Development Of A Spent Oil-Fired 100 Kg Crucible Furnace For Small Scale Foundry Industries

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Abstract

A 100 kilogram capacity crucible furnace fired with spent engine oil was developed. The spent engine oil otherwise regarded as waste in Nigeria was converted to heating energyfor the developed crucible furnace. This work was aimed at reducing the cost of melting iron in Nigeria. Bulk of the materials used in the construction were sourced locally from metal scraps. The furnace drum which has an overall capacity of 0.1404m^3 was fitted with a chimney to allow the escape of combustion gases. From the design, 0.3 m^3/s volume of air supplied to the crucible furnace with an available volumetric capacity of 0.1404 m^3 at the rate of 2119.38W/m^2 produced an estimated melting heat of 113271.2 KJ/hr with a melting rate of 100 kg/hr. The crucible furnace was designed to use the spent engine oil with a heating energy content of 45948 kJ/kg. The designed operating temperature of the crucible furnace was 1400^{o}c while the experimental temperature of 1280^{o}c was achieved. The experimental efficiency of the crucible furnace was 59.4 % as against the designed efficiency of 63 %. It is thus recommended that this design can be used as a foundation for building better and cheaper crucible furnace for foundry industries in Nigeria.

Keywords - *Spent engine oil, crucible furnace,foundry industries, melting heat, rate of heat transfer.*

I. INTRODUCTION

There are about 160 foundries in Nigeria at various levels of life or death conditions. For a nation to advance technologically, it must be able to harness, converts its mineral resources and fabricate most of its equipment and machines locally. In the production of mineral resources, the Melting of metals has become one of the tremendous industrial practices in the fore front. This is because metals are versatile elements whose fields of applications are very wide in human lives. The melting and heat treatment of metal in foundries is very important in manufacturing process. Iron melting in Nigeria dates back to the Nok culture of 2000 years ago in the Middle belt area of the country while on the Southern plains, bronze casting has been practiced by the Binis for over a thousand years [1]. Archaeologists have traced early iron works, blacksmith artefact and artistic castings to Ife and Igboukwu communities [2].

According to [3], the British colonial government in Nigeria set up engineering workshops at EbuteMetta, Enugu and Zaria to serve the railway system with each of the workshops having functioning foundry where castings were produced for needed spare parts. Adeosun and Osoba (2008) reported that the metal can be melted directly or indirectly to a molten or solid mass for the purpose of effecting a physical, chemical or metallurgical change in the mass[5]. An ideal furnace is one in which all energy produced is utilized, this is practically unachievable and there is no thermal processing equipment with efficiency of 100% [6].

One of the most widely used furnaces is the oil-fired crucible furnace. The oil-fired crucible furnace uses the combustion of diesel as a fire source to heat the crucible and melt the solid metal inside it. Some of the advantages of oil-fired crucible furnace are low investment costs, easy operation and maintenance ability, capable of melting small batches of various alloys, the melt can be treated directly in the crucible and the alloy can be quickly and easily replaced as necessary [7].

Oyewale and Olawale (2011) designed and constructed a Mini-Electric Arc Furnace to melt 5kg of steel/cast iron scraps, using locally produced Soderberg electrodes. Tests carried out on the furnace showed that it required 60 minutes to heat up the furnace to the melting temperature of cast iron (115^{0}C – 140^{0}C). Furthermore, it took about 95 minutes to melt the first charge of 2kg resulting in a melting rate of 21.05g/minute.Alaneme and Olanrewaju (2010) designed and fabricated a diesel fired heat-treatment furnace using locally sourced materials which was aimed at eliminating the use of heating elements requiring electric power which is poorly supplied in the country. The performance of the furnace was observed to have a fast heating rate of 61.24^{0}C/min to attain a pre-set temperature of 900^{o}C and a fuel consumption rate less than 1.41litres/hr.

