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(REVIEW ARTICLE)

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The positive effect of designing a gas fired reverberatory furnace in recycling aluminum scraps in our environment

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Abstract

A furnace is a device for high furnace heating, through (fuel or gas combustion, co-generation, electric or induction). A gas fired reverberator furnace was designed,a reverberator furnace is mainly used for the extraction of tin, copper, aluminum and nickel metals as well as in the production of certain concretes and cements. It is a metallurgical or process furnace that isolates the materials being processed from contact with fuel, but not from contact with combustion gases.The furnace was fired with liquefied petroleum gas (butane) at a constant temperature of 660.3 degrees was maintained in order to melt metals efficiently. The reverberator furnace side walls were lined with refractory bricks and glass fibers to reduce heat loss to the amount. The device was observed to use only one-third(1/3) of the time used by the conventional bituminous coal charged. Addition of oxygen enhances the combustion rate, thereby reducing the time in melting. An efficiency of about 76% was obtained from design analysis as melted scraps were used in the production of simple tools.

Keywords: Gas fired reverberator furnace; Thermal conductivity; Conceptual and detailed design; Material Used for Fabrication; Virtual Design

1. Introduction

A furnace is a device in which the chemical energy of a fuel or electrical energy is converted into heat, in turn is used to raise the temperature of the material. Furnaces operating at low temperatures are called ovens (Folayan, 2001). A reverberator furnace is a furnace which the materials under treatment is heated indirectly by means of a flame deflected from the roof.Aluminum is one of the most recycled metals in the world; it takes less amount of energy to produce through recycling than to mine a new one, which makes a lucrative business. A furnace is a device used for high temperature heating, thus the name furnace is derived from Greek word “FORNAX- OVEN” (Hasanam, 2018). Heat energy sources to a furnace may be supplied directly by fuel oil, natural gas, electricity or induction heating. In any foundry practice heat is required to melt different metals and alloys for casting. This has resulted in the invention of technology. Furnace is the term to identify a closed space where heat is applied to a body, to increase its temperature. Metals alloys and sometimes non-metals are heated in the furnace (vasanth, et al 2022). The first furnace was perhaps in the medieval period, and was used for melting bronze and casting bells. Types of furnace include; Combustion type furnace, Oil, coal, gas fired, electrically heated furnace, resistance, arc, induction and electron beam furnace, and modern furnace type induction, cupolas, crucible and reverberator furnace.

The work of Chukwudi and Ogunedo,(2000) is centered on the design and fabrication of a reverberator gas furnace in the sense that it only melts aluminum scraps of 1kg (small amount of aluminum). Reverberator furnaces have large melt

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reservoirs, ensuring a steady supply of melted aluminum for multiple die casting processes. In many manufacturing plants, one centrally located reverberator furnace can supply concurrent casting operations(Yakubi, Harada, and Terai, 1993).The type of furnace used for melting aluminum largely depends on the size and nature of the casting operation.For large casting operations such as the casting of aluminum wrought, large refractory lined furnaces are used (Dhiraj, et al 2022, Otarawanna, and Dahle, 2011). Furnace design is a complex process, and the design can be optimized based on multiple factors. Furnaces in foundries can be anysize, ranging from mereonce to hundreds of tons, and they are designed according to the type of metals that are to be melted. A reverberator furnace is a furnace in which the material under treatment is heated indirectly by means of a flame deflected downward from the roof. Reverberator furnaces heat the metal to melting temperatures with direct fired wall-mounted burners (Sumitshrivastva, 2014). Aluminum smelting and refining are primarily used to produce pistons, engine and body parts for vehicles, beverage cans, doors, and aluminum foil. It may also be used as sheet metal, aluminum plate, rods, bars and wires, aircraft components, windows, and door frames.Aluminum is 100% recyclable and experiences no loss of properties or quality during the recycling process.It takes less energy to recycle aluminum than to mine and refine new sources.

2. Statement of problem

The massive amount of different metal scraps is increasing daily, causing serious environmental pollution. Thus the need to recycle the scraps, to utilize them as a raw materials and turning them into new products , it is on this background that the design of a gas fired reverberator furnace is capable of re-melting aluminum for further processing into useful products came about. With this exercise, the likely hood of metal scraps causing environmental hazard would be reduced to its nearest minimum.

