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Design & FEA Based Analysis of Shell and Tube Heat Exchanger

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Abstract

This researchpaper consists of work done on finite element analysis of shell and tube heat exchanger by designing shell and tube heat exchangeron the basis of LMTD methodology and then the dimensions of shell and tube heat exchanger were found out, followed by static structural and thermal analysis in ANSYS .The main objective of doing research work is to find out the maximum stress and total deformation due to pressure acting on shell side and tube side. Also, the analysis of directional heat flux due to effect of temperature and thermal stress on different parts of shell and tube heat exchanger has been carried out.

Keywords: Shell and tube heat exchanger,

1. Introduction

Shell and tube heat exchangers are used widely in various thermal engineering applications. The main advantage of shell and tube heat exchangers is that they have large heat transfer surface area per unit volume. Also shell and tube heat exchangers can operate across various ranges of temperature.The various types of flow in a heat exchanger are parallel flow, counter flow and cross flow, hence value of LMTD varies for all the three type of heat exchanger. This particular research paper consists of designing of shell and tube heat exchanger which is carried out for parallel flow heat exchanger. (flow for both fluids i: e through shell side and tube side is from same direction)

Tube bundles, which holds all the tubes and tube sheet intact in its position, increases the heat transfer area.Baffle plates gives the proper guidance to fluid on shell side increasing heat transfer area but baffle plates also creates disturbance in the flow resulting into increase in value of U(overall heat transfer coefficient) velocity of fluid and pressure drop which demands pump of higher capacity, which increases the cost.

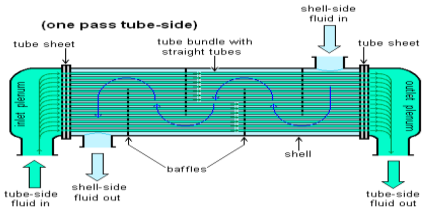


Fig. 1. Shell and tube heat exchanger

So, generally fluids having lower values of U is preferred. (depending on fluids which are being used[1]. The analysis is carried out at hydrostatic testing pressure which is 1.95 times more than actual working pressure in order to ensure safe and efficient working of heat exchanger. The main objective of this research work is to minimize the stress, deformation and heat flux by topological optimization.

An extensive research work has been carried out on the Shell and Tube heat exchangers by changing different parameters to meet the industrial requirements. Su That Mon Than, Khin Aung Lin, Mi Sandar Mon[7] found procedure for finding out area of heat transfer and drop in pressure and also checked whether the assumed design works or not. The concern was to obtain an effective heat transfer rate keeping in mind the allowable pressure drop.Yusuf Ali Kara, Ozbilen Guraras [8] determined the dimensions of the shell, diameter of tube and minimum heat transfer surface area required to meet the required over all heat transfer coefficient considering minimum allowable shell side pressure drop.M.Serna and A.Jimenez [9] showed a compact mathematics to establish relationship between shell-side pressure drop with the exchanger area and the film coefficient based on the Bell–Delaware method. Andre L.H. Costa, Eduardo M. Queiroz [10]approached the optimization of the design of shell and tube heat exchangers. They implied on minimal thermal area required for getting the required heat transfer considering maximum allowable pressure drop. M. El-Fawal, A. A. Fahmy and B. M. Taher [4] formulated a computer program for economical design of shell and tube heat exchanger using specified pressure drop in order to minimize the cost of the equipment. Ender Ozden and Iiker Tari [5] designed a shell-and-tube heat exchanger; considering the baffle spacing, baffle cut and diameter of shell along with overall heat transfer coefficient and the pressure drop are analysed. CFD analysis is carried out for a single shell and single tube pass heat exchanger with turbulent flow. Then output is determined by analysing the CFD results of outlet temperature and pressure drop.

