DESIGN AND FABRICATION OF A CUPOLA FURNACE FOR MATERIAL PROCESSING.

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Abstract: Foundry cupola furnace capable of melting cast iron to the desired pouring temperature was designed, constructed and tested. Coke which is the by product of coal is used as a fuel, a centrifugal blower that delivers air at the required pressure and flow rate for proper combustion to take place inside the furnace. To provide greater utilization of heat inside the furnace, the lining of the furnace was performed with Alumina and fire clay refractory that can withstand the operating temperature and thermal stresses arising from the pressure and temperature developed inside the furnace. Analysis such as that of buckling load on the stands, thermal stresses developed in the cupola shells, load on the bolts were carried out so that, careful selection of materials is performed. The main focus in this Design is to improve continuous working hours, reducing preparation time, reducing losses in melting, reducing slag formation and to increase the combustion efficiency of coke and overall productivity and to improve the quality and Mechanical properties of steel using Cupola.

Keywords: Coke, melting, Cupola, Refractory and Furnace.

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INTRODUCTION

Since the discovery of the earth's minerals, metal casting has played an important role in society. An integral part of every technological advance, casting have allowed us to build equipment to feed our people, fight for defense, build infrastructures and manufacture cars, trains, air planes e.t.c The production of melting metal to make casting has traditionally been an art of form, an expression of human creativity carried out for both aesthetic and practical reasons. The objective of metal casting has been to produce useful implements for human consumption as well as beautiful works of art. It is clear on examination of ancient art of casting, as well as modern industrial castings that their production requires significant skills as well as technological know how.

The ancient artisan used traditions and learned skills passed down through the ages, as well as experience to produce acceptable castings. The modern producer of industrial castings make use of these same skills, but supplements them with understanding of the fundamentals principles of fluid flow, heat transfer, thermodynamics and metallurgical micro structural development.

Metal casting remains all basically essential industry, as necessary to space vehicles as it was to mankind's very first machines. As science is applied more and more, so the skill, education and pay of foundry men goes up and ever up, increasing in turn the total wealth of the world. There is no better example of true creation of national wealth than the work of foundry man. He takes a raw material and through both art and science, creates a product that add direct value to our society's ever progressing way of life. All these contributions of foundry work towards better way of life, cannot be achieved without the most important or the backbone of the foundry itself, this is nothing but a foundry furnace, which takes in a solid raw materials and transformed it into a molten iron of desired pouring temperature through the application of heat generated by the healing elements or fossil fuel. Known as the original recycler,(D Taylor et al) the foundry industry through proper utilization of heat generated inside the foundry furnace, gives a new useful life to as many as 15 million tons of scrap metal each year that would otherwise be rendered useless. The metal casting process is the simplest, most direct route to a near net-shape product, and often the least expensive. This process in its fundamental form requires a mold cavity of the desired shape and molten metal to pour into the mold cavity. Human beings have been producing castings for thousand of years, most often pouring metals into molds made of sand.

Casting serves as the most universal of all known methods of shaping metal. Through casting, a wide range of size or products can be obtained. There is little weight or size limitation upon castings; the only restriction is imposed by the supply of molten metal and the means of lifting and handling the output. Components of few grams as well as those weighing many tons can be produced by casting. In 1966, a unique steel casting of length 11.2 metres and weight 257000 kilograms was produced, some year in the former USSR, a horizontally stamping machine weighing 270,000 kilogrames was produced [Dr C.O.Nwajagu(1994)]. Casting is applied both in batch and in mass production of objects with simple as well as intricate shape.

MELTING FURNACES

A furnace is an apparatus in which heat is liberated and transferred directly or indirectly to a solid or fluid mass for the purpose of effecting a physical or chemical change. The source of heat is the energy released in the oxidation of fossil fuel (commonly known as combustion) or the flow of electric current through the mass to be heated.

A CLASSIFICATION OF FURNACES USED FOR MELTING:

Furnace for the melting of metals can conveniently be classified into four main groups according to the degree of contact which takes place between the charge and the fuel or its products of combustion as follows:

Furnaces in which the charge is in intimate contact with the fuel and the products of combustion:

The most important furnace in this group is, of course, the foundry cupola, in which the iron being melted is charged to the furnace along with the coke. The thermal efficiency of such a furnace will obviously be high since, in addition to the direct heat transfer from burning fuel to charge, heat losses will be small because of the continuous nature of the process.

Furnaces in which the charge is isolated from the fuel but is in contact with the product of combustion:

A furnace of this type is the open-hearth furnace for the manufacture of steel. Many other furnaces of similar design exist in which the same method of firing is employed; the fuel being either lump coal, pulverized coal, coke, oil or gas. They can generally be classified as reverberatory furnaces.