As important as oil-fired crucible furnaces to the foundry and manufacturing process, its availability seem to be limited in Nigeria and when available most of them are imported and this is costing the country a huge sum of foreign exchange. The importance of metal melting furnace cannot be over emphasized in developed, developing and under developed countries. Metal melting furnaces has not been readily available in Nigeria, and the available ones are very expensive for low and medium scale entrepreneurs, thereby stunting the growth of metal forging industries in Nigeria.

The available furnaces have been posed with the problem of fueling; coke, furnace oil which is a medium grade 2 oil and diesel being the most common fuel used in metal melting furnaces has been expensive, thereby making the available furnaces expensive to run.Energy plays a significant role in boosting economic growth, and the demand for fossil fuels continues to increase over the years [10]. The depletion of world oil reserves of fossil fuels leads to the development of biofuels and other alternatives sources of energy to substitute fossil fuels [11].Therefore the proposed crucible furnace will be exploring the viability of using spent engine oil and metal scraps will be sourced locally in order to reduce the cost of production thereby making it readily available for interested entrepreneur.

II. METHODOLOGY

A. *Design Analysis*

a). *Crucible Pot*

Considering the proposed capacity of the furnace to be 50kg with density of charge i.e. density of molten cast iron to be 6980kg/m^3 therefore the volume of the proposed crucible pot can be ascertained from the relationship between density, volume and mass i.e.

$$\text{Density} = \frac{Mass}{Volume} \quad (1)$$

Therefore volume of crucible pot $V_c = \frac{50}{6980} = 0.00716m^3$

Taking diameter of charge D_c = 0.13m

Therefore;

$$Vc = \pi r^2 h \quad (2)$$

Where h = height of the crucible pot

$$h = \frac{V_C}{\pi r^2} = \frac{0.00716}{0.01327495} = 0.53m$$

Considering the dimension of the crucible pot i.e. h = 0.53m, D_c = 0.13m, for the furnace to have good heat retention capability and to be able to accommodate the crucible pot of this capacity, the height (H) of the furnace must be well above the crucible pot which was assumed to be 812 mm to create allowance for furnace cover.

b). *The Refractory Lining*

For a furnace of this sort to attain the required temperature with the most economical amount of fuel there has to be a refractory lining to reduce the rate of heat transfer from the furnace to the surrounding. According to [12], the inner surface of the furnace drum was lined round with a double layer of bricks of 70mm thickness using the refractory mixture comprising of sodium silicate, kaolin, sawdust and water as a binder to fill the spaces in between bricks in order for them to hold firmly together. The base of the furnace was lined with double layer of bricks of about 140mm thickness using the same mixture of kaolin, sodium silicate, saw dust, water and refractory cement as binder (Fig. 1).

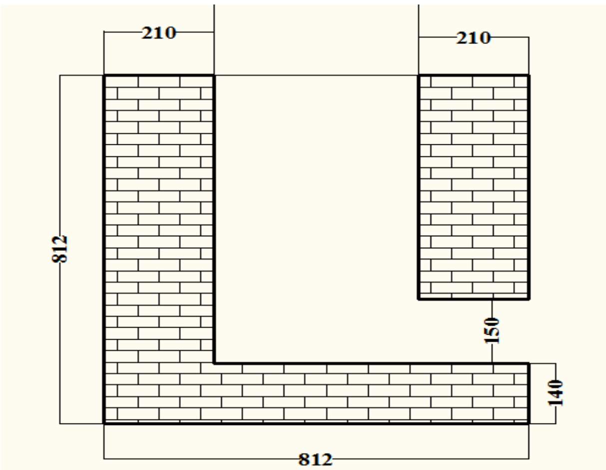

Fig. 1. Sectioned view of furnace lining

c). *Furnace Drum*

The furnace drum was taken to have the following dimensions; height of drum, H_d = 812mm, diameter of drum, D_d = 812mm.

