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Energy Balance in Induction Furnace and Arc Furnace Steelmaking

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ABSTRACT
Various routes of steelmaking are being practiced throughout the world; oxygen steelmaking and electric steelmaking are two major routes amongst them. Electric steelmaking is further divided in induction furnace steelmaking and arc furnace steelmaking. Induction furnace route is prominent in many countries; especially in Asia. While a lot of literature is available for arc furnace steelmaking, very little is available for the induction furnace route of steelmaking. For any process to study; energy balance is the initial step. In the present work, efforts are being made to represent energy balance of induction furnace. The data is obtained from the working steel plant in India. The data of induction furnace has been compared with arc furnace obtained from the literature. Various factors affecting the energy input and output for both the type of furnaces have been discussed.

Keywords: Induction furnace, arc furnace, energy balance, steelmaking

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I. INTRODUCTION

The assessment of energy consumption is of fundamental interest to any steelmaker across the world. Energy balance is the first step to study any process. A correct analysis of energy exploitation is important to allow better control of the steelmaking process. In case of electric steelmaking, the precise explanation of input and output energies gives proper insight about the process and its driving forces.

The world average of electric steelmaking is about 30% [1]. Oxygen steelmaking is the most popular route with about 70% share. For last so many years China is the highest producer of steel. It produces about 50% of world's total crude steel. In the China, majority of the steel is produced through oxygen steelmaking route. If steel production data is studied without China, oxygen steelmaking to electric steelmaking ratio is about 53:47. Both the routes deviate just by 3% from the centre point, where oxygen steelmaking is on the higher side. In last few years Electric Induction Furnace (EIF) steelmaking has become very popular. India, which is the second largest steel producer in the world produces about 30% of its annual production through induction furnace route. For many countries in Africa and in Indian sub-continent, induction furnace is the most preferred route of steelmaking. In the segment of long products with plant capacity upto 1 MTPA, induction furnace steelmaking is preferred over Electric Arc Furnace (EAF) steelmaking. Both, EAF route and EIF route of steelmaking fall under the category of electric steelmaking. Both the routes have distinct advantages and limitations considering production capacity, quality of steel, operating conditions, raw material requirement, operating expenditure, capital investment, etc. A lot of data is available on EAF steelmaking as against very little data is available for EIF steelmaking. To study any process, the first step is to comprehend energy balance. For EIF, unlike EAF, literature illustrating energy balance is not available.

In the present paper efforts have been made to discuss various parameters of EIF and EAF steelmaking. The operating data for EIF steelmaking has been obtained from the working steel plant in India with proper permission. The data thus obtained for EIF has been utilised for energy balance. The energy balance of induction furnace is compared with the data available for arc furnace from the literature. The comparison has been done on per ton basis of steelmaking.

ELECTRIC STEELMAKING

The furnaces utilizing electrical energy for steelmaking are called electric furnaces; and hence the term electric steelmaking. These furnaces are mainly used for recycling of steel scrap for steel melting throughout the world. With scarcity of steel scrap use of Directly Reduced Iron (DRI) has become popular [2]. In the present work, discussion has been kept limited to steel scrap remelting.

1.1 STEELMAKING IN ELECTRIC ARC FURNACE

EAF steelmaking is very popular route for scrap remelting. EAFs are used for the production of variety of steels such as plain carbon steel, alloy steel, stainless steel, etc. in the form of long products and flat products. The furnace sizes vary from few kilograms to as big as 250T. Small size furnaces are popular in foundries. Normally, steel plant EAFs start from 15T and above. Initially EAFs were operated with double slag practice i.e. preparation of oxidizing slag at first and then preparation of reducing slag at the end of a process. These operating conditions led to high processing time, low production rate, increased electrode consumption, high electricity consumption, etc. The overall result is high operating cost. Recent developments in EAF include Ultra High Power (UHP) supply, use of oxy-fuel burners, foamy slag practice, bath stirring for better homogeneity, electrode cooling, water cooled panels for side walls, etc. EAFs use basic lining for steelmaking. Basic lining with oxidizing slag leads to refining of steel in terms of phosphorous. Other elements such as C, Si, Mn and to some extent Fe are also oxidized due to oxygen injection. In other words, change in chemistry during EAF steelmaking is inevitable. Final chemistry is adjusted by adding ferro alloys in the ladle. Hence, use of ladle furnace is must in EAF steelmaking. It is important to note that chemical heating has been introduced in EAF steelmaking which reduces electrical energy consumption [3,4].

