Experimental Investigation of Process Parameters for Conservation of Energy in Ferrous Foundries

Pankaj Maurya[1], Dr. Gajanan Patange[2], Apurva Indrodia[3],

[1]*Researcher, Production Department, Ahmedabad Institute of Technology, Gujarat, India*
[2]*Assistant Professor, Mechanical Department, CHARUSAT University, Gujarat, India*
[3]*Assistant Professor, Production Department, Ahmedabad Institute of Technology, Gujarat, India*

ABSTRACT

The continued crises in energy and the lack of efficient energy conservation practices in many foundries, there arises a need to identify the factors that have the higher potential to save the energy. The study in this paper would present the Energy Audit of the "melting unit" of the foundry when using 'different quality of raw materials'. This evaluation would cover only three process parameters of the melting sector of the foundry – viz. charge material, charging practice and radiation loss. This will give us a brief overview of the energy consumption of the foundry for melting different quality of charge materials, and thus the same can be compared with the difference in cost incurred to the foundry by the use of such qualities of scrap as their raw material for production. It will also present the study for the radiation loss that occurs during the melting phase. This study of radiation loss will help us to provide with the actual comparison of the amount of the energy that can be saved by the utilization of such technique. The results obtained from this study would help the foundries to choose proper quality of raw material, and thus will enhance the efficiency and would reduce the cost of production of the foundry.

Keywords: - *charge material, charging practice, radiation loss, energy audit*

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1. Introduction:

Cast iron has found its applications in various fields over the past century. The use of products manufactured from different forms of cast iron, viz. grey cast iron, white cast iron, malleable cast iron and ductile cast iron, has found its applications in almost form of industries. The burgeoning growth of the cast iron production has been so fast, that in present times it has become one of the largest manufacturing industries in the world.

Cast iron is basically obtained from pig iron, which is the product of smelting iron ore in the blast furnace. Cast iron is sometimes melted in a special type of blast furnace known as cupola, but in modern applications, it is more often melted in electric induction furnaces or electric arc furnaces. After the melting is complete, the molten cast iron is poured into the holding furnace or ladle, and then they are poured in the sand mold to get the desired shape of the castings.

The use of Induction furnace has been increased rapidly due to the numerous advantages that it has to offer which other type of furnaces fail to do. But one the main problems which the foundry faces while using the induction furnace is its high energy requirement.

Foundry is an energy intensive sector, where the electricity is required for molding operations, air compressors, fans and lights, cranes and hoists, post machining operations and many more. So the electricity consumption of the foundry is high. And for the foundries which uses induction furnace to melt the metal, they have even higher consumption of electricity, where maximum amount of energy is been consumed by the induction furnace itself.

1.1 Induction Furnace

Induction furnaces are used to melt both ferrous and non-ferrous metals. There are several types of induction furnace available and all operate by utilizing a strong magnetic field created by passing an electric current through a coil wrapped around a furnace. The magnetic field in turn creates a voltage across, and subsequently an electric current through the metal. The electrical resistance of the metal produces heat, which in turn melts the metal.

Because there is no contact between the charge and the energy-carrier, the induction furnace is suited for the melting of steel, cast iron and non-ferrous metals, so long as a suitable lining material can be found. Furnace capacities range from 10kg up to 60 tonnes.

There are mainly three types of Induction Furnace. They are
(1) Coreless Induction Furnace
(2) Channel Furnace
(3) Pressure Pour Furnace

(1). *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.

(2). *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.

(3). *Pressure Pour Furnace:*
A pressure pour is, in essence, a channel furnace, 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.

1.2 Coreless Induction Furnace

In a coreless induction furnace, a water-cooled, helical copper coil surrounds a refractory-lined cavity containing the charge material. An induced current is produced in the charge material by an alternating current in the coil. Once the charge is molten, stirring action occurs as a result of the interaction of currents in the melt with the magnetic field. Stirring velocity increases at higher power and lower frequencies.

