

DEVELOPMENT OF A CRUCIBLE FURNACE FIRED WITH SPENT ENGINE OIL USING LOCALLY SOURCED MATERIALS

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ABSTRACT: The developed crucible furnace has the capacity to melt 30 kg of Al-Si alloy scraps in 20 minutes during which 7 litres of spent engine oil was used up at a flow rate of $5.833 \times 10^{-6} \text{ m}^3/\text{sec}$. The overall thermal efficiency of the developed crucible furnace was 46.74% on its performance evaluation. Its operating cost is cheaper since, spent engine oil is relatively available and the incessant increment in the price of fossil fuel will no longer have effects on the production costs. The performance of the equipment is better than the traditional ways of non-ferrous metals recycling exercise and its adequate implants for conversion of waste engine oil and Al-Si alloy scraps to wealth.

KEYWORDS: crucible, furnace, Al-Si alloy, spent engine oil, thermal, efficiency, performance.

INTRODUCTION

Components made from non-ferrous materials tend to display a marked decrease in performance level after years of service and have to be discarded. Re-melting and re-casting of scraps of such components helps to enhance availability of the component, (Abubakre, 2001). Acquisition of standard equipment for this type of recycling is challenging, thus there is need to look inward and locally fabricate crucible furnace for melting non-ferrous scraps metals to meet these needs. The Nigerian automobile and electricity generator assembly industries stand to benefit most from this drive.

There are three common types of crucible furnaces. These are:

- (a) The stationary pot: this is the simplest form of crucible furnace. The molten metal is ladle out directly for casting;
- (b) The lift - out pot: this consist of a pot that can be lifted out of the furnace by means of a tongs for pouring; and
- (c) The tilting pot: here, the entire furnace is tilted to pour out the molten metal directly into the ladle or moulds, (Gupta, 2008).

The available local means of non-ferrous metals recycling process is slow and time consuming moreover, a large quantity of heat is always wasted during the operation as well. The major source of energy supplied to the system is usually from charcoal produced from hardwood, palm kernel shells and wood.

Crucible furnace can be fired by different kinds of fuels such as butane gas, diesel, charcoal, coke, biodiesel and briquette. The use of spent engine oil is adopted in this research work as a means of reusing the used lubricating oil that is ordinarily disposed off in manner that causes environmental pollution. The uses of spent engine oil as alternative to industrial fuel, reduces the operating cost of the equipment therefore, the aim of this research work is to develop a crucible furnace fired with spent engine oil using locally sourced materials.

A furnace is a device in which the chemical energy of a fuel or electrical energy is converted into heat. This is then used to raise the temperature of the burden or stock placed within it for melting or smelting, (Gupta, 2008). Furnaces operating at low temperatures are often called ovens depending on their purposes, these are furnaces used for melting and roasting of metals.

A furnace consists of: (The Carbon Trust, 1993):

- (a) refractory materials for lining the furnace to retain heat at high operating temperatures;
- (b) steel shell to contain the refractory materials;
- (c) burners that use solid, liquid or gaseous fuels to raise and maintain the temperature within the combustion chamber. Coal or electricity can also be used;
- (d) charging and discharging doors through which the chamber is loaded and unloaded;
- (e) chimney to remove waste exhaust gases from the combustion chamber; and
- (f) loading and unloading equipment such as roller tables, conveyors, tong, charging machines and furnace pushers.

In most third world nations, one of the cheapest ways to melt non-ferrous metal commercially in a crucible furnace is by using combustion fuel (i.e oxidation of fossil fuel). Furnace design may vary according to its function, heating duty performed, heating method applied or type of fuel used (UNEP, 2006). Musa, (2012) and Bello, (2004) compared diesel and butane gas as fuel in firing crucible furnace for melting aluminum scraps. It was discovered that butane gas brought the aluminium scraps to its pouring temperature within 45 minutes while diesel fuel spent 50 minutes and at lower cost.

Toshikazu and Ryoya, (2012) investigated the use of kerosene crucible furnace in their work. The furnace was able to attained 750°C. While this temperature was fairly sufficient for melting aluminium, it was inadequate for other non-ferrous metals.

