Development of a Small-Scale Oil Fired Furnace for Refractory Lining Temperature Distribution Evaluation*

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Abstract

Metallurgical furnace is the bedrock of modern production processes. Assessment of temperature distribution across the refractory lining materials is essential in the study of the performance and life span of the refractory material. In this work, a 50 kg capacity spent engine oil fired crucible furnace was constructed from locally sourced materials. A total of twelve (12) thermocouple probes were embedded in the refractory lining wall at predetermined intervals. The probes nearer to the surface (that is, S_{11}, S_{21} and S_{31}) presented temperatures that rose steeply and peaked between approximately 409.75 and 655.50 *°C* while the temperatures registered by the other probes inside the lining wall were all less than 100 *°C.* The firing of the furnace lasted for 1 hour and 10 minutes. Supply of fuel was momentarily disturbed at the 17th and 57th minutes. The probes showed that the heat intensity was higher at positions close to the mid-section of the combustion chamber. The heat generated was sufficient to melt Al-Si alloy scrap metals that was used to cast items of several shapes. The heat retentions between the furnace cover and the upper layers of the combustion chamber at level S_3 made the region to gain more heat than level S_1.

Keywords: Furnace, Refractory Lining, Temperature Distribution

1 Introduction

Service condition for furnace lining exposes it to thermal, mechanical as well as, chemical loadings and stresses. This is why lining walls have to be replaced frequently thus causing loss in revenue and increase in downtime in various material processing plants where various kind of furnaces are employed (Ramanenka, *et al.*, 2019; Crivits, 2016; Briggs and Uzoma, 2019; Andreeva *et al.*, 2019).

Due to the critical nature of the furnace lining these plants, it becomes necessary to conduct studies targeted at their optimal use and service conditions. The studies must evaluate the thermomechanical responses of the furnace linings to induced loads. The literature already contains numerous publications addressing challenges with similar themes but they mostly based their investigations on numerical experimentation analysis executed through computer based tools (Atanda *et al.*, 2014; Jin *et al.*, 2016; Vázquez-Fernández *et al.*, 2019; Ramanenka, *et al.*, 2019; Lei, *et al.*, 2013Parra *et al.*, 2006; Boisse *et al.*, 2002). There is therefore a need for more research works seeking to correlate the findings in numerical experimentation analysis with outcomes of physically conducted experiments. In many studies the refractory lining materials of a metallurgical furnace was treated as a single homogeneous slab, such that transmission of heat through it is uniform, mostly. There is a need to investigate this with a view to unravel the characteristics of the lining materials during service or under various thermomechanical loading.

Documented efforts directed at the construction of oil-fired crucible furnaces from indigenous materials and suitable for small and cottage scale enterprises exist in the literature. For example, Olalere *et al.* (2015) and Famurewa, 2019 accounted for the development of crucible furnace from predetermined aggregate of Kaolin, Bentonite and Termite hill material. The furnace attained *1100 °C* and was used to melt *Al-Si* scrap metals. The pit furnace built in Suresh and Nagarjun (2016) was fired using biodiesel derived from non-edible oil seeds whose calorific value was estimated to be about *90%* comparable to that of normal diesel. It was demonstrated to attain *1000 °C* and melt *40 kg* of aluminum in *40 min.* Sai Varun *et al.* (2018) developed a tilting rotary furnace using a pilot burner with a push button igniter, insulated with ceramic fiber cloth and propane gas was used as fuel because of it was more readily available. In this study, a 50 *kg* melting capacity crucible furnace was built from locally sourced material formed from aggregation of kaolin, termite hill material and bentonite. It was fired using spent engine oil delivered by gravity. Heat transfer characteristics of the lining was studied using a system of impregnated thermocouple probes.

2 Resources and Method Used

2.1 Materials

The materials used in this work consist of a 50 kg capacity crucible furnace that was locally constructed, 12 channel temperature data logging

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system, twelve (12) type-K thermocouple probes, spent engine oil fuel and Al-Si alloy scrap metal materials for casting.

Five samples of equal quantities of kaolin material was collected from locations 150 *m* apart within the Ipinsa kaolin deposit field that is 1.053 *km* away from the Federal University of Technology, Akure, along Benin/Ilesha express way, Ondo State, Nigeria. Akure is located within the humid south western region of Nigeria on latitude 7˚16' N; longitude 5˚13' E.