The oxides of aluminium (alumina), silicon (silica) and magnesium (magnesia) are the most important materials used in the manufacturing of refractories. Another oxide usually found in refractories is the oxide of calcium (lime). Fire clays are also widely used in the manufacture of refractories.

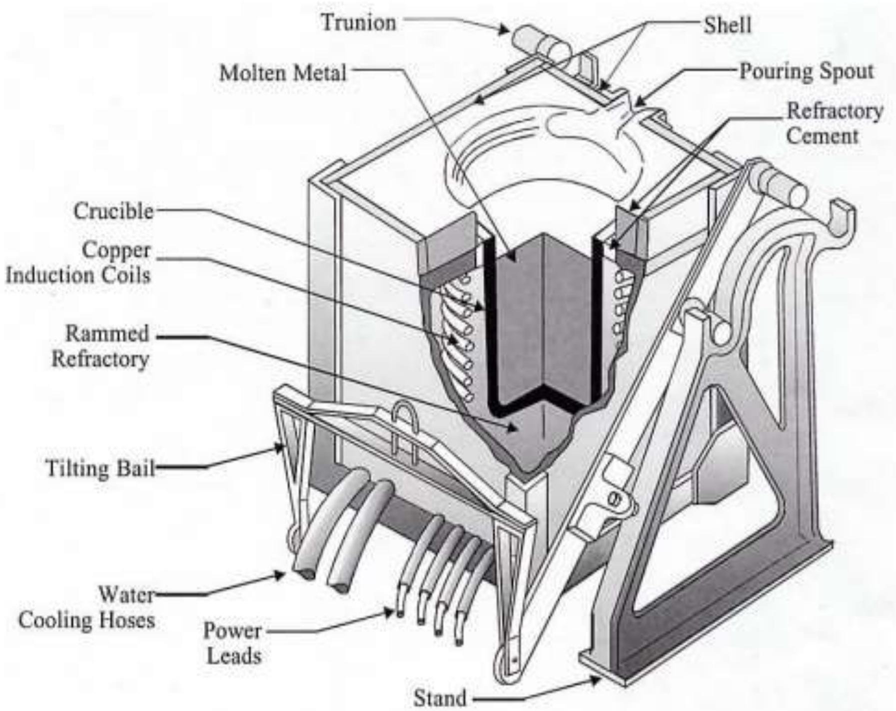


Figure 1. Coreless Induction Furnace

2. Losses in Induction Furnace

The Sankey diagram below shows that 20 - 30% of electrical energy supplied to a coreless furnace is absorbed by the cooling water system. There has been considerable effort to improve the efficiency of coil design and refractory lining construction to reduce these losses. As the coil and crucible diameters increase, the area of exposed metal surface also increases, along with heat losses through the lid. In addition, the larger the furnace diameter the more difficult it becomes to de-slag, increasing operator discomfort from greater heat exposure. However, the larger the furnace diameter the more readily it can be charged, decreasing the risk of charge bridging or damage to the top of the crucible refractory lining. When considering the 'optimum' crucible there will always be a trade-off between energy efficiency and ease of operation.

A major heat loss to the cooling water system of coreless induction furnaces is via conduction through the refractory lining. The lining thickness can be used to control heat loss, but, as this dimension also affects the coupling between the charge and the coil, power factor values and electrical efficiency, only limited scope for energy conservation is possible. Some foundries use the refractory lid to close the furnace opening to stop the heat loss (radiation loss) from the molten metal during melting, while some foundries also adopt a policy of ensuring that the lids are well-fitted and sealed at the finish of melting, thereby retaining the maximum amount of heat before recharging.

