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COMPARATIVE ANALYSIS OF SHELL AND TUBE HEAT EXCHANGER WITH DIFFERENT TUBE MATERIALS

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Abstract: **A heat exchanger is a fundamental instrument for transferring heat from one fluid (liquid or gas) to another, utilized in many different applications and industries. The performance, longevity, and general efficiency of these heat exchangers are greatly influenced by the materials that are used in their construction. This research represents a detailed comparative analysis of shell and tube heat exchangers utilizing copper and nitinol tubes, focusing on their performance under various operating conditions also specializing in their significance in diverse industries which includes power generation, chemical processing, HVAC etc. Copper is significantly used because of its higher thermal conductivity. However, it has risks, of corrosion and shape deformation at excessive temperatures. The Unique Nitinol is a durable alternative for high-temperature applications due to its exceptional elasticity and resistance to distortion. Through the use of ANSYS CFX Solver computational fluid dynamics (CFD) models, the study assesses pressure drop and temperature variations under various operational circumstances. The findings show that nitinol exhibits less pressure drops than copper, suggesting possible benefits in terms of energy economy, system optimization, material choice and also can be used in different industries like Oil refineries, Steam power generation, nuclear power station etc.**

Keywords: Shell and Tube Heat Exchanger, Copper, Nitinol, ANSYS CFX, Temperature Contour, Pressure drop.

I. INTRODUCTION

A heat exchanger is a fundamental instrument for transferring heat from one fluid (liquid or gas) to another, utilized in many different applications and industries. Its main purpose is to allow two fluids to exchange heat energy while maintaining their physical separation. Numerous industries, including HVAC (heating, ventilation, and air conditioning), automotive, chemical processing, power generation, and refrigeration, among others, depend on this process for their energy recovery and heating/cooling systems. The performance, longevity, and general efficiency of these heat exchangers are greatly influenced by the materials that are used in their construction. In this paper, we conduct an in-depth analysis of two different materials used as tubes in shell and tube heat exchangers: copper and nitinol. Although copper has long been used due to its great heat conductivity and resistance to corrosion, it's important to realize that copper also has drawbacks, namely with regard to malleability and the possibility of fouling and deterioration over time. Even though copper has good corrosion resistance, moderate deformation resistance, and strong thermal conductivity, it may lose more pressure at higher temperatures. Copper is easily oxidized at high temperatures, which increases the risk of corrosion or tube blockage and pressure loss. Although copper is widely used, its drawbacks force researchers to investigate substitute materials, such Nitinol, a shape-memory alloy made of titanium and nickel. Nitinol, being a shape memory alloy with unique properties such as super elasticity, may exhibit better resistance to deformation and maintain its structural integrity at high temperatures. This could result in lower pressure loss compared to copper tubes under similar operating conditions. By carefully evaluating the advantages and disadvantages of both materials and providing insightful information about their suitability for specific heat exchange applications, this analysis aims to assist engineers and industry stakeholders in making informed decisions about material selection in shell and tube heat exchanger design.

II. INTRODUCTION OF SHELL AND TUBE HEAT EXCHANGER

Shell and Tube Heat Exchangers are vital components in industrial processes, transferring heat between two fluids. The shell contains multiple tubes through which one fluid flows, while the other fluid flows over the tubes. This facilitates efficient heat transfer through the tube walls, making them widely used in various industries.

- **Principle of Operation:** The hot fluid enters the exchanger and flows through the tubes, while the cold fluid passes over the tubes. Heat is transferred from the hot fluid to the cold fluid through the tube walls. This method ensures efficient heat exchange due to the large surface area provided by the numerous tubes.