The kaolin material was properly blended together and spread to dry under room temperature for 48 *hrs*. The same condition was applied to the termite hill materials extracted from a termite hill within the University premises. Processed bentonite procured within Akure metropolis was also subjected to the same condition. Afterwards, they were all properly mixed together to form a homogeneous mixture based on a ratio of 5:4:1 respectively (Olalere *et al*, 2015; Famurewa, 2019).

The physical and thermal properties of the materials as well as, the elemental composition as obtained from X-ray diffraction analysis is presented in Tables 1 and 3.

2.2 Temperature Probe and Measurements

The furnace refractory lining wall was divided into three segments such that the first line of thermocouple probes is *200 mm* from the bottom and the next line is separated by another *200 mm* as shown in Fig. 1 and 2. Four thermocouple probes were embedded within the lining materials at radial distances of *250.5 mm*, *300.5 mm*, *350.5 mm*, and *400.5 mm* from the centre of the combustion chamber of the crucible furnace for the three level of probe arrangements shown in Fig. 2.

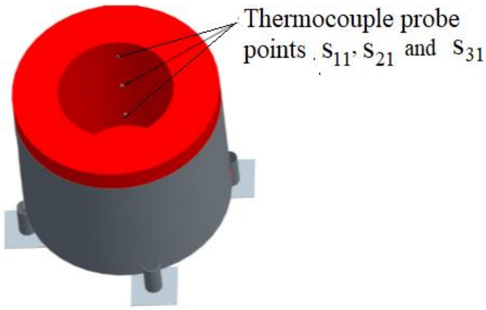


Fig.1 Thermocouple Sensors Positions on the Refractory Lining Wall

Table 1 Physical and Thermal Analysis Results

Samples	Bulk Density (g/cm^3)	Apparent Porosity (%)	Permeability (%)	Linear Shrinkage (%)	Shock Resistance (*MPa*)	Thermal Conductivity (*W/M/K*)
Kaolin	1.36	67.38	55.89	1.56	97.20	2.15
Termite hill material	1.02	48.79	26.65	1.13	75.70	1.82
Bentonite	1.20	61.77	51.13	1.43	87.10	1.75
Aggregate of all three materials	1.19	59.07	50.18	1.31	82.10	1.89

Table 2 The X-ray Mineralogical Test Results

Elemental composition	Kaolin (%)	Termite Hill Materials (%)	Bentonite (%)	Aggregate Used (%)
SiO_2	51.39	46.89	51.04	49.33
Al_2O_3	27.94	24.79	28.17	32.15
Fe_2O_3	0.78	0.86	0.79	0.83
P_2O_5	0.05	0.09	0.08	0.07
TiO_2	0.13	0.08	0.14	0.25
CaO	0.76	0.59	0.83	0.87
MgO	0.23	0.18	0.24	0.23
Cr_2O_3	0.017	0.018	0.029	0.028
K_2O	0.68	0.74	0.071	0.87
Na_2O	0.36	0.32	0.38	0.49
CuO	0.03	0.05	0.11	0.11

