Energy Efficient Cupola Furnace via Hybridization with a Biomass Gasifier

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Abstract – The energy efficiency of any foundry largely resides on efficiency of the melting process. High price and limited supply of coke will continue to press the need for devising a way to cut down its demand or developing more energy-efficient solutions for the melting process. This work tries to address the issue by proposing and analyzing a way of reducing coke consumption in a foundry cupola studied, by hybridizing it with biomass wood gasifier. Wood fuel is very cheap and readily available. It can be used to heat the blast air going through a cupola furnace by burning in a gasifier. 800 °C of gas at 16 g/s will be available to heat up the blast air entering the studied cupola of Asia Sewing Machine's foundry to at least 475 °C if hybridized with the 20 KWe downdraft biomass gasifier model studied by Sharma. This is enough to cut down the coke consumption by 133 Kg from 430 Kg used to melt 3450 Kg of metal charge at present. Analysis has shown the coke energy efficiency to improve from 43% to 62.4%. The stoichemetric air/fuel ratio required for both the gasifier and the cupola is found to be 7.86 and 10.52 respectively for proper combustion of their respective fuel. The chemistry in the various stages of the cupola furnace and reasons for that huge percentage of heat energy loss during melting process was properly discussed. It is possible to achieve a less coke demanding cupola furnace by hybridizing with a biomass gasifier. This would greatly reduce the amount of coke consumption in a foundry by using a cheaper and more readily available energy source that consumes gradually to supply a hot air blast (wood etc).

Index Terms – coke, wood, cupola furnace, blast air, flue gas, cupola zones, molten metal, slag.

1. INTRODUCTION

Cupola has always been the primary choice for melting in iron foundries for many years now. This can be linked to some of its unique characteristics which are responsible for its widespread use as a melting unit of cast iron. The amount of energy requirement per unit is far less compared to other furnaces like electric furnace [1]. Cupola has always been the most cheapest and efficient means of melting in foundries. It is the cheapest means of producing gray cast iron as it doesn't require electricity or a sophisticated control unit. And considering the whole environmental chain and level of effect of other means of melting, cupola is more cleaner and eco-friendly [2]. Moreover, a cupola furnace can be operated intermittently without stopping. The molten metal can be periodically tapped while the furnace is being recharged. This makes it possible to manage production time. But environmental pollution and energy crisis have been a matter of serious concern, the world over [3]. A controlled temperature is also difficult to maintain inside a cupola. Even though it is proven possible to melt all kind of metal (ferrous and non-ferrous) in a cupola furnace, it is found favorable mostly in melting ferrous metals.

1.1. Motivation

The concern over the energy efficiency of processes has been growing with the recent rising costs of energy. Foundries attentions are beginning to be diverted towards minimum operating cost by investing more in capital equipments improvement. Realizing that becoming more energy efficient reduces overall cost. The energy efficiency of any foundry largely resides on the efficiency of the melting process. Melting practices does not only determine how effective energy is being utilized or production cost is being managed, but it also defines the quality control, composition, and the physical and chemical properties of the output product [4]. Unfortunately in today's foundry, so much capital goes in to fuel in the form of coke. Due to its high demand, a lot of industries are impacted by the large price swings. If this value could be cut down, there will be a tremendous amount of energy saving and the cost of production will also be slashed. This is the sole aim of every production body; to minimize cost and save energy. Factors like higher demand and limited supply will continue to press the need for devising a way to cut down coke fuel demand or developing energy-efficient solutions for melting in cupola furnaces. Even though the energy utilization in the melting process has been a considerable concern in foundry operations, the industry are still using melting technologies with low energy efficiencies. Therefore, it is only fair if a means is found to cut down the cost of the energy. Research efforts have been expanded to develop a means to maximize the percentage of energy used from burned coke in cupola [5, 6, 7]. This can also be achieved by delivering the raw hurt gas from a biomass gasifier through insulated mains to heat the blasting air of a cupola furnace as illustrated in figure 1. As gasifier fuel are mainly biomass solid fuel (organic fuel), which are cheaper and readily available. Biomass fuel is obviously cleaner and can be recycled. It is also a means of waste recycling [8].

