Induction Furnace - A Review

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Abstract— **A new generation of industrial induction melting furnaces has been developed during the last 25 years. Present practices followed in Induction Furnaces are discussed in this paper. Through a literature review account of various practices presently being followed in steel industries using Induction Furnaces has been carried out with a view to gather principal of working. Apart from this a pilot study has also been carried out in few industries in India.**

We provide some recommendations for the productivity improvement .Due to non availability of the proper instrumentations the effect of the ill practices can not be precisely judged. If this is properly measured, the percentage of productivity improvement in steel melting Induction Furnace can be calculated.The review is carried out from the literature in the various journals and manuals.

Keywords- Induction Furnace, molten metal , productivity, Melt rate

I. INTRODUCTION

The development of Induction Furnaces starts as far back as Michael Faraday, who discovered the principle of electromagnetic induction. However it was not until the late 1870's when De Ferranti, in Europe began experiments on Induction furnaces. In 1890,Edward Allen Colby patented an induction furnace for melting metals. The first practical usage was in Gysinnge, Sweden,by Kjellin in 1900 and was similar to the Colby furnace with the primary closest to the core. The first steel made in an induction furnace in the United States was in 1907 in a Colby furnace near Philadelphia. The first induction furnace for three –phase application was built in Germany in 1906 by Rochling-Rodenhauser. Original designs were for single phase and even two phases were used on the three phase furnace.

The two basic designs of induction furnaces, the core type or channel furnace and the coreless, are certainly not new to the industry. The channel furnace is useful for small foundries with special requirements for large castings, especially if off-shift melting is practiced. It is widely used for duplexing operations and installations where production requirements demand a safe cushion of readily available molten metal. The coreless induction furnace is used when a quick melt of one alloy is desirable, or it is necessary to vary alloys frequently. The coreless furnace may be completely emptied and restarted easily, makes it perfect for one-shift operations (10).

Induction furnaces have increased in capacity to where modern high-power-density induction furnaces are competing successfully with cupola melting (Fig.1). There are fewer chemical reactions to manage in induction furnaces than in cupola furnaces, making it easier to achieve melt composition. However, induction melting is more sensitive to quality of charge materials when compared to cupola or electric arc furnace, limiting the types of scrap that can be melted. The inherent induction stirring provides excellent metal homogeneity. Induction melting produces a fraction of the fumes that result from melting in an electric arc furnace (heavy metal fumes and particulate emissions) or cupola (wide range of undesirable gaseous and particulate emissions as a result of the less restrictive charge materials).

A new generation of industrial induction melting furnaces has been developed during the last 25 years. The development of flexible, constant power-tracking, medium-frequency induction power supplies has resulted in the widespread use of the batch melting methods in modern foundries. These power units incorporate heavy-duty silicon-controlled rectifiers that are able to generate both the frequency and the amperage needed for batch melting and are able to achieve electrical efficiency levels exceeding 97%, a substantial improvement over the 85% efficiency typical of induction power supplies of the 1970s. The new designs allow maximum utilization of furnace power throughout the melting cycle with good control of stirring .Some of the largest commercial units are capable of melting at nearly 60 tons per hour and small furnaces with very high power densities of 700 to 1,000 kWh/ton can now melt a cold charge in 30 to 35 minutes. (4)

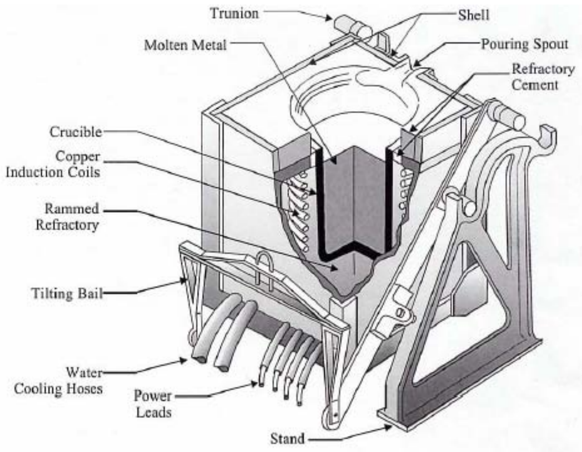


Fig.1:Schematic of induction furnace

A. Domestic Steel Sector Scenario

1) *Present Scenario :*After 2 years of depressed market, the steel market has suddenly shown competitiveness. It is noted that induction-melting furnaces in various parts of the country are at present operating to near capacity. However, the power is not supplied to the units fully. Revolution is taking place to make steel in India by utilising various technologies. India is therefore, emerging as a country with innovative idea to make steel, which is not followed by other countries in the world. In the first decade of twenty first century, major existing integrated steel plants will face a challenge in producing Long products from Induction Furnaces in producing steel economically and efficiently. (3)

The iron and steel sector has been experiencing a slow down in the last few years. The major reasons for the slow growth in the steel sector during the last few years include:-

(a) Sluggish demand in the steel consuming sectors

(b) Overall economic slow down in the country

(c) Lack of investment by Government/private sector in major infrastructure projects. sector investment is yet to materialise in the core sectors of the economy. This has also contributed to slowing down demand for steel.