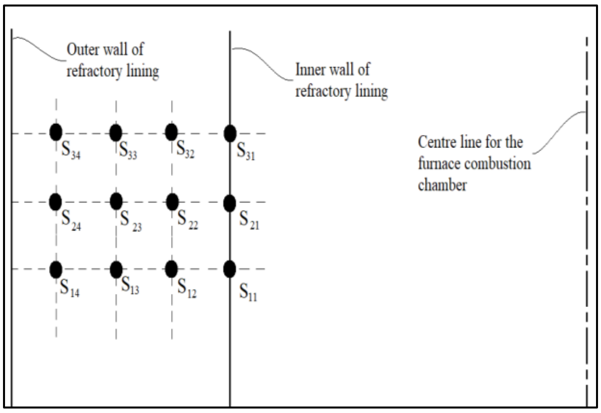


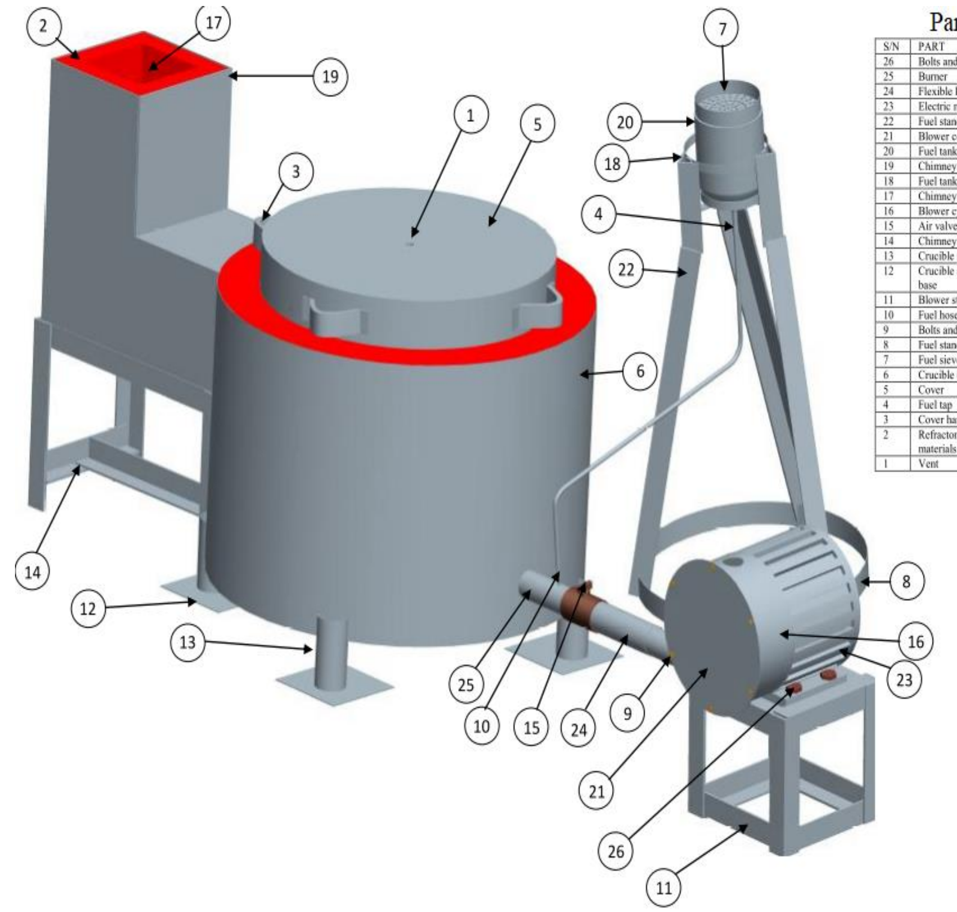
Fig. 2 Layout for Temperature Sensors Within the Furnace Refractory Lining Wall

2.3 Design Analysis and Specifications:

The geometric dimensions and density data used in constructing the furnace metal casing and refractory material wall lining are as follow:
Furnace diameter = *902 mm*,
Furnace height = *602 mm*,
Refractory bricks density = $4900\ kg/m^3$.
The bricks produced were of two different sizes:
The smaller size: *200 mm x 100 mm x 50 mm*; and
The bigger size: *200 mm x 100 mm x 100 mm*.

The smaller bricks were used to lining the cover, chimney assembly and the bottom of the combustion chamber of the furnace while the bigger ones were used to lining the wall of the modified crucible furnace. The weight, W of the bricks were estimated based on density to be *48.069 N* and *96.138 N*. This bricks and mortar made of the same aggregate material was used in building the refractory lining wall within the metal casing. A complete computer aided 3D modelling of the furnace assembly is shown in Fig. 3.

Curing operation was carried out in four stages over a period of 31 days, it enhanced the mechanical strength and minimize defects. It was warmed mildly with fire by burning wood lightly in it for about six hours daily for four days to gradually remove moisture. Lastly, it was subject to intense heat treatment, while being covered, for two hours daily for another two days. Each time, it was allowed to cool down slowly. These operations are shown in Fig. 4. At this stage, formation of mullite ($3Al_2O_3.2SiO_2$) has taken place and all excess silica crystals converted to cristobalite.



Part List

S/N	PART	QTY	MATERIALS
26	Bolts and nuts	4	Mild steel
25	Burner	1	Mild steel
24	Flexible hose	2 yards	Rubber
23	Electric motor	1	
22	Fuel stand	1	Mild steel
21	Blower cover	1	Mild steel
20	Fuel tank	1	Mild steel
19	Chimney guide	2	Mild steel
18	Fuel tank guide	1	Mild steel
17	Chimney	1	Mild steel
16	Blower cylinder	1	Mild steel
15	Air valve	1	Plastics
14	Chimney stand	1	Mild steel
13	Crucible stand	4	Mild steel
12	Crucible stand base	4	Mild steel
11	Blower stand	1	Mild steel
10	Fuel hose	4 yard	Rubber
9	Bolts and nuts	6 pieces	Mild steel
8	Fuel stand base	1	Mild steel
7	Fuel sieve	1	Rubber
6	Crucible cylinder	1	Mild steel
5	Cover	1	Mild steel
4	Fuel tap	1	
3	Cover handle	4	Mild steel
2	Refractory materials	lumps	Kaolin aggregate
1	Vent	1	

