



Design and Fabrication of Aluminium Melting Furnace using Locally Available Materials

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Abstract The increasing demand for aluminium scrap (as waste constituent) in our environment cannot be over emphasized. Hence, an improved system of continuous aluminium recycling as a secondary aluminium production is designed and constructed. A gas-fired crucible furnace is designed and fabricated for melting scrap aluminium. This furnace is a modified model suitable for laboratories and workshops. This furnace is designed and fabricated using locally available materials and butane gas as the thermal energy source in heating up the system to the melting point of aluminium (660.4 °C). The molten aluminium is casted to a desired shape and size either as ingot or end product.

Keywords Aluminum, Furnace, Heat Efficiency, Materials.

1. Introduction

Secondary aluminium production (recycling) saves 95% energy needed to produce aluminium from its ore [1]. Hence, it is more of economic importance that aluminium recycling becomes a major source of aluminium production [2]. Aluminium is primarily used to produce pistons, engine and body parts for cars. Beverages cans, doors, sliding door and aluminium foil. It may also be used as sheet metal, aluminium plate and foil, Rods, bars and wire, aircraft components, windows and door frames. The leading users of aluminium include the container and packaging industry, the transportation industry, building and construction industry [3]. Aluminium can either be produced from bauxite ore (primary aluminium refining) or from aluminium scrap (secondary aluminium refining). Refinement of aluminium ore is sufficiently expensive that the secondary production industry commands much of the market. It is recorded that about 40% of aluminium of aluminium in the US is recovered from secondary refining [4]. Hence, the interest of this project lies on the secondary aluminium production.

Furnace is a space surrounded on all sides by walls and a roof for heating metal or glass to very high temperatures [5]. The earliest furnace was excavated at Balakot, a site of the Indus valley civilization. Then, furnace was most used for the manufacturing of ceramics objects [6]. Furnaces operate in aggressive environment, where several components-molten metal, furnace lining, atmospheric gases, and products from combustion of fuels-coexist at extreme high temperature. Aluminium melting furnace derives its heat from solid fuel (coke and breeze), natural gas, electricity, or other source of energy. Furnaces vary in design, geometry, production capacity (melting rate), materials of construction, and mode of operation [7]. Other factors related to the energy source also affect the furnace design which includes how the energy is transferred to the molten material, how combustion gases are removed, and what refining and treating equipment must enter the furnace, how long the holding periods are, and how the molten metal will be tapped. Several factors come into play besides the core ingredient of heat and metal as illustrated in figure 1 below:



