Model and analysis of shell and tube heat exchanger by using exhaust gases of diesel generator

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ABSTRACT

In this paper, a 125KVA diesel generator which loses the exhaust gases at a temperature of 350°C. That waste heat is recovered by replacing the silencer of the power plant by a heat exchanger. Heat exchanger is an efficient device in which the process of heating or cooling occurs. The main function of heat exchanger is to provide flow path for hot and cold fluid without mixing of fluids. A host of units know as shell and tube exchangers are built of round tubes mounted in cylindrical shells with there axis parallel to that of the shell. Fluid flow in the Heat exchanger is considered as a fluid dynamic problem and is modelled using finite element method. The flow field in the tube due to the oscillation conditions of inlet flow is analyzed. The pressure pulsation at the tube inlet is employed to produce a flow pulsation, which is caused by superimposing an oscillating pressure gradient on the steady driving pressure of the flow. These are employed as heaters or coolers for a variety of applications. Most heat exchanger problems ultimately result from faulty or inadequate information at the design stage. Computational Fluid Dynamics or CFD is the analysis of system involving the fluid flow, heat transfer and associated phenomena such as chemical reactions by means of computer based simulation. It is an approach and a tool for analyzing the Fluid Dynamic problems. To implement the CFD, ANSYS software is used as a tool. Now a day’s fluid flow analysis is a challenging criteria and is even in research to obtain the flow linearity and complete fluid flow at various environmental conditions.

KEYWORDS: Computational Fluid Dynamics, Heat Exchanger, Fluid Flow, ANSYS

1. INTRODUCTION

In a 125KVA diesel generator the exhaust gases (flue gases) are leaving the chimney at a temperature of about 350°C presently the exhaust gases are waste to the atmosphere. This waste heat is recovered by using a heat exchanger placed instead of silencer of the power plant. The flue gases are cooled using a shell and tube heat exchanger. A wide variety of heat exchangers are employed in industrial applications which is used to exchanger heat between two fluids either in direct contact (or) indirect contact with each other (Hatami, 2015). Exchangers have variety of names depending on their modes of heat transfer. Heat flow in the tube has received significant attention in thermal engineering due the enhancement of heat transfer coefficients. In general, the pulsating flow field consists of a steady flow part and as oscillating pressure (Vamsi, 2015). In this study we have considered only pressure distribution of the pulsating flow. A wide variety of heat exchangers are employed in industrial applications, which can be served for this equipment is to exchange heat between two fluid either in direct contact or indirect contact with each other. Exchanger has variety of names depending on their modes of heat transfer. These names serve to identify the modes of heat transfer of the system and in many cases also infer the image of the shape and appearance of the unit Rating Engineering recognize that heating partial or total Condensation highly viscous flows etc. are considerations, which may profoundly affect the desirable shape of the heat exchanger.

Shell and tube heat exchanger: As a piece of mechanical hardware, a tubular heat exchanger consists of two Intertwined pressure vessels. The inlet header, outlet header, inside of the tubes and the Inlet / outlet nozzles commonly referred to as the “tube side” chamber. The remaining space in the heat exchanger between the shell and the tube is the other pressure vessels Known as the “shell side” chamber. Two fluid at different temperatures enter the two pressure chambers exchange across the tube walls throw a combined conductions- convection mechanism and then exit throw the outlet nozzle. The shell and tube heat exchanger is the most common of the various types of unfired heat transfer equipment used in industry. It is recuperative type heat exchanger. Although it is not especially compact, it is robust and it can be designed for large surface areas having pressure greater than 30bar and temperature greater than 260°C (4-18).