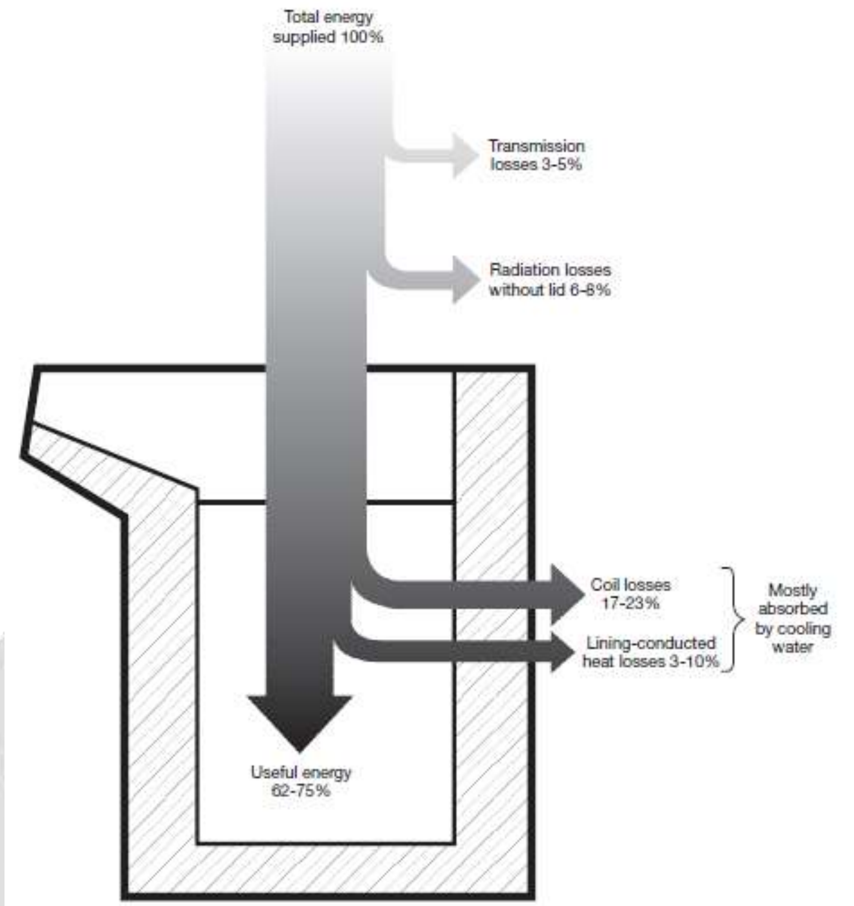


Figure 2 Energy losses in a mains frequency coreless furnace (Sankey Diagram)

3. Energy Study of Foundry

The foundry has many processes that need to be carried out in order to produce a casting, and each of them has their own share of cost in the final production cost. Though they seem trivial in the eyes of a common man, but when the study is been carried out for the energy study of the foundry, then all such aspects needs to be considered. A diagram below shows the process energy cost distribution for all the major sectors of the foundry.

Based on the International Energy Agency (IEA)'s statistical data published in 2012, the iron and steel industry has the technical potential to reduce its energy consumption by approximately 20% of the current total energy consumption of the sector, by applying best available technology (BAT). Research is also examining ways to improve melt loss, which directly affects the net melting energy consumption. This analysis assumes that yield and scrap losses are proportional to energy losses.

The process energy cost is necessary to identify the areas where the foundry can implement new techniques to cut down the production cost, and thus improve the profit. But apart from this process energy cost, the major factor which plays an important role in the cost savings of the foundry is the energy consumption by each sector of the foundry. The standard distribution of the energy consumption of the different sectors of the foundry is been given in the table below. Any deviation from this data shows that the particular sector of the foundry has the potential for the energy savings.

