Design analysis to Improve the performance of Ribbed tube for Heat Transfer Fluids

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Abstract: The rapid increase in the demand for energy has necessitated the need for both reducing the energy consumed as a result of inefficient use and improving the energy from the perspective of heat. This has become one of the significant activities of the engineers who design and operate the system. In the previous couple of decades various research have been conducted on improving the heat transfer. These researchers concentrated on finding a procedure to increase the heat transfer but also accomplishing high productivity. Accomplishing higher rate of heat transfer through different improvement methods can bring about considerable savings in the energy, along with developing compact and low cost equipment with greater thermal effectiveness. Hence this research aims at evaluating the design parameters to improve the performance of ribbed tubes. The optimal performance evaluation of water + water vapour, Distilled water, therminol 55 and therminol 66 was conducted in the previous study for examining the pattern of flow of the fluids within the ribbed tube. This study concentrates on improving the heat transfer coefficient of the fluids by varying the size of the ribbed tubes. Higher the heat transfer coefficient higher would be the performance. Four different cases of with different dimensions of the ribbed tube for all the four fluids are analysed and conclusions are drawn based on the comparison of the four cases.

Keywords: Ribbed tube, heat transfer coefficient, Therminol, heat transfer

1. Introduction

For enhancing the heat transfer of liquids in tubes that are smooth, diverse passive and active techniques, for example, helical inserts, internal ribs, twisted tapes, flow spoiler have been applied by different scientists (Popov et al., 2012). Ribbed tubes are generally utilized to upgrade the performance of heat transfer and are examined by numerous scientists. Data from the experiments and the respective relationships of the coefficient of heat transfer and loss in friction pressure within the ribbed tubes were developed for various heat transfer liquids, including supercritical water pressure, steam-water, water, air, cryogenic (Pan et al., 2011; Yang et al., 2011). Empirical correlations for predicting the coefficient of heat transfer and friction variable of working liquids in the ribbed cylinders. Customary liquids, for example, kerosene, air, steam-water, water cannot fulfil the expanding need for cooling in the applications of energy, for example, heat recuperation boilers due to the impediment of the temperature of working liquid (Huang et al., 2015). For the regular heat recuperation boilers, the transfer of energy takes place via the walls of the tube for heating the operating liquid. The working liquid is then directly passed through the heat exchanger. The highest temperature of the working liquid is the dominating component for using the energy since high temperature prompts high efficiencies within the heat exchanger.

Therminol heat transfer liquids are one of the classes of thermic liquids that are applied in petrochemical sectors and thermal engineering since it gives the superior stability and performance in the frameworks with the temperature of operation ranging between - 73 to 400°C (Selvakumar et al., 2015). It is relevant to make reference to that the information on the convective transfer of heat of Therminol liquids is restricted. Therminol-55 fluid stage of heat transfer exists as fluid over a wide temperature range. It is a eutectic blend of biphenyl and diphenyl oxide and generally utilized as heat transfer liquids in low pressure/non-pressurized indirect heating framework. In any case, lesser thermal conductivity and capacity of heat and high viscosity of Therminol affect the performance of heat transfer negatively. Subsequently, there are difficulties and chances to improve the performance of heat transfer of Therminol by techniques employing ribbed tubes. In this paper, the performance of heat transfer and fluid flow of Water + water-vapour, distilled water, therminol-55, therminol-66 for different dimensions of the ribbed tube are simulated in ANSYS and the results are presented.

2. Literature review

Various studies have been developed to determine the heat transfer coefficient of various fluids in ribbed tubes, this section discusses some of them. Sławomir, and Karol, (2016) modelled the flow and thermal phenomena of the tubes that were ribbed internally. The model allowed the investigation of transient-state forms. The main objective of these estimations was, among others, to discover the liquid enthalpy distribution, flow of mass and internal pressure of the ribbed tubes and also determining the coefficient of heat transfer. An examination of the obtained outcomes demonstrated great intermingling between the CFD modelling and the numerical program. The divergences in the distribution temperature of the liquid may result from the use of an alternate model for determining heat transfer coefficient and the various strategies for deciding thermophysical properties of water. From the above, it tends to be seen that while modelling the phenomena of flow and thermal that occurs in both ribbed and smooth cylinders, the choice of fitting relations depicting the transfer of heat and the water thermophysical properties for the parameters viable is necessary.

