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Energy Balance In Steel Liquefaction In Induction Furnaces And Electric Arc Furnaces

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Abstract: *Various methods of liquefaction of steel are used all over the world; steelmaking in converter furnaces and steelmaking in electric arc furnaces and induction furnaces are two main areas among them. Steel production in electric furnaces is divided into steel production in induction furnace and electric arc furnace. In many countries, induction furnace liquefaction is common and is used mostly in private production enterprises. There is a large amount of literature on electric arc furnace steelmaking, and less information on induction furnace steelmaking. To study any process; the energy balance is preliminary. In this article, an attempt is made to express the energy balance of an induction furnace. The information is given in light of the processes of steel liquefaction at production enterprises. The data of the induction furnace were compared with other furnaces obtained from the literature. Various factors affecting energy input and output for both types of furnaces are discussed.*

Keywords: *Induction Furnace, Electric Arc Furnace, Energy Balance, Steel Casting*

Introduction

Estimating energy consumption is of primary interest to any steel producer in the world. Energy balance is one of the first steps to study any process. Accurate analysis of energy use is essential for better control of the steelmaking process. A clear explanation of the input and output energies in steelmaking in electric furnaces provides a proper understanding of the process and its driving forces.

The global average of steel production in electric furnaces is about 30% (Turakhodjaeva, 2020). Steel production in converter furnaces is one of the directions with a share of about 70%. China has been the largest producer of steel in recent years(Khurgin, 2018). It is the world's leading producer of steel from common solid materials. Most of the steel in China is produced in converter furnaces. If the steel production data is examined without China, the ratio of converter furnace steel production to electric steel production is about 53:47. In both types of furnaces, steel liquefaction varies by only 3% from the center point, where the percentage of steel production is higher in the converter furnace. Induction furnace steel production has increased significantly over the past few years. India, the world's second largest producer of steel, produces about 30 percent of its annual production in induction furnaces(Tabar et al., 2010). Induction furnace steel production is high in many African countries and the Indian subcontinent. Casting products used in continuous casting with very large factory capacity are more productive in an electric arc furnace than in an induction furnace. Steel liquefaction processes in electric arc and induction furnaces work at the expense of electric power. Both directions have their own advantages and disadvantages, taking into account the production capacity, the quality of steel obtained, working conditions, the need for secondary solid materials, operating costs, etc. There is a lot of data on steel liquefaction in an electric arc furnace, but less information on steel liquefaction in an induction furnace. The first step in studying any process is to consider the energy balance. Factors indicating the energy balance in steel liquefaction in an induction furnace are much less than in an electric arc furnace(Rothwell & Stock, 1981).

Various parameters of steel production in induction and electric arc furnaces are discussed in this research paper. Operational data for the production of steel in an induction furnace were obtained on the basis of steel liquefaction of production enterprises. Thus, the data obtained for the induction were used for the energy balance. The energy balance of the induction furnace is compared with data available for other furnaces in the literature. The comparison was made based on tons of steel production(Rothwell & Stock, 1981).

Production of steel in electric furnaces

Furnaces that use electricity to produce steel are called electric furnaces. These furnaces are mainly used around the world to process steel scraps for liquefaction of steel. Different small aggregates and various slags are also used for the reduction of large aggregates (Turakhodjaev, 2021). This research mainly focuses on the comparison of energy balances for steel liquefaction in two electric furnaces.