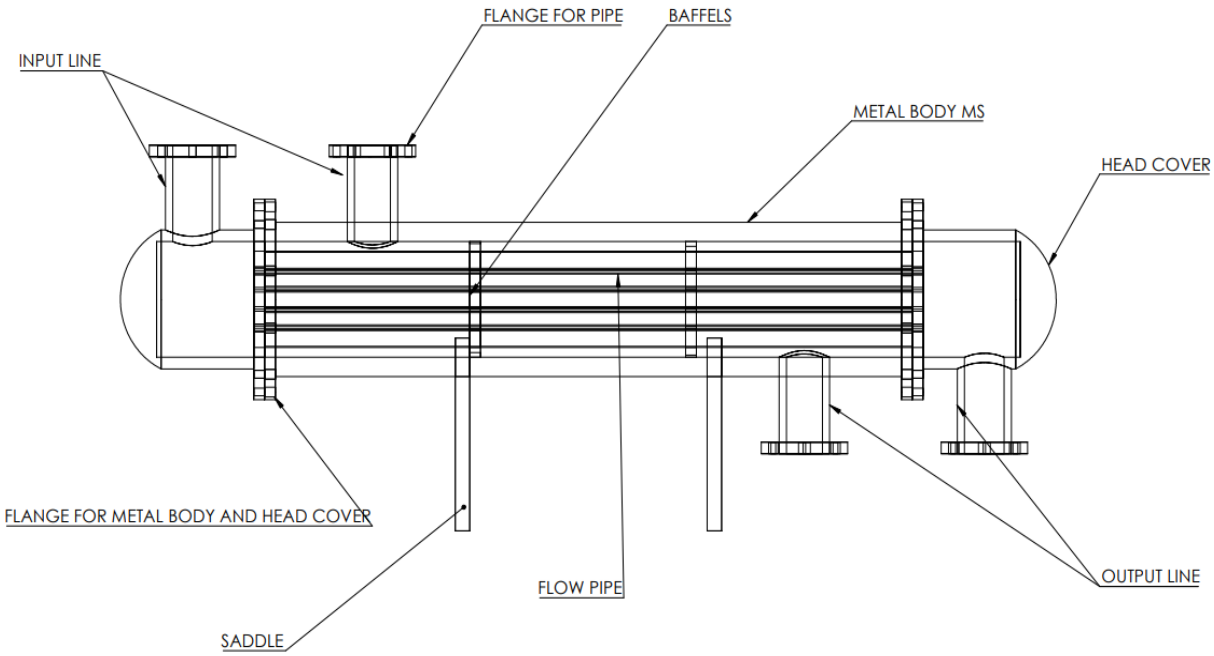

Fig 1. Line Diagram of Shell and Tube Heat Exchanger with their parts

III INTRODUCTION OF MATERIALS:

- **Copper:**
  The remarkable mechanical and thermal properties of copper make it a preferred material for heat exchanger design. Shell and tube heat exchangers provide as an example of the adaptability and effectiveness of copper tubes in facilitating heat transfer processes. In numerous industries, copper is a highly preferred material due to its exceptional thermal conductivity, which ensures the highest possible efficiency in the transfer of thermal energy.
- **Shape Memory Alloys:**
  A class of smart materials known as shape memory alloys (SMAs) has a unique capacity to "remember" a specific shape and return to it in response to a given stimulus, most commonly a change in temperature. The reversible phase transition of the material is responsible for this property. Super elasticity and the shape memory phenomenon which allow SMAs to return to their original shape in response to external stimuli are two of their most well-known characteristics. Actuators, aviation parts, medical equipment, and many more industries that require precise and repeatable motion employ them.
- **Types of Shape memory alloys**
  The most common types of shape memory alloys (SMAs) include:

1. Nitinol (Nickel-Titanium)
2. CuAlNi (Copper-Aluminium-Nickel)
3. CuZnAl (Copper-Zinc-Aluminium)
4. Fe-Pt (Iron-Platinum)