Babalola *et al.*, (2012) worked on the design and fabrication of tilting furnace for producing aluminium matrix composites. The furnace had 20 kg capacity and their research was centred on a liquid state fabrication of metal matrix composite using stir casting method. This casting method is however expensive for small and medium operations.

Ighodalo *et al.*, (2011) did a study evaluating the performance of a charcoal-fired furnace for recycling aluminium scraps. The efficiency of the furnace was 11.5%. This value was low as a result of the large quantity of energy wasted due to the open nature of the furnace. The case of electrically powered stationary pot crucible furnace designed by Titiladunayo and Fapetu, (2011) for pyrolysis show cased the benefits of electrically power furnaces but its cost of operation was exorbitant.

A furnace fired with diesel was considered by Govardhan *et al.*, (2011) this work lacked physical validation but the computer based experimentation and computational fluid dynamics (CFD) analysis showed the temperature distribution during the oscillating combustion in a crucible furnace.

Alaneme and Olanrewaju, (2010) work on diesel fired stationary pot crucible furnace for both heat treatment and salt bath was motivated by this challenge. The documented works of fuels for combustion in crucible furnace has shown that the need to obtain a fuel that is readily available and cheap remains a major challenge plaguing the foundry business in Nigeria.

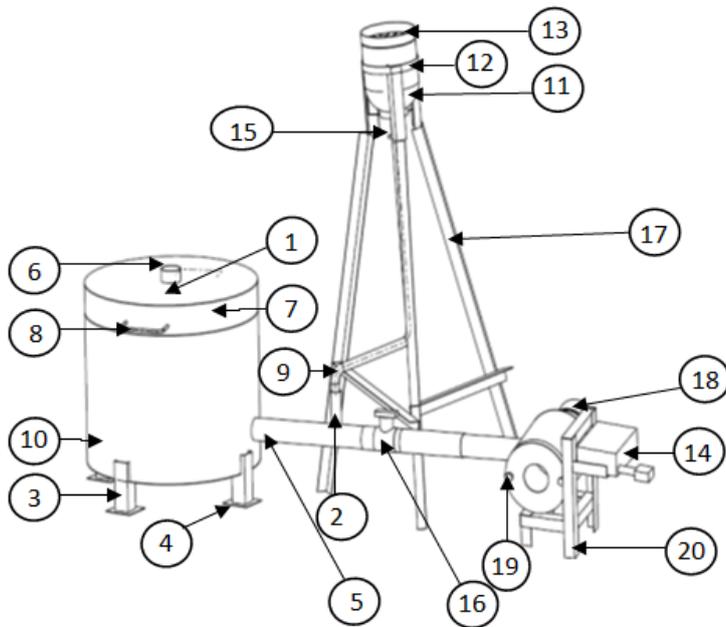
MATERIALS AND METHODS

Crucible furnace fired with spent engine oil using locally sourced materials was developed for foundry laboratory use and training of students at The Federal University of Technology, Akure, Nigeria. The major materials used for the development of the furnace were: 2 mm mild steel plate, refractory materials (Ipinsa kaolin, Termite hill materials and Bentonite) and 2 mm angle iron bar. The crucible furnace was fabricated in conformity with both the design calculations and drawings. The detail design can be found in Olalere, (2015). The cylindrical steel shell is of 801 mm diameter and 601 mm height, its stands on a 100 by 100 mm hollow pipe of 150 mm height. The cover was made of 803 mm diameter and 150 mm height, the chimney was rightly positions at the centre of the cover to be of 90 mm diameter and 120 mm height.

The burner was positioned tangentially to the side of the cylindrical steel shell and was made from a mild steel pipe of 60 mm diameter and 700 mm long with a fitted nozzle constructed from an hollow copper pipe of 10 mm diameter, the fuel tank was constructed using an R22 empty gas cylinder as fuel tank and position on a stand of 1450 mm height since, the fuel flow was by gravity as shown in Figure 1.