Modelling the transfer of heat using CFD inside helically ribbed cylinders demonstrated that improved inner surface obviously impacts on the process of heat transfer (Majewski, and Grądziel, 2016). In the cases evaluated, the difference in outflow temperature of liquid within the ribbed tube is by around 10% higher compared to plain tubes. For a short separation, there is an unmistakable increment of process of heat transfer. CFD model for a single phase flow demonstrated the influence of ribbed tubes on the strong body temperature is not as perceptible as that in two stage flow with high quality of steam. The temperature of the medium tube was found to be greater compared to plain tubes. These distinctions are associated with the determined medium coefficient of heat transfer. For plain and ribbed tubes, this amount has comparable qualities. The choice of turbulence model greatly affects the outcomes. This examination comprises the results obtained from the transitional SST, k-ε and k-ω disturbance models, particularly for estimating coefficient. It is associated with a superior portrayal of phenomena for various flow structures. Numerical and experimental simulations on friction factor and coefficient of heat transfer of Therminol 55 fluid stage heat transfer liquid was carried out by Xu et al., (2016) in a ribbed cylinder with inner and outer diameter of 15mm and 19mm, rib height and pitch of 1mm and 4.5mm. Xu et al., (2017) also carried out simulations and experiments on heat transfer and flow conduct of Therminol-55 fluid stage heat transfer liquid in a ribbed with inner and outer diameter of 20mm and 25mm, rib height and pitch of 1mm and 4.5mm. Trial results of both studies showed a considerable improvement in the thermal performance and heat transfer of Therminol 55 fluid in the ribbed tube contrasted with those of the smooth tubes when the Reynolds number extents from 500 to 11,500. The numerical outcomes demonstrated that the ribbed tube can improve heat transfer and the performance of liquid flow of Therminol.

Li et al., (2016) conducted a numerical investigation of pressure drop and heat transfer for turbulent flow in a progression of 15.54-mm inner diameter for helically ribbed tubes. The geometric parameters range were number of rib begins (10 to 40), helix point (25 to 55 degrees), and height of the rib (0.3 to 0.6 mm). The impact of grid independence was broadly analyzed. The computational outcomes coordinated well with the trial information to verify the precision of the numerical model. The impact of every primary parameter, rib begins, helix edge, and height of the rib, on the drop in pressure and transfer of heat is examined. Considering fouling in reasonable circumstances, the proportion of pitch over rib height is a significant parameter to choose the tubes. It is fitting to choose tubes with pitch over height of the rib ratio > 3.5, which have better transfer of heat and lower fouling potential.

Yang et al., (2019) examined numerically the enhancement of heat transfer of supercritical CO_2 flowing inside the warmed vertical cylinder with rib setups. By the examination of buoyancy impacts and the impact of vortex structures on the field of flow, the component of enhancing the heat transfer is perceived. Results showed that, buoyancy impacts on stream and convective transfer of heat are essentially debilitated by the rib-initiated vortices. Besides, rib-prompted secondary flow and upgraded kinetic energy in the close wall region additionally lead to improving the heat transfer. With an increase in height of the rib or reduction in rib pitch can further improve convective transfer of heat in ribbed tubes. Field synergy investigation was additionally performed for studying the impacts of rib designs on the stream field.

