ISSN: 2277-9655
[Kumar* *et al.*, 7(7): July, 2018] Impact Factor: 5.164
IC™ Value: 3.00 CODEN: IJESS7

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

EXPERIMENTAL ANALYSIS OF SHELL AND TUBE HEAT EXCHANGER BY USING ABAQUS

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DOI: 10.5281/zenodo.1320859

ABSTRACT
This paper presents a model of counterflow shell and tube type heat exchanger in which water was working as heat transfer interacting fluid. To perform thermal analysis of shell and tube type heat exchanger we were first decided to design a heat exchanger. This was capable of cooling water from 55 ºC to 45 ºC using water at room temperature (25 ºC). The designing was completed according to the Kern's method as well as to suit the norms of tubular exchanger manufacturer's association (TEMA). After thermal model design calculation our purpose was to ensure the correctness in design. Heat exchanger was designed on CAD software and its thermal analysis tested on ABAQUS 6.13. It was also fabricated based on the data obtained from mathematical modelling and tested under actual loading conditions. Altered materials were used for heat exchanger components during its thermal analysis. All these observations along with their discussions have been discussed in detail inside the paper.

KEYWORDS: Thermal analysis, Shell and tube type heat exchanger, Kern's Method, ABAQUS 6.13.

I. INTRODUCTION
A heat exchanger is a device which transfers the energy from a hot fluid to a cold fluid with maximum heat transfer rate and minimum operating costs. A shell and tube heat exchanger is the most common type of heat exchanger in oil refineries and other large chemical processes, and is suited for higher-pressure applications. As its name implies, this type of heat exchanger consists of a shell (a large pressure vessel) with a bundle of tubes inside it. One fluid pass inside bundle of tube in the heat exchanger while the other fluid pass through shell. Shell and tube heat exchangers in their various construction modifications are probably the most widespread and commonly used basic heat exchanger configuration in the process industries [1-5]. It is very convenient for many processes especially when product purity requires to be guaranteed. This arrangement also allows for large quantities of heat to be transferred quickly, and it is relatively easy to maintain consistent operating conditions. It provides surface in the form which is relatively easy to construct in a wide range of sizes and which is mechanically rugged enough to withstand normal shop fabrication stresses, shipping and field erection stresses, and normal operation conditions. There are many modifications of the basic configuration which can be used to solve special problems. The shell and tube heat exchanger can be relatively easily cleaned, and those components most subject to failure – gaskets and tubes – can be easily replaced. Finally good design method exists, and the expertise and shop facilities for the successful design and construction of shell and tube exchangers are available throughout the word. However a lesser attention has been given on the heat transfer capabilities of the materials [6-9]. 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.

Industrial applications

Chemical process, petrochemical & refining, food & dairy (Non sanitary only), power generation, nuclear, water plants

Sanitary Applications

Brewery process, juice, sauce, soup, syrup & oils, sugar, portable water and clean in place solutions, chocolate & peanut butter, cheese, dairy, whey products, Blood, plasma and meat

Pharmaceutical applications

Ultra-pure water, pure steam, blood, plasma & growth media, formulated pharmaceutical
In this research paper, we will experiment on performance analysis of shell and tube heat exchanger fabricated model under different operating condition by analytical method like Kern and simulation with ABAQUS [9-10].

II. THEORITICAL ANALYSIS

Shell and tube heat exchangers are design normally by using either Kern's method or Bell-Delaware method. Kern's method is mainly used for the preliminary design and provides conservative results whereas; the Bell-Delaware method is more accurate method and can provide complete results. It can predict pressure drop and heat transfer coefficient with better accuracy [11-13]. In this paper we have designed a simple parallel and 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: Values of parameters
m_h = m_c = 0.222 kg/sec (As per pump rating)
C_{ph} =C_{pc}= 4180 j/kg°C
t_{h1} = 55℃
t_{h2}= 45℃
t_{c1} = 25℃
By energy balance equation
$Q = m_h c_{ph}(t_{h1}\text{-}t_{h2}) = m_c C_{pc}(t_{c2}\text{-}t_{c1})$ (1)
Q = 0.222×4180(55-45) = (0.222×4180) (t_{c2}-25)
t_{c2} = 25+10 = 35°C.
Rate of heat transfer $(Q) = m_h C_{ph}(t_{h1-}t_{h2})$ (2)
= 0.222×4180×10
Q = 9279.6 watts