Fig. 3 Computer Aided 3D Modelling of the Assembled Crucible Furnace Unit

Fig. 4 Curing Operation on the Constructed Furnace

The length of the mild steel sheet folded to achieve the required diameter of the cylindrical steel shell for the crucible furnace was determined geometrically based on estimation of the furnace circumference which is given by 2,834.08 *mm*

The blower supplied constant blast of air at adequate pressure to the burner assembly, thus helping to accelerate the fuel into the combustion chamber for fuel atomization. It also helped in expelling the ash of burnt materials used for preheating the furnace and fume from the combustion chamber through the chimney. The fuel tank was positioned on a tripod of 1.35m height above the burner nozzle. The quantity of fuel discharged was determined based on Equation 1.

$$Q = AV \tag{1}$$

where: V is flow velocity (m/s), A is area (m^2) and Q is the fuel discharge rate (m^3/s). The weight of spent engine oil in the tank, after warming to 40 ℃, was estimated to be 32.50 N in Equation 2 using

$$W = \rho V g \tag{2}$$

The fuel pressure can be determined using (Equation 3)

$$P = P_o + \rho g h \tag{3}$$

where: P_o , atmospheric pressure is $101{,}325\ Pa$, h , height of the fuel tank above burner level is 1.35 m and ρ is the density of the fluid = $876\ kg/m^3$ such that

$P = 101{,}325 + 876 \times 9.81 \times 1.35 = 112.93\ kPa$

The steady flow of the fuel can be determined using Energy equation /Bernoulli's Equation (Equation 4)

$$\frac{P_1}{\rho g} + \frac{V_1{}^2}{2g} + Z_1 = constant \tag{4}$$

where:

P_1 is atmospheric pressure (kPa),

v_1 is fuel velocity (m/s), g is acceleration due to gravity (m/s^2), ρ is fluid density, z_1 is fuel tank height from the burner inlet (m). The fluid power, E is the flow rate power in a smooth fuel pipe line can be determined from Equation 5.

$$E = \rho g h Q \tag{5}$$

2.4 12-Channel Temperature Data Logger

The twelve channel Arduino based thermocouple data logger with 1 millisecond sampling time shown in Fig. 5 was constructed for the purpose of real-time temperature measurement by the probes at the nodes shown in Fig. 1 and 2.

Fig. 5 12 Channel Temperature Data Logger

2.5 Heat Distribution in the Modified Crucible Furnace

The mode of heat distribution by combusts of spent engine oil in the combustion chamber of the modified crucible furnace are through all three (3) mode of heat transmission (Conduction, Convection and Radiation) to the stock and this is called the actual heat load of the furnace.

2.6 Heat transfer per unit area

The rate of heat conduction through any medium in a specified direction (say, in the x-direction as shown in Fig. 6) is expressed by Fourier's law of heat conduction for one-dimensional heat conduction as Equation 6.

$$Q = KA\frac{\partial t}{\partial x} \tag{6}$$

where: Q is heat transfer coefficient (W/m^2K), K is thermal conductivity of the material (I), A is area (m^2), ∂t is change in temperature (K) and ∂x is change in x - direction.

The rate of heat loss per unit area of the refractory bricks in one direction was estimated by using Fourier law of heat conduction as shown in Fig. 6. Where: A represents the refractory bricks and B

represents the mild steel plate and the crucible furnace was considered as a plane wall;

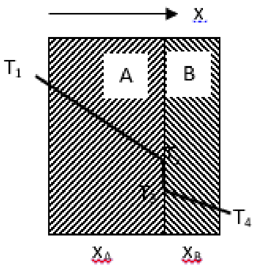


Fig. 6 Temperature Profile in x- Direction

Applying Equation (10)

where: x_A= *200 mm = 0.2 m*, x_B= *2 mm = 0.002 m*, K_A= *1.4 W/mK*, K_B= *45 W/mK*, T_1 is inside temperature of 1500℃ and T_4 is outside temperature of 34 ℃.

$$\frac{Q_{cond.}}{A} = \frac{\Delta T}{\frac{L_a}{K_a} + \frac{L_b}{K_b}} = 10{,}258.92\ W/m^2$$

The total heat transfer per unit area of the lining refractory materials adopted in this research work is 10.26 *kW/m²*. This shows that the higher the thickness of the refractory materials the lower the heat transfer rate per unit area of the lining materials.