1.2. Objectives

The main objective of this research work is to model through analysis, a more energy efficient cupola furnace through hybridization with a biomass gasifier. Hybridizing biomass gasifier with cupola furnace to nourish the metal to a certain temperature could not only cut down the coke fuel consumption, but also raise the energy efficiency by partly utilizing more cheap and readily available fuel in the gasifier. Blast air temperature has to be readily increased before even entering the tuyeres without increasing the amount of coke, but reducing it instead. This means substituting some part of the coke used and cutting down the production cost. However, this comes with an initial cost of setting up a gasifier, more setup to be monitored/maintained and additional operational skills. The cupola data would be collected but gasifier is not to be tested in this study. Instead, performance and operational data will be borrowed from the work of Sharma, for an already tested and analysed 20 kWe, Solid Biomass Downdraft Gasifier [9]. At the end of this study, the possibility of cutting down coke consumption in cupola by hybridizing with a biomass gassifier would be shown by means of analyzing energy efficiency. It expected that small scale and even large scale foundries could consider putting this hybridized model into practice if proven to be beneficient. By and large, the study has to meet up with the following objectives;

I. To collect operational data from an existing cupola furnace suitable for justifying its fuel consumption.

II. Analyze the possibility effect of after hybridizing cupola furnace with an external source of additional heat (biomass wood gasifier).

III. Justify the reduction in coke fuel consumption after hybridization.

IV. Analyze the fuel to be used by both the furnace and the gasifier by showing their stoichemetric air/fuel ratio.

V. Calculate the heat required for melting the metal charge.

VI. Show the energy efficiency of the cupola furnace, before and after hybridization.

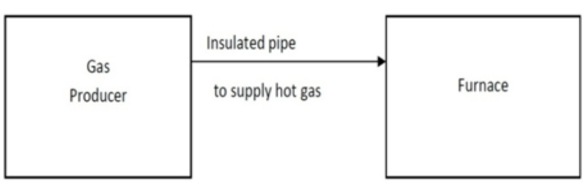


Figure 1: An illustration of gasifier – furnace hybridization.

Source [Self]

2. MATERIALS AND METHOD

A practical visit/study was conducted to monitor and collect performance data of a cupola furnace from a foundry industry here in Jaipur.

The industrial sized Cupola furnace at *Asia Sewing Machine* industry is a big furnace that can accommodate even more than 4500 kg of metal composition at a time, other composition excluded. But for that particular melting session, only about 4000 Kg of pig iron and related scrap was melted. It is equipped with a spark arrester at the top to stop spark particles and dust from escaping, and lined from the inside with refractory bricks that insulates the inside of the furnace from losing a significant amount of heat. Due to its height and size, it was designed in such a way that the metal scrap is fed with the aid of an electrically operated conveyor, mounted on a rail, through the charging door. The tapping hole, through where the molten metal is collected, is relatively at the lower part and the front of the furnace. The slag hole is directly at the opposite side of the tap hole and slightly above its level. Slag is collected through the slag hole as it floats on top of the molten metal. The entire furnace is resting on four (4) huge legs of steel columns. There is a drop door hinged to one of the supporting legs. When the cupola is fully charged, a leg support at the bottom door is provided so that the door remains intact and do not fall down as a result of the heavy weight of the charge materials. The drop door provides access to the inside of the cupola for maintenance purpose. There is a chamber known as the tuyeres, situated along the circumference of the shell and connected to an inlet that supplies air from a blower. There is also a pressure gauge installed just before the tuyeres inlet, to measure and control the amount of air passing through. A picture of the cupola cross section can be seen.

Figure 4: A picture of the cupola at Asia sewing Machine foundry.

Picture taken at Asia Sewing Machine, Jaipur.

2.1. Choice of gasifier model

Biomass gasifier is available in three different designs depending upon the operating conditions and purpose for which it is to be used [10]: downdraft, updraft and crossdraft gasifier system. And the heat required for this purpose best fit a downdraft gasifier due to its economy and flexibility.

