

# Design and thermal analysis of shell and tube type condenser

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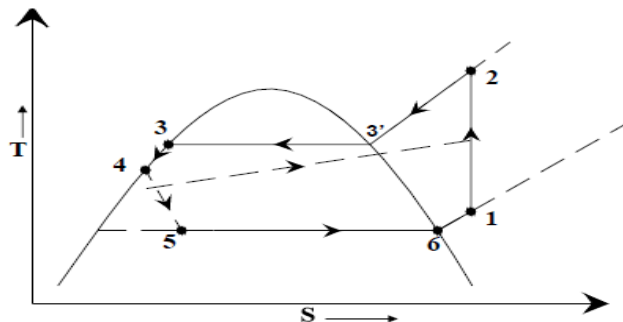
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**Abstract**— In present day shell and tube heat exchanger is the most common type heat exchanger widely used in oil refinery and other large chemical process, because it suits high pressure application. The process in solving simulation consists of modelling and meshing the basic geometry of shell and tube heat exchanger using CFD package ANSYS 12.0. The objective of the project is design of shell and tube heat exchanger with helical baffle using catia software and study the flow and temperature field inside the shell using ANSYS software tools. The heat exchanger contains 27 tubes and 5490 mm length shell diameter 540 mm. The helix angle of helical baffle will be varied from 0 to 200 degree. In simulation, we will show how the temperature and heat flux vary throughout the surface of the condenser. The flow pattern in the shell side of the heat exchanger with continuous helical baffles was forced to be rotational and helical due to the geometry of the continuous helical baffles, which results in a significant increase in heat transfer coefficient per unit pressure drop in the condensers.

**Keywords**— ANSYS 12.0,Baffles, CFD, Simulation

## I. INTRODUCTION

Condenser is an important component of any refrigeration system. In a typical refrigerant condenser, the refrigerant enters the condenser in a superheated state. It is first de-superheated and then condensed by rejecting heat to an external medium. The refrigerant may leave the condenser as a saturated or a sub-cooled liquid, depending upon the temperature of the external medium and design of the condenser. Figure 1.1 shows the variation of refrigeration cycle on T-s diagram. In the figure, the heat rejection process is represented by 2-3'-3-4. The temperature profile of the external fluid, which is assumed to undergo only sensible heat transfer, is shown by dashed line. It can be seen that process 2-3' is a de-superheating process, during which the refrigerant is cooled sensibly from a temperature  $T_2$  to the saturation temperature corresponding condensing pressure,  $T_{3'}$ . Process 3'-3 is the condensation process, during which the temperature of the refrigerant remains constant as it undergoes a phase change process. In actual refrigeration systems with a finite pressure drop in the condenser or in a system using a azeotropic refrigerant mixture, the temperature of the refrigerant changes during the condensation process also. However, at present for simplicity, it is assumed that the refrigerant used is a pure refrigerant (or an azeotropic mixture) and the condenser pressure remains constant during the condensation process. Process 3-4 is a sensible, sub cooling process, during which the refrigerant temperature drops from  $T_3$  to  $T_4$ .



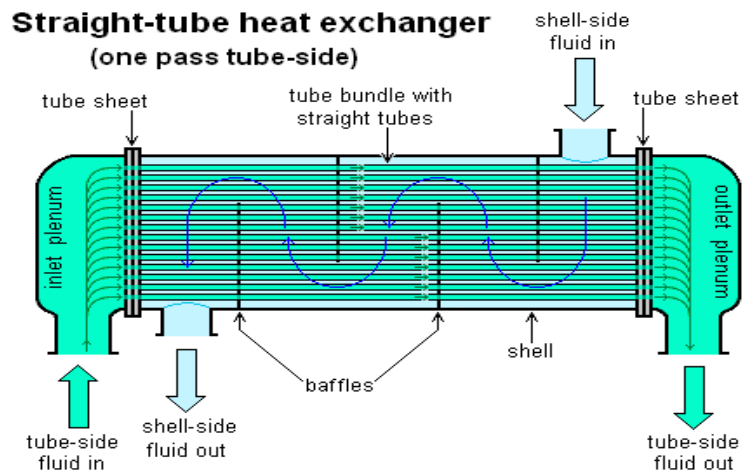
## II. THEORY AND APPLICATION

Two fluids, of different starting temperatures, flow through the condenser. One flows through the tubes (the tube side) and the other flows outside the tubes but inside the shell (the shell side). Heat is transferred from one fluid to the other through the tube walls, either from tube side to shell side or vice versa. The fluids can be either liquids or gases on either the shell or the tube side. In order to transfer heat efficiently, a large heat transfer area should be used, leading to the use of many tubes. In this way, waste heat can be put to use. This is an efficient way to conserve energy.

