ANALYSIS AND REDUCTION OF HEAT TRANSFER IN A FURNACE OF REFINERY

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Abstract. The primary goal of this work is to examine the current materials for insulation utilized in the furnace of a refinery unit and to limit the waste heat dissipation through the radiant wall subbing with legitimate insulation materials. There are some exceptional materials whose properties are appropriate for reducing the heat loss in the furnace walls which could clearly decrease the heat loss through the radiant walls. By critical examination of these materials, the external temperature of the furnace is determined to prove that these materials can be utilized as substitution to those of the standard insulation materials.

1. INTRODUCTION

Energy saved is energy produced. In India, any effort on energy management protects the environment. Refineries are energy consuming industry as they convert heavy crudes into products like LPG, Aviation turbine fuel, Motor spirit, Octane, Diesel, Kerosene, Bitumen, Paraffin wax, Fuel oil, Naphtha, Hexane and Petrochemical feed stocks. It has many units which includes three crude distillation units, Hydro cracker unit, fluid catalytic cracking unit, continuous catalytic reforming unit, visbreaker unit, isomerisation unit, Diesel hydro Desulphurization unit, diesel hydro treating unit, Lube hydro-finishing unit, NMP extraction unit, Propylene unit and Petrochemical feedstock unit. Refineries implement Advance Process Control (APC) and optimization techniques in all its processing units to reap the benefits of heats of reaction in furnace. The Design of the furnace differs as to its functions, based on heating load, kind of fuel burnt and method of inducing air into the combustion chamber. Heat is produced can be augmented economic benefits. [3] That can be achieved by implementing online strategies to regulate higher-level objectives such as quality control, energy optimization and improved stability of the process unit. An attempt has been made in this project to study and improve the environmental conservation measures. A dedicated environment management team functions exclusively to plan, implement, operate and monitor all environment-related activities.

1.1. Industrial Furnace

The persistence of an industrial furnace is to achieve a better processing temperature in contrast with the open-air system, as well as the efficiency gains of the closed system. Industrial furnace classically deals with temperature higher than 400 degree Celsius. An industrial furnace is equipment used to deliver heat for a process or can serve as reactor which makes available
continuous heats for reactions to happen. An industrial furnace generates heat by mixing fuel with air/pure oxygen, or either from electrical energy. The residual heat will exit the furnace as flue gas. The design of the furnace is in such a way to consume fuel and heat as less as possible in a given time that requires low labor cost. An industrial furnace serves the purpose of heating that it serves as a reactor to provide heat to the reaction [1]. The basic features of the furnace stand constant while the design of the furnace evolve according to the needs. These evolved new designs of furnace are said to comply with the international standards as prescribed by ISO 13705 (Petroleum and natural gas industries — Fired heaters for general refinery service) / API Standard 560 (Fired Heater for General Refinery Service). Industrial furnaces are used many areas some of the noticeable areas in which industrial furnace are utilized includes chemical reaction furnaces, cremation, oil refining, and glasswork. The combustion happens in furnace by entrainment of fuel and air into the combustion chamber of the furnace. The fuel enters the furnace by the means of burner and on the other hand the air is taken into the chamber through a blower specifically designed to satisfy the air requirement of the fuel inducted. a furnace can have more than one burner to heat up a set of tubes arranged in a cell. Burners can also be mounted in the floor, walls or roof of the furnace depending on the requirements. The flames from the burner heat up the tubes, which subsequently heats up the fluid that is flowing inside the tube, the former part of the furnace is called as radiant section or fire box. This is the place where combustion takes place, and the heat primarily transferred by means of radiation around the tubes inside the chamber. Since the heating fluid is circulated inside the heated tubes, the fluid acquires the desired temperature. The gases from the combustion are known as flue gas. After the flue gas leaves the firebox, most furnace designs include a convection section where more heat is recovered before venting to the atmosphere through the flue gas stack.

2. Problem Definition

After the field study in a refinery and literature reviews, the problem lies mainly with the insulating materials of a furnace in the refineries. Over a period of time, the furnace walls are weekend due to high outer temperature and it affects the performance. The furnace should be replaced once in two or three years. For better performance the operating cost also will become more. This project attempts to investigate / analyze the different insulating material in order to increase the life time of insulating walls. In the following section, detailed analysis is made to suggest an alternate insulating material.

