CARITAS UNIVERSITY AMORJI-NIKE, EMENE, ENUGU STATE
Caritas Journal of Engineering Technology
CJET, Volume 4, Issue 1 (2025)

Article History: ***Received: 18th December, 2024 Revised: 20th January, 2025 Accepted: 2nd February, 2025***

DEVELOPMENT OF PUMPS AND SOURCE OF COMBUSTION IN AUTOMATED TILTING FURNACE

Udeh Ubasinachi Osmond
Ohaebeke Benson Chinedu
Oriaku Chika Edwin
Caritas University Amorj-Nike, Emene, Enugu State Nigeria

Abstract

*The previously used tilting crucible furnace in our foundry workshops are associated with many challenges such as lack of manpower involved in carrying the crucible pot with the tongs or the ladle alongside the with the molten metal at such a high temperature from the crucible furnace. The development and fabrication of automated tilting crucible furnace has a five main components which includes; the furnace shell, the refractory wall(lining) the burner, and its pipe, fuel tank and crucible pot, the furnace is a crucible type of furnace which melt only aluminium scraps. The furnace body is enclosed in a cylindrical metal sheet measuring 355mm diameter and 445mm high and it is lined internally with superior refractory bricks of 50mm thickness. The furnace by calculation has these specifications; circumference of 395mm and 0.395m^3, weight of 30kg. the melting process is done in a crucible rammed externally with fired clay and made from heat resistance sheet at temperature of 700*C to 800*C. An air blast from electrically powered centrifugal blower is atomized with spent engine oil of which flow down by gravity and is controlled by throttle valve in the fuel line and from the heat source when they mixed inside the combustion chamber.*

Keywords: crucible, foundry, furnace, manpower

Introduction

They are many types of use in furnace and their firing requirements, like diesel, propane, butane, fuel oil alternative oil and kerosene. It is found to be capital intensive and high maintence cost.
Diesel Fuel combustion produces a high energy density, but also significant emission of particulate matter (PM), nitrogen oxides (NOx) and Sulphur dioxides (SO2). (EPA, 2022). Diesel combustion is influenced by fuel injection, spray dynamics, and chemical kinetic. fuel is a complex mixture of hydrocarbons, with an average molecular formula of C12H26.Additionaly, local regulations, fuel availability and specific furnace can influence the choice of fuel. Applications of fuel widely used in transportation (truck, buses, cars), Industrial applications (generator, compressors) and power generation,

Pentene is a hydrocarbon that may be used as a source of fuel component in combustion process, but it uses is less common due to it lower energy density and higher volatility compared to diesel. (liu et al 2018) it can produce similar emission to diesel, although the exact composition may vary depending on the specific combustion conditions, (Goa et al,2019). Pentene is used as a solvent, refrigerant, and fuel component in gasoline blends

Fuel; The combustion of fuel in furnace is a complex process depends on various factors including fuel types, furnace design, and operating condition (Turns, 2019),

Benefits

2 High temperature; Achieve extremely high temperature for various industrial processes
3 Efficient energy; convert chemical energy into thermal with high efficiency
4 Flexibility; can use various fuel and adapt to different processes
5 Scalability; suitable for small to large industrial applications
6 Cost effective; provides a cost effective ways to generate heat energy.

Additional benefit includes

Improve product quality; precise temperature control enhances product quality

Improve productivity; faster processing times and higher outputReduce emission; other combustion can minimize emission

Reliability; furnace can operate continuously with minimal down time.

Overall combustion in furnace can play a vital role in various industry process offering high efficiency energy conversion and flexibility' making it a crucial component in many industries

Calculation of stoichioetric air

Constituents	% by weight
Carbon	85.9
Hydrogen	12
Oxygen	0.7
Nitrogen	0.5
Sulphur	0.5
H2O	0.35
Ash	0.05

GCV of fuel 10880 kcal/kg

Calculation for requirement of theoretical amount of air considering a sample of 100kg of furnace oil

The chemical reactions are;

Element	molecular weight kg/kgmole
C	12
O2	32
H2	2
S	32
N1	28
CO2	44
SO2	64
H20	10

