Development of Low Heat Treatment Furnace

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Abstract

This work centres on the development of a low heat treatment furnace in accordance to the International Electric Equipment (IEE) regulations. The design closely revealed the parameters and the features needed such as: the casing design, the insulating system, the heating system, the electrotechnicals and the safety/ control system. Invoking the IEE regulations enabled a pragmatic method of design, materials selection and calculations for the construction of the furnace that matches the international standard. The final result gave a maximum temperature reading of 880^{0}C in the furnace heating zone and 21^{0}C temperature reading at the surface of the external casing after a period of 90minutes. The result obtained makes it possible to heat treat both ferrous, non-ferrous metals and their alloys in other to alter their microstructure and to enhance their properties for needed application in service with maximum safety and precaution in place.

Keyword: heat, furnace, low, ferrous, non-ferrous, IEE

1.0 Introduction

The heat treatment furnace is a heating chamber that is a refractory or lagged enclosure, which contains the charge and retains heat that should be measurable as well as controllable (Rajan *et.al.,* 1988)

According to the literature given by International Electric Equipment (IEE) regulations, basic standard parameter for the construction and design of a furnace comprises the following: the casing design, the insulating system, the electrotechnicals, and the safety/ controls system.

1.1 Aim: The aim of the work is to develop a low heat furnace capable of heat treating ferrous, non –ferrous and their alloys.
1.2 Motivation: The main motivation for the work is to make available low heat furnace that can be used to heat treat ferrous, non-ferrous and their alloy with ease with high degree of safety and affordable cost and with little or no skilled-personnel maintenance.
1.3 Previous works: Alot of work have been done in the area of heat treatment furnace. Recent among them is Ojiegbe, K. k. (2005) where he looked at the Design and Construction of a Diesel- Fired Heat Treatment Furnace. Also, Anamu, 2007 also looked at the refurbishment of a muffle furnace for tertiary institution laboratory use. Andrew Gascoign, 2011 wrote extensively on how to build a home heat treatment furnace. He enumerated the various step of doing-it-yourself for heat treatment furnace from home. His work is mainly for a furnace that can be used at home. In the light of this, we set out to develop a low heat treatment furnace that can be use for heat treating ferrous, non-ferrous and their alloys.

2.0 Methodology and Materials Selection

2.1 Design Considerations and Calculations

Owing to the fact that the normal temperature of the human body ranges from 35^{0}C to 43^{0}C (Okeke *et al.*, 1989), any temperature value obtained at the outer casing above such range will be harmful to man.

Hence, to curb the possible effect of burnt as a result of temperature value above the said range of temperature; a design calculation is carried out taking some assumptions and constants into consideration to achieve a temperature of less than 35^0C at the outer casing. This will equally enable the safety of charging and unloading of the specimen with ease. This implies that the consideration starts from what is needed to how it can be achieved.
It is assumed that the maximum temperature attainable in an ideal case is 1200^0C, but due to heat losses incurred, assumption is made such that 950^0C is reached in 1hour.

2.1.1 Quantity of Heat From Source

The heat source is generated from the industrial heating element which is assumed to take a period of 1hour to attain its maximum loading capacity. This is supported by the Joule- Lenz's law.

$$E = I^2Rt$$

Where;

E=electrical energy
I=current flowing in the circuit
R=resistance to flow in the circuit
t= time- taken for maximum heating

But from Ohm's law; $V = IR$

V=voltage across the circuit (Okeke et al., 1989)

Hence, $E = \frac{V^2t}{R}$

Given that;
V=240volts
R=1.85Ω
t=3600secs

Then; $E = \frac{(240)^2 \times 3600}{1.85}$
= 112,320,287.6J

But, rate of heat flow; $Q = \frac{E}{t}$
$= \frac{112{,}320{,}287.6\text{J}}{3600}$
= 31,200.0799J/s