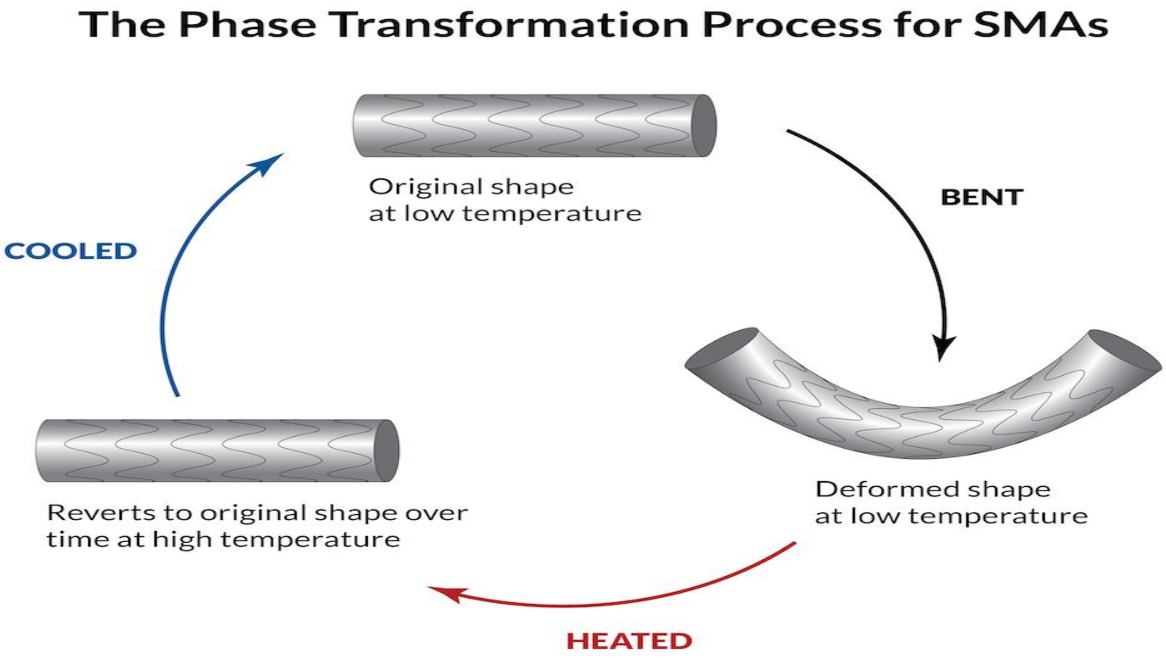

Fig 2. The Phase Transformation Process for Shape Memory Alloy

- **Working of Shape memory alloys:**
- Deformation: When a SMA is in its high-temperature phase called austenite, it can be easily deformed into a different shape. This is the phase in which the material's original shape is "remembered. "
- Fixation: The deformed shape is "fixed" by cooling the SMA below a critical temperature known as the Martensite Start Temperature (Ms). This cooling induces a phase transformation from austenite to martensite, locking in the temporary shape.
- Recovery: When the SMA is heated back above a critical temperature called the Austenite Start Temperature (As), the martensite phase transforms back into austenite. During this transformation, the material returns to its original, pre-deformed shape.

- **Introduction of Nitinol**

  The most popular and commonly used SMA is Nitinol. It is made up of titanium and nickel in about equal amounts. Because of its capacity to retain a predetermined shape and exert a great deal of force during transformation, it has a variety of engineering applications. In place of copper tubes, this kind of shape memory alloy will be utilized in the shell and tube heat exchanger. Nitinol's remarkable shape memory feature is what makes it so desirable for heat exchanger applications. Nitinol tubes have the ability to drastically change shape in response to temperature changes and then return to their original shape when the temperature drops again. Heat exchangers employ this property to increase fluid flow and enhance the efficiency of heat transmission. Nitinol tubes can change shape in reaction to temperature variations, improving heat exchange by guaranteeing better fluid contact between hot and cold.

IV CFD ANALYSIS

Computational fluid dynamics (CFD) analysis begins with the creation of the necessary geometry for every system, and then mesh production. The discretization of the domain into small volumes, known as meshing.

Further modeling involves defining the dominion's boundaries and starting circumstances, which culminates in modeling the complete system. Once the iterative solution processes are complete, we can use the analysis's numerical and graphical output.

Parameters	Specification
Length of Heat Exchanger	3000mm
Shell outer diameter	550mm
Tube outer diameter	25mm
Tube inner diameter	22mm
Tube pitch Layout	Square arrangement

Tube Pitch	80mm
Baffle Number	6
Baffle cut	25%
Baffle Pitch	250mm

Table 1: Geometry specification of Shell and Tube Heat Exchanger

- **Meshing:**
- Meshing is an integral part of the engineering simulation process where complex geometries are divided into simple elements that can be used as discrete local approximations of the larger domain. The mesh influences the accuracy, convergence and speed of the simulation.