C + CO⇛ CO2

H2 +1/202 ⇛ H20

S + 02 ⇛ S02

Constituent of fuel

C +02 ⇛ C02

12 32 =44

12kg of carbon requires 44kg of oxygen to form 44kg of carbon dioxide therefore 1kg of oxygen refigures 32/12kg =2.67kg 0f oxygen

(85.9) C+(85.9×2.64)02 ⇛ 315.25CO2

2H2 =O2 2H2O

4 + 32 ⇛ 36
4kgof hydrogen required 32kg of oxygen to form 36kg of water therefore 1kg hydrogen requires 34/34kg that is 8kg of oxygen
(12) H2 (12×8) O2 ⇛ H2O
S +O2 ⇛ SO2
32 +32⇛ 64
32kg of Sulphur requires 32kg of oxygen to form 64kg Sulphur dioxide, therefore 1kg of Sulphur required 32/32 =1 kg of oxygen.
(0.5) S + (0.5×1) 02⇛ 1.0 SO2
Total Oxygen required (229.07+96+0.5) = 325.57 kg
Oxygen already present in 100kg fuel (given) =0.7kg
Additional oxygen required=325.57 _0.7

Therefore, quantity of dry air required (air contains 23% oxygen by wt.) = (324.87)/0.23kg of air
Theoretical Air required= (1412.45)/100=14.12kg of air/kg of fuel

Calculation of theoretical CO2 Content in flue gas
Nitrogen in flue gas=1412.45_324.87+ 1087.58kg
Therefore, CO2% In a dry flue gas by volume is calculated as below;
Moles of CO2 in flue gas = (314,97)/44 =7,16
Moles of N2 in flue gas = (1087.58/28 =38.84
Moles of SO2 in flue gas =1/64 =0.016

Theoretical C02% BY VOLUME = moles C02 $= \frac{\text{moles of C02}}{\text{Total moles(dry}} \times 100 =$

7.16/7.16 +38.84+0.016×100 =15.5%
2.6 Calculation of constituents' flue gas with excess air
%C02 measured in flue gas =10% (measured)

% Excess air == $\frac{\text{theoritical C02\%}}{\text{ActualC02\%}}$

%Excess air= $\frac{15.5}{10} - 1 \times 100 = 55\%$...

Theoretical air required for 100kg of fuel gas burnt =1412.45kg
Total quantity of air supply required with 55% excess air =1412.45×1.552189.30kg
Excess air required =2189.30 1412.45 =776.85kg
02 =776.85×0.23=178.68
N2=776.85-178.68 =598.17KG
The final constitution of flue gas with 55% excess air for every 100kg fuel
C02 =314.97kg
H20 =108.00kg
SO2 =1kg
02 = 178.68kg
N2 =1087.58 +598.17 =1685.75kg

Pumps used in furnace and types

The molting metal pump can be either mechanical or electromagnetic, pumps are used for forced circulation of molting metal in furnace which is critical to optimize furnace operation to improve productivity and reduce time, improve metal yield, chemical and temperature homogeneity.

There are many types and it come in various sizes, shape and speeds depending on the type of jobs to be done or capacity of the furnace.

In addition, pumps are essential to transfer molten aluminum safely from furnace to furnace to crucible or pump out air.

- In the foundry, pumps system transfers molten metal from the furnace to a casting cell, moving metal efficiency while preventing turbulence and oxides buildup, its essential low rate and operation safety also are keys

Centrifugal pumps; used for circulating and transferring molten metal. It's equally to rotating the impeller to increase the pressure of a fluid. They are commonly used in furnace for;

a. Fuel oil supply.
b. Combustion air supply.
c. Cooling water circulation

To overcome these limitations, furnace operator and designers may consider

1. Selecting pumps specifically designed for high temperature and corrosive environments
2. Implementing advanced materials and coating to reduce corrosion and wear
3. Optimizing pumps design and operation for efficiencies performance
4. Regular maintenance and monitoring to prevent issues
5. Considering alternative pumping technologies, such as electromagnetic pumps

By observing these limitations and taking steps to address them, furnace operators can ensure reliable and efficient operation of their tilting furnace system