Condensers with only one phase (liquid or gas) on each side can be called one-phase or single-phase condensers. Two-phase condensers can be used to heat a liquid to boil it into a gas (vapor), sometimes called boilers, or cool a vapor to condense it into a liquid (called condensers), with the phase change usually occurring on the shell side. Boilers in steam engine locomotives are typically large, usually cylindrically-shaped shell-and-tube condensers. In large power plants with steam-driven turbines, shell-and-tube surface condensers are used to condense the exhaust steam exiting the turbine into condensate water which is recycled back to be turned into steam in the steam generator.

### SHELL AND TUBE CONDENSER DESIGN

There can be many variations on the shell and tube design. Typically, the ends of each tube are connected to plenums (sometimes called water boxes) through holes in tube sheets. The tubes may be straight or bent in the shape of a U, called U-tubes. In nuclear power plants called pressurized water reactors; large condensers called steam generators are two-phase, shell-and-tube condensers which typically have U-tubes. They are used to boil water recycled from a surface condenser into steam to drive a turbine to produce power. Most shell-and-tube condensers are either 1, 2, or 4 pass designs on the tube side. This refers to the number of times the fluid in the tubes passes through the fluid in the shell. In a single pass condenser, the fluid goes in one end of each tube and out the other.



Surface condensers in power plants are often 1-pass straight-tube condensers. Two and four pass designs are common because the fluid can enter and exit on the same side. This makes construction much simpler.

There are often baffles directing flow through the shell side so the fluid does not take a short cut through the shell side leaving ineffective low flow volumes. These are generally attached to the tube bundle rather than the shell in order that the bundle is still removable for maintenance.

#### 1) Selection of tube material

To be able to transfer heat well, the tube material should have good thermal conductivity. Because heat is transferred from a hot to a cold side through the tubes, there is a temperature difference through the width of the tubes. Because of the tendency of the tube material to thermally expand differently at various temperatures, thermal stresses occur during operation. This is in addition to any stress from high pressures from the fluids themselves. The tube material also should be compatible with both the shell and tube side fluids for long periods under the operating conditions (temperatures, pressures, pH, etc.) to minimize deterioration such

as corrosion. All of these requirements call for careful selection of strong, thermally-conductive, corrosion-resistant, high quality tube materials, typically metals, including copper alloy, stainless steel, carbon steel, non-ferrous copper alloy, nickel, and titanium. Poor choice of tube material could result in a leak through a tube between the shell and tube sides causing fluid cross-contamination and possibly loss of pressure.

1) **Applications and uses:-**

The shell-and-tube heat exchanger is by far the most common type of heat exchanger used in industry. It can be fabricated from a wide range of materials both metallic and non-metallic. Design pressures range from full vacuum to 6,000 psi. Design temperatures range from -250°C to 800°C. Shell-and-tube heat exchangers can be used in almost all process heat transfer applications.

The shell-and-tube design is more rugged than other types of heat exchangers. It can stand more (physical and process) abuse. However, it may not be the most economical or most efficient selection especially for heat recovery applications or for highly viscous fluids. The shell-and-tube heat exchanger will perform poorly with any temperature crosses unless multiple units in series are employed.

Typical applications include condensers, boiler and process heaters and coolers.

The simple design of a shell and tube condenser makes it an ideal cooling solution for a wide variety of applications. One of the most common applications is the cooling of hydraulic fluid and oil in engines, transmissions and hydraulic power packs. With the right choice of materials they can also be used to cool or heat other mediums, such as swimming pool water or charge air. One of the big advantages of using a shell and tube condenser is that they are often easy to service, particularly with models where a floating tube bundle (where the tube plates are not welded to the outer shell) is available.