Nomenclature

Design Parmeters [16]

Q heat transfer load (KJ)

m_h mass flow rate on hot side(kg/hr.)

m_c mass flow rate on cold side(kg/s)

c_{ph} specific heat on hot side(KJ/kg K)

c_{pc} specific heat on cold side(KJ/kgK)

A heat transfer area (m^2)

U overall heat transfer coefficient (W/m^2 K)

T temperature (K)

Θ_{LMTD} logarithmic mean temperature difference

N number of baffles

Material Properties (Materials Used In Analysis) [13]-[14]-[15]

	Structural steel	Copper
Density (kg/m^3)	7400	8900
Young Modulus (N/m^2)	180	120
Ultimate yield strength (MPa)	250	70
Poisson’s Ratio	0.295	0.355
Maximum service temperature (° C)	500-600	400-650

2. Model formulation

Inthe following analysis, LMTD method is used for calculating heat transfer rate with one tube pass and the overall dimensions of shell and tube heat exchanger are determined.

Table 1
Calculating heat transfer by LMTD and determining overall dimension of shell and tube heat exchanger[12]

Equation	Application
$Q_h = m_h c_h (th_1 - th_2)$(1) $Q_c = m_c c_c (tc_2 - tc_1)$(2)	Heat energy balance equation
$Q_{ex} = UA\theta_m$(3)	Heat transfer area
LMTD $\theta m = (\theta 1-\theta 2)/loge(\theta 1/\theta 2)$(4) For parallel flow:- $\theta_1 = t_{h1} - t_{c1}$, $\theta_2 = t_{h2} - t_{c2}$(5)	Logarithmic mean temperature difference for parallel flow

2.1 Methodology of shell and tube heat exchanger

The calculations are carried out on the basis of LMTD method, followed by determination of dimensions of heat exchanger asshown below [17]

Cold side /Shell side (Water)
t_{c1} =25°C C_p(specific heat) =4.186 KJ/KgK (water)
t_{c2}= 32°C Mass flow rate (m) = 920 Kg/hr (calculated) from eqn (2)
Hot side/Tube side (gas)
t_{h1} = 250°C Cp(specific heat) =0.624 KJ/KgK (methane)
t_{h2} = 150°C Mass flow rate (m) = 1600 Kg/hr

Overall heat transfer coefficient[6] = 8 W/m^{2}K
(For gases p = 2 – 8 bar) we take U between 5 – 35 W/m^{2}K
$Q_h = m_h c_h (t_{h1} - t_{h2}) = Q_c = m_c c_c (t_{c2} - t_{c1})$ Placing values we get Q = 99952 kCal/HrFrom eqn (1) & (2)
LMTD $\theta_m = (\theta_1-\theta_2)/loge\ (\theta_1/\theta_2)$
So for parallel flow: - $\theta_1 = t_{h1} - t_{c1}$ = 225 °C & $\theta 2 = t_{h2} - t_{c2}$ =118 °C,On placing value in the above equation we get value of LMTD as 165.785, Q_{ex}= UAθm where Q_{ex}, U and θ_m is known so we get heat transfer area as A = 75 m^2

Outer Diameter (O.D) of Tube is 114 mm (Fixed),Thickness of Tube is 4 mm (Fixed)
Tube Pitch 60 mm
Tube Arrangement Triangular
Shell Internal Diameter 1,400 mm
Shell Thickness 8 mm
Shell External Diameter 1416 mm
Total length of tubes is given by A/ (3.14*O.D/1000) = 210 m
Length of each tube = 3.5 m (Fixed).So total number of tubes required for effective heat transfer area of 75 m^{2}is 56 numbers.

2.2 Assumptions While Designing Heat Exchanger [16]

To calculate the heat transfer by the expression .Q = UA θ_m, where Q is overall heat transfer coefficient, A is heat transfer surface and$\theta_m$is logarithmic mean temperature differencethere are certain assumptions are considered which are as below.

1.The specific heat and mass flow rate of both the fluids are constant.

2. The heat exchanger is perfectly insulated and so that heat loss to the surrounding is almost negligible.

3. There is no conduction of heat along tubes of heat exchanger and changes in kinetic and potential energy are negligible.

2.*3 Model of shell and tube heat exchanger* [17]

The model of shell and tube heat exchanger is modeled shown below

Fig.2. Exploded view of shell and tube heat exchanger

3. Finite element analysis

Fig 2. shows the model of shell and tube heat exchanger whose static structural analysis hasbeen done in ANSYS.