When it comes to producing just enough gas for certain load, and hence more flexible to adapt, a downdraft gasifier is always the choice to work with. Charcoal dust, and tar content of fuel has little or no effect on its performance [11]. However, the gasifier is not simulated in this work. The focus of this study lies in the assessment of hybridization of a gasifier with a cupola furnace and not it detailed simulation. An advanced 20KWe *downdraft wood gasifier* operating on kiker wood or Acacia nilotica, developed in Indian Institute of Science, Bangalore [12], was utilized as a model to be simulated in this work. The gas generated and the burned wood both moves downward as the process is taking place. The source of air for the gasification process is both, the three (3) air tuyeres placed radially around the circumference of the oxidation region, and the opening at the top of the gasifier. All the heat generated can be channeled through a duct integrated to the gasifier. All the necessary experimental data has already been generated by Sharma [9], based on model with the same configuration. The photograph view of the gasifier can also be seen in figure 5 as provided by Sharma [9].

Figure 5: A Photographic View of 20 kWe, Solid Biomass Gasifier.

Source: Sharma [5]

2.2. Materials

2.2.1. Wood

The solid fuel used as source of energy in the gasifier by Sharma [9], was sun dried Kiker wood (Acacia nilotica). The three basic classes of wood i.e., soft-wood, hard-wood and ordinary-wood, were investigated in the work. The distribution of cellulose, hemicelluloses and lignin in these classes of wood can be seen in table 1 [13]. Table 2 shows the percentage chemical composition of a hard wood [14].

Table 1: The distribution of cellulose, hemicellulose and lignin in different classes of wood.

Type of wood	Cellulose	Hemicellulose	Lignin
Hard-wood	0.43	0.35	0.22
Soft-wood	0.43	0.28	0.29
Ordinary-wood	0.50	0.25	0.25

Source: [13]

Table 2: Percentage chemical composition of a hard wood.

Carbon, C	50%
Hydrogen, H	6%
Oxygen, O	43%
Nitrogen (N) + Sulphur (S)	1%

Source: [14]

2.2.2. Coke

Coke is obtained as solid residue from the destructive distillation of coal in the temperature range of 1200-14000C. The extensive ranges in which the compositions of coal vary by weight as established by an ultimate analysis are given below [15].

Table 3: Constituents of coal by % in weight.

Carbon	77.2%
Hydrogen	5.2%
Oxygen	5.9%

Sulphur	2.6%
Nitrogen	1.2%
Ash	7.9%

Source: [15]

Foundry coke burns with smoke, and heat can be generated (calorific value) of up to 31000 KJ/Kg [18]. Coke is produced by heating coal in the absence of air (pyrolysis) to remove moisture and other volatile component, making it high carbon-rich. The temperature at which coke burns is more than enough for the melting process. Because melting temperatures of most compositions of iron are usually in the range 1370 to 1600°C (2500°F to 2900°F), depending on the kinds of iron produced [16].

Foundry coke is the primary source of fuel at Asia Sewing Machine foundry because there are at present no reliable quantitative relationships regarding the effect of coke properties on cupola furnace operation [16].

2.3. Method

1. Cupola furnace

Figure 6 (a and b) are model representation of the cupola furnace at the Asia Sewing Machine foundry, from which data was collected, for proper illustration.

The melting process is carried out in five (5) stages for each operation, and each process last for an hour.

Figure 6a: A model of the cupola furnace at Asia Sewing Machine foundry.

