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Process Parameters Analysis of Ethylene Glycol-Water and Air-Glycol System in Shell and Tube Heat Exchanger

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ABSTRACT Process parameter analysis plays a vital role in today's modern world in all industries. The demand for energy consumption in industries has made designers build efficient heat exchangers. One of the most used heat exchangers is the shell and tube heat exchanger. This work is based on analyzing velocity profile, temperature, and pressure in shell and tube heat exchangers. Thermal analysis and flow analysis is considered as basic method to be performed along with some basic structural analysis by means of individual analysis of heat transfer components. The simulation also provides insights into the flow behavior and temperature distribution in the heat exchanger, which can be used for optimizing the design and operation of the device. Results based on those analyses are collected and experimented to get the required output values. In this study, we utilize COMSOL Multiphysics, a powerful computational tool for simulating heat transfer phenomena, to model and analyze the performance of a shell and tube heat exchanger. In this process, we use water - ethylene glycol system and an air- glycol system as a component in the shell and tube side. Across industries and disciplines, simulation modeling provides valuable solutions by giving clear insights into complex systems. The main objective of this study is to investigate the thermal performance of the heat exchanger by simulating the fluid flow and heat transfer processes inside the tubes and the shell.

Keywords: shell and tube heat exchanger, analysis, thermal performance, comsol software.

1. Introduction

A heat exchanger is a device that is used to transfer heat between two or more fluids at different temperatures. Heat exchangers are widely used in many engineering applications, including power generation, chemical processing, refrigeration, and air conditioning [2]. Heat exchangers can be classified into different types based on their construction and how the fluids are transported. There are several types of heat exchangers, including shell and tube, plate and frame, and spiral heat exchangers. In a shell and tube heat exchanger, the hot fluid flows through the tubes while the cold fluid flows through the shell [2] [3]. Heat exchangers work on the principle of thermal conductivity, which allows the transfer of heat from one fluid to another. The fluids can be separated by a solid wall or may flow in direct contact with each other. [5] The heat transfer occurs through the walls of the tubes, and the two fluids are kept separate from each other. The performance of a heat exchanger is determined by its effectiveness, which measures the amount of heat transferred from the hot fluid to the cold fluid [1]. Other important factors that affect the performance of a heat exchanger include the fluid flow rates, the heat transfer coefficient, and the pressure drop across the exchanger [3]. Heat exchangers play an important role in energy conservation and are widely used in the chemical, petrochemical, food and beverage, and pharmaceutical industries, among others. They can also be used for various purposes in homes and buildings, such as recovering heat from waste water or exhaust air to preheat incoming water or fresh air. There are three main types of heat transfer: conduction, convection, and radiation. COMSOL Multiphysics is finite element analysis, solver, and simulation software that enables the modeling of various physics-based systems and designs. It allows users to create virtual models and simulations of real-world scenarios, from simple electrical circuits to complex multi-physics phenomena. The software uses a graphical user interface (GUI) and has a wide range of physics and engineering modules available, including electromagnetic, structural mechanics, fluid dynamics, heat transfer, acoustics, and chemical reactions [5]. Users can create their own custom equations and boundary conditions or select from a library of pre-built models. COMSOL is used by engineers, scientists, researchers, and educators in industries such as aerospace, automotive, energy, biomedical, and more. It offers a powerful set of tools for designing, testing, and optimizing products and processes, helping users to save time and reduce costs in their work. Overall, COMSOL is a valuable tool for anyone looking to simulate and analyze the behavior of physical systems and designs [4].

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2. Material and Methods

Heat exchanger is a device that is used to transfer heat from one fluid or gas to another, without the two substances mixing with each other. Heat exchangers are commonly used in many industries, such as power generation, chemical processing, and HVAC systems. The basic principle of a heat exchanger involves two fluid streams that are separated by a solid wall. Heat is transferred from one fluid to the other through the wall, either by conduction or convection, depending on the design of the heat exchanger [3].