(d) Cost escalation in the input materials for iron and steel. .(7)

In the national steel policy recently announced by the Govt. of India, it is expected that FDI in the steel industry along with domestic investment will take place in large integrated steel plants. So, all the focus and of the steel policy is on the Primary Steel Sector while completely ignoring the Secondary Steel Sector.(1)

Induction melting furnaces in India were first installed to make stainless steel from imported SS Scrap. But in years 81-82 some entrepreneurs, who were having small size induction furnaces making stainless steel, experimented in making mild steel from steel melting scrap, they succeeded. More firms in northern India produced steel (Pencil Ingots) by using 500 kg to 1 tonne induction furnaces. The power consumption was found to be about 700 kWh/tonne, which was nearly 100 units less than EAFs. Bigger size Induction furnaces were then installed first in North India and then in other states of India. By 1985-86, the technology of making mild steel by Induction Furnace route was mastered by Indian Technicians. Induction furnace manufacturers saw the potential and started manufacturing bigger size/capacity furnaces. By 1988-89 period 3 tonne per charge induction furnaces were installed (became standard) all over India. The chemistry of melt was adjusted by adding mill scale, if opening carbon of bath was more. Good quality of steel melting scrap was used. In 1991-92, the Government license and control on steel making and rolling was removed. Then more induction furnaces were installed all over India. The use of sponge iron made it possible to adjust chemistry of melt. Thus good quality of Mild Steel pencil ingots are being produced with no tramp elements.(3)

2) Ferrous Scrap: The word “Ferrous” comes from the Latin word “Ferrum”. Most people associate scrap with waste or rubbish. However, our Industry prefers to refer to ourselves as “Recyclers”, who play a very important role, in not only feeding the Steel Industry but also protecting the environment by converting waste into wealth for society.

Indian Steel Mills mainly import Shredded or Heavy Melting grades only. HMS is nearly 65% of the imports.

3) Global Requirement For Scrap: With global steel production at 1 billion tonne mark, merchant scrap requirement is estimated in the current year at 318 million tonnes. By the year 2010, requirement for merchant scrap is likely to go up to 388 million tonnes. As the GDP grows in developing countries, the generation of merchant scrap will increase and additional processing capacities and scrap yards will have to be installed to meet the demand for quality scrap needed for the increasing steel demand.(2)

II. Construction And Working

Combustion furnaces and induction furnaces produce heat in two entirely different ways.In a combustion furnace, heat is created by burning a fuel such as coke, oil or natural gas. The burning fuel brings the interior temperature of the furnace above the melting point of the charge material placed inside. This heats the surface of the charge material, causing it to melt.

Induction furnaces produce their heat cleanly, without combustion. Alternating electric current from an induction power unit flows into a furnace and through a coil made of hollow copper tubing. This creates an electromagnetic field that passes through the refractory material and couples with conductive metal charge inside the furnace. This induces electric current to flow inside the metal charge itself, producing heat that rapidly causes the metal to melt. Although some furnace surfaces may become hot enough to present a burn hazard, with induction, you heat the charge directly, not the furnace.

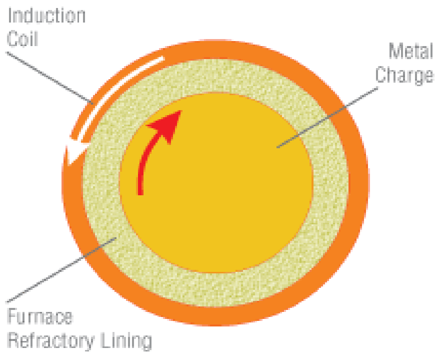


Fig. 2: Current flowing in one direction in the induction coil induces a current flow in the opposite direction in the metal charge. This current heats the metal and causes it to melt

A. *Induction Electrical System Configurations:*

Induction furnaces require two separate electrical systems: one for the cooling system, furnace tilting and instrumentation, and the other for the induction coil power. A line to the plant's power distribution panel typically furnishes power for the pumps in the induction coil cooling system, the hydraulic furnace tilting mechanism, and instrumentation and control systems. Electricity for the induction coils is furnished from a three-phase, high voltage, high amperage utility line. The complexity of the power supply connected to the induction coils varies with the type of furnace and its use.