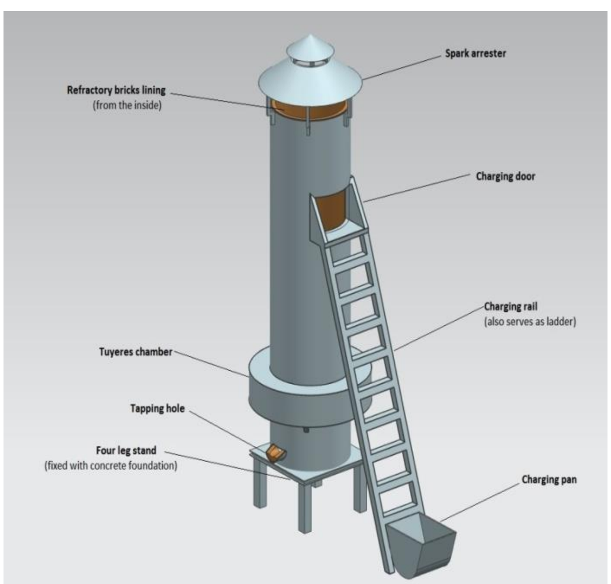
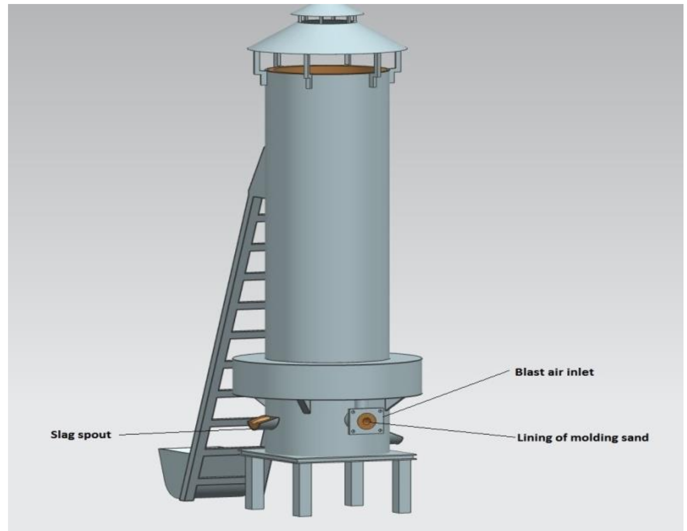


Figure 6b: A model of the cupola furnace at Asia Sewing Machine foundry.



Source: (self)

I Preparation:

The cupola was cleaned and the slag stuck around the tuyeres and the slag hole was ensured to be cleaned. Broken bricks were repaired, using silica sand. A layer of refractory sand was applied over the burnt area of the fire brick lining.

A bed of molding sand is then rammed to the base of the cupola from the inside, sloping toward the tap hole to ensure better flow of the molten metal.

II Firing:

Fire was started on the sand prepared using fire wood, then coke of 430 Kg was dumped from the charging door when the wood was completely in flame until it was slightly above the tuyeres.

Following up with a moderate air blast enough to keep the coke burning, it was ensured that it was completely hot red. The amount of air required for melting a unit or badge of iron depends solely on the coke iron ratio.

III Charging

For charging, the furnace has a rail for conveying the charge to the charging door at the top as it is difficult to do that manually due to the charge weight and the furnace height. It was charged with the aid of a conveyor that moves all the way up to the charging door. The conveyor is electrically controlled from control buttons and a lever situated at a position not too far from the furnace, and the operator has a clear view. The charged metal also contain, apart from the pig iron, scrap of metal, risers, runners and sprues cut out from the previous castings. The charging was carried out in an alternate manner;

layer of metal, Ferro-manganese, limestone as flux and then coke. The flux protects the iron from oxidation and removes impurities.

The industry has an ethic of carrying out the operation with charge composing of (75% metal + 10% Ferro-manganese), 11% coke, and 3% flux (limestone). Limestone is the main flux here because of its ability to capture coke ash and all other impurities in the furnace to form slag. The slag, itself, has the advantage of protecting the surface of the molten metal from foreign contaminants and reducing rapid heat lost before pouring.

IV Iron soaking

When the coke was properly ignited, air supply was cut off and the metal was allowed to soak for a period of about 40 minutes. During this stage, heating took place slowly because air supply was cut off.

V Air blasting

Air blast was opened after the metal was ensured to be soaked. Air blast of 2.22Kg/s was kept in circulation from the blower, until metal melts completely. This is when the molten metal began to find its way out from the bottom tapping hole. The furnace was kept active by feeding composition of metal, coke and flux at the same rate molten metal was collected. So as to fully utilize the heat generated in the furnace.

The whole operation was brought to an end after the melting process was repeated ten times for similar ratio of composition. This took a period of 10 hours, with an average of 1 hour for each cycle. The data below was collected for the entire process.

