International Journal of Mechanical and Materials Engineering (IJMME), Vol.6 (2011), No.1, 67-74

# DEVELOPMENT AND PERFORMANCE EVALUATION OF A SALT BATH FURNACE

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Received 18 February 2010, Accepted 28 January 2011

## ABSTRACT

This research work is centered on the design of a low cost – efficient salt bath furnace using locally sourced materials for the purpose of carrying out thermochemical treatments of small and minor components for improved properties in service. Working drawings were produced; and mild steel sheet was used for the construction of the furnace casing while other materials for the construction were selected based on functions and properties of the materials, cost considerations and ease of fabrication into component parts. Testing was carried out to evaluate the performance of the furnace. From the results obtained, it was observed that the salt bath furnace has fast heating rate 12.53$^0$C/min and a fuel consumption rate of 2.1 litres/hr, which is comparable to rates of conventional brands of diesel fired salt bath and muffle furnaces purchased from abroad. The lower cost of design of the furnace coupled with its good heat retaining capacity, uniform heating rate, long estimated life time, safety and ease of maintenance justifies the usage.

***Keywords:*** Design, salt bath furnace, thermochemical treatment, atomizing nozzle, muffle furnace

## 1. INTRODUCTION

The development of materials with properties that will suite service requirements is very fundamental in metallurgical and materials research (Fleming, 2001). In metallic materials, heat treatment has been an age – long process utilized to induce structural modification in the material to achieve some desired properties. This process often relies on the use of furnaces to heat and cool the material following some predefined heating routine cycle (Netsushori, 1998; Howes, 2007; Hasanuzzaman et al. 2010). The desired structural modification can hardly be obtained without the use of the furnace. So furnaces play a crucial role in the development of metallic materials.

Furnaces utilized for heat-treatment purposes are basically muffle furnaces and salt bath furnaces. The working principles of both furnace types are well outlined by Rajan et al., (1989). Muffle furnaces are common in Nigeria because it is cheaper and suitable for conventional heat-treatment processes. However, these furnaces have limitations in carrying out thermo-mechanical heat-treatment operations which are aimed at modification of the structures of steel and alter the surface chemistry towards a desired purpose. Other limitations to the use of muffle furnaces include: non uniform heating rate, slow heating rate, uncontrolled furnace atmosphere (Srinivasan et al, 1997). These factors put limitations on the quality of products produced using the muffle furnace: and is partly responsible for the substandard quality of grades of steel components that are produced in Nigeria. The salt bath furnace on the other hand is a much more reliable furnace to utilize because of its versatility; and high performance yield. The salt bath furnace can be utilized for conventional heat-treatment processes and for various thermo-chemical heat-treatment processes such as: carburizing, nitriding, and cyaniding (Yutaka, 2000). It is equally useful for preheating, isothermal quenching, austempering just to mention a few. Apart from its versatile process usefulness, it also has the advantage of giving uniform heating of the material and controlled atmosphere (Reid, 2006). These advantages make the use of salt bath furnaces an indispensable facility in heat treatment operations. It is however worrisome that salt bath furnace are not used by most of our small and medium scale metallurgical factories and most universities/ research institutes because of the cost of procurement from overseas. Thus the numerous advantages derivable from it are not being harnessed as a result of the cost factor. The huge advantages of the salt bath furnace make it alluring for an attempt to be made to design the furnace using locally sourced materials. This research work is an attempt to produce a low cost functional and efficient diesel-fired salt bath furnace.

## 2. MATERIALS AND METHOD

### 2.1 Materials

The materials that were utilized for the fabrication of the furnace are: 1mm thick steel sheet, 50 by 50mm square pipe, 10mm thick steel rod, chrome based alloy-steel pot, silica bricks, temperature controller, thermocouple, switch, wire light indicators, sodium cyanide salt, fume suction, diesel, paint, black tape, thread tape, body filler, adhesives, plug, burner and mild steel test samples of predetermined chemical composition.

#### *2.1.1 Materials Selection*

**Steel Sheet**

The steel sheet selected is a mild steel of composition: 0.15%C, 0.45%Mn, 0.18%Si, 0.18%Si, 0.031%S, 0.001%P, 0.0005%Al, 0.0008%Ni and balance Fe. The composition was determined spectrometrically with the use of a spark spectrometric analyzer. It was selected for the fabrication of the bath casing ahead of Aluminium and stainless Steel because of its light weight, excellent formability, availability, and low cost of purchase.

