.

v) DC (direct current) arc furnaces represent a different concept in arc furnace design. Most DC furnaces are with single electrode where current flows down from the carbon electrode to an anode mounted in the bottom of the furnace. Reduced electrode consumption of the order of 50 to 60 % is the major benefit of a dc furnace compared to a convectional three-phase arc furnace. Noise levels for the dc furnaces are lower. Lower maintenance costs are claimed and refractory costs are less for sidewall but more for the furnace bottom. A dc arc furnace requires an addition of the bottom electrode (anode), a dc reactor, and a thyristor all of which add cost to a dc furnace. The electrode technology limits diameter to a

maximum of 700 mm allowing a dc current of 100kA and 70 MVA power for single electrode furnace. Furnace size is limited to 200 tons. Further developments are in progress.

Process operating technologies

Most of the developments in process operating technologies are in AC- electric arc furnaces as these furnaces are popular.

i) Bottom stirring

In convectional arc furnaces there is little natural electrical turbulence within the bath. Due to absence of stirring large piece of scrap can take a long time to melt and may require oxygen lancing. Argon or nitrogen stirring

- Eliminates temperature and concentration gradients
- Shortens tap-to-tap times
- Reduces refractory, electrode and power consumption and
- Improves yield of iron and alloys

Industrial systems for bottom stirring are either with direct contact plug or with indirect contact plug. In direct contact plug, the plug is in contact with molten metal, whereas in indirect one the plug is embedded in a porous bottom refractory. In the indirect contact, the plug is not directly in contact the molten metal. The gas enters the bath via the porous refractory hearth which results in stirring over a large area when compared with direct plug as shown in the figure 16.2. Figure 16.2 shows the direct contact and indirect contact plug for bottom stirring. Note that in indirect contact large area of the bath is stirred as compared with direct contact plug.
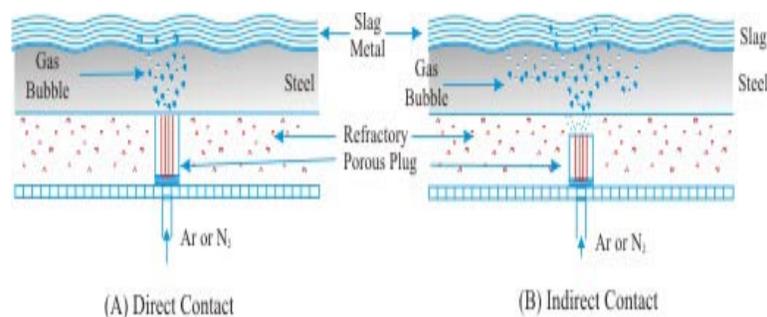

Figure 16.2: Industrial bottom stirring systems in electric arc furnace

ii) **Foamy slag practice**

In EAF steelmaking, progressive melting of scrap increases the irradiative heat transfer from arc to the side walls of the furnace. By covering the arc in a layer of slag, the arc is shielded and more energy is transferred to the bath. The foaming slag during this period is beneficial.

The effectiveness of slag foaming depends on slag basicity, FeO content of slag, slag temperature and availability of carbon to react with either oxygen or FeO of slag. Slag foams in steelmaking due to entrapment of gas bubbles. Gas producing reactions in steelmaking are:

a) Reaction between FeO of slag with carbon

$$(FeO)_l + C = [Fe] + \{CO\} \qquad\qquad (1)$$

b) Between carbon and oxygen dissolved in metal

$$[C] + [CO] = \{CO\} \qquad\qquad (2)$$

c) Between chromium oxide and carbon:

$$Cr_2O_3 + 3C = 2Cr + 3CO \qquad\qquad (3)$$
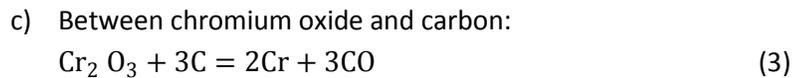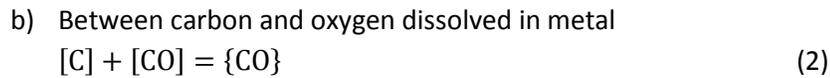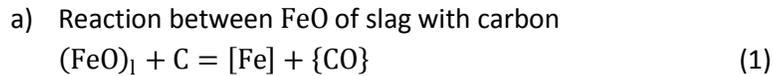
Reactions 1 and 2 are important in carbon steelmaking whereas reaction 3 is important in stainless steel making. Slag foaming is discussed in lectures 4 and 5.

Injection of carbon and oxygen at several places in the bath assures slag foaming practice, when carbon content of the bath is insufficient. Typically carbon injection rates for slag foaming are 2.5 to 5 kg/ ton of steel. In high powered furnaces carbon injection is 5-10 kg/ton of steel.

In stainless steel making Cr_2O_3 forms in preference to FeO due to higher affinity of Cr to oxygen. The solubility of chromium oxide in the slag is considerably weaker in comparison to FeO for the same basicity and thermal conditions. The oxygen/carbon injection technique in the high chromium alloy steel production and to foam the slag is difficult. Moreover, additional chromium will also be lost due to oxygen injection.

