Development and Performance Evaluation of Indirect Resistance Furnace

[1]P. O. Oghenerukevwe, [2]A. O. Emu
[1 & 2]Department of mechanical engineering, Delta State Polytechnic, Ozoro, Delta State, Nigeria.

Abstract
An indirect resistance furnace was developed and constructed to melt approximately 40kg of steel/cast iron scraps. In the design, efficiency of heat utilization as well as ease of operation and maintenance of the furnace was primarily considered, among other things. Materials selection and design details were aimed at ensuring reliability of the furnace. Value analysis method was employed in the selection of materials while mathematical modelling approach was employed in design calculations cum analysis. Test carried out showed that it required about 70 minutes to heat up the furnace to the melting temperature of cast iron (1150^0C – 1400^0C). It took about 95minutes to melt the first charge of 5kg resulting in a melting rate of 52.63g/minute.

Keywords: *Furnace, melting rate, heating rate, cast iron, temperature.*

I. INTRODUCTION

Furnace is a term used to identify a closed space where heat is applied to a body in order to raise its temperature. The source of heat may be fuel or electricity. Commonly, metals and alloys and sometimes non – metals are heated in furnace. The purpose of heating defines the temperature of heating and heating rate [1]. A furnace is an apparatus in which heat is generated and transferred directly or indirectly to a molten or solid mass for the purpose of effecting a physical, chemical or metallurgical change in the mass [2]. Furnace is an equipment isolated from the surrounding by an insulated wall and is used to transfer heat to the material to be melted or heat treated within the furnace [3]. An ideal furnace is one in which all energy produced is utilized, this practically unachievable and there is no thermal processing equipment with efficiency of 100% [4]. A furnace of high efficiency is therefore a system in which energy losses are minimal. In practice, however, a lot of heat is lost in several ways. The losses include energy conversion losses, furnace wall losses, furnace opening losses and the likes [5]. In order to prevent these losses, materials that are can retain and conserve heat known as refractory materials are therefore used as lining materials for the furnaces. Refractories are porous, multi – component and heterogeneous materials composed of thermally stable mineral aggregate, a binder phase and additives [6]. Refractory wall of furnace is a key component which is used as induction layer.

This work is therefore concerned with the fundamental area of research i.e. the improvement of the design of the design of the resistance furnace for more efficient heating. This affects, among other things, productivity of the furnace as well as the quality of the melt produced. Accordingly, this design of an electric, indirect – action, resistance furnace is based on the following objectives:

- Designing a suitable heating system capable of attaining the required furnace temperature of 1500^0C.
- Designing a refractory lining capable of withstanding the high temperature and melt conditions.
- Minimizing melt contamination during melting; and designing a convenient discharge system for pouring of the melt.

II. MATERIALS AND METHODS

A. Design Description

This furnace design is basically focused on the indirect – action type with rectangular cross – section, and capable of melting cast iron scraps at a temperature of 1500^0C. The designed teeming mechanism is similar to that of existing drop - bottom type. Figure 1 and 2 shows the structures as well as the arrangement of furnace components. The heating element is placed inside slots provided on the walls. A bore is made on the floor to facilitate discharge of the melt through the discharge hole on the floor. On the wall opposite the door, a flue is provided and this is to further minimize contamination of the melt by gaseous product of possible reactions during melting. A slip control mechanism is incorporated to control the flow of melt through the hole.

A thermocouple, which is connected to an indicator, is placed on the opposite wall to monitor furnace temperature. The refractory lining is lagged on the outer surface and the two layers cased with metal sheet. The whole structure is placed on four – legged metallic stand.

B. Design Specifications

The design specifications are as tabulated in table 1. The maximum working temperature of the furnace is 1500^0C and designed to enclose a working space of $0.09m^3$. The maximum charge per heat is 400kg.

Table 1: Design Specifications

Parameters	Specifications
maximum working temperature	1500^0c
working space	1.0 x 0.3 x 0.3 m
maximum charge/heat	40kg

Design Considerations

On the basis of the stated specifications and other service requirements, the following are primarily considered in the design:

- Efficiency of energy utilization;
- Life span of the heating element;
- Minimization of melt contamination;
- Operation/maintenance philosophy;
- Control philosophy; and
- Safety of working environment.

These factors are considered in the selection of materials and design calculations.

