Design and Temperature Analysis on Heat Exchanger with TEMA Standard Codes

Adesh Dhope[1], Omkar Desai[2], Prof. V. Verma[3]

[1]*Student, Department of Mechanical Engineering,Smt. KashibaiNavale college of Engineering,* ***adesh.dhope12@gmail.com***
[2]*Student, Department of Mechanical Engineering,Smt. KashibaiNavale college of Engineering,* ***omkard4@gmail.com***
[3]*Assistant Professor, Department of Mechanical Engineering,Smt. KashibaiNavale college of Engineering,* ***vverma@sinhgad.edum***

ABSTRACT

A heat exchanger is a device that is used to transfer thermal energy (enthalpy) between two or more fluids, at different temperatures and in thermal contact. In this problem of heat transfer involved the condition where different constructional parameters are changed for getting the performance review under different condition. An excel program has been developed for the ease of calculation and obtaining result after changing different parameters. The tube diameter, tube length, shell types etc. are all standardized and are available only in certain sizes and geometry. The design of a shell-and-tube heat exchanger usually involves a trial and error method where for a certain combination first the design variables and the heat transfer area is calculated and then all other different combination is tried to verify if there is any possibility of increasing the heat transfer coefficient. Since several discrete combinations of the design configurations are possible, the designer needs an efficient strategy to quickly locate the design configuration having the minimum heat exchanger cost. The tube metallurgy and baffle spacing are being changed the results are obtained for this case. A characteristic of heat exchanger design is the procedure of specifying a design as well as analysis. Heat transfer area along with pressure drops and checking whether the assumed design satisfies all requirement or not which can be accomplished by analysis. For the analysis of results SOLIDWORKS software is used. The CFD of flow and FEA for saddle support is carried out to verify the results.

Keywords***: Shell and Tube heat exchanger, Performance analysis, Optimization, M S Excel, solid work.***

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1. INTRODUCTION

The most common type of heat exchanger used in practical i.e. in industrial applications is shell and tube heat exchanger. Shell & Tube type of heat exchanger consists of different components like large number of tubes packed in shell with axis parallel to axis of shell. It consists of two different fluids in which heat transfer takes place as one of the fluid flows inside the tube while another fluid flows through shell. To enhance the heat transfer and maintain the uniform distance between the tubes generally baffles are commonly placed. It also forces the shell side fluid to flow across the shell which is responsible for heat transfer.
A variety of different internal constructions of components are used in shell and tube exchangers, depending on the desired heat transfer and pressure drop performance and the methods employed to reduce thermal stresses, to prevent leakages, to provide for ease of cleaning, to contain operating pressures and temperatures, to control corrosion, to accommodate highly asymmetric flows, required design of supports based on von mises stress and so on.

Shell-and-tube exchangers are classified and constructed in accordance with the widely used TEMA (Tubular Exchanger Manufacturers Association) standards (TEMA, 1999), DIN and other standards in Europe and elsewhere, and ASME (American Society of Mechanical Engineers) boiler and pressure vessel codes. TEMA has developed a notation system to designate major types of shell and tube exchangers.

TEMA Standards: The standard of the Tubular Exchanger Manufacturers Association (TEMA) describe various components in detail of shell and tube heat exchanger (STHE). STHE is divided into three parts: the front head, the shell and the rear head. Each part has different construction and specific function. The construction of front and rear head as well as flow patterns in the shell are defined by the TEMA standards

The three most common types of shell-and-tube exchangers are (1) fixed tube-sheet design, (2) U-tube design, and (3) floating-head type. In all three types of heat exchanger, the front-end head is stationary while the rear-end head can be either stationary or moving depending on the thermal stresses in the shell, tube, or tube-sheet, due to temperature differences as a result of heat transfer. The exchangers are built in accordance with three mechanical standards that specify design, fabrication, and materials of unfired shell-and-tube heat exchangers

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1.1 Design Procedure for heat exchanger