Shell and Tube Heat Exchanger:

A shell and tube heat exchanger is a type of heat exchanger used to transfer heat between two fluids. The design consists of a cylindrical shell with a bundle of tubes inside it. One fluid flows through the tubes while the other fluid flows around the tubes in the shell, creating a counter-current flow pattern. The shell is usually made of metal, and the tubes can be made of metal, plastic, or other materials and are designed to withstand the pressure and temperature of the fluids. The tubes are often arranged in a pattern inside the shell and are held in place by tube sheets and are designed to maximize the heat transfer surface area. Fluid flows through the shell and the tubes, with heat being transferred between them. The fluid flowing through the tubes is known as the "tube side" fluid, while the fluid flowing through the shell is known as the "shell side" fluid. The fluid that needs to be cooled or heated flows through the tubes, while the fluid that provides the cooling or heating flows over the tubes, in the space between the shell and the tubes. Heat is transferred from the fluid inside the tubes to the fluid outside the tubes, through the tube walls. The fluids can be gasses or liquids, and the heat transfer can be either heating or cooling [6]. The tubes are often coiled or bent in a U-shape to increase the surface area available for heat transfer. The advantage of using a shell and tube heat exchanger is that it allows for a large surface area for heat transfer in a relatively compact design. Additionally, it is easy to clean and maintain and can handle high-pressure and high-temperature applications. Design considerations for a shell and tube heat exchanger include the choice of materials, the sizing of the heat transfer surface area, the fluid flow rates, and the heat transfer coefficient. The design of a shell and tube heat exchanger depends on factors such as the desired heat transfer rate, the pressure drop, the materials used, and the space available for installation [6]. The performance of a shell and tube heat exchanger depends on several factors, including the heat transfer coefficient, the fluid flow rate, and the temperature difference between the two fluids. The design considerations also include tube diameter, tube length, and tube spacing also play a role in determining the efficiency of the heat exchanger [1]. In this project, different types of materials in shell and tube heat exchanger are used to analyze.

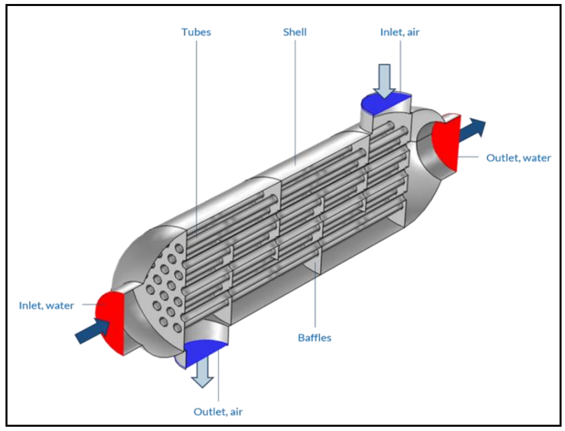

Fig. 1: Diagram of shell and tube heat exchanger

COMSOL software:

COMSOL Multiphysics is finite element analysis software used to simulate and analyze physical systems, primarily in the fields of physics, engineering, and the life sciences. It allows users to create and solve models based on partial differential equations (PDEs) and supports various physics phenomena, including electromagnetic, structural mechanics, acoustics, fluid flow, heat transfer, and chemical reactions. It is Multiphysics simulation software designed for engineers, scientists, and researchers. It enables users to simulate and analyze complex physical systems involving multiple physics phenomena, such as electromagnetic, structural mechanics, fluid dynamics, heat transfer, and chemical reactions.

In the present study the process parameters Velocity (spf), Pressure (spf), Wall Resolution (spf), Isothermal Contours (ht), Wall Lift-off and Temperature along streamlines of Shell and Tube heat exchangers were analyzed by using COMSOL software and simulated output diagrams given.

3. Results

Case 1: Ethylene glycol - Water System

In this case study, an air-toluene system has been selected. Ethylene Glycol is used as a cold fluid, and Water is used as a hot fluid.