Now *LMTD*

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

Where ΔT_1 = t_{h1}-t_{c2}= 55-35 = 20°C and ΔT_2 = t_{h2}-t_{c1} = 45-25 = 20°C

Now LMTD = $\frac{\Delta T2(\frac{\Delta T1}{\Delta T2}-1)}{\ln(\frac{\Delta T1}{\Delta T2})} = \frac{\Delta T2(R-1)}{\ln(R)}$ (here, R = $\Delta T_1/\Delta T_2$) = $lim_{R\to 1}\frac{\Delta T2(R-1)}{\ln(R)}$ (3)

= $lim_{R\to 1}\frac{\Delta T2}{(1/R)}$ (by Hospital's rule)

LMTD = 20°C

Dimensions of shell and tube

Assuming U_0= 650 w/m^2°c
Area of heat exchanger (A) =$\frac{Q}{U_0\Delta T}$ = 9279.6/(650×20) = 0.713815m^2 (4)
Choosing tube as = 22mm (OD), 20mm (ID) and length (l) = 1.2m
Actual available length = 1.15m
(Considering 0.05m would be in tube sheets.)
Number of tubes (N_t) = $\frac{0.713815}{\pi\times 0.022\times 1.15}$= 8.9808
N_t = 9
Assuming square pitch
Pitch (P_t) = 1.3×outer diameter of tube (d_{t0}) = 1.3×22 = 28.6mm
Tube bundle diameter

$D_b= d_{t0}(\frac{N_t}{K_1})^{1/n_1}$ (5)

For square pitch and single tube pass
K_1 = 0.215
n_1 = 2.207
D_b= 0.022× $(\frac{9}{0.215})^{1/2.207}$ = 0.124903m.
Assuming Additional clearance = 34mm
Inner diameter of shell (D_i) = 124.903+34 = 159mm

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

Assuming shell thickness = 2mm
So outer diameter of shell (D_0) = 159+2×2 = 163mm

Baffle

Let number of baffles = 5
No. of baffle spacing = 4
Baffle spacing (B) = (1200/4) = 300mm
Diameter of baffles = 136mm
And thickness of baffles = 2mm
The first and the last baffles are complete, while the rest three are 25% cut in order to assure the shell side flow.
h_i = 1839.818 w/m^2°C
$h_0 = h_i$(ID/OD) (6)
h_0 = 1599.840 w/m^2°C

Checking overall heat transfer coefficient (U_0)

At the outer surface of tubes

$$U_0 = \frac{1}{\frac{1}{hi}(\frac{r_o}{r_i}) + \frac{r_o}{k}\ln(\frac{r_o}{r_i}) + \frac{1}{h_o}} \quad (7)$$

U_0 = 794.811 w/m^2°C

III. GENERATINGSTEADY STATE HEAT EXCHANGER MODELAND ITS THERMAL SIMULATION USING ABAQUS 6.13

We have proposed a software model of shell and tube type heat exchanger exactly of the above derived dimensions. After generating model we have put all parts under the above stated thermal loading conditions and tested out the same under steady state thermal simulation. ABAQUS 6.13 has been used for proposed heat exchanger model generation and its further analysis [14]. The solution phase involved three major steps which are described in detail under next sub headings:

- Generating software model
- Meshing
- Steady state thermal simulation

Generating of software model

Using the above derived dimensions of shell, tubes and baffles we have made a software model using Auto CAD 2013. Auto cad is a commercial software application for 2D and 3D computer-aided design (CAD) and drafting available since 1982 as a desktop application. Design generating of shell and tube heat exchanger model is much easier in auto cad as compared to ABAQUS software [8-12]. Auto cad provides good graphics user interface. After designing model you can easily import model into abacus as shown in figure 1.