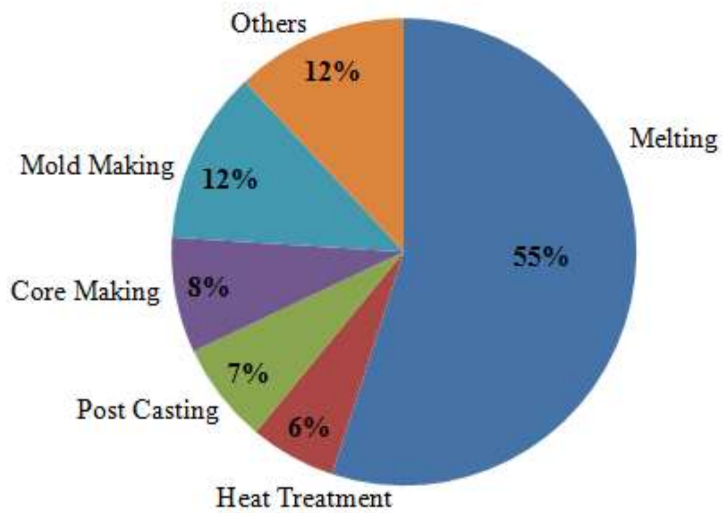


Figure 3: Process Energy Cost Distribution of the foundry [15]

Table 1: Standard Distribution of Energy Consumption [2]

Sr.No	Sections	Energy Consumption
1	Melting	70%
2	Moulding and core making	10%
3	Sand plant	6%
4	Lighting	5%
5	Compressor	5%
6	Other	4%

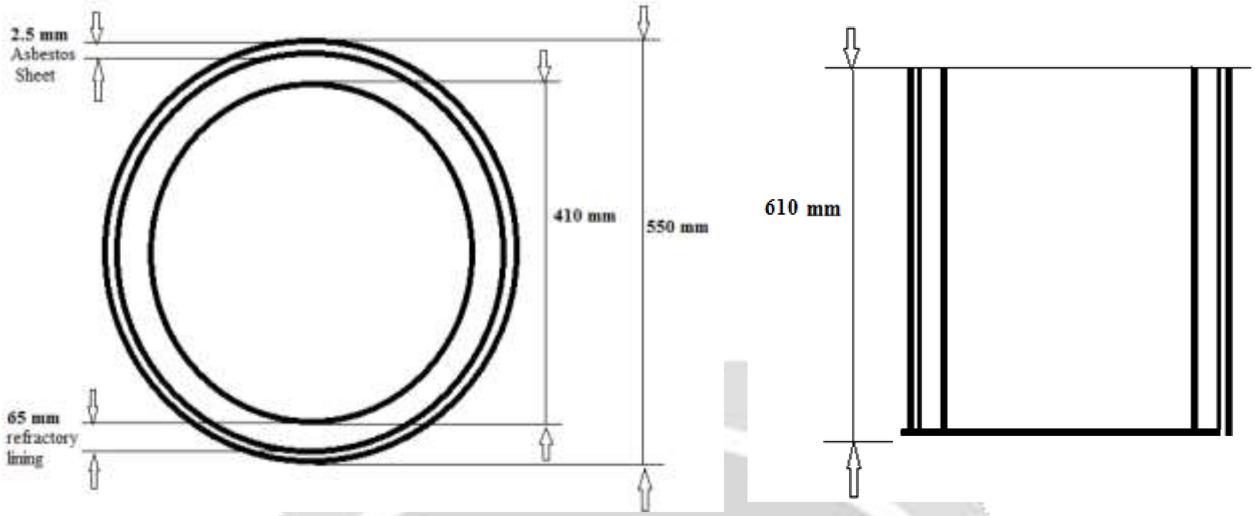
The energy consumption table above shows the standard percentage electrical distribution in the foundry industry as defined by the Confederation of Indian Industry (CII standard). [2]

As we can see in the above table that the highest energy consumption in the foundry is by the melting sector, so we can say that the melting unit of the foundry has the highest potential for the energy savings. So we will carry our experiments related to melting unit only, so we can end up with some conclusive results by performing various experiments.

4. Experimental Work

There are many process parameters in the melting sector of the foundry which can contribute to the conservation of energy if they are taken proper care of. But to constrict our study, we have considered only three process parameters viz. charge material (quality), charging practice (size), and radiation loss.

The process is been carried out in the induction furnace of capacity 500 kg, water cooled, and having the maximum output power of 550 kW. The dimensions of the furnace are as follows.