Input Parameters

Parameters	Expression	Value	Description
u_water	0.1[m/s]	0.1m/s	Inlet velocity, water
u_ethylene glycol	1[m/s]	1m/s	Inlet velocity, ethylene glycol
T_water	150[degC]	423.15k	Inlet temperature, water
T_ethylene glycol	5[degC]	353.15k	Intel temperature, ethylene glycol

Table 1: Input parameters of ethylene glycol-water system

Output Parameters

Heat Transfer Coefficient	Inlet Pressure, Water	Inlet Pressure, Ethylene glycol
5.8697	37.868	13.120

Table 2: Output parameters of ethylene glycol-water system

Analysis

1a. Velocity (spf*)

The lower velocity of the fluid flowing through the tubes reduces the pressure drop but can also reduce the heat transfer rate due to laminar flow, which has lower mixing and heat transfer coefficients.

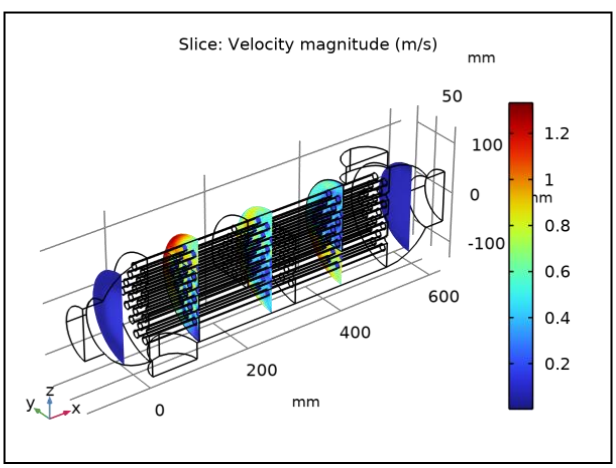

Fig. 2: Slice: Velocity magnitude (m/s)

From Fig. 2, the maximum velocity is **1.2 m/s** and the minimum velocity is **0.2m/s. If** the velocity increases, the heat transfer rate and pressure drop also increase and the fouling rate will be decreased. The first two baffles have a low heat transfer rate and low-pressure drop because of the lower velocity. The Second baffle behind the baffle side a higher heat transfer rate and pressure drop will occur. The fouling rate is inversely proportional to the velocity. If the velocity increases the fouling rate will be decreased and vice versa.

*spf - single phase fluid

1b. Pressure (spf*)

From Fig. 2, the maximum pressure is **8.2 Pa** and the minimum pressure is **-0.78 Pa.** If the pressure drop is too high, it can cause reduced flow rates, lower heat transfer rates, and even damage to the heat exchanger due to excessive pressure. In the inlet section of the shell and tube heat exchanger the maximum allowable pressure will occur, the outlet section the minimum allowable pressure will occur. So the flow rate and heat transfer rate of the outlet pipe is maximum compared to the inlet pipe. The pressure drop also affects the boiling and condensing points of the fluids.

*spf - single phase fluid

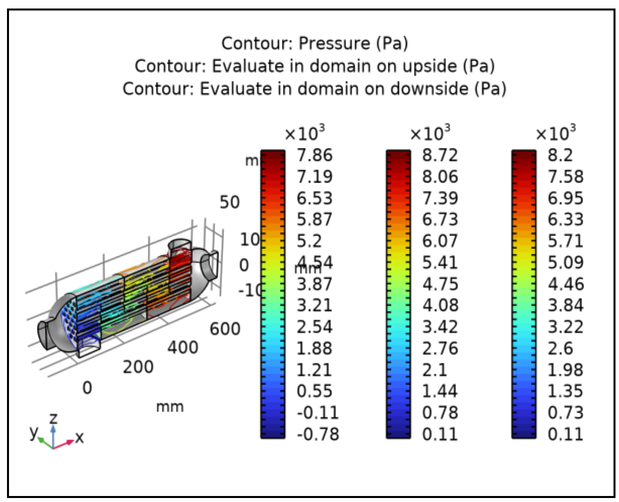

Fig. 3: Contour: Pressure (Pa) Contour: Evaluate in domain on upside (Pa) Contour: Evaluate in domain on downside (Pa)

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1c. Wall Resolution (spf*)