Metal charged per cycle = 3450kg

Coke charged per cycle = 430kg

Ferro-manganese per cycle = 460kg

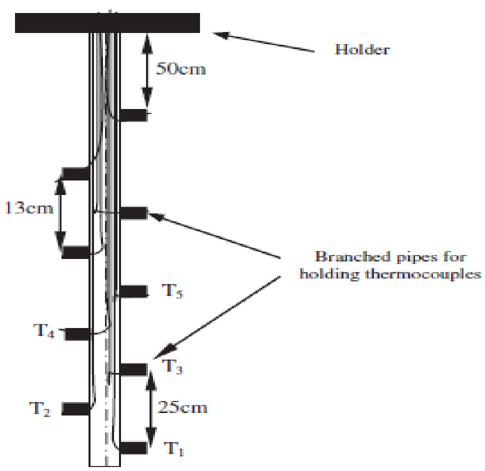
Limestone per cycle = 117kg

Time taken to tap molten metal = 1 hr

BIOMASS WOOD GASIFIER

According to Sharma [9], the gasifier was initially filled with charcoal to the tuyeres before it was preloaded with wood pellets. The purpose of the charcoal is to ignite the wood charge. After switching on the blower, Sharma tried to record the pressure drops at various tine interval of the gasifier operation. A thermocouple was used to measure the temperature inside the gasifier bed (figure 7). Here we are only interested in the raw output of the gasifier and no need to filter or cool the output gas, therefore, the cooling and cleaning unit will be neglected in this work. Only the data before those processes will be considered. Sharma [9], carried out the experiment using various ignition techniques. Including, directly starting up the burning of the wood with a torching flame at the entry level of the tuyeres. But the reactor has to be always left 15 – 20 minutes for the entire fuel to be in flame Sharma [9].

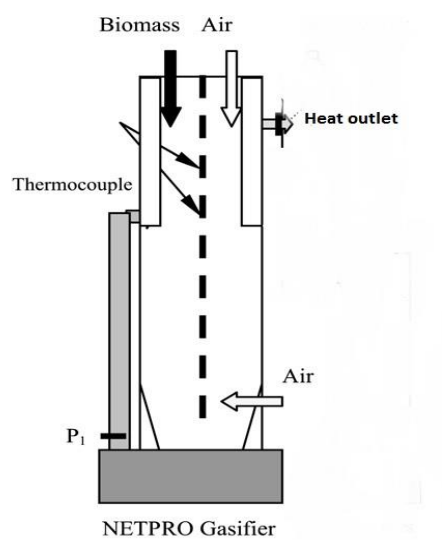
Figure 7: The structure holding the thermocouples for temperature measurement inside the gasifier bed.



Source: Sharma [9].

For the hardwood feedstock, gas of calorific value 3894 KJ/m^3 was achieved as output from the gasifier, at a typical gas flow rate of 16 g/s [6]. However, a certain gas flow rate is hard to maintain and, therefore, fluctuates to 4.7 g/s with a throat temperature of 1150 °K (877°C) [5]. For these reasons, the output temperature of 800 °C is the lowest to be expected from the gasifier model and would be used for this purpose. The block diagram of the gasifier system is given below, according to Sharma [9].

Figure 8: Block diagram of the gasifier system.



Source: Sharma [9].

3. RESULTS AND DISCUSSION

3.1. Results

3.1.1. Mass of charged material

The weight of charged material is taken before being fed into the furnace. It is always on the basis of 85% total metal charge. For this process:

Metal charged per cycle = 3450kg

Ferro-manganese per cycle = 460kg

Total weight of iron charged = 3450 + 460 = 3910kg

Limestone per cycle = 117kg

Coke charged per cycle = 430kg

3.1.2. Fuel analysis

3.1.2.1. Wood

The percentage chemical composition of the wood used can be seen in table 2. Where Carbon is 50%, Hydrogen 6%, Oxygen 43% and Nitrogen + Sulphur constitute to the amount of 1%. From these values, the stoichiometric air/fuel mixture can be calculated. Assuming the equivalent fuel sample formula to be:

$C_aH_bO_cN_dS_e$ …………………… 1

Since the percentage of nitrogen and sulphur both amount to 1%, it can be assumed that both carry 0.5% for this purpose. Therefore, according to the percentage;

