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By Vindhya Vasiny Prasad Dubey, Raj Rajat Verma, Piyush Shanker Verma & A. K. Srivastava

Shri Ramswaroop Memorial College of Engineering & Management, India

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Keywords: counter flow shell and tube type heat exchanger, kern's method, ansys 14.0, steady state thermal simulation, thermal materials.

Nomenclature

m	mass flow rate of fluid (kg/second)
C_p	specific heat of fluid (J/kg-℃)
t	temperature of fluid (℃)
Q	amount of heat transfer taking place (watts)
LMTD (or ΔT)	Logarithmic Mean Temperature Difference (℃)
U_0	overall heat transfer coefficient (w/m^2°c)
A	area of heat exchanger (m^2)
ID	inner diameter
OD	outer diameter
l	length of heat exchanger (m)
N	number of tubes
D_b	tube bundle diameter (mm)
d	diameter of tubes (mm)
D	diameter of shell (mm)
B	baffle spacing (mm)
P_r	Prandtl number
R_e	Reynold's number
Nu	Nusselt number
h	heat transfer coefficient (w/m^2°c)

Subscripts

i	inner surface parameter
o	outer surface parameter
t	tube side parameter
s	shell side parameter
w	wall temperature parameter
h	hot fluid parameter
c	cold fluid parameter
1, 2	for inlet and outlet respectively
max	maximum amount of the quantity

Constants

K_1 ,n_1	constants depending on the pitch and type of pass

I. Introduction

Heat exchanger is a mechanical device which is used for the purpose of exchange of heats between two fluids at different temperatures. There are various types of heat exchangers available in the industry, however the Shell and Tube Type heat exchanger is probably the most used and widespread type of the heat exchanger's classification. It is used most widely in various fields such as oil refineries, thermal power plants, chemical industries and many more. This high degree of acceptance is due to the comparatively large ratio of heat transfer area to volume and weight, easy cleaning methods, easily replaceable parts etc. Shell and tube type heat exchanger consists

Author α σ ρ: UG Student, Mechanical Engineering Department, Shri Ramswaroop Memorial College of Engineering & Management, Lucknow. e-mail: sarvabhaumic@gmail.com
Author ω: Professor & Head of Department, Mechanical Engineering Department, Shri Ramswaroop Memorial College of Engineering & Management, Lucknow.

of a number of tubes through which one fluid flows. Another fluid flows through the shell which encloses the tubes and other supporting items like baffles, tube header sheets, gaskets etc. The heat exchange between the two fluids takes through the wall of the tubes. In the past decades the design and analysis of Shell and Tube Type Heat Exchanger has been done through various modes viz. theoretically, experimentally, by making software models etc. However a lesser attention has been given on the heat transfer capabilities of the materials. It was due to practical limitations as well as it was also not possible to change the material of tubes or shell again and again and test them under the severe loading conditions. But, now the intense development of CAD facility has given us the tool by which we may introduce number of materials and their combinations to the actual working conditions, and henceforth find their accuracy and compatibility with the desired functions. The works reviewed that have done the same work in the described field are summarized as follows:

Hari Haran et.al proposed a counter flow heat exchanger and after designing it, made a software model using PRO-E by using the derived dimensions and performed the steady state thermal simulation on ANSYS. For simplification of theoretical calculations they have also done a C code which is useful for calculating the thermal analysis of a counter flow of water-oil type shell and tube heat exchanger. They have compared the results obtained after thermal simulation and that obtained from the manual designing and found an error of *0.0274* in effectiveness.

Paresh Patel and Amitesh Paul had performed thermal analysis of shell and tube type heat exchanger using ANSYS, and CFD analysis has been carried out for different materials like steel, copper and aluminium and on the basis of results obtained they have described which material gives best heat transfer rates.

A. Gopi Chand et.al showed how to do the thermal analysis by using theoretical formulae and for this they had chosen a practical problem of counter flow shell and tube heat exchanger of water and oil type, by using the data that came from theoretical formulae, they designed a model of shell and tube heat exchanger using Pro-E and did the thermal analysis by using FLOEFD software and compared the result that obtained from FLOEFD software and theoretical formulae. For simplification of theoretical calculations they have also done a MATLAB code which is useful for calculating the thermal analysis of a counter flow of water-oil type shell and tube heat exchanger. The result after comparing both was that they were getting an error of 0.023 in effectiveness.