**Properties of tube material:-**

1. Copper :

Density (at room temp.)	8.96 gm/cm <sup>3</sup>
Liquid density (at melting point)	8.02 gm/cm <sup>3</sup>
Melting point	1357.77 k
Boiling point	2835 k
Heat of fusion	13.26 kJ/mol
Heat of vaporization	300.4 kJ/mol
Molar heat capacity	24.44 kJ /mol k
Thermal conductivity	401 tt/m k

2. carbon steel :-

Density	7.85 kg/m <sup>3</sup>
Thermal expansion ( 10 <sup>-6</sup> k )	11 – 16.6 k
Melting point	1173 k
Thermal conductivity	24.3 – 65.2 w/m-k
Specific heat	450 – 2081 J/kg-k

Tensile strength	276-1882 Mpa
Yield strength	186 – 758 Mpa

3. Alloy steels

Density	7.85 kg/m <sup>3</sup>
Thermal expansion (10 <sup>-6</sup> k )	9 - 15
Thermal conductivity	26 -48.6 w/m-k
Specific heat	452-1499 J/kg-k
Tensile strength	758 – 1882Mpa
Yield strength	366-1793

4. Stainless steel:-

Density	7.75-8.1kg/m <sup>3</sup>
Thermal expansion ( 10 <sup>-6</sup> k )	9.0 – 20.7
Melting point	1644 – 1727 k
Thermal conductivity	11.2 - 36.7 w/m-k
Specific heat	420 -500 J/kg-k
Tensile strength	515 -827 Mpa
Yield strength	207 – 552 Mpa

**Properties of shell material**

**1. Alloy steel**

Density	7.85 kg/m <sup>3</sup>
Thermal expansion ( 10 <sup>-6</sup> k )	9 - 15
Thermal conductivity	26 -48.6 w/m-k
Specific heat	452-1499 J/kg-k
Tensile strength	758 – 1882Mpa

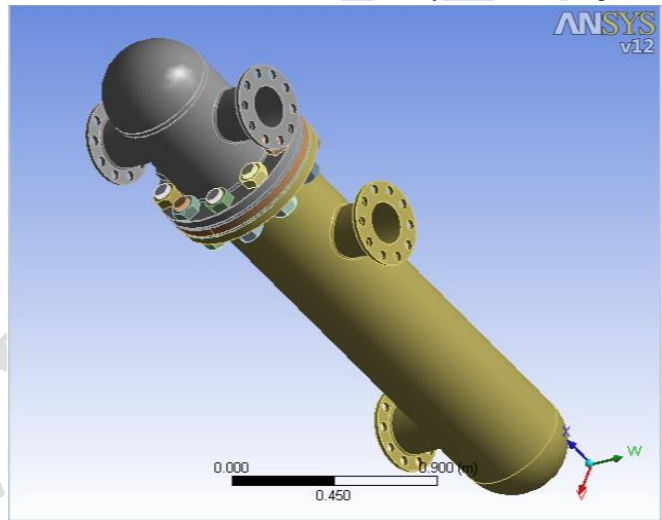
Yield strength	366-1793
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**2. Stainless steel**

Density	7.75-8.1kg/m <sup>3</sup>
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Tensile strength	515 -827 Mpa
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**III. METHODOLOGY**

We have designed all the components of the shell and tube type condenser and then assembled them together. After designing it, we have generated the exploded view. The assembled view of the assembly is shown in figure below:-



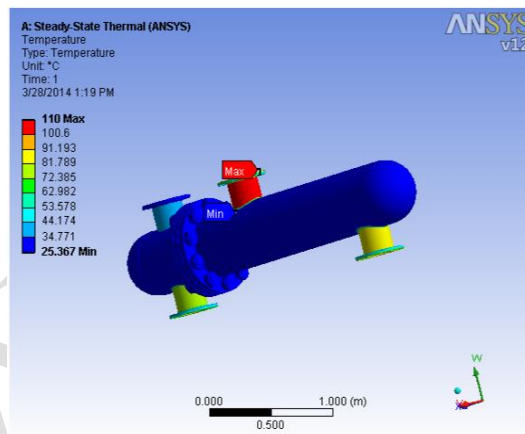
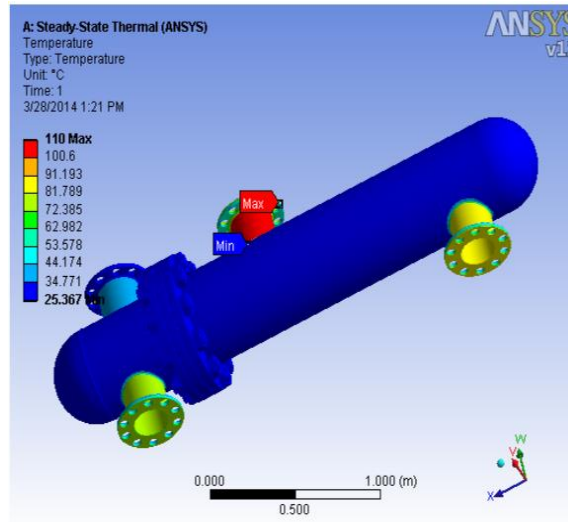
**Analysis of parts using ANSYS-**  
 Steps involved-