Objectives of the study

- To design a reverberatory furnace.
- To construct the furnace shell.
- To line the furnace shell using refractory bricks and glass fiber.
- To place the industrial burner in the furnace shell.
- To incorporate an internally fitted thermocouple used for measuring temperature.
- To construct a frame capable of carrying the furnace.
- To connect the furnace with a gas cylinder and oxygen cylinder.

3. Conceptual and Detailed Design

The selection of a proper material for engineering purposes is one of the most difficult problems for the designer. The best material is one which serves the desired objective to obtain maximum availability at minimum cost (Okah-Avae, 2015). The following factors were considered in selection of materials for design of gas fired reverberator furnace.

- Availability of the material
- Suitability of the material for the working conditions
- Manufacturing consideration
- Physical properties like color, density
- Corrosion resistance
- The cost of the material
- Use of standard parts

3.1. Virtual Design

fig shows the Auto-Cad design of the gas reverberator furnace and how it will look like at the end of construction.

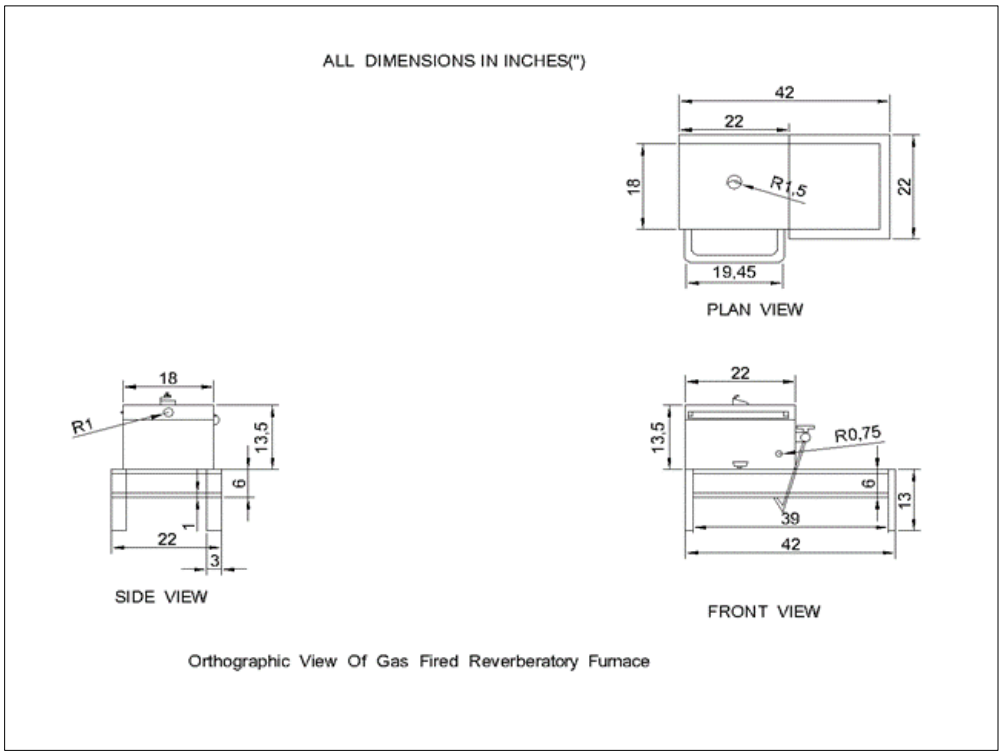

Figure 1 Orthographic view of a Gas Fired Reverberatory Furnace

3.2. Orthographic View of Gas Fired Reverberator Furnace

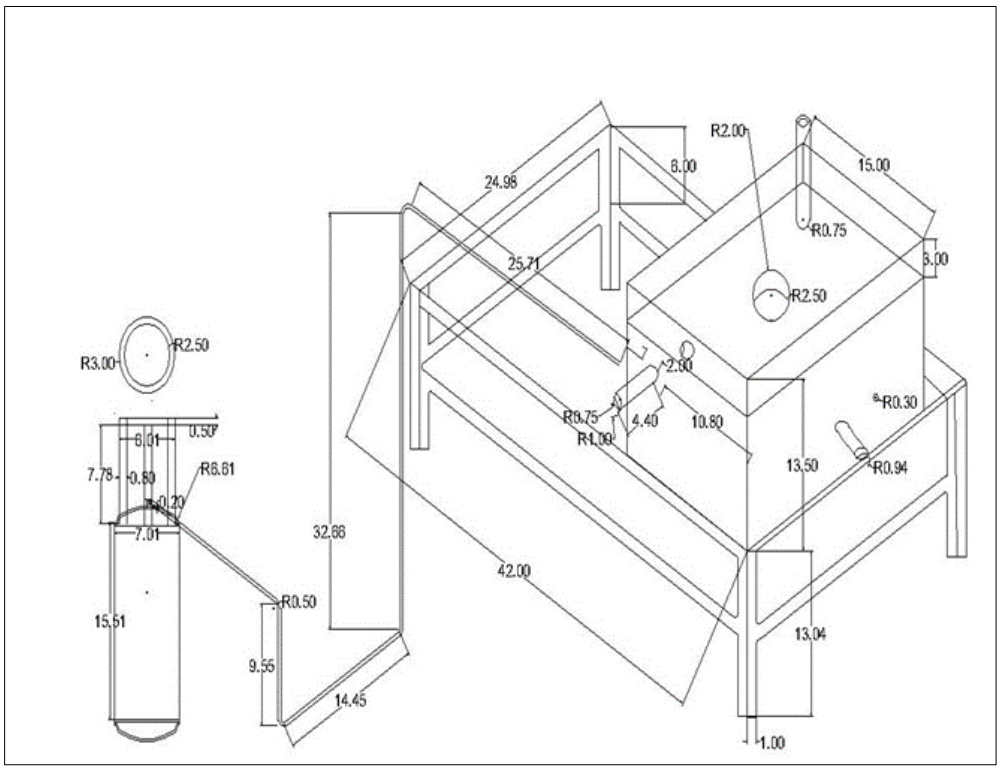

Figure 2 2 D Design of a Reverberatory Furnace

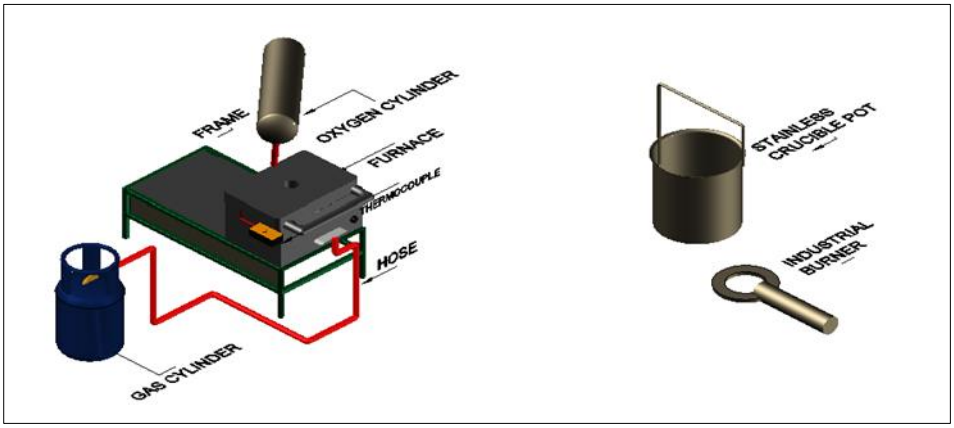

Figure 3 Isometric Design of a Gas Fired Reverberatory Furnace

4. Materials used in fabrication

The materials used in this work were obtained from local markets within Delta and Anambra (Onitsha). They include mild steel, stainless crucible pot, angle bar, refractory bricks, cements, thermocouple, gas cylinder, oxygen cylinder.

5. The development of the gas fired reverberatory furnace

The major criterion in the development of the fuel fired crucible furnace was to ensure minimum heat losses from the furnace to the surrounding. Adequate insulation was provided to achieve this and also to optimize the furnace efficiency. The rate of heat transfer across the crucible furnace depends on the thermal properties of the refractory material and the interface characteristic.

