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Design and Construction of a Scrap Melting Furnace Fired by Waste Lubrication Oil

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***Abstract**: The incessant power supply in Nigeria has made it difficult for thermal equipment such as an electric furnace to have a cost effective operation. This research paper focusses on the design and construction of a non-ferrous melting furnace fired by a waste lubrication oil (WLO). The purpose of this work is to construct a furnace that uses WLO as a source of energy. The material selection and heat balance were carried out; the fabrication of the furnace (with 0.3079m^3 combustion chamber) was made of steel, lined with alumina refractory clay having thermal conductivity and refractoriness of 38.5W/m.^{o}C and 1300^{o}C respectively. This provides a high rate of heat transfer to the metal scraps and low heat conduction to the surrounding. WLO having calorific value and fire point of 38,000 kJ/kg and 143^{o}C respectively, was used as source of heat energy. Test conducted on the fabricated furnace, shows that it has the capability of melting 5 kg of aluminium scraps in 30 minutes (melting rate of 0.167 kg/min). The overall thermal efficiency of the furnace was 23.2% on its performance assessment, which suggest a fairly good heating rate. With a useful heat input, the furnace was able to melt the 5 kg of aluminium at a pouring temperature of 660^{o}C using 0.82 litres of WLO. Furthermore, the performance of the furnace shows that the furnace can operate at a heating rate of 25°C/min.*

Keywords—Foundry, Refractory material, waste oil, Thermal conductivity, Refractoriness and Aluminium scraps.

1. INTRODUCTION

In a foundry workplace, a crucible furnace is a piece of equipment used to melt metals for casting operations. The furnace is the most important piece of equipment in the foundry industry, which applies rational metal shaping techniques. Almost all industries, according to Asibeluo (2015), rely on castings, which would be impossible to make without the furnace. The foundry industry supports a variety of industries, including automobiles, machine tools, aircraft, electrical, plumbing, and communication.

Induction furnaces, which are commonly used in foundries and capable of producing 65 tons of steel per charge; crucible furnaces made of refractory materials such as ceramic to handle high temperatures; cupola furnaces made of long chimney-like furnaces filled with coal-coke, additives and lit for which metal is added directly to the furnace; and electric arc furnaces, which use electrodes, according to Amelt (2019).

Chukwudi and Ogunedo (2017), asserted that non-metal recycling, particularly aluminum recycling, is one of Nigeria's and the world's most profitable companies. Its popularity can be ascribed to the fact that recycling aluminium scrap uses less energy than recycling mining and ferrous metals. As a result, it is vital to harness the available supply of energy in order to stimulate and support the productivity of small and medium-sized businesses in the Nigerian aluminum recycling industry. The re-melting of these scrap aluminum products will go a long way toward increasing product availability while reducing dependency on the international market, thereby enhancing the foreign reserve. Similarly, obtaining melting equipment for this purpose has become extremely difficult, creating the necessity to seek internally for the manufacturing of some critical components for our technological advancement. As a result, many ways of melting aluminum, such as crucible furnaces, are being utilized in the country, whether on an industrial or small-scale basis (Beneth and Martins, 2018).

Environmental pollution results from the disposal of waste lubricating oil in the environment, which is a serious problem for researchers. Therefore, this research paper looked into the possibility of using waste oil from engineering machines as a fuel in the development of a waste oil burner. The development of a waste oil furnace provides a means of reusing WLO as supplementary or alternative fuel for furnaces.

The aim of this research is to design and construct a melting furnace fired by WLO. The objectives are to:

i. Carry out conceptual design and material selection
ii. Carry out detail design and construction
iii. Conduct performance evaluation

Many theories have been proposed in the field of furnace design, vis-a-viz the mechanism of heat transfer through furnace wall. However, the review of related literature for this study is focused on the design and fabrication of furnaces using different types of fuel or source of energy.

Using locally produced Soderberg electrodes, Oyawale and Olawade (2011), built a mini electric arc furnace that can melt 5kg of steel and cast iron waste. The results reveal that heating the furnace between 1150°C and 1400°C took 60 minutes, and melting the first charge of 2kg took 95 minutes at a melting rate of 21.05g/minute.