Design parameters:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Fluid</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>C Hot Fluid</td>
<td>: Flue Gases</td>
<td>: Mild Steel</td>
</tr>
<tr>
<td>Cold Fluid</td>
<td>: Water</td>
<td>: Stainless Steel</td>
</tr>
<tr>
<td>Shell Material</td>
<td>= Mild Steel</td>
<td></td>
</tr>
<tr>
<td>Tube Material</td>
<td>= Stainless Steel</td>
<td></td>
</tr>
<tr>
<td>Thi</td>
<td>= 3500C</td>
<td></td>
</tr>
<tr>
<td>Tei</td>
<td>= 300C</td>
<td></td>
</tr>
<tr>
<td>Tho</td>
<td>= 1000C</td>
<td></td>
</tr>
<tr>
<td>Tco</td>
<td>= 1600C</td>
<td></td>
</tr>
</tbody>
</table>
Assume tube OD = 19.05mm
Thickness of tube = 1.24446mm
Tube ID = 16.56mm
Shell OD = 334mm
Shell ID = 322mm
Length of the Exchanger L = 1.8m
Volume flow Rate of Flue Gas from the Diesel Engine = 10,000m³/Hr
Flue Gas Velocity = 95m/sec
Quantity of Fuel Consumption per Hour of Diesel Engine = 126 Lit/Hr

To Find the Mass Flow Rate of Flue Gas

\[ m = \frac{10,000}{3600} \]
\[ m_f = \frac{10,000 \times 0.571}{3600} \]
\[ m_f = 1.586 \text{ kg/sec} \]

This Mass Flow Rate can be Divided into Two Silencers.

\[ m_f = \frac{1.586}{2} = 0.793 \text{ kg/sec} \]

Properties of Fluids:

**Hot Fluid (Flue Gas)**

\[ \rho_h = 0.571 \text{ kg/m}^3 \]
\[ C_{ph} = 1.1365 \text{ KJ/Kgk} \]
\[ M_h = 29.95 \times 10^{-6} \text{ kg/ms} \]
\[ P_r = 0.645 \]
\[ K_h = 52.685 \times 10^{-3} \text{ w/mk} \]

**Cold Fluid (Air)**

\[ \rho_c = 0.959 \text{ kg/m}^3 \]
\[ C_{pc} = 1.165 \text{ kg/kgk} \]
\[ m_c = 21.675 \times 10^{-6} \text{ kg/ms} \]
\[ P_r = 0.689 \]
\[ K_c = 31.69 \times 10^{-3} \text{ w/mk} \]

**Mass Flow Rate of Cold Fluid**

\[ Q = m_h C_{ph} (\Delta T)_h \]
\[ Q = m_c C_{pc} (\Delta T)_c \]
\[ 0.793 \times 1.1365 \times (350 - 100) = m_c \times 1.165 \times (160 - 30) \]
\[ m_c = 1.4877 \text{ kg/sec} \]

**Capacity Rating of the Blower**

\[ Q = \text{ Ava} \]
\[ m_c = \frac{1.4877}{1.165} \]

\[ Q = 1.2769 \text{ m}^3/\text{sec} \]
\[ 1 \text{m}^3 = 35.33 \text{ ft}^3 \]
\[ Q = \frac{1.2769 \times 35.33}{35} = 2700 \text{ C.F.M} \]

The Capacity Rating of the Blower = 2700 C. F. M

**Total Area of Discharge Pipe of Blower**

\[ A = 254 \times 254 \]
\[ A = 0.0645 \text{ m}^2 \]

**Velocity of Air From the Blower**

\[ Q = AV_a \]
\[ 1.2769 = 0.0645 \times V_a \]
\[ V_a = 19.79 \text{ m/sec} \]

**Actual heat transfer surface area:**

\[ Q = \text{ FUA LMTD} \]
Where F - Correction Factor
Overall Heat Transfer Coefficient 250 (Assumed Value)

LMTD – Log Mean Temp Difference

A – Surface Area

Assume: flow in Counter Direction LMTD for Counter Flow

\[ LMTD = \frac{\ln \left( \frac{\Delta T_1}{\Delta T_2} \right)}{\ln \left( \frac{160 - 30}{160 - 100} \right)} \]

\[ \Delta T_1 = 350 - 160 = 190 \]
\[ \Delta T_2 = 100 - 30 = 70 \]

\[ LMTD = \frac{190}{\ln \left( \frac{190}{70} \right)} = 120.18^\circ C \]

Correction factor: The correction factor is a function of the shell and tube fluid temperatures and the number of tube and shell pass. It is normally correlated as a function of two dimension less temperature ration.

\[ R = \frac{T_{ci} - T_{co}}{T_{hi} - T_{ho}} = \frac{30 - 160}{100 - 350} = 0.52 \]
\[ P = \frac{T_{hi} - T_{ho}}{T_{ci} - T_{co}} = \frac{100 - 350}{30 - 160} = 1.923 \]