**Furnace Pot**

The pot is a chrome based alloy steel pot with the following composition- 0.6%C, 0.30%Si, 2.00%Mn, 0.025%S, 0.018%P, 18%Cr, 10.5%Ni, and 3.0% Mo. The steel alloy material was selected in preference to titanium due to its low cost and availability. In addition, the chrome based alloy steel pot has very high melting point of $1920^0$C, which is far above the maximum operating temperature of the furnace.

**Furnace Lining Material**

Silica Brick was selected as lining material for the furnace because of its low cost, high refractoriness, and very low thermal conductivity.

Other components and parts selected for the design where influenced by cost, availability, efficiency and reliability.

## 2.2 Design

*2.2.1 Design Principles*

The molten salt bath furnace consists essentially of a container made of metal. This container holds molten salt in which the work pieces are immersed. The mode of heat transfer to the work piece is by convection through the liquid bath. The molten bath possesses high heat capacity which results in the work piece being heated up very quickly. The design philosophy was to fabricate a molten salt bath furnace that will work efficiently at an affordable cost of production. Thus the following design considerations were taken:

- Power consumption (diesel) required to operate the furnace should be at a minimum;
- The component parts should be easily replaceable in case of damage or failure; and
- The design should be simple for easy construction and ease of operation; and safety of the operator must be guaranteed.

*2.2.2 Design Conception and Assumptions*

**Furnace Pot**

The salt bath furnace was conceived to be used for the heat-treatment of small components and parts: thus the following design dimensions were used for the construction of the furnace pot: Diameter = 100mm, Height = 170mm, Flange = 25mm, Flange thickness = 10mm, Hanger on flange = 10mm.

Casing

The Salt bath furnace casing is the main housing of the furnace it was designed to have a cylindrical shape for simplicity of construction. Also the design was made taking into consideration that the control box should be attached to the casing, and the control box must have holes for easy wiring and uniform de-steaming. The size of the burner was utilized in the design of the burner nose inlet. The configuration of the exhaust duct was made rectangular and big enough to give allowance for lining. It must also be long enough to ensure the safety of the operator. The height of the refractory lining from the burner nose inlet to the bottom of the furnace should not be less than 200mm in order to increase the life span of the furnace and its environments. The dimensions of the casing are given below: Height of the casing = 500 mm; Diameter of the casing = 400 mm; Exhaust duct outlet = 200 by 150 mm; Width of the exhaust duct = 800 mm.

**Fume Extractor and Support**

The fume extractor was designed with dimension of 50 by 50mm square pipe. This dimension is compatible with the diameter of the furnace pot. The extractor line must be high enough to prevent the operator from inhaling the fume sucked, thus the height of the extractor line from the floor was made to be 2010mm. The orthographic projection and isometric view of the salt bath furnace are shown respectively in Figures 1 and 2.

