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Studies on Melting Techniques for Energy Conservation in Foundries

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Abstract— The melting process often we include refining and treating the metal, But the choice of which type of melting to use depends on a number of factors: a)type of alloy being melted, b)the local cost of electric power, and c) local environmental regulations. This article discusses theStudies on melting Techniques, principles, furnace types, charging practices of metal melting methods, namely induction melting, cupola melting, arc melting, crucible melting, reaction melting, and vacuum melting, and the refractories and charging practice of reverberatory furnaces. Molten metal treatment of steels and aluminum also is discussed in the article. Melting needs a definite amount of energy, which is material dependent property, for example, an amount of heat energy equivalent to the latent heat of fusion of cast iron has to be supplied to convert the cast iron from solid state to liquid state at melting point

Keywords— Melting process, Metal melting methods, Reverberatory furnaces, Energy equivalent etc.

I. INTRODUCTION

This Technical paper deals with various areas related to molten metal in a foundry. The efficiency in melting is the main factor in determining the energy consumed per ton of castings dispatched and result in energy conservation.

More than two thirds of energy utilities in an iron foundry are used for the melting and holding and any improvement effected in this area can bring about considerable difference to the profits. Melting needs a definite amount of energy, which is material dependent property, for example, an amount of heat energy equivalent to the latent heat of fusion of cast iron has to be supplied to convert the cast iron from solid state to liquid state at melting point. The same logic would hold good for heating the scrap from room temperature to melting point. This can not be improved. However, what can be done is to minimize the losses and conserve energy.

There are two major melting furnaces are available for cast iron production, namely cupola and Induction furnace.

II. CUPOLA MELTING

Cupolas have a bit too many variables as compared to induction furnace. This makes the control of cupola far more difficult than any other furnace. The response time also is very high and therefore effectiveness of any change takes long time to manifest in terms of an observable output.

In west, cupolas have got highly mechanized with computerized charge weighing and recording systems. These systems have in-built facilities to modify the charge mix depending upon the requirements. These cupolas also come with computerized systems for monitoring various operating parameters. These may be the combustion ratio, blast temperature, blast pressure, output metal temperature etc. Some furnaces also have computerized control systems, which modify the parameters in a reactive manner. The levels of control systems incorporated are as elaborate as that of a modern blast furnace. This has been made possible since the furnace have very high output. It is highly unlikely that any of the Indian Cupolas would see a level of mechanization of operating parameters to this degree.

Cupolas of smaller capacity found in use in India will continue to be operator dependent and the skills of a melter would have to be relied upon.

A. RAM MATERIALS

Raw materials such as coke, scrap, flux, foundry returns, and pig iron are used for melting of Cast iron are discussed in this section.

1) COKE

The properties of coke influence the operation of a cupola. Using only a coke of uniform combustibility, size and good mechanical properties can effect efficient operation of cupola. The ideal properties of a foundry coke are given in Table 1.

1. Table 1 Properties of Foundry coke

Sl. No.	Properties	Range
1	Moisture (%)	Less than 3.0
2	VM (%)	Less than 2.0
3	Fixed carbon (%)	More than 86.0
4	Ash	Less than 12.0
5	Sulfur	Less than 0.8
6	Size	Above 1/10 to 1/12 of cupola lined/diameter

Indian cokes have earned notority for their sulfur and ash content. It might not be possible for the foundries to stick to

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these specifications and might have toes whatever is available. However, the Foundrymen must be aware of the ideal properties and try and control what is within his ambit. The moisture, volatile matter and ash bring down the fixed carbon that gives the heat. High levels of these materials have to be handled in the furnace and expelled out. This takes further heat. The two-way effect of these materials viz., reducing the combustible material and requiring thermal energy for their disposal increases the coke consumption in a cupola substantially.

