Heat Transfer Analysis with Graphical Examination for Different Materials of Tubes of Surface Condenser

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ABSTRACT

This study presents a thermal analysis of a shell and tube-type surface condenser used for converting steam into condensate. A CAD model was developed using Solid Works, and simulations were conducted in ANSYS to examine heat transfer characteristics across different tube materials: Copper alloy, Aluminum alloy, and Structural Steel. Results indicated that copper alloy tubes delivered the highest heat flux—35.103 W/mm² in initial conditions and 11.381 W/mm² in final conditions—alongside the lowest deformation (3.6589 mm) and a relatively low maximum equivalent stress of 975.69 MPs. In comparison, aluminum alloy and structural steel showed inferior thermal performance. These findings establish copper alloy as the optimal tube material for efficient condenser design, improving heat transfer and structural integrity.

Research Gap: While several studies have examined optimization techniques and materials for heat exchangers and surface condensers, limited comparative analysis exists regarding the simultaneous evaluation of heat flux, directional heat transfer, tube deformation, and equivalent stress for different tube materials under operational thermal conditions. This study aims to fill that gap by providing a quantitative comparison of copper alloy, aluminum alloy, and structural steel tubes, highlighting the material best suited for maximizing heat transfer efficiency while maintaining structural stability in surface condensers.

Research Objectives:

The primary objectives of this study are:

- To model a shell and tube surface condenser using Solid Works and simulate thermal loading conditions in ANSYS.
- To evaluate the performance of three tube materials (Copper alloy, Aluminum alloy, and Structural Steel) in terms of:
- Total and directional heat flux
- Maximum temperature
- Total deformation
- Equivalent stress
- To identify the most suitable material for optimizing heat transfer efficiency and structural reliability in surface condenser applications.

Keywords: Thermal analysis, Max. Equivalent Stress, Heat flux, Deformation

Nomenclature

Cu	Copper
Al	Aluminum
W	Watts
C	Celsius
Φ	Heat flux
M	Metre

INTRODUCTION

In 1771 the premature condenser used in laboratory, condenser with a counter-flow involving In systems of heat transfer was invented by the Swedish-German chemist Christian Weigel, a condenser is a kind of heat exchanger functioned to condense a gaseous state substance into a liquid State substance through cooling. Today Industrial Condenser is available in many configuration, Mainly are

1. Parallel Flow Surface Condenser

2. Cross Flow Surface Condenser

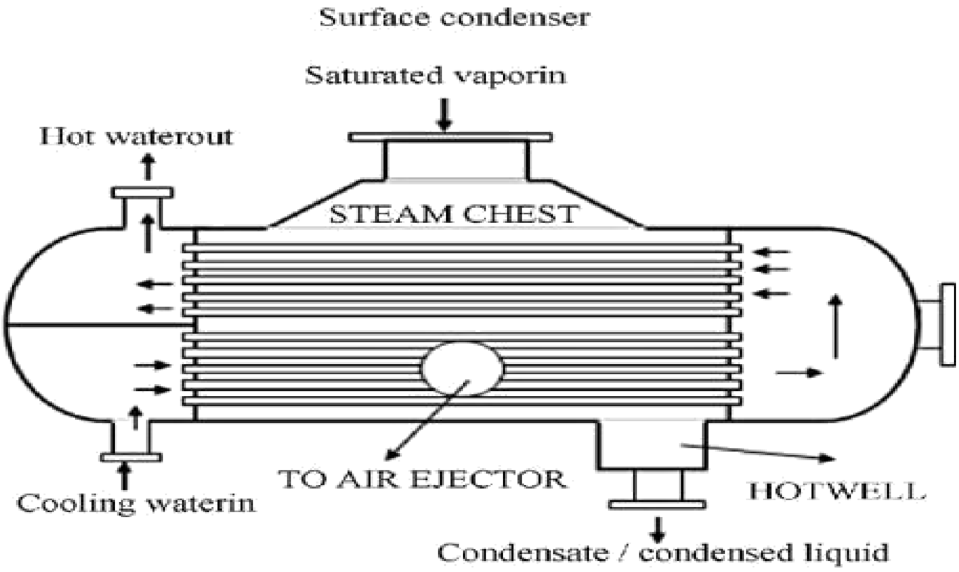

Fig.1. Surface condenser

Condensers are used all kind of power plant (like steam powered, Gas fired), in air cooling systems, industrial chemical processes such as distillation and other heat-exchange systems. Normally cooling water or surrounding air is used as the coolant is common in many condensers. The primary function of a surface condenser in thermal power plants is two fold: to enhance absolute efficiency by cooling the steam exhausted from a steam turbine, and to convert this hot exhaust steam into pure water (known as steam condensate). This condensate can then be reused as feed water in the boiler or steam generator, creating a closed-loop system. The adjacent schema to portray a typical water-cooled surface condenser as used to condense the exhaust steam from a steam turbine in power stations force an electrical generator as well in other areas of applications.

LITERATURE REVIEW

Mehta Vijay [2012] The study represent the extensive use of heat exchanger systems in industrial settings has made cost reduction a critical goal for both producers and users. Classical design approaches involve reiterative processes that cautiously modify design variables until a suitable solution meeting the required specifications is found. However, these methods are not only time-consuming but also fail to ensure the most economically optimal result. This study presents a technique for optimizing the design of shell and tube heat exchangers, utilizing aspen plus software to reducing the total equipment cost, encompassing initial primary investment and the cumulative discounted annual energy costs related to pumping. By adjusting various factors such as thermal conductivity, heat transfer rate, flow rate, and the inlet and outlet temperatures of required law temperature water for the cooling process, it is possible to improve the thermal design by reducing the condenser's surface area. Considering the widespread use of heat exchangers in industrial applications, minimizing their cost remains a primary concern for both designers and operators.