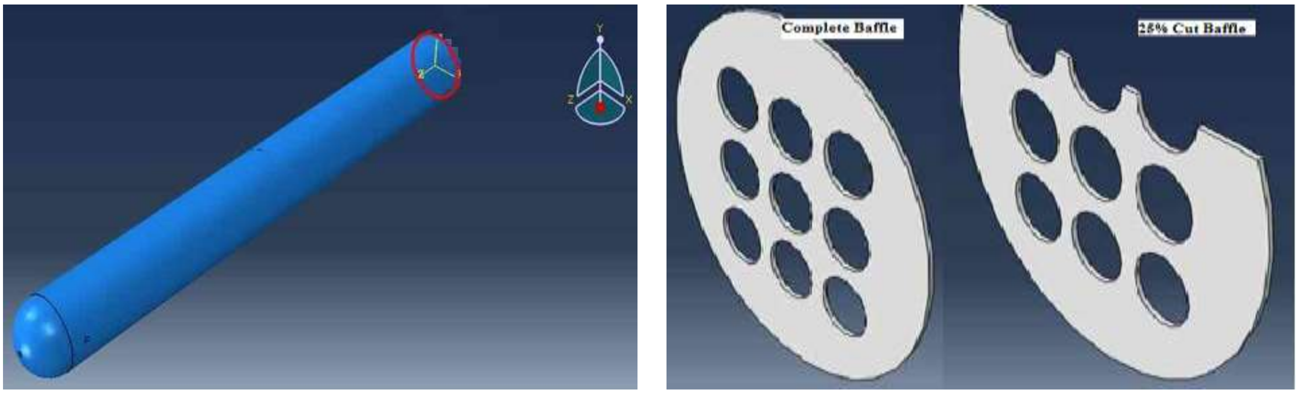

Fig. 1 Shell and baffle in ABAQUS

Meshing

The meshing was generated to perform finite element analysis. In generating the mesh a compromise between computer speed and mesh quality was adopted. Mesh was generated on tubes that show in figure 2.

Steady state thermal simulation

This is the final and the most important step of our analysis. We have applied thermal loads on the various faces and edges for simulation to get the value of thermal flux in complete assembly.

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Impact Factor: 5.164
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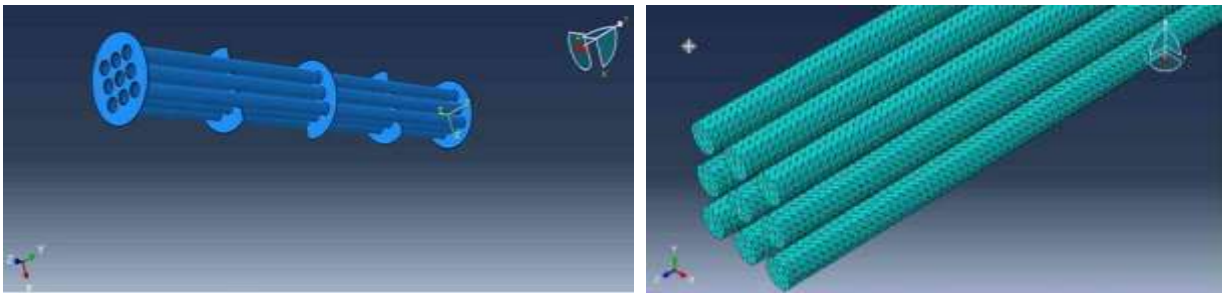

Fig.2 Tubes and Baffles with tube meshing in ABAQUS

Results after simulation

In thermal analysis we have assigned copper material for tubes and baffles while the outer shell made with stainless steel. After assigning the materials we have test on setup under loading conditions and results obtained the values of temperature distribution as well as heat flux on different surfaces.

IV. FABRICATION OF ACTUAL WORKING MODEL

Once we have ensured that our designing is fulfill our desired purpose then we have fabricated an actual working model of derived dimensions and obtained experimental results to complement our research. We have also records the effect of ambient temperature over the effectiveness of the heat exchanger as shown in table 1 to 4. The actual working model setup consists of the following components as shown in figure 4.