A channel furnace that holds and pours liquefied metal can operate efficiently using mains frequency provided by the local utility. By contrast, most coreless furnaces for melting require a medium to high frequency power supply. Raising the frequency of the alternating current flowing through the induction coils increases the amount of power that can be applied to a given size furnace. This, in turn, means faster melting. A 10 ton coreless furnace operating at 60 Hz can melt its capacity in two hours. At 275 Hz, the same furnace can melt the full 10 ton charge in 26 minutes, or four times faster. An added advantage of higher frequency operation is that furnaces can be started using less bulky scrap and can be emptied completely between heats. The transformers, inverters and capacitors needed to "tune" the frequency required for high-efficiency induction furnaces can pose a serious electrical hazard. For this reason, furnace power supplies are housed in key-locked steel enclosures, equipped with safety interlocks.

B. *Safety Implications:*

Typically, the induction coil power supply and the other furnace systems are energized from multiple electric services. This means that foundry workers cannot assume that the power to the furnace coil has stopped because service has been interrupted to the furnace's cooling system or hydraulic pumps. Review the lock out/tag out section provided in this safety guide.(5)

C. *Input And Output Paameters Of The Induction Furnaces:*

In order to study the prevailing practices in steel plants using Induction Furnaces, the following parameters have been identified as

1) Raw Material: Induction Furnaces are using Steel melting scrap, Sponge Iron & Pig Iron/Cast Irons. On an average the ratio of these items is 40% sponge Iron + 10% Cast Irons or Pig Iron. The technology of melting these input materials varies according to the availability of raw materials and location of the plant and inputs of sponge iron consumed is as high as 85 % as charge mix on bigger furnaces. (3)

2) Power Supply: An A.C.current from the transformer is fed to the rectifier of the furnaces electronic circuit. This converts A.C. to D.C, voltage is smoothed out by a D.C. choke, and then fed to the inverted section of the furnace. Here the D.C is converted to a high frequency A.C. current and this is fed to the coil.(5)

3) Refractory Lining: The material used for lining is crushed quarts. This is a high purity silica material. The linings are of two types, acidic lining and basic lining.(8)

4) Water: The cooling system is a through-one-way- flow system with the tubular copper coils connected to water source through flexible rubber hoses. The inlet is from the top while the outlet is at the bottom. The cooling process is important because the circuit of the furnace appears resistive, and the real power is not only consumed in the charged material but also in the resistance of the coil. This coil loss as well as the loss of heat conducted from the charge through the refractory crucible requires the coil to be cooled with water as the cooling medium to prevent undue temperature rise of the copper coils.

5) Molten Metal : The molten metal is the desired output of the Induction furnace. The quantity depends upon the capacity of the furnace, and the quality depends upon the raw material and alloy composition. The tapping temperature depends upon the type of steel, as well as the distance of end use of the molten metal.

6) Waste Heat: The surface of the molten metal bath is exposed to atmosphere. This results in the major thermal energy loss through radiation. The Coils of furnace are water cooled this also results in heat loss.

7) Slag : During the operation of electric induction melting furnaces, non metallics are produced from the various sources described earlier. Depending on the specific process being used and the type of iron or steel being melted, the composition of the slag will vary.

8) Slag Composition: The composition of furnace and ladle slags is often very complex. The slags that form in electric furnace melting are the results of complex reactions between silica (adhering sand on casting returns or dirt), iron oxide from steel scrap, other oxidation by products from melting, and reactions with refractory linings. The resulting slag will thus consist of a complex liquid phase of oxides of iron, manganese, magnesium and silicon, silicates and sulfides plus a host of other compounds, which may include alumina, calcium oxides and sulfides, rare earth oxides and sulfides and spinels and fosterites. (4)

III.TYPES OF INDUCTION FURNACES

A. Coreless Induction Furnaces:

The coreless induction furnace is a refractory lined vessel with electrical current carrying coils surrounding the refractory crucible. A metallic charge consisting of scrap, pig iron and ferroalloys are typically melted in this vessel..(4)

B. Channel Furnaces :

In a channel furnace, induction heating takes place in the “channel,” a relatively small and narrow area at the bottom of the main bath. The channel passes through a laminated steel core and around the coil assembly.