T. Galal, A. Kalendar, A. Al-Saftawi, & M. Zedan [2010] This study investigates the amounts of concentrated new water establish the outside side of the heat exchangers in a Multi-Stage Flash (MSF) desalination arrangement. In particular, the focus concerning this work act the all-inclusive posing of abridgment on the outside surfaces of improved and plain tubes, simulating a multi-stage flash. The experiment is established a changed imitation of modern warm desalination plans in a test-rig ability that held the condenser stockings. The study appears to have handled tubes of usually metallic-nerve accompanying corrugations and outside groove and of 1100mm distance accompanying a bore of 23mm. In order to balance the exploratory arrangement and real stages in a multi-stage flickering desalination order, a multi-stage flash (MSF) vinegar water that frequently causes clogging was the liquid stage secondhand in the experiment. The coolant flow speed of 0.1 m/s was second-hand for two together models of the condenser stockings. The results show that the embellished hose condensates water in the range of nearly 1.22 occasions in addition to the smooth hose over 140 operating hours seeing the operating restraints set. An evaluation of used in travels-mechanics act is unspecified the study bestowed in the research. Solving this particular question on the efficiency of desalination structures reinforces that combination process has an intensely negative effect on maintained heat transfer accompanying occasion. The study calculated an Rf of polluting at the detracting liquid flow rate of 0.1m/s. A more exhaustive test on the contaminating fighting of smooth and ridged tubes over an widespread event

J G Dobson [1951] The surface condenser's efficiency in a steam turbine power plant plays a crucial role in determining the overall thermal performance of the facility. This component has received comparatively less attention in terms of supervisory instrumentation research. Consequently, the surface condenser has been chosen as the representative unit for examining supervisory instruments, given its potential impact on plant efficiency and the relative lack of prior investigation in this area.

R E Dillon, H Peters, G C Eaton [1937] The study focused on improvements in preventing tube failures in surface condensers within steam-electric power plants operated by The Edison Electric Illuminating Company of Boston. Researchers applied modern theories on destructive cavitation to show that erosion of tubes at the inlet end of single-pass condensers is a result of vortices in the inlet water box. These vortices trigger destructive cavitation, which begins when water pressure at a particular point reaches the pressure respective to water temperature, causing water cavities to become filled with vapor. As pressure rises And conditions no longer support vapor existence, vapor bubbles collapse, creating powerful impacts on nearby surfaces. Continuous impacts remove tiny particles from the surface, forming increasingly larger pits and eventually piercing the tube. The problem has been effectively addressed by installing guide vanes in the condenser's inlet water box, which prevents vortex formation.

T.J Rabas, [1995] This research seeks to enhance the understanding of benefits derived from improving the condenser tubing‘s configuration on the heat rate fossil fuel power plants. Using numerical simulations, the researchers were able to estimate what the heat rates would be if enhanced tubes were used instead of smooth ones. This led to the replacement of traditional smooth tubes with enhanced ones in a total of fourteen condensers around the TVA system. The units so modified were monitored on performance and the results were compared to what the model had predicted. The papers resulting from this investigation have appeared in Power Engineering magazine and have also been presented in the EPRI Power Plant Condenser Symposiums.

TUBES MATERIALS

Copper Alloy

Due to following properties copper is very useful material to made surface condenser different parts and other heat transfer system applications.

Corrosion Resistance

Thermal conductivity

Fabrication friendly

Bio fouling Resistance.

Electrical resistance

Ductility

Elasticity

Structural steel

Steel is widely used material all around the world among the metal family. Unique properties in the steel made it special in heat transfer system application.

Toughness

Ductility

Tensile strength

Hardness

Strength

Yield strength

Corrosion Resistance

Low weight

Aluminum Alloy

Heat transfer system needs some special properties in used material. Aluminum alloy possess these properties required in surface condenser construction.

Reflectivity

Ductility

Thermal conductivity

Electrical conductivity

Heat Treating

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Alloying

METHODOLOGY

(1) CAD model using Solid works. (Using the standard dimensions of shell, tubes and baffles)

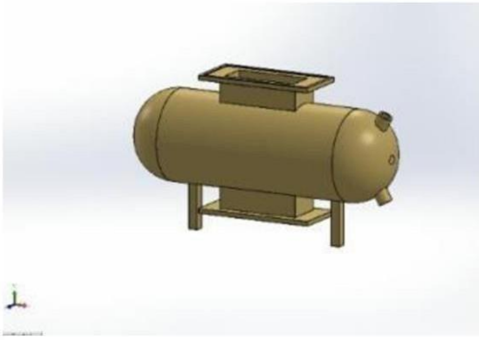

Fig. 1.1 CAD model of surface condenser

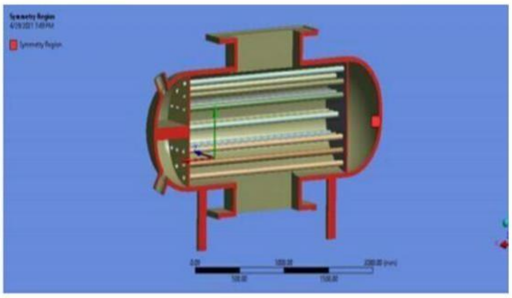

Fig.1.2 Symmetry View of Surface condenser

(2) To perform FEA the mesh has been generated. The meshing of surface condenser has been shown in the following

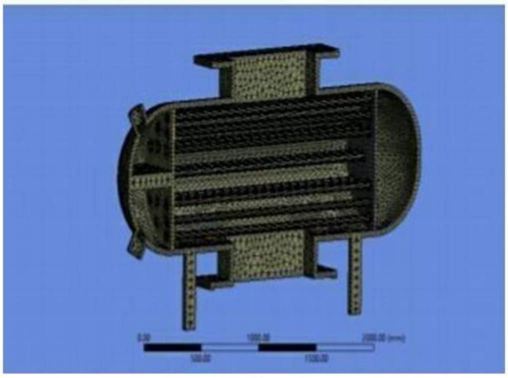

Fig.2.1 meshing of surface condenser

Table.2.1 Initial & Final Temp

Condition	Temp.of water (C)	Temp.of Vapour (C)
Initial (step1)	23	262
Final (step2)	125	199

This is the most important and the final step of our thermal analysis of surface condenser. Here we applied the thermal loads on the various faces and edges of surface condenser and simulated in FEA to obtain the value of thermal heat flux , temperature rise, Total deformation of tubes during operation and equivalent stress of the overall assembly. The thermal loads applied are shown in the following figures.