From Fig. 4, the maximum wall resolution is **32mm** and the minimum wall resolution is **12mm.** The role of wall resolution in a shell and tube heat exchanger is to accurately capture the heat transfer and fluid flow phenomena occurring near the wall surface. The high wall resolution occurs at the outlet of the air domain. higher wall resolution provides more detail and accuracy in capturing the boundary layer, which is the region of fluid flow near the wall where the velocity and temperature gradients are the highest.

spf - single phase fluid

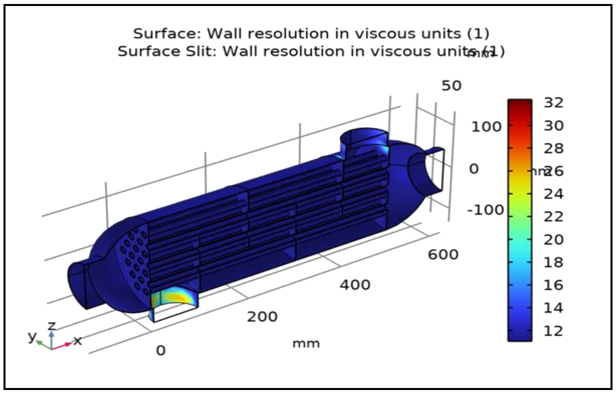

Fig. 4: Wall Resolution in viscous units (1)

1d. Isothermal Contours (ht*)

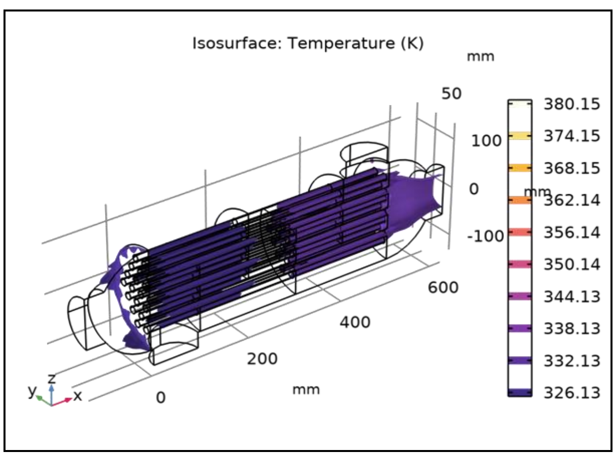

Fig , 5: Is surface: Temperature(K)

From Fig. 5, the maximum isothermal contour is **380.15 K** and the minimum isothermal contour is **326.13 K.** Isothermal contours also aid in determining the flow direction and velocity profile of the fluid within the heat exchanger. Isothermal contours refer to the lines that connect points on the heat transfer surface that have the same temperature. These contours can be plotted on a diagram of the heat exchanger to help engineers understand how heat is transferred from one fluid to another.

*ht - heat transfer

1e. Wall Lift-off

In a shell and tube heat exchanger, the tubes are typically supported by tube sheets that are attached to the shell. As the temperature of the fluid inside the tubes increases, the tubes expand, but the shell does not expand as much. This creates a difference in expansion that generates a force, known as wall lift that lifts the tubes off of their supports. From fig 5, the maximum wall lift is **1.2 mm** and the minimum wall lift is **0.2mm**.

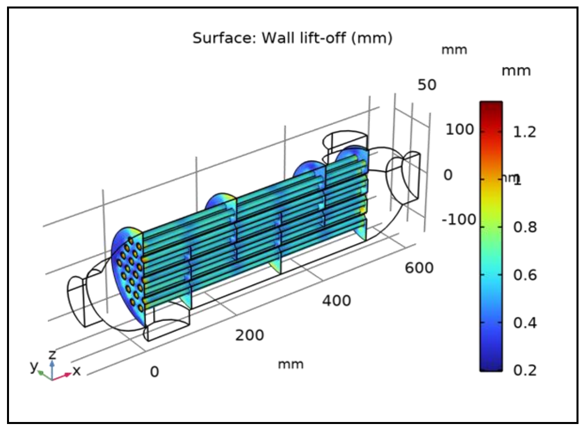

Fig. 6: Surface : Wall lift off(mm)