C. Pressure Pour Furnace:

A pressure pour is, in essence, a channel furnace, as described above, that is carefully sealed so that the metal can be moved out of the furnace by way of pressurizing the chamber above the molten metal bath in the furnace.

D. Safety Implications:

Accident investigation reports indicate that most foundry accidents happen due to one of the following reasons:

• The introduction of wet or damp metal into the melt, causing a water/molten metal explosion

• Lack of operator skill during temperature taking, sampling or the addition of alloying compounds, causing metal splash.

•Dropping large pieces of charge material into a molten bath, causing metal splash

• Improper attention to charging, causing a bridging conditions

• Failure to stand behind safety lines, causing a tapping situation

• Coming into contact with electrical conductors, overriding safety interlock switches or coming into contact with incompletely discharged capacitors, causing electric shock or electrocution

• Lack of operator training (5)

IV. TECHNOLOGY ABSORPTION AND GAPS

A. Need For Adoption Of Foreign Technology Using DRI As Raw Material

Of late, main problems faced by steelmakers are short supply, fluctuating prices together with extremely heterogeneous nature and presence of tramp elements of steel scrap. Use of direct reduced iron (DRI) as a partial replacement to scrap, to some extent does help in overcoming this hurdle. However, unlike scrap and even pig iron, DRI is characterized by high porosity, low thermal and electrical conductivities which, in turn, poses problems in its melting.(6)

With the scarcity of scrap and production of DRI in the country, an inherent difference in the process between the advanced countries and India has been created. The Indian technologists/engineers will have to meet the situation with intelligent adaptation of the available technology.There are however a few companies in the world that use DRI as metallic input in their EAF divisions and have mastered this technology. They are ;

i) Krakatau, Indonesia (using gas based DRI)

ii) Sidbec Dosco, Canada (using coal based DRI)

iii) New Zealand Steel, New Zealand (using coal based DRI)

iv) ISCOR, South Africa (using gas based DRI)

v) Vespasiano, Brazil (using gas based DRI)

vi) HSW, Germany (using gas based DRI) Equipment suppliers like Mannesmann Demag have considerable experience in steel making with DRI in AC EAF's. The companies mentioned above could also be approached for process know-how.(11)

B. Technological Up gradation

The old slogan that in Induction Melting Furnaces you do not “make” steel but only “melt” which is like “Garbage in” and “Garbage out” has been proved wrong. The ingenuity of making all types of steels has been mastered by technologists of Induction melting Furnaces..(3)

Over the past 30 years, the U.S. foundry industry has seen a significant change in melting methods and associated molten metal handling systems. Further, there has been a steady and continued deterioration in the quality of metallic scrap and other iron unit feed stocks. The net result is that slag generation and slag related melting problems have become relatively widespread in recent years. A search of the foundry technical literature to gain a better understanding of methods and practices needed to improve slag control over the past 30 years will produce only a handful of technical articles. A new flux, Redux EF40L, has been developed that controls build-up in melting furnaces without adverse effects on refractory Linings. (9)

The newer power supplies improve the overall melting efficiency and furnace production at lower operation and fixed costs. Induction furnaces have benefited from improvements in the following areas:

Scrap Charging Systems: Scrap sorting and charging systems that achieve higher density charges show increase in efficiency through increase in coil efficiency and shortening of melting time.

Furnace Designs: Newer furnaces with more efficient and larger power supplies (KWh capacity per ton) reduce energy consumption.

Furnace Covers: The use of furnace cover is critical to energy efficiency once the metal is molten. The simplest system is to keep a slag on the molten metal, reducing radiation losses from the top surface.

Harmonics Controls: Harmonics problem, or feedback of electrical equipment on the power source, can be caused by the high power of the furnace power supplies. These power interface problems include low-power factor, high-frequency harmonics, line voltage notching, and inter-harmonic distortions. Special technologies and equipments have been developed to minimize the negative influence of induction furnaces on the power supply.

Multiple-Output Power Supplies: Dual-output or "butterfly" operations utilize a single power supply and two furnaces with mechanized or electronic switching. This results in continuous and completely controllable power to two furnaces at the same time.

Refractories: Push-out lining systems use a large plug to quickly remove the old lining for easy disposal. This system reduces time and cost for periodic lining changes, lowers refractory dust, and is less likely to damage back-up lining than manual refractory removal. (4)

V. PILOT STUDY OBSERVATIONS AND FINDINGS

The exhaustive literature review has been carried out for study of working principal of induction furnace, its construction and to account the various practices followed in induction furnace operations.