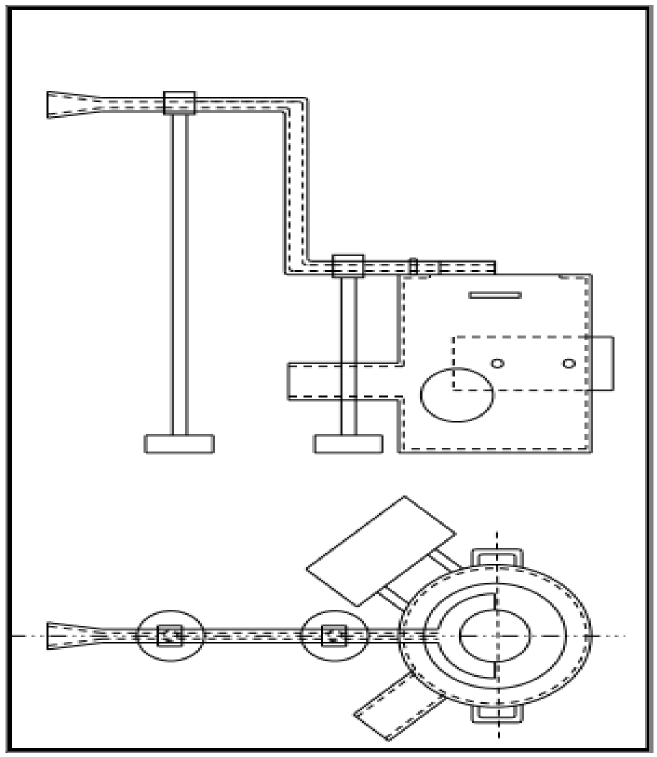
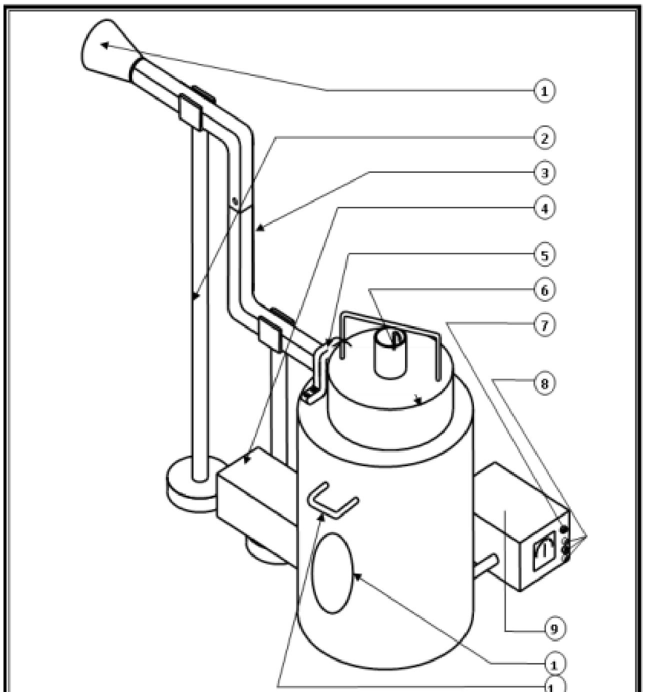


Figure 1: Orthographic view of the Salt Bath Furnace

## 2.3 Constructing the Furnace

*2.3.1 Construction of the casing*

The required dimension for the casing was cut and folded on a bending machine in order to form the cylindrical shape. A circular steel sheet of 400mm diameter was cut and welded to the base of the cylinder so that it becomes a solid cylinder. Steel rod were cut into required dimensions and bended at 20mm of the end of the before joining it to the cylindrical casing. The duct hole was created on the cylindrical casing and the duct was welded to the casing after it has been fabricated. The whole of diameter 150mm for the burner nose was created. After the welding operation has been carried out, welded joints were grinded to remove carbon chips. This was followed by the application of body filler on the casing and it was painted after air drying in order to give a smooth and good looking surface.




| NO. | DESCRIPTION |
|---|---|
| 1 | FUME SUCTION OUTLET |
| 2 | FUME EXTRACTOR STAND |
| 3 | FUME EXTRACTOR LINE |
| 4 | EXHAUST DUCT |
| 5 | BRACKET |
| 6 | REFRACTORY LINNING |
| 7 | LIGHT INDICATOR |
| 8 | SWITCH |
| 9 | CONTROL BOX PANEL |
| 10 | INLET |
| 11 | FURNACE HANDLE |

Figure 2: Isometric View of the Salt Bath Furnace

*2.3.2 Construction of the furnace extractor line and support*

Two square pipe 50 by 50 mm was cut to the required dimensions. The pipes were welded to a flange where it would be coupled. Four holes of 10mm diameter were drilled on the flange and the pipes were bended to make a right angle. At the upper end of the square pipe, a truncated cone fabricated from mild steel sheet having 150mm and 50mm as the base and top diameter respectively was welded to one of the pipes. This cone holds the suction system. The fabrication of the support involved cutting of 1" mild steel pipe to the required size and it was welded to 1mm steel sheet of diameter 100mm. The round steel sheet serves as the foot of the support. A 50mm bar was cut to a length of 156mm; it was bended at both end and was welded to the upper end of the support. The fabricated support helps in holding the extractor firmly.