- Shell & tube type heat exchanger
- Stand to support the heat exchanger
- Two submersible pumps for maintain flow
- Connecting pipes and electrical connections for power supply
- Water storage tank and K- type thermometer for temperature measurement

Fig. 4 Fabricated setup of shell and tube heat exchanger

For parallel flow

Table 1 Hot water flowing in shell and cold water flowing in the tubes (32 ºC)

Sr. no.	Hot water inlet (°C)	Hot water outlet (°C)	Cold water inlet (°C)	Cold water outlet (°C)	Degree of cooling (°C)	Degree of heating (°C)	Effectiveness of heat exchanger
1.	55.1	48.3	25.2	29.4	6.8	4.2	0.22742
2.	55.4	47.9	25.2	30.3	7.5	5.1	0.24834
3.	55.0	47.5	25.2	30.0	7.5	4.8	0.25167

Table 2 Hot water flowing in tubes and cold water flowing in shell (Ambient tem. 33 ºC)

Sr. no.	Hot water inlet (°C)	Hot water outlet (°C)	Cold water inlet (°C)	Cold water outlet (°C)	Degree of cooling (°C)	Degree of heating (°C)	Effectiveness of heat exchanger
1.	55.1	47.4	25.2	31.3	7.7	6.1	0.25752
2.	55.4	47.6	25.2	31.3	7.8	6.1	0.25827

For counter flow

Table 3 Hot water flowing in tubes and cold water flowing in shell (Ambient tem. 33 ºC)

Sr. no.	Hot water inlet (°C)	Hot water outlet (°C)	Cold water inlet (°C)	Cold water outlet (°C)	Degree of cooling (°C)	Degree of heating (°C)	Effectiveness of heat exchanger
1.	55.3	47.5	25.5	31.1	7.8	5.6	0.26174
2	55.3	46.7	25.2	30.7	8.6	5.5	0.28571
3.	55.1	46.3	24.9	30.8	8.8	5.9	0.29139

V. RESULTS

Here we have tested five arrangements of materials with thermal loads. The record of arrangements with heat flux is described in table 4.From experimentation it is clear that if we choose 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 material. The second better material was aluminium for tubes and baffles because it was in light weight and it was second larger heat transfer material. But aluminium was faced some problems during welding of tubes and baffles. Steels has also moderate heat transfer rate but it is more popular due to his cheapest cost.

Table 4 Heat flux of different Materials used in heat exchanger

Sr. no.	Material of Shell	Material of Tubes & Baffles	Maximum Heat Flux (W/m^2)
1.	Steel 1008	Copper	37556
2.	Steel 1008	Aluminium	25625
3.	Steel 1008	Steel 1010	23564
4.	Aluminium	Aluminium	1.3287×10^5
5.	Copper	Copper	2.1036×10^5

VI. CONCLUSION

This experiment was concerned about the study of various factors that affect the performance of shell and tube type heat exchangers. We concluded that the results of real model and software model are within range. After performing experiment we found the following results:

- The above result presents the ABAQUS analysis results for shell and tube heat exchanger so we can say that ABAQUS was a good software tool to reduce time consuming theoretical work.
- Analysis had been done by changing the tube materials and it found that copper material had higher heat flux (2.1 x 105 W/m^2).
- The value effectiveness of heat exchanger found by ABAQUS software was 0.336.
- The value effectiveness of heat exchanger found from Kern's method was 0.333.
- Effectiveness of heat exchanger was 0.29 more when hot water flowing through tubes and cold water flowing through shell in parallel flow.
- Effectiveness value of counter flow heat exchanger varying from 0.26 to 0.29 was more than parallel flow.

Nomenclature

m - Mass flow rate of fluid (kg/second)
C_P- Specific heat of fluid (J/kg-°C)
C - Capacity rate of fluid (W/°C)
t - Temperature of fluid as used in designing (°C)
t' - Experimental value of temperature of the Fluid (°C)
$LMTD$ - Logarithmic mean temperature difference (°C)
Q - Amount of heat transfer taking place (watts)
U (U_o) - 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)
Pr - Prandtl number
Re - 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

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ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

CITE AN ARTICLE

Kumar, S. (2018). EXPERIMENTAL ANALYSIS OF SHELL AND TUBE HEAT EXCHANGER BY USING ABAQUS. *INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY*, *7*(7), 240-246.