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Development and Performance Evaluation of a Heat Treatment Furnace

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***Abstrct* - A heat treatment furnace which incorporates an alarm system had been designed and fabricate with its performance evaluated in this work. Most of the materials used for its design and production were locally sourced in Nigeria. Some design considerations, assumptions and designs were made before the actual work started. Mild steel plates and bars were the major metallic structural materials used. They were joined together by manual arc welding process, use of nuts and belts, screws etc. Refractory bricks and fiber glass were used to line the furnace for the purpose of insulation in order to have good heat retaining capacity inside the chamber of the furnace and minimize heat loss to the surrounding. A digital temperature and time control/monitor unit was also produced and electrically connected to the furnace to monitor and read the temperature of the furnace via a thermocouple. The programmed soaking temperature is displayed digitally on the screen provided on the control unit. After assembly, the performance of the furnace was evaluated and it was observed that it has a tolerance of ±2.0^{0}c at a maximum temperature of 1005^{0}c in 70 minutes which translates to efficiencies of 83.75% in terms of maximum temperature reached and 71.8% in terms of heating rate based on design values of 1200^{0}c maximum temperature and 14.35^{0}C/min heating rate. The total cost of the furnace less labour was evaluated to be (N182,000) one hundred and eighty-two thousand naira only. The alarm system always triggers on to alert the operator when the programmed soaking time elapses.**

Keywords: Furnace, Heat Treatment, Performance Evaluation.

1.0 INTRODUCTION:

Properties of Engineering materials, especially metals and their alloys stems from their microstructures. Alteration of any of the properties implies an alternation of the material's microstructure. This change in the microstructure of a material is achieved chiefly through heat treatment. Heat treatment had been defined as the controlled heating and cooling operation applied to metals and alloys in solid states so as to obtain the desired properties (Radhankrishna, 2008). Beth (2006) defines heat treating as a process whereby the mechanical properties of metal are altered deliberately by controlled heating and cooling of the metals. As a result, heat treatment involves thermal cycling between heating and cooling, which most metals and their alloys can be subjected to. Though most metals can be heat treated, the degree of responsiveness to the thermal cycling differs from one metal to another. In fact one of the major reasons why steels show versatility (especially wide range of mechanical properties) found in no other metal is their responsiveness to heat treatment. The furnace is the most important equipment used in the heat treatment process. Heat treatment furnace with effective temperature sensing, heat retaining capacity and controlled environment are necessary for heat treatment operations to be successfully performed (Alaname and Olaruwaju, 2010). Some of the processes require heat cycles for durations of few minutes to several hours depending on the material and the property desired (George, 2002; Netsushori, 1998).

Though a lot of research had been conducted and design successfully implemented on heat treatment furnace, little or no attention had been given to high level accuracy of the timing of heat treatment durations, which this present work seeks to address. This is achieved by incorporating an alarm system that will alert the operator when the soaking time elapses, thereby making the furnace user's friendly and also checks the problems of over soaking; and thus providing a high sensitive and reliable heat treatment furnace.

2.0 MATERIALS AND METHODS

2.1 Materials

Most of the materials used in the production of this furnace were locally sourced in Nigeria. Some of the materials used are mild steel plate, angle steel bar, refractory bricks, fibre glass, refractory cement, hinges, heating element e.t.c.

2.2 Methods

2.2.1 Design considerations and assumption

Due to the fact that normal human body temperature ranges from 35^{0}c to 43^{0}c (Okeke and Anyakoha, 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 temperatures, a design calculation was done following standard procedures to achieve a temperature less than 35^{0}C at the outer casing (Monyem etal, 2012; Ikoba etal, 2012; Agbro etal, 2014). This will equally enable the safety of charging and uncharging of samples to be heat treated with case.

It was assumed that the maximum temperature to be attained inside the furnace chamber environment is 1200^{0}C and this temperature is assumed to be reached within 1 hour.