*2.3.3 Lining of the Furnace*

The lining of the Salt bath furnace was carried out in three stages which are:

Flooring: This involved mixing of dry silica sand and water in a predetermined proportion. The mixing was carried out manually and then poured into the furnace casing. This was followed by mixing kaolin and clay in a proportion 1:1 with water in accordance with Bodunrin (2007). The resultant mix was used for laying beds for the bricks.

Setting of bricks: This involved arranging the bricks on the prepared bed both at the sides and bottom of the furnace casing. This was followed by mixing of kaolin and clay in a proportion 1: 1.2 with $0.012m^3$ of water. The furnace pot was placed between the bricks and resultant mix was used in shocking and plastering of the well positioned refractory bricks.

Drying: This requires the lining to dry in air for two weeks, cracks were noticed due to shrinkage and the cracks were filled by prepared clay, kaolin mix. After air drying the lining possessed green strength and this strength was improved by subjecting the lining to firing. This firing was carried out for two hours in seven days in order to remove the moisture content of the lining and hence improve the strength of the refractory lining.

*2.3.4 Assembling*

The assembling of the salt bath furnace was carried out manually and it involved the following:

- Positioning of the furnace.
- Coupling of the burner parts.
- Fixing of the suction system.
- Coupling and standing of the extractor line.
- Fixing of the exhaust extension.
- Positioning of the burner.
- Setting the alignment of the burner and the extractor system.
- Tightening of bolts and nuts.
- Fixing the thermocouple in the furnace pot.
-

**2.3.5 Electrical Connections**

Well insulated wires were used in other to prevent shocks and hazards. The sparker transformer, sparker timer, thermocouple and light indicators were connected to the temperature controller while the suction system was connected to the main switch of the salt bath furnace. The circuit diagram for the entire connection is shown in Figure 3.

**2.4 Testing**

The photograph of the Salt bath furnace after installation is presented in Figure 4. The performance and working efficiency of the furnace was evaluated by determining the furnace heating rate, fuel consumption rate, and ability to maintain constant temperature.