At a burning temperature of 850°C, heat flows in the form of radiation mostly, followed by convection. The radiating wall is made up of insulating materials of which bricks are the first layer to get exposed to the flow of heat of the burning fuel. The mortar, which is the primary constituent for building the brick insulation sometimes, may get perforated due to some factors like a three year maintenance period due to newly replaced burners which shows good performance on the old built bricks may cause damage or losing the brick quality. Due to this leakage, the walls of the furnace gets heated up, layering out the epoxy paint which emits heat around the furnace. The usage of fuel increases, at the same time, power and energy increases. The amount of oxygen required to burn the fuel has to be increased simultaneously. The present insulation materials used in the furnace wall are Insulating Fire brick, Stainless Steel 316 foil, Calcium Silicate and Asbestos. The temperature measured inside the furnace T1 is about 850 and outside the wall is about 85. This investigation is carried out to reduce the heat transfer in the walls of the furnace by using alternate insulation materials by carrying the heat analysis for various materials. The insulation materials listed in the market are Polyethylene foam, Fiberglass rigid panel, papercrrete, Cellular concrete, glass, Poured concrete, Cardboard, Material Fiber, Mica, Cellulose and Polystyrene. Hence investigating the parameters like less thermal conductivity, High melting point, Harmless to humans, Resistance to corrosion and cost involved the materials like Silica Aerogel, Ceramic Fiber board are considered as alternatives.
The elements of focus of the analysis are investigated here.

3. Materials and Methods

Furnaces are most certainly employed in the industry to deliver the heat, by burning solid, liquid or gaseous fuels. Furnaces fundamentally comprises of a refractory lined chamber containing series of tubes. These tubes carry the process fluid that has to be heated. Sizes of the tubes and furnace are designed basically for burning of fuel with air to engender hot gases. A great variety of geometries and sizes are used and much of the skill employed in their design based on experience and prior literature studies. However, all furnaces have in common the general feature of heat transfer from hot gas source to a cold sink, and in the past few decade theoretical models of increasing complexity and power have been developed to aid the designer in understanding the process of heat transfer better enabling them to design the furnace in a most sophisticated way. The insulating materials suggested to be used in the furnace are listed below

3.0.1. Insulating Firebricks

Firebricks employed as insulating materials has major difference from commercial construction bricks. The chemical composition of Insulation fire bricks consists of 22% – 25% of alumina in its total weigh percentage and 75-78% of silica along with oxide form of ferrous, titanium and other essential metallic components. Presence of the mentioned chemical composition at right proportion helps the insulating bricks to be stable in high temperature environment due to its proportionally low thermal conductivity at substantially higher energy efficiency. In addition to fire refractory bricks materials such as ceramics and kilns were also employed due to their matching property with fire bricks. The firebricks were chosen since it abides the following prime properties to serves the purpose as follows, distinguishingly heavier by weight, lower in porosity and its decomposition will take place at least between 1800 – 2000 degrees Fahrenheit. This higher insulating value has thermal conductivity between 1.005 W/mK to 1.15 W/mK, bulk density between 1.80 tons per kg/m3 to 2.4 tons per kg/m3, Apparent Porosity between 28% to 32%, Modulus of Rupture between 4.75 MPa to 5.25 MPa and bulk density between 1900 Kg/m3 to 2200 Kg/m3.

3.1. Stainless Steel foil

Heat treated steel is a group of iron-based compounds that contain at least roughly 10-12% chromium, heat treating keeps the iron from rusting, just as giving warmth safe properties. Various sorts of tempered steel incorporate the components carbon, nitrogen, aluminum, silicon, sulfur, titanium, nickel, copper, selenium, niobium, and molybdenum. Explicit sorts of heat treated steel are regularly assigned by a three-digit number e.g: 304 spotless. Hardened steels protects itself from ferric oxide arrangement resulting from the rupture of the chromium in the compound, which leads to formation of latent film that shields the hidden material from erosion formation, and can self-recuperate within the sight of oxygen. Consumption obstruction can be expanded further, by Increasing the chromium substance to levels above 15%, Addition of 10% or higher measures of nickel, and Addition of molybdenum. Expansion of nitrogen likewise improves protection from erosion formation and increments mechanical quality. Accordingly, there are various evaluations of hardened steel with differing chromium and molybdenum substance to suit the condition.