Therefore the volume of furnace drum can be calculated using the relation below;

$$VF = \pi R^2 H \quad (3)$$

$$VF = 3.142 \times 406^2 \times 812 = 420546\text{mm}^3$$

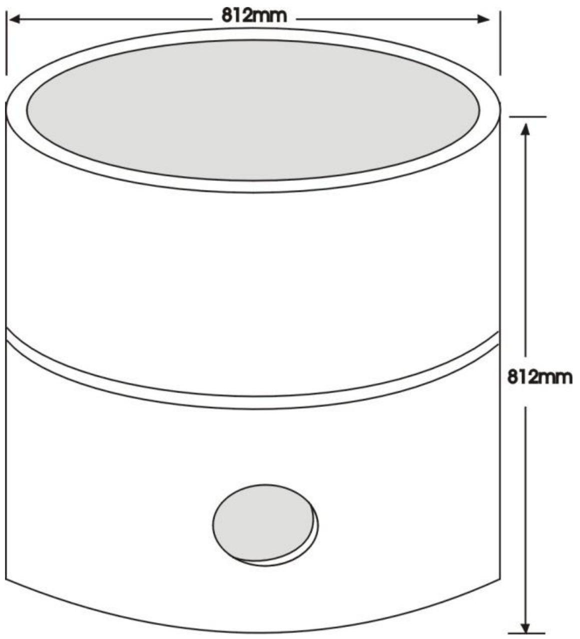

Fig. 2. Furnace drum

Radial distance of flame gap = Diameter of the furnace drum – radial thickness of refractory lining – thickness of refractory cement – diameter of crucible pot

= 802 – 390 – 40 – 130 = 242 mm

Therefore combustible volume of furnace drum after lining can be calculated as;

Volume of combustible space

$$Vs = \pi r^2 h \quad (4)$$

$$Vs = 3.142 \times 206^2 \times (812 - 240) = 76.3\text{m}^3$$

d). *Design specifications of the air blower*

The air blower is rated as follows;

Outlet pressure = 1700Pa, (from blower)

Speed = 2850 rpm Power = 0.55 KW

Voltage = 220 V Current = 2.5 Amperes

Average rate of air flow from blower = 18m^3/min

Average rate of fuel flow = 0.045m^3/min

Ratio of air discharge to fuel discharge = 18/0.45 = 400:1

f). *Efficiency of the Furnace*

The efficiency of the furnace is the ratio of the heat input to useful output. The required operating temperature of the furnace (T_f) was taken to be 1400°c since the melting temperature of cast iron ranges between 1230°c and 1500°c and ambient temperature was taken to be 27°c.

$$\text{Efficiency} = \frac{\text{Heat input}}{\text{Heat output}} \times 100\% \quad (5)$$

The theoretical efficiency of the crucible furnace is calculated as follows:

Mass of aluminium per hour (M_a)= 100 kg/hr

From properties of materials table (1kJ/kg K = 1kJ/kg ^{0}C)

Specific heat of aluminium (C_a) = 904J/kg K = 0.904kJ/kg K

The designed temperature is 1400°c

Melting point of aluminium is 630°c

Temperature rise, up to melting point (T) = 1400 – 27 = 1373^{0}C

Energy content required to raise temperature of metal aluminium to melting point = weight x specific heat (solid) x temperature rise.

i.e. $Q_m = M_a C_a T = 100 \times 0904 \times 1373 = 124119.2 kJ/hr$ (6)

Energy content of spent engine oil is 45,948 kJ/kg

Therefore, the efficiency equation can be written as;

$$\varepsilon = \frac{Q_m - C_{vf}}{Q_m}(100) \quad (7)$$

where;

Q_m = 124119.2 kJ/hr

C_{vf} = 36900 kJ/l

$$\therefore \varepsilon = \frac{124119.2 - 459480}{124119.2}(100) = 63\ \%$$

The theoretical efficiency was estimated to be 63 %

3.2.1 *Rate of heat transfer through the furnace wall*

According to [13], the rate of heat transfer through the furnace wall was given to be;

$$Q = \frac{A(T_1 - T_4)}{\frac{L_A}{K_A} + \frac{L_B}{K_B} + \frac{L_C}{K_C}} \quad (8)$$

A = refractory bricks (L_A= 0.08m, K_A = 0.138W/m°C)

B= Binder (mortar:$L_B = 0.005$m, K_B 0.48W/m°C)