The fuel efficiency of such furnace, will obviously be lower than that of cupola furnaces, since there is a bigger heat loss in the outgoing products of combustion (in a cupola the products of combustion actually pass amongst the incoming charge and give up their heat to it, where as in a revereratory furnace, they merely pass across its surfaces and give up a corresponding smaller amount of their heat).

The principal example of this group is the furnace employing a crucible which may be heated by either coke, gas or oil. The charge may be almost completely isolated from the products of combustion if the crucible is fitted with a lid.

The main disadvantages of the crucible furnace are that both fuel efficiency an output are low. Whilst the crucible furnace may be ideal for melting small amount of an alloy, it is a slow method of melting where large scale output is concerned.

DESCRIPTION OF THE FURNACE (CUPOLA):

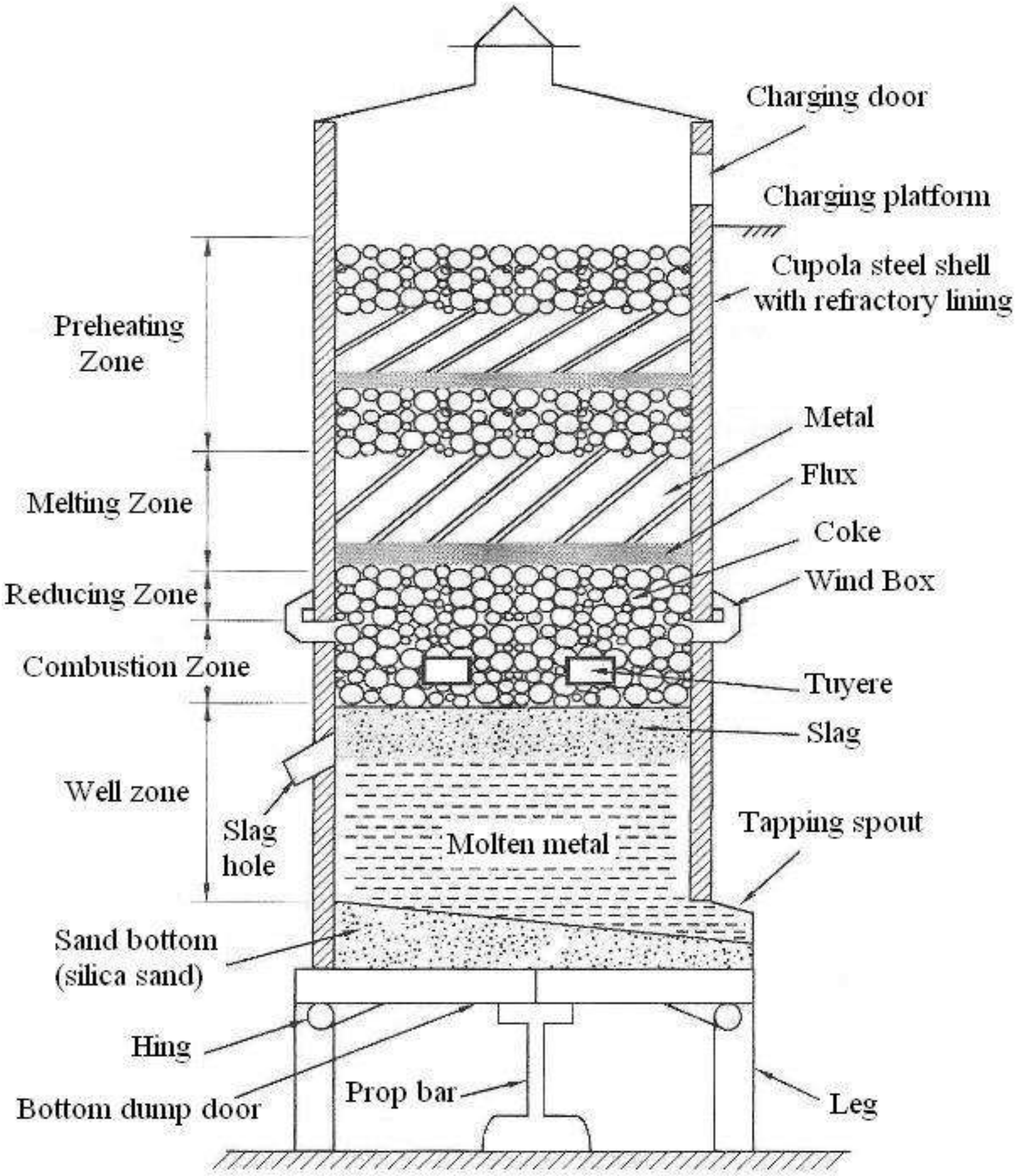
A cupola melting furnace is a vertical furnace as shown in the diagram fig. 1. the structure is as follows:

The inside diameter (D): is the inside diameter of he cupola and it has a strong influence on the productivity of the furnace. The productions is expressed by the quantity of molten metal per hour (kg/hr) and is also dependent on the consumption of coke and the quantity of air blown.