P. S. Gowthaman and S. Sathish proposed analysis of two different baffles in a shell and tube heat exchanger by using ANSYS FLUENT. It was found that the use of helical baffles in heat exchanger reduces Shell side pressure drop, pumping cost, weight, fouling etc as compared to segmental baffle for a new installation.

Ender Ozden and Ilker Tari had investigated the design of shell and tube heat exchanger by numerically modelling, in particular the baffle spacing, baffle cut and shell diameter dependencies of heat transfer coefficient and pressure drop. The flow and temperature fields are resolved by using a commercial CFD package and it is performed for a single shell and single tube pass heat exchanger with a variable number of baffles and turbulent flow. The best turbulent model among the one is selected to compare with the CFD results of heat transfer coefficient, outlet temperature and pressure drop with the Bell-Delaware method result. By varying flow rate the effect of the baffle spacing to shell diameter ratio on the heat exchanger performance for two baffle cut value is investigated.

II. Mathematical Modelling

Shell and tube heat exchangers are designed normally by using either Kern's method or Bell-Delaware method. Kern's method is mostly used for the preliminary design and provides conservative results whereas; the Bell-Delaware method is more accurate method and can provide detailed results. It can predict and estimate pressure drop and heat transfer coefficient with better accuracy. In this paper we have designed a simple counter flow shell and tube type heat exchanger to cool the water from 55℃ to 45℃ by using water at room temperature by using Kern's method. The steps of designing are described as follows:

a) First we consider the energy balance to find out the values of some unknown temperature values. Certainly some inputs like hot fluid inlet and outlet temperatures, cold fluid inlet temperature, mass flow rates of the two fluids are needed to serve the purpose. The energy balance equation may be given as:

$$Q = m_h c_{ph}(t_{h1}\text{-}t_{h2}) = m_c C_{pc}(t_{c2}\text{-}t_{c1})$$

b) Then we consider the LMTD expression to find its value:

$$LMTD = \frac{(\Delta T1 - \Delta T2)}{ln(\frac{\Delta T1}{\Delta T2})}$$

Where, $\Delta T_1 = t_{h1}\text{-}t_{c2}$ and $\Delta T_2 = t_{h2}\text{-}t_{c1}$.

c) Our next step is to calculate the area required of the heat exchanger (on the basis of assumed U_0), number of tubes, tube bundle diameter, diameter of shell and its thickness with the help of following expressions:

$$A = \frac{Q}{U_0 \Delta T}$$

$$N_t = \frac{A}{\pi d_{t0} l}$$

$$D_b = d_{t0}\left(\frac{N_t}{K_1}\right)^{1/n_1}$$

$$D_i = D_b + \text{additional clearance}$$

$$D_o = D_i + 2 \times \text{thickness}$$

d) Then we calculate the proper baffle dimension viz. its diameter, thickness and baffle spacing.

e) Our next step is to find out heat transfer coefficients on the inner and outer surface of the tubes using following correlation:

$$\text{Nu} = 0.27(Re)^{0.63}(P_r)^{0.36}(P_r/P_{rw})^{0.25}$$

f) Then by the values obtained by the above equation we calculate the actual value of heat transfer coefficient and check whether the actual value is greater than the assumed one or not.

g) After rigorous mathematical calculations we have found out following values of interest:

$m_h = m_c = 0.222$ kg/sec

t_{h1}=55°C , t_{h2}=45°C , t_{c1}=25°C , t_{c2}= 35°C.

A =0.713815m^2

d_{t0} = 23 mm

d_{ti} = 20 mm

N_t = 9

D_i = 136 mm

D_o = 142 mm

Number of baffles = 5

Diameter of baffles = 136 mm

B = 300 mm

The first and the last baffles are complete, while the rest three are 25% cut in order to assure the shell side flow.