The lining of the developed crucible furnace was carried out using an aggregate of Ipinsa kaolin, Termitite hill materials, Bentonite and Water, the lining materials was made up of refractory bricks materials embedded in the kaolin paste to form a thickness of 200 mm left behind a diameter of 401 mm as the combustion chamber of the developed crucible furnace to accommodate both the crucible pot, the loading and unloading equipment.

The burner is the heat-releasing device used to combust the fuel with an oxidizer to convert the chemical energy in the fuel to thermal energy. Various types of burners are available and may be classified based on method of mixing, fuel and oxidizer types and method of producing draft, (Baukal, 2004).



S/N	Description	Qty	Materials
20	Blower Stand	1	Angle Iron
19	Bolts Head	6	Steel
18	Electric Motor	1	
17	Fuel Tank Stand	3	Angle Iron
16	Air Regulator	1	Plastic
15	Fuel Regulator	1	Brass
14	Power Control Box	1	Mild Steel Plate
13	Fuel Sieve	1	
12	Fuel Tank Cylindrical Guide	1	Mild Steel Plate
11	Fuel Tank	-	Steel
10	Cylindrical Shell	1	Mild Steel Plate
9	Fuel Hose	-	Rubber
8	Cylinder Cover Handle	2	Mild Steel Rod
7	Cover Cylindrical Shell	1	Mild Steel Plate
6	Chimney	1	Mild Steel Pipe
5	Burner Assembly	1	Mild Steel Pipe
4	Cylindrical Shell Stand Base	4	Mild Steel Plate
3	Cylindrical Shell Stand	4	Rectangular Steel Pipe
2	Fuel Inlet	1	Mild Steel Pipe
1	Cylindrical shell cover	1	Mild Steel Plate

Figure 1: Crucible Furnace Assembly Drawing

EXPERIMENTATION

The developed crucible furnace was set up and charged with 30 kg of Al-Si alloy scraps, a K-types thermocouple was incorporated to measure the degree rise in temperature within the combustion chamber of the equipment. The fuel tank was filled with twelve (12) litre of spent engine oil, the furnace was ignited then the blower was put on, subsequently both the fuel in flow and the air regulator was regulated to have a complete combustion of the fuel. The duration for the melting operation was noted by using a stop watch. Immediately, the melting operation is completed the spent engine oil inside the fuel tank was measured and it was discovered that seven (7) litres of spent engine oil was combusts for the operation. The total operation time is twenty (20) minutes during which the developed crucible furnace was attained a temperature of 1500°C. The thermal efficiency of the equipment was estimated based on some of this experimental results and standard values.

RESULTS AND DISCUSSIONS

Heat energy liberated during combustion in the combustion chamber was transferred to the stock in the furnace. Heat transfer may occur through conduction, convection or radiation. These may also occur simultaneously but one will often predominate. In industrial processes radiation is often the dominant mechanism and forced convection also plays an important role (Baukal, 2004). The more efficient the heat transfer processes, the higher the overall furnace efficiency and thus the lower the fuel consumption and flue gas emission.

The thermal efficiency (τ_T) of the developed crucible furnace can be determined by measuring the amount of heat absorbed by the stock and dividing this by the total amount of fuel consumed;

$$\tau_T = \frac{\text{Heat output}}{\text{Heat input}} (100) \tag{1}$$

The quantity of heat (Q) that will be transferred to the stock can be calculated from equation (2):

$$Q = mC_p(T_1 - T_2) \tag{2}$$

where, Q = Quantity of heat absorbed by the stock, (J)

m = Weight of the stock, (kg)

C_p = Mean specific heat of the stock, (J/kg/K)

T₁ = Final temperature of the stock, (K)

T₂ = Initial temperature of the stock.(K)

During the experiment the final temperature (T1) was measured to be 1500°C using a K-types thermocouple, the ambient temperature (T2) was measured to be 34°C using a digital multi-meter and was used as the initial temperature.

The experimental results gotten from the spent engine oil combustion property carried out using the ASTM standard are the specific gravity (0.8882) and the calorific value (41,870 kJ/kg). The detail procedure used for the experiment can be found in the work of Olalere, (2015). The standard value used is the specific heat capacity for Al-Si alloy (913 J/kg).

