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Design and Construction of a Gas-Fired Furnance Chamber Using Locally Sourced Kaolin

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ABSTRACT: The furnace chamber which is an important component of a furnance was designed and constructed.
Kaolin or white clay was used in the constructed due to its availability and accessibility locally. The thickness of the kaolin is 10.5 cm or 105 mm.
Fiber class was used as the insulating material due to its efficiency. The furnance chamber is rectangular in shape and has provision for burner mounting, flue gas exit (chimney) and a charging door. The whole structure is encased with 1.2 mm steel sheet.
KEYWORDS: Furnace, Furnace Chamber, Kaolin, white Ciay.

I. INTRODUCTION AND LITERATURE REVIEW

Furnace have been known for a long time since the 14th century it came into existence with the invention of the art of pottery making. Pottery work are usually heated for strength and in addition to obtaining colour during the process of heating.

Our ancestors knew already at the very beginning that clay jars could be made stronger and water resistant by heating them in the flame of an open fire. They also know that glass could be produced by smelting together sand wood ash as recorded by Bulavin and Rapoport (1986).

During the many centuries of their evolution of furnaces for manufacturing ceramics and other articles from the primitive furnace or kaolin to the modern continuous furnaces of very high productivity which are in use today.

A furnace is an enclosed device or a structure lined with refractory material in which heat is generated directly or indirectly by means of gas, oil coal or electricity to either melt or to improve on the properties of the materials being heated.

While refractory are costly and expendable, it is important that they should be well chosen and well laid with suitable refractory cements. When designing the furnace chamber in order to have proper foundational knowledge, special attention was given to the work done in the past by other researchers.

In the work of Paul. A. Tari (1993) detailed analysis of furnace classification and crucible furnace was presented. An area of great relevance as concisely treated. Considering the experience, he underwent in the wall of the furnace top in form of an arc instead of flat slab method which has assisted to improve the conventional heat transfer mechanism. The integral walling of the furnace was produced of locally sourced kaolin casted to form the wall thereby being a good castable lignite and thereby reducing the cost of the composite inner wall of the furnace chamber being that the locally sourced kaolin has pores or inter-stices of air in the bricks which serves as a dam thereby trapping more heat in the furnace chamber and reducing the heating-up period of the furnace.

In respect to Imade. F.B. (1993) contribution, he said that the furnace chamber is in batch form which will be fired by the gas will also be atomized to enhance the combustion process.

II. METHODOLOGY

2.1 FURNANCE DESIGN

Several concepts for the refractory lining of a furnace are in use, they are as follows.

2.2 COOLING CONCEPT

This concept is based on the phenomenon that frozen slag protects the refractory lining against attack, i.e. the process that diminishes lining life takes place in the adhere slag layer, normally a carbon (semi-graphite) material is used.

2.3 MICRO-POROUS CONCEPTS

The original Japanese concept is developed to prevent pig iron penetration in (carbon) refractory lining by applying micro-porous.

2.4 HOT PRESSED CONCEPT

This is the North-American concept, is based on the use of hot processed bricks that are soft (able to absorb thermal stresses) and less soluble in carbon.

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2.5 **CERAMIC CUP CONCEPT**

Instead of a carbon lining a ceramic material is used, in this way the dissolution of carbon of the refractory lining is prevented. In some cases the ceramic material is placed in front of carbon material and sometimes only a ceramic tube (wall) is used. The Ceramic Research Centre identify the best refractory material by performing thermal (heat loss) and stress calculations.
Research on potential refractory lining material and quality control on the supplied material (7)
The properties of the materials are as follow.
Maximum service temperature ----------- = 1600 ^{o}c
Thermal Conductivity ----------------- =1.04 w/m^{o}c
Emissivity------------------- = 0.75S

2.6 **ASSUMPTION MADE ON HEAT REQUIREMENT**

The following assumption were made during the design of the material that form the inner part of the furnace

(a) Every form of heat transfer were considered in the computation of heat transfer.
(b) One-dimensional heat flow pattern with uniform heat transfer in all direction are operated in the furnace.
(c) All heat lost if any, across the opening for burners insertion and furnace door are neglected.
(d) Total heat transfer across the refractory are basically considered. Finally, it is also of great importance to consider the following factors.
(i) The rate of heat transfer in the furnace.
(ii) The total amount of heat generated in the furnace.
(iii) The degree of insulation of the furnace walls.