1f. Temperature along streamlines

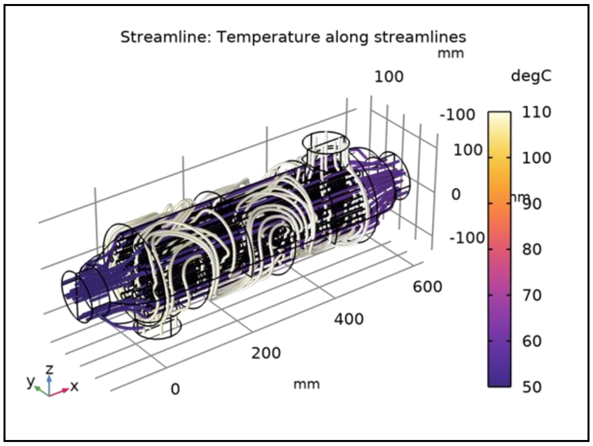

Fig. 7: Streamline : Temperature along Streamlines

Streamlines can also be used to analyze the flow of the heating medium, such as steam, within the shell side of the heat exchanger. This can help to identify areas of high or low heat transfer rates, as well as areas of temperature stratification or mixing. By understanding the flow patterns and temperature distributions of both fluids, engineers can optimize the heat exchanger design to achieve the desired heat transfer performance. From fig 6, the maximum temperature of the stream line is **383 K** and the minimum temperature of the stream line is **323 K**

Case Study 2: Air-Glycol System

In this case study, an air-water system has been selected. Water is used as a cold fluid, Air used as a hot fluid.

Input Parameters

Parameter	Expression	Value	Description
u_air	0.1[m/s]	0.1m/s	Inlet velocity, air
u_glycol	1[m/s]	1m/s	Inlet velocity, glycol
T_air	80[degC]	353.15 k	Inlet temperature, air
T_glycol	150[degC]	423.15 k	Intel temperature, glycol

Table 3: Input parameters of air – glycol system

Output Parameters

Heat Transfer Coefficient	Inlet Pressure, Glycol	Inlet Pressure, Air
4.5767	39.560	18.150

Table 4: Output parameters of air - glycol system

Analysis

2a. Velocity (spf*)

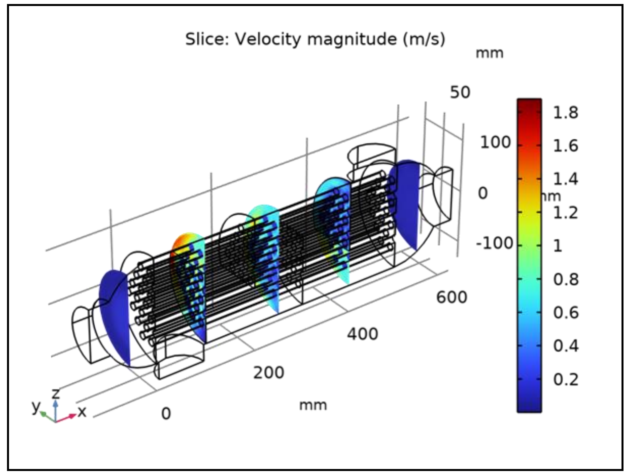

Fig. 8: Velocity Magnitude(m/s)

From Fig. 8, the maximum velocity is **1.8 m/s** and the minimum velocity is **0.2 m/s**. In this scale red color denotes the maximum velocity and the blue color denotes the minimum velocity. Here the maximum velocity occurs in the behind of the second baffle, so that place has a high heat transfer rate and pressure drop. But the fouling rate of that particular place is very less compared to other places. The minimum velocity occurs in the tube side, so in those places having a low heat transfer rate, low pressure drop and high fouling rate. The green color shows the mid velocity, The heat transfer coefficient is directly proportional to the mid-velocity of the fluid flowing through the tubes. Therefore, as the mid-velocity increases, the heat transfer coefficient also increases, resulting in higher heat transfer rates.