C: 12a = 50 => a = 4.2

H: 1b = 6 => b = 6

O: 16c = 45 => c = 2.8

N: 14d = 0.5 => d = 0.03

S: 32e = 0.5 => e = 0.02

Substituting the values in equation 1, the combustion equation can be written as:

$C_{4.2}H_6O_{2.8}N_{0.03}S_{0.02} + xO_2 + x\frac{79}{21}N_2 \rightarrow pCO_2 + qH_2O + rSO_2 + sN_2$ ……………..2

Balancing equation 2;

C: 4.2 = p => p = 4.2

H: 6 = 2q => q = 3

S: 0.02 = r => r = 0.02

O: 2.8 + 2x = 2p + q +2r = 2(4.2) + 3 +2(0.02)

⇨ 2x = 11.44 => x = 5.72

N: $0.03 + 2x\frac{79}{21} = 2s = 0.03 + 2\ (5.72)\ (3.76)$

⇨ $s = \frac{43.04}{2} = 21.52$

The balanced equation can now be written as:

$C_{4.2}H_6O_{2.8}N_{0.03}S_{0.02} + 5.72O_2 + 5.72\frac{79}{21}N_2 \rightarrow 4.2CO_2 + 3H_2O + 0.02SO_2 + 21.52N_2$ …………….3

The stoichiometric air/fuel (A/F) ratio required is:

$$\frac{5.72(32) + 5.72\left(\frac{79}{21}\right)28}{100} = \mathbf{7.86.}$$

3.1.2.2. COKE

The chemical composition of coke is also given in table 3. It can be seen that a typical coal has 77.2% C (carbon), 5.2% H (hydrogen), 1.2% N (Nitrogen), 2.6% S (sulphur), 5.9% O (oxygen) and 7.9% ash by weight. We can further to calculate the molar composition by dividing each of the mass percentage by the molar weight of the constituent.

Element % mol/I00g	***g/mol C***
C: 12a = 77.2	=> a = 6.433
H: 1b = 5.2	=> b = 5.200
O: 16c = 5.9	=> c = 0.369
N: 14d = 1.2	=> d = 0.086
S: 32e = 2.6	=> e = 0.081
Ash	= 7.9%

Hence, the chemical formula that describes the coke can be written as;

$C_{6.433}H_{5.2}N_{0.369}S_{0.081}O_{0.086}$ …………………. 4

The combustion stoichiometry of this fuel must include the minor species, ash, and oxygen in the fuel. Making the simplifying assumptions described above, we may write the stoichiometry as;

$C_{6.433}H_{5.2}N_{0.086}S_{0.081}O_{0.369} + \alpha(O_2 + 3.78N_2) \rightarrow pCO_2 + qH_2O + rSO_2 + sN_2$ ……… 5

Balancing the equation gives;

C: 6.433 = p → p = 6.433

H: 5.2 = 2q → q = 2.6

O: 0.369 + 2α = 2p + q + 2r = 2(6.433) + 2.6 + 2(0.081) = 15.628

⇨ 2α = 15.628 – 0.369 = 15.259

α = 7.630

N: 0.086 + 2α(3.78) = 2s → 0.086 + 2α(3.78) = 2s

0.086 + 2(7.630)(3.78) = 2s

⇨ s = 28.884

S: 0.081 = r → r = 0.081

The balanced combustion eqution can now be written as:

$C_{6.433}H_{5.2}N_{0.086}S_{0.081}O_{0.369} + 7.630O_2 + 28.84N_2 \rightarrow 6.433CO_2 + 2.6H_2O + 0.081SO_2 + 28.884N_2$…… 6

Then the stoichiometric air/fuel (A/F) ratio required will be:

$$\frac{7.630(32)+28(28.84)}{100} = \mathbf{10.52}$$

3.1.3. Quantity of heat required to melt the metal charge

The heat content of molten metal is calculated base on material and its temperature. The heat capacity for various elements that constitute for gray cast iron at certain temperature can be seen in the table 4 [17]. Hence, the quantity of heat carried away by the molten metal can be calculated, by integrating them according to their percentage in the material, as follows [17].

Table 4: Heat capacity per ton of each element.