Steel production in an electric arc furnace

In the production of steel in an electric arc furnace, it is mainly obtained by reliquefaction of solid materials. Electric arc furnace continuous casting is mainly used to produce various steels such as carbon steel, alloy steel, stainless steel, etc. Kiln sizes vary from a few kilograms to 250 tons. Small – sized furnaces are increasingly being used in foundry production enterprises. Usually, electric arc furnaces with a capacity of 15 tons and larger are used in steel production enterprises. Initially, the electric arc furnace was operated with a two-stage slag process, i.e., initially using oxidizing elements to form the slag, and at the end of the process, recovering Fe from the slag to FeO was used. These operating conditions account for high processing time, production speed, increased electrode consumption, high electricity consumption, and other factors. The overall result is higher operating costs. Recent developments in electric arc furnace include Ultra High Power supply, use of oxygen fuel, foamed slag practice, better mixing of liquid metal, electrode cooling, water cooled panels for side walls and more. An electric arc furnace uses a core liner to produce steel. The main lining with oxidizing slag allows to remove a certain amount of phosphorus, which is a harmful element in steel. Fe and other elements such as C, Si, Mn are also oxidized due to oxygen in the air. In other words, the amount of elements in the alloy changes during steelmaking in an electric arc furnace. Standardization of the chemical composition of the alloy is improved by adding ferroalloys to the liquid metal composition. Therefore, in the production of steel in an electric arc furnace, it is necessary to use a ladle. It should be noted that chemical heating reduces the consumption of electric energy in the production of steel in an electric arc furnace (Rothwell & Stock, 1981).

Production of steel in an induction furnace

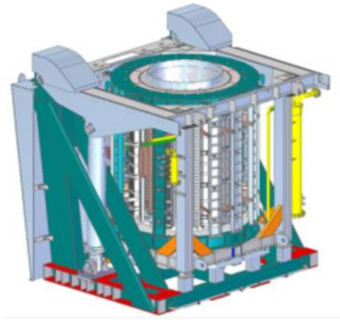
Another electric furnace widely used in steel production is the induction furnace. Induction ovens became widespread about 40 years ago. Initially, they were used only in foundries. The development of the process of obtaining cast products by continuous casting and the availability of large – scale furnaces allowed the induction furnace to find its way into steel production. At present, furnaces from 8 to 60 tons are used mainly in production enterprises for steel production. Induction furnace plants mainly use scrap steel as raw material. Modern methods implemented in the field of steel production in a modern induction furnace include(North et al., 1981):

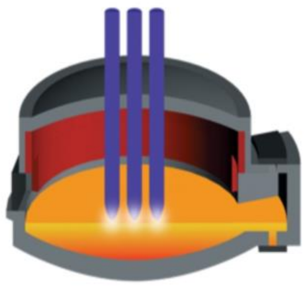
- Use of embedded technology based on a microprocessor that uses a single electronic microcircuit that allows for the fastest and most accurate control of active electricity sent to the liquefaction furnace;
- Multiple rectifiers and inverters are used in the furnace power unit for digital signal processing, allowing optimal use of high – power and high – power furnace energy;
- The use of fiber optics for communication between the digital controller and the thyristor leads to noiseless and fast signal processing;
- Using ethernet port to establish communication between furnace power unit and remote computer;
- Use of conveyors and electromagnets in the SMS warehouse to ensure high speed of the furnace;
- Development of processing units by pressing which helps to use scraps of uniform shape and size for production of steel in induction furnace;
- The slag treatment unit also helps in dust removal, which increases the overall productivity of slag in the steelmaking process(Leelataviwat et al., 2009).

In an induction furnace, the chemical composition of the bulk product obtained by liquefaction with steel scraps is different. The main reason for this is that a certain amount of slag used in liquefaction burns in the oven. If iron ore and ferroalloys are not added to the liquid metal, the chemical composition of the slag and the liquid metal will be different. The effect of alloy melting on the chemical composition of the liquid metal in the furnace bath, energy consumption, and slag formation is not discussed. It should be noted that almost all steelmaking induction furnaces use an acid lining, that is, the lining of the furnace is composed of SiO_2 mass or Al_2O_3. The nature of the lining does not allow for the formation of a slag with basic properties. Therefore, it is very difficult to reduce the harmful elements sulfur and phosphorus in the alloy in the furnace. In the induction furnace itself, an attempt is made to refine the steel by forming a slag with basic properties (Valida, 2022), but the process is time – consuming and increases the cost of the process (Nosir S, 2022). An attempt is made to clean the liquid metal in an induction furnace and in a ladle outside the furnace. Currently, induction steel cleaning is not used for steel production(Wilson et al., 2002).