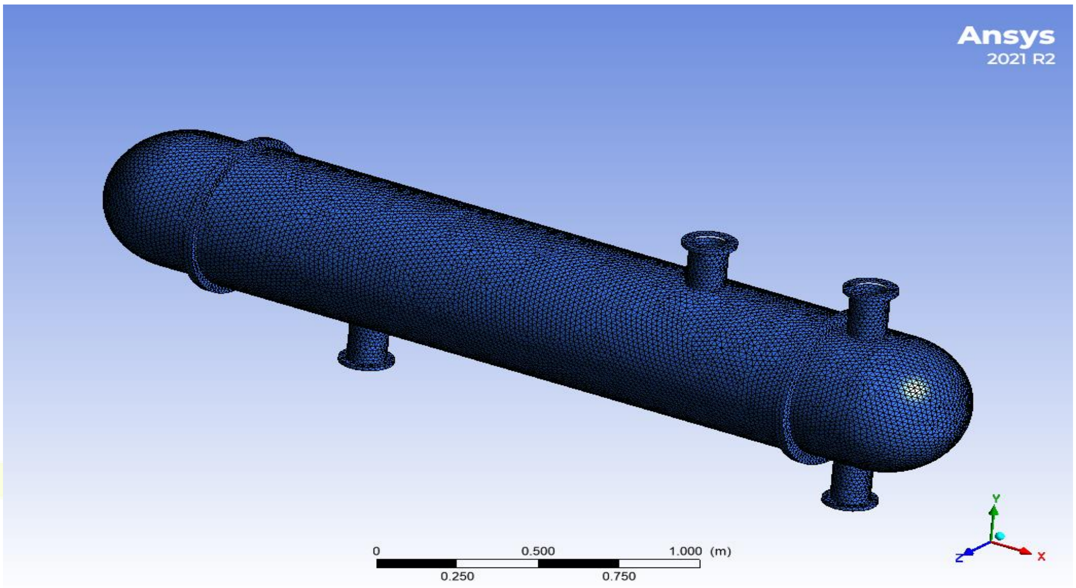

Fig 3: Meshing diagram of Shell and Tube Heat Exchanger

Number of Nodes	3192635
Number of Elements	13000307

Table 2: Mesh Count

V ANALYSIS SETUP:

The mesh is checked and quality is ensured. The analysis is done separately for both the material Copper and Nitinol. The ANSYS software CFX Solver is used. The boundary condition or the type of Analysis for transferring heat is selected INTERFACE. In each analysis, different parts of the heat exchanger geometry are assigned as corresponding fluid (e.g.: water) and solids (e.g.: copper, nitinol etc.) as per the comparison criteria. Boundary conditions are assigned according to the need of the model. The model and flow are selected is Turbulent Model. The inlet conditions are defined as 'mass flow inlet' and outlet conditions are set as 'outflow'. Two inlets and two outlets are defined by considering hot fluid side and cold fluid side. Each wall is separately specified with respective boundary conditions. Each wall is set to no slip condition. Except the tube wall, other walls & baffles wall are set to zero heat flux condition.

- **Boundary Condition:**
- Thermal boundary conditions (temperature or heat flux) on the outer surface of tubes and shell.
- Flow boundary conditions for fluid flow inside the tubes and shell.
- Water liquid is selected as fluid flow through both cold and hot fluid.
- For 2 different cases, different material is used for pipe: Copper, Nitinol

- **Case 1 For Low temperature Analysis**

2.465 kg/s mass flow inlet is selected for cold inlet with inlet temperature of 20°C.
1.219 kg/s mass flow inlet is selected for hot inlet with inlet temperature of 100°C.

- **Case 2 For High temperature Analysis**

  2.465 kg/s mass flow inlet is selected for cold inlet with inlet temperature of 500°C.
  1.219 kg/s mass flow inlet is selected for hot inlet with inlet temperature of 620°C.