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Quality of heat generated from the industrial heating element was evaluated as 1548.39 J/s using a combination of Joule-Lenz's law and 0hms law given by Okeke and Anyakoha (1989) as

$$E = \frac{V^2 t}{R} \quad (1)$$

Where: E = Electrical Energy
t = Time (s)
R = Resistance (Ω)
V = Voltage across the circuit (v)

Temperature of the brick wall facing inside the furnace (T_b) was evaluated form Newton's law of cooling as 1148.39^{0}c using equation (2)

$$Q = H_{air} A_b (T_{air} - T_b) \quad (2)$$

Where: Q = Quality of heat generated
H_{air} = Convective heat coefficient of air
A_b = Surface area of the bricks wall in the heating Chamber

Temperature of the outside brick wall before the fibre glass (T_s) was calculated using Fourier's law given by equation (3) (Rajput, 2010) to be 956.13^{0}C

$$Q = K_b A_b \frac{T_b - T_s}{dx} \quad (3)$$

Where: K_b = thermal conductivity of brick (1.28 w/mk) (Marks Handbook)
dx = thickness of the brick wall.
A_b = A_s

Temperature of the space occupied by fibre glass (T_f) was also determined to be 31.300C using furrier's equations:

$$Q = K_f A_f \frac{T_s - T_f}{dx} \quad (4)$$

Where: K_f = thermal conductivity of fibre glass (0.0436 w/mk)

A_f = Surface area of the space occupied by the fibre glass
dx = thickness of the fibre glass

Finally, the temperature of the external wall casing (T_e) also utilizes the Fourier's equation for its evaluation as 30.71^{0}C using equation (5)

$$Q = K_e A_e \frac{T_f - T_e}{dx} \quad (5)$$

Where: K_e = thermal conductivity of steel (21W/mk)
A_e = Surface area of the mild steel
dx = thickness of the mild steel

As earlier stated, the human body temperature ranges from 35^{0}C to 43^{0}C. Hence, from the temperature of the furnace casing being 30.71^{o}C makes it very safe for the operator during heat treatment. The detailed design diagram is shown in appendix 1.

2.2.2 Fabrication Procedure and Electrical connection

The casing was made form a 7mm thick flat sheet of mild steel in combination with angle steel bar 5mm thick measuring 98mm x 98mm. After measuring, marking out, and cutting to size as indicated in the design, all the pieces were joined together using manual metal are welding, nut and both, screw etc process, to produce the casing as shown in Fig. 1. Initially, the top was left open to allow for the laying of fibre glass and bricks. Also at the two opposite end of the sides, 150 x 150mm opening was provided for the door (front) and for the space where the electrical wires and thermocouple can pass through (back)

After the casing was ready, it was lined with two refractory materials – fibre glass and refractory bricks. The bricks were laid side by side to each other and were bonded by a mortar made by mixing a refractory cement and water to paste using the standard ratios. Laying of the brick continued until the surface of the heating chamber was formed. The heating chamber formed a square-end cuboid shape of 150 x 150 x 400mm. A gap of 20mm was left opened between the metal plate and the wall brick, which was filed with fibre glass to improve the insulation. Fig. 2 shows a cross section of the furnace depicting fibre glass and bricks laid inside the furnace casing.

The assembled furnace was allowed to dry naturally as any breach or cracks observed were repaired as the mortar dries. Since mortar contracts and cracks during drying, the need to properly repair became imperative in order to enhance the working efficiency and the life span of the furnace (Alaneme and Olarewaju, 2010).

After drying for about 10 days, the control (temperature and time) unit and the heating elements were electrically connected for the functionality of the furnace. The thermocouple is placed in the heating chamber of the furnace to read the temperature and it is connected to the temperature controller. Ac power source is connected to the system through an industrial switch. The schematic diagram of the electrical circuit is shown in Fig. 3.

3.0 Performance Evaluation

The thermocouple wire tip is positioned in the furnace close to floor of the heating of chamber from behind the furnace to ensure accurate temperature reading of the specimen and not that of the furnace environment sensed. The temperature and time controller is digital for easy and accurate reading to be taken from the furnace.

3.1 Maximum Attainable Temperature

The furnace was designed to heat up to a maximum temperature of 1200^{0}C in 1 hour. However, a maximum temperature of 1005^{0}C was attained in 70 minutes, which translates to heating rate of 14.36^{0}c/min. This is quite high when compared to most muffles furnaces with heating rate between 5 -8^{0}C/min.