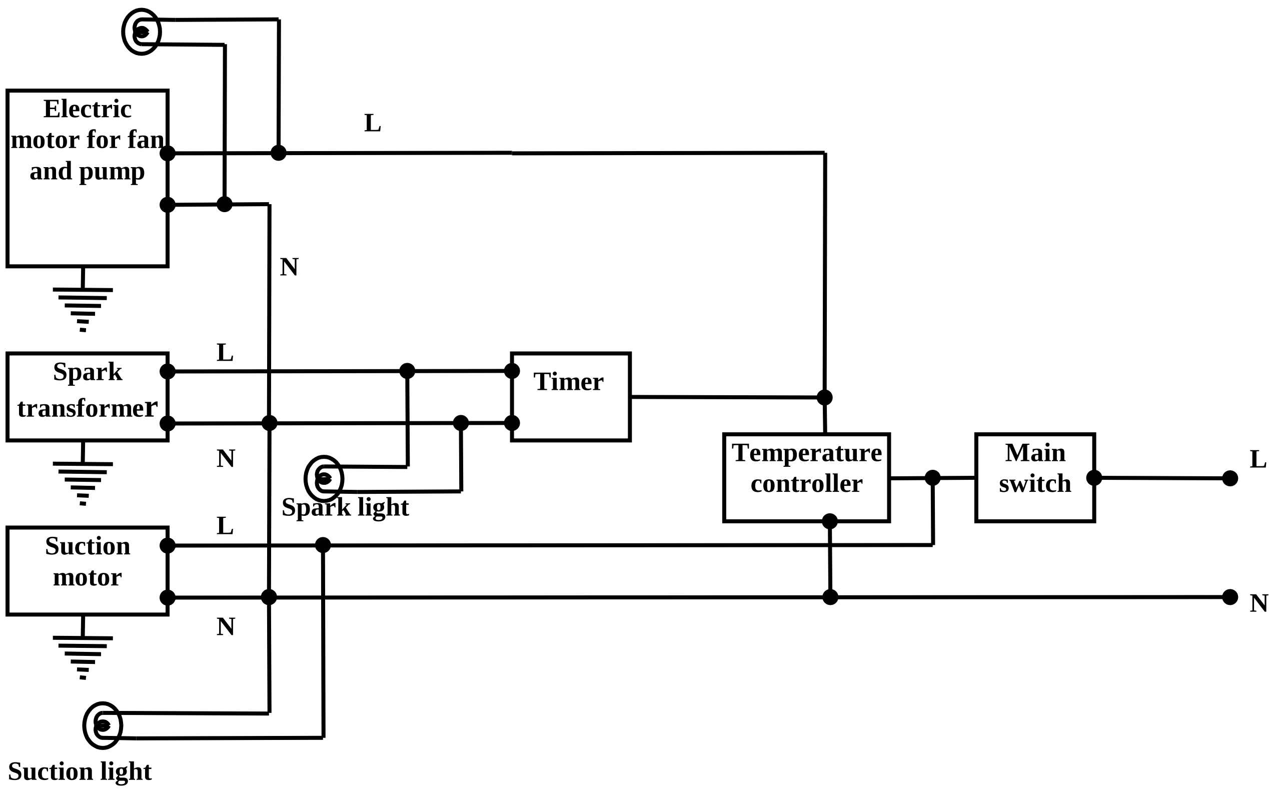



Figure 3: Circuit Diagram of the Electrical Connections of the Salt Bath Furnace

Figure 4: The salt bath furnace after Installation

To assess these performance factors, three steel samples were subjected to liquid carburizing treatment using the newly constructed salt bath furnace. The carburizing treatments were performed at $800^0$C and $870^0$C, while the third sample was used as control sample.

The treatment operation was performed by filling the furnace pot with sodium cyanide (NaCN) salt. The furnace was switched on and the required temperature was regulated on the temperature controller. While the furnace heat up to $870^0$C, the samples were preheated on the exhaust duct since the salt bath furnace was not designed to have a preheating pot. At $600^0$C, the sodium cyanide salt melted and the preheated sample was charged into the furnace when the desired temperature has been reached. The furnace was held at that temperature for 120 minutes after which the sample was discharged and quenched in oil. The same procedure was repeated for the test sample carburized at $800^o$C. The sample was held there for 120 minutes after which it was quenched in oil. Hardness test was carried out at different sections of the test samples to determine the effectiveness of the carburizing process. The results of the hardness test are presented in Table 1.

## 3. PERFORMANCE EVALUATION

The performance of the furnace was evaluated by using its functionality (Temperature Sensing, fuel consumption rate, and heating rate), aesthetics, maintainability, cost analysis, estimated life time and carburizing efficiency as basis for assessing the efficiency of the furnace.

### 3.1 Functionality of the Furnace

**Effectiveness of Temperature Sensing**

The thermocouple tip is positioned in the salt bath 1/3 one – third from the base and the salt at molten is convectional, so there is homogeneity of the temperature in the inner pot. The temperature controller is digital which makes the reading sensed to be accurate; also there is regular temperature check using an external probe to calibrate the temperature controller thereby guaranteeing effective temperature reading.

**Fuel Consumption Efficiency**

The fuel consumption rate is a very important criterion for determining whether the furnace is efficient especially from the running cost effectiveness point of view. The fuel consumption rate was evaluated by determining the burner fuel efficiency. Experimental test observations showed that an average of 2.6 litres of fuel (diesel) was consumed in 75 minutes. This gives an estimated 2.1 litres/hr consumption rate. This rate of fuel consumption reduces with longer holding time during the thermochemical treatment as the design of the salt batch is such that the fuel supply to the burner switches off once the temperature of the furnace exceeds the preset temperature of the furnace by $2^0$C and is restored automatically once the temperature drops $2^0$C from the pre-set temperature. In addition, fuel leakages were not observed during the use of the furnace indicating that the furnace has reasonably good fuel economy. The fuel consumption rate is comparable to that of conventional diesel fired salt bath furnaces and air muffle furnaces (Alaneme and Olanrewaju, 2010; Olanrewaju, 2000).