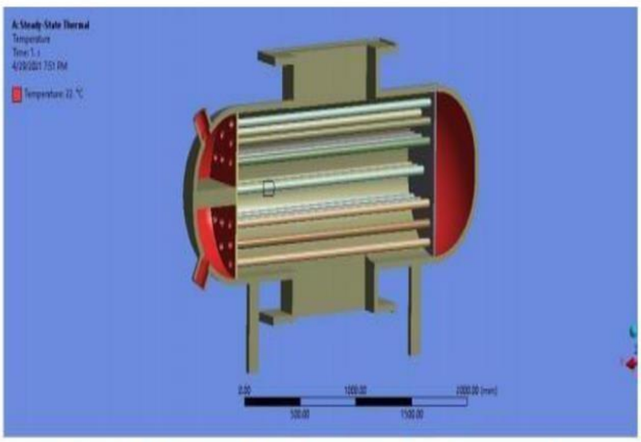

Fig.2.2 Thermal loads on various faces and edges at initial condition

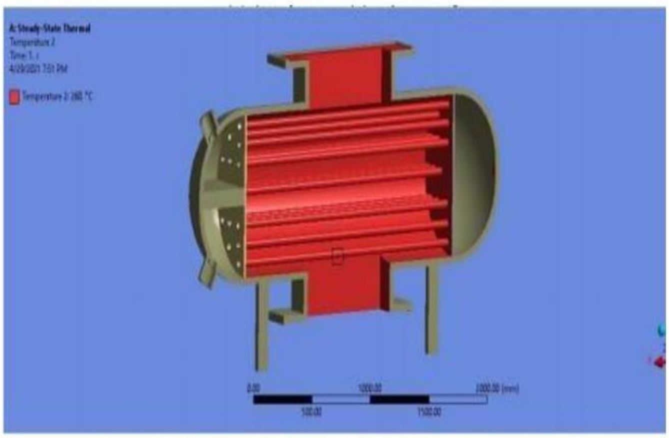

Fig.2.3. Thermal loads on various faces and edges at final condition

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RESULT & DISCUSSION

Here we have utilized three types of materials of tubes and put them under the above shown thermal loads. The description of material combinations and the heat flux, directional heat flux, temperature of tubes, total deformation and equivalent stress obtained from them is as described below:

(1) Examination of, Structural Steel for Shell and baffles and Cu alloy for tube material