Additionally, they are
Limitation in heat transfer
Limitation in combustion
Limitation in fuel ignition and mixing
Limitation in ignition and combustion stability
These limitations can impact furnace performance efficiency and overall productivity,
Technical specification
Crucible size varies from 10kg to 500kg (22lbs to1102lbs)
Temperature range up to 1800*c(3300*f)
Heating rate; up to 20%/min(68*f/min)
Temperature uniformity; +-

The Theory of the Furnace

The material used in this furnace work were sourced locally to minimize cost and all the materials were selected following some considerations, eg, availability of the materials, cost effectiveness, ability to withstand heat, thermal properties,high tensile ability,high resistance to heat andcorrosion, low maintenance and high recyclability, high ductility,high cryogenic toughness, welderbility, etc.

Components made from non-ferrous materials to display a marked decreased in performance level after years of source and have to be discarded. Re-melting and re-casting of scraps of such components helps to enhance availability of the component, (Abukarku, 2001). It's very challenging in the purchase of standard equipment to handle the recycling. To overcome these challenging, there is need to fabricate crucible furnace from locally sourced materials for melting these non-ferrous scraps that can benefit everyone especially electricity, automobile and industries.

Features/ components of an Automated tilting crucible furnace

1 The furnace cover
2 Crucible/furnace casing
3 Refractory wall/lagging bricks
4 Crucible pot
5 Two horse power geared electric motor
6 25mm shaft
7 Universal joint
8 Puma bearing
9 3500rpm electric air blower

10 4 × 4mm angle iron
11 Fuel line/hollow pipe
12 19mm bolt and nuts
13 Push button switches
14 Fuel tank with tap
15 Connection wire/ control panel
16 Control tap
17 2× 2mm square iron for tank stand

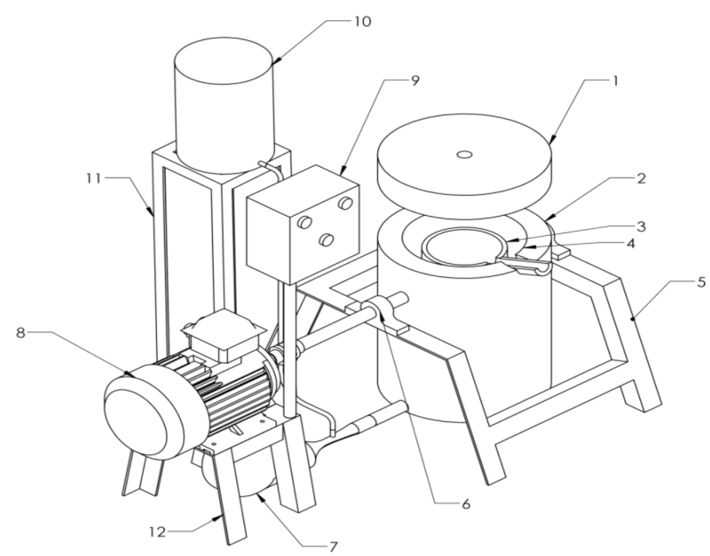

Fig 1.0: Front view of automated tilting crucible furnace drawing

Table 1.0: Design Specification of the crucible

Design Details	Specification
Inner right of crucible	395mm
Inner Diameter	255mm
Outer diameter of crucible	355mm
OuterHeight of crucible	445mm
Insulation materials	Bricks and fire clay
Insulationmaterial thickness	50mm
Capacity of crucible	30kg
Heat required to melt aluminum	650℃
Heat resistance of bricks	1100℃

Calculations used in determining the dimensions of the fabrication of the crucible furnace
Surface area of a crucible cylinder (s)$2\pi r(htr)$
Where height (h) =445mm
Outer diameter (d)=355mm
Radius of outer diameter (r) 177.5mm
Surface area of a crucible cylinder (s)=$2\times3.142\times1776$
S=1115.41×622.5
S=694342.73m^2

Quantity of heat required to melt Aluminum
Melting point of Aluminum =650℃

Room temperature =36°C
Capacity of metal (Aluminum) to be melted =30kg
Q=Mc(T2_T1)
Where Q =Quantity of heat (J)
C = the specific heat capacity of the liquid (kj/kg)
M = mass liquid being heated
T2 _T1 = Change in temperature
M =1,5liters =30kg
C = 2306.12
T2 =650°C
T1 =36°C
Q = 30×2306.12 (650-36)
Q =42478730.4J