To replace electrically driven heating elements that are unreliable in Nigeria due to a shortage of electricity, Alaneme and Olanrewaju (2010) devised a diesel-fired heat-treatment furnace with locally obtained components. He determined that the furnace warms up quickly, at 61.24°C per minute, at a pre-set temperature of 900°C and uses less than 1.41 litres of fuel each hour.

Bhat et al. (2012) evaluated the performance of a charcoal-fired furnace used to recycle aluminum waste. The result shows that the furnace's efficiency was 11.5 percent, which is low due to the high amount of energy squandered due to the open type furnace.

Folayan (2014) designed a coal-fired crucible furnace to improve on the gas-fired crucible furnace. Because coal is not readily available in many regions of the Nigeria, charcoal was proven to be the most readily available fuel. Titiladunayo and Fapetu (2011) developed an electrically driven stationary pot crucible furnace for pyrolysis and recognized the advantages of electric furnaces, however the cost of operating was prohibitive. Beneth and Martins (2018), design and build an oil-fired crucible furnace with a high heating efficiency for melting aluminum scrap while reducing heat losses and optimizing heat output.

Asibeluo and Ogwor (2015) created a diesel-fueled cast-iron crucible furnace with a capacity of 50 kg. The overall combustion capacity of the furnace drum is $0.1404m^3$. It is equipped with a chimney to allow combustion gases to easily escape. The air blower delivers $0.3m^3/s$ of air into the furnace, resulting in a 40:1 air/fuel ratio. The cast-iron crucible furnace is designed to burn four gallons of diesel fuel with a 139000kJ/gallon rating, which is enough to melt 50 kg of cast iron in 90 minutes. The cast–iron crucible furnace's designed operating temperature range is 1300°C to 1400°C.

2 METHODOLOGY

The outline of research methodology followed in this study consist of the following:

2.1 Conceptual Design

The conceptual design of the proposed equipment consists of three primary components- furnace, air blower and fuel storage tank as shown in Fig. 2.1

2.2 Material Selection

The material selection considered for the design and construction of the furnace is provided in Table 2.1.

Table 2.1: Material Selection

Part	Material Selected	Material Properties
Casing	Mild steel	High strength, toughness, durability and good weldability
Refractory	Alumina powdered clay	High Refractoriness and low thermal conductivity

Table 2.1 continues: Material Selection

Part	Material Selected	Material Properties
Crucible pot	Chrome based steel	High heat resistance, strength and thermal conductivity
Tong	Steel	High strength
Burner fuel	WLO	High calorific value and low flash point

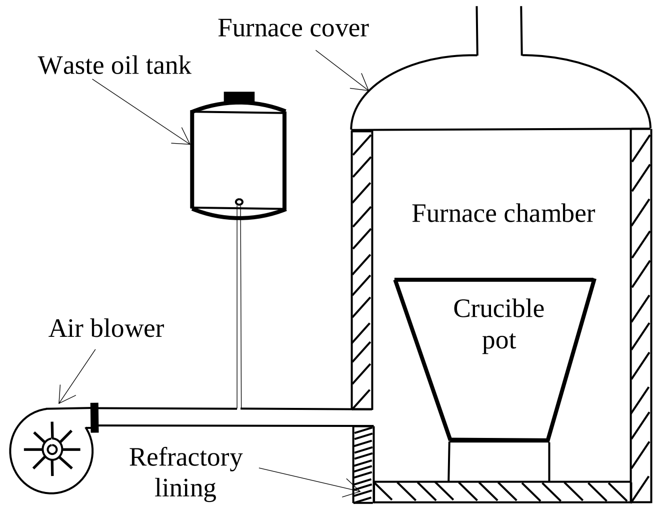

Fig. 2.1: Conceptual design of the waste oil furnace

2.3 Design Calculations

The design calculations carried out in this work focused on the heat balance determination and efficiency of the system.