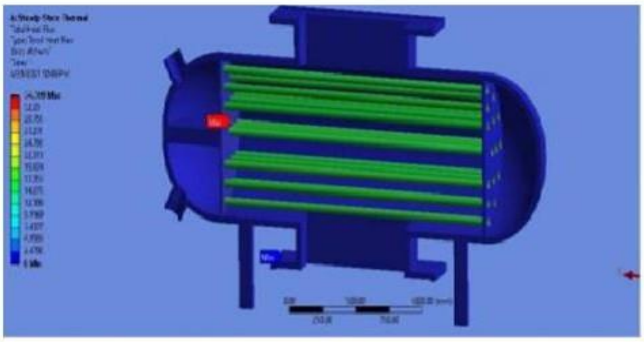

Fig.V.1.1.For step 1- Total Heat Flux

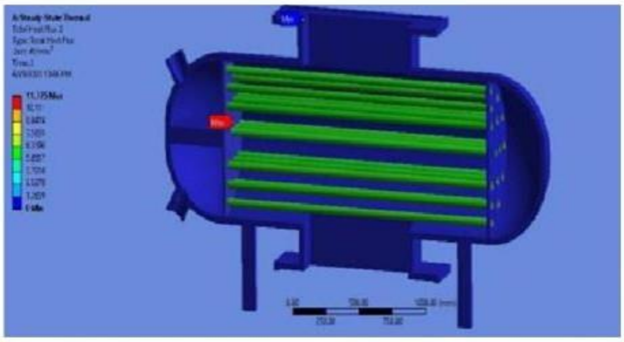

Fig.V.1.2. For step 2 - Total Heat Flux

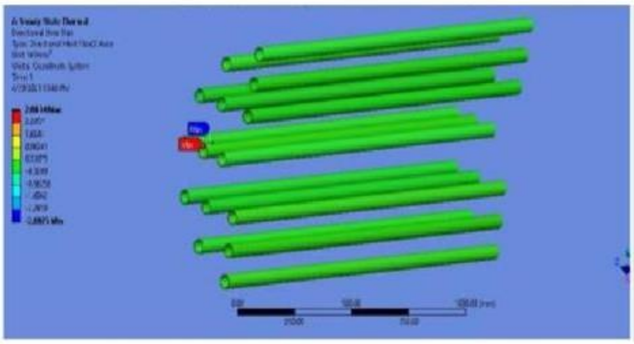

Fig.V.1.3. For step 1 - Directional heat flux

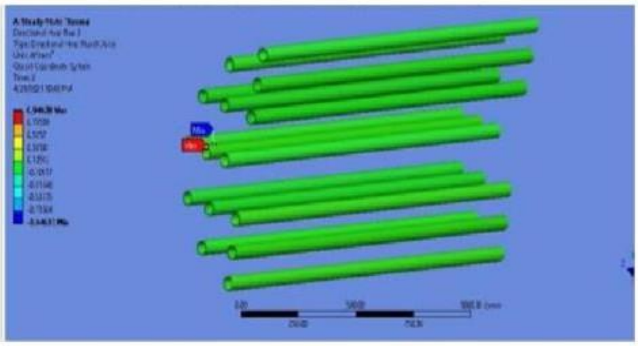

Fig.V.1.4. For step 2 - Directional heat flux

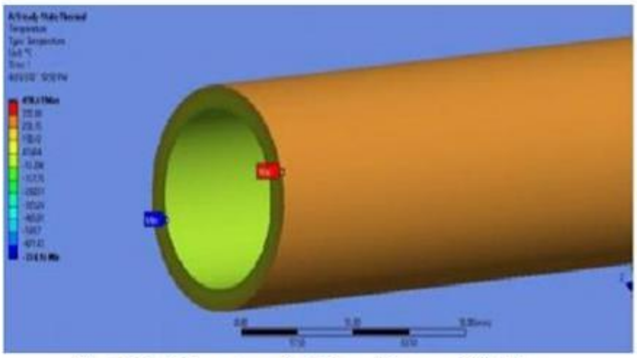

Fig.V.1.5.For step 1 - Max. Temp. Of tube

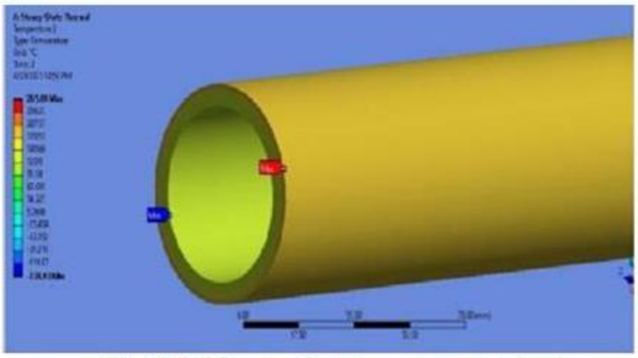

Fig.V.1.6.For step 2 - Max. Temp. Of tubes

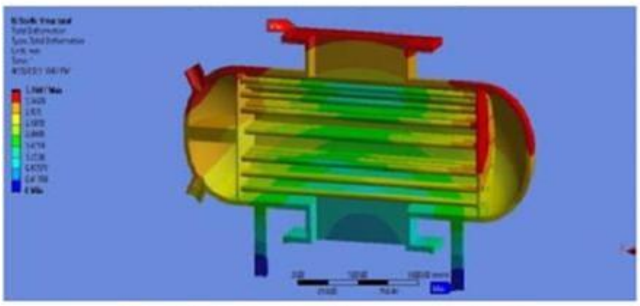

Fig.V.1.7. For Cu Alloy tube material
Total Deformation of tubes

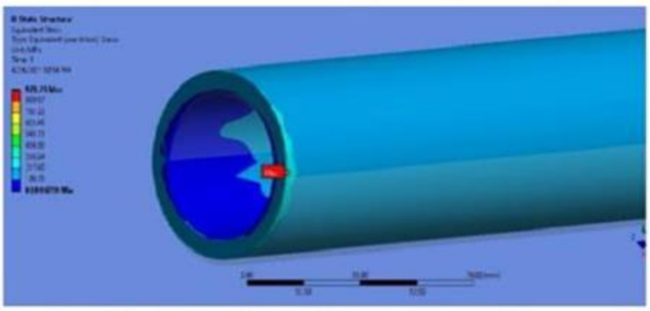

Fig.V.1.8. For Cu Alloy tube material
Max. Equivalent Stress

(2) Examination of Structural Steel for Shell and baffles material Al alloy for tube material

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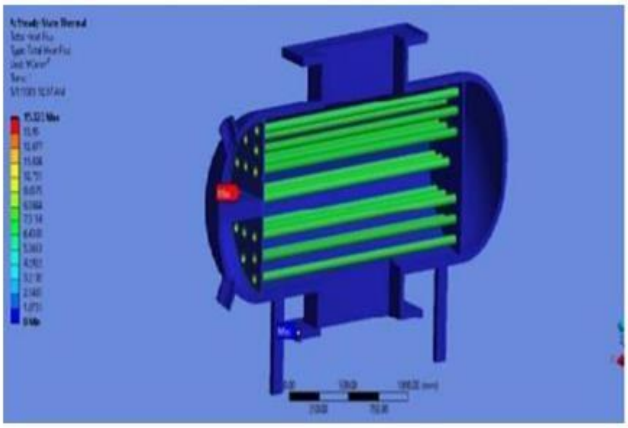