Metal element	Heat capacity (kcal/t × 10^3)		
	1400°C	1500°C	100°C
C	533.2	580.5	47.3
Si	725.8	751.6	25.8
Mn	313.0	332.0	19.0
Ni	258.0	274.3	16.3
S	222.7	239.9	17.2
Fe	298.4	315.6	17.2

Source: [17].

For gray cast iron;

C = 3.3%: Q = (580.5 + 47.3) × 0.033 = 20.701 (kcal/t × 10^3)

Si = 1.9%: Q = (751.5 + 25.8) × 0.019 = 14.769 (kcal/t × 10^3)

Mn = 0.6%: Q = (332 + 19) × 0.006 = 2.106 (kcal/t × 10^3)

S = 0.07%: Q = (239.9 + 17.2) × 0.0007 = 0.180 (kcal/t × 10^3)

Fe = 94.2%: Q = (315.6 + 17.2) × 0.942 = 313.498 (kcal/t × 10^3)

Q_m (total) = 20.701 + 14.769 + 2.106 + 0.180 + 313.498 = 351.254 (kcal/t × 10^3)

= 1469.65 KJ/kg

Since cast iron requires 1469.65 KJ/Kg of heat energy to rise to a temperature of 1600°C (1873°K), then 3910 Kg requires;

Theoretical energy, Q_T = 1469.65 × 3910 = 5746331.5 KJ

3.1.4 Heat energy supplied by the charged coke

The calorific value of any type of fuel, solid or liquid, is the amount of heat it will be able to produce by burning it at constant pressure and under normal conditions. The calorific value of coke is 31000 KJ/kg i.e. for every kg of coke burned, 31000 KJ of heat energy is released.

Therefore;

For the 430kg of coke burned, (430 × 31000) KJ of energy was release into the furnace.

= 13330000 KJ of heat energy= Actual energy, Q_A

3.1.5 Energy efficiency of the furnace

The energy efficiency of a melting process is calculated by dividing the amount of theoretical energy needed to melt a metal and raise it to its pouring temperature by the actual amount of energy consumed in melting, treating, holding and handling the material [4].

Energy Efficiency,

$$\eta = \frac{Theoretical\ Energy\ Required}{Actual\ Energy\ Used} \times 100 \ \ldots .\ 7$$

$$= \frac{Q_T}{Q_A} \times 100$$

$$= \frac{5746331.5}{13330000} \times 100 = 43\%$$

43% is the efficiency of energy utilization of the cupola furnace before hybridization. Several factors affect the energy efficiency of a furnace. Some of these factors will be further discussed in the next section of this chapter.

It can be seen from the work of Sharma [9], the gasifier would be able to provide gas of average temperature 800 °C at a blast flow rate of 4.7 g/s, for nourishment through the tuyeres. Air blast of 2.22Kg/s from the blower of the furnace, itself, is supplied through the same tuyeres. This would easily raise the temperature of the blast air and, at the same time, nourishes the charged metal to temperature of not less than 500 °C (assuming all sort of energy loss). That brings us to a new amount of coke energy utilized (after nourishment).

For a mass flow rate of 4.7g/s = 0.0047Kg/s (from the gasifier);

And 2.22Kg/s from the blower

m = 2.22 + 0.004 =2.224Kg/s

Where the molecular weight of dry air = 28.966 kg/kmol [19]

At "normal" 1kmol of gas occupies 22.414 m^3 (assuming it obeys Ideal gas Law)

There is 3600 s/h, so 2.224 kg/s is 8006.4 kg/h

8006.4kg/hr × 1kmol/28.966kg × 22.414m^3/kmol

m = 6195.4Nm^3/hr

To find out the amount of coke compensated by the hot blast air from the gasifier, we employ the equation 8 [5].

$$C_p m \Delta T = q m_c \quad \ldots\ldots\ldots\ldots\ldots\; 8$$

Where;

C_p = 1.29 KJ/Nm^3 °C [5]

m = blast air mass flow rate = 6195.4Nm^3/hr

$\Delta T = T_2 - T_1$ = Increase in temperature as a result of air blast = 500 – 25 = 475°C

q = combustion heat of coke (calorific value) = 31000KJ/Kg

m_c = Equivalent mass of coke burnt = ?