Amount of Aluminum melted per liter of spent engine oil
1 liter of spent engine oil to melt 1 kg of aluminum
∴ 30liters = 30kg aluminum
Melting rate of aluminum
Melting Rate = Total mass of changed ($\frac{\text{Total mass of changed(kg)}}{Totaltimetakentomeltthemetal}$

$$\frac{30}{30}$$

=1.0kg/min
Thermal Efficiency of the crucible furnace
Efficiency = $\frac{Q(Input)}{Q(output)} \times 100\%$
Where
Q(input) = Quantity of heat required for melting_
Q(output) = Quantity of heat required for melting Aluminum
Calorific value of spent oil is 8000kj
∴EFFICIENCY$\frac{42478730.4-8000\times+\frac{100}{1}}{242478730.4}$=99.98%

Procedure used in fabricating the crucible furnace
1. Furnace cover= The furnace cover was formed with 5mm thick mild steel, it was rolled into a circular cylinder of 355mm diameter, and has a height of 80mm with a hole (chimney) at the center 120mm. this also lagged with bricks and fire clay as the binding material while the remaining hole(chimney) at the center

2. Furnace body/ casing = The furnace body was formed with 5mm thick mild steel sheet. It was rolled into a circular cylinder of 355mm diameter and has abase of circumference of 1115mm.The furnace body and the base welded properly before lagging. A hole of 60mm was drilled by the side of the furnace body for inlet air and fuel into the combustion chamber. A hollow pipe of 60mm diameter is welded loosely on that drilled hole at the side of the furnace body which serves as air and fuel line.Also apipe of 50mm diameter was attached on side of the furnace body in the same axis of the fuel line, the shaft fixed to the puma bearing which is mounted to the frame on the ground. And one of the shaft is projected to another with electric motor.

Oil firing Burner;
The burner is the principal device for the firing of fuel. The primary function of burner is to atomize fuel to millions of small droplets so that the surface area of the fuel is increased enabling intimate contact with oxygen in air. The finer the fuel droplets are atomized, more readily will the particles come in contact with the oxygen in the air and burn combustion.

The mixing is achieved by burner parts designed to create high turbulence. If insufficient turbulence is produced by the burners, the combustion will be incomplete and samples taken at the stack will reveal carbon as evidence.

Since the velocity of air affects the turbulence, it becomes harder and harder to get good fuel and air mixed at higher turndown ratios since the air amount is reduced. Towards the highest turndown ratio of any burner, it becomes necessary to increase the excess air amount to obtain enough turbulence to get proper mixing. The better burner design will be one that is able to properly mix the air and fuel at the lowest possible air flow or excess air.

An important aspect to be considered of burner is turndown ratio. The turndown ratio is the relationship between the maximum and minimum fuel input affecting the excess air level.eg a burner whose maximum input is 250000kcals and minimum rate is 50,000 kcals has a turndown ratio of 5 to 1

I. Experimental Result

After fabrication of the furnace, experimental test was carried out to evaluate the performance of the furnace. The test was conducted heating the aluminum scraps of 30kg capacity in the crucible furnace. At interval of time, the temperature is varied to increase and some record of time and the temperature is taken shwn inTable 1.1 and a graph 1.1 is showing the characteristic curve of various temperature the furnace verses the heating time.

Table 4.1; Experimental values with loads

In the no load test carried out, the sequence of testing procedures was followed and the furnace was tested empty without loading aluminum. The results were; time taken to raise the temperature tom 600*c and above was 30minutes.