6. Design calculations

6.1. Mass of Aluminum scrap that can be Held in the Furnace Box

The mass of the aluminum scrap that can be held in the furnace box is obtained by considering the interior of the furnace after lining.

The interior dimensions of the furnace are given as:

Radius of the furnace box (interior) r =10.16cm =0.1016m

Height of furnace box burners H =27.94 cm =0.2794m

Density of aluminum ρ=2700kg/m3

Volume of a cylinder V = $AH = \pi r^2 H$

Volume V = $3.142 \times 0.1016^2 \times 0.2794 = 0.0090619$

$$\text{Density of aluminum} = \frac{mass\ of\ aluminum\ scrap}{volume\ of\ furnace\ box}$$

$$2700 = \frac{mass\ of\ aluminum\ scrap}{0.0090619}$$

Mass of aluminum = $2700 \times 0.0090619 = 24.5kg$

6.2. Some Materials and Their Thermal Conductivities (Yan, et al 2022)

Table 1 Materials and their conductivity

Materials	Thermal conductivities (W/Mk)
Fibre glass	0.04
Dense refractory brick	1.2-1.4
Breeze block	0.10-0.20
High porosity brick	0.15-0.25
Mild steel	20-22
Insulating bricks	0.15
Fire clay brick	1.4
Dry sand	1.5
Gravel	0.7

Convective heat transfer coefficient of air (h)= 500W/m^{2}K[**Rajput, 2008**]. Thermal conductivity of heavy and dense fire brick k_b=1.28W/mK**(Otarawanna, and Dahle, 2011).** Thermal conductivity of lightweight and high porosity bricks k_b=0.22W/mK**(Otarawanna, and Dahle 2011**). See fig.3.10for heat transfer through a composite wall.

6.3. Radiated Heat Transfer to the charge (scrap) inside the furnace

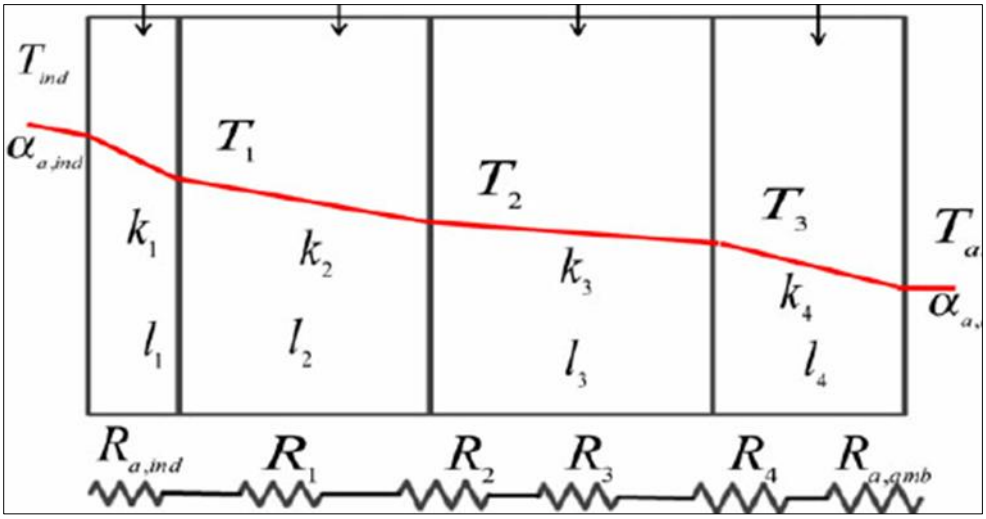

Figure 4 Heat transfer through a composite wall

Heat transfer $Q_G=\sigma_E A\ (T_g^4 - T_1^4)$

$$\sigma = 5.67 \times 10^{-8} w|m^2 \text{ (Stefan-Boltzmann Constant)}$$

E = emissivity of red brick = 0.94

E = emissivity of fiber glass = 0.75

Temperature of gas T_g= T at 1800^0K

AmbientTemperature T_1 =1000^oK

$$Q_G = 5.67\times10^{-8} \times 0.94 \times 0.75 \times 0.03243\ (1800^4 - 1000^4)$$

$$=12312.124W|m^2$$

$$Q_G = 12.312kW|m^2$$

Time required to raise the temperature from 35^0c to700^0C

This is the heating time of the furnace, which is one of the basic design criteria that must be met.