3.2 Tolerance

The furnace was programmed to hold at several temperatures (below 1200^{0}C) in the course of testing, it was observed that at all the holding temperatures (both high and low), and the fluctuation lies between ± 2.0^{0}C.

This is highly commendable when compared to other muffle furnaces with tolerance range of ± 5 to ± 10^{0}C. Also, the alarm system triggers on upon attainment of the soaking time to alert the operator that the set time has been reached in order to avoid over soaking and maintain high level of precision and quality control/assurance.

3.3 Outer Casing Temperature

The measured temperature of the outer casing of the furnace ranges between 28 to 32^{0}C, at temperature within 1005^{0}C and below, which makes furnace environment tolerable for the operator and those in the surrounding neighborhood. This indicates that the furnace refractories have good heat retaining capacity. Thus the lining has good efficiency and effectiveness in the prevention of heat transfer from the heating chamber to the surroundings. Measurements were repeated five times as a standard with scientific practical equipment testing (Aluko, 2004).

3.4 Efficiency in Terms of Maximum Temperature and Heating Rate

From section 3.1 above, the designed maximum temperature is 1200^{0}C to be attained in 1 hour. This translates to a heating rate of 20^{0}C/mms. While the maximum temperature reached in use is 1005^{0}C in 70 minutes. This translates to a heating rate of 14.36^{0}C/mms. Therefore, efficiency in terms of:

(i) Maximum temperature is

$$\text{Efficiency} = 1 - \left(\frac{1200-1005}{1200}\right) = 0.8375 = 83.75\%$$

(ii) Heating rate is

$$\text{Efficiency} = 1 - \left(\frac{20-14.36}{20}\right) = 0.718 = 71.8\%$$

4.0 COST ANALYSIS

Most of the materials used for the furnace design and production were locally sourced. Table 1 shows the entire material used and their cost. The total cost of the furnace production is approximately one hundred and eighty-two thousand (N182, 000.00) only, less labour cost. The production cost of the furnace is cheap in comparison to similar designs from abroad. When it is mass produced, cost per unit will reduce.

5.0 CONCLUSION

The design and fabrication of a heat treatment furnace has been successfully completed. The manufactured furnace is cheap when compared to the ones imported from Overseas because most of the materials were locally sourced. It has an efficiency of 83.75% and 71.8% based on design values in terms of attainment of maximum temperature and heating rate respectively. It had also shown high level of tolerance of ± 2.0^{0}C at temperatures below 1005^{0}C. The manufactured furnace also has good heat retention capacity, which makes it very safe for use. The incorporated alarm system will always alert the operator when the soaking time, during each heat treatment cycle elapses. Thus, a better result will be achieved since precision and accuracy of specimens monitoring is guaranteed.

Based on heating up to a temperature of 1005^{0}C, the furnace can be used to heat treat both ferrous and non-ferrous metals and alloys in order to alter their microstructure and enhance their properties for the needed application in service. Hence, this furnace is highly recommended for use. Furthermore, in order to reduce the dead weight of the furnace, the future models should use light sheet metal for the casing and substitute more fiber glass for bricks.