2.2 Design Assumptions and Constants

Convective coefficient of air (h_{air}) = 500W/m^{2}k (Rajput, 1999)
Door efficiency (£) = 1(assumed)
Heating time (t) = 1hour
Resistance in the circuit (R) = 1.85Ω
Thermal conductivity of the brick (K_b) = 1.28W/mk (Mark's Handbook)
Voltage across the circuit (V) = 240volts

2.2.1 TEMPERATURE OF BRICK WALL (T_b) Heat transfer from the furnace air to the brick wall is by convection. Hence, utilizing the Newton's law of cooling;

$$Q = h_{air}A(T_{air} - T_b)$$

Where: A=total surface area of the brick
= 0.17864m^2
31,200.0799 = 500x0.17864 (950-T_b)
$T_b = 600.220\text{C}$

2.2.2 TEMPERATURE OF INTERNAL WALL CASING (T_i) The heat transfer from the brick wall to the internal wall casing is by conduction, and it utilizes the Fourier's law:

That is; $Q = K_bA\frac{dT}{dx}$
$K_bA(T_b - T_i)/dx$
Where;

A= total surface area of the casing, having a cube configuration, with side, L= 308mm

$A = 6L^2$

$A = 6 \times (308)^2$ = 0.569184m^2

dx= thickness of the brick

= 100mm or 0.01m

31,200.0799= 1.28 X 0.569184(600.22-T_i)/0.01

T_i= 171.97^{0}C

2.2.3 TEMPERATURE OF AIR SPACE (T_s*); BETWEEN THE INTERNAL AND THE EXTERNAL CASING* the heat transfer in the air space environment from the internal wall casing is due to convection. Newton's law is still invoked.

$Q = h_{air}A(T_i - T_s)$

Where;

A= Difference in the area between the external and the internal wall casing.

The external wall casing can be computed thus;

A_{ext}(area of the external casing) = (420x500) + 2(450x500) + 2(420x450) + (420x500x£)

= 1,248,000mm^2

= 1.248m^2

For the internal casing;

A_{int}(area of the internal casing) = 0.569184m^2

Hence,

$A = A_{ext} - A_{int}$

= 1.248 – 0.569184

= 0.678816m^2

31,200.0799= 500 X 0.678816(171.97 - T_s)

T_s= 80^{0}C

2.2.4 TEMPERATURE OF EXTERNAL CASING (T_E) The heat transfer from the air space to the external wall casing of the furnace is basically by convection, and can be expressed by invoking the Newton's law of cooling.

$Q = h_{air}A(T_s - T_E)$

Where;

A= total surface area of the external casing which takes a rectangular configuration.

= 1.2480m^2

31200.0799= 500 X 1.2480(80 - T_E)

T_E= 30^{0}C

2.2.5 THE VOLUME OF EXTERNAL CASING The external volume houses the entire furnace system and conforms to a rectangular box. It is calculated following the expected temperature at its surface (T_E= 30^{0}C)

$Volume = L \times B \times H$

=420x450x500

=94,500,000mm^3-

=0.0945m^3

2.3 Design Considerations and Materials

The considerations contained in this work are based on the logical necessity of furnace parameters as recommended by the IEE regulations. It is aimed at meeting the desired standard as expected for an electrical heated furnace.

2.3.1 The Furnace Casing Design

The Internal and External Casing

Description: It comprises both the internal and external casing. The internal casing serves as support for the refractory box. It must be rigidly constructed to accommodate the weight of the bricks. Whereas the external casing (as one of the construction consideration incorporated in this design), houses the entire furnace system, with the charging door and electrotechnicals attached to it.

With the introduction of the external casing in the new design, the temperature around the walls of the casing falls so that one can freely touch the furnace without being exposed to danger of high temperature or burnt.

Materials: Flat sheet of mild steel 1.5mm thickness was selected for it appreciable ductility, strength and toughness that supports its formability.
Tools and equipment used: Marking out tools (scribers, dividers, pencils), measuring tools (steel rule, tri-square), punch, sledge hammer, hand file, emery paper, anvil, bending machine, carbon electrodes and welding machine.