It is the time required to heat the aluminum scrap from ambient room temperature of 30^0C to 700^0C in a furnace capable of attaining 1933^0C.

The representative formula is given as:

$$T - T_S / T_O - T_S = 9^{-hAt/\,pcv}$$

Where h is the transfer coefficient of aluminum = 75w/m^0C. p is the density of aluminum scrap =2700kg/m^3 T_0 is the initial temperature of aluminum scrap =30^0c. T_S = the maximum temperature of the furnace chamber = 1933^0c .T = the required temperature = 8^0c. C is the specific heat capacity of aluminum = 900J/Kg ^{0}C. A is the area of unlined furnace = 0.1086m^2 and V is the area of unlined part of the furnace = 0.01411m^3

T = 24mins

It will take 24 minutes to heat 24.5kg of aluminum to attain a uniform temperature of 670^oC

6.4. Efficiency of the furnace

$$\text{Furnace efficiency} = \frac{Theoreticalheatrequiedformelting(°C)}{Actualenergyconsumed(°C)}$$

$$\text{Furnace efficiency} = \frac{practicalmeltingtemperature(°C)}{theoreticalmeltingtemperature(°C)} \times 100$$

Therefore, practical melting temperature$= 500°C$

Theoretical melting temperature$= 660.3°C$ (Melting point of Aluminum)

$$\text{Furnace Efficiency} = \frac{500°C}{660.3°C} \times 100\%$$

$$\text{Furnace Efficiency} = 0.757231 \times 100\%$$

$$= 75.7231\%$$

Therefore, the Efficiency of the Gas fired reverberator furnace is 75.7231%

7. Observations

Careful observations were made on the machine components and the response time of the most components used in fabrication.

7.1. Observations on the individual components during and after testing

7.1.1. Observations on the Temperature Increase in the Furnace

From fig.4.2 below, A test was carried out to analyze the time spent in melting aluminum scrap and the temperature increase was recorded at different time intervals. The results are shown in fig.4.2

Table 2 Component Observation (After and Before)

Components	**During**	**After**
Thermocouple	The thermocouple increases when the furnace is heating up	It was observed that, after the fire flame was put off, the temperature of furnace starts reducing which was indicated in the thermometer.
Burner	There was an increased in the flame when oxygen was added	After three trails, the burner was heated up, and was allowed to cool before the last trial
Gas cylinder	When there was a linkage in the gas hose the combustion was very slow	There was no obvious observation after testing.
Oxygen cylinder	Without pressure gauges, it's very difficult to account for the amount of pressure that enters the furnace. Secondly, when much oxygen is entering into the furnace the fire flame goes out.	There was no obvious observation after testing.
Furnace	The combustion in the furnace was very high when oxygen was added	It takes a long time before the furnace cools down because it reaches a temperature of about 660^{o}C.
Aluminium Scrap	The time for melting depends on the quantity of aluminium scrap in the crucible pot. Large volume of scraps takes much time to melt	The slag formed during melting is always at the top of the molten aluminium. In addition, Aluminium solidifies immediately it is removed from the fired about20secs

Table 3A Table of Temperature against Time (With Oxygen)

TEMPERATURE (OC)	**TIME (min)**
35	0
169.2	3
216.6	6
275.3	9
329.8	12
365.6	15
400	18
428.5	21
468.3	24
480.3	27
500	30

7.2. A Graph of Temperature against Time with Oxygen Cylinder

From fig.4.2. The graph was plotted using the result (see table 4.3) achieved during our testing, and it was observed that Temperature accelerates with time but not uniformly. This indicates that, the heat path increases and conduction has taken place. In addition, it can also be seen from the graph that the combustion taking place is fast because of the addition of oxygen cylinder.