$$m_c = \frac{C_p m \Delta T}{q} \quad \ldots\ldots\ldots\ldots\ldots\; 9$$

$$= \frac{1.29 \times 6195.4 \times 475}{31000} = 122.5\text{Kg}$$

But, coke has a carbon content of 92.2% of combustible elements (C, H, N, S)

$$\frac{122.3}{0.922} = 132.8\ approx.\ 133Kg$$

Therefore;

If 430 – 133 = 297Kg of coke will be burned for the same operation when hybridized with a gassifier,

297 × 31000 = 9207000 KJ is the new amount of coke energy expected to be utilized.

The anticipated coke energy efficiency of the cupola after hybridization would be;

$$\eta_H = \frac{5746331.5}{6717824} \times 100 = 62.4\%$$

4. CONCLUSION

During participation in a melting session at Asia Sewing Machine Industry, Jaipur, data were collected on the charge ratio and the foundry melting operational procedure. From these data, parameters like quantity of heat required to melt the charged metal and the heat supplied from the charged coke were deducted and the energy efficiency of the cupola furnace was computed and establish to be 43%. This is as a result of the significant amount of heat lost to the atmosphere through the flue gas and other means, which was properly discussed.

Therefore as the main objective of this work, output data of a 20 KWe model biomass gasifier were borrowed from a previous work and was mathematically simulated with the heat energy requirement of the current furnace as a hybrid system: By associating the heat energy output of the gasifier as a means of heating the blast air supplied to the cupola furnace through it tuyeres. The heat output of the gasifier at 800 °C and a blast flow rate of 4.7 g/s, could heat up the blast air supplied to the furnace and in return nourish the charged metal by at least of 475°C. This effect was seen when the new energy efficiency based on coke fuel consumption was calculated to be 62.4%. At least 133 Kg of coke will be promisingly saved by hybridizing with the 20KWe downdraft gasifier utilized as model. The fuel/air ratio for stoichemetric combustion of wood and coke was calculated and found to be 7.86 and 10.52 respectively. These values point out the part of air per part of fuel required for complete combustion in gasifier and the furnace respectively. The chemistry in the various stages of cupola furnace during melting process was also properly discussed.

It, therefore, can be concluded that it is possible to achieve a more energy efficient cupola furnace by hybridizing with a biomass gasifier. This would greatly reduce the amount of coke consumption in a foundry by using a cheaper and more readily available energy source that consumes gradually to supply hot blast air to the furnace (e.g. wood).

4.1. Suggestions and future scope

The following can be suggested for this particular work;

- It is possible to use other types of biomass fuel to fuel the gasifier, as cheaper alternatives can be explored.
- It is also possible to achieve higher temperature of blast air by increasing the volume of air supplied to the gasifier during operation.
- The interior of the mains for transferring heat from the gasifier to the tuyeres should be properly lined with refractory, or high heat resistant material should be used so as to avoid heat loss and breakdown.
- An attempt can be made to completely substitute coke as fuel in a cupola furnace by externally powering it using a biomass gassifier.

The adaptation of such technology in foundries can lead to a promising short term and low cost solution that improves the existing operation without scraping out or compromising the old practice. So many other means of introducing hot air blast can be explored as an alternative to supplying preheated air into a cupola. The real time construction and hybridization of an industrial size cupola furnace with a biomass gasifier has been left out due to inadequate resources, fund and time. This can be performed in the future and hence the majors to counter the losses discussed in the previous chapter may be considered.

4.2. Summary

A research was conducted to collect the data of melting procedure of a cupola furnace at Asia Sewing Machine, Jaipur. Using the input data, various related parameters were calculated and the possibility to hybridize it with a biomass gasifier was considered. Yes, huge amount of energy from coke is lost during melting process in a cupola and due to that, energy cost can be cut down by introducing a means of nourishing the charge to a certain temperature through preheating the blast air. Other means of achieving this are present, like using a heat exchanger to retrieve some of the energy carried away by the escaping flue gas, but has been found out to be more capital intensive and required frequent maintenance. Biomass fuels, like wood, are cheaper and readily available, especially here in India. Wood is chosen because of its property of burning slowly.

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