1.2 STEELMAKING IN ELECTRIC INDUCTION FURNACE

Another electric furnace which is used extensively for steelmaking is induction furnace. EIFs started becoming widespread about 4 decades back. Initially they had limited use only in the foundries. With continuous technological developments and availability of bigger size furnaces enabled EIFs to find their way in steelmaking. Presently, popular sizes for steelmaking range from 8T to 60T. Induction based plants mainly use steel scrap as a raw material. The modern developments that are done in modern induction furnace steelmaking route are,

- Microprocessor based embedded technology using single electronic motherboard which enables fastest and precise control of active electrical energy fed to the melting furnace.
- Digital signal processing enables optimum use of energy in large capacity and high power furnace where multiple rectifiers and inverters are used in furnace power unit.
- Use of fibre optics for communication between digital controller and thyrister which leads to noise free and lag free signal processing.
- Ethernet port facility for communication between furnace power unit and remote computer.
- Use of conveyors and electric magnets in SMS shed to feed the furnace at a higher rate.
- Development of scrap processing units which help in using uniform and sized scrap for steelmaking in induction furnace.
- Scrap processing unit also helps in removal of dust which improves overall yield of scrap during steelmaking.

In Induction furnace steelmaking with steel scrap chemistry of the steel made remains unchanged. The scrap chemistry and molten metal chemistry remain same unless sponge iron or DRI added into it. As mentioned earlier, in the present paper, discussion has been kept limited to melting of scrap. Melting of sponge iron and its effect on bath chemistry, energy consumption and slag generation is not discussed. It is important to note that almost all steelmaking induction furnaces use acid steelmaking i.e. furnace lining is silica ramming mass or alumina ramming mass. The nature of lining does not allow to form basic slag. Hence, refining of steel in terms of S and P is difficult within the furnace. Efforts are being made [5] to refine the steel in induction furnace itself by making basic slag; but the process is time taken and increases the process cost. ELdFOS process [2] has been developed to refine steel using induction furnace – ladle furnace combination. As of now, refining of steel in induction furnace is not being practised for steelmaking applications.

II. ENERGY BALANCE

To understand any process, energy balance is the first step. Over the years, EAF has been used extensively for steelmaking. A large number of data has been available for EAF steelmaking [6-13]. The same is not the case for EIF steelmaking. Very little literature is available giving idea about the process [2,14]; but details of input and output energies are not available. Since last two decades induction furnace has started putting its feet firmly in steelmaking, especially for the production of plain carbon steel and construction grade steel.