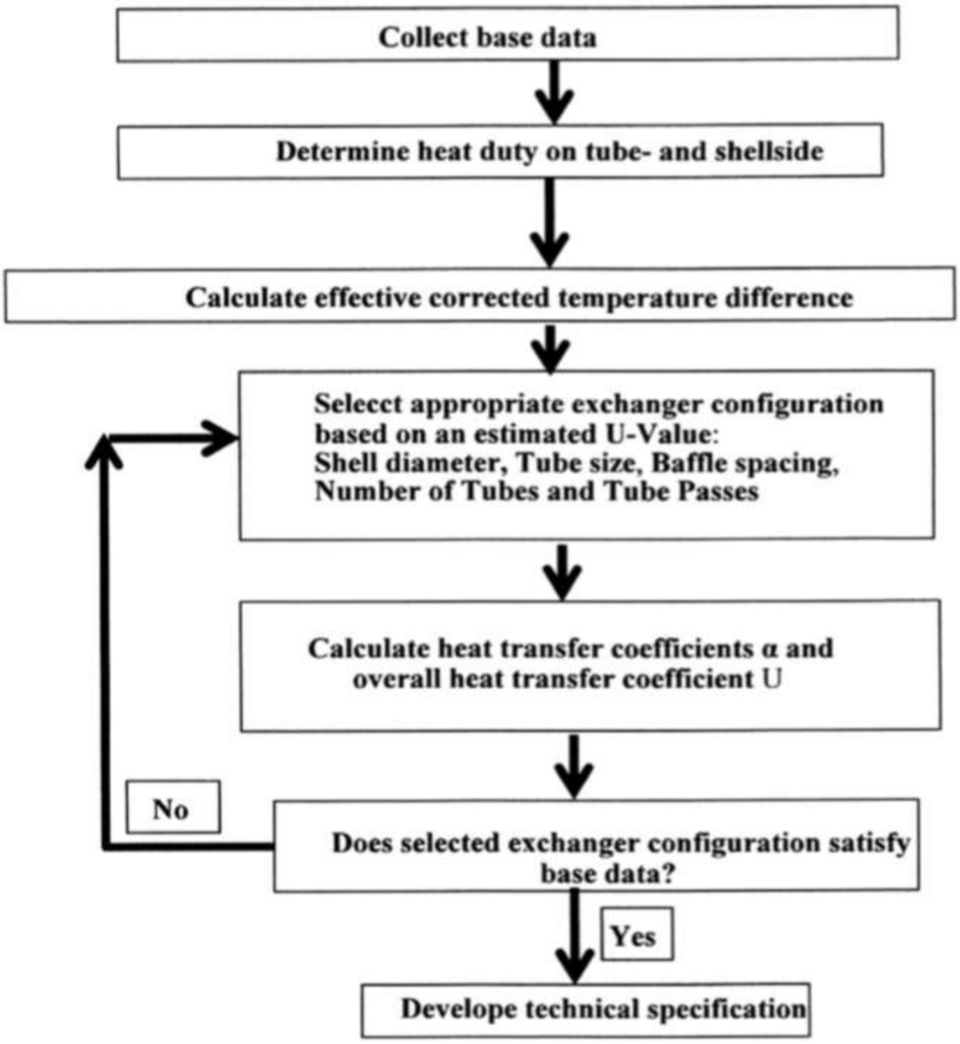

Fig. no 1 Procedure flowchart for thermal design of Heat Exchanger

U= overall Heat Transfer Co-efficient
Hi= Heat Transfer Co-efficient (Tube side)
Ho= Heat Transfer Co-efficient (Shell side)
Mc= Mass Flow rate of cold fluid
Mh=Mass Flow rate of Hot fluid
Cpc= Heat Capacity of Cold Fluid
Cph=Heat Capacity of hot Fluid
Tco= Outlet Temperature of Cold Fluid
Tci= Inlet Temperature of Cold Fluid
Tho= Outlet Temperature of Hot Fluid
Thi= inlet Temperature of Hot Fluid

The thermal analysis of a shell and tube type of heat exchanger involves the determination of the overall heat-transfer coefficient from the individual film coefficients of convective heat transfer mode.