From HMT Data Book Page No. 161

\[ F=1 \]

Stream flow rates: Allocating the fluids with the lowest flow rate to the shell inside normally give the most economical design.

\[ Q = FUA LMTD \]
\[ A = \frac{225.3 \times 10^3}{1 \times 250 \times 120.18} \]

To find the no” of tubes

\[ A = n \pi d_0 L \]
\[ 7.499 = n \pi \times 19.05 \times 10 - 3 \times 1.8 \]
\[ n = 69.61 \triangleq 70 \]

n = 70 tubes

Equivalent Diameter

For square pitch

\[ d_e = 4 (pt^2 - \pi d_0^2) \]
\[ d_e = \frac{1.27}{d_0} (pt^2 - 0.785d_0^2) \]

Where Pt
\[ = 1.25 d_0 \]
\[ = 1.25 (19.05) \]
\[ P_t = 23.8125 mm \]

\[ d_e = \frac{1.27}{0.01905} (0.0238125^2 - 0.785 \times 0.1905^2) \]
\[ d_e = 0.01881 m \]

Tube Sheet Lay – Out

<table>
<thead>
<tr>
<th>Number of Passes</th>
<th>1</th>
<th>2</th>
<th>4</th>
<th>6</th>
<th>8</th>
</tr>
</thead>
<tbody>
<tr>
<td>K1</td>
<td>0.215</td>
<td>0.156</td>
<td>0.158</td>
<td>0.0402</td>
<td>0.0331</td>
</tr>
<tr>
<td>n1</td>
<td>2.207</td>
<td>2.291</td>
<td>2.263</td>
<td>2.617</td>
<td>2.643</td>
</tr>
</tbody>
</table>

The bundle diameter will depend not only on the number of tubes but also on the number of passes, as spaces must be left in the pattern of tubes on the sheet to accommodate the passes partition. As an estimate of the bundle Db can be obtained from the following equation.

\[ N_t = k_1 \frac{(D_b / d_e)^{n1}}{d_e} \]

\[ D_b = d_e \frac{(N_t / k_1)^{n1}}{d_e} \]

Where

\[ N_t = \text{Number of Tubes} \]
\[ D_b = \text{Bundle Diameter in mm} \]
\[ D_o = \text{Tube Outside Diameter in mm} \]

Constant for Use

Square Pitch P_t = 1.25 d_0

For Single Pass Arrangement

\[ K_1 = 0.215 \]
\[ n_1 = 2.207 \]

\[ D_b = d_e \frac{(N_t / k_1)^{n1}}{d_e} = 19.05 \times (70 / 0.215)^{1.207} \]
\[ D_b = 262 mm \]
Bundle Dia, D_b = 262 + 18.71 = 280.76 mm
Shell Inner Diameter = 280.76 + 25.4 = 306.16 mm
Shell Outer Diameter = 306.16 + 25.4 = 331.56 mm
Shell O. D = 331.56 mm < 334 mm

So the Design is Safe

**Baffle Spacing**

Baffle Diameter = D_s – 1 / 16\(^{in}\) = 322 – 1.6\(^{in}\) = 320.4 mm
Baffle Spacing l_b = 0.4 X D_s = 0.4 X 322 = 128.8 mm

**Cross Flow Area Calculation:**

\[
A_s = \frac{(P_1 - d_o)O_2 X l_b}{P_1} = \frac{(23.8125 - 19.05) X 322 X 128.8}{23.8125}
\]

\[
A_s = \frac{8294 \text{ mm}^2}{A_s}
\]

\[
A_s = \frac{0.008294 \text{ m}^2}{0.793}
\]

Shell side mass velocity

\[
G_s = \frac{m_s}{A_s} = \frac{95.6 \text{ kg/m}^3}{0.008294} = 56.8 \text{ kg/s/m}^3
\]

**Reynolds Number Calculation**

\[
Re = \frac{G_s d_e}{\mu} = \frac{95.6 \times 0.01881}{29.95 \times 10^{-6}} = 6.0041 \text{ Re} = 60041 > 10,000
\]