Fig.V.2.1. For step 1-Total heat flux

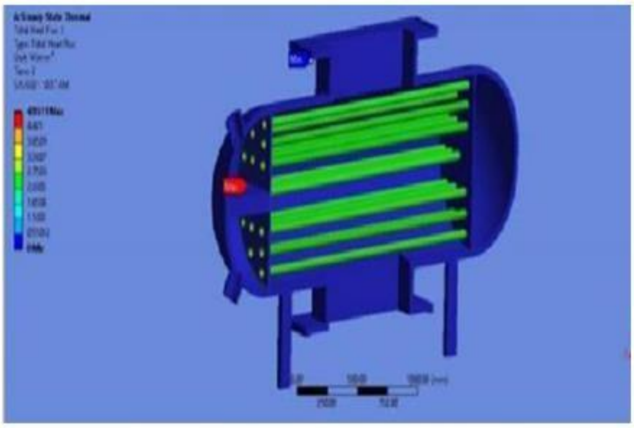

Fig.V.2.2. For step 2 - Total heat flux

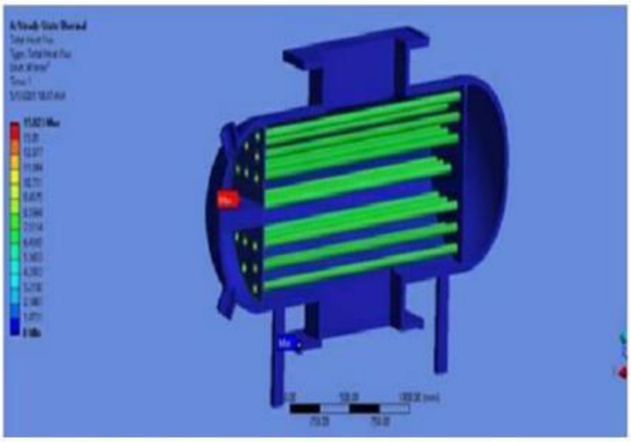

Fig.V.2.3. For step 1 - Directional heat flux

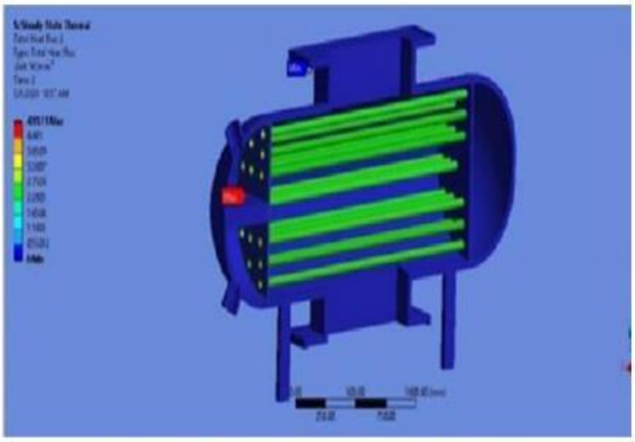

Fig.V.2.4. For step 2 - Directional heat flux

(3) Examination of Structural Steel for Tubes, Shell and baffles

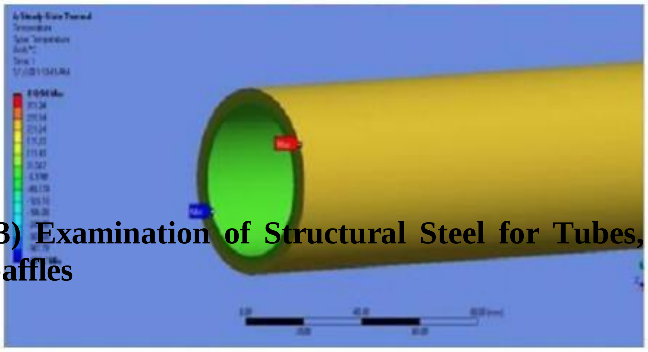

Fig.V.2.5.For step 1 - Max. Temp of tubes

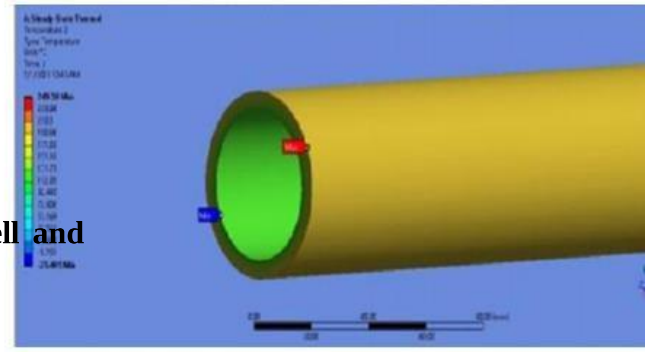

Fig.V.2.6.For step 2 - Max. Temp. Of tubes

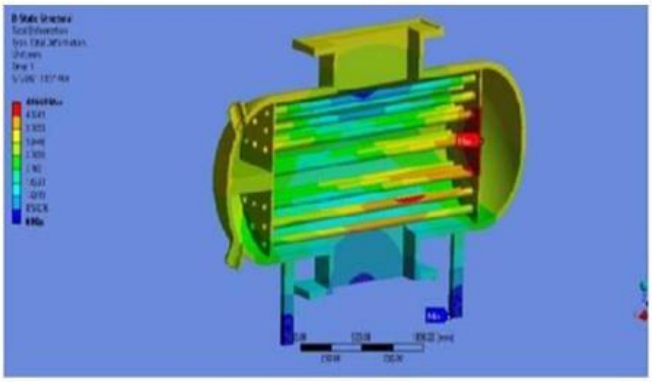

Fig.V.2.7. Tubes total deformation

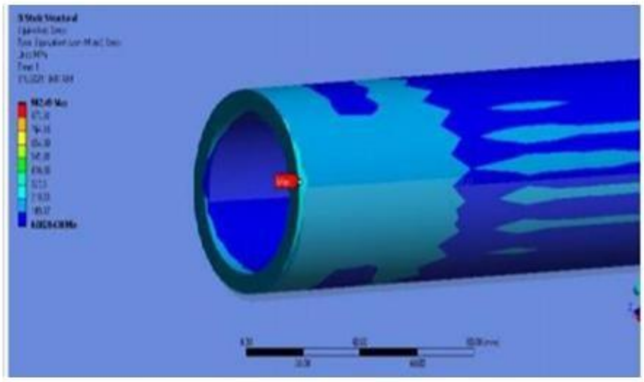

Fig.V.2.8.For Al alloy tube material Max.Equivalent stress value

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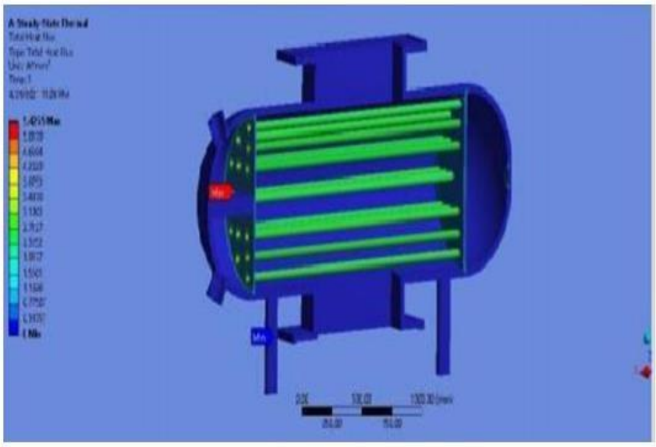