i) Heat Energy Requirement for Melting Aluminium

Heat energy (sensible heat) required for melting aluminium metal from room temperature (T_c) to melting point (T_m)

$$Q_1 = mc_{p1}(T_m - T_c)\ (Sinha\ and\ Goel, 1973) \quad (1)$$

Specific heat capacity of solid aluminium, c_p, = 0.91 kJ/kg.K (Suresh and Nagarium, 2016)
Specific heat capacity of molten aluminium, c_p, = 1.18 kJ/kg.K (Kothandaraman and Subramanyan, 2014)
Latent Heat of Fusion of Aluminium = 321 kJ/kg
Melting Point of Aluminium = 660°C
Ambient temperature T_c = 25°C
Mass of Aluminium melted = 5 kg
Substituting the values above into (1)

$$Q_1 = 5 \times 0.91\ (933 - 298) = 2889.25\ kJ$$

The latent heat energy required to completely convert the solid to molten aluminium at the melting temperature is given by the expression in (2)

$$Q_2 = ml\ (Sinha\ and\ Goel, 1973) \quad (2)$$

Substituting the values above into (2)

$$Q_2 = 5 \times 321 = 1605\ kJ$$

The heat energy (super heat) required to raise the temperature of molten metal from its melting point of 660ºC to the required pouring temperature (750ºC) is given as:

$$Q_3 = mc_{p2}(T_p - T_m)\ (Sinha\ and\ Goel, 1973)$$
(3)

Substituting the values above into (3)

$$Q_3 = 5 \times 1.18\ (1023 - 933) = 531\ kJ$$

Therefore, the total heat (Q_4) required for melting aluminium from room temperature to the pouring temperature is expressed in (4)

$$Q_T = Q_1 + Q_2 + Q_3 \quad (4)$$

Substituting all the values obtained from previous calculations

$$Q_T = 288925 + 1605 + 531 = 5025.25\ kJ$$

ii) Efficiency of the Furnace
The total amount of energy produced by the waste oil in the furnace chamber is given by equation (5):

$$Q_w = mc_v \quad (5)$$

The calorific value, c_v, of the waste oil = 38,000 kJ/kg
The mass, m, of waste oil used for melting 5 kg of aluminium = 0.82 kg
Substituting the above values in (5)

$$Q_w = 0.62 \times 35000 = 21{,}700\ kJ$$

The efficiency of the furnace is expressed by equation (6)

$$\eta_F = \frac{Q_T}{Q_w} \times 100 \quad (6)$$

Substituting Q_T and Q_w into (6)

$$\eta_F = \frac{5025.25}{21{,}700} \times 100 = 23.2\ \%$$

2.4 Design and Technical Specification of the Waste Oil Furnace

The design and technical specification of the waste oil furnace is given in Table 2.2.

Table 2.2: Product Specification

S/N	Items	Details
	A. Air blower	
1	Type	Centrifugal
2	capacity	600kW
	B. Feed system	
3	Mechanism	Gravity
4	Hose type and diameter	Polymer / 5 mm
5	Storage tank	10 L cylinder
	C. Auxiliary fuel	
6	Type	Methane gas
7	Calorific	50,000kJ/kg
	D. Combustion pipe	
8	Material type	Galvanized steel pipe
9	Internal/External dia.	60 mm / 64 mm
	E. Frame	
10	Material	Steel angle bar
11	size	40 mm
	F. Furnace	
12	Maximum temperature	920ºC
13	Heat capacity	25°C/min
14	Heating rate	0-20ºC/min
15	Feed rate	0.167 kg/min
16	Mode of operation	Manual batch
17	Source of heat	WLO
18	Chamber size	0.3079 m^3
19	Furnace structure	Double layer 3mm thick steel casing
20	Furnace chamber	Single layer kaolin clay insulation
21	Temperature indicator	Thermocouple
22	Melting material	Non-ferrous
	G. Refractory material	
23	Type/thickness	Alumina/50 mm
24	Density	3980 kg/m^3
25	Thermal conductivity	38.5W/m.ºC
26	Specific heat capacity	820J/kg.ºC
27	Fusion temperature	1300ºC

2.5 System Components

All the components used for the construction of the waste oil furnace are discussed in this section.

i) Refractory Material
Alumina refractory powder was used to line the furnace wall to prevent heat loss from the furnace chamber to the surrounding. Fig. 2.2 shows sample of the refractory material.