(a) **(b)**

Figure 4. (a) Top view, and (b) Cross-sectional view of the dimensions of induction furnace

The materials being melted are put into the furnace in a batch of 500 kg during each melt cycle. There are total 13 experiments that consist of 13 different sets of mixtures of materials that are being melted at different times. The 500 kg mixture comprised of 260 kg Pig Iron, 150 kg MS Scrap, and remaining 90 kg of weight of casting scrap.

The experiment also consists of 13 sets of experiments that is performed for the calculation of the prevention of radiation loss. All the other parameters during the experiment remain the same. For the prevention of the radiation loss, the polycrystalline wool of 4cm thickness is been put on the opening of the furnace. The total melt time is 55 minutes, out of which the furnace is been kept open for 20 minutes for the charging and de-slagging of the melt, and for the rest 35 minutes the opening is been covered with the polycrystalline wool to prevent the radiation loss.

The different materials used during the experiment are as follows:

(a)

(b)

(c)

(d)

(e)

(f)

(g)

(h)


(i)


(j)


(k)


(l)


(m)


(n)

(o) **(p)**

Figure 5. (a) Pig iron (big pieces) **(b)** Pig iron (small pieces) **(c)** Old Casting scrap (small pieces) **(d)** Old Casting scrap (big pieces) **(e)** Old casting scrap (small and rusty) **(f)** Runners/risers and excess casting parts (dirty surface) **(g)** Runners/risers and excess casting parts (clean surface) **(h)** Very small or compact casting scrap (rusted) **(i)** Very small or compact casting scrap (not rusted) **(j)** Machined Casting scrap (fresh and clean) **(k)** Chips formed during machining **(l)** Iron Powder **(m)** Recycled Scrap (small pieces) **(n)** Recycled Scrap (big pieces) **(o)** MS Scrap **(p)** the casting which the company manufactures where the experiments were carried out

The experimental results obtained during melting them for both with and without radiation loss is been given in the table below.

Sr. No.	Charge Material	Open Top	Closed Top
1	Pig Iron (**Big Pieces**) + M.S. Scrap + Old Casting Scrap – (Small Pieces)	357	330
2	Pig Iron (**Small Pieces**) + M.S. Scrap + Old Casting Scrap - (Small Pieces)	337	319
3	Pig Iron (Small) + M.S. Scrap + Old Casting Scrap – (Big Pieces)	343	323
4	Pig Iron (Small) + M.S. Scrap + Old Casting Scrap – (*Small and Rusted/Dusty)*	351	332
5	Pig Iron (Small) + M.S. Scrap + Runners/Risers & Excess Casting Parts (*Dirty Surface*)	341	323
6	Pig Iron (Small) + M.S. Scrap + Runners & Risers (*Clean Surface*)	333	316
7	Pig Iron (Small) + M.S. Scrap + Very small / compact casting scrap - Rusted	335	319
8	Pig Iron (Small) + M.S. Scrap + Very small / compact casting scrap – Not Rusted	327	312
9	Pig Iron(Small) + M.S. Scrap + Machined Casting Scrap - Fresh & Clean	334	317
10	Pig Iron (Small) + M.S. Scrap + Chips formed during Turning	323	310
11	Pig Iron (Small) + M.S. Scrap + Iron Powder	318	306
12	Pig Iron (Small) + M.S. Scrap + Recycled slag – Small Pieces	346	330
13	Pig Iron (Small) + M.S. Scrap + Recycled slag – Big Pieces	339	317

Table 2. Experimental results for radiation loss and without radiation loss

Thus from the above table it can be observed that the radiation loss is higher in few of the mixtures. Thus the total savings of units of electricity by preventing radiation loss can be shown in the form of graph.