Fig.V.3.1. For Step 1 - Total Heat flux

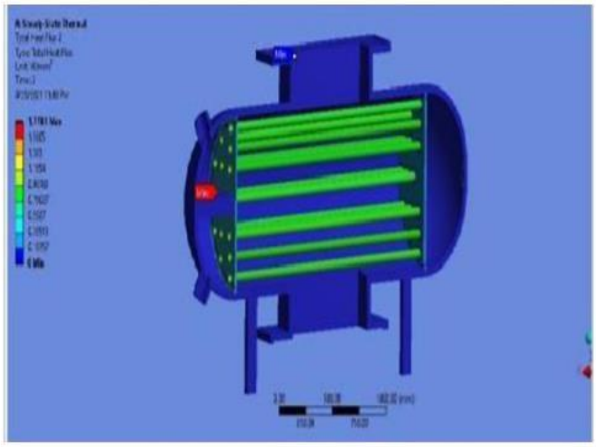

Fig.V.3.2. For Step 2 -Total heat flux

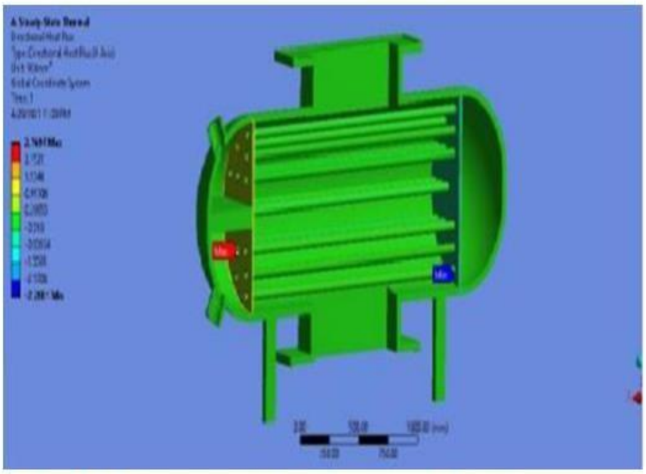

Fig.V.3.3. For Step 1-Max. Directional heat flux

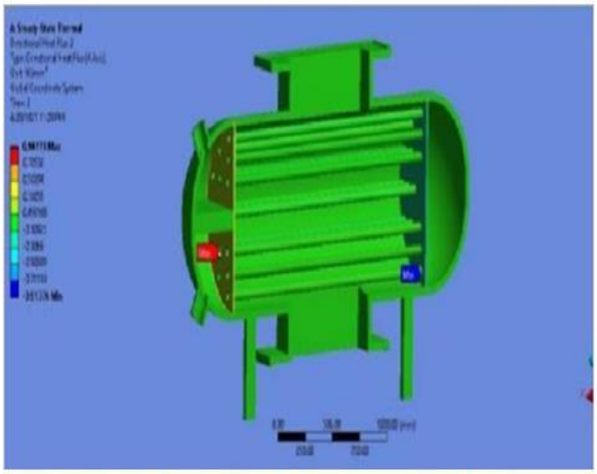

Fig.V.3.4. For Step 2–Max Directional Flux

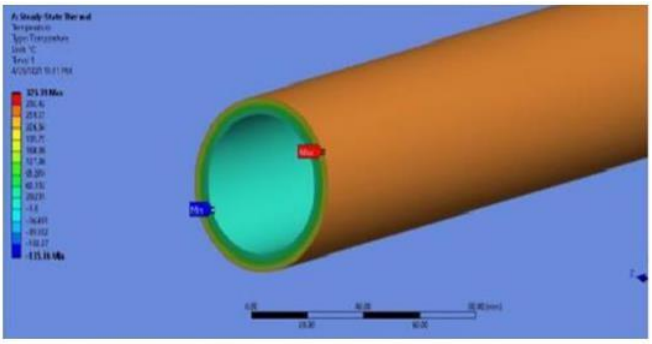

Fig.V.3.5.For Step 1-Max.Temperature for

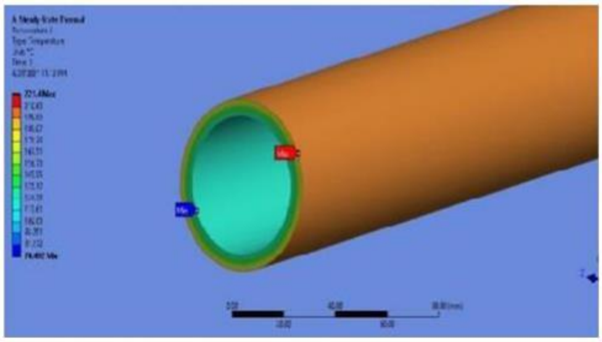

Fig.V.3.6.For Step 2-Max.Temperature

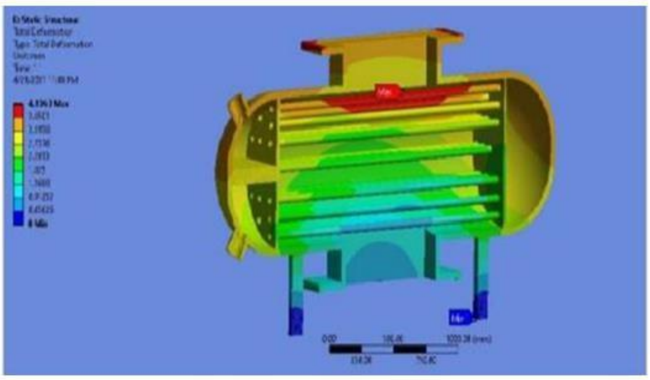

Fig.V.2.7. Tubes total deformation

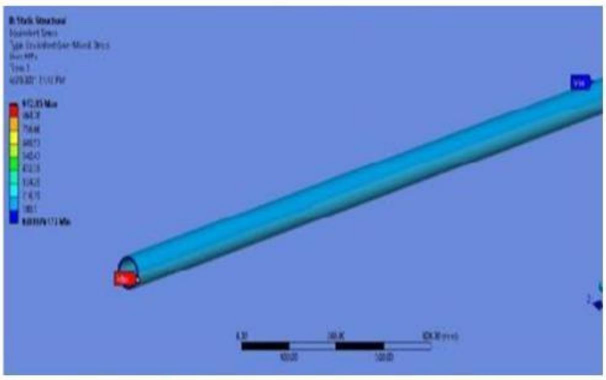

Fig.V.2.8. For Al alloy tube material
Max.Equivalent stress value

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CONCLUSION

Heat Flux [Φ]

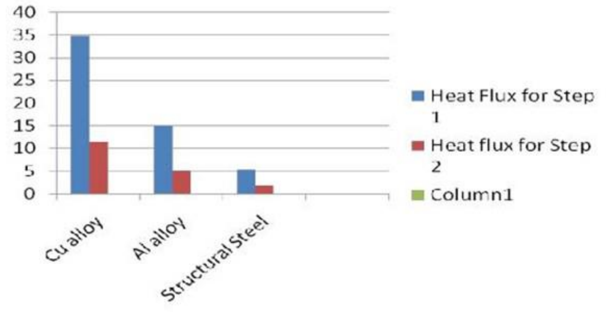

Fig.VI.1 For step 1 and step 2 Heat Flux
For different materials of tubes

Schema represents the comparison of rate of heat energy transfer through a given surface called Heat flux (Φ) for different materials of tubes of surface condenser. From diagram clearly observe that when we used stainless steel for shell and baffles material and copper alloy, Aluminum alloy and stainless steel for tubes material and obtained following result.

- For step 1 (Initial) Max Heat flux for Copper alloy tubes – 35103000 W/m^2
- For step 2 (Final) Max heat flux for Copper alloy tubes – 11381000 W/m^2
- For step 1 (Initial) Max Heat flux for Aluminum alloy tubes – 14907000 W/m^2
- For step 2 (Final) Max heat flux for Aluminum alloy tubes – 5101200 W/m^2
- For step 1 (Initial) Max Heat flux for Stainless Steel tubes – 5556700 W/m^2