3.1 Mesh generation

Obtaining accurate results in Ansys depends on themeshing type and element size. Due to complex structure of Heat exchanger Tetrahedron meshing was carried out which is most suitable for complex structure. Tetrahedron meshing is used and element of size 5 mm (Coarse) has been selected to get accurate results. After meshing we get 33697693 nodes and 17359792 elements as seen in Fig.5 (a) and Fig.5 (b).

Tetrahedron Meshing images are shown as below

Fig.5(a) Tetrahedron meshing view 1

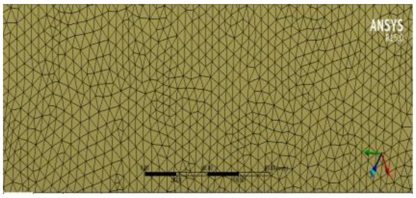
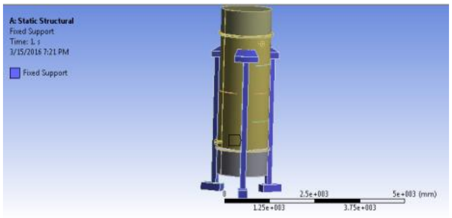
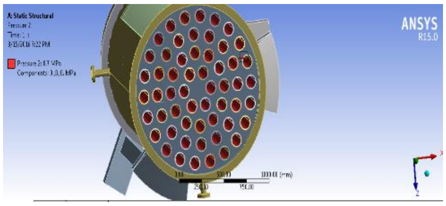


Fig.5(b) Tetrahedron Meshing view 2

3.1Boundary conditions

Boundary conditions which are applied are shown in figure 6 and 7 as below





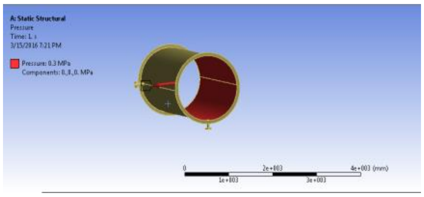
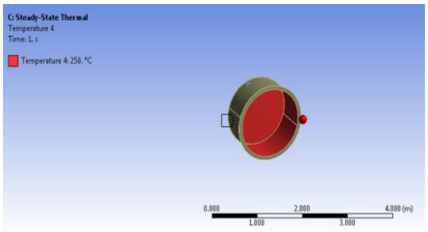
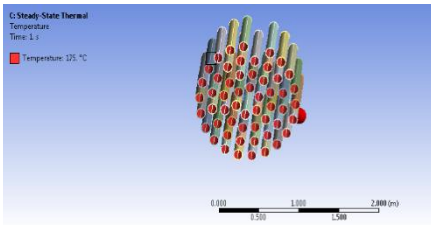


Fig.6 (a) Fixed support **Fig.6 (b)** Pressure inside tubes **Fig.6(c)** Pressure inside shell





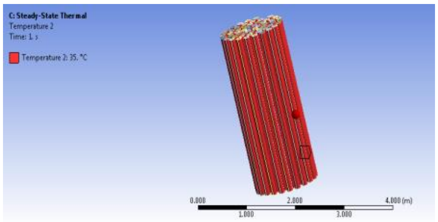


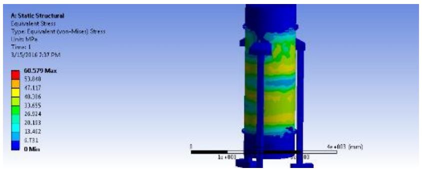
Fig.7 (a) Temperature inside box **Fig.7 (b)** Temperature inside tubes **Fig.7(c)** Temperature outside tubes

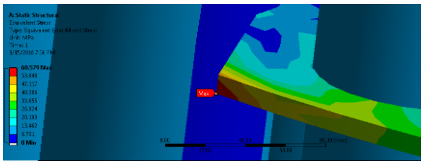
As shown in figure 6(a)legs of heat exchanger are considered as fixed supports, in figure 6(c) hydrostatic testing pressure, 3 baris considered which is 3 times more than working pressure so worst case for this analysis is considered and for tubes as shown in figure 6(b) hydrostatic testing pressure is 7 bar but the working pressure is 4 bar but again worst case is considered for analysis. In analysis two materialsi:e stainlesssteel and copper are considered.