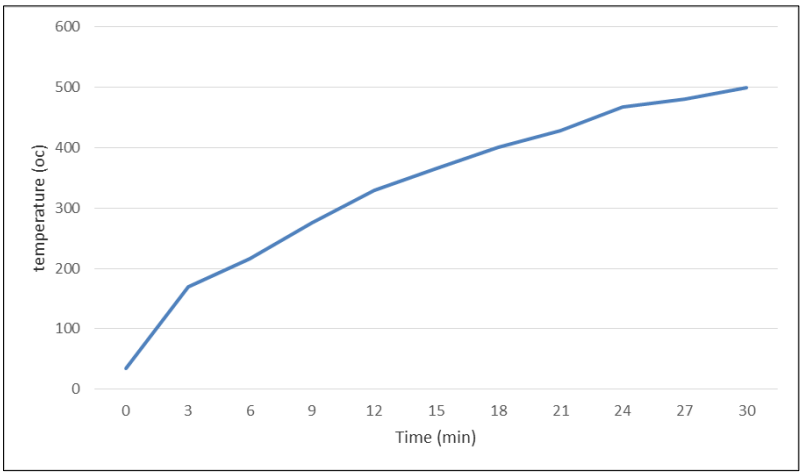

Fig 5. A Graph of Temperature against Time with Oxygen cylinder

Table 4 A table of temperature against time (without oxygen cylinder)

TEMPERATURE(^{O}C)	TIME(min)
30	0
78	3
141	6
161	9
191.4	12
236	15
236.1	21
236.2	24
236.7	27

7.3. A graph of temperature against time without oxygen cylinder

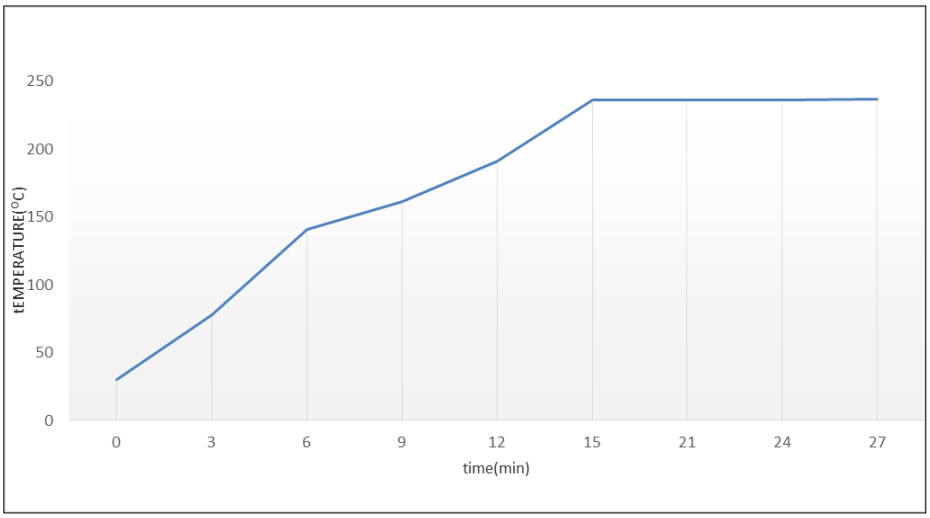

Figure 6 A Graph of Temperature Against time without oxygen cylinder

From fig. 4.3. The graph was plotted using the result (see table 4.4) achieved during our testing, and it was observed that Temperature accelerates with time but not uniformly. It can also be seen from the graph that, the temperature increases to 236 degrees celsius with a time range of 15min, but when temperature got to 236.1^0C, it was no longer increases with time but was at a steady state. This was because furnace has reached its maximum temperature as a result to lack of air entering the furnace.

8. Conclusion

In summary, the result obtained from the gas fired reverberatory furnacemakes it possible to heat treat both ferrous metals, non-ferrous metals and their alloys in order to alter their microstructure and to enhance their properties for needed application in service with maximum safety and precaution in place. The graph explains that as time increases the temperature also increases indicating that combustion has taken place.

The furnace was loaded with aluminum scraps from kitchen utensil, window frames, canned drinks, aluminum roofing sheet. Then after firing for about 20-25 minutes, the aluminum scraps melted indicating that the furnace is able to attain temperature of 670^oC, which is the melting temperature of aluminum. Due to the affordability and reliability of this furnace, it is therefore recommended to small scale metallurgical firms for the purpose of recycling of aluminum.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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