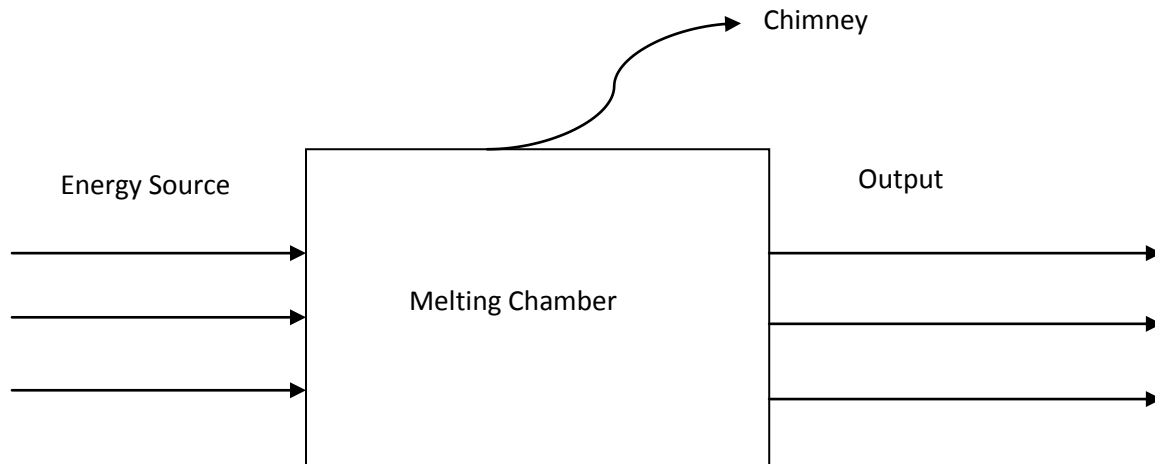


Figure 1: Schematic diagram of furnace operation

The operating temperature required in the furnace depends on the melting and pouring temperature of the materials being melted. They can range from about 350 °C (650 F) for zinc alloy to 1700 °C (3100F) for alloy steels. But for aluminium, the operating temperature is from 650 °C and above. There are various types of furnace. They are mainly classified according to their energy source, and application – in this case melting, or holding purpose. Different furnaces types are: Crucible Furnace, Induction Furnace, Dosing Furnace, Immersion Furnace, Reverberatory Furnace, Stack Furnace, etc. The furnaces of interest in this research work are the crucible furnace and reverberatory furnace [8-10].

2. Materials and Methods

2.1. Materials Selection and Criterion

The materials used in the course of this research work are sourced locally and selected based on their thermal properties, insulation ability and availability. The selected materials and there specifications are shown in the table below

Table 1: Materials Components/Specifications

S. No.	Components/Materials	Quantities	Specification
1	Metallic plate	½ sheet	2mm mild steel
2	Refractory bricks	10 pieces	Ceramics
3	Insulating materials	1	Fibre glass
4	Burner	1	Locally fabricated
5	Gas cylinder	1	5kg
6	Gas line/pipe	1	1500mm
7	Crucible pot	1	Ceramics
8	Gas	5kg	Butane
9	Refractory	¼ bag	White
10	Gas regulator	1	1.0kg/hr

2.2. Design Model

The design of this research work is based on thermodynamic analysis of furnaces, materials availability, energy source and transfer. The following parameters guided during the design and fabrication of this melting furnace



- Thermodynamic analysis/Governing equation: This considers conservation of energy and Newton's law of cooling in determining heat transfer coefficient, heat flux, flow rate, and temperature distribution across the composite furnace wall. In other to account for energy balance, furnace efficiency, and capacity/performance, equation and formulations are called into play. These equations enable proper calculations and design functions of the system determined, and are based on the first law of thermodynamics. An energy balance can be expressed as

$$H_{input} = Q + H_L \quad (1)$$

Where,

Q is the heat transferred to the melted metal,

H_{input} is the energy generated from the fuel combustion

H_L is the heat loss

- Materials availability: Materials for the construction of the furnace are selected due to their availability and ability to withstand the desire temperature and purpose of the system.
- Energy source and transfer: Cooking gas (butane) is combusted in air (oxygen) and the heat produced is directly used as the thermal energy source. Energy transfer applicable in the design is multimode, which is a combination of radiation, convention and a little of conduction.

2.3. Structural Design

The structure of the furnace is cylindrically designed. This cylindrical structure is so desired, technically due to effectiveness in thermal distribution within the furnace chamber. The structure is explicitly detailed in the drawing below

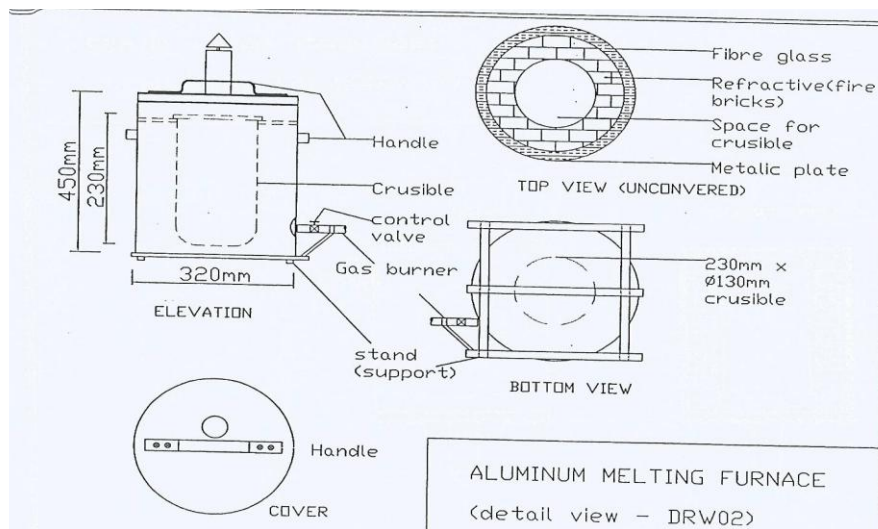


Figure 2: Detailed Aluminium Furnace Drawing

2.4. Major Feature of the Furnace

The design model is a modification having the following under listed features;