2.7 Heat Loss Across the Modified Crucible Furnace Wall

The most essential point in furnaces design is its ability to resist fusion at highest temperature. The refractory materials aggregate used played a major role in this aspect, the refractory bricks are used for lining the roof, fire arches and other parts subjected to intense heat in the melting furnaces kilns.

The Fig. 7 shows the cross-sectional view of the modified crucible furnace walls. The walls consist of refractory bricks with thermal conductivity *of 0.8 W/mK* and the mild steel shell with thermal conductivity of *63 W/mK*.

The estimated heat loss across the wall of the modified crucible furnace refractory materials lining with kaolin materials aggregate was deduced using the equation of heat transfer analysis (Equation 7)

$$Q = \frac{2\pi L(T_1 - T_3)}{\frac{1}{r_1 h_1} + \frac{\ln\left(\frac{r_2}{r_1}\right)}{K_A} + \frac{\ln\left(\frac{r_3}{r_2}\right)}{K_B} + \frac{1}{r_3 h_3}} \quad (7)$$

where: Q is total heat transfer in the crucible furnace;

r_1 is the radial distance between the centre of the combustion chamber and the face of the lining material = *0.2510 m*;

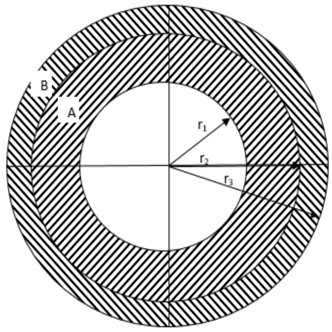


Fig. 7 Cross Sectional View of the Improved Crucible Furnace Walls

r_2 is radial distance between the centre of the combustion chamber to the face of the cylinder steel shell = *0.4510 m*;

r_3 is radial distance between the centre of the combustion chamber to the external surrounding of the cylinder steel shell = *0.4512 m*;

h_1 is assumed convective heat transfer co-efficient of combustion chamber air = *100 W/m² ºC*;

h_3 is assumed convective heat transfer co-efficient of surrounding outside air = *30 W/m² ºC*;

k_A is thermal conductivity of the refractory materials = *0.8 W/mK*;

k_B is thermal conductivity of the mild steel plate = *63 W/mK;*

A is thickness of the refractory materials; and

B is thickness of the mild steel plate.

Q = *918,984.87 J*

2.8 Radiation

The mechanisms of heat transfer from one body to another differ greatly with temperature. The phenomena of conduction and convection are affected primarily by temperature difference. Moreover heat transfer at higher temperature becomes quite significant because the radiated energy is proportional to the 4th power of the temperature of the body (Makarov, 2014). Based on the second law of thermodynamics Stefan-Boltzman gave the equation for the radiation heat transfer as Equation 8.

$$d_q = \sigma A T^4 \quad (8)$$

This is known as the fourth power law in which T is the absolute temperature and σ is a dimensional constant known as Stefan Boltzman constant and ε is emissivity of the body. The equation can be modified for the hot radiation source and receiving body by taking the temperature differences into consideration (T_1 and T_2) and putting the fourth power. The equation for the black body is expressed as Equation 9.

$$q = \sigma\varepsilon(T_1^4 - T_1^4) \quad (9)$$

where; emissivity, ε is *1*, $\sigma = 4.92 \times 10^{-8}\ kcal/hr.m^2 K^4 = 5.6697 \times 10^{-8}\ W/m^2.K^4$, Emissivity for both fire brick and steel is *0.75* and *0.95* respectively, and $q = 31{,}145.95\ W/m^2.K^4$.

3 Results and Discussion

The constructed crucible furnace was setup, preheated with the thermocouple sensors cables connected accordingly. The equipment was covered and the blower was powered on and the spent engine oil flow line was unlocked to allowed the fuel to run freely through the fitted nozzle to the burner assembly.

Fig. 8 Preheating Operation

The initial temperature log on in the data acquisition measuring device was not starting from zero because, the modified crucible furnace was preheated before the commencement of the experiment. The connection of the devices and the modified crucible furnace is presented on Fig. 7 and 8.

3.1 Temperature Measurement and Data Collection

The arrangement for the 12 thermocouple probes in the refractory lining wall of the furnace has been shown in Fig. 1 and 2. Real-time temperature measurement data was acquired for the 1 hour and 10 minute duration of firing between 12:28 *pm* and 13:38 *pm*. The ambient temperature remained ranged between 31 and 36.75 *ºC* in the course of the firing. Figs 9 through 11 presents time based plots of these temperature variation.