Fig. 2.2 Sample of the refractory material

ii) Crucible

The crucible pot is a steel container in which the ferrous metals are charged in and melted under a very high temperature. The crucible pot fabricated for this study is shown in Fig.2.3

Fig. 2.3: Crucible pot

iii) Furnace chamber and cover

The furnace chamber (see Fig. 2.4) is a double wall enclosure used as the combustion chamber, where heat is generated and transferred to the melting pot while the furnace cover (shown in Fig. 2.4) prevent excessive loss of heat to the surrounding and also increase the retention time of combustion air needed for the complete chemical reaction with the waste oil

Fig. 2.4: The furnace chamber and cover

iv) Air Blower

A blower is a device for generating and circulating high velocity air flow needed for the combustion of the waste oil. This is achieved by drawing ambient air into the furnace chamber. Figure 2.5 shows the air blower selected for this study.

Fig. 2.5: A centrifugal air blower

v) Waste oil storage tank

The waste oil storage tank provides temporary storage volume for the oil and also the pressure (being placed on an elevated height) for the oil to flow under gravity. Fig 2.6 shows the oil storage tank used for this study.

Fig. 2.6: Waste oil storage tank

2.6 Assembly of Components

The various components of the waste oil furnace were assembled together as shown in Fig. 2.7.

2.7 Working Principle

To operate the furnace, it must first be preheated with methane gas supply while the electric air blower is turned on in order to ignite the oil and generate the initial combustion and infuse heat into the furnace chamber. The crucible is charged with ferrous metal and the lid is closed during operation. After a steady combustion is maintained by this process, the waste oil valve is opened to allow waste oil drip at the tip of the nozzle. The oil undergoes combustion and when a steady flame is achieved, the methane gas supply is cut off. The flame rises from the bottom of the furnace, swirls around the crucible, and warms it. The fuel is switched off and the lid is opened after the metal has melted and achieved the proper temperature. A tong is then used to remove the crucible from the furnace. The molten metal is discharged into a mold cavity after the slag that has collected on the surface of the melt is removed.

Fig. 2.7: The prototype waste oil furnace connected to a burner

2.8 Performance Test

The performance of the WLO fired furnace was evaluated by charging 5 kg of aluminium into the crucible, the developed furnace successfully melts the aluminium within 30mins into molten state. The residues and slag were carefully removed. The test takes into consideration the following:

i. The time taking for the aluminium to completely melt and attain the pouring temperature of 750ºC
ii. The mass of waste oil consumed in the process of melting aluminium to the pouring temperature
iii. The quantity of heat liberated in the furnace chamber
iv. The determination of the efficiency of the furnace.

Fig. 2.8 shows the performance test carried out in progress.

Fig. 2.8: Performance test in progress

The results of the performance test conducted with the waste oil furnace to determine the temperature and time interval to completely melt 5 kg of aluminium is presented in Table 3.1

Table 3.1: Furnace time-temperature results

Time (min.)	Temperature attained (ºC)	Heating rate (ºC/min)
5	154	30.8
10	315	31.5
15	450	30.0
20	590	29.5
25	660	26.4
30	785	26.1

Considering the results obtained in Table 3.1, the furnace has a relatively good heating rate which tends to be high in the first 15 minutes of the test operation due to the fact that an initial preheating of the furnace was done using methane gas supply. The melting of the aluminium scraps was achieved after 25 minutes of operations and further melting took a total of 30 minutes to achieve the casting (pouring) temperature of 785ºC. The fuel consumption of 0.8L was used to achieve this melting operation, suggesting a low cost of operation when compared to other source of heat like diesel oil, electrical or gas source.

The waste oil furnace's efficiency was calculated to be 23.20 percent, which is within the efficiency range of some conventional furnaces, indicating that a significant portion of the heat generated in the furnace was used in the metal melting process.

4 CONCLUSION

The waste oil furnace was used to melt 5 kg of aluminium scrap, thereby achieving the objective of recycling aluminium scraps that would have been otherwise disposed of as a waste item. The WLO that would have also been disposed of in the surrounding was utilized as source of heat for the furnace, hence making the cost of construction and operation to be very economical. The developed furnace will not only melt aluminum but also any metal that has melting temperature below 1000ºC.

Furthermore, the waste oil furnace is considered to be very suitable for use in small scale foundries.

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