3.2. Calcium Silicate

Calcium Silicate is the substance compound Ca2SiO4. It is likewise alluded to by the abbreviated exchange name Cal-Sil or Calsil. Calcium Silicate is usually utilized as a sheltered option in contrast to asbestos for high-temperature protection materials. Modern evaluation channeling and hardware protection is regularly manufactured from Calcium Silicate [3]. Its creation is a
standard piece of the educational program for protection disciples. Calcium Silicate contends in these domains against rockwool restrictive protection solids, for example, perlite blend and vermiculite fortified with sodium Silicate. Although it is famously viewed as an asbestos substitute, early employments of Calcium Silicate for protection despite everything utilized asbestos filaments. Hydrated calcium silicate sheets were given by their maker in a helpful size of 160 mm by 160 mm by 30 mm. Their mass densities were controlled by discrete estimations of test mass and physical measurement. It is to be noticed that the maker’s cited densities relate near the qualities decided for the samples subsequent to being presented to 1000 C. Around 50 g of every material was ground to a powder and the powder thickness decided utilizing a standard test technique ordinarily utilized for deciding the thickness of water driven concrete powder, utilizing isopropanol as the estimating arrangement. The powder thickness estimation was performed on two separate examples from every material and the normal worth is determined earlier. The deliberate powder densities of the first materials of 2540 kg/m3 to 2550 kg/m3 contrast well and a formerly distributed estimation of 2541.5 kg/m3 with a standard deviation of 26.6 kg/m3. For a comparable material. In the wake of warming to 1000 C, no critical change was seen in the materials’ powder thickness.

3.3. Ceramic Fiber
Ceramic fibre is one among the several synthetic materials, those can generally withstand the temperature above 1000°C. under this category initially Aluminium Silicate fiber was developed in late 1950s, that was widely renowned as refractory ceramic fiber. [2] due to the high production cost involved in the production, the limited availability of the raw material these are only utilized in high temperature application alone where high degree of insulation is required. The manufacture of the fiberboard starts with the chipping of fresh or recycled wood material. The wood materials are initially expurgated and sorted into small pieces of finite and uniform sizes. These chips are washed continually with fresh water to ensure the cleanliness of the materials for dirt and sand. A magnetic conveyor can be used to remove the small pieces of ferric metals and nails. On account of, Medium Density Fiberboard (MDF) chips are steamed to soften them for defibration. Modest quantity of paraffin wax is added to the steamed chips and they are changed into fluffy strands in a defibrator and soon thereafter splashed with glues, such as urea-formaldehyde (UF) or Phenol formaldehyde gum (PF). Wax keeps strands from clumping together during storage. Chips on account of particle board are likewise splashed with an appropriate adhesive before the subsequent stages. Filaments or chips are organized into a uniform tangle on a transport line. This tangle is pre-compacted and afterward hot-squeezed. Hot-squeezing enacts the adhesives and pastes the strands or chips together. Board is then cooled, cut, sanded and possibly veneered or overlaid.

3.4. Silica Aerogel
Silica Aerogel is a porous ultra-light material synthesised from a gel where the liquid component of the gel is alternated by a gas. Silica Aerogel possess extremely low thermal conductivity than any other material hence, it can be a better alternative for the regular industrial insulators. They are good insulators because they are entirely of gases which are very poor conductors of heat. It is Silica-based and can be derived from Silica gel or by a modified Sober process. The lowest-density Silica nano foam weighs 1,000 g/m3, which is the evacuated version of the record-Aerogel of 1,900 g/m3. The density of air is 1,200 g/m3 (at 20 C and 1 atom). As of 2013, aero graphene had a lower density at 160 g/m3, or 13% the density of air at room temperature. This Aerogel has remarkable thermal isolative properties, having an extremely low thermal conductivity from 0.03 W/mk in atmospheric pressure down to 0.004 W/mk in modest vacuum. Its melting point is 1,473 K (1,200 C; 2,192 F). Until 2011, Silica Aerogel held 15 entries in Guinness World Records for material properties, including best insulator and
lowest-density solid [6].