**Heating Rate**

The heating rate of the salt bath furnace was equally evaluated as it serves as a measure of the time taken to attain the desired temperature, and the duration of the treatment. The furnace was heated to $940^0$C and a time of 75 minutes was taken to attain the temperature. This test routine carburizing heat treatment was repeated for five consecutive times and the same average time of 75 minutes was taken to reach the temperature of $940^0$C. This gives a heating rate of $940^0$C/75mins = $12.53^0$C/min ($0.21^0$C/s). This heating rate is quite high in comparison to $7.08^0$C/ min of the 30/60 capacity salt bath furnace designed in Germany by Degussa (2006). The furnace heats to a carburizing temperature of $850^0$C in 120 minutes. Also imported muffle furnaces like that designed by the Park Thermal Equipment Company in Canada, which takes averagely 150 minutes to heat up to a carburizing temperature of $870^0$C that is a heating rate of $5.8^0$C/min ($0.96^0$C/s) (Reid, 2006). Thus the Salt bath furnace designed can be said to be very efficient in service in comparison to standard furnaces of different makes from outside the country. Equally critical in the performance evaluation is its sensitivity and ability to maintain a constant temperature during isothermal treatments. This was evaluated by studying temperature changes when the salt bath furnace was utilized for the liquid carburization treatment of the mild steel test samples at $870^0$C. It was discovered that after the melting of the molten salt (sodium cyanide salt) the furnace maintained a steady temperature of $870^0$C with a tolerance of + or – $0.5^0$C. This gives a very good tolerance comparable to the tolerance of efficient modern salt bath furnaces (Liu, et al., 2008) which allows for the desired metallurgical effects to be obtained. The furnace lining also shows its effectiveness by preventing high rate of heat transfer from the heating chamber to the furnace surroundings.

### 3.2 Maintainability of the Salt bath Furnace

The furnace service life and efficiency can be enhanced by simple maintenance strategy, and by following safety measures which are outlined in section 3.3. Bailing out of the cyanide salt when it is still in the molten state after every operation is a necessity - this is because the salt is hygroscopic and has the potentials of corroding the inner pot if not removed. The cyanide salt should always fill the inner pot whenever the furnace is to be used. After the removal of the molten salt at the end of heat-treatment, a salt neutralizer should be applied into the inner pot as the temperature of the empty inner pot reduces to below$150^0$C. All metallic containers, rods and plates used that had contact with the cyanide salt should be washed in hot water before drying in hot air to avoid rapid attack of the salt on the metal. There is no cost incurred for the hot water/hot air cleaning and drying operation, since the excess heat from the exhaust can be utilized to heat up the water and air needed for the exercise. An external probe is used at regular intervals (at least after 10 heats) to calibrate and confirm the accuracy of the temperature readings of the temperature controller. The outer casing and exhaust piping should be repainted bi-yearly using heat resistant paint.

### 3.3 Carburizing Efficiency

Table 1 presents the results obtained after routine hardness tests were carried out on test specimens to evaluate the performance of the salt bath furnace. It is observed that the case and core hardness value is higher when a carburizing temperature of $870^0$C is utilized in comparison with the selection of a carburizing temperature of $800^0$C. Also the case and core hardness increases with the use of longer carburizing holding time. The trend observed is consistent with the results reported by Gupta (2007) who performed similar treatments using conventional furnaces. Since the developed salt bath furnace yields similar results under the same test conditions as the conventional furnaces, then it could be said to be reliable for use for thermochemical treatment of steel materials.

Table 1 Variation of Case and Core Hardness at different temperatures and holding time with the use of the Salt bath Furnace

| Sample | Treatment | Case Hardness (HRA) | Core Hardness (HRA) |
|---|---|---|---|
| A | $870^0$C for 60mins, oil quench | 57.4 | 52 |
| B | $870^0$C for 120mins, oil quench | 60.8 | 54.4 |
| C | $800^0$C for 60mins, oil quench | 55 | 51 |
| D | $800^0$C for 120mins, oil quench | 57 | 52.5 |
| E | As – received (untreated) | 50 | 50 |

### 3.4 Cost Analysis

The bill for Engineering Management and Evaluation for the newly designed furnace is presented in Table 2. The total cost is #212, 440 ($1416.27), although a preheating pot was not incorporated. If the preheating pot is incorporated, the furnace will cost about #500,000 ($3333.33). The minimum cost of acquiring a fuel – fired salt bath furnace from abroad ranges between #3million and #5million for a small size. This clearly indicates that the newly designed furnace is cheaper since the parts were sourced locally. If the furnace is to be produced on a large scale, the cost of acquiring the furnace will be cheaper since components will be purchased in bulk which will attract some discounts.