Ash from the coke forms principal constituent of a slag. The coke ash is normally acidic in nature with about 60% of Silica, 30% of alumina and 10% of Ferric oxide. This also contains some oxides of manganese, magnesium and alkali earth's. The ash is fused in the melting zone and needs fluxes. Higher the ash content, higher would be the need for fluxes and poor would be the energy conservation as the flux material has been heated to be molten and react with ash. The ash content of Indian coke is higher than 25% and the metal to coke ratio with Indian coke is about 1:7.

The coke should not be fragile. A fragile coke creates fines while handling and after being charged into the cupola. This disturbs the flow of air/gas and liquid metal in the furnace and brings down the efficiency of the cupola very substantially.

2) SCRAP

Scrap may be a source of difficulty in a cupola. It is difficult to segregate every bit of scrap added. In the process, elements like tin, aluminium, antimony, lead may get picked in small quantities. These elements may result in poor graphite shape, size and distribution in gray iron. In the case of SG iron, such elements may act as de-nodularizers. In extreme cases, these materials can result in carbides in gray iron and areas of gray structure in SG iron.

The size and shape of the scrap is also critical. Very bulky and small size steels scrap (like borings) and small gray iron can seriously impede the movement of the material and consequently effect the air flow up. This causes adverse conditions for combustion and increases in the fuel consumption substantially.

3) FLUXES

Fluxes are used react with the ash from the coke and the scarped refractory from the lining to make a fluid slag. The fluxes are basic in nature and they react with the slag of the cupola which is normally acidic in nature. The normal flux used is limestone. While selecting limestone care must be taken to see that the $CaCO_3$ content is as high as possibility (the ideal purity recommended is 97%). The acid content (SiO_2, Al_2O_3) of the limestone should be minimum, since on melting the acid and basic components of limestone react first. This results in the need of increased addition of limestone. This addition of limestone leads to strain on coke, which should have to be increased. Addition of flourspar and soda ash can be made to increase the fluidity of the slag.

4) AIR

Air is one of the necessary materials for a cupola. The air requirement is about 1 ton / ton of iron produced and is far more important than anyother input material. The input air may have varying temperature, humidity, pressure and uniformity of delivery.

The best practice would be to have metering and control unit for air inflow, which can help in monitoring and in making finer adjustments to airflow. To avoid uncertainties in the humidity and temperature of inlet air, it would be advisable to have a dehumidification plant and pre-heating arrangement using the flue gases. The location of tuyers also may be reviewed. The balanced draught with tuyers in two or more rows can help in improving the energy efficiency of a cupola. These systems cannot be a ready-made solution but has to be designed and tailor made for a specific cupola.

5) PIG IRON

This is the latest troublesome of all the raw materials of a cupola. The level of carbon, silicon and manganese is high in the foundry grade pig iron. This is the ideal situation for cast iron since it also needs these elements at higher percentages. The phosphorous and sulfur contents are also high. This is not for gray iron. In fact, little higher percentages of phosphorous adds fluidity and sulfur of final product is more dependent on coke than on pig iron.

B. OPERATION

The successful operation of a cupola depends upon the ability to control the combustion of coke with air. This can be ensured by combination of coke and air supplied at proper rate. With such a condition, the control of composition, temperature and slagging can be achieved in an energy efficient manner.

1) COKE AND AIR SUPPLY

The rate of charging of coke and the rate of delivery of air must be controlled to have the best and energy efficient operating conditions in a cupola. The coke air balance is best indicated by the composition of flue gas which should contain about 12-14% CO_2 and 11-15% CO.

It would be highly advisable for a foundry to set the air supply requirements as precise as possible since it can result in the coke getting fully combusted and excess air being not there to take excessive heat out of the furnace.

These calculations need to be corrected for coke: metal ratio, temperature of input air, humidity of air and oxygen enrichment. Excess coke may result in wasted coke, slow melting rate, and high carbon in iron, lower temperature and excessive refractory wear. Over supply of oxygen may cause burnout of the bed coke, oxidation of iron, loss of silicon and manganese, low carbon content and low metal temperature.