C= metal shell ($L_C = 0.05$m, $K_C = 45$W/m°C)

T_1 =design temperature aimed at 1400°C

T_4 =ambient temperature 27°C

$$\frac{Q}{A} = \frac{1400 - 27}{\frac{0.08}{0.138} + \frac{0.005}{0.48} + \frac{0.05}{45}}$$

$$\frac{Q}{A} = \frac{1373}{0.5797 + 0.0104 + 0.001111}$$

$$= \frac{1373}{0.59121}$$

Theoretical rate of heat transfer = 2322.36W/m^2

III. CONSTRUCTION OF 100 KG CRUCIBLE FURNACE

The 100 kg crucible furnace was designed majorly to melt aluminum. However, the 100 kg cast–iron crucible furnace can also be used to melt other metals which fall within its designed operation temperature range. The major components of the 100 kg Cast-iron crucible furnace are as follows:(i) The Furnace Drum (ii) The furnace cover (iii)The Air Blower (iv)Fire bricks (v) Nozzle (vi) Furnace Cover Opening/Closing Mechanism

A. *Furnace Drum and Lining*

The fabrication of the furnace was done based on the design calculation. The entire fabrication was done before lining because after lining the furnace become very heavy and immoveable. The lining process began with evenly spreading a mixture of kaolin and sodium silicate at the base of the furnace drum before laying the bricks horizontally, in between each brick there is a thin layer of the mixture of about 5mm thick, after the first layer, the second layer follows immediately and it was allowed to dry for about 24 hours, then the bricks that makes up the wall of the furnace was laid vertically and also allowed to dry up.

B. *Furnace Cover and Lining*

The furnace cover alongside the opening mechanism was constructed using a 3mm thick plate, 5mm thick flat bar, short cylindrical pipe of diameter of 2’’ and 2mm thickness, 5mm solid rod and an externally threaded solid rod. Underneath the cover, angle bars were welded in order to hold the lining firmly to the cover.

Unlike the furnace drum, the lining of the furnace cover was done by crushing the refractory bricks to powder and mixing it with the mixture of sodium silicate and kaolin and water, the welded angle bars underneath the plate holds the mixture to the cover after solidification.

C. *Fabrication of the Nozzle (Burner*)

The burner as shown in Fig. 3 was fabricated using a cylindrical pipe of 2 inches in diameter and 2mm of thickness, a passage for the fuel was created by drilling a half inch circular hole and the diameter of the discharge end of the burner was reduced in order to channel the mixture of air and fuel into the combustion chamber of furnace. The other end of the burner was attached to the air pipe conveying air from the blower. A support is constructed underneath the burner in order to carry the weight of the burner and the pipes affixed to it.

