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chemical composition of various raw materials used in steel making, etc. Moreover, efficiency of the furnace is also one of the important parameters. Over the years operating efficiencies of the furnaces have been improved due to technological innovations, which may also lead to variation in the CO_2 generation per ton of the steel produced. From these literatures illustrative number for CO_2 emission may be considered as 2000-2500 kg / T of steel produced for BF-BOF route; and 60-100 kg/T of steel produced for EAF steelmaking route. The values are depicted in (Table 1).

It can be observed that CO_2 generation in BF-BOF route is much higher compared to EAF route. The obvious reason for the vast difference is attributed to large amount of carbon combustion, mainly, in blast furnace and basic oxygen furnace. The process involves ironmaking prior to steelmaking. Where as in EAF, steel scrap is the major input raw material. The steelmaking involves melting of scrap as well as carbon combustion.

Electric Furnace Steelmaking and Emissions

In electric steelmaking, the main raw material is steel scrap and the main source of heating is electrical energy. Various emissions taking place at electric steelmaking have been depicted in Figure 2. In electric steelmaking two types of emissions have been observed [12] 1. Direct emission 2. Indirect emission. The emissions are depicted in Figure 2A. The emission taking place at steel melt shop during steelmaking is considered as direct emission. The electricity used by electric furnaces is generated at thermal power plants by combustion of carbon; hence, the emission at power plant is termed as indirect emission. Figure 2B depicts direct emission as Emission I-a and Emission I-b for electric arc furnace and electric induction furnace, respectively. Indirect emission is shown as Emission II. For electric furnaces, the scrap may be sourced from automobile waste, various machine parts, refinery scrap, mining industry scrap, etc. Some amount of oil, grease or sticky carbonaceous materials are attached to the surface of these scraps. At the time of melting, these carbonaceous materials get burned and produce fumes which mainly contain carbon dioxide. These fumes are processed, the dust is removed, cleaned and emitted into the atmosphere. This type of CO_2 emission is common for both electric arc furnace and electric induction furnace.

At arc furnace steel melt shop, in addition to electrical energy, the furnace also uses chemical energy for steelmaking. Chemical energy is obtained by combustion of various carbon bearing fuels. The fuels can be in the form of liquid, gas or solid. Combustion of these fuels generate CO_2. In arc furnace, chemical energy is mainly used to

Induction Furnace Steelmaking, Carbon Flow and Co_2 Emission

One of the ways to understand CO_2 emission for steelmaking is to study the carbon flow diagram using material flow analysis. Material flow analysis is an organised representation of the flow of the quantities of various materials within a system. The outcome can be measured by connecting the sources and flow patterns with various transitional and final products. It is one type of depiction of law of conservation of mass. Figure 3 depicts material balance and carbon balance diagram of induction furnace steelmaking. Figure 3A presents material balance of induction furnace steelmaking for the production of 1 ton of liquid steel. Steel scrap and ferro alloys are the main input materials for induction furnace, while liquid steel, fumes and slag are output. Scrap also brings in some carbonaceous materials in the systems that are stuck to it. As the furnace is open from the top, the scrap is always in the contact with ambient air. The oxygen of air oxidizes the scrap which forms slag. It is important to note that slag is a mixture of oxides, even though there is no oxide in the input raw materials. At the same time sticky or oily carbonaceous materials get burnt by the atmospheric oxygen to form carbon dioxide. The balance nitrogen of the air goes out of the system as flue gas. Therefore flue gas mainly contains carbon dioxide and nitrogen. Thus, even though air is not charged along with input raw materials, it plays a role in slag formation and in flue gas formation. The same concept of ingress of air is also considered during the calculation of material balance in electric arc furnace [13]. Based on the above phenomena calculation of material balance is carried out in induction furnace which is depicted in Figure 3A. Considering the weight of liquid metal and slag formation, the calculation of yield of steel scrap is carried out. The amount of ingress air is calculated based on oxide formation i.e. slag and flue gas generation. The air is basically calculated stoichiometrically in the material balance.

Material balance calculation is the key factor for carbon balance;

on sticky carbonaceous materials attached to the scrap, CO_2 emission is estimated to be 3-5 kg CO_2 per ton of steel produced. Accordingly, the values of CO_2 emission for all the steelmaking routes can be rewritten as depicted in Table 2.

For electric furnaces, electricity is generated at thermal power plants by the combustion of fossil carbon which Emit CO_2. Modern EAFs consume about 380-600 kWh/t electrical units [14-16], while induction furnace consumes about 500-530 kWh/t on liquid steel production [17] using scrap. It is important to consider auxiliary loads for both EAF and IF. e major components for auxiliary load are air pollution control system, water cooling pump house, overhead cranes and continuous casting machines. Considering foamy slag practice and deliberate combustion of fuel for chemical energy, EAF pollution control system is heavier compared to induction furnace. e plant data suggests, EAF consumes about 80 kWh/t as an auxiliary load while IF consumes about 40 kWh/t. us, for EAF plants total electricity consumption is about 460 kWh/t, while for IF plants electricity consumption is about 550 kWh/t. the same is presented in Table 3. As discussed previously, electricity is generated in thermal power plants which emits carbon dioxide for the generation of electricity. Generation of carbon dioxide for the generation of one electrical unit is di erent for di erent countries [18]. In the present studies, average value of 0.8 kg CO_2 for the production of 1 kWh of electrical unit is considered. With these numbers, CO_2 generation for EAF and IF can be calculated as depicted in Table 3. Table 3 compares CO_2 generation in arc furnace and induction furnace. For both the steelmaking processes total electrical units have been calculated and converted them to CO_2 emission which indirect emission. Another CO_2 emission is at SMS which is direct emission. Total of direct and indirect CO_2 emission also calculated and depicted in Table 3.

Conclusion

Electric steelmaking is one of the very important routes of steelmaking across the world. All the operating parameters such as energy requirement, material balance, CO_2 emissions, etc. have to be calculated separately for EAF and IF. EAF uses both, chemical energy and electrical energy for steelmaking; while IF uses only electrical energy. Considering operating practices, direct emission i.e. CO_2 emission at melt shop for induction furnace is much less compared to arc furnace. Carbon emission for each route is normally studied by e carbon ow diagram. For induction furnace steelmaking, carbon ow has been presented for the rst time. It has been observed that direct CO_2 emission in induction furnace steelmaking is mainly because of the burning of sticky carbonaceous materials attached to the scrap. Carbon dioxide emission for IF steelmaking varies from 3-5 kg CO_2/T of steel; while for arc furnace direct CO_2 emission is about 60-100 kg CO_2/T. For both the electric furnaces direct and indirect emissions have been de ned and calculated in the present studies. Although present work considers use of steel scrap as the main input raw material, it is equally important to study carbon emission when directly reduced iron is used in electric furnaces. e scope of study of DRI melting in induction furnace concerning to carbon emission has been reserved for the future studies.

Conflict Of Interest

e author declares that he has no con icts of interest.

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