*spf - single phase fluid

2b. Pressure (spf*)

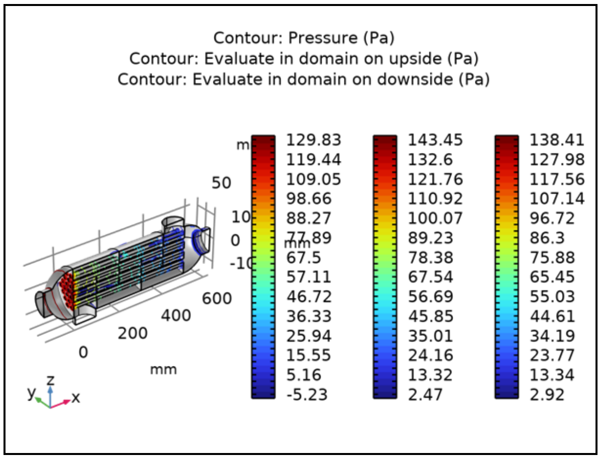

Fig. 9: Contour : Pressure(Pa) Contour : Evaluate in domain on upside(Pa) Contour : Evaluate in domain on downside

From Fig. 9, the maximum pressure is **143.45 Pa** and the minimum pressure is **-5.23 Pa .**In this scale the red color shows maximum pressure and the blue color shows the minimum pressure. Here maximum pressure occurs at the inlet of the shell, in that place having a low flow rate, low heat transfer rate and that particular place the tube was highly damaged. The minimum pressure occurs at the entrance of the pipe side, in that place having high flow rate, high heat transfer rate and that particular place the tube was less damaged compared to the shell side. Apart from that the light greens color shows mid pressure value, if the mid pressure is too low, it can cause the fluid to bypass the tubes and flow directly through the shell, again reducing the heat transfer rate. Therefore, it is important to maintain an appropriate mid pressure to ensure proper fluid flow and efficient heat transfer.

*spf - single phase fluid

2c. Wall Resolution :

The wall resolution in a shell and tube heat exchanger refers to the thickness of the wall that separates the fluid flowing through the tubes from the fluid flowing through the shell. This wall thickness is important because it affects the heat transfer rate and the overall efficiency of the heat exchanger. The appropriate wall resolution for a given shell and tube heat exchanger depends on various factors, such as the type of fluids being used, the temperature and pressure of the fluids, and the desired heat transfer rate. Generally, thicker walls offer greater durability and can handle higher-pressure differentials, but thinner walls provide better heat transfer rates. Wall thickness is typically specified by the manufacturer based on the design and intended use of the heat exchanger. It is important to follow the manufacturer's recommendations to ensure the proper performance and safety of the heat exchanger. From fig 9 the wall resolution is 11.6

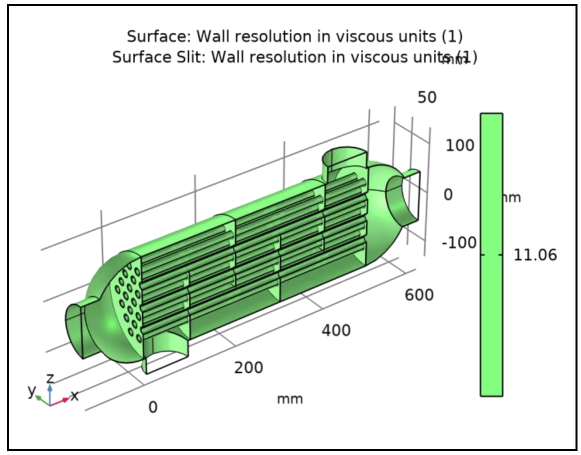

Fig. 10: Wall resolution in the viscous unit(1)

2d. Isothermal Contours (ht*)

From Fig 11, the maximum isothermal contour is **349.4 K** and the minimum isothermal contour is **289.9K.** Isothermal contours are lines that connect points on the heat exchanger where the temperature is the same. By analyzing the distribution of isothermal contours across the heat exchanger, engineers can optimize the design of the exchanger to maximize heat transfer efficiency and minimize pressure drop. Here the first half of the shell and tube maximum isothermal contours occurs and the rest of the part mid & minimum isothermal contour occur.