Energy balance

Energy balance is the most important to understand any process. Over the years, the electric arc furnace has been widely used for steel production. A lot of data is available for electric arc furnace steel production. Induction furnace steelmaking is not well – informed and there is very little literature on the process. Also, there are no details about the input and output energies of the induction furnace. In the last two decades, the volume of induction carbon and structural steels has increased(Persson et al., 2006).

	KWh/T %				KWh/T %	
				Steel	382.6	72.2 %
Electrcal Energy	515	97.2 %		Slag	22.3	4.2 %
				Off Gas	14.3	2.7 %
				Transformer	6.4	1.2 %
				Power Supply Unit	24.4	4.6 %
Volatiles from Scrap	15	2.8 %		Coil loss	61.5	11.6
			a) Total: 530 KWh/T	Thermal Losses	18.5	3.5

	KWh/T %				KWh/T %	
Electrcal Energy	397	56.4 %		Steel	350	49.7 %
Carbon Oxidation	153	21.7 %		Slag	51	7.3 %
Burner Natural Gas	35	5 %		Off – gas	254	36 %
Metal Oxidation	59	8.4 %				
Volatiles from Scrap	47	6.7 %		Roof and Side walls	45	6.4 %
Electrode Consumption	13	1.8 %	b) Total: 704 KWh/T	Miscellaneous	4	0.6 %

Picture 1. Energy balance in electric steel production (a) induction furnace (b) electric arc furnace

A typical energy balance for steel production in induction and electric arc furnaces (Valida B, 2024) is shown in Figure 1. Energy balances for refluidization are shown for both furnaces. The left side shows the input energy and the right side shows the output energy. Induction furnace information is obtained from manufacturing enterprises that produce steel using induction furnaces. The comparison is made for the production of one ton of steel(Persson et al., 2006).

An induction furnace uses electricity as the input energy source. Being an electric oven, the power supply unit has inherent losses. Such losses are called converter losses, inductor losses, condensate losses, etc., and are considered power supply unit losses. The melting crucible of an induction furnace consists of a copper cable, which also causes losses in terms of Joule heating. In addition, heat losses during fluidization occur due to various heat transfer mechanisms, such as conduction, convection, and radiation(Swinburn & Ravussin, 1993). The remaining energy is distributed in gas, liquid metal and slag. During liquefaction, volatile substances separated from solid materials turn into flames. Fire is caused by the combustion of volatile substances by atmospheric oxygen. The amount of heat produced by the combustion of these volatiles is very low and is removed from the system without heat transfer. Whatever heat is generated, its maximum amount is consumed by the nitrogen present in the air. Figure 1 (a) shows the distribution of energy in different systems of an induction furnace(Hill, 2006).

Unlike an induction furnace, in an electric arc furnace, chemical energy plays a very important role in helping to reduce the use of electricity(Oke, 1988). The total energy provided is used in liquid metal, slag, heat losses, waste gas and various other losses. Input energy is given in the form of carbon oxidation, combustion of natural gas and volatile substances, oxidation of various elements in metal and oxidation of graphite electrode. Along with these chemical energies, electrical energy enters the system through the electrode arc. The energy balance of an electric arc furnace is shown in Fig. 1 (b).

It can be observed that the total specific energy consumption for one ton of steel produced in an induction furnace is lower compared to an electric arc furnace. In terms of electricity, electric arc furnace consumes more than induction furnace, but it should be noted that if electric energy is the only source of heat for induction furnace, chemical energy contribution for electric arc furnace is more than 40%.

Discussion

The practice of working in any production enterprise is different from one another. Accordingly, the distribution of energy in the process is also different. It is important to take into account all the factors that affect the process and make a proper analysis based on this.

An electric arc furnace uses an arc to liquefy solid materials, but the heat transfer efficiency of the arc is considered very poor. Therefore, chemical energy is added to reduce the arc. Arcing also causes oxidation of the graphite electrodes, which leads to additional costs in the liquefaction process. All input and output energies are shown in Fig. 1 (b)(Fernandez-Fernandez et al., 2006).