A pilot study has also been carried out in few industries in India. These industries are using induction furnaces as a part of the process. Following are the observations.

A. Melt Rate

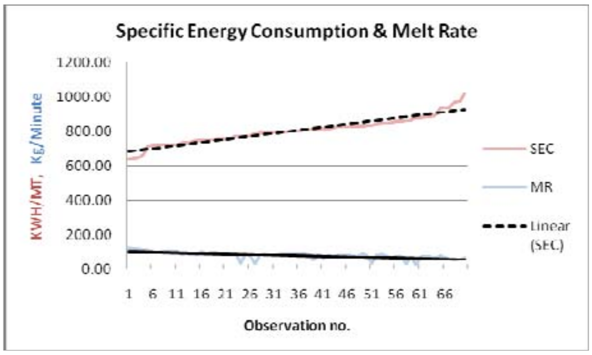


Figure 3: Melt Rate in Kg/Min Vs kWh /Mt MS

From figure 3 we can conclude that, Though the furnace and other working parameters are same, there is a variation in melt rate.

Remarkable variation in Specific power consumption is also observed. As the Melt rate increases the specific energy consumption decreases.

B. Operating KW

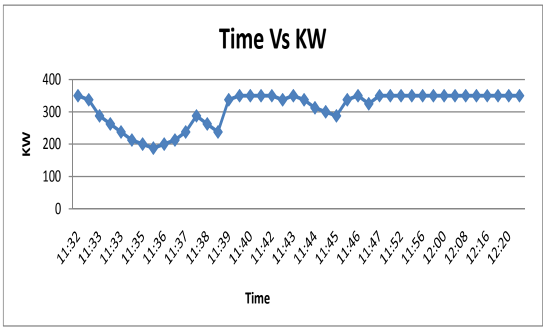


Figure 4: Time Vs KW

As can be seen from the KW readings, the furnace doesn't draw full power during this initial stage resulting in increased energy losses and more time is required for molten metal to form at the base of the crucible to speed up further melting.

C. Scrap Quality

Mostly the raw material is charged as per the availability, and no particular sequence or proportion is followed.

Scrap is not sorted or graded. If the carbon content is found more while sampling, ,the melter usually prefer to add sponge iron (low carbon) or proceed for the excessive stirring. Both these results in greater specific consumption.

D. Heat Tap To Tap Time

The time for a heat also depends upon the type of scrap. The time required for a heat is around 192 minutes for the 2 heats which were monitored. The heat time increases to 300-320 minutes. Longer heat time translates into more power input for same amount of metal.

E. Deslagging Practice

During deslagging the charging stops for nearly 3-5 minutes, the metal is overheated as metal input is zero during this interval of 3-5 minutes. If the power supply is not lowered by operating the potentiometer, the molten metal starts boiling due to excessive temperature. In this case the melter turn off the power supply, this results in heat loss through water flowing through coil.

Once the metal temperature falls slightly the power is again kept on which consumes more energy. If the slag sticks to the linings of furnace, it creates difficulty for charging the scrap, this also decrease the performance of the furnaces. While removing the slag built up from the walls the lining may also damaged.

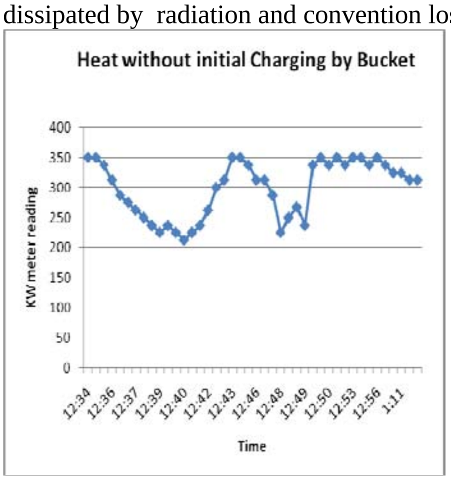
F. Metal Quantity

It is observed that frequently the level of molten metal at the time of tapping is below the lip of crucible.