- **Case 3 For different mass flow rates**

  0.05 kg/s mass flow inlet is selected for cold inlet with inlet temperature of 20°C.
  0.04 kg/s mass flow inlet is selected for hot inlet with inlet temperature of 100°C.

VI RESULTS AND DISCUSSION:

- **For Case 1 For Low temperature Analysis**
  2.465 kg/s mass flow inlet is selected for cold inlet with inlet temperature of 20°C.
  1.219 kg/s mass flow inlet is selected for hot inlet with inlet temperature of 100°C.

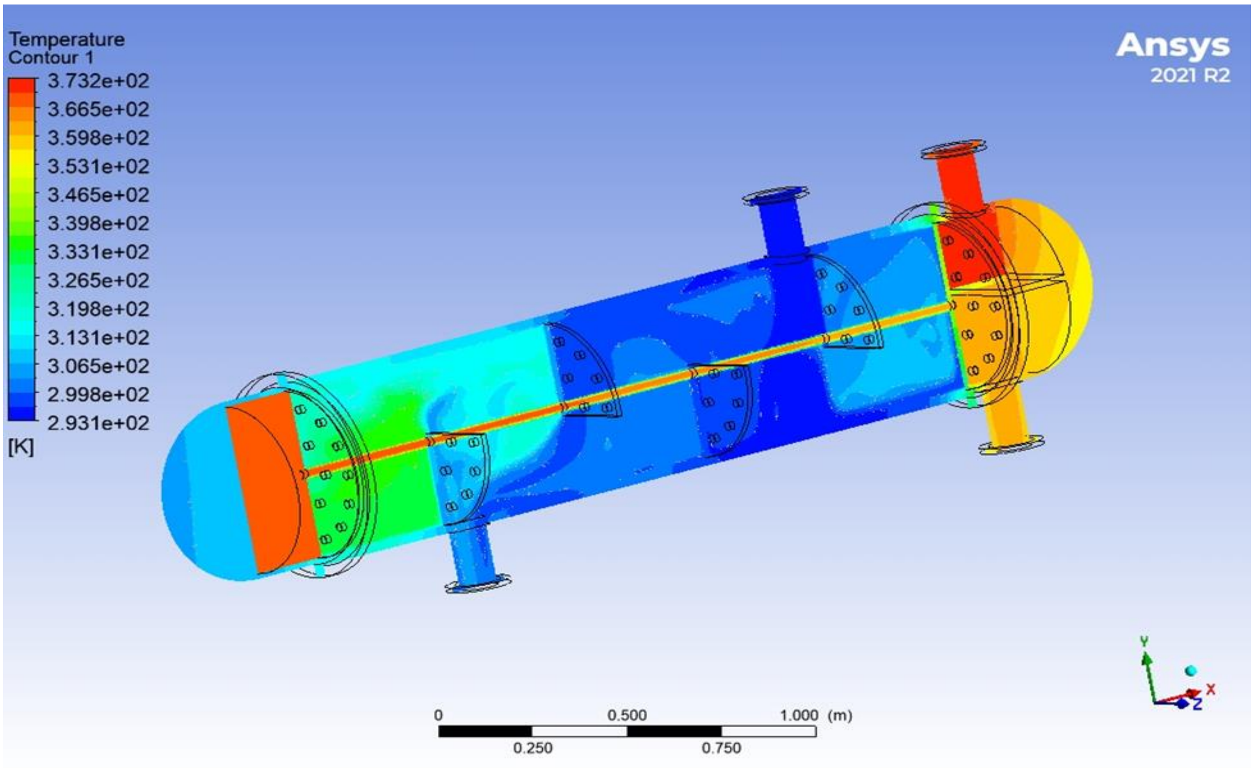

Fig 4: Temperature contour diagram for Low temperature analysis for both materials Copper & Nitinol

The colours utilized in temperature contour plots in Ansys CFX Solver signify various temperature ranges or levels within the simulated domain. These colours help in the visualization of temperature gradients and distribution, offering important insights into heat transfer phenomena. The following is an explanation of the common colour scheme and its significance in temperature contour plots:

In the first case the analysis is done for the low temperature therefore the hot fluid passing through the inlet, tubes of heat exchanger and outlet of heat exchanger is in red zone. Colours that are red and orange in a heat exchanger may show where heat is being transferred from a hot fluid to a cold fluid or a solid surface. The fluid passing through the second inlet is in blue or cooler zone. These colours denote lower temperatures because they show areas where heat is being absorbed or lost. Cooler colours, for instance, can designate regions in a heat exchanger where heat is being absorbed by cold fluid from a solid surface or a hot fluid.