Procedure: for the construction of the external casing (figure), measuring tools were used to measure two of 500mm x 450mm plates for the sides of the furnace.

Another two of 450mm x420mm was also cut using the power hacksaw for top and base parts of the casing. Also, a 500mm x 420mm sheet was cut and used for the back covering of the casing. The edges of the sheets were bent using the bending machine. Flat hole was made on the top of the cover through the internal casing to the furnace-heating environment (breather hole) for the exit of gases from the furnace using punch and sledge hammer.

2.3.2 The Charging Door

Description: The construction of the charging door was designed to open in the upward and closed in the downward direction. The essence of this design is to reduce the charging and unloading time so that heat loss during it operation is reduced.

Materials: Flat sheet of mild steel 1.5mm thickness.

Tools and equipment used: Marking out tools, power hacksaw, measuring tools, welding machine, carbon electrodes, bending machine, sledge hammer, hand file, emery paper, anvil and chisel.

Procedure: Measuring tools were used to mark out 500mm x 420mm on the full sheet sample (figure), power hacksaw was used to cut the sheet to dimension. The edges were bent at an angle, from top to base using a bending machine (5^0, measured from base).

More so, 420mm x 200mm sheet was marked and cut using measuring tools and hacksaw respectively. Hole was made on the sheet using chisel (flat face chisel) to position the temperature controller and two other round holes were made to position both the light indicator and the main switch.

2.3.3 The Electrotechnicals

2.3.3.1 Temperature Controller

Description: Hence, after considerable research and for economic reason, a temperature controller that could read a maximum of 1200^0C was provided since it is closed to the expected maximum temperature of 810^0C. It is positioned on the 420mm x 200mm metal sheet below the charging door where it safety is ensured.

2.3.3.1 Main Switch and Light Indicator

Description: The main switch and light indicator are also part of the electrotechnicals. The main switch and light indicator are also part of the electrotechnicals. The main switch controls the power source input as it allows electric power to flow into the circuit when switched-on and prevents the inflow when switched-off. The light indicator signals the furnace operator if electrical energy flows uninterruptedly into the heating element. When the light is on, it signals continuity in the circuit but if the light is off, it signals discontinuity. They are positioned on the 420mm x 200mm metal sheet just below the charging door where the temperature is very minimal and fusing or damage is prevented during operation.

Materials: The electrical- carrying light/current are made of thermosetting materials so that they do not fuse or damage easily, and are placed on the outer casing.

2.4 Method of Assembly /Fabrication

After the successful completion of the construction processes, such as the furnace casing, which comprise the outer casing and the charging door, introduction of the electrotechnicals namely; temperature controller, the main switch and the light indicator, and taking into consideration the required suitable engineering materials, all parts are assembled together as shown in figure 2.

The assembly is made possible with the use of arc welding, boring and screwing with the use of appropriate tools. Electrical parts are also joined and insulated with tape to prevent shocks or discontinuity in the circuit.

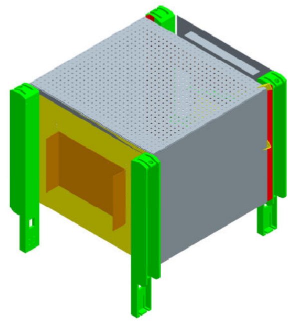

Fig 1: the modelled furnace

Fig 2: The completed furnace

S/N	PART	PROPERTIES DESIRED		MATERIALS USED	SPECIFICATION
		MECHANICAL	OTHERS		
1	External casing	(a) High tensile strength (b) Toughness	(a) Availability (b) Ease of fabrication (c) Cheap	Mild steel	1.5mm(thickness)
2	Base support (Angle iron)	(a) High tensile strength (b) High hardness (c) Heat resistant	(a) Availability (b) Good weldability (c) Cost	Mild steel	2mm(thickness)
3	Cylindrical rod	(a) High thermal strength (b) High tensile strength	(a Good weldability (b) Cheap and availability	Mild steel	
4	Charging door and base	(a) High tensile strength (b) Good toughness (c) high thermal strength	(a) Ease of fabrication (b) Cheap and availability	Mild steel	1.5mm(Thickness)

Table 2: Summary of Materials Selection and Specification

2.5 Performance Evaluation

2.5.1 Maximum Attainable Temperature With the aid of optical pyrometer, the initial maximum temperature attained was 905^{0}C, but with subsequent operations, average maximum attainable temperature is given as 880^{0}C.