$$U = \frac{1}{\frac{1}{H_i} + \frac{1}{H_o}}$$

To calculate the LMTD, firstly determine the output temperature of shell. It is calculated by,

$$Q = m_c \times C_{Pc} \times (T_{Co} - T_{Ci})$$

$$T_{hout} = T_{Hin} - (\frac{Q}{m_h \times C_{Ph}})$$

As the temperature difference across between cold and hot fluid varies along the length of heat exchanger, it always convenient to have a mean temperature difference that is ΔT_m which further can be used in

$$Q = UA_s\Delta T_m$$

To develop the relation for equivalent average temperature between the two fluids parallel flow heat exchanger is considered. At inlet of heat exchanger, the temperature difference between cold and hot fluid is large but at outlet it decreases exponentially. As per the expectation, the cold fluid temperature increases and hot fluid temperature decreases along the heat exchanger, for which the temperature of cold fluid cannot exceed the temperature of hot fluid no matter how long the heat exchanger is.

Log Mean Temperature Difference,

$$LMTD = \frac{\Delta T_2 - \Delta T_1}{\ln(\frac{\Delta T_2}{\Delta T_1})}$$

$$\Delta T1 = T_{hi} - T_{Co}$$

$$\Delta T2 = T_{ho} - T_{ci}$$

Multipass shell & tube heat exchangers consists a mixture of co-current and countercurrent flow pattern. For this particular reason, the mean temperature difference is derived by multiplying it by correction factor, F, which is called as the LMTD correction factor

$$\Delta T_m = F \times LMTD$$

Temperature correction factor can be given as

$$F = \frac{\sqrt{(R^2+1)}\ln[\frac{(1-S)}{(1-RS)}]}{(R-1)\ln[\frac{2-S[R+1-\sqrt{(R^2+1)}]}{2-S[R+1+\sqrt{(R^2+1)}]}]}$$

Where,

$$R = \frac{T_{ci} - T_{co}}{T_{ho} - T_{hi}}$$

$$S = \frac{T_{ho} - T_{hi}}{T_{ci} - T_{hi}}$$

Further the provisional area can be calculated as follows,

$$A_s = \frac{Q}{U \times \Delta T_m}$$

Total number of tubes to obtain desired temperature can be calculated by taking the ratio of total provisional area available for heat transfer to area of single tube, which is as follows,

$$Nt = \frac{Q}{\pi \times D_0 \times L}$$

Different parameters of tube like tube pitch and tube bundle diameter can be calculated by standard formulas mentioned as in TEMA Standards

$$Pt = 1.25 \times Do$$

$$Db = Do \times (\frac{Nt}{K1})^{\frac{1}{n1}}$$

Where values of factors k1 & n1 are taken from TEMA standard codes
K1=0.319
N1=2.142

Shell Diameter (Db)

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$$Db = Do + BDS$$

Where BDS= Bundle Diameter Clearance

Baffle Spacing

$$Bs = 0.4 \times Ds$$

Cross Flow Area Calculation

$$\text{Cross Flow Area} = \frac{(Pt - Do)Ds \times Bs}{Pt}$$

Shell Side Mass Velocity

$$Gs = \frac{shell - side\ flowrate}{cross\ sectional\ flow\ area}$$

To obtain a better heat transfer co-efficient triangular or rotated square pitch is preferred in tube bundle as the flow is against the tubes and cleaning can takes place between the tube rows. So for these reasons rotated square pitch is used. Different patterns are shown in fig.2

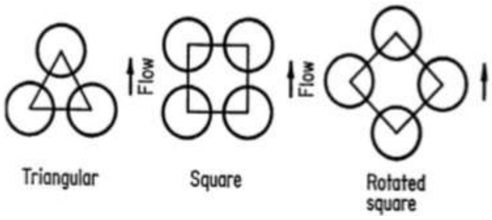

Fig. no. 2: Tube arrangement in shell and tube heat exchangers

Shell Equivalent diameter for square pitch design

$$De = \frac{1.27}{Do \times (Pt^2 - 0.785Do^2)}$$

Calculations for Reynolds number

$$Re = G_s \times \frac{D_e}{\mu}$$

Prandtle number

$$Pr = \frac{\mu \times C_P}{K}$$

Pressure drop in shell

$$\Delta P_s = 8j_f (\frac{D_s}{d_e})(\frac{L}{l_B}) \frac{\rho\, u_s^2}{2} (\frac{\mu}{\mu_w})^{-0.14}$$