- Model generation
- Choosing model type
- Creating working plane
- Importing solid models from IGES files
- Generating the mesh
- Selecting surfaces and applying load/pressure
- Obtaining the solution

#### IV. THERMAL ANALYSIS

##### TEMPERATURE

Following analysis shows the temperature distribution over the entire surface of the condenser .It is visible in the figure that the maximum temperature occurs at the hot fluid entrance and the minimum occurs at the surface of the condenser .

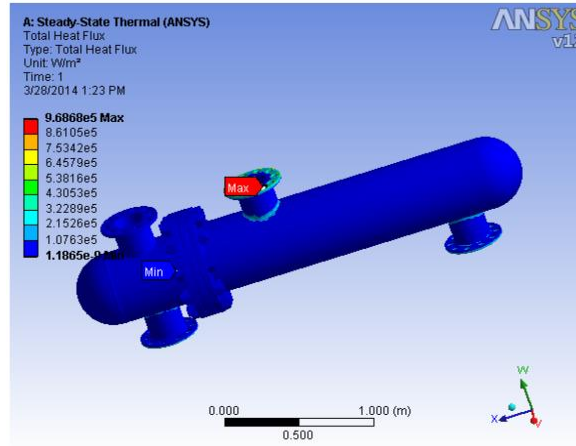


##### STEADY STATE HEAT FLUX

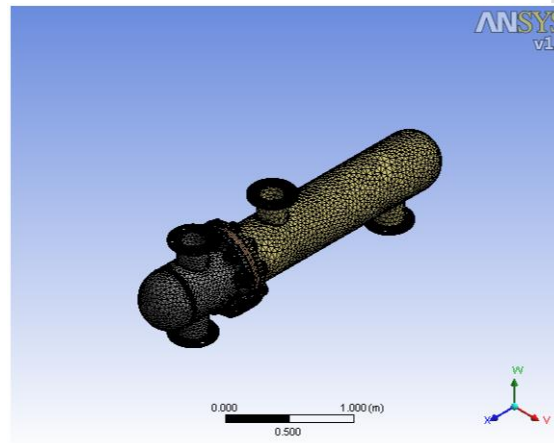
Following analysis shows the heat flux distribution throughout the surface of the condenser. It can be seen that maximum heat flux occurs at the inlet of the hot fluid and the minimum occurs at the surface of the condenser  
Heat flux occurs by the convection mode:

$$q = h (t_s - t_\infty)$$

$t_s$  = surface temperature ,  $t_\infty$  = surrounding temperature  
where surface temp. varies from 110 °c to 22.008 °c and surrounding temperature is 27 °c.  
Hence, corresponding heat flux varies from  $8.819 * 10^5$  to  $3.749 * 10^{-9}$  w/m<sup>2</sup>.



**MESH VIEW**



**DESIGNS CALCULATIONS**

$m_c$  = mass flow rate of cold fluid. =0.9 kg/sec  
 $m_h$  = mass flow rate of hot fluid =2.5 kg/sec  
 $C_{pc}$  = Specific heat of cold fluid= 4.2 KJ/Kg°K  
 $C_{ph}$  = Specific heat of hot fluid= 2.5 KJ/Kg°K  
 $T_{h1}$  = Inlet temperature of hot fluid= 383°K  
 $T_{h2}$  = Outlet temperature of hot fluid=360°K  
 $T_{c1}$  = Inlet temperature of cold fluid = 308°K  
 $T_{c2}$  = Outlet temperature of cold fluid  
 $\rho$  = Density of oil= 850 Kg/m<sup>3</sup>  
 $U_o$  = Overall heat transfer coefficient = 350 W/m<sup>2</sup>°K  
 $\Sigma$  = Effectiveness of heat exchanger  
 $\Delta T_{lm}$  = Logarithmic mean temperature difference  
 $Q$  = Total heat transfer=  $m_c c_c \Delta T_{lm}$   
 $Q$  = heat gain by the cold liquid= heat loss by hot liquid  
 $Q = m_c c_c \Delta T_{lm} = m_h c_h \Delta T_{lm}$   
 $0.9 \times 4.2 \times (T_{c2} - 308) = 2.5 \times 2.5 \times (383-360)$   
 $= 346.029$   
 Outlet temperature of cold liquid  $T_{c2} = 346^\circ K$   
 $Q = m_c c_c \Delta T_{lm} = 0.9 \times 4.2 \times (346 - 308) = 143.74 \text{ KW}$   
 Rate of heat transfer  $Q = 143.74 \text{ KW}$