	Parameters	**Temperature [K]**	**Pressure [Pa]**		**Parameters**	**Temperature [K]**	**Pressure [Pa]**
Low Temperature Data for NITINOL	COLD IN	293.15[K]	199958[Pa]	**Low Temperature Data for COPPER**	COLD IN	293.15[K]	199958[Pa]
	COLD OUT	302.85[K]	199891[Pa]		COLD OUT	312.656[K]	199890[Pa]
	DIFFERENCE	8.935[K]	67[Pa]		DIFFERENCE	19.506[K]	68[Pa]

	HOT IN	373.148[K]	199990[Pa]		HOT IN	373.149[K]	199990[Pa]
	HOT OUT	361.93[K]	199384[Pa]		HOT OUT	347.767[K]	199382[Pa]
	DIFFERENCE	11.218[K]	606[Pa]		DIFFERENCE	25.382[K]	608[Pa]

Table 3: Result for low temperature analysis for both materials

- **Case 2 For High temperature Analysis**

2.465 kg/s mass flow inlet is selected for cold inlet with inlet temperature of 500°C.

1.219 kg/s mass flow inlet is selected for hot inlet with inlet temperature of 620°C.

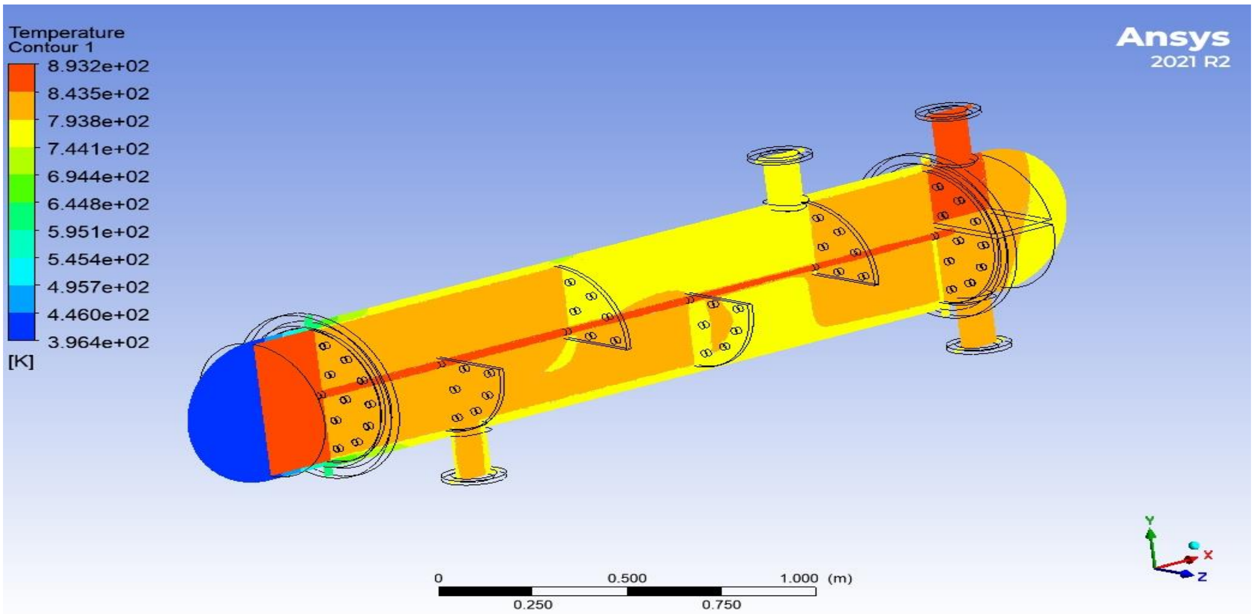

Fig 5: Temperature contour diagram for High temperature analysis for both materials Copper & Nitinol