- The body and chamber: the body is formed from a cylindrical shaped of 2mm steel sheath. The body form a melting chamber enclosing the insulating materials (fibre glass), refractory bricks, and crucible.
- The burner: the burner is externally attached to the body and tangentially positioned to burn the supplied gas using atmospheric oxygen as the heat source to the melting chamber.
- The crucible: the crucible is a locally made ceramic pot placed in the melting chamber for the purpose of holding the molten aluminium to the time of casting.
- Roof/cover: the use of furnace cover is critical to energy efficiency. This is constructed with the same materials as the body, from refractory or ceramics with low thermal conductivity, which reduces conduction and radiation heat loss.



- v. Vent/chimney: a controlled vent of 5 mm diameter pipe is attached to the cover, for reduction of internal furnace pressure gradient built across the ceiling, and waste gas exit.

2.5. Fabrication Procedure and Assembly

2 mm mild steel sheet metal can was cut to dimension and shaped to form the cylindrical structure of the furnace. Fibre glass was used as insulating materials, cut and placed internally on the sheet-metal can floor and wall, before refractory lining set in. The refractory lining was built inside a sheet-metal can of 450 mm high and 320 mm in diameter. Drill and ream 80 mm hole in diameter on the side of the cylinder. Then the firebricks are neatly cut to sizes and shaped for the furnace floor and wall. The refractory lining consists of ganister and pieces of firebricks. Ganister is a mixture of equal parts of pulverized firebricks and fire clay and the mixture having the consistency of rather stiff mortar. The bottom of the can is covered with ganister of about 30 mm deep, and tamped down to eliminate air pocket. The pieces of firebricks are placed in the positions and pressed down into the ganister so that their top surface will be level 6mm below the hole in the side of the can. Ganister is choked into the spaced between the pieces of firebrick.

After a 3-day drying-out period, the gas is ignited and allowed small flames to burn for 30 minutes to complete the curing of the lining. When the furnace is cooled the lining was inspected for cracks which are almost certain to develop. The cracks were filled with prepared refractory cement of fireclay and allowed to dry out before the next firing. Crack filling is repeated until no more cracks develop.

2.6. Furnace Design Calculations

The various parameters, methods and techniques used to design the furnace, quantify the losses from the furnace and performance assessment of the furnace is as shown in the calculations below. The two major parameters used in determining furnace capacity are as follows:

a. Energy Consumption, Cap_{ec} ; this describes the amount of energy or heat intake by the furnace. In other word, the actual quantity of heat used in melting a unit of aluminium. The unit for capacity is KJ/Kg or Btu/Ib (British unit/pound). It is determined by this equation;

$$\begin{aligned} Cap_{ec} &= 5.5[KW] \text{ (from burner rating)} \\ &= 5.5[KJ/Sec] = 5.5 \times 3600 = 19800[KJ/hr] = 4729[kcal/hr] \\ &= 4729[Kcal/Kg] \end{aligned}$$

Using the conversion factor, 1 kcal/kg = 4.1868 KJ/Kg = 1.8 Btu/Ib

Hence, $Cap_{ec} = 4729 \times 4.1868 = 19800KJ/Kg$ or 8512.2 Btu/Ib

b. Stock Capacity, Cap_{sc} ; this capacity refers to the quantity of stock (in this case, mass of aluminium) that can be melted at a certain period of time. This is determined by the size of the crucible by volume or mass (in Kg)

$$Cap_{sc} = 5Kg \text{ (maximum)}$$

2.6.1. Heat Supplied to the Furnace

Heat supplied to the furnace is the heat input to the furnace chamber as a result of gas combustion from the burner. This is determined by the ratings on the gas regulator which has 1.0Kg/hr.