*ht - heat transfer

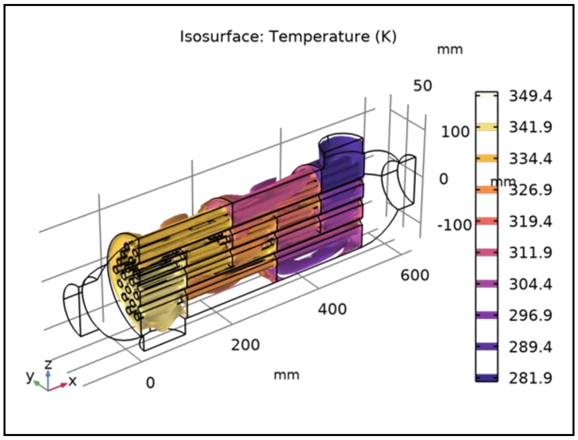

Fig. 11: Isosurface contours(ht)

2**e.Wall Lift-off**

From fig 10, the maximum wall lift of is **3 mm** and the minimum wall lift of is **1 mm.**Wall lift can also help to improve heat transfer efficiency by increasing the turbulence of the fluid flow. As the tube wall is lifted, the fluid flow is disrupted, which can create more mixing and turbulence in the fluid, enhancing heat transfer across the tube wall. Here maximum wall lift off occurs in the upper and lower side of the baffles, excessive wall lift can also have negative effects on the heat exchanger performance. It can cause vibrations and noise, which can damage the tubes and the support structure over time. Additionally, if the wall lift is too high, it can cause the tubes to come into contact with each other, which can lead to wear and tear and eventually lead to tube failure. The minimum wall lift off occurs inside the pipe, compared to baffles the tubes are less damaged.

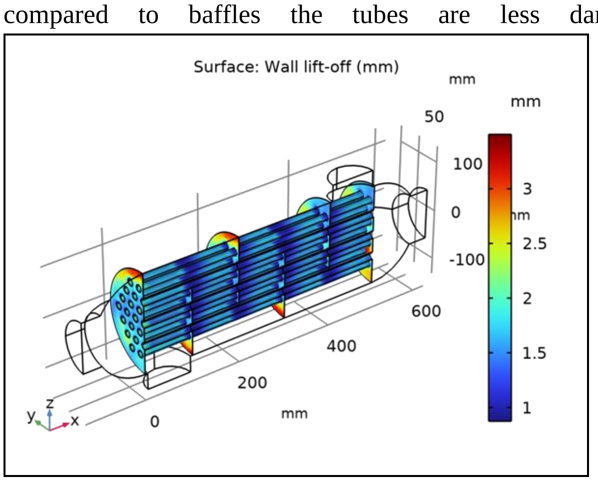

Fig. 12: Surface : Wall lift-off(mm)

2f.Temperature along streamlines

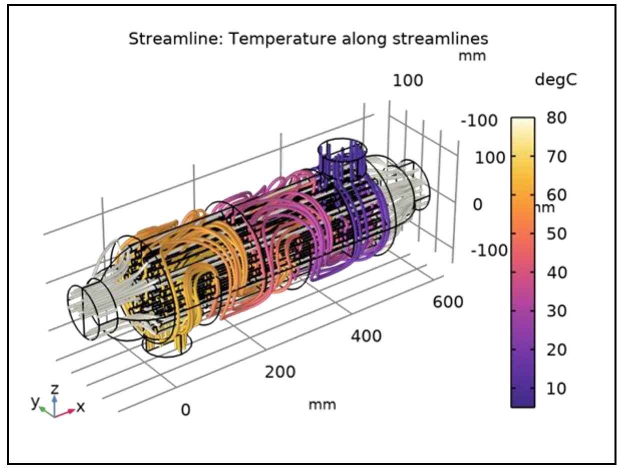

Fig. 13: Streamline : Temperature along Streamlines

From fig 13, the maximum streamline temperature is **363 K** and the minimum streamline temperature is **283 K.** Here the maximum streamline temperature occurs near the inlet of the water domain, the streamline temperature can also affect the overall thermal efficiency of the heat exchanger. A higher streamline temperature can cause an increase in the temperature difference between the two fluids, which can lead to a higher overall thermal efficiency. However, a too high streamline temperature can also cause thermal stresses and reduce the lifespan of the heat exchanger.