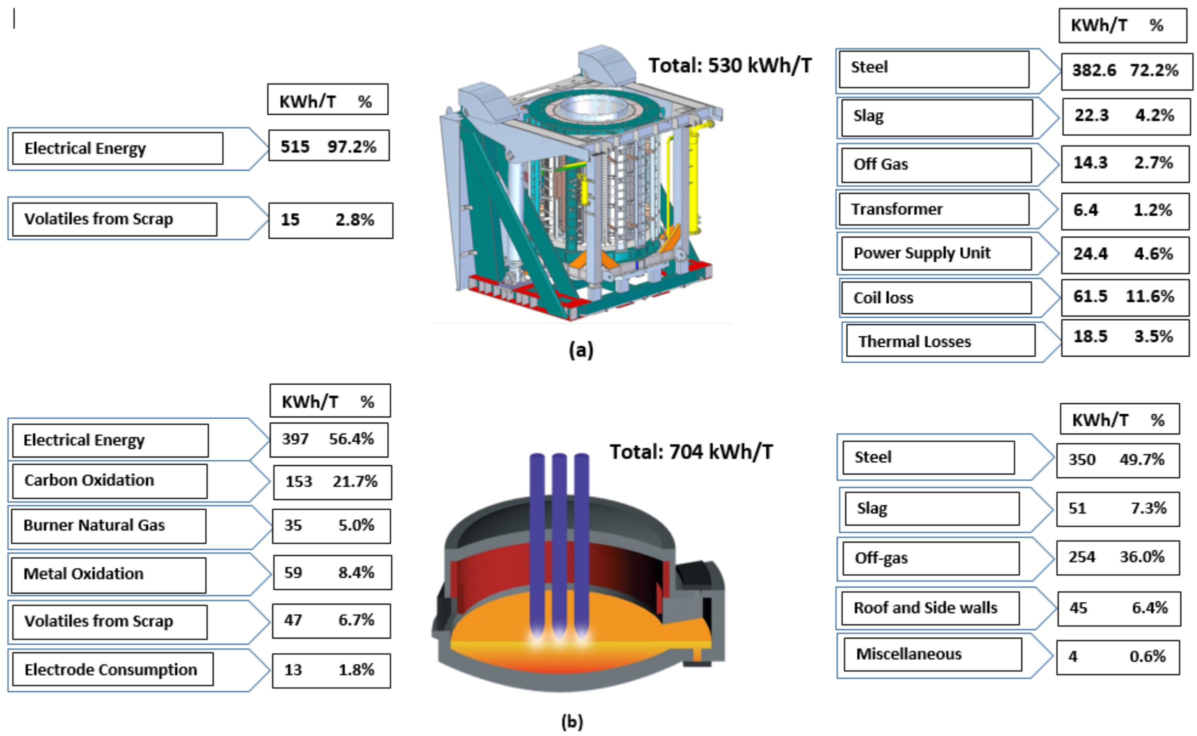

Figure 1Energy Balance in Electric Steelmaking (a) Electric Induction Furnace (b) Electric Arc Furnace

A typical energy balance for induction furnace and arc furnace [13] steelmaking has been depicted herewith in Figure 1. For both the furnaces energy balance has been presented for scrap remelting. The left hand side depicts input energy while right hand side depicts output energy. The data for EIF has been collected the from Electrotherm Steel Plant, India, which makes steel using induction furnaces. The comparison has been done for the production of one ton of steel.

Induction furnace uses electrical energy as the source of input energy. Being an electrical furnace, there are some inherent losses of power supply unit. Such losses are termed as converter loss, bus bar loss, capacitor loss, etc. which are considered as the losses of power supply unit. The melting crucible of an induction furnace is made up of copper coil which also incurs the loss in terms of Joule’s heating. Additionally, during melting thermal losses arise by various heat transfer mechanisms such as conduction, convection and radiation. Rest of the energy is distributed in off gas, liquid metal and slag. For the duration of melting, volatiles attached to scrap burn into flames. The flame formation is attributed to the combustion of volatiles by atmospheric oxygen. The amount of heat generated by combustion of these volatiles is very little and goes out of the system without any heat transfer. Whatever heat is generated, maximum about of it is consumed by the nitrogen present in the air. Figure 1(a) depicts energy distribution in various systems of an induction furnace.

Unlike EIF, in EAF chemical energy plays very important role which helps reduction in electrical energy utilization [3,4]. The total energy supplied is utilized in liquid metal, slag, thermal losses, off gas and various other losses. Input energy is supplied in the form of carbon oxidation, combustion of natural gas and volatiles, oxidation of various elements in the metal and oxidation of graphite electrode. Along with these chemical energies, electrical energy is fed into the system by electrode arcing. The energy balance of EAF is depicted in Figure 1(b).

It can be observed that overall specific energy consumption per ton of steel produced in EIF is less compared to EAF. In terms of electrical energy EIF consumes more compared to EAF; however it is important to note that for EIF electrical energy is the only source of heat, whereas for EAF contribution of chemical energy is more than 40%.

III. DISCUSSION

In any steel plant operating practices differ. Accordingly, distribution of energy in the process also vary. It is very important to capture all the factors affecting the process and based on that proper analysis is to be carried out.