III. Problem Formulation

In this paper we are concerned with the study of heat transfer capabilities of various thermal materials that are generally used for shells, tubes or baffles of shell and tube type heat exchanger.

The fact which is noticeable is that the purpose of heat exchange can be done through any moderate conductor of heat, however the study of material prope- 0 rties becomes necessary when we have to exchange a large amount of heat within a minimum stipulated time in order to meet out process and production standards as well as to secure the time economy. Also in the large installations it is always desired that the material could handle the overload situations as and when demanded, hence we may employ a good conductor instead of moderate one, but cannot use moderate one where good heat transfer capabilities is demanded. Under these circumstances it is inevitable to ensure the good heat transfer capabilities of the materials.

Here we are considering four materials viz. copper, aluminium, steel 1008 and steel 1010. We have to check their heat transfer capabilities under the above designed conditions and select the most suitable one. We are also concerned about choosing an economical combination of materials assigned to shell, tubes and baffles.

IV. Solution Method

In this paper we have proposed a software model of shell and tube type heat exchanger exactly of the above derived dimensions. After generating the model we have put those parts under the above stated thermal loading conditions and solved out the same under steady state thermal simulation. The results obtained were quite familiar with general considerations about the hierarchical nature of thermal conductivities of the concerned materials. ANSYS 14.0 has been used for the purpose of model generation and its further analysis. The solution phase generally involved three major steps which are described in detail under next sub headings:

a) Making of software model,

b) Mesh generation,

c) Steady state thermal simulation.

a) *Making of Software Model*

Using the above derived dimensions of shell, tubes and baffles we have made a software model using ANSYS 14.0. The parts individually as well as in assembly are as shown below-