So, the Flow becomes Turbulent

\[
\frac{h_s d_e}{k_s} = 0.36 \times (Re)^{0.55} \times (Pr)^{0.33} \times \left(\frac{\mu}{\mu_{ref}}\right)^{0.34} = 0.36 \times (60041)^{0.55} \times (0.645)^{0.23} \times 1
\]

\[
h_o = \frac{132.31 \times 52.685 \times 10^{-3}}{0.01881} = 370.6 \text{ W/m}^2 \text{k}
\]

**Tube Side Parameters**

\[
Re = \frac{p vd_i}{\mu} = \frac{0.959 \times 19.79 \times 16.56 \times 10^{-3}}{21.675 \times 10^{-6}}
\]

\[
Re = 14500 > 10,000
\]

So the flow becomes turbulent

\[
\frac{h_l d_i}{k_t} = 42.28
\]

\[
h_l = 80.90 \text{ W/m}^2 \text{k}
\]

To Find the Overall Heat Transfer Coefficient Neglecting the Fouling Resistances

\[
U_0 = \frac{1}{\frac{1}{h_0} + \frac{1}{h_i}} = \frac{1}{370.6} + \frac{1}{80.9} \left(\frac{19.05}{16.56}\right)
\]

\[
U_0 = 59.1 \text{ W/m}^2 \text{k}
\]

The value obtained is which in the limit of value assumed so the design is safe.

**Pressure Drop Calculations**

**Tube Side Pressure Drop**

\[
\Delta P_t = \frac{f G S^2 L n}{2 \rho d_i \Theta t}
\]

\[
f = 0.079 \text{ Re}^{0.25} = 0.079 \times (14500)^{0.25}
\]

\[
f = 0.007199
\]

\[
\Delta P_t = \frac{0.007199 \times (98.65)^2 \times 1.8 \times 1}{2 \times 0.959 \times 16.56 \times 10^{-3} \times 1}
\]

\[
\Delta P_t = 3970 \text{ N/m}^2
\]

\[
\Delta P_t = 3.97 \text{ kN/m}^2 < 10 \text{kN/m}^2
\]

So, the Design is Safe

**Shell Side Pressure Drop**

\[
\Delta P_s = \frac{f G S^2 D_{SL}}{2 \times 10^6 \times d_s \times l_s} \text{ KN/m}^2
\]

\[
f = 1.78 \times \text{ Re}^{0.2} = 1.78 \times (60041)^{0.2}
\]

\[
f = 0.1971
\]

\[
\Delta P_s = \frac{0.1971 \times (95.6)^2 \times 0.322 \times 1.8}{2 \times 10^6 \times 0.01881 \times 0.1288} = 0.2155 \text{ kN/m}^2 < 10 \text{kN/m}^2
\]

\[
\Delta P_s = 215.5 \text{ N/m}^2
\]
The pressure drops are within the limits so the design is safe.

Modelling of heat exchanger using CREO 2.0: From the above calculations the shell and tube exchanger design in CREO 2.0 and the model is shown below Fig. 1 and 2. CREO 2.0 is a parametric solid modeling system - models are defined by dimensions which are easy to change and the models have some 'intelligence'. CREO 2.0 is a good way of implementing concurrent engineering, which is the way design is increasingly organized. 'Concurrent engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacturing and support.'

**SIMULATION**

**Modal Analysis:** Modal analysis is conducted to find thermal analysis of shell and tube heat exchanger.
CFD analysis: Simulation is conducted to find out the advanced geometry acquisition, mesh generation, mesh optimization, and post-processing tools to meet the requirement for integrated mesh generation and post processing tools for today’s sophisticated analyses.
Conventional design does not give real heat transfer effect. To overcome such problems step is taken for a new design of a counter flow shell and tube type heat exchanger. Heat exchanger dimensions are calculated initially by design procedure. Then the calculations are used for modeling. Thus the modeling is created successfully in CREO 2.0. While carrying out this project we are able to study about the 3D modelling software (CREO 2.0) to develop our basic knowledge to know about the industrial design. The modeling is done by the above procedure. Next the modeled Heat exchanger is to be Computational Fluid Dynamics (CFD) software ANSYS FLUENT. From this work we conclude about 72% of heat is recovered and 28% heat is lost to the atmospheres.

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