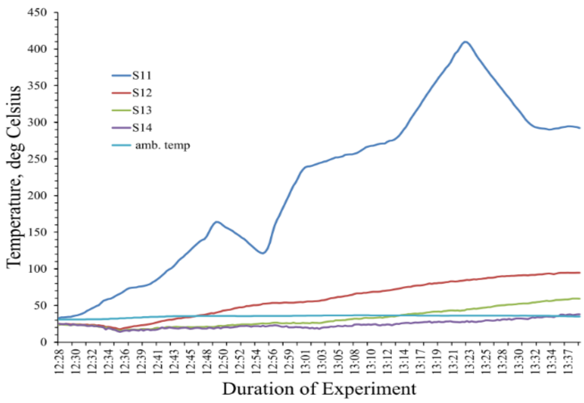


Fig. 9 Temperature Measurements Taken by Probes on the Bottom Level

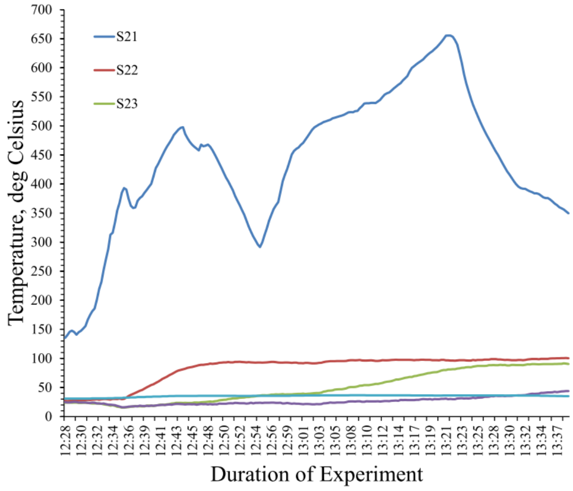


Fig. 10 Temperature Measurements Taken by Probes on The Middle Level

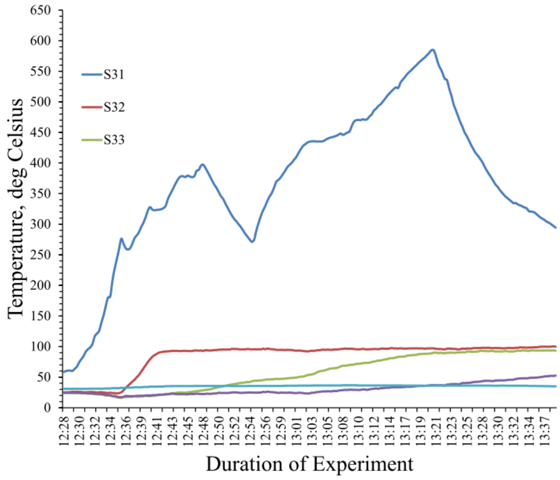


Fig. 11 Temperature Measurements Taken by Probes on the Top Level

The furnace temperature peaked at 655.50 *ºC*. The initial temperature measured on the surface (*250.50 mm*) of the lining wall of the combustion chamber at the first level, second and third segments of the equipment were *33*, *135.5* and *58.5 ºC*, at *300.50* mm radii distance its *25*, *27* and *25.25* respectively. While at *350.50 mm* radii distance its *23.75*, *23.75* and *24 ºC* respectively and at *400.50 mm* radii distance its *25*, *24.75* and *25.5ºC* respectively. At this time the ambient temperature was *31ºC*.

After firing for *7.8330 min* the temperature rose to *393.75*, *655.50* and 555.00 *ºC* respectively at the face of the refractory materials. At *300.50 mm* radii distance at the three stages the heat transfer rate were *83*, *96.25* and *96ºC* respectively. At *350.50 mm* radii distance it's been *43.25*, *81* and *89.75ºC* respectively and finally, at *400.50 mm* radii distances it's were *27.25*, *30.25* and *36.75ºC* respectively at an ambient temperature of *36.25ºC*.

The combustion process experienced momentary seizures or interruptions twice (that is at 17th and 57th minutes) as evident from the graphs for S_{11}, S_{21} and S_{31}. S_{11} temperature peaked at 409.75 *°C*, S_{21} at 655.50 *°C* and S_{31} at 584.25 *°C*.

3.2 Thermal Efficiency of the Modified Crucible Furnace

Heat transfer in this situation may either occur through conduction, convection or radiation, or it could occur concurrently, in which case, one mode will often predominate. The more efficient the heat transfer processes, the higher the overall system efficiency and the lower the fuel consumption and emission per unit product.