Log mean temperature difference for counter flow heat exchanger

$$\Delta T_{lm} =$$

$$\Delta T_1 = T_{h1} - T_{c2}$$

$$\Delta T_2 = T_{h2} - T_{c1} =$$

Area of shell A = =

$$\text{Area of tube} = 9.318 \text{ m}^2$$

$$A_t = m_h / \rho v = 2.5/850 \times 0.35 = 0.0084 \text{ m}^2$$

**No. of tubes**  $A_t = n\pi d^2/4$

$$n = A_t \times 4 / \pi d^2 = 26.93 = 27 \text{ tubes}$$

**Length of tubes** :-  $A = n\pi dL$

$$L = = 5.49 \text{ m}$$

**Shell outer diameter**  $D_o = = = 0.540 \text{ m}$

Effectiveness  $\Sigma =$

$$C_{max} = \text{maximum of } C_h \text{ or } C_c$$

$$C_{min} = \text{minimum of } C_h \text{ or } C_c$$

$$C_{min} = C_c = m_h \times C_{pc} = 0.9 \times 4.2 = 3.78$$

$$C_{max} = C_h = m_h \times C_{ph} = 2.5 \times 2.5 = 6.25$$

$$\Sigma = 0.507050$$

## V. RESULT AND DISCUSSION

### STEADY STATE THERMAL ANALYSIS

Model (C4) > Analysis

Object Name	Steady state Thermal(C5)
State	Solved
Definition	
Physics Type	Thermal
Analysis Type	Steady state
Solver Target	Ansys Mechanical
Options	
Generate Input only	No

Model (C4) > Steady state Thermal (C5) > Initial Condition

Object Name	Initial Temperature
State	Fully Defined
Definition	
Initial Temperature	Uniform Temperature
Initial Temperature Value	22°C

Model (C4) > Steady state Thermal (C5) > Analysis Settings

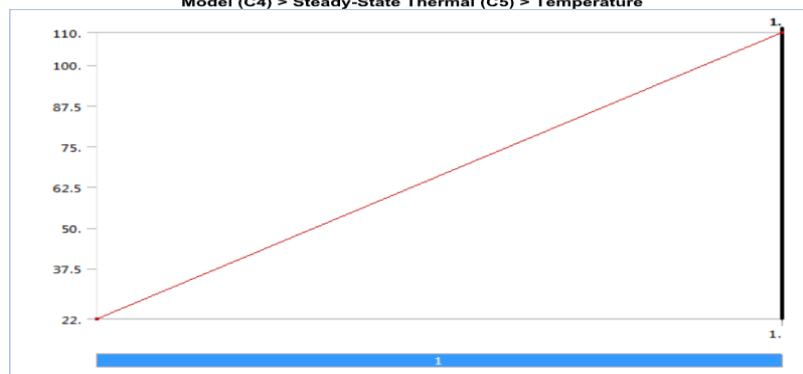
Object Name	Analysis Settings
State	Fully Defined
Step Controls	
No. of steps	1.