The novel technology utilizes the reduction of iron and chromium oxide by carbon as well as thermal dissociation of limestone contained in small briquette. (See the reference given at the end of the lecture)

iii) Scrap preheating
Preheating of scrap brings thermal energy into the furnace. Preheating of scrap to 540°C brings 81kwh/ton of additional energy. Scrap preheating gives the following advantages:

o Reduction in energy consumption by 40-60 kwh/ton depending on the scrap preheat temperature
o Electrode consumption reduces by 0.3 to 0.36 kg/ton
o Refractory consumption decreases by 0.9 to 1.4 kg/ton
o Tap to tap time reduces by 5 to 8 minutes.

It is important to note that scrap preheating technology needs to be developed. Thermal energy is required to preheat the scrap and is economical only when the waste heat from the furnace is utilized. For this purpose it is important to know the energy balance of the electric furnace. The energy balance of an EAF, as shown in the indicates that 20% of the total energy leaves the furnace in the
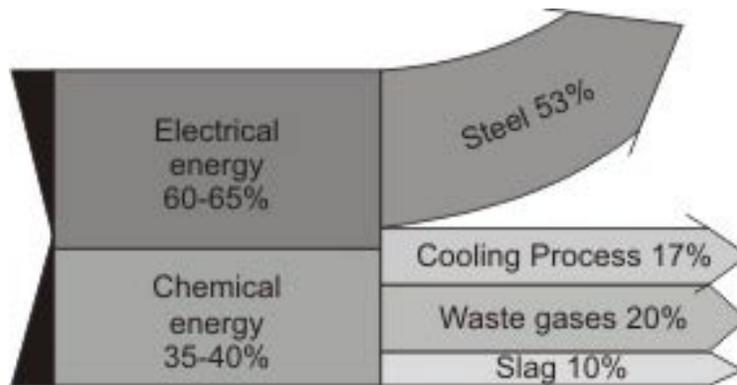
Figure 16.3 Energy balance of an electric furnace steelmaking

waste gases and represents about 130 kWh/ton of steel produced. Efficient utilization of thermal energy of exit gas is the key to realize the advantages of preheating of scrap. Batch preheating and continuous preheating are the available technologies. In CONSTEEL, scrap and exit gases move counter current to each other. It is possible to preheat the scrap to ~320°C.

Usage of Chemical Energy

The high electrical energy costs pushed EAF steelmakers to look for alternative energy sources. One such source is the chemical energy derived from chemical reactions. In recent years the chemical energy supply amounts to 35% to 40% of the total energy in most of the modern EAFs. (See figure 16.3)

 i) Oxidation reactions

The main oxidation reactions are oxidation of iron and carbon besides oxidation of silicon and manganese. The oxidation of iron though generates more energy than oxidation of carbon but iron oxidation results in loss in productivity.

$Fe + 0.5O_2 = FeO;$ Heat content $6kW/m^3O_2$

$C + 0.5O_2 = CO;$ Heat content $3.5kW/m^3O_2$
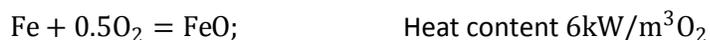
Hence oxygen injection must be controlled such that iron oxidation is kept minimum. For bath carbon levels above 0.3%, all oxygen reacts with carbon to produce CO. Below 0.3% C, the efficiency of carbon oxidation to form CO drops and more and more FeO is generated in the slag.

For scrap carbon levels below 0.1%, FeO levels in the slag can be quite high and represents an unavoidable yield loss. Increased carbon injection is necessary to control slag FeO levels and to prevent excessive refractory wear. Efficiency of heat transfer from oxidation reactions is extremely high due to the fact that these reactions are occurring in the bath. Greater penetrability of oxygen jet ensures the occurrence of oxidation reactions in the bath.

ii) *Post combustion*

It is a practice of generating additional energy for melting steel by using the right amount of extra oxygen to combust CO and H_2 which evolve within the EAF. Carbon monoxide is generated in an EAF by

- Partially combusted hydrocarbons entering the furnace with the scrap
- Combustion of charged and injected carbon via $C + 0.5O_2 = CO$
- The reduction of FeO by carbon during slag foaming

Hydrogen is generated by:

- The cracking of hydrocarbons (oil in scrap, methane)
- The reduction of water: $H_2O + CO = H_2 + CO_2$ or $H_2O + C = H_2 + CO$

In EAF, carbon monoxide and hydrogen may be available at the freeboard, whereas the foaming slag contains carbon- monoxide. It must be noted that oxygen flow should have low velocity to promote mixing with the furnace gases and to avoid scrap oxidation and rebound of oxygen from the scrap to the water cooled panels. Post combustion in the slag typically aims at combustion of 20 to 30% of the CO generated in slag and $70 - 80\%$ at the free board.

For post combustion speed of oxygen injection must be low and also uniform distribution of oxygen is required.