In the second case the analysis is done for the high temperature therefore the hot fluid passing through the inlet, tubes of heat exchanger and outlet of heat exchanger is in red zone. As we earlier discussed that colours that are red and orange in a heat exchanger may show where heat is being transferred from a hot fluid to a cold fluid or a solid surface exchanger where heat is being absorbed by cold fluid from a solid surface or a hot fluid. In this image the blue zone is less as compared to the first case because the temperature at all zones of heat exchanger is high.

	Parameters	**Temperature [K]**	**Pressure [Pa]**		**Parameters**	**Temperature [K]**	**Pressure [Pa]**
High Temperature Data for NITINOL	COLD IN	773.139[K]	200000[Pa]	**High Temperature Data for COPPER**	COLD IN	773.139[K]	200000[Pa]
	COLD OUT	799.561[K]	199933[Pa]		COLD OUT	799.352[K]	199929[Pa]
	DIFFERENCE	26.422[K]	67[Pa]		DIFFERENCE	26.213[K]	71[Pa]
	HOT IN	893.129[K]	200000[Pa]		HOT IN	893.13[K]	200000[Pa]
	HOT OUT	847.077[K]	199394[Pa]		HOT OUT	838.632[K]	199393[Pa]
	DIFFERENCE	46.052[K]	606[Pa]		DIFFERENCE	54.498[K]	607[Pa]

Table 4: Result for High Temperature analysis for both materials

- **Case 3 For different mass flow rates**
  0.05 kg/s mass flow inlet is selected for cold inlet with inlet temperature of 20°C.
  0.04 kg/s mass flow inlet is selected for hot inlet with inlet temperature of 100°C.