The useful height of the cupola (H): This is the distance from the lower series of tuyeres to the charging hole. The useful height has strong effect on the effect utilization of heat from the exit gases.

The openings for introducing the air to the coke bed are known as tuyeres. Surrounding the cupola at the tuyeres is a wind box or jacket for the air supply. The air blast, furnished by a centrifugal-type blower enters the side of the wind jacket. The entire weight of the cupola rests on a steel plate, which is supported above the floor by four columns, suitably spaced so that the hinged bottom doors can swing freely. The opening through which the metal flows to the spout is called the tap hole. Opposite the pouring spout at the rear of the cupola is another spout for slag disposal. This opening is slightly below the tuyerers to prevent slag running into them.

At the bottom of the cupola a quantity of sand is rammed upto the tap hole with a slight inclination towards the tap hole. The opening for charging is situated at the upper part of the shaft of the cupola. The inside of the cupola is lined with refractory material and the chimney of the cupola is situated above the opening for charging and ends with a spark arrester. The air chamber or wind jacket is connected with blower by means of an air pipe.



Cupola Furnace Figure-1 [2]

DESIGN PARAMETERS FOR THE COMPONENTS

The above mentioned components and parts that described the cupola are designed and determined as follows:

Determination of the Cupola's inside diameter

Cupola are usually rated in capacity by their inside diameter; a practical rule of thumb is that for each square inch cross section 10lb of iron can be melted (Dr C.O.Nwajagu(1994)). Applying the above rule for determining the inside diameter of 300 kg capacity, the following calculations and are carried out ;

The internal diameter of the cupola

D = 0.25m

= 250mm

Determination of the Tuyeres Cross sections

Tuyeres are the openings round the circumference of the cupola shell for introducing the air to the coke bed inside the furnace, for standard cupola design it is found that the total area of the tuyerers is 20% of the total cross sectional area of the cupola (Dr C.O.Nwajagu(1994))

Hence, from eqn (1) A = 0.0427m^2

Let the total cross sectional areas of the tuyeres be A'

$$\therefore A' = \frac{20}{100} \times A \text{...} eqn.2$$

$$A^I = \frac{20}{100} \times A \quad = \frac{20}{100} \times 0.0491$$

$$A^I = 0.0098 m^2$$

The Tuyeres can be situated in a serial or in two or three series. A more uniform distribution of the injected air, along the perimeter of the cupola and its sufficiently deep penetration towards the center of the shaft is achieved in cupola will multi-series [Dr C.O.Nwajagu(1994)]

The number of Tuyeres In one serial depends on the internal diameter of the cupola. The Tuyere In the lower serial is the basic and 80% of the quantity of the air blown passes through it. This cupola design uses 2 series of Tuyeres and each series is designed with four number of tuyerers,. Therefore the first series of the tuyeres takes 80% of the total cross –sectional area of the tuyeres, and second series takes, 20% of the total area. [D.Taylor Lyman,(1996)]

Let A_1 be the total area of tuyeres in basic (first) series of the tuyeres:

$A_1 = \frac{80}{100} \times A^1 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots eqn..3$

From eqn (2), $A^1 = 0.0098m^2$

$$A_1 = \frac{80}{100} \times 0.0098$$

$$A_1 = 0.00784$$

The total number of tuyerers In first series is four

$\therefore N = 4$

The area of an individual tuyere in first series is:

$$= 0.00196$$

Where d is the diameter of the individual tuyere in first series.

$d = 0.04996m$ or 50mm

Similarly for the second series of tuyeres,A= $0.0019m^2$ and d =25mm

Outer diameter of the cupola:

The outside diameter of the cupola depends on the thickness of the refractory lining, the size of the furnace and the thickness of the steel shell used, for a small cupolas of 500mm internal diameter and below, a mild steel of 4 to 8mm thickness is satisfactory [2]. For this cupola design of 250mm internal diameter a steel shell of 5mm thickness is used and therefore, the outer diameter is found to be:

D1=400mm

Thickness of the lining:

To provide a greater utilization of heat inside the furnace, by minimizing the heat losses by conduction to the atmosphere, and to prevent attack of the heat to the steel shell, the cupola has to be lined with a materials of higher refractoriness.

A refractory lining of 7.5mm thick is adopted in this design[4], and the lining materials is chosen from a high temperature materials as can be seen in material selection. Total lining thickness is 15mm.