Therefore; the heat input into the system was estimated using this relation;

$$Q_{input} = L_f \times T_t \times S_g \times C_v \tag{3}$$

where,

L_f = quantity of fuel combust,

T_t = total time taken to combust the fuel,

S_g = specific gravity of the combust fuel

and *C_v* = calorific value of the combust fuel.

$$Q_{input} = 7 \times 0.33 \times 0.8882 \times 41,870,000 = 85,906,437.54 \text{ J}$$

The heat output from the developed crucible furnace was estimated using equation (2) as follows;

$$Q_{output} = 30 \times 913(1500 - 34)$$

$$Q_{output} = 40,153,740 \text{ J}$$

The thermal efficiency of the developed crucible furnace was estimated using equation (1) as follow;

$$\eta_T = \frac{40,153,740}{85,906,437.54} (100)\%$$

$$\eta_T = 0.4674(100) \% = 46.74\%$$

The efficiency of the developed crucible furnace is actually encouraging because is more effective and efficient in performance than the charcoal-fired furnace for recycling aluminium that was evaluated by (Ighodalo, 2011).The efficiency obtained for the furnace was 11.5% and he concluded that low value obtained is as a result of large energy wastage due to the open nature of the furnace.

ENERGY BALANCE IN THE DEVELOPED CRUCIBLE FURNACE

Energy balance is an analyses of a process in which all energy states and flow (inputs and outputs) through a predefined enveloped (system boundary) are quantified. It is one of the numerous tools to evaluate the performance and efficiency of furnaces. Figure 2: indicates energy balance principles used in this work:

$$Q_{in} = Q_{out} + Q_{losses} \tag{4}$$

$$\sum \dot{m}_i = \sum \dot{m}_o \tag{5}$$

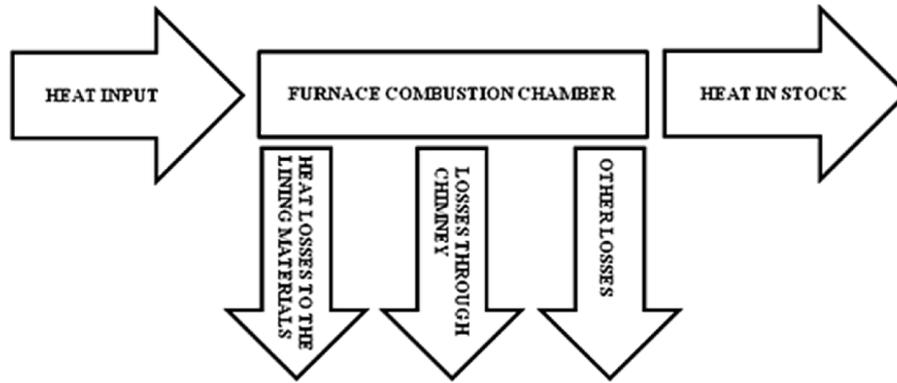


Figure 2: Heat Losses in the Developed Crucible Furnace

Flue gas losses: part of the heat remains in the combustion gases inside the furnace. This loss is also called waste-gas loss or stack loss.

Loss from moisture in fuel: fuel usually contains some moisture and some of the heat is used to evaporate the moisture inside the furnace.

Losses due to presence of hydrogen in fuels that normally results in formations of water and carbondioxide during the combustion exercise of fuel.

Loss through openings in the furnace: radiation loss occurs when there are openings in the furnace enclosure and these losses can be significant, especially for furnaces operating at temperatures above 540°C. A second loss is through air infiltration because the draft of furnace stacks/chimneys causes a negative pressure inside the furnace, drawing in air through leaks or cracks or whenever the furnace doors are opened.

Furnace skin / surface losses, also called wall losses: while temperatures inside the furnace are high, heat is conducted through the roof, floor and walls and emitted to the ambient air once it reaches the furnace skin or surface.

Other losses: there are several other ways in which heat is lost from a furnace, although quantifying these is often difficult. Some of these include;

Stored heat losses: when the furnace is started the furnace structure and insulation is also heated, and this heat only leaves the structure again when the furnace shuts down. Therefore this type of heat loss increases with the number of times the furnace is turned on and off.