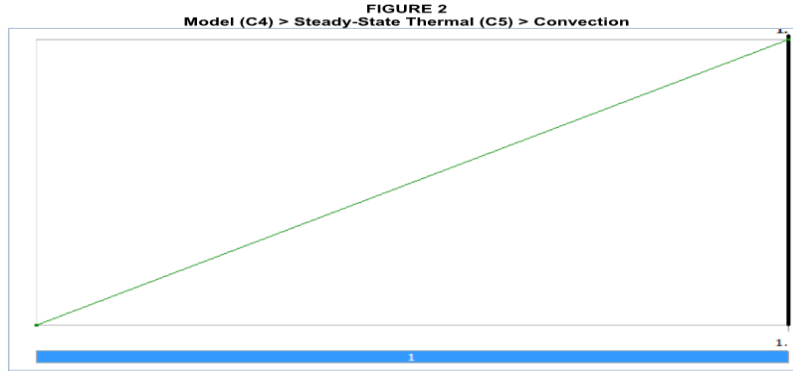
Current Step number	1.
Step End Time	1.s
Auto Time setting	Program controlled
<b>Solver Controls</b>	
Solver Type	Program controlled
<b>Nonlinear Controls</b>	
Heat Convergence	Program controlled
Temperature Convergence	Program controlled
Line search	Program controlled
<b>Output Controls</b>	
Calculate Thermal Flux	Yes
Calculate Results At	All time points

Model (C4) > Steady state Thermal (C5) > Loads

Object Name	Temperature	Convection	Temperature 2	Temperature 3	Temperature 4
State	Fully Defined				
<b>Scope</b>					
Scoping Method	Geometry Selection				
Geometry	3 Faces		1402 Faces		3 Faces
<b>Definition</b>					
Type	Temperature	Convection	Temperature		
Magnitude	111°C (ramped)		87°C (ramped)	37°C (ramped)	73°C (ramped)
Suppressed	No				
Film Coefficient		3039W/m <sup>2</sup> C(ramped)			
Ambient Temperature		27°C (ramped)			

FIGURE 1  
Model (C4) > Steady-State Thermal (C5) > Temperature





Model (C4) > Steady state Thermal (C5)> Convection

Steps	Time(s)	Convection Coefficient [W/m <sup>2</sup> °C]	Temperature °C
1	0.	0.	22.
	1.	3039.	27.

**SOLUTION**

Model (C4) > Steady state Thermal (C5)> Solution

Object Name	Solution(C6)
State	Solved
<b>Adaptive Mesh Refinement</b>	
Max Refinement Loops	1.
Refinement Depth	2.

Model (C4) > Steady state Thermal (C5)> Solution (C6)> Solution Information

Object Name	Solution Information
State	Solved
<b>Solution Information</b>	
Solution Output	Solver Output
Update Interval	2.5 s
Display Points	All

Model (C4) > Steady state Thermal (C5)> Solution(C6)> Results

Object Name	Temperature	Total Heat flux
State	Solved	
<b>Scope</b>		
Scoping Method	Geometry Selection	
Geometry	1402 Faces	
<b>Definition</b>		
Type	Temperature	Total Heat flux

<b>By</b>	<b>Time</b>	
<b>Display Time</b>	<b>Last</b>	
<b>Calculate Time History</b>	<b>Yes</b>	
<b>Identifier</b>		
<b>Use Average</b>		<b>Yes</b>
<b>Results</b>		
<b>Minimum</b>	<b>22.008°C</b>	<b>3.7493e-009 W/m<sup>2</sup></b>
<b>Maximum</b>	<b>110 °C</b>	<b>8.8194e+005 W/m<sup>2</sup></b>
<b>Minimum occurs on</b>	<b>Part 1</b>	<b>Part 4</b>
<b>Maximum occurs on</b>	<b>Part 1</b>	
<b>Information</b>		
<b>Time</b>	<b>1s</b>	
<b>Load step</b>	<b>1</b>	
<b>Sub step</b>	<b>1</b>	
<b>Iteration number</b>	<b>1</b>	

## VI. CONCLUSION

Thermal analysis of the shell & tube type condenser with 1 shell pass & 2 tube pass was performed using the ANSYS 12.0 software. The analysis shows the temp & heat flux distribution over the entire surface of the condenser. The inference derive from the analysis for the time of 1 sec variation shows that the temp distribution occurs in the range of 22.008 °c to 110 °c with the maximum temp of 110 °c occurring at the hot fluid entrance and minimum temp of 22.008 °c occurring at the surface of the condenser.

Similarly, The heat flux distribution occurs in the range of  $8.8194 \times 10^{5w}$  to  $3.749 \times 10^{-9}$  watt/m<sup>2</sup> with the maximum value of heat flux occurs at hot fluid entrance and minimum value occurs at surface Also by performance the manual calculations we obtained effectiveness of the condenser which is 0.507050.

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