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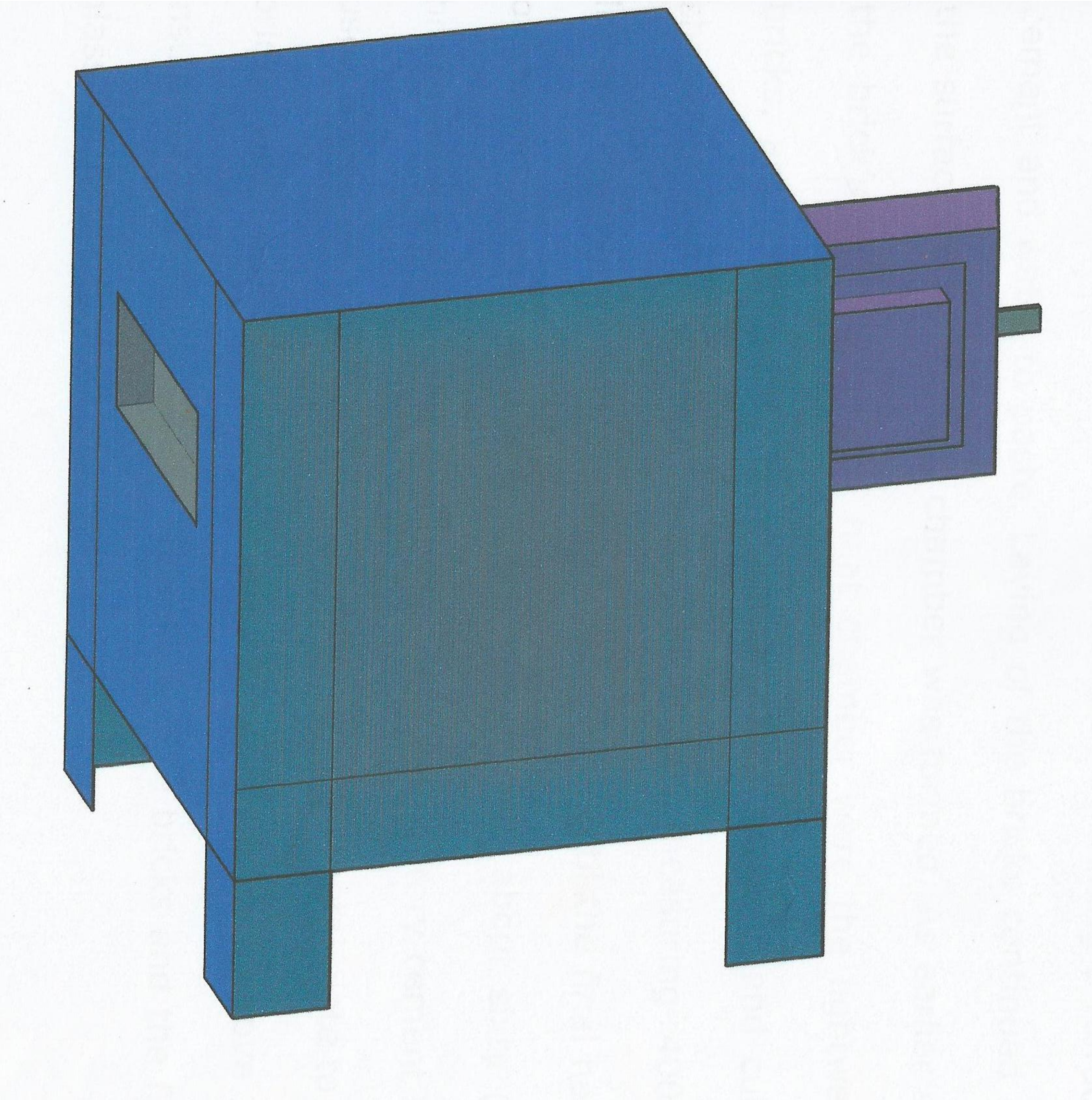