The air requirement is about 8.5 cum for 1 Kg of coke. Therefore, for a metal coke ratio of 7:1 and for 1 ton melting capacity, cupola needs 1220 cum of air. The air supply rate would be about 20 cum/minute.

2) BED COKE

The bed coke height is defined as the height of the coke bed above the tuyeres at the start of charging. As the melting progresses, the coke bed height comes down. The direct indication of the reduction in the height of the bed coke is the drop in temperature of the molten metal. The bed coke can burn off due to excessive supply of air. This may result in lower CO and higher CO_2 content in the flue gases. There will be excess O_2 passing through the charge and this may oxidizes the iron. The exhaust would start appearing more and more brown in Colour as against the white Colour of normal operation.

The buildup of coke bed due to shortage of air (or O_2) will result in lower temperature and reduced melting rate. Therefore, bed coke functions as an area intense heat to melt and super heat the material under conditions favorable to the iron.

3) MELTING RATE AND TEMPERATURE

The operating characteristics of a cupola, namely, melting rate and temperature are dependent on operation parameters- coke bed, coke charge and air supply. When coke - air balanced and bed coke height is maintained, higher air supply result in higher temperature of the molten metal. The increase in air blast and iron- coke ratio results in increasing melting rate.

While varying any parameter the position should be such that air coke should be balanced. The flue gases best judge this balance and analysis of the gases may be used as a method of control.

4) METAL COMPOSITION

The metal composition control is facilitated by promotion of the proper combustion condition during melting. By this, there will be consistent compositional changes in melting, which can be anticipated. The metallic charge materials then would dictate the composition, and the metal composition is effected through a typical charge calculation. The typical composition changes are given in Table.2

These figures are indicative in nature and cannot be applied generally to all conditions. The exact nature of the losses has been established over a period of time by trial and error.

C. ENERGY BALANCE

The Indian cokes are poor in quality with ash contents exceeding 25% which results in low temperature, high coke consumption and high slag volume. This also results in Indian cupolas becoming prone for bridging and the in ability to make high-grade cast iron and thin section with cupola metal.
As one could observe, the major energy loss is in the top (flue) gases. The effective way to counter this would be to use hot blast cupola. The flue gases are used preheat the incoming combustion air to150 – 250^0 C. In this system, the flue gases containing high CO content is trapped at the top of the cupola and allow completing the combustion with the injection of additional air in a heat exchanger. This can increase the iron heat about 30% and bring about a similar reduction in the coke combustion. If it coke –metal ratio is maintained, the temperature of tapping may be higher by about 30-50^0C enabling the manufacture of thin walled castings.

Table 2 Compositional Changes in Cupola Melting

Element	**Melting Gain or Loss**
Silicon	IO% Loss
Carbon	10 –20 % gain
Manganese	15% loss
Phosphorous	No change
Sulfur	Add 0.05-0.08% to the calculated sulfur value

D. OTHER DEVELOPMENTS

The developments in cupola melting are the water cooling and divided blast. The water-cooled cupola has the advantage of having of lower thickness of inner lining refractory and effectively the capacity is higher for a particular diameter. These cupolas can be operated on longer cycle, thus making them more energy efficient. Divider blast cupola has tuyeres in 2 or more rows compared to single row unconventional cupolas. This affects better distribution of air and uniform melting. The liquid metal output and the temperature are also found to be better.

Oxygen enrichment of the blast increases the thermal efficiency and results in energy conservation. The oxygen enrichment leads the following positive aspects:

a) Results in higher melt temperature, a higher carbon pickup and lower silicon loss. This means that part of pig iron can be replaced with cheaper steel scrap or returns.
b) Reduces coke consumption for the same temperature.
c) Results in heating being very rapid and minimizes the defects due to Cold metal.