### 3.5 Safety

The position of the furnace is a well ventilated area which reduces the risk of inhaling cyanide fumes and it also helps to reduce the heat radiation from the furnace to the furnace environment. Thus other operations can comfortably be carried out near the furnace environs with out the fear of heat radiation. Also the furnace is non-flammable, has very low volatility and it does not pollute the environment. The temperature of the salt bath was accurately maintained since the thermocouple is well placed in the furnace pot. Moreover, temperature controller was well calibrated.

The salt bath furnace protects the test sample being heat treated from oxidation or scaling by excluding air during immersion. After immersion, a thin salt “cocoon” remains on the test samples to shield it from oxidation prior to quenching and the thin salt is washed or removed after quenching. No distortion or cracks was detected on the test samples on quenching.

### 3.6 Aesthetics (Finishing)

The casing of the salt bath furnace is machine folded using roller folding machines to ensure a very smooth surface is achieved for subsequent finishing operations. The parts of the steel sheets utilized for the design were seam welded to give good finishing. The spraying of the casing was done on a highly prepared surface; and a metallic base paint was used to beautify and also to protect the furnace casing from corrosion.

### 3.7 Estimated Life Time

The service life of furnaces is best estimated by evaluating the life time of the heat exchanger which usually is the most expensive part of the furnace (Canada Mortgage and Housing Corporation, 1996 - 2011).

Table 2 Bill for engineering management and evaluation

| MATERIALS | SPECIFICATION | QUANTITY | COST(₦) |
|---|---|---|---|
| 1mm Steel Sheet | Mild Steel | | 6500 |
| 10mm Steel Rod | Mild Steel | | 5000 |
| 50×50mmSquare Pipe | Mild Steel | | 2000 |
| 2” Steel Pipe | Mild Steel | | 2450 |
| Body Filler | | 2 | 1250 |
| Paint | Premier | 2 | 3000 |
| Red Oxide | Apex | 1 | 500 |
| Welding Electrode | Mild Steel | Lot | 1000 |
| Silica Bricks | | Lot | 15000 |
| Binder and Kaolin | | Lot | 3000 |
| Furnace Pot | | 1 | 10000 |
| Burner | 30/6 | 1 | 65000 |
| Fume Suction | | 1 | 5000 |
| Diesel | | 50 Litres | 10000 |
| Salt | Sodium Cyanide | | 25000 |
| Temperature Controller | Nutronix(1000ºC) | 1 | 32000 |
| Thermocouple | Nutronix | 1 | 2500 |
| Timer | Nutronix | 1 | 1500 |
| Switch | Nutronix (220V) | 1 | 600 |
| Plug | 15 Amps | 1 | 100 |
| Wire | Industrial and Flexible | lot | 2000 |
| Tape | Black, Thread | 5 | 360 |
| Transportation | | | 10000 |
| Labour | | | 5680 |
| TOTAL | | | 212,440 |

The most expensive part of the developed salt bath furnace is the burner (heat exchanger) which was purchased at the rate of #65,000.00 ($433.33). The average burner life span is over 20 years if the manufacturers guide is followed and the recommended simple routine maintenance performed regularly. The major parts of the burner are the electric motor (of maximum ½ Horse Power) that drives the pump, the spark transformer that occasionally ignites the atomized diesel, the nozzle that atomizes diesel and the fan blades attached to the line of the electric motor. Of all these major parts only the electric motor requires occasional annual maintenance necessitated by the nature of electricity supply in which there are instances of high voltage power supply. The estimated life time of the developed salt bath furnace is conservatively 20years which is comparable to life spans of furnaces designed in developed countries (Canada Mortgage and Housing Corporation, 1996 – 2011).

## 4. CONCLUSION

The design, construction and performance evaluation of a diesel-fired salt bath furnace using locally sourced materials was carried out in this research work. The results obtained during testing of the furnace reveal that the furnace has a heating rate of $12.53^0$C/min and a fuel consumption rate of 2.1 litres/hr, which is comparable to rates of conventional brands of diesel fired salt bath and muffle furnaces purchased from abroad. The lower cost of design of the furnace coupled with its good heat retaining capacity, uniform heating rate, long estimated life time, safety and ease of maintenance justifies the usage.

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