Fig. 1 : Furnace Casing

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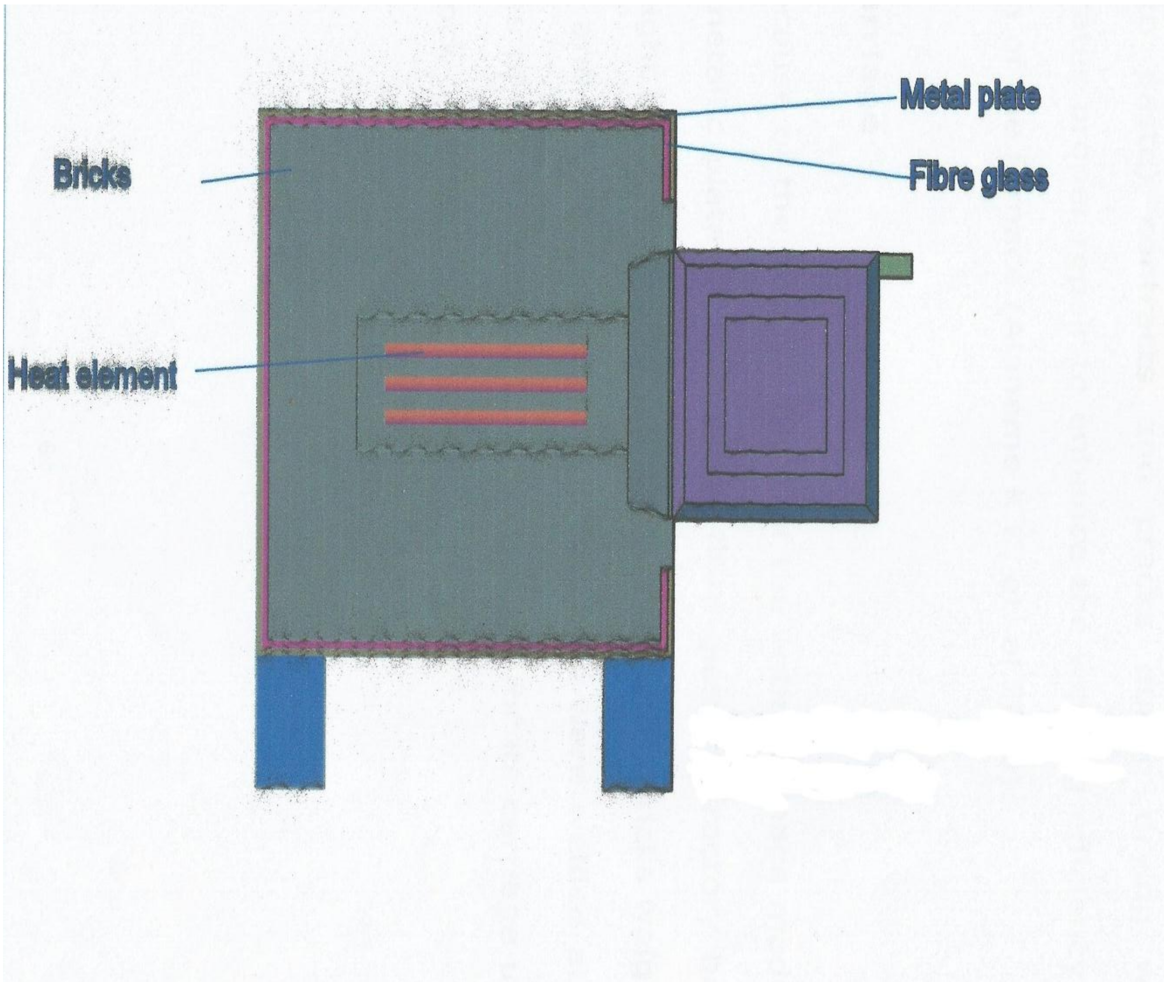