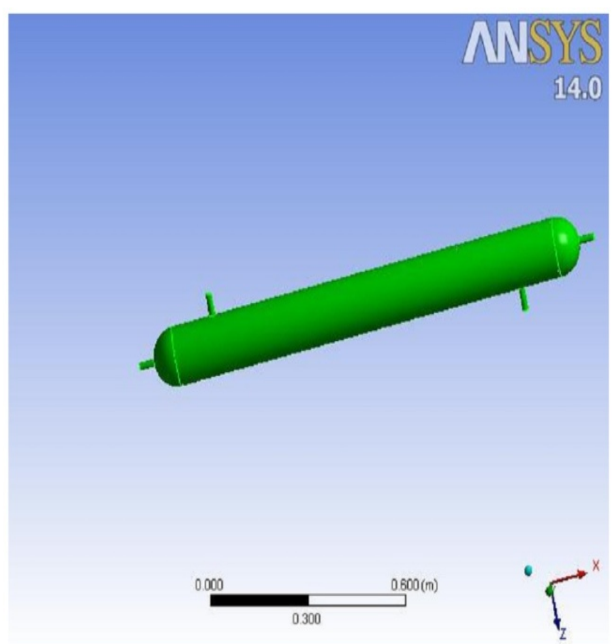

Figure 1 : Shell

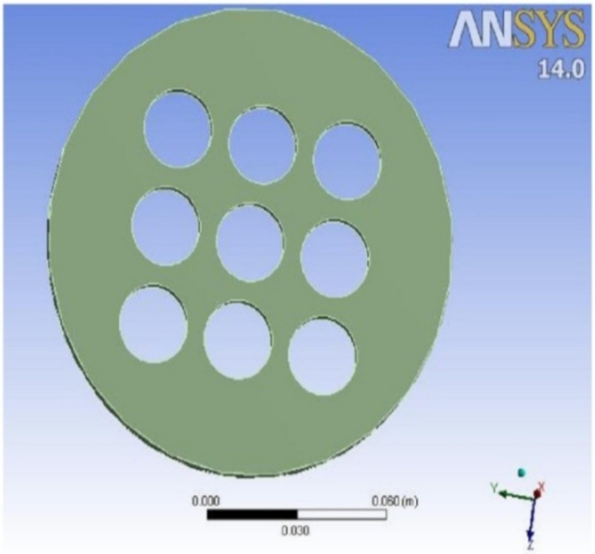

Figure 2 : Complete Baffle

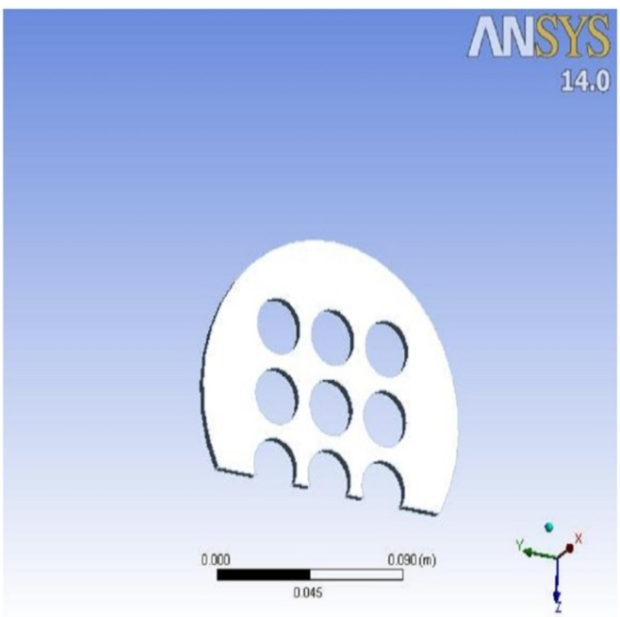

Figure 3 : 25% Cut Baffle

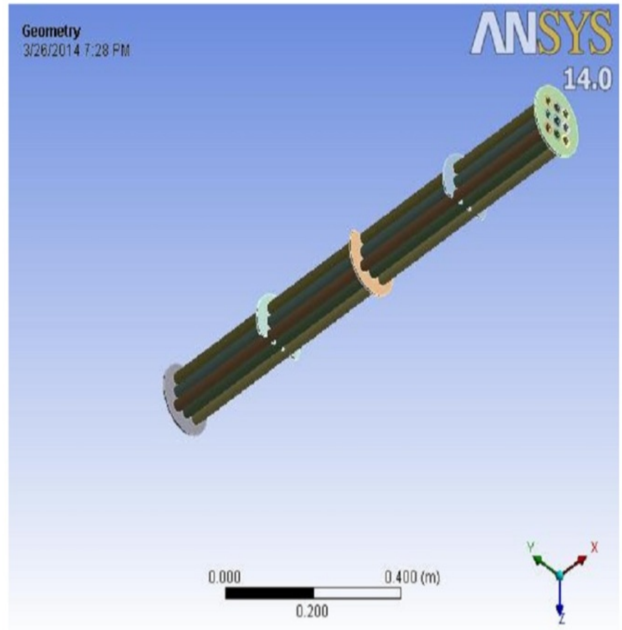

Figure 4 : Arrangement of Tubes and Baffles

b) *Mesh Generation*

The mesh has been generated to perform finite element analysis. In generating the mesh a compromise between computer speed and mesh quality has been adopted. The generated mesh along with its information has been shown in the following figure:

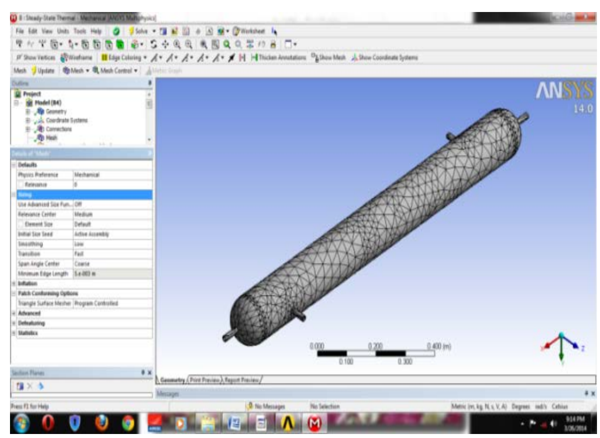

Figure 5 : Mesh Generation

c) *Steady State Thermal Simulation*

This is the final and the most important step of our analysis. Here we have applied the thermal loads on the various faces and edges and simulated to get the value of thermal flux of the overall assembly. The thermal loads applied are shown in the following figure-