C. Materials Selection

This is a key step in the design process as it links the design calculations with a working design. Such important economic and practical factors as availability, size limitations and tolerances on available materials, variability in properties and cost are considered for proper selection.

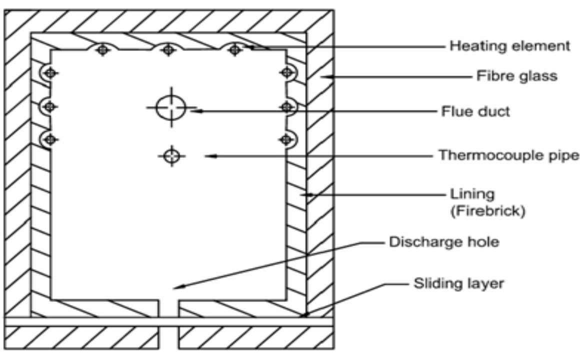

Fig 1: Sectional Drawing of the furnace

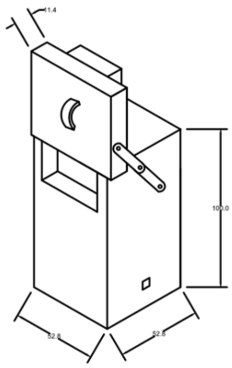

Fig 2: Isometric sketch of the furnace

Value analysis method [7] of materials selection is particularly employed because of its guiding principle of identifying and removing unnecessary costs without compromising the quality and reliability of the design. Table 2 shows the materials selected via this method for the furnace components.

Table 2: Selected materials for the furnace

Component	Material
Heating element	Silicon carbide
Refractory lining	Fireclay brick
Lagging	Fibre glass
Thermocouple	Platinum/Platinum – Rhodium (Type)
Metal case	Wrought iron sheet

D. Thermal Analysis

The thermal load of the furnace is determined from the heat balance calculation for a periodically operating furnace as follows: Heat input to the furnace, Q_{in}, is equal to heat output, Q_{out}.

Q_{out} = useful heat required to melt the material + heat losses by conduction through the lining + heat losses by radiation through open doors of the furnace + heat losses through the flue duct + loss of heat accumulated in the lining + unaccounted losses. i.e.

$$Q_{out} = Q_{us} + Q_C + Q_{rad} + Q_{FL} + Q_{acc} + Q_{un} \quad (1)$$

1) **Useful Heat, Q_{US}:** This is calculated using the formula;

$$Q_{us} = GC_M t_{Mf} \quad \text{kJ/period} \quad - \quad (2)$$

Where G is the mass of cold cast iron, kJ/period
C_M is the mean specific heat capacity of metal, kJ/kg^{o}C
t_{Mf} is the final temperature of metal, ^{o}C

2) **Heat Loses by Conduction Through the Lining:** This is determined using;

$$Q_c = \frac{3.6(t_1 - t_a)F_C}{\frac{S_1}{K_1}+\frac{S_2}{K_2}+\frac{1}{\propto}} \quad KJ/h \qquad - \qquad (3)$$

Where t_1 is the temperature of the internal surface of the lining, ^oC.

t_a is the temperature of surrounding air (assumed to be 27^oC).

S_1 and S_2 are the thickness of refractory lining and insulation, m.

K_1 and K_2 are the conductivity of the lining and insulation, W/m^oC.

$\propto$ is the coefficient of heat transfer from lining to air, equal to $19.8 W/m^2.^oC$.

F_C is the surface area of the lining, m^2.

3) **Heat Losses by Radiation Through Open Door:** This is calculated using:

$$Q_{rad} = 7.2\ Co \left(\frac{T}{100}\right) 4\ F\phi\varphi. \quad \text{kJ/period} \quad - \quad (4)$$

Where C_o is the emissivity of a black body, 5.768 $W/m^2.K^4$

T is the average temperature in the furnace, K

F is the surface area of the door, m^2

ϕ is the diaphraming coefficient.

φ is the time (fraction of a period) when the door is open.

4) **Heat Loses Through the Flue Duct, Q_{FL}:** Heat loss through the flue duct is in two ways;

- Heat loss with the flue; and
- Heat radiated through the duct.

Heat loss with the flue is calculated using;

$$Q_F = M_F C_F t_F \quad \text{kJ/period} \qquad - \qquad (5)$$

Where M_F is the mass of flue, kg/period.