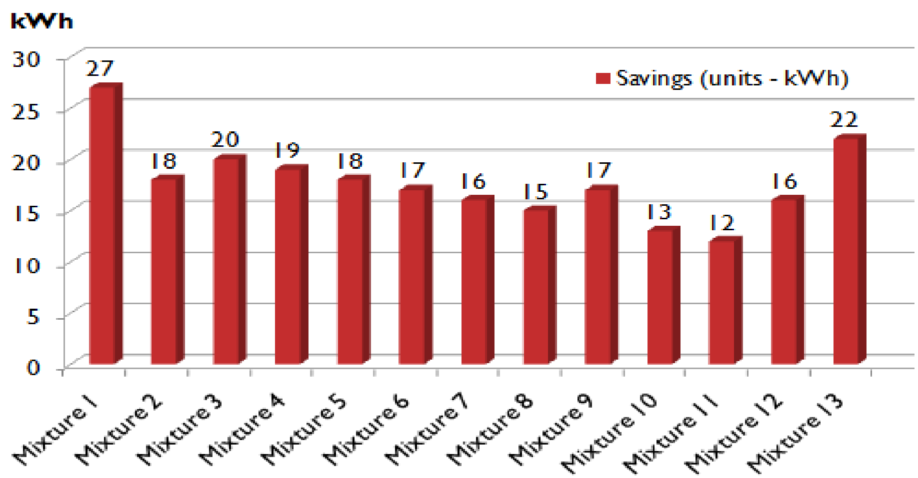


Figure. 6 Graph showing the total number of units that can be saved by the prevention of radiation loss

5. The cost analysis of the process

In the market, all the different casting scraps come at different prices depending upon the type and quality of the material. Our experiment consists of those different quality of casting scrap, so their cost analysis becomes an important aspect in deciding whether that particular casting scrap is worth using or not. The same analysis would be done by comparing it with the total cost of the melting of those casting scrap to give a better comparative result.

For the comparative result of the cost of the raw materials and their melting cost, the below table is generated. The table consists of the values like the cost of the raw materials as per the market conditions, and the value of per unit cost of the electricity, and the total difference in the cost of the raw material and the melting cost.

Mixture No.	Current Rate of Casting Scrap (INR)	Pig Iron Cost (INR)	Total Scrap Material Cost (For 90kg) (INR)	Units Consumed (kWh)	Unit Cost (x 12 INR)	Cost difference (material vs. unit consumed) INR	Total Pig Iron Cost (For 260kg)+ Total Unit Cost	Total cost addition (INR)	Difference
1	26	33	2340	357	4284	1944	8580 + 4284	12864	280 Rs more
2	"	35	2340	337	4044	1707	9100 + 4044	13144	
3	24.5	"	2205	343	4116	1911			
4	22.5	"	2025	351	4212	2187			
5	26.5	"	2385	341	4092	1707			
6	27	"	2430	333	3996	1566			
7	27	"	2430	335	4020	1590			
8	27.5	"	2475	327	3924	1449			
9	27.5	"	2475	334	4008	1533			
10	28	"	2520	323	3876	1356			
11	28.5	"	2565	318	3816	1251			
12	23	"	2160	346	4152	2080			
13	24	"	2070	339	4068	1908			

Table 4 Comparison of the cost of the material and the cost of the melting

In the provided chart, here the mixture 1 is not been shown during the presentation, because it is just marked in the above table only to show that the melting cost of mixture 1 is obviously higher than that of the mixture 2; where they both have same casting scrap as their raw material and just the pig iron is changed in both of them. So this shows that the pig iron used in the mixture 1 is not at all suitable to be used in terms of the cost analysis.

The above values obtained as the difference in the cost of the raw materials and their melting cost, they can be represented in a simpler way in the form of the chart. The higher the value of the cost difference, the costlier it would be to melt that raw material as per its market value of the raw material and the corresponding value of electricity consumed to melt them.