4. Results and Discussion

4.1. Analysis of heat transfer rate of present insulating material.

The heat transfer rate of the current materials has been calculated using the basic heat conduction equation that has been provided by Fourier’s law of heat conduction and the overall heat transfer rate is taken as 827.02 W/m² from the basic experiments conducted in the furnace and the temperatures at the inner and outer wall is measured as 850°C and 85°C respectively. The physical properties of the replacement materials is given in the table 1.

The value of $Q = 1264.447$ W/m² obtained is considered as constantly acting on the inner wall of insulation for the measured practical values. We observed different temperature regions on the same outer wall as there is increase in temperature due to eroded regions of the furnace due to some internal defects in the insulation.

| S.no | Replaced material | Thickness (mm) | Thermal conductivity (W/mk) |
|------|-------------------|----------------|----------------------------|
| 1    | Insulating firebrick | 114            | 0.38                       |
| 2    | SS-316 Foil       | 0.1            | 13.4                       |
| 3    | Silica Aerogel    | 10             | 0.016                      |

Table 1. PHYSICAL PROPERTIES OF REPLACEMENT MATERIALS

4.2. Economic Calculations

From the values of the heat transfer obtained from the above calculation the amount of fuel savings is estimated by using the equation given below:

\[
\text{Heat flow of already installed material} = \text{Heat flow of replaced material} \times \frac{\text{Fuel oil used for replaced material}}{\text{Heat flow of replaced material}}
\]

Break even analysis was done with the existing data pertaining to the furnace to determine the quantity of the insulating material required. Form the standard costs of the insulating materials given in the table 2 the total cost of the materials is estimated and break even point has been determined using the formula

\[
\text{Break even point} = \frac{\text{Total cost of insulation material}}{\text{Cost of fuel saved per kg}}
\]

| S.No | Material   | Area | Cost () |
|------|------------|------|---------|
| 1    | Firebrick  | 1m²  | 780     |
| 2    | SS-316 Foil| 1m²  | 250     |
| 3    | Silica Aerogel | 1m² | 3500    |

Table 2. COST OF THE INSULATION MATERIAL

4.3. Replacement of already existing material

The insulation wall shall be replaced with silica aerogel and ceramic fiber board instead of calcium silicate block and asbestos mill board because of its heat transfer rates. The reasons for suggesting Silica Aerogel is as follows:

(i) Lower thermal conductivity which in turn reduces the heat transfer rate.

(ii) Also reduction in thickness of insulation material which is 10mm which also reduces the cost involved.
Table 3. CHARACTERISTICS OF SILICA AEROGEL AND CERAMIC FIBER BOARDS

| Material      | Thermal conductivity(W/mk) | Heat Transfer Q (W/m2) | Cost () |
|---------------|----------------------------|------------------------|---------|
| Silica Aerogel| 0.016                      | 827.02                 | 3500    |
| Ceramic Fiber | 0.1                        | 956.25                 | 1800    |

Therefore Q = 827.02 W/m².
Breakeven point = 385 days.

The reasons for suggesting Ceramic fiber board is as follows:

(i) Lower thermal conductivity which in turn reduces the heat transfer rate.
(ii) Also reduction in thickness of insulation material which is 50mm which also reduces the cost involved.

Therefore Q = 956.25 W/m².
Breakeven point = 435 days.

5. Mathematical Model of the problem
For the purpose of modelling the above problem Finite volume method for two-dimensional diffusion problem as in fig 1. Two-dimensional steady state diffusion equation is given by

\[
\frac{\partial}{\partial x} \left( \Gamma \frac{\partial \phi}{\partial x} \right) + \frac{\partial}{\partial y} \left( \Gamma \frac{\partial \phi}{\partial y} \right) + S_\phi = 0
\]

Integrating the above equation (1) over a control volume as shown in figure 1 gives the following equation

\[
\int_{\Delta V} \frac{\partial}{\partial x} \left( \Gamma \frac{\partial \phi}{\partial x} \right) dx dy + \int_{\Delta V} \frac{\partial}{\partial y} \left( \Gamma \frac{\partial \phi}{\partial y} \right) dx dy + \int_{\Delta V} S_\phi \Delta V = 0
\]