Adopting the following methods can enrich the oxygen:

a) Blast enrichment through feeding oxygen into the main blast before entering tuyeres

b) Injection at the tuyeres using a stainless steel injector
c) Injection into the well just beneath the tuyeres using water-cooled copper injector.

The oxygen injection is very effective with divided blast. However, the economics of the added cost of oxygen has to be considered before adopting such measures

E. BENCH MARKING

The cupola operation in our country has been studied extensively by the institute of Indian Foundrymen (IIF). The National centre for Technical Services (NCTS), Pune has conducted the study and has come up with a number of observations. The recommendations of NCTS for efficient cupola operation are summarized below.

- Cupola should be equipped with minimum required instrumentation-air pressure gauge, blast volume meter, bed height gauge, weighing scale, temperature gauge.
- Blower with 'V' pulley drive and motor with 1440 RPM should be used.
- Tuyeres should be 15% of the cross section of the cupola and tuyeres be tapered 10 towards the inside of cupola.
- Refectories should be used as follow

Well : IS10 grade
Combustion & Melting zone : IS8 grade
Cupola stack : IS6 grade
Below charging Door upto 3-4 feet : Hollow Cast Iron blocks
Above charging door : Fire bricks

- The Pig Iron should be selected such that the carbon content is more than 4.0%
- The heredity of scrap should be ascertained before using. For Example, some of the thin walled items have excessive phosphorus content. Such scrap should be avoided.
- Steel scrap should be rust free
- Scrap should be free from paint, oil & such impurities. It would be better to use chunky fabrication shop scrap.

Based on such standard practices, the following bench marking has been evolved by IIF:
Refractory Consumption : 7-8 Kg per Ton of Metal
Burning Loss : 6% of metal charged
Coke Consumption : 10-13% of the metal (Excluding Coke bed)

III. INDUCTION FURNACE MELTING

The coreless induction furnace is an equally popular melting unit as cupola for cast iron. The ideal power consumption per ton of cast iron (at 1450) is around 600 units. However, most foundries consume around 800 units though they are able achieve 600 units once in a while and not on a sustained basis. Some foundries consume as much as 1000 units per ton.

The energy conservation in the case of induction melting depends entirely on how efficiently the operations of the foundry are conducted. The heat input is very high per unit time. For example, from melt down to tapping it takes only 10-15 min. Therefore, the laboratory should be extremely efficient to furnish the result within this time. Any delay in giving the result would delay the melt leading to high-energy consumption.

This aspect also necessitates use of good scrap of known chemistry so that the charge calculation made would be resulting in a composition as desired and minimize the sampling to just one at the melt down.

A. QUALITY OF SCRAP

Induction furnaces generally need pedegre scrap. This is necessary for multiple reasons.

a) A scrap with rust results in the silica lining getting eroded fast. The lining & sintering of an induction furnace is an energy intensive operation.
b) A pedegre scrap would result in minimum compositional adjustments when the metal is melted down. This would necessitate only minimum holding.
c) Very bulky (swarf) scrap takes longer time to melt, thus makes the furnace less energy efficient.

B. QUALITY OF RAMMING MASS

The Induction furnaces can be lined either with acid (silica) ramming mass or basic (magnesia) ramming mass. The basic lining is preferred since it gives longer life than acid lining resulting in energy conservation in term's energy for sintering. However, most foundries prefer acid lining because it has a binder in the form of boric acid and is less complicated. However, for SG irons where the slag could be basic in nature if lime is used for desulphurisation, the lining may get adversely affected.

Whatever the lining material may be used for induction furnace, its purity has to be assessed and monitored. Reduced purity levels reduce the fusion point of the ramming mass. This leads to increase in wear of the lining.

IV. CONCULATION

This paper is meant to invoke a feeling and belief that energy conservation is important for survival of a foundry. This paper highlights that energy conservation is need not necessarily mean that the adaptation of new technologies at additional investment. The conservation could come only from improving the existing operations before looking at newer methods, processes and techniques without adding any investment.

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