Hence, the heat input, $H_{input} = 49510 \text{ KJ/Kg} \times 1.0Kg/hr = 49510 \text{ KJ/hr}$

Using the conversion factor; 1 KJ/hr = 0.23884 Kcal/hr

$$49510 \text{ KJ/hr} \times 0.23884 = 11824.97 \text{ Kcal/hr}$$

The heat output is calculated as follows:

$$Q = m \times C_p \times \Delta T. \tag{2}$$

Where,

Q = quantity of heat stock in Kcal/hr

M = weight of the stock melted per unit time Kg/hr

C_p = mean specific heat of stock in Kcal/Kg $^{\circ}C$

ΔT = change in temperature from the initial temperature of stock before it enters the furnace to the final temperature of stock, $^{\circ}C$

Substituting the values;



$$= 5 \times 0.22 \times (750 - 25) = 797.5 \text{Kcal/hr}$$

$$797.50 \div 0.23884 = 3339.05 \text{ KJ/hr} = 0.9275 \text{KW or } 927.5 \text{W}$$

From equation 1

$$\text{Heat loss, } H_L = H_{\text{input}} - Q = 49510 - 3339.05 = 46170.95 \text{ KJ/hr}$$

2.6.2. Furnace Performance/Efficiency

From Newton's law of cooling equation;

$$q = \frac{Q}{A} = h_c \Delta T. \quad (3)$$

Where,

Q = heat flow rate

A = area of cylinder

h_c = heat transfer coefficient

ΔT = temperature difference across wall

$$A = \frac{\pi d^2}{2} + \pi d h_l = 1.571 \times (320)^2 + 3.142 \times 320 \times 450 = 613259.7 \text{mm}^2 = 0.6132597 \text{m}^2$$

$$\Delta T = 750 - 25 = 725^\circ\text{C or } 998 \text{K}$$

Substituting the values;

$$h_c = \frac{Q}{A \Delta T} = \frac{927.5}{0.6132597 \times 998} = 1.52 \text{ W/m}^2\text{K}$$

2.6.3 Temperature Drop across the Composite Wall

$$T_a - T_b = \frac{q_1 \ln \frac{d_1}{d_2}}{2\pi k_1}. \quad (4)$$

K, is the thermal conductivity for different wall materials.

Substituting the values

$$750 - T_b = 5203.9 \ln(306/238) \div 2 \times 3.142 \times 1.4 = 9$$

Hence,

$$T_b = 750 - 9 = 741^\circ\text{C}$$

For T_c ;

$$T_b - T_c = \frac{q_1 \ln \frac{d_3}{d_2}}{2\pi k_2}. \quad (5)$$

$$741 - T_c = 5203.9 \ln(318/306) \div 2 \times 3.142 \times 0.040$$

$$T_c = 55^\circ\text{C}$$

For T_d ;

$$55 - T_d = \frac{q_1 \ln \frac{d_4}{d_3}}{2\pi k_3}$$

$$T_d = 114^\circ\text{C}$$

2.6.4. Determination of Composite Wall Thickness

Steady-state, one dimensional heat flow through insulation systems is governed by Fourier's law

$$Q = K \cdot A \cdot \frac{(dT)}{t}. \quad (6)$$

Where,

Q = rate of heat flow, w

A = cross sectional area normal to heat flow, m^2

T = thickness of insulating materials

dT = temperature difference in material, $^\circ\text{C}$

From equation 6;



$$t = K.A. \frac{(dT)}{Q} \quad (7)$$

Applying equation (7) for each wall;

For t_a ;

$$t_a = k_1 . A. \frac{(T_a - T_b)}{Q} = 1.4 \times 0.6133 \times (750 - 741)/927.5 = 0.008\text{m}$$

For t_b

$$t_b = k_2 . A. \frac{(T_b - T_c)}{Q} = 0.040 \times 0.6133 \times (741 - 55)/927.5 = 0.018\text{m}$$

For t_c

$$t_c = k_3 . A. \frac{(T_c - T_d)}{Q} = 11.5 \times 0.6133 \times (55 - 114)/927.5 = 0.448\text{m}$$

3. Results and Discussions

3.1. Results

After a thorough analysis and calculations, the following parameters were used during the designing and fabrication of aluminium melting furnace using locally available materials. The obtained parameters as calculated are shown in Table 2 below.