2.7 **DESIGN SPECIFICATION**

The design specification for the furnace are as follows.

(1) Temperature of 100^{o}c is required for melting non-ferrous metals, hence it is been designed to meet the above specification.
(2) The crucible is directly fired by a burner with a gas supply.
(3) The furnace is to be used for melting non-ferrous metals in the crucible for laboratory purposes.

2.8 **CALORIFIC VALUE CALCULATION**

The mathematical representation of calorific value is given by
QV = Ê V × C.Vi -------------- (1)
I=ì
Where QV = Net Calorific value
Vi = Volume contributed by component ì
CVi = Calorific value of component ì
n = Number of component
From the above properties the net calorific value of butane is 111776.7 J/m^3 or 45705.9 J/kg and 46054.8 J/kg respectively.
Volume of propane = 0.07
Volume of butane = 0.93
Substituting the values of propane and butane in equation 1.
We have
QV = 45705.9 × 0.93 + 46054.8 × 0.07
QV = 42506.49 + 3223.84
QV = 45730.3 J/kg
Heat lost by radiation and dissolution ranges between 5% and 25%.
Therefore, taking a convenient percentage of 17.87% (9)
Factor of safety

$$QV_{net} = QV + \frac{(\text{Factor of safety})\,QV}{100}$$

$$QV_{net} = 45730.3 + \frac{17.87 \times 45730}{100}$$

QV_{net} = 45730 + 8172
QV_{net} = 53902.5 J/kg
QV_{net} = 53900 J/S = 53.9 kw

2.9 **DESIGN CALCULATION IN FURNANCE**

The external dimension of the furnaSce are as follow 0.55m by 0.45m by 0.35m

Thickness of refractory = X_a (Unknown)

Steel sheet thickness = 1.2 mm = 0.0012 m

Estimated inside temperature = 1000^oc

Estimated outside temperature = 25^oc

Since steady heat was transferred through the wall, it is assumed that the heat computation is done through the basis of total surface area. Therefore, total surface area of the furnance chamber is Area of chimney side + Area of charging door view + Area of burner end view + Area of top corner and floor.

Total Surface Area = 0.189 + 0.163 + 0.16 + 0.16 + 0.15

= 1.172 m^2

= 1.2 m^2

2.10 **CALCULATING THE HEAT REQUIRED**

From the net calorific value calculation, the heat which the gas developed in the furnance is 53.9 kw. This consist of the heat dissipated through all the heat transfer mode namely conduction, convection and radiation.

For Radiation heat transfer

$Q/A = ES (T_1 - T_2)$ .... (2)

$Q/A = 0.75 \times 5.669 \times 10^{-8} (1000^4 - 10^4)$

$= 42.5$ kw/m^2

For Radiation heat transfer is

$Q/A \times A_1$ (total)

$Q = 42.5 \times 1.178 = 50.09$ kw/m^2

2.11 Heat Transfer by Convection

Holman (10) stated that natural convection heat transfer are free

i.e. $h_0 = 10$ w/m^0k

A temperature of 1000^oc is needed in the furnance

From $\Delta T = Q/h_o (T_2 - T_1)$

Therefore, the state surface film temperature T_f

$T_f = \frac{T_1 + T_2}{2} = \frac{1000 + 25}{2} = 512.5^o$c

$(512.5^o c + 273)$ k = 785.5 k

This is the arithmetical mean temperature between the wall and free stream temperature in the furnance from standard table at 785.5 k.

The properties of air are

$V = 81.1 \times 10^{-6}$ $m^2/s^o c$

$P_V = 0.679$

R = 0.05692 w/m^oc

Where V= Kinetic viscosity

P_V = Prandi number

R = Thermal Conductivity

The modified Grashof number for constant heat flux is given as

$$\text{Grashof} = G_{rae} = \frac{gBQ_c^4}{RV^2} \quad \text{..................} (4)$$