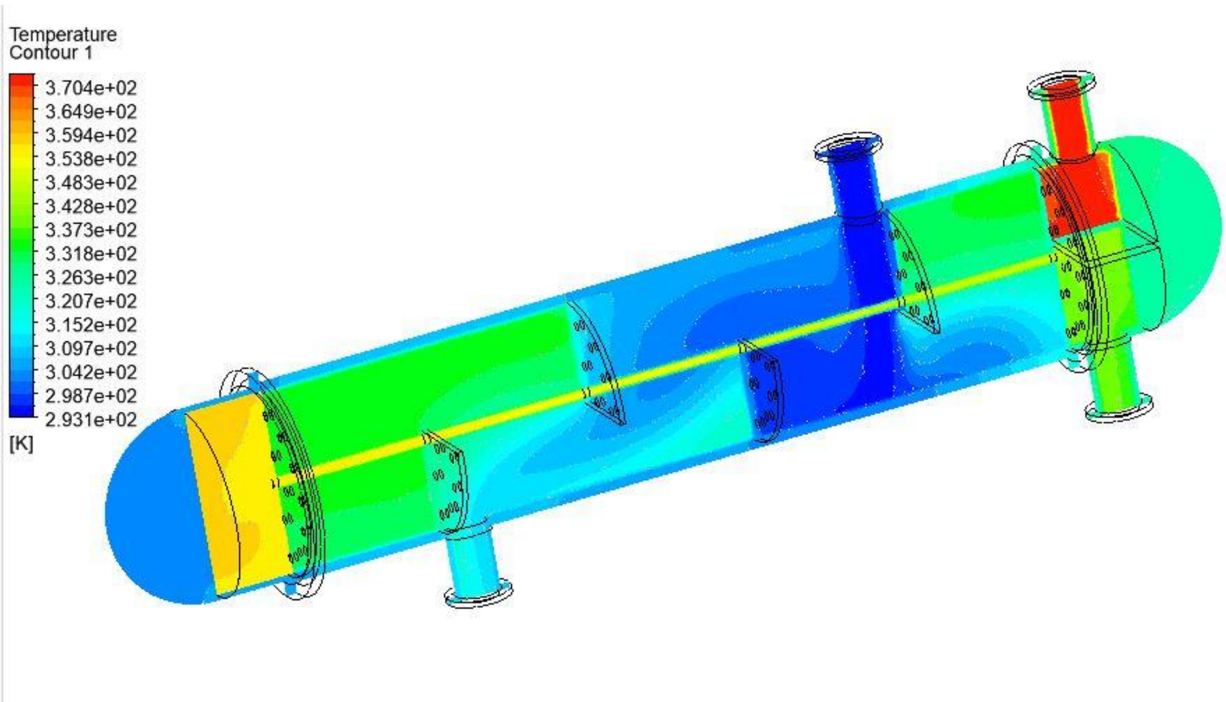

Fig 6: Temperature contour diagram for analysis for different mass flow rates for both materials Copper & Nitinol

	Parameters	Temperature [K]	Pressure [Pa]		Parameters	Temperature [K]	Pressure [Pa]
Temperature Data for NITINOL at different mass flow rates	COLD IN	293.15[K]	200000[Pa]	**Temperature Data for COPPER at different mass flow rates**	COLD IN	293.15[K]	199958[Pa]
	COLD OUT	314.1[K]	199989[Pa]		COLD OUT	322.656[K]	199980[Pa]
	DIFFERENCE	20.85[K]	11[Pa]		DIFFERENCE	29.506[K]	20[Pa]
	HOT IN	373.148[K]	200000[Pa]		HOT IN	373.149[K]	200000[Pa]
	HOT OUT	337.336[K]	199980[Pa]		HOT OUT	330.93[K]	199970[Pa]
	DIFFERENCE	35.812[K]	20[Pa]		DIFFERENCE	11.218[K]	30[Pa]

Table 5: Result for analysis for different mass flow rates for both materials

In the third case the analysis is done for the different mass flow at normal temperatures therefore the hot fluid passing through the inlet is in red colour. The tubes of heat exchanger and outlet of heat exchanger is in yellow and green zone representing the moderate temperature. Colours that are red and orange in a heat exchanger may show where heat is being transferred from a hot fluid to a cold fluid or a solid surface. The fluid passing through the second inlet is in blue or cooler zone. These colours denote lower temperatures because they show areas where heat is being absorbed or lost. Cooler colours, for instance, can designate regions in a heat exchanger where heat is being absorbed by cold fluid from a solid surface or a hot fluid.

- **Discussion:** The results from the Table 3, Table 4, Table 5, represents two main parameters, which is Temperature Difference and Pressure Difference. From above results at different condition like low temperature, high temperature, and different mass flow rates it is concluded that the pressure drop of Nitinol is less as compared to Copper in each condition. The pressure drop is necessary for the shell and tube heat exchanger in different manners like Flow rate and heat transfer, Energy Consumption, System design and sizing, Material selection, Maintenance and Life cycle cost. Higher pressure drops mean more energy is needed to push the fluids through the heat exchanger, resulting in higher operating costs. Proper sizing ensures that the pressure drop remains within acceptable limits, optimizing the efficiency of the overall system. High pressure drops can put mechanical stress on the materials used in the heat exchanger, influencing choices regarding material selection and construction methods to ensure durability and safety. As final discussion we can say that the currently Copper is most used material for shell and tube heat exchanger but the material Nitinol can be considered for high temperature application in shell and tube heat exchanger in the form of tubes used in industries like Steam power generation, Oil refineries, nuclear power plant where pressure drop is an important factor.

VII CONCLUSION

This paper aimed to thoroughly compare the tubes used in shell and tube heat exchangers made of copper and Nitinol, with a focus on clarifying the inherent drawbacks of copper. The research aims to examine in detail some of copper's shortcomings, such as its vulnerability to oxidation and pressure loss and deformation at high temperatures, which can have a negative effect on the longevity and performance of heat exchangers. Simultaneously, the research strives to investigate the possible benefits Nitinol may provide as a substitute material, taking into account its special qualities like super elasticity and corrosion resistance. The paper aimed to offer a better knowledge of the behavior of these materials under diverse operational conditions.

VIII ACKNOWLEDGMENT

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