VI. RECOMMENDATIONS

A. Initial Scrap Charging By Bucket

In usual practice just after the tapping of heat the initial charging is done manually by using shovels or some big lumps of metal scrap or pressed bundles of low grade scrap. In some cases it is done with the help of crane, the big metal box is filled with scrap is hanged with crane and it spread the scrap over the furnace surface. Due to this practice though the furnace appears to be charged fully it is not a dense charge. After some time it is observed that the furnace is not drawing the full power. This results in more time for heat and more energy consumption. It is suggested that a charging bucket be used initially to charge the scrap into the crucible. This enables the saving in charging time as well as the charge is in dense form due to compaction, so furnace will draw full power from the beginning (Fig.5). Bucket charging also enables in reducing the furnace off time. During off time the percentage losses are are higher as heat is carried away by cooling water and also being dissipated by radiation and convention losses



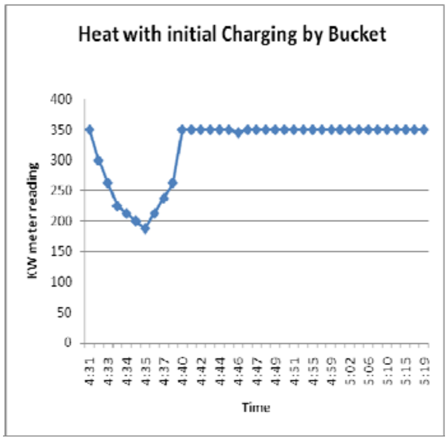


Fig 5: Comparative graph showing the effect of bucket charging

B. Control On Furnace Power During De-slagging Operations

The power to the Furnace should be controlled during the period of de-slagging after judging condition of the molten bath. As soon as no solid scrap remains in the bath or just before this, the power in the furnace is to be reduced using potentiometer settings. This will avoid overheating of the molten metal and off time of the furnace can be reduced.

C. Ensuring Full crucible before Tapping

It is recommended that the melter ensures the crucible is filled upto the maximum extent. The molten bath is available at the end of heat which can melt the light scrap very fast and specific energy consumption is also low for this last portion.

D. Scrap Preheating

The hot gases releasing after the complete melting of raw material, we can reuse these hot gases to heat the scrap or raw material so that the moisture present in it get removed. And after this we can use this heated scrap due to which it takes less time for complete melting and ultimately the cycle time decreases. Scrap preheating has the potential to reduce energy required for melting operations. Preheating systems, such as a second furnace is the most promising. More efforts for research is needed to develop a comprehensive energy transfer model linking the furnace operation with gas generation and scrap preheating.

E. Minimum Holding Time

Steel melting energy efficiency can be improved if there is no time delay in holding the molten metal where additional energy is required to maintain the temperature of the molten metal until it is poured.

F. Proper Scheduling Of Furnace

If the furnace can be scheduled so that it can operate at continues full power, the energy requirements for, melting steel can be reduced substantially.

G. Quality Of Scrap

For better melting of raw material, dense charge should be provided to the induction furnace. e.g. for increasing density of M.S. Scrap shredded machines can be used, also bundling press can be used to make bundles of loose light weight scrap and tuning and boaring.

VII.CONCLUSION

Through the exhaustive review of literature, the basic operations of Induction Furnace and importance of its individual parameters are studied. Pilot study is carried out in few industries in India, to verify the working practices and parameters of the Induction Furnaces. It is found through observations that, there are many differences in operations in various industries. In few cases lack of standardisation of process is also observed.

In this paper we are focusing on improving the efficiency of steel melting processes. After actually watching all the steel melting process, we came to know that, what are the various losses and where heat is lost. Hence for improving its efficiency and for reducing the losses we have made recommendation like Scheduling of operations, Molten metal delivery, Preheating, No time delay in holding the molten metal, Reuse of hot gases, Using the good quality raw material, Proper charging practice. If this comes in regular practice obviously it helps to increase its efficiency. Material and energy losses during these process steps represent inefficiencies that waste energy and increase the costs of melting operations. Modifying the design and/or operation of any step in the melting process may affect the subsequent steps. It is, therefore, important to examine the impact of all proposed modifications over the entire melting process to ensure that energy improvement in one step is not translating to energy burden in another step.

Although these technologies require little or no capital for deployment, engineering assistance is needed for the facility to reap its maximum benefits. For example steel melting energy efficiency can be improved if there is no time delay in holding the molten metal where additional energy is required to maintain the temperature of the molten metal until it is poured. If a furnace can be scheduled so that it can operate at continuous full power, the energy requirements for melting steel can be reduced substantially. While reviewing the literature, it is observed that till this time an attempt is not made by the concerns to study the impact of variation of one parameter on others. Through the planned design of experimentation, the effect of individual parameters can be studied and its overall effect on productivity can be found out.

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