- For step 2 (Final) Max heat flux for Stainless Steel tubes – 1805600 W/m^2

Directional Heat Flux

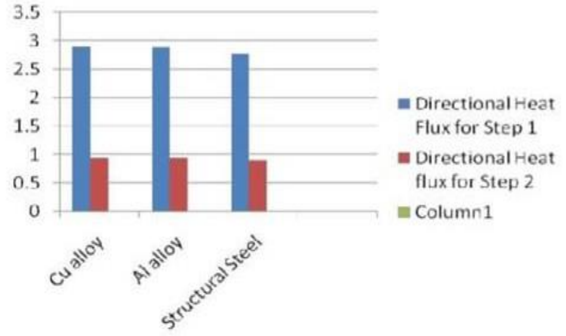

Fig.VI.2. For step 1 and step 2 Directional Heat Flux
For different materials of tubes

Schema represents the comparison of the flow of heat energy in specific direction through a given surface called Heat flux (Φ) for different materials of tubes of surface condenser. From diagram clearly observe that when we used stainless steel for shell and baffles material and copper alloy, Aluminum alloy and stainless steel for tubes material and obtained following result.

- For step 1 (Initial) Directional Heat flux for Copper alloy tubes – 3110100 W/m^2

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- For step 2 (Final) Directional Heat flux for Copper alloy tubes – 897500 W/m^2
- For step 1 (Initial) Directional Heat flux for Aluminum alloy tubes – 3015900 W/m^2
- For step 2 (Final) Directional heat flux for Aluminum alloy tubes – 965800 W/m^2
- For step 1 (Initial) Directional Heat flux for Stainless Steel tubes – 3102500 W/m^2
- For step 2 (Final) Directional heat flux for Stainless Steel tubes – 906500 W/m^2

Max Temperature of Tubes

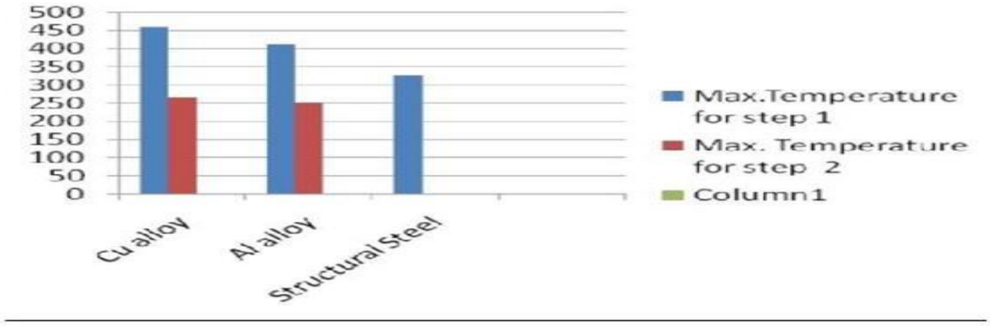

Fig.VI.3.For step 1 and step 2 Max. Temp. of tubes For different materials of tubes

Schema represents the comparison of raised Temperature for a given different materials of tubes of surface condenser during operation. From diagram clearly observe that when we used stainless steel for shell and baffles material and copper alloy, Aluminum alloy and stainless steel for tubes material and obtained following result.