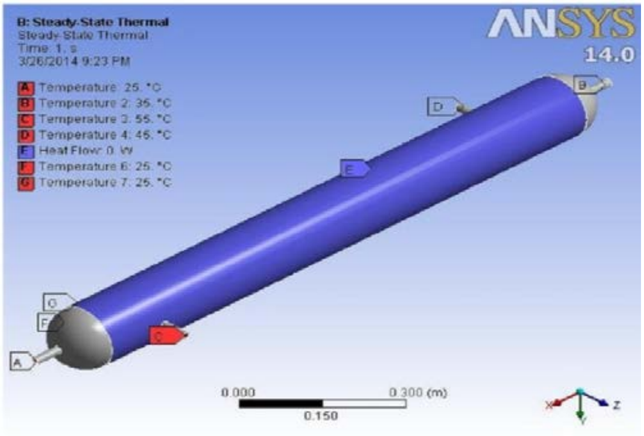

Figure 6 : Thermal Loads on Various Faces and Edges

V. Results & Discussion

Here we have employed five combinations of materials and put them under the above shown thermal loads. The description of material combinations and the heat flux obtained from them is as described below:

a) First we have assigned *Steel 1008 as the material of Shell* while the *tubes and baffles have been assigned Copper.* Under this condition the *maximum value* of heat flux obtained is *37667* w/m^2 while the *minimum value* is *0.064988* w/m^2.

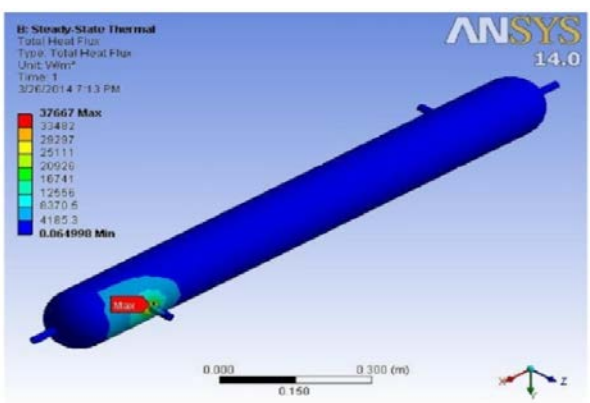

Figure 7 : Shell (Steel 1008), Tubes and Baffles (Copper)

b) Then we have assigned *Steel 1008 as the material of Shell* while the *tubes and baffles have been assigned Aluminium.* Under this condition the *maximum value* of heat flux obtained is *25718* w/m^2 while the *minimum value* is *0.0043108* w/m^2.

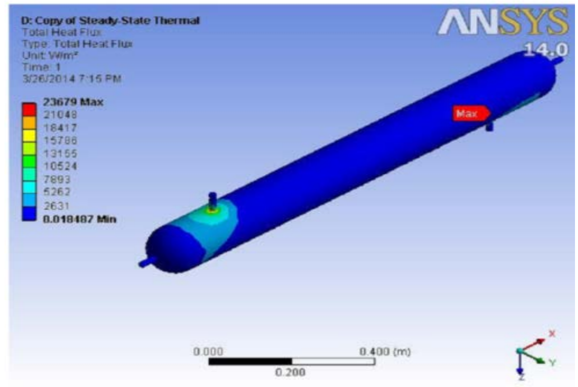

Figure 8 : Shell (Steel 1008), Tubes and Baffles (Alluminium)

c) Then we have assigned *Steel 1008 as the material of Shell* while the *tubes and baffles have been assigned Steel 1010.* Under this condition the *maximum value* of heat flux obtained is *23679* w/m^2 while the *minimum value* is *0.018487* w/m^2.