Determination of Cupola's useful height (H):

In the cupola, hot gases rising from the, melting zone exchange heat with descending charge materials. Therefore, the cupola useful height is the distance from the first series of the tuyeres to the charging hole and is termed as preheating zone. If this height is too short, inadequate charge preheating takes place and excess heat escapes in the top gases. Therefore, the larger the useful height, the better the heat exchange processes. Often for optimum performance, in determining the useful height it is assumed that the ratio:

$\frac{H}{D} = 4$..*eqn*.3.7 [D.Taylor Lyman,(1996)]

$\therefore$ From the calculated internal diameter D

D = 250mm

$$\Rightarrow \frac{H}{250} = 4$$

$$H = 250 \times 4 = 1000mm$$

Where H is the useful height of the cupola.

The Blast Pressure

Proper blast pressure is requires to penetrate the coke bed. Incorrect air pressure adversely affects the temperature, cabon pick-up and the melting rate of the cupola.

The blast pressure is a function of the cupola diameter. An empirical correlation for the blast pressure is suggested below:

$$P = 0.005D^2 - 0.0134D + 39.45$$

$$= 9.90Kpa$$

Blast Rate (air Volume flow rate)

The blast rate is one of the most important control parameters in a cupola., apart from higher coke consumption, a higher blast rate creates an oxidizing atmosphere, resulting in excess oxidation of iron and elements like silicon and manganese. Too little blast air does not generate enough heat for efficient combustion and leads to lower metal temperature, slower melting and higher coke consumption. Although it is possible to calculate the blast rate from first principles, a rule of thumb for determining the optimum blast rate based on the cupola cross sectional area is often used. The optimum blast rate has been found to be 115m^3/min per square metre [Knvandin V.A, B.L. Markov (1980)]

Now, base on the above rule, the air blast or volume flow rate is calculated as follows:

From the calculated area of the cupola

A = 0.0491

$$\Rightarrow V = \frac{115 \times 0.0491}{1}$$

$$v = 5.6465 m^3 / \min$$

To account for the air losses in the system, 20% of this value is added to the calculated actual value[Knvandin V.A, B.L. Markov (1980)]

$$\frac{20}{100} \times v \quad = \frac{20}{100} \times 5.6465 = 1.1293$$

$$\Rightarrow \text{The total volume flow rate}$$

$$V = V + 1.1293$$

$$= 5.6465 + 1.1293$$

$$= 6.7758 m^3 / \min = 0.1129 m^3 / s$$

≏ 7m^3/min

To calculate the mass flow rate of the air:

$\dot{m} = \rho AV$...3.9

Where AV = $\dot{v}$ = Volume flow rate

$$\dot{m} = \rho AV$$

Taking density of air at 40^{0}C

ρ = 1.127 Kg/m^3

$\therefore \ \dot{m}$ = 1.127 x 6.7758

= 7.64 Kg/min

= 0.1273 Kg/sec

The air velocity from the blower is now calculated using

$$V = \frac{m}{A\rho}$$

Where m = Mass flow rate A = Cross sectional are of the pipe

≏ 10m/s

The flow velocity of the flow is now calculated as 10m/s

Testing

1. Composition of the charges are

   Cast iron scraps = 150kg

   Coke = 25kg

   Lime stone = 6kg

   Steel scraps = 10kg

   Silicon = 1kg

   The above composition is used as a charge although for the coke 8kg of the coke is used to preheat the furnace,. The process are shown in the table below.

Processes Preheating

EXPERIMENT	CAST IRON SCRAPS(Kg)	COKE (Kg)	LIMESTONE (Kg)	STEEL SCRAPS(Kg)	SILICON (Kg)	TIME BEFORE TAPPING(min)
1	50	7	2	3	0.3	6
2	50	6	2	3	0.3	8
3	50	4	2	4	0.4	16

Results

CHARGING	MASS OF SLAG (Kg)	MASS OF MOLTEN IRON (Kg)
FIRST CHARGE	8	43
SECOND CHARGE	7	48
THIRD CHARGE	4	48.5

DISCUSSION

From the above result obtained it is observed that the melting rate increased with increase in time of operation. The slag had shown a reduction in its quantity due to reduction in coke consumption as can be seen from the result.

With regard to the metallurgical properties of the final output, the first and second products obtained are bit harder then the last product. This obviously due to increase in the silicon this obviously due to increase the silicon contain of the last composition, thus silicon increased the machinability of the final product.

CONCLUSION

An increase in the silicon composition has obviously improved and increased the machinability of the final product. The result has shown an improvement in continuous working hours, reduction in preparation time, reduced losses in melting, reduced slag formation and to increase the combustion efficiency of coke and overall productivity and to improve the quality and Mechanical properties of steel using Cupola. The thermal efficiency is satisfactory at 73%. The produced cupola could further assist manufacturers who wish to build larger furnaces for commercial application with reduced cost implication. Furthermore, the fabricated cupola as modified during test running proved to be more economical having the optimum technical and operational characteristics in the areas of its productivity, efficiency, reliability, simplicity, ease of operation and maintainability.

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