Fig. 2 : Cross-Section of the Furnace

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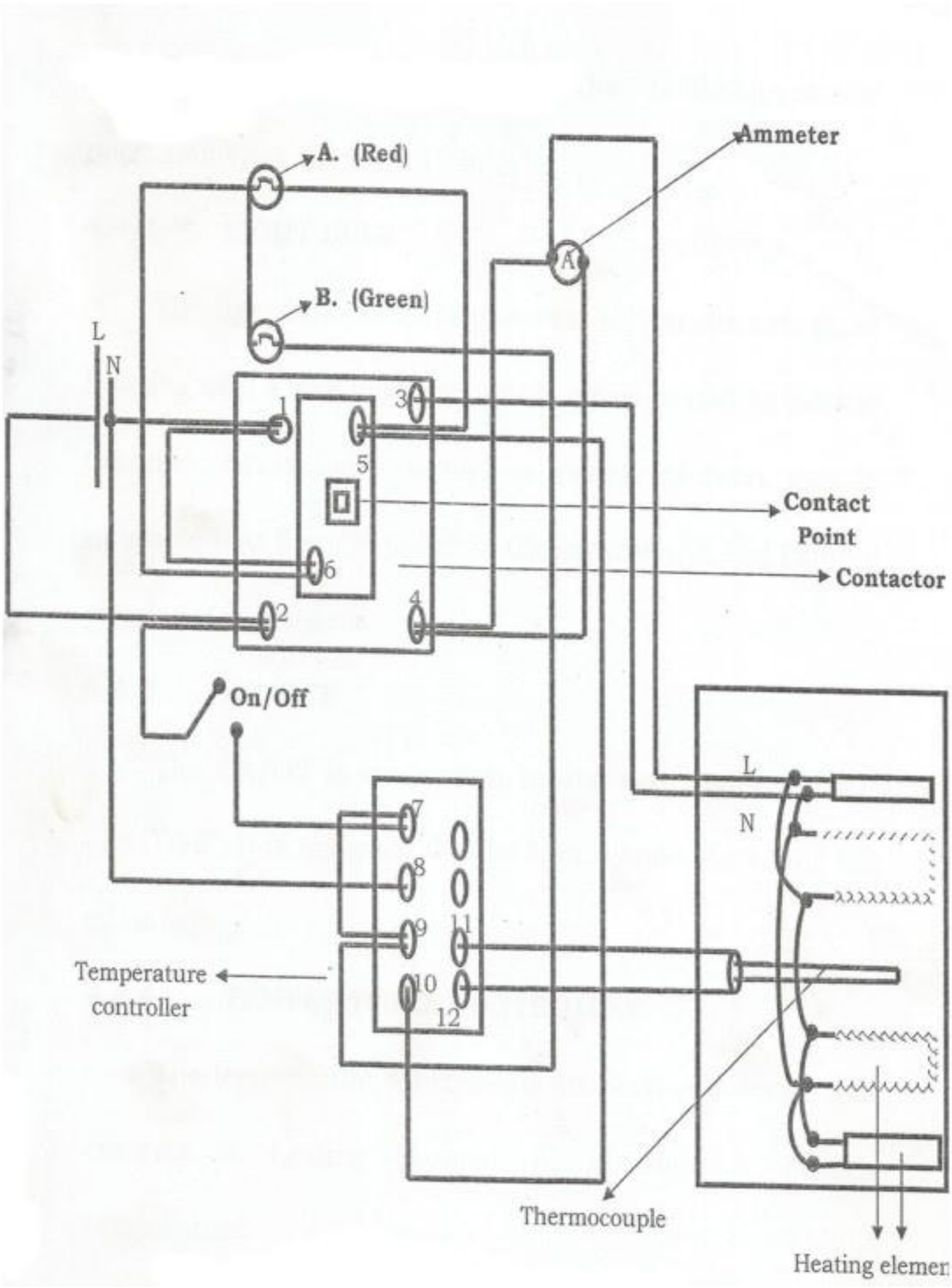