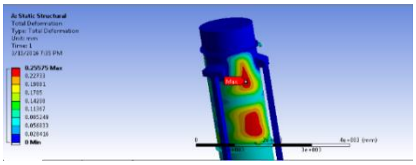
4. Results and Discussion

4.1 Static structural analysis

In this paper, Static structural analysis of shell and tube heat exchanger is carried out for SEGMENTAL BAFFLE PLATE at specified boundary conditions for two different materials i:e copper and structural steel and important results are summarized as below.



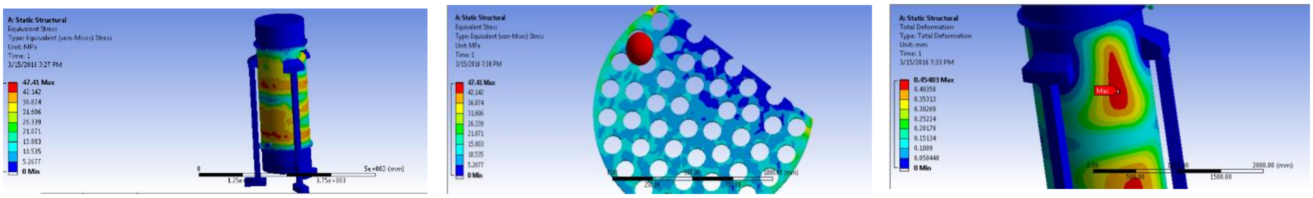




Case: A **Case: B** **Case: C**

Fig .8. Case (A) to (C) Results of Von Mises Stress and deformation results for structural steel

The results as shown in figure 8 for case (A) to (C) are for structural steel and the maximum stress is 60.579 Mpa and maximum deformation is 0.2525 mm and the critical portion (max stress/deformation) is also shown in figure case (B) for structuralsteel. Now the same analysis is done by using same boundary conditions and copper as material and results are summarized below.



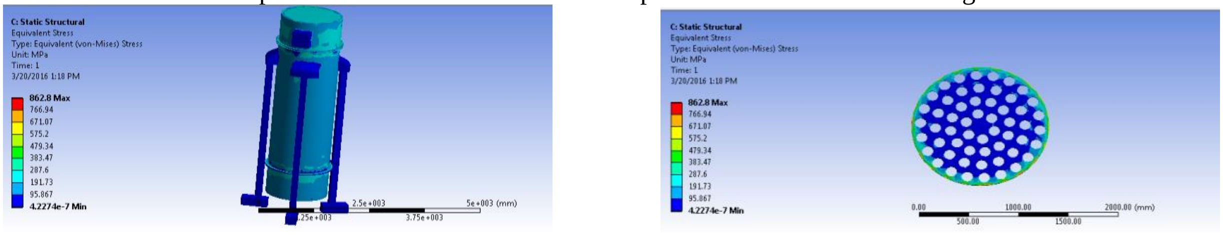
Case: ACase: BCase: C

Fig.9. Case (A) to (C) Results of Von Mises Stress and deformation results for copper.

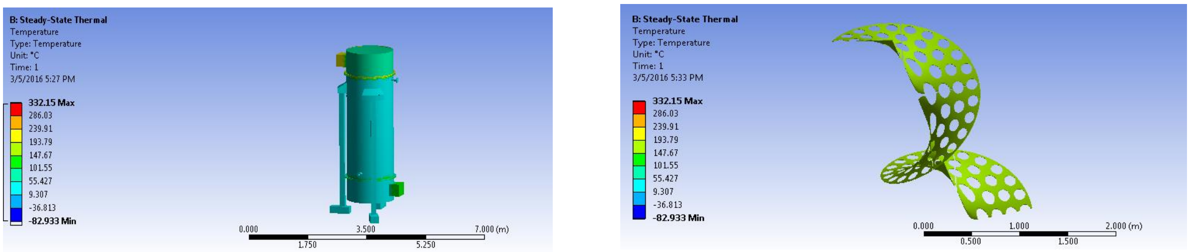
As shown in figure 9 case (A) to (C) when using the same boundary conditions and using copper material the maximum stress is found out to be 48 Mpa and maximum deformation is 0.46 mm.Now as in case of structural steel and copper after static structural analysis we find that maximum stress is 61 Mpa and 47 Mpa and the ultimate yield strength of structural steel and copper are 205 Mpa and 70 Mpa which is within safe limits .Now we can see that deformation is more in case of copper than that of structural steel. Also we can use copper under pressure of 10 bar but when the pressure exceeds more than 10 bar stainless steel must be preferred because of higher ultimate yield strength.