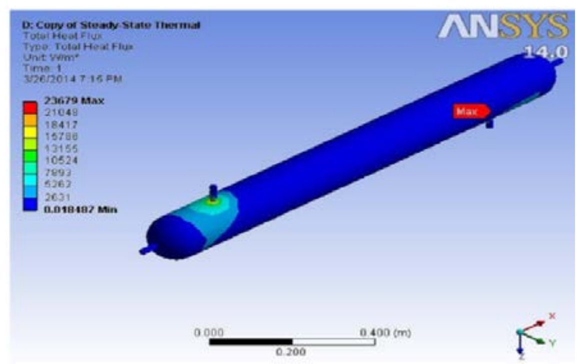

Figure 9 : Shell (Steel 1008), Tubes and Baffles (Steel 1010)

d) Then we have assigned *Aluminium to the whole assembly.* Under this condition the *maximum value* of heat flux obtained is *1.2497* $\times 10^5$ w/m^2 while the *minimum value is 0.097569* w/m^2.

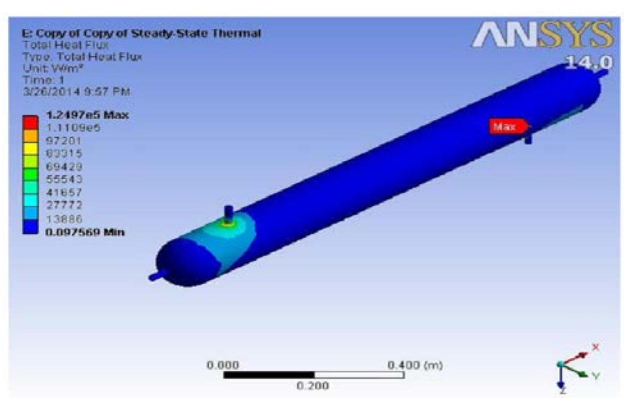

Figure 10 : Alluminium is Assigned to Shell, Tubes and Baffles

e) Then we have assigned *Copper to the whole assembly.* Under this condition the *maximum value* of heat flux obtained is *2.1048* $\times 10^5\ w/m^2$ while the *minimum value is 0.16433* w/m^2.

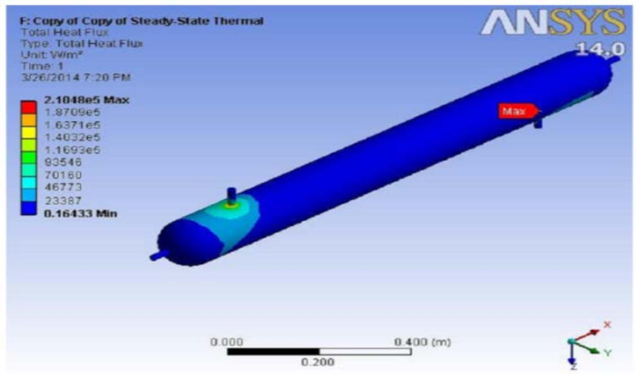

Figure 11 : Copper is Assignes to Shell, Tubes and Baffles

VI. Conclusion

The results of the above study may be summarized as follows:

SERIAL NO.	MATERIAL OF SHELL	MATERIAL OF TUBES & BAFFLES	MAXIMUM HEAT FLUX (w/m^2)	MINIMUM HEAT FLUX (w/m^2)
1.	STEEL 1008	COPPER	37667	0.064988
2.	STEEL 1008	ALUMINIUM	25718	0.0043108
3.	STEEL 1008	STEEL 1010	23679	0.018487
4.	ALUMINIUM	ALUMINIUM	1.2497$\times 10^5$	0.097569
5.	COPPER	COPPER	2.1048$\times 10^5$	0.16433

From this study it is clear that if we assign copper to the whole assembly then we shall get the best possible value of heat flux amongst the discussed materials; however that will also be a very costly affair. Secondly the outer surface of shell is generally insulated so that it may be assumed that no heat transfer is taking place in between shell and surroundings. Hence it will be a good deal to assign shell steel and tubes and baffles copper. In case we may also employ aluminium as the material of tubes and baffles, as it is second to none than copper as far as heat transfer is concerned, amongst the discussed materials. One additional property of aluminium is its light weight. However aluminium also possesses some problems during welding hence it may become difficult to join tubes and baffles. Steels are also moderate conductors of heat and can be employed, in case greater material economy is desired.

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