1.No load on the furnace
2. Furnace with load of 5kg at one test
3. Continuous load test

The result obtained are as follows

Table 1.1: TIME (min) Temperature(°C)

0	36
5	141
10	248
15	351
20	454
25	556
30	650

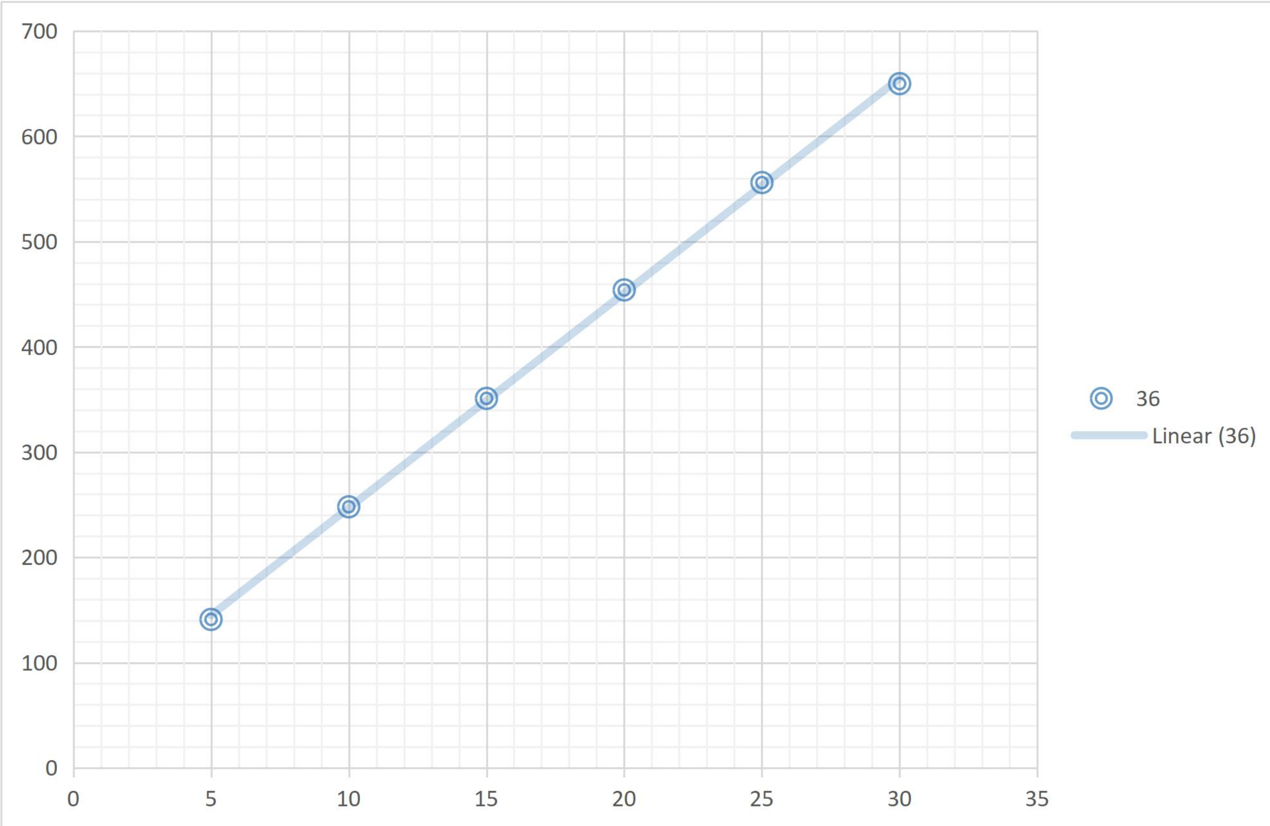

Fig 1.1(a): Graph the characteristic curves of temperature (°C) against Time(min)