Fig. 3 : Electrical Circuit Diagram

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Appendix 1: Working Diagram

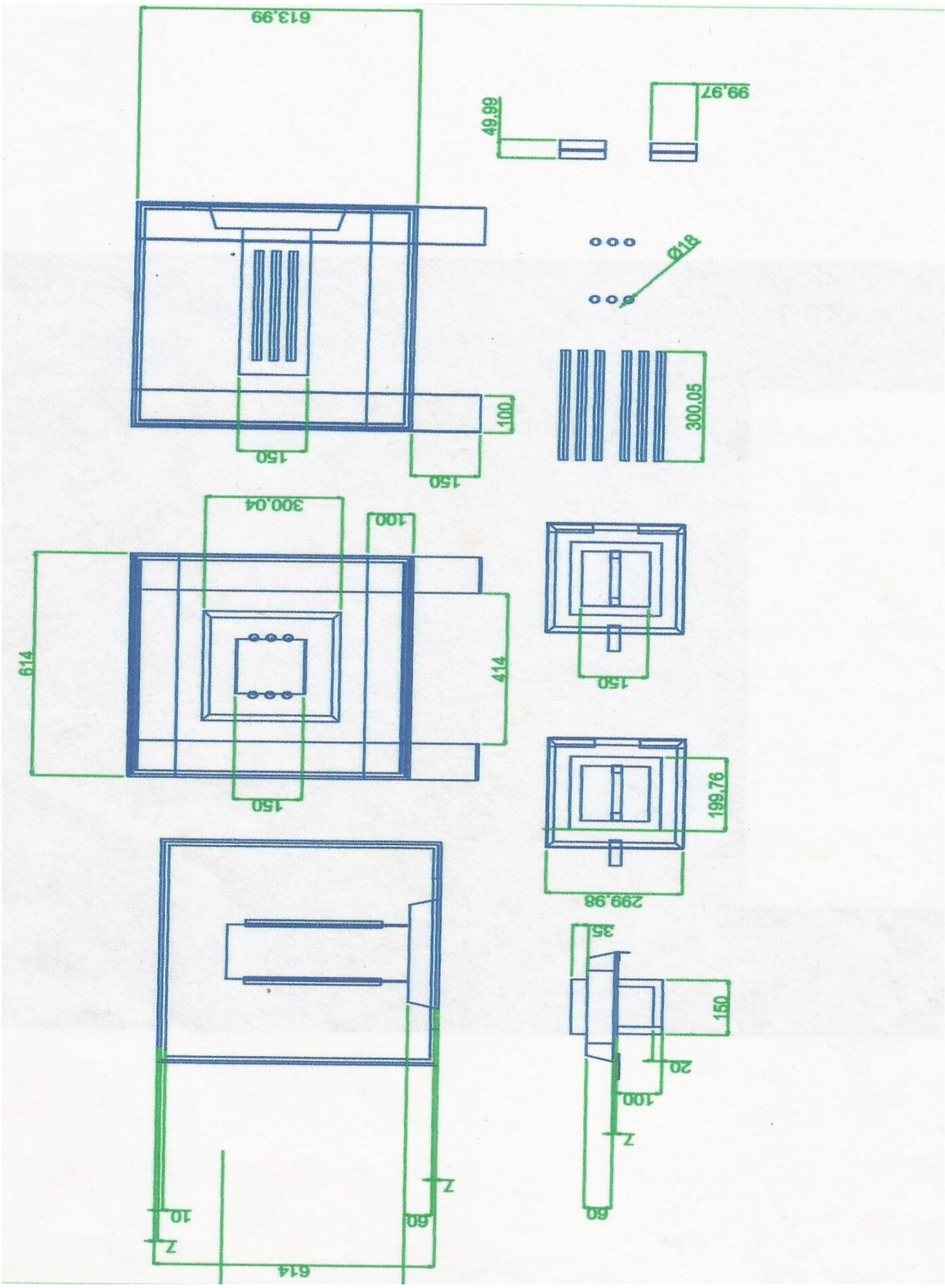

TABLE 1: BILL OF ENGINEERING MEASUREMENTS AND EVALUATION (BEME)

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S/N	MATERIALS	SPECIFICATION	QTY	UNIT PRICE (N)	TOTAL COST (N)
1.	Mild steel plate	7mm thickness 51 by 102mm	1	15,000	15,000
2.	Angle steel bar	5mm thickness 6000mm length	2	6,300	12,600
3.	Refractory bricks	75 x 150 x 230mm	60	200	12,000
4.	Refractory cement		1 bag	14,000	14,000
5.	Fibre glass		Lot		2,000
6.	Welding electrodes	Gauge 10	1 packet	1,500	1,500
7.	Door hinges		4	100	400
8.	Cutting stone		2	500	1,000
9.	Heating elements	650mm spring element 2.5kw rating	2	10,000	20,000
10.	Temperature controller		1	28,500	28,500
11.	Ammeter/voltmeter		1	2,500	2,500
12.	Probe		1	3,500	3,500
13.	Contactor		1	10,000	10,000
14.	Heating cable		10m	500	5,000
15.	Pannel casing			22,500	22,500
16.	Electrical cable insulation pod, plastic junction box		lot		5,000
17.	Industrial switch		1	2,500	2,500
18.	Body filler and paint		4 cups	1,000	4,000
19.	Logistics/ miscellaneous				20,000
	Total				182,000