Material handling losses: the equipment used to move the stock through the furnace, such as conveyor belts, walking beams, bogies etc, also absorb heat. Every time equipment leave the furnace they loses their heat, therefore heat loss increases with the amount of equipment and the frequency by which they enter and leave the furnace

$$Q_{input} = Q_{output} + Q_{refractory\ materials} + Q_{other\ losses} \quad (6)$$

where;

Q_{input} : Heat derived from combusts of the spent engine oil;

Q_{output} : Heat absorbed by the crucible pot and the stock/scrap materials;

$Q_{refractory\ materials}$: Heat absorbed by the refractory materials; and

Q_{losses} : (Flue gas, Moisture in fuel, Hydrogen in fuel, Openings in furnace, Furnace surface/skin and Other) losses.

The Q_{input} into the system is 100% and Q_{output} is the efficiency of the equipment which is 46.74% and $Q_{refractory\ materials} = 0.82\%$.

The approximate heat losses from the furnace to the surrounding of developed crucible furnace can be calculated from the relations;

$$\begin{aligned}
 Q_{\text{other losses}} &= Q_{\text{input}} - Q_{\text{output}} + Q_{\text{refractory materials}} \\
 &= 85,906,437.54 - (40,153,740 + 707,774.66) \\
 &= 85,906,437.54 - 40,861,514.66 \\
 &= 45,044,922.88 \text{ J} \\
 &= (100 - 46.74 + 0.82)\% = 52.44\% .
 \end{aligned}$$

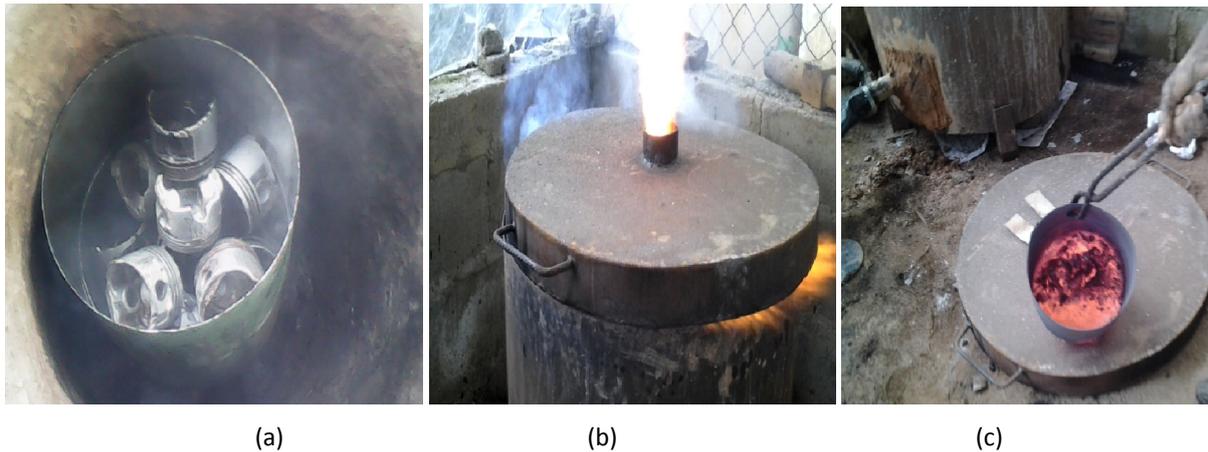


Plate 1: Melting of Al-Si alloy scrap materials: (a) charged crucible furnace; (b) crucible furnace during melting operation; and (c) molten metal lifted out from the developed crucible furnace.

CASTING OPERATION

The moulds boxes were aligned with the aids of the identification marks on both the cope and drag moulding box, remove the slag from the molten metal and lift out the crucible pot with the aids of pair of tongs, immediately pour the molten metal into the already prepared sand mould for the casting process after some few seconds when solidification of the molten metal has completed the cast component was removed from the mould by lifting up the cope pattern box. The step was as shown on plate 2 (a); (b); (c) and (d).