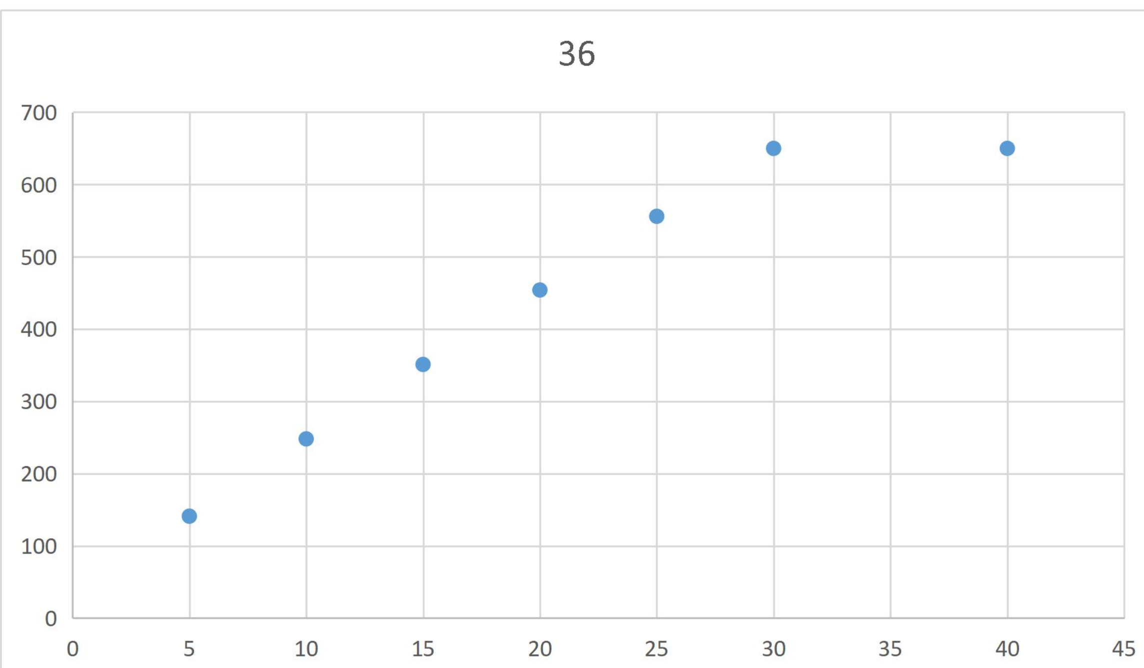

Fig 1.1(b): Graph the characteristic curves of temperature (°C) against Time(min)

0	36
5	141
10	248
15	341

20	454
25	550
30	650
40	650
50	650
60	650

a. At 650°C, 30min was the holding time for the aluminum to melt completely 30kg of aluminum was 30mins

b. The quantity of oil consumed is 1.5 liters

With load continuous methods;

It was carried out by adding more quantities of aluminums (5kg) to determine time taken to melt each addition and the result was obtained

The under listed parameter was measured before and during the experiments

. Ambient temperature =36°C

. Temperature of the product of combustion Tg=260°C

. Initial temperature of oil Tf=15°C

. melting temperature =650°C

. Furnace external temperature =105°C

. Furnace environmental temperature =750°C

Conclusion

The Automated tilting furnace crucible was successfully designed, fabricated and performance evaluation was done using spent engine oil synchronized with electric air blower to fire the furnace to melt aluminum scraps and casting were done on sand mould. The furnace capacity was 30kg, and melting of aluminum scrap happened at temperature of 650°C for period 30 minutes and the amount of oil used is 1.5 liters. The furnace was designed to obtain a maximum temperature of 1300°C.

Some conclusion was made;

1.The automated tilting crucible furnace proved more effective than the manual starred tilting furnace thereby alleviating the challenges of human labour.

2.The furnace also proved effective for melting aluminum and other non-ferrous metals with low melting point

3. The process of melting proves to be more economical and time saving since the source of fuel used is available and affordable.

4. Since the maximum capacity is 30kg, is therefore suitable for small scale use in foundries and tertiary institutions

References

1.Engineering metallurgy (part 2, metallurgical process Technology, second Edition.)RAYMON A, HIGGINS

2. Toshukazu and Ryoya, (2021) investigated the use of kerosene crucible furnace in the work. It was able to attain 750°C. The temperature was fairly sufficient for melting aluminums

3.Ighodalo et al. (2011) did a study of evaluating the performance of a charcoal fired furnace for recycling aluminum scraps. The efficiency of the furnace was 11.5%

4. The electric crucible furnace designed by Titladunayo and Fapetu, (2011) for pyrolysis showcased the benefits electrically powered furnace but the cost of operation and maintenances is high.

5. ALaneme and Olanrewaju, (2010) worked on diesel fired stationary pot crucible furnace for both heat treatment and salt both was motivated by this challenges

6. Rehabilitation of mini furnace in the foundry workshop. A project by OSILI KOSISOCHUKWU (CARITAS 2015/2015