C_F is the mean specific heat of flue, $KJ/kg.^OC$

t_F is the average temperature of waste gases leaving the furnace.

5) **Loss of Heat Accumulated in the Lining:** This is calculated using;

$$Q_{acc} = V_l \rho_l C_l t_l \qquad \text{kJ/period} \qquad (6)$$

Where V_l is the lining volume, m^3.

ρ_l is the density of lining, kg/m^3.

C_l is the specific heat of lining, $kJ/kg.^oC$.

t_l is the average temperature drop of lining, ^oC.

6) **Unaccounted Losses:** Un accounted heat losses from the furnace are taken to be 10% of calculated heat losses i.e.

$$Q_{un} = 0.1\,(Q_C + Q_{rad} + Q_{FL} + Q_{acc}) \qquad (7)$$

Therefore,

$$Q_{out} = Q_{us} + Q_C + Q_{rad} + Q_{FL} + Q_{acc} + Q_{un} = 420429.7 \text{kJ/period}$$

Converting this to KW gives

$$\frac{420429.7}{7200} = 58.4kW = Q_{in}$$

Rated power of the furnace P_r is then calculated using

$$P_r = K_s Q_{in} \quad kW \qquad - \qquad (2)$$

Where K_s is known as the safety factor = 1.3 [8]. Therefore,

$$P_r = 1.3 \times 58.4 = 75kW.$$

E. Materials needed for construction

1) **Number of bricks required for walls:** The standard dimension of a straight brick is 229 x 0.114 x 0.064m. Surface area of the largest side of brick is 0.229 x 0.114m^2. Then, for the side walls, the number of bricks required.

$$= \frac{surface\ area\ of\ one\ side\ of\ furnace\ \ x\ 4}{surface\ area\ of\ largest\ side\ of\ brick}$$

$$= \frac{1\ x\ 0.3\ x\ 4}{0.229\ x\ 0.114} = 46$$

Hence allowing for losses, about 50 bricks will be required.

For the floor and roof, the number of bricks required.

$$= \frac{0.3\ x\ 0.3\ x\ 2}{0.229\ x\ 0.114} = 7$$

Allowing for losses, about 10 bricks are required. Therefore total number of fireclay bricks required is 10 + 50 = 60 bricks.

2) **Fibre glass required**

$$= 1.128 \times 0.428 \times 4 + 0.4282 \times 2 = 2.3m^2$$

Hence a roll of 6 m x 0.5 m is required.

3) **Iron sheet required**

$$= 1.228 \times 0.528 \times 0.5282 \times 2 = 3.2m^2$$

Allowing for losses a sheet of about 5 m^2 surface area is required.

III. RESULTS AND DISCUSSION

Tests were carried out on the indirect resistance furnace to assess its operation and evaluate its performance. Table 3 and 4 shows the test results. The indirect resistance furnace performance was evaluated in terms of heating and melting rate, and insulation resulting.

Table 3: Test Data

Test	Mass of charge (kg)	Time of operation (min)
1	0	70
2	0	68
3	0	72
4	5	100
5	5	90
6	5	95
7	10	132
8	10	134
9	10	127

Table 4: Average Melting Rate

Average mass of charge (kg)	Average time of melting (min)	Average melting rate (g/min)
0	70	
5	95	52.63
10	131	76.34

The furnace has been tested under no load and loaded conditions. This was done for nine days. The reach time to the demanded temperature of melting point of cast iron (1150 – 1400) has been measured for each condition. The average reach time for no load condition has been found 70 minutes whereas, the average reach time for the first loaded conditions is 95 minutes resulting in a melting rate of 52.63g/min. The reach time in loaded condition takes more time because of physicochemical reactions [9]. The refractory material used also showed high insulation and thermal stability. Throughout the tests, no crack was observed in the refractory lining.

IV. CONCLUSION

The furnace design was successfully modified and constructed over a period of three (3) months. The new design dealt with the problem identified from the previous design. The opening of the furnace was changed successfully, and the design is more efficient in utilization of heat. The test shows that the performance is satisfactory. The heating rate and the melting rate are comparable to existing standard furnaces attaining a temperature of well over 1000^0C within an hour and melting the first charge in about 95 minutes.

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