4.2 Static Thermal Analysis [2]-[11]

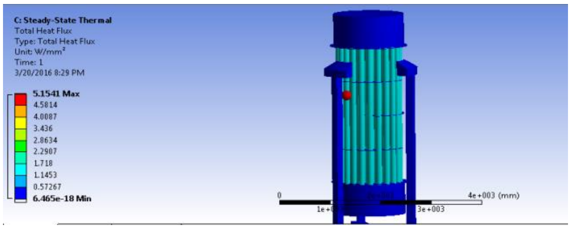
In static thermal analysis, only stainless steel as a material is considered for HELICAL BAFFLE PLATE and then Maximum temp and Heat flux is considered as output the results are shown in Fig.10.



Case: A **Case: B**



Case: C **Case: D**



Case: E

Fig.10. Case (A) to (E) Static thermal analysis for helical baffle plate

So design is safe and also there is negligible effect of thermal stress on helical baffle plateNow, as far as temperature is concerned maximum temperature is 302.45 °C and service temperature of stainless steel is 600 ° C and the heat flux is average around 6.5 W/mm^2.

5. Conclusion

Following are the graphs which shows the relationship between parameters

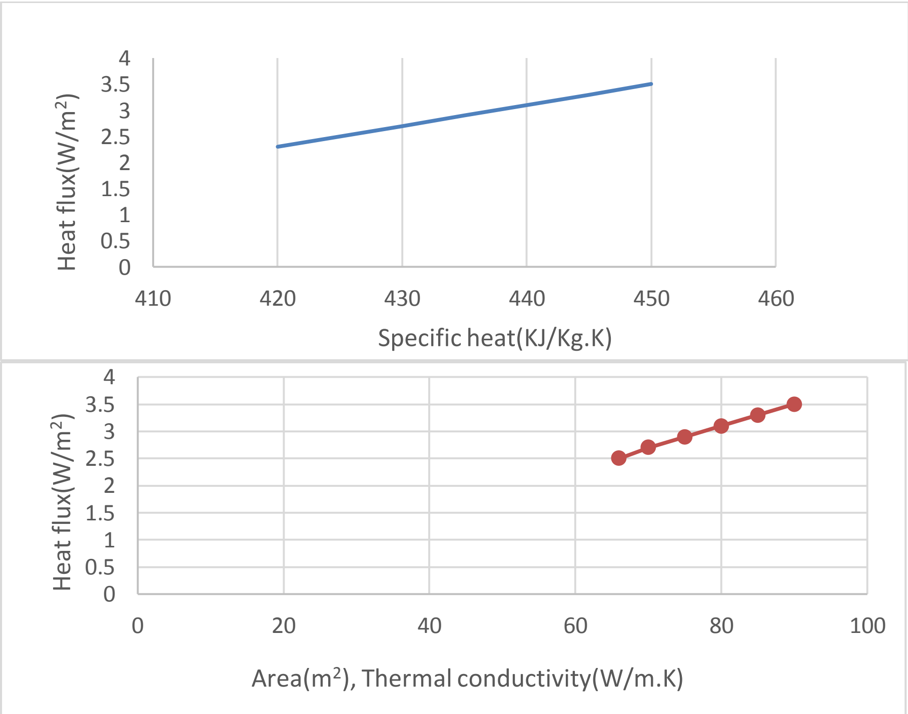


Fig.11. Different parameters affecting Heat transfer rate(Heat Flux)

When analysis of shell and tube heat exchanger has been carried out in Ansys, In case of Stainless Steel 304 ,it can withstand maximum deformation and copper can withstand maximum stress.
Heat Flux increases with increase in heat transfer area , Thermal conductivity, Specific heat , as shown in figure 11 .
When the analysis was done as in case of helical baffle plate we found that the effect of stress was minimized as compared to segmental baffle plate and irespective of the use of type of baffle plate the deformation occours on the portion of shell.

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