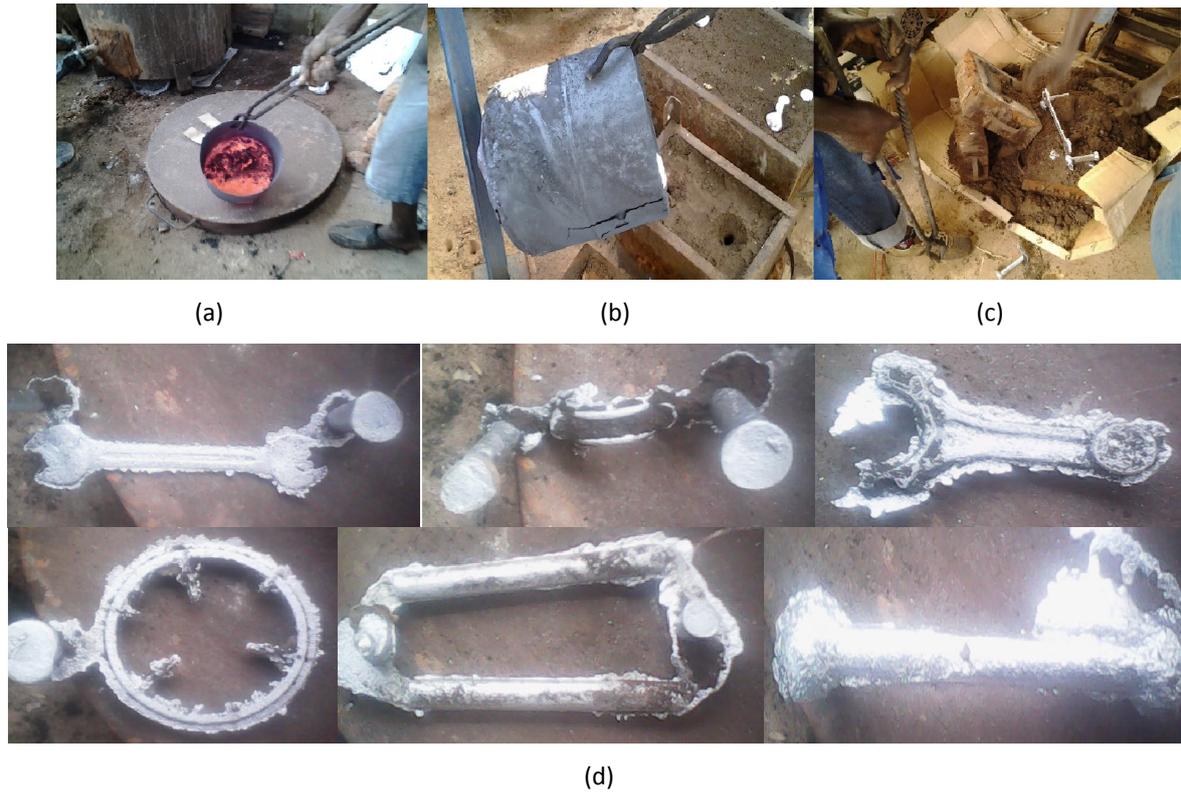


Plate 2: Casting operation:
 (a) molten metal ready for pouring into the mould cavity; (b) pouring of the molten metal into the mould cavity;
 (c) removal of as cast materials after solidification exercise; and (d) displayed of as cast components.

FETTLING OPERATION

The gate and riser of the cast components was cut off to have a good surface finishing as shown in plate 3.



Plate 3: Cast component after surface finishing

CONCLUSION

The developed crucible furnace was fired using spent engine oil and when fired it was used to melt Al-Si alloy scraps materials (automobile engine pistons) from which spanner, connecting rod, small shaft and kerosene stove cooking pot hanger cast using sand casting moulds. Seven (7) litres of the spent engine oil was used up in 20 minutes at a flow rate of $5.833 \times 10^{-6} \text{ m}^3/\text{s}$. Its thermal efficiency reached 46.74% based on computation while the total heat loss estimated was 53.26%.

The equipment is also cheaper when compared to the foreign ones in terms of operating cost and maintenance. The small scale entrepreneurs can venture into the Al-Si alloy scraps recycling exercise to useful components.

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