Where

B = 1/TF = 1/7 = 1/785.5 =0.00127k^{-1}

B = temperature co-efficient of thermal conductivity in 1^oc

X = Wall thickness

G = Acceleration due to gravity

Therefore, substituting the values in to equation (4)

$$* G_{rae} = \frac{9.81 \times 0.00127 \times 9750 (0.102)^4}{0.05692 \times (81.1 \times 10^{-6})^2}$$

$$* G_{rae} = \frac{0.01315}{3.744 \times 10^{-10}} = 3.512 \times 10^7$$

Hence to calculate heat transfer co-efficient (h_{ae}) the equation will be

$h_{ae} = R/_{ae}(0.17) (G_{rae} \times PV)^{1/4}$ .... (5)

$$h_{ae} = \frac{0.05692 (0.17) [(3.512 \times 10^7) (0.679)]^{1/4}}{0.102}$$

$h_{ae} = 6.629$ w/w^2 ^{o}c

The mean value of the heat co-efficient is given as

$h = 4/3^{hae}$

$$h = \frac{4 \times 6.629}{3}$$

$h = 8.839\ w/m^2\ {}^oc$

The mean value of the heat co-efficient is given as

$h = 4/3^{\ hae}$

$$h = \frac{4 \times 6.685}{3}$$

$h = 8.914\ w/m^2\ {}^oc$

The overall heat transfer can be calculated since h_o and h are known.

2.12 Combination of Conduction and Convection Heat Transfer

$$Q/A\ (\text{overall}) = \frac{T_1 - T_2}{1/h + X_a/R_a + X_b/R_b + 1/h_o} \quad \ldots\ldots\ldots\ldots\ldots (6)$$

Where

X_a = Thickness of bricks

R_a = Thermal conductivity of the brick

X_b = Thickness of the steel sheet

R_b = Thermal conductivity of steel

$$Q = \frac{A\ (T_1 - T_2)U}{1/h_o + X_a/R_a + X_b/R_b + 1/h}$$

Recall that

$Q = Qv_{net} - Q_{radiation}$

$Q = (53.9 - 50.09)\ kw/m^2 = 3.81\ kw/m^2$

Thickness of the bricks will be

$$\frac{3.81 \times 10^3}{\text{Total Surface Area}} = \frac{T_{1} - T_2}{1/h_o + Xa/Ra + X_b/R_b + 1/h}$$

$$\frac{3.81 \times 10^3}{1.2} = \frac{1000 - 10}{1/10 + \frac{1.2 \times 10^{-3}}{52} + \frac{X_a}{1.04} + \frac{1}{8.914}}$$

$$3175 = \frac{990}{0.213} + \frac{X_a}{1.04}$$

$676.3 + 3.75\ (X_a/1.04) = 990 - 676.3$

$$\frac{X_a}{1.04} = \frac{313.7}{3175}$$

$$\frac{X_a}{1.04} = 0.0988$$

$X_a = 0.0988 \times 1.04$

$X_a = 0.1027\ m$

$X_a = 102.7\ m$

Adding up to 103mm

Considering factor of safety

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$X_a = 105mm$

With effective thickness of 105 mm or 10.5 cm of brick lining, the furnace is constructed with a burner of power of 55kw.

III. RESULT AND DISCUSSION

The gas fired furnace was tested in a foundry workshop. The temperature of the furnance was determined approximately by noting the different colours produced by the metal during the firing process.

The operating temperature that was achieved by the use of a gas value was 1000^{o}c using a steel specimen heated in the furnance. This temperature was achieved after 30 minutes of firing.

During the testing, it was observed that the pressure drop along the gas line resulted in a temperature drop at a constant volume as staled by the gas law which was noticed as the intensity of the flame diminished and the gas flow rate reduces. However, the temperature obtained was about 1,050^{o}c, the furnance was used to melt some aluminum scraps, some other metals within the range of temperature can also be melted.

IV. CONCLUSION

A full analysis of various classification of a furnace has been presented. A simple way of designing and constructing a furnace chamber was made. In this study, the shape of the furnace is rectangular, refractory material used is locally sourced kaolin and glass fibre insulation was added at the wall of the chamber. Spaces were made available for temperature probes at the top and side walls to measure the temperature in the chamber.
Clearance was provided in the crucible to allow for the process of expansion. At the front view, opening were provided for pouring out slag since crucible is integral with the inner wall. The furnance can be opened at the top to replace any deformed refractory and also provision was made for chimney so that products of combustion can escape from the Furnance chamber for refined melting. There is also a side door for the purpose of charging, two openings for the burner were provided for direct firing of charge.

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