The above-mentioned two cases are the results that we obtained from shell and tube heat exchanger by using COMSOL software.

Comparisons Of Shell And Tube Heat Exchanger:

S. No	Material	Velocity (m/s)	Pressure (Pa)	Wall lift-off (mm)	Isothermal contour (K)	Streamline temperature (K)

1.	Glycol - Water System	Min: 0.2 Max: 1.2	**Min: 0.78 Max: 8.2**	Min: 0.2 Max: 1.2	**Min: 326.13 Max: 380.1**	Min :323 Max:383
2.	Glycol - Air system	**Min: 0.2 Max: 1.8**	Min:-5.23 Max: 143.4	**Min: 1 Max: 3**	Min: 281.9 Max: 349.4	**Min :283 Max:353**

Table 5: Comparisons of shell and tube heat exchanger

From table 5 in general, increasing the velocity of the fluid increases the heat transfer rate between the fluids in the heat exchanger. This is because a higher velocity increases the turbulence in the fluid flow, which in turn increases the rate of heat transfer. However, increasing the velocity also increases the pressure drop across the exchanger, which can lead to increased pumping costs. The velocity also affects the fouling rate in the exchanger. Fouling occurs when deposits of solids or other materials accumulate on the surface of the heat transfer surfaces, reducing the efficiency of the heat exchanger. Higher velocities can help to reduce fouling by keeping the fluid moving and preventing deposits from settling on the surface. So depending on the velocity **Glycol - Air system** provides better efficiency. If the pressure drop is too high, it can cause reduced flow rates, lower heat transfer rates, and even damage to the heat exchanger due to excessive pressure. Thicker walls offer greater durability and can handle higher-pressure differentials, but thinner walls provide better heat transfer rates. Depending upon the wall lift-off **Glycol - Water System** provides a better heat transfer area, and **Glycol - Water System** has a thinner wall lift-off. The maximum isothermal contour also affects the efficiency of the heat exchanger. A well-designed heat exchanger should have a maximum isothermal contour that is as close to the surface as possible, as this maximizes the surface area available for heat transfer and minimizes the thermal resistance across the surface.

The role of the maximum streamline temperature is to determine the maximum allowable temperature difference across the heat transfer surface. If the maximum streamline temperature is too high, it can lead to excessive thermal stresses and potential failure of the heat exchanger. Therefore, it is important to design the heat exchanger such that the maximum streamline temperature is within the allowable limits. The maximum streamline temperature also affects the efficiency of the heat exchanger. A well-designed heat exchanger should have a maximum streamline temperature that is as close to the inlet temperature of the hot fluid as possible, as this maximizes the temperature difference across the heat transfer surface and therefore maximizes the heat transfer rate. In addition, the maximum streamline temperature can be used to optimize the design of the heat exchanger. By adjusting the flow rates and the geometry of the heat transfer surface, it is possible to adjust the position of the maximum streamline temperature and therefore optimize the performance of the heat exchanger. Depending upon the Isothermal contour **Glycol - Water System** provides a high efficiency. Considering all properties **Glycol – Air System** is the best pair of fluids used in the shell and tube heat exchanger.

4. Discussion :

Through the simulation, the software enables the evaluation of key parameters such as temperature distribution, heat transfer rate, pressure drop, flow behavior,. wall lift off, and streamline temperature within the heat exchanger. These insights help in understanding the thermal and flow behavior of the system and identifying potential areas for improvement.

By simulating different types of materials, engineers can optimize the heat exchanger's performance, improving its efficiency, reducing the damage, and enhancing heat transfer rates.

Considering these three systems(air-glycol, water- glycol) Air – Glycol System is the best pair of fluids used in the shell and tube heat exchanger. Because it has a high velocity in the range of **0.2-0.8m/s** which provides better heat transfer rate, wall lift of in the range of **1-3mm** which gives durability, less streamline temperature in the range of **283-353K** which gives high efficiency.

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