Calculate number of tubes per pass

$$Ntpp = \frac{N_t}{No.of\ passes}$$

Calculate tube side mass velocity

$$Gm = \frac{tube - side\ flow\ rate}{Ntpp \times \frac{\pi \times d_1^2}{4}}$$

Results obtained from above calculation are used for 3D Modeling of Heat Exchanger which is shown in Fig no. 3 The modeling is done using software named SOLIDWORKS 15.0 A complete assembly is shown in fig. no 3 It also consist of saddle supports which are ideally preferred for horizontal pressure vessel. The base of saddle is fixed on a concrete base.

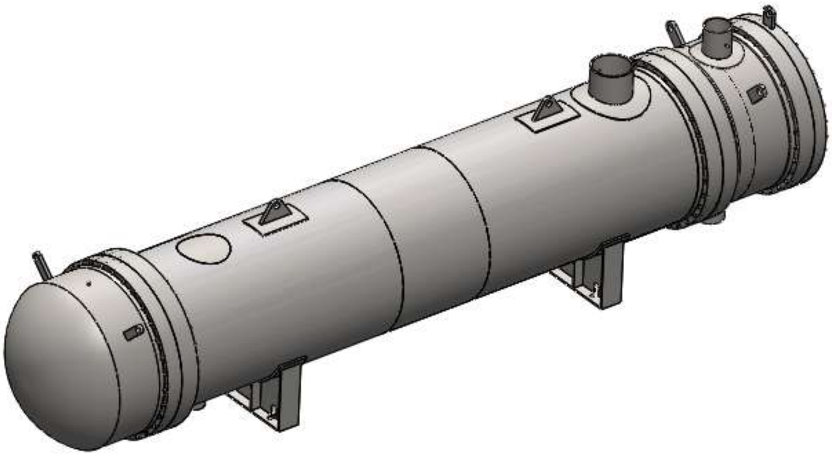

Fig. no.3: 3D Model Sizing from calculations

1.2 Problem Statement

Tube Length	3048	mm
Tube Diameter	6.4	mm
BWG_Copper and Copper Alloy	27	
Tco	80	deg
Tci	20	deg
Mass flow rate	1.2	Kg/s
Heat Capacity Cp	4.18	KJ/Kg
Heat Capacity Ch	4.31	KJ/Kg
T_{hin}	160	Deg
M geothermal	2	kg/s
Ch	4.31	KJ/Kg
Shell Side	470	W/m2C
Tube Side	690	W/m2C

2. RESULTS

Two different analysis are carried out on this total CAD Model for checking whether designed product can stand up the problem statement. Different analysis carried out on CAD model are

(1) FEA analysis of saddle supports
(2) CFD analysis of temperature gradient

2.1 FEA Analysis

FEA Analysis is carried out on the saddle support. FEA analysis is carried out in SOLIDWORKS software. FEA analysis on support is carried out the determine whether the total weight of assembly is sustained by supports within specified deflection limits.

(1) To carry out FEA analysis firstly material is applied to total assembly.
(2) Then bottom surface is fixed as it is located in concrete.
(3) Then it is followed by applying forces on the top surface.
(4) After that whole part is meshed to obtain analysis results.
(5) Von Mises and deformation results are obtained from software.

Input data for analysis:

- Material: plain carbon steel
- Tensile strength: 400 $\frac{N}{mm^2}$
- Poisson's ratio: 0.28

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- Young's modulus: 210 GPA
- Density:7800 $\frac{kg}{m^3}$
- Plate thickness :26mm

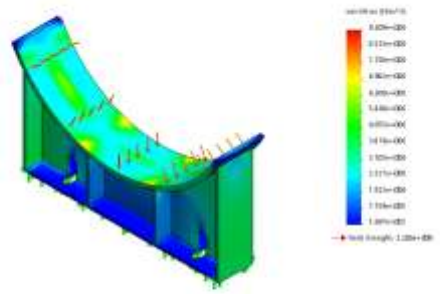

Fig. No. 4 Von Mises stresses

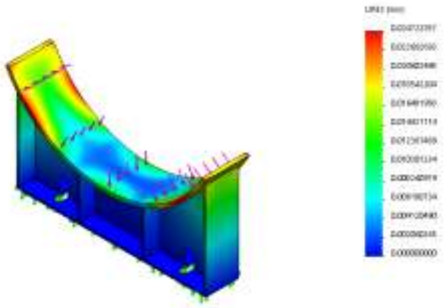

Fig. no. 5. Deformation

2.2 CFD analysis

CFD analysis is also carried out on SOLIDWORKS software. To carry out CFD analysis following steps are carried out