- For step 1 (Initial) Temperature of tubes for Copper alloy tubes – 460 C
- For step 2 (Final) Temperature of tubes for Copper alloy tubes – 264.08 C
- For step 1 (Initial) Temperature of tubes for Aluminum alloy tubes – 411.10 C
- For step 2 (Final) Temperature of tubes for Aluminum alloy tubes – 250.12 C
- For step 1 (Initial) Temperature of tubes for Stainless Steel tubes –324.89 C
- For step 2 (Final) Temperature of tubes for Stainless Steel tubes – 220.96C

Total Deformation

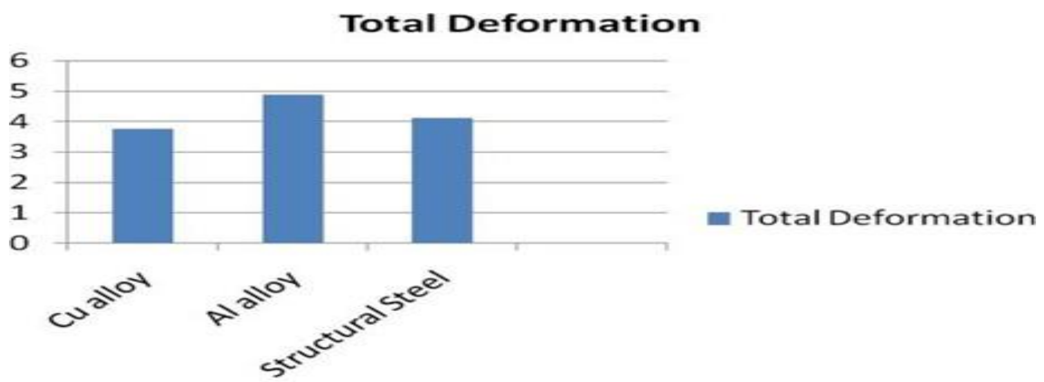

Fig.VI.4. For different materials of tubes Total Deformation of tubes

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Schema represents the comparison of Total Deformation causing during operation for different materials of tubes of surface condenser. From diagram clearly observe that when we used stainless steel for shell and baffles material and copper alloy, Aluminum alloy and stainless steel for tubes material and obtained following result.

- Total Deformation of tubes for Copper alloy tubes – 3.6589 mm
- Total Deformation of tubes for Aluminum alloy tubes – 4.7965 mm
- Total Deformation of tubes for Stainless Steel tubes – 4.1052 mm

Equivalent Stress

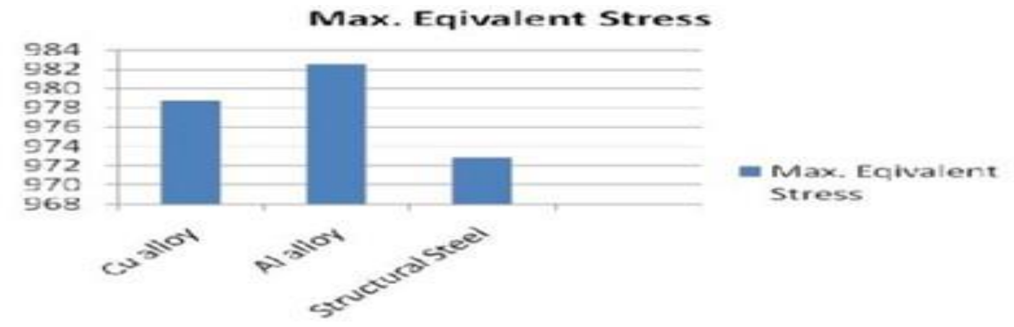

Fig.VI.5. For different materials of tubes Max. Equivalent Stress

Schema represents the comparison of produced equivalent stress during operation for different materials of tubes of surface condenser. From diagram clearly observe that when we used stainless steel for shell and baffles material and copper alloy, Aluminum alloy and stainless steel for tubes material obtained following result.

- Max Equivalent Stress for Copper alloy tubes – 975.69 MPa
- Max Equivalent Stress for Aluminum alloy tubes – 981.39 MPa
- Max Equivalent Stress for Stainless Steel tubes – 972.79 MPa

The research findings indicate that optimal heat flux is achieved by using copper alloy for tubes and structural steel for the shell and baffles. This configuration yields maximum heat flux values of 35103000 W/m^2 and 11381000 W/m^2 for steps 1 and 2, respectively. In comparison, aluminum alloy tubes produce maximum heat flux of 14907000 W/m^2 and 5101200 W/m^2 for steps 1 and 2, while an all-structural steel assembly results in maximum heat flux of 5556700 W/m^2 and 1805600 W/m^2 for the same steps. Additionally, copper alloy tubes exhibit the least total deformation compared to aluminum alloy and structural steel tubes. The maximum equivalent stress values are 975.69 MPa for copper alloy, 981.39 MPa for aluminum alloy, and 972.79 MPa for structural steel. Consequently, copper alloy emerges as the superior material for tubes, offering the highest heat flux, minimal deformation, and relatively low equivalent stress.

Our analysis reveals that copper alloy tubes are superior for high directional heat flux, low deformation, and low stress. In contrast, when examining structural steel tubes for surface condensers, we found that the maximum tube temperature reaches 324.89°C and 220.96°C for steps 1 and 2 respectively, which is lower compared to copper alloy and aluminum alloy tube materials. Structural steel offers advantages such as low cost, light weight, and resistance to corrosion. Therefore, structural steel is a suitable material for tubes under these temperature conditions.

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