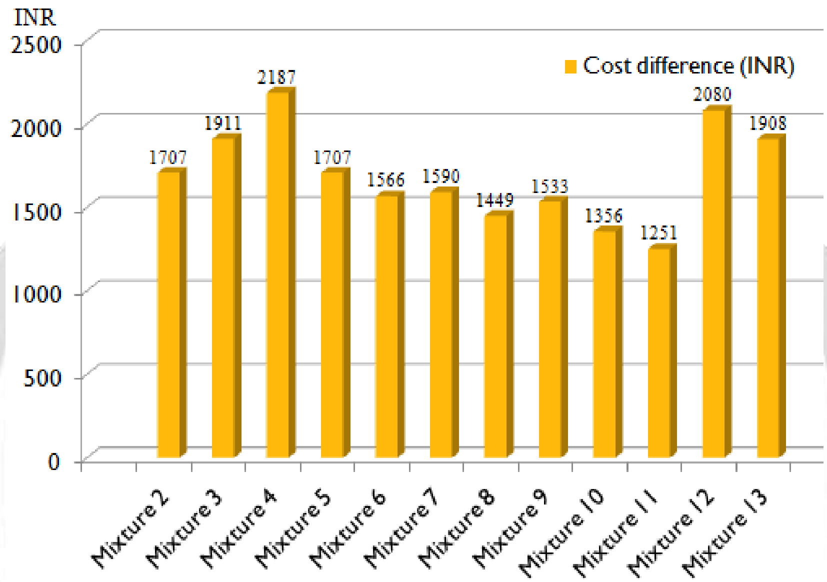


Figure. 7 Graph showing the cost difference of the melting cost and the cost of the raw materials

It can be observed from the above chart that the mixtures 4 and 12 have the highest cost difference in terms of their melting cost and their raw material cost. So this shows that they are not suitable to melt in the induction furnace when their corresponding electricity consumption is been taken into account to melt the material. They can be easily used in the other types of furnace.

6. Slag Produced during melting

When the metal is being melted, then all the impurities present in the raw materials get accumulated at the top of the molten metal as they are light in weight in comparison to the molten metal. Thus, they can be removed from the molten metal by addition of fluxes like sodium carbonate, calcium fluoride, calcium carbide, borates, olivines, sodium chloride (rock salt), calcium aluminates and ilmenite.[20]

The melting of different quality of casting scrap material produces different amount of slag, depending upon the dirt, dust, sand and other impurities like different oxides present in the raw material. The following result is necessary in determining the selection of the material based on how much loss of the material the company has to sustain by the use of that particular quality of the material. The following values are the average of the two sets of experiments performed.

Mixture No.	Charge Material Mixture	Amount of Slag Produced (kg)
1.	Pig Iron (**Big**) + M.S. Scrap + Old Casting Scrap – (Small Pieces)	14.8
2.	Pig Iron (**Small**) + M.S. Scrap + Old Casting Scrap - (Small Pieces)	13.2
3.	Pig Iron (Small) + M.S. Scrap + Old Casting Scrap – (Big Pieces)	13.4
4.	Pig Iron (Small) + M.S. Scrap + Old Casting Scrap – (***Small and Rusted/Dusty)***	16.4
5.	Pig Iron (Small) + M.S. Scrap + Runners/Risers & Excess Casting Parts (***Dirt Stuck on Surface***)	14.4
6.	Pig Iron (Small) + M.S. Scrap + Runners & Risers (***Clean Surface***)	12.6
7.	Pig Iron (Small) + M.S. Scrap + Very small / compact casting scrap - ***Rusted***	13.8
8.	Pig Iron (Small) + M.S. Scrap + Very small / compact casting scrap – **Not Rusted**	13.5
9.	Pig Iron(Small) + M.S. Scrap + Machined Casting Scrap - **Fresh & Clean**	13.0
10.	Pig Iron (Small) + M.S. Scrap + Chips formed during Turning	12.7
11.	Pig Iron (Small) + M.S. Scrap + Iron Powder	17.1
12.	Pig Iron (Small) + M.S. Scrap + Recycled slag – **Small Pieces**	15.6
13.	Pig Iron (Small) + M.S. Scrap + Recycled slag – **Big Pieces**	15.1

Table 5 Slag Produced during the melting operation

The values of the amount of the slag generated during the melting of each mixture can be expressed in the form of a chart for the easy analysis.