(1) Set a location for different fluid for this problem statement set water in tube side and air as shell side
(2) Further the boundary conditions are applied on the different inlet and outlet of air as well as water inlet and outlet.
(3) Allow the CFD solver to do calculations.

Input data:

Inlet velocity :2m/s
Thermodynamic property :75 deg
Static pressure:101325 pa
Inlet velocity :5m/s

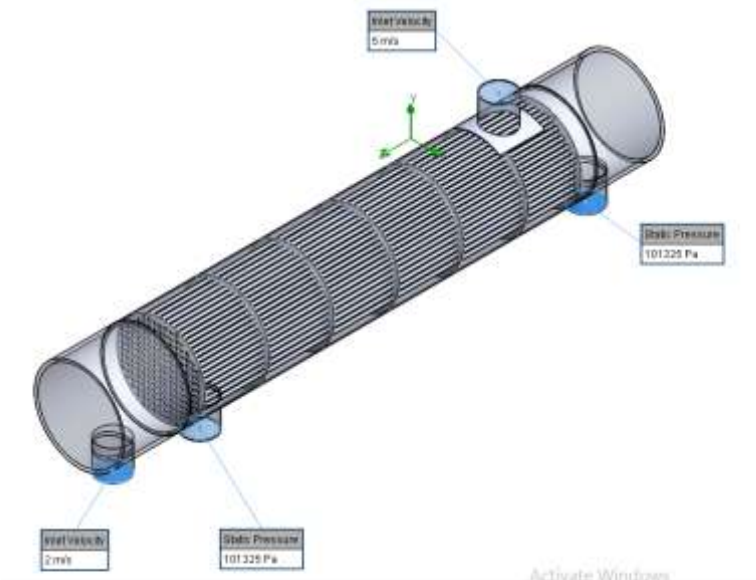

Fig. No. 6: Applying boundary conditions

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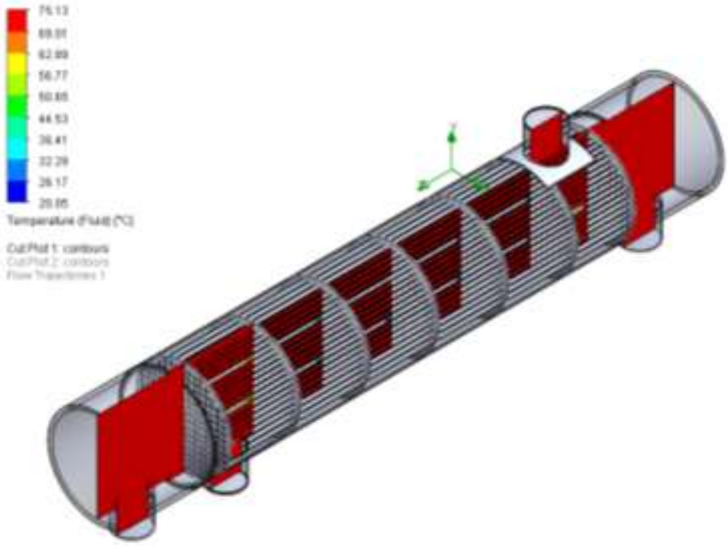

Fig. no. 6: Temperature gradient variation simulation

3. CONCLUSION

(1) From FEA analysis results the von mises stresses does not exceed the design stress so designed dimensions are correct.

(2) Deformation obtained from analysis is less than 1.2mm which is acceptable as the allowable deformation is up to 5mm

(3) From CFD analysis result obtained shows a constant temperature gradient which is a desired effect

(4) From obtained dimensions the CFD and FEA shows acceptable results which proves the design can be used as product which satisfies the problem statement.

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