2.5.2 Temperature Fluctuations The overall temperature of the furnace heating environment varied between 850^{0}C and 880^{0}C, whereas the temperature at the casing varies between 23^{0}C and 27^{0}C. Measurements were repeated five times as a standard with scientific practical equipment testing (Aluko, 2004).

2.5.3 Time to Attain Maximum Temperature Although, theoretical expectation for achieving the temperature of 880^{0}C was supposed to be 60minutes, it actually takes about 83minutes to attain the temperature of 880^{0}C.

2.5.4 Possible Heat Treatment Applications Since the maximum attainable temperature is 880^{0}C. Comparing this with some certain heat treatment operations and their relative process temperature, it will be possible to carry out the following heat treatment processes: Annealing, normalizing, tempering, quenching, certain hardening processes`.

2.6 Operation Procedure The operation procedures of the furnace involve placing the material to be heated in the furnace after which the door of the furnace should be close. Thereafter, switch on the furnace from the mains. Then, turn the knob of the temperature controller to the desired heat treatment temperature. After attaining the temperature and holding for a reasonable time, switch off the furnace before removing the sample from the furnace

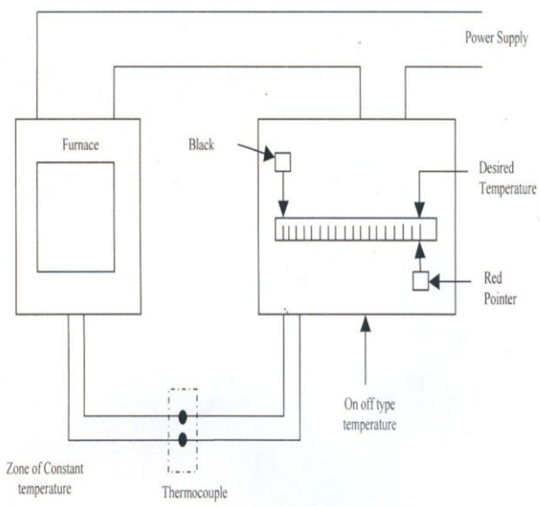

Fig.3: Circuit diagram for ON-OFF Automatic Temperature Controller.

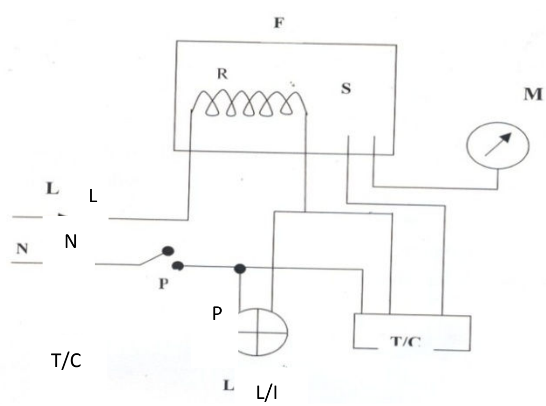

Fig 4: circuit diagram for the electrical connection

Where:
N = Negative
L= Life
P = Main switch
L/I = Light indicator
T/C = Temperature controller

3. Conclusion

The Furnace was specifically designed for controlled heating of element/material of temperature range of 1500 but it can equally be adapted for use in other heating operations of same temperature range. The result obtained makes it possible to heat treat both ferrous, non-ferrous metals and their alloys in other to alter their microstructure and to enhance their properties for needed application in service with maximum safety and precaution in place.

4.0 Acknowledgement

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