Table 2: Obtained Parameters

S. No	Parameter	Symbol	Values	Units	
1	Capacity	Cap	19800	KJ/Kg	
			8512.2	Btu/lb	
2	Heat Input	H_{input}	11824.97	Kcal/hr	
			49510	KJ/hr	
3	Heat Output	Q	797.5	Kcal/hr	
			3339.05	KJ/hr	
4	Initial temperature	T_1	15	$^{\circ}\text{C}$	
5	Final Temperature	T_2	820	$^{\circ}\text{C}$	
6	Efficiency	E	28.24	%	
7	Heat loss	H_L	46170.95	KJ/hr	
8	Mass of Aluminium Produced	M	4.98	Kg	
9	Area of Furnace	A	0.6133	m^2	
10	Heat Flux	Q	5203.9	w/m^2	
11	Heat Transfer Coefficient	h_c	1.52	$\text{w}/\text{m}^2\text{K}$	
			T_a	750	
			T_b	683	
			T_c	113	$^{\circ}\text{C}$
13	Temperature across furnace wall	T_d	114		

3.1.1. Furnace Performance and Evaluation

The aluminum melting furnace was evaluated to ascertain its performance by melting aluminum scraps at a temperature of 660°C over a period of 300 seconds. The results obtained were tabulated as indicated in Table 4 and graphically in Figure 4.

Table 4: Performance Analysis of the Melted Aluminum Scrap on the Furnace

Time (Seconds)	Temperature (Degree)
0	35
30	200
120	400
260	600
300	720



It was observed that the temperature of the melting furnace was maintained at 720 °C over a period exceeding 300 seconds and this shows that the furnace was designed to attain a maximum temperature of 720 °C.

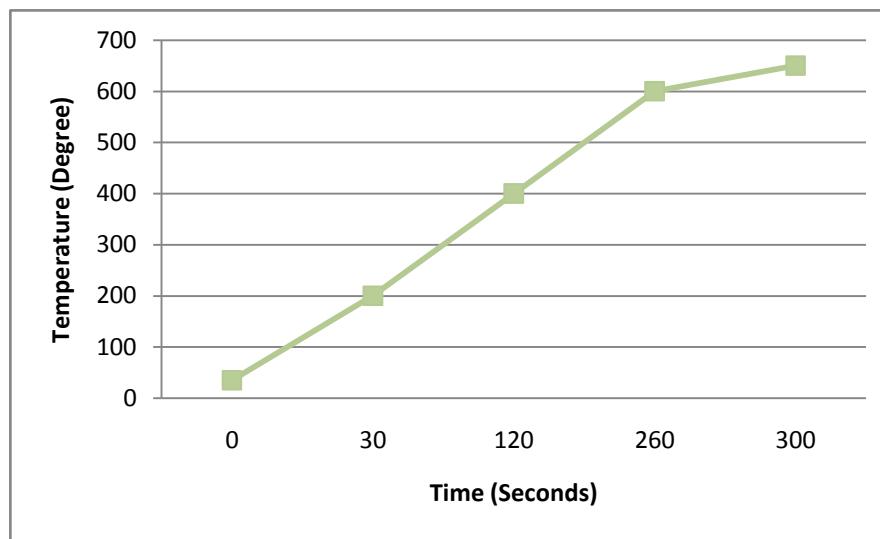


Figure 4: Melting Furnace Performance

3.2. Discussion

The results obtained above from Table 4 shows that the melting furnace can achieve its main objective of recycling laboratory size aluminium (5 Kg) in a single operation. A significant improvement in efficiency of 28 % was recorded compare to 4-6 % in using the traditional furnace [12]; it also takes a shorter time to melt the aluminium with great reduction in the energy consumption. Hence, the success of this research work supersedes that of the traditional techniques.

4. Conclusion

This research work was undertaken to design and fabricate an aluminum melting furnace for laboratory and workshop use. The furnace was constructed putting into consideration; its temperature attainment, capacity of metals it can hold, operators safety, space to be occupied in the workshop floor/laboratory, cost restrictions, availability of the materials used, its maintainability and portability. This research has revealed that the locally fabricated aluminum melting furnace for laboratory and workshop operations have an efficiency of 28%, low energy consumption and shorter time of operation. Hence, a more effective and performing furnace were developed. The developed Aluminum melting furnace will not only melt Aluminium but also ant metal that have a melting temperature below 720 °C. The actualization and realization of this research work is a boost to the development of local manpower capacity in Nigeria and also to advance the reliability of engineering materials in service.

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