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 needed to melts the stocks. Burners can be classified based on method of mixing, fuel and oxidizer types and by its draft production method.

The thermal efficiency of the modified crucible furnace can be determined by measuring the amount of heat absorbed by the stock and dividing it by the total amount of fuel consumed during the melting operation;

Thermal efficiency of the improved crucible furnace is expressed as Equation 10.

$$\varepsilon = \frac{Heat\ output}{Heat\ input}\ x\ 100\% \qquad (10)$$

The quantity of heat (Q) that was transferred to the stock can be calculated using Equation 11

$$Q = m \times C_p(T_1 - T_3) \qquad (11)$$

$$= 50\ x\ 913\ (1310 - 36.5) = 58{,}135{,}275.00\ J$$

where,

Q is the quantity of heat absorbed by the stock, m is the weight of the stock in *kg*, C_p is the mean specific heat of the stock, T_1 is the final temperature of the stock,

T_3 is the initial temperature of the stock.

Final temperature: *1310 °C*

Initial temperature: *36.50 °C,*

Specific gravity of the spent engine oil= *0.8882*,

Calorific value of the spent engine oil = *41,870 kJ/kg*,

Weight of stock = *50 kg,*

Specific heat capacity of Al-Si alloy scrap metals melted = *913 J/kg,*

Fuel consumption = *8 litre* in *25 minutes* (*8 litre* in *0.4167 hour*).

The heat input is given by *8 litre* in *0.4167* hour multiply by the product of both the (Specific gravity and Calorific value) of the spent engine oil;

Therefore;

$$Heat\ input = 8\ x\ 0.4167\ x\ 0.8882\ x\ 41{,}870{,}000$$

$$123{,}963{,}113.30\ J$$

$$Efficiency\ \eta = \frac{Heat\ output}{Heat\ input}\ x\ 100\%$$

$$= \frac{58{,}135{,}275.00}{123{,}963{,}113.30}\ x\ 100\% = 46.90\%$$

An immeasurable quantity of heat evolved from the combustion chamber through the hot flue gases, cracks, other opening in the furnace as potentials and sensible heat. All these heat when added together amount to the actual heat supplied to the furnace through combustion of fuels for efficient utilization of the furnace.

Apart from the actual heat load, all other losses are terms as waste heat but, if this wasted heat is properly utilize or recovery through sensible means an equivalent amount of saving in the fuel consumption can be done, therefore improving the overall efficiency of the furnace. Heat losses from furnace can be classified into three categories:

(a) Heat loss from the furnace wall;
(b) Heat loss through waste gases; and
(c) Heat loss from opening and cracks.

3.3 Heat Balance in the Furnace

The mass and heat (energy) balances are based on the laws of conservation of energy. Thus, the material and energy entering and leaving the system must be the same. But this theory is not always correct for a nuclear fuel where mass disintegrate to give energy.

In a liquid fuel combustion furnace, the fuel consumption rate and the heat losses must be taken into consideration at the design stage (Dzurˇnák *et al.*, 2019; Zdeněk, 2006; Oholl, 2020). Thermal efficiency of a furnace (which is the ratio of the quantity of heat consumed to the total quantity of heat supplied) varies from 10 - 60% or even as high as 90% and above because, of small amount of heat/energy utilized for useful purpose as shown in Fig. 7.

To establish an accurate heat balance all the parameters must be expressed in the same unit for easy comparison. The input and energy are separately taken as given below;

3.4 Heat Input

(i) Chemicals or potential energy of fuel: sensible heat of fuel, air for combustion and charge, electrical or mechanical energy supplied to auxiliaries such as fans and pumps;
(ii) Heat evolved due to exothermic reaction (if any).

3.5 Heat Output

(i) Total heat content of the outgoing materials (sensible or latent heat);
(ii) Heat absorbed in endothermic reaction or in charge of phase or in raising temperature and then the charge;
(iii) Total heat of the exit gases (sensible and latent heat of steam going out, potential heat of the fuel);
(iv) Heat losses through walls roofs, cracks and fissures by conduction and radiation
(v) Heat losses due to loading and unloading of the furnace; and
(vi) Miscellaneous and special losses to the process involved.

To establish the actual performance of the system a comprehensive heat balance for each parts must be prepared which may not be possible, so the chemical/potential energy is calculated from the product of mass of the materials, difference in temperature and specific heats is expressed in Equation 12 as

$$\sum \dot{m}_{in} = \sum \dot{m}_{out} \quad (12)$$

The illustration of the energy balance in the furnace is shown in Fig. 12.