The chart below shows the amount of the slag generated from each mixture composition

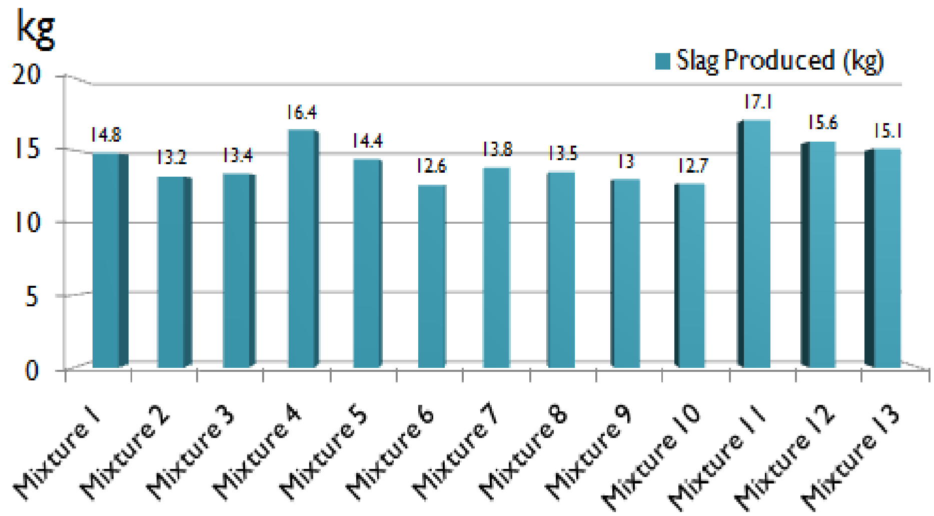


Figure. 8 Graph showing the weight of slag produced during the melting

From the above graph and the corresponding values, it can be noticed that the melting of the mixtures 4, 11 and 12 have the maximum production of slag during the melting. Thus the company has to bear the metal losses associated with it when melting such mixtures.

The loss of the metal associated with the production of the slag can be termed in the cost analysis form, where the cost of the raw material is been taken as the comparative term along with the amount of the slag produced. The related information of the comparative study is been shown in the form of the table, as shown below.

Mixture Number	Slag Produced (kg)	Cost of the Casting Scrap (INR)	Total Loss in the form of Slag (INR)
1	14.8	26	385
2	13.2	26	343
3	13.4	24.5	328
4	16.4	22.5	369
5	14.4	26.5	382
6	12.6	27	340
7	13.8	27	373
8	13.5	27.5	371
9	13	27.5	358
10	12.7	28	356
11	17.1	28.5	487
12	15.6	23	359
13	15.1	24	362

Table 6.5 Cost analysis of the Total loss incurred from the slag production

7. CONCLUSION

From the above experiments performed, it can be observed that the radiation loss is less in those mixtures which are compact in size. It is also observed that the radiation loss plays an important role in the conservation of the energy. So it is recommended that the foundries should always cover the top open surface of the furnace with the refractory material to prevent the heat from escaping into the atmosphere. Also from the cost analysis of the process it can be observed that there are some materials which are not suitable to be melted in the furnace as they might add up the manufacturing cost. The study of the slag generation during the melting of each mixtures shows that those materials which have more dirt stuck to their surface, or the materials which are rusty, they have more amount of the slag generation. Thus these types of materials are less suitable to be melted in the furnace. Thus from the above all experiments, it can be concluded that the foundry remains are the best scrap material to be used for the melting. But as the material demand would not be fulfilled by the foundry remains (as they are very less in quantity), so the best possible alternative to it would be the small casting scrap which are not rusty. Thus by such study, the foundries can have tremendous help in increasing their profits.

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