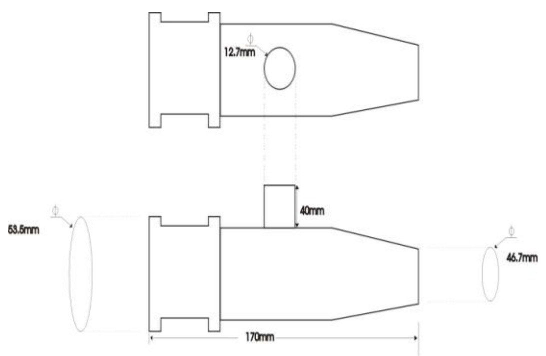

Fig. 3: Nozzle burner

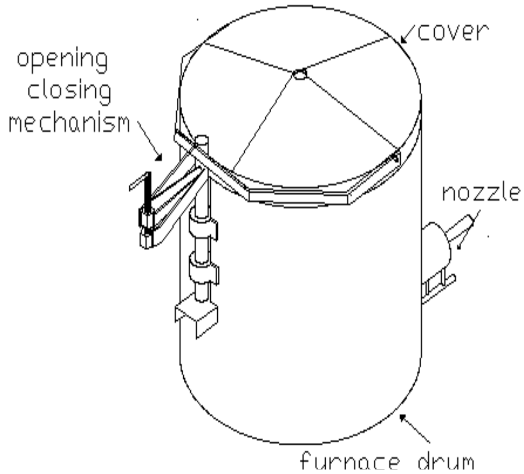

Fig 4: the developed crucible furnace

D. *Working Principle of the Crucible Furnace*

A small quantity of red-hot charcoal was introduced into the combustion chamber before opening the fuel line to allow the introduction of fuel into the burner to be in drops before opening the air-line, this will enable the charcoal not to get exhausted before the introduction of fuel. The air was blown over the oil to atomize as well as oxidize it for combustion. As the mixture of air and oil blows over the pre-heat coal it helps to sustain the combustion. As this continues over time, the temperature rises gradually within and around the crucible pot, thereby melting its content.

The furnace temperature reading was done using a thermocouple with a digital output through the chimney on the cover. When the crucible content was fully melted and is ready for pouring, the crucible was lifted out by means of a lifting tong, which was handled by two persons and then poured into the prepared mould cavity. The hole on the side of the furnace was made to keep a balance between the pressure within and outside the system.

IV. RESULTS AND DISCUSSION

The inner temperature of the furnace was 1280^{o}c at the combustion chamber after 60 minutes of operations. At this stage aluminium whose melting temperature is about 630^{0}c was already in its molten state ready for casting.

A. *Actual Rate of Heat Transfer through the Furnace Wall*

Tthe rate of heat transfer through the furnace wall as given by equation 8;

$$Q = \frac{A(T_1 - T_4)}{\frac{L_A}{K_A} + \frac{L_B}{K_B} + \frac{L_C}{K_C}}$$

A = refractory bricks (L_A= 0.08m, K_A = 0.138W/m°C)

B= Binder (mortar:$L_B = 0.005\text{m}, K_B\ 0.48\text{W/m°C}$)
C= metal shell ($L_C = 0.05\text{m}, K_C = 45\text{W/m°C}$)
T_1 =design temperature aimed at 1280°C
T_4 =ambient temperature 27°C

$$\frac{Q}{A} = \frac{1400 - 27}{\frac{0.08}{0.138} + \frac{0.005}{0.48} + \frac{0.05}{45}}$$

$$\frac{Q}{A} = \frac{1253}{0.5797 + 0.0104 + 0.001111}$$

$$= \frac{1253}{0.59121}$$

Actual rate of heat transfer = 2119.38W/m^2

B. *Actual Quantity of Heat used for Melting*

The quantity of heat required for melting / combustion of the fuel as given by equation 6:

$$Q_m = C_m \times T_m \times G_m$$

where:
C_m = 0.904 kJ/Kg
T_m =1280-27 =1253K
G_m= 100kg/hr
Q_m= 0.904 x 1253 x 100 = 113271.2 kJ/hr

C. Actual Efficiency of the Furnace

Using equation 7;

$$\varepsilon = \frac{Q_m - C_{vf}}{Q_m} \times 100$$

$$\varepsilon = \frac{113271.2 - 45948}{113271.2} \times 100 = 59.4\ \%$$

V. CONCLUSION

A crucible furnace using spent engine oil as heating fuel has been developed. On completion of thiswork the furnace could accommodate a crucible pot of 100kg capacity and the inner temperature was 1280^{0}C with an initial ambient temperature of 27 ^{0}C and actual efficiency of 59.4 %. Though the furnace was designed for a temperature of 1400^{0}c but it was able to attain 1280^{0}c which shows that apart from aluminium, the cast iron can as well be melted.

Finally this project has proved beyond reasonable doubt that, given the right environment and necessary support, local raw materials can be efficiently used to design a heating equipment that can provide the basics upon which our small and medium scale foundry enterprises can thrive, in order for them to be able to produce spare parts and machine components which could have been imported from overseas, thereby saving foreign exchange. Its comparative cost advantage when compared with imported ones gives it additional credit.

A. *RECOMMENDATIONS*

From the performance of the developed crucible furnace, these recommendations were proffered:

- That the design should be adopted by foundry technologists
- The foundry industries should embrace this design as a basis for further improvement and cost reduction in iron melting processes.
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