In EAF, arcing is used to melt the scrap, but the arc heat transfer efficiency is very poor; hence, chemical energy is introduced to reduce arcing. Arcing also leads to oxidation of graphite electrodes which incurs additional cost in melting operation. All the input and output energies are depicted in Figure 1(b).

Though EIF and EAF both come under the regime of electric steelmaking, chemical energy plays very important role in modern EAF. Natural gas or any other fuel is combusted above the liquid bath using oxy-fuel burner to carry out chemical heating. This energy is compensated against electrical energy. Another very important practice carried out in EAF steelmaking is foamy slag practice. In this process, carbon and oxygen are injected in the liquid steel bath and slag directly. The formation of CO bubbles generates chemical energy by carbon oxidation. Additionally, similar to BOF operation, direct oxygen is also injected into the liquid bath in EAF prior to formation of foamy slag. The oxygen injection oxidizes Si, Mn, C, Fe and P, which generates chemical energy by exothermic reactions but at the same time reduces the yield of steelmaking process.

It is important to note that the scrap used in EIF is similar to EAF.The steel scrap obtained for steelmaking is obtained from various sources such as automobile scrap, white goods scrap, scrap obtained from various industrial machines, domestic steel scrap, utensils, etc. All these applications make the scrap oily and various volatile materials are attached to it. Many a times it carries grease and various lubricants. These materials burn prior to melting of scrap. Burning of these materials lead to fume generation. Some amount of energy is also liberated due to its combustion. It should be noted that induction furnace works on full volume condition. There is no empty space available above the liquid metal. Moreover during melting cycle, the furnace is to be charged continuously from the top. Many a times the scrap is pushed inside the furnace with the help of scrap pusher. The pushing is also done from the furnace the top. While all these operations are going on, the furnace is under continuous operation. The heat generated within the scrap by induction eddy currents helps combustion of volatile materials which are stuck on the scrap surface. The combustion of these volatiles takes place by oxygen in atmospheric air. Though the combustion generates the heat; it is carried away by the fumes which immediately leave the furnace without any heat transfer between the fumes and the scrap or furnace lining. In absence of sufficient air, many a time the volatiles may leave the furnace in unburned condition. On the contrary, in case of arc furnace, scrap is charged either once or twice during melting cycle. It is not continuous charging. The melting takes place in a closed vessel. Pure oxygen is injected for the combustion of these volatiles. Moreover, about 60-70% volume remains empty above the liquid metal level. Here it is important to note that the heat generated by combustion of volatiles gets transferred to wall. Thus, EAF gets advantage of combustion of volatiles; which contributes significantly as an input energy. Thus, EAF utilizes various sources of heat as input energy. Use of chemical energy and contribution of each component depends on the availability of particular fuel, but at the same time oxygen is available easily and is utilized in combustion of the supplied fuel and is also used for foamy slag practice. Use of natural gas, diesel or LPG depends on economics and ease of availability. As mentioned earlier, EAFs are operated with basic lining. Basic lining allows formation of basic slag which helps refining of steel in terms of P. Final refining and chemistry adjustment is carried out in ladle furnace which is operated with highly basic and reducing slag.

As mentioned earlier and depicted in Figure 1 (a), induction furnace uses only electrical energy as input energy. Induction furnaces are operated on full volume condition. Oxygen injection into the furnace leads to liquid metal splashing, which restricts gas injection in the furnace. Absence of oxygen injection avoids metal oxidation. Hence, metal yield in EIF is always more than EAF by 2-3%. No use of any other fuel in EIF results in low amount of fume generation with low temperature compared to EAF.

IV. CONCLUSION

It is important to note that specific energy consumption specific energy consumption of steelmaking in EIF is less compared to EAF. As far as production of plain carbon steel with long products is concerned, induction furnace is cost effective solution. Considering refining capability of EAF, it is preferred to produce alloy steel and special quality steel. EIFs have restriction in size compared to EAF, as the latter is available in the size as high as 250 T. With the development of modern induction furnaces working on digital platform, the EIFs have become more efficient and are preferred over EAFs for the production of plain carbon steel or construction grade steel with plant capacity upto 1 MTPA.

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