Thus

$$Q_{input} = Q_{output} + Q_{losses} \quad (13)$$
$$= Q_{output} + Q_{refractory\ materials} + Q_{other\ losses}$$

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

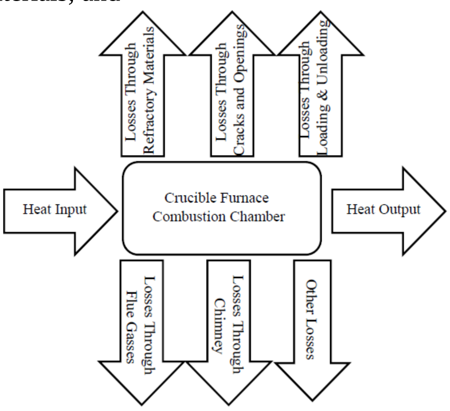


Fig. 12 Energy Balances in the Furnace

$Q_{Other\ Losses}$: (Flue gas, moisture in fuel, hydrogen in fuel, openings in furnace, furnace surface/skin and other) losses.

$$Q_{Refractory\ Materials} = \frac{Q_{heat\ transfer}}{Q_{input} - Q_{output}} \times 100\% \quad (14)$$

$$= \frac{918{,}984.87}{65{,}827{,}838.30} \times 100\% = 1.3960\%$$

The Q_{input} into the system is *100%* and Q_{output} is the efficiency of the equipment which is *46.94%* and $Q_{Refractory\ Materials}$ is *1.3960%*.
$Q_{Other\ Losses} = (100 - 46.94 + 1.3960)\% = 51.6640\%$

This shows that the sum of $Q_{Other\ Losses}$ is more than the useful heat during the experimentation which is due to the greater heat loss from the flue gas through the chimney of the equipment. This heat loss can be recovered by interconnection of another camber in which the heat can be used for heat treatment of metallic materials or components.

3.6 Casting Operation

The modified crucible furnace was set up and preheated for a period of 15 minutes; the spent engine oil was sieved into a container and heated, to reduce the fuel viscosity, lower both the flash point and fire point of the spent engine oil. The fuel regulator was locked when filling the fuel tank with the fifteen (15) liters of the already preheat spent engine oil and ignite the equipment, Fig. 13a, b and c below shows the prepared sand mould production while Fig. 11 shows the cast component before surface finishing.

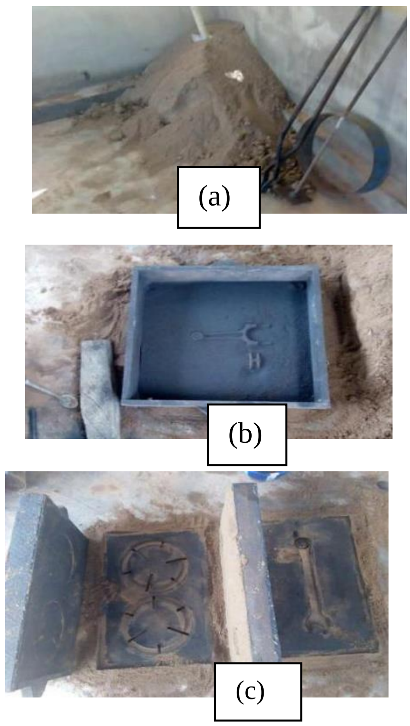


Fig. 13 (a) Green Sand, (b) Parting Sand Application, and (c) Finished Sand Mould

3.7 Fettling Operation

The gate and riser of the cast components were cut off to have a good surface finishing of the products displayed in Fig. 14 using a hack saw. They were subsequently polished using grinding wheel and files.

Fig. 14 Cast Component Before Surface Finishing

4 Conclusion

A spent engine oil fired crucible furnace was constructed with refractory lining made from an aggregate of kaolin, termite hill material and bentonite mixed in a ratio of 5:4:1 respectively. The furnace was fired for 1 hour 10 minute to melt Al-Si alloy materials that was used in casting several shapes. The thermal efficiency of the furnace was estimated at *46.90 %*.

The probes whose positions were farthest from the combustion region had the least rise in temperature in the course of the combustion. Only the temperatures measured by outer probes, that is, S_{11}, S_{21} and S_{31} rose considerably above 100 ^oC, the other temperature probes within the refractory lining wall had temperatures that were lower than 100 ^oC and the ambient temperature varied from 31 and 36.75 ^oC.

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