Noting that \( A_e = A_w = y \) and \( A_n = A_s = x \) we get

\[
\begin{align*}
\Gamma_\varepsilon A_e \left( \Gamma \frac{\partial \phi}{\partial x} \right) e &- \Gamma_w A_w \left( \Gamma \frac{\partial \phi}{\partial x} \right) w + \Gamma_n A_n \left( \Gamma \frac{\partial \phi}{\partial y} \right) n - \Gamma_s A_s \left( \Gamma \frac{\partial \phi}{\partial y} \right) s + \vec{S} \Delta V = 0
\end{align*}
\]

Flow across West face

\[
\Gamma_w A_w \left( \Gamma \frac{\partial \phi}{\partial x} \right) w = \Gamma_w A_w \left( \frac{\phi_E - \phi_W}{\delta x_E} \right)
\]

Flow across East face

\[
\Gamma_e A_e \left( \Gamma \frac{\partial \phi}{\partial x} \right) e = \Gamma_e A_e \left( \frac{\phi_E - \phi_P}{\delta x_e} \right)
\]

Flow across South face

\[
\Gamma_s A_s \left( \Gamma \frac{\partial \phi}{\partial y} \right) s = \Gamma_s A_s \left( \frac{\phi_S - \phi_P}{\delta y_s} \right)
\]

Flow across North face

\[
\Gamma_n A_n \left( \Gamma \frac{\partial \phi}{\partial y} \right) n = \Gamma_n A_n \left( \frac{\phi_N - \phi_P}{\delta y_n} \right)
\]

Substituting above expressions in (3) we get

\[
\Gamma_e A_e \frac{\phi_E - \phi_P}{\delta x_e} - \Gamma_w A_w \frac{\phi_E - \phi_W}{\delta x_W} + \Gamma_n A_n \frac{\phi_N - \phi_P}{\delta y_n} - \Gamma_s A_s \frac{\phi_S - \phi_P}{\delta y_s} + \vec{S} \Delta V = 0
\]

Representing , source term as surface tensor and body force terms and rearranging the above equation we can get.
\[ \left( \frac{\Gamma_w A_w}{\delta x_{wp}} + \frac{\Gamma_e A_e}{\delta x_{pe}} + \frac{\Gamma_n A_n}{\delta y_{pn}} - S_p \right) \phi_p = \left( \frac{\Gamma_w A_w}{\delta x_{wp}} \right) \phi_W + \left( \frac{\Gamma_e A_e}{\delta x_{pe}} \right) \phi_E + \left( \frac{\Gamma_s A_s}{\delta y_{sp}} \right) \phi_S + \left( \frac{\Gamma_n A_n}{\delta y_{pn}} \right) \phi_N + S_u \]

The above equation is in the form of general equation for two dimensional problem that can be easily approached using FVM the face coefficients. The above equation can be solved by applying tridiagonal Matrix Algorithm (TDMA) the algorithm was solved using the computer code generated using Python and the results of the solver is plotted.

\[ a_p \phi_p = a_w \phi_w + a_e \phi_e + a_s \phi_s + a_n \phi_n + h \]

Governing equation,
\[ \left[ \frac{\partial}{\partial x} \left( R \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left( k \frac{\partial T}{\partial y} \right) = 0 \right] \]

Where \( a_w = -k \Delta x A_w, a_e = -k \Delta x A_e, a_s = -k \Delta y A_s, a_n = -k \Delta y A_n \) \( a_p = a_w + a_e + a_s + a_n \)

Also, \( A = \Delta x \times \) thickness of plate.

The simulation results of the developed code are done and given in the figure 2. This shows the temperature contour of the boundary conditions stated as per the temperature of furnace.
in the refinery under consideration.

6. Conclusion

Literature survey and field study confirmed the importance of insulating material in the furnace operations. Technological development in the materials and manufacturing provides newer materials for various applications. In this project work, the alternate materials have been considered and the experiments are conducted. The results show that, by using the suggested alternate materials like Ceramic Fiber and Silica Aerogel instead of Calcium Silicate and Asbestos, the heat transfer is reduced and fuel consumption is also reduced which in turn increases the profit of the industry. Hence suggested materials for replacement best suits the present and future scope of the industry by reducing the additional cost involved in maintenance.

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