Although induction and electric arc furnaces are both included in the mode of electric steel production, chemical energy plays a very important role in the modern electric arc furnace. Natural gas or other fuel is burned over liquid metal using an oxygen fuel injection device to provide chemical heating. This energy is offset against electricity. Another very important practice in electric arc furnace steelmaking is the foamed slag practice. In this process, carbon and oxygen are added directly to the liquid metal and slag. The formation of CO bubbles generates chemical energy through the oxidation of carbon. Also, similar to the converter operation, direct oxygen is fed into the liquid bath in the electric arc furnace prior to foaming slag formation. Oxygen oxidizes Si, Mn, C, Fe, and P, which generates chemical energy through exothermic reactions, but also reduces the profitability of the steelmaking process(Dhurandhar et al., 2015).

It should be noted that the slag used in the induction furnace is the same as the slag that is liquefied in the electric arc furnace. Steel scraps for steel production are obtained from various production enterprises, for example, car scraps, various slags, scraps from various industrial machines, local steel scraps, containers, etc. are used. Most of the solid materials contain oil and various oils. These materials burn before liquefying the slag. Combustion of these materials produces smoke. Due to its burning, a certain amount of energy is also released. The induction oven works at full capacity. Liquid metal becomes a fiber in a crucible. In addition, during the liquefaction cycle, the furnace must be continuously loaded with solids from above. Many times, solid materials are loaded into the furnace using a loader. Loading is also done at the top of the oven. As long as all these operations are going on, the oven will work continuously. The heat generated in the slag as a result of the currents of liquid metal formed in the induction furnace helps to ignite the volatile materials stuck to the surface of the slag. Combustion of these volatile substances occurs under the influence of oxygen in atmospheric air. Although it generates heat through combustion; it is removed by the vapors immediately exiting the furnace without any heat transfer between the vapors and the furnace or furnace lining. Without enough air, volatiles can often leave the furnace unburned. In contrast, in an electric arc furnace, the solids are loaded from the furnace window once or twice during the fluidization period. This is not a constant hard load. The liquefaction process takes place in a closed oven. Pure oxygen is injected into the furnace to burn these volatiles. In addition, approximately 60 – 70% of the volume of the liquid metal surface remains empty. It should be noted that the heat generated as a result of the combustion of volatile substances is transferred to the wall. Thus, the combustion of volatile substances in an electric arc furnace has the advantages; which contributes significantly as input energy. Thus, the electric arc furnace uses different heat sources as input energy. The use of chemical energy and the contribution of each component depends on the availability of the particular fuel, while oxygen is readily produced and used in the combustion of the supplied fuel and is also used in the slag foaming process. The use of natural gas, diesel, etc. will depend on economic aspects and the availability of resources. As mentioned above, the lining of electric arc furnaces is considered reasonable. A basic lining allows the formation of a basic slag that helps clean the steel in the furnace by P. Final cleaning and chemistry adjustment is done in a slag furnace with highly basic and reducing slag(Foken, 2008).

As mentioned above and illustrated in Figure 1(a), an induction furnace uses only electricity as input energy. Induction ovens work at full capacity. Oxygen in the air cannot react with the liquid metal due to heat generation from the liquid metal in the furnace along with a certain amount of gas. For this reason, metals being liquefied in an induction furnace are less oxidized. Based on this, the efficiency of metal liquefaction in an induction furnace is always 2 – 3 % higher than in an electric arc furnace. Not using any other fuel in an induction furnace results in a lower temperature smoke compared to an electric arc furnace.

Conclusion

In summary, it was found that the specific energy consumption of steel production in an induction furnace is lower than that of an electric arc furnace. As for the production of carbon steel by seamless casting, induction furnace liquefaction is a cost – effective solution. Considering the machinability of the electric arc furnace, the production of alloy steel and special quality steel is preferred. Induction and electric arc furnaces have limitations in terms of furnace size in comparison, as induction furnaces are also smaller than electric arc furnaces. As a result of the development of modern induction furnaces running on a digital platform, induction furnaces have been found to be more efficient and preferable to electric arc furnaces for the production of carbon and structural steel with a plant capacity of up to 1 ton.

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