Iii) *Oxy – fuel burner*

Oxy-fuel burner uses natural gas or oil, together with pure oxygen to produce an extremely high flame temperature. Oxy- fuel burners are used to melt unmelted scrap between the electrodes and to provide heat to cold spot. On most modern UHP furnaces, the primary function of burners is to provide heat to cold spots to ensure even scrap melting and to decrease the melting time necessary to reach a flat bath. Typically industry practice indicates that 0.133 MW of burner rating should be supplied per ton of furnace capacity. Others recommend 32 k Wh/ ton of burner power to eliminate cold spots in a UHP furnace and 50 to 200 kWh/ ton of burner power for low powered furnaces.

iv) **Carbon injection**

Injection of carbon brings following benefits:

i. For 100 percent scrap practice or when carbon content of the bath is insufficient to produce CO for slag foaming, carbon injection is beneficial.
ii. Carbon oxidation produces CO which on post combustion generates thermal energy.

It is to be noted that carbon injection requires oxygen injection to onset carbon oxidation.

Requirements for chemical energy usage

The chemical energy usage requires to develop a device to inject oxygen in different modes:

- ✓ Hold mode (to prevent plugging)
- ✓ Burner mode (to heat and melt scrap)
- ✓ Soft lancing mode (for post combustion)
- ✓ Supersonic lancing mode (for decarburization and slag foaming)
- ✓ Carbon injection mode (when slag foaming is required)

Injectors are either fixed type or moveable type. Submercible hand lances arc used through the slag door. Large opening in EAF shell is required. Slag and metal splashing restricts the device movement. Excessive repairs and down- time are associated with this technology.

An innovative design is CO-jet injectors which are fixed type and can be mounted on the furnace shell. CO-jet injectors are highly flexible in usage. The reader may see the references given in this lecture.

The next lecture deals with charge mix in EAF steelmaking.

Future of EAF steelmaking

The EAF needs a metallurgical reactor that has the largest growth potential both in terms of production capacity and technology evolution. Future EAF will be equipped with all modern technologies- like Ultra high power input (up to $1500 \, \text{kVA/t}$), latest oxygen and carbon injection technology and design features- like ultra high shell design, heavy mill type components.

This combination leads to an Electric Arc Furnace where the tap to tap times can be extremely short and the corresponding productivity reaches the level of larger furnace sizes or converter plants.

The two main reasons for this are:

- The possibility of a higher electrical power input and
- A far higher efficiency of chemical energy, decarburization and scrap preheating compared to the same size (tap weight) standard furnace.

It is interesting to compare a conventional 120ton EAF with the ultimate 120 ton EAF.

Conventional 120 ton EAF	Ultimate 120 ton EAF
2- bucket charge Scrap bucket 130 m^3 Furnace volume 145 m^3	1-bucket charge Scrap bucket 185 m^3 Furnace volume 210 m^3
Transformer design upto 1,000kVA/t, 120MVA for 120 ton tapping weight, Secondary voltage up to 1,200V	Transformer design upto 1,500kVA/t, 180MVA for 120 ton tapping weight, Secondary voltage up to 1,500V

Utilization of chemical energy	Utilization of chemical energy
3 oxygen gas burners 3 refined combined burners (RCB) 2 carbon injectors	3 oxygen gas burners 5 refined combined burners (RCB) 4 carbon injectors 4 post combustion injectors

Refined Combined Burner (RCB) technology combines a conventional oxy/gas burner with a supersonic oxygen injection lance and is designed to optimize the injection of carbon and oxygen into EAF. It supplies chemical energy through chemical reactions of fuel and gas, oxygen, and carbon injected into the furnace.

 References:

S.Cantacuzene et.al.: Advanced EAF oxygen usage at Saint-Saulve steelworks,Ironmaking and steelmaking, 2005, vol 32, p203

d.Janke et.al.: Scrap-based steel production and recycling of steel, Mater. Technol. , 34(6) 2000, P.386

M.J.U.T. van Wijngaarden et.al.: Bottom stirring in an EAF: Performance results at Iscor Vereeniginh works, The Jl. Of South African Institute of Mining and Metallurgy, Jan. 1994, P.27

G.L.Dressel: Use of DRI in EAFs: Iron and steelmaker, October 1988, P 121

M.Gojic: Current state and Development of steelmaking processes: Metalurgija, 43(2004) 163

J.Reichel et.al.: EAF foamy slag in stainless steel production…., Archives of Metallurgy and Materials, Volume 53, 2008, P1

A.A. Mottahedi et.al.: Intern. Jl. Of Chem Tech. research vol 1 Jan-.March 2009, P 62

J.Jones: Optimization of EAF operations through offgas system analysis, Electric Furnace Conference Proceedings, 1999, P 459

M.Hissig: The d-c shaft furnace, Iron and steel engineer, May 1994, P. 25

H.G.Muller et.al.: D-c electric arc furnace- A trend-setting technology in steelmaking, Iron and steel engineer, May 1994,P34

T.Jiemin et.al. EAF technology evolution by continuious charging, Ironmaking and steelmaking, vol.. 32, 2005, P 191