3. Research methodology

The initial step of this research is the process of meshing after which the physics of the fluid flow settings are setup. The fluid is considered to behave as an incompressible flow. The segregated flow solver is used to solve the governing equations using k-ω SST turbulence model. The previous study (Patil and Selokar, 2019) concentrated primarily on optimally designing the system for improving performance of different liquid phase heat transfer fluids in ribbed tube. The considered working fluids were Therminol 55, Therminol 66, Liquid-vapour mixture and water liquid phase heat transfer fluids. The performance of the ribbed tube with Therminol 55, Therminol 66, Liquid-vapour mixture and water liquid phase heat transfer fluids were evaluated and from the results it was concluded that the developed model of therminol-66 with the v-shaped groove in the pipe demonstrated a better performance compared to that modelled by Xu et al., (2016b). In the current study the heat transfer coefficient of the liquids water, water-vapour, Therminol 55 and Therminol 66 is evaluated for ribbed tubes of different dimensions. This is the further continuation of Patil and Selokar, (2019) in which the experimental system comprises of the test section, heat transfer fluid, heat exchanger and cooler, tank for storage. The heat transfer liquid temperature was maintained constant inside the cooler. The four fluids i.e Therminol 55, Therminol 66, Liquid-vapor mixture and water liquid phase heat transfer fluid were analysed for examining the pattern of flow within the ribbed tube based on the numerical techniques. And the Nusselt number obtained for all the fluids shown in table 1 implies that the Therminol 66 was the best fluid with the highest nusselt number.

Table 1. Nusselt number (previous study)

Fluid	Nusselt number
Therminol 66	104
Therminol 55	102
Water + Water vapor	3.24
Distilled water	40.06

The dimensions of the ribbed tube considered for the study are provided in Table 2 below. The results obtained for each of these case is illustrated in the next section.

Table 2. Different dimensions of the ribbed tube considered for the study

Param eters	CASE 1	CASE 2	CASE 3	CASE 4	Param eters	CASE 1	CASE 2	CASE 3	CASE 4
	PIPE	PIPE	PIPE	PIPE		THRE AD	THRE AD	THRE AD	THRE AD
OD	70	55	47.5	45	L	3	3	3.5	5
ID	60	45	37.5	35	T	1.5	1.5	1.25	2.5

L	80	110	100	80	H	1.5	2	1.5	1.5
					Pitch	10	10	10	10

All the dimensions are in mm. OD - outer diameter, ID - inner diameter, L - length, T - thickness, H - height.

4. Simulation Results

The results obtained for the four cases considered are illustrated below.

CASE 1

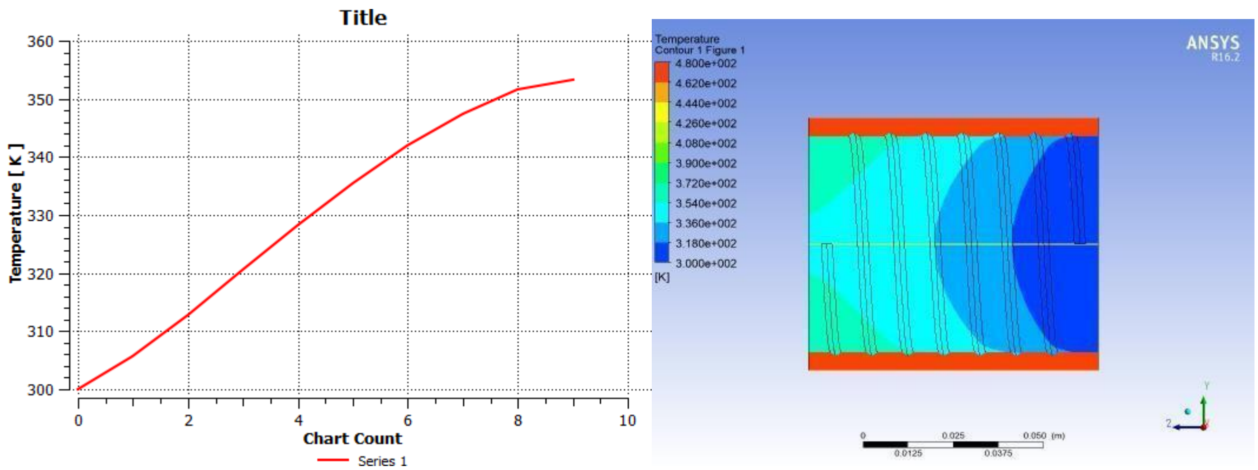

Figure 1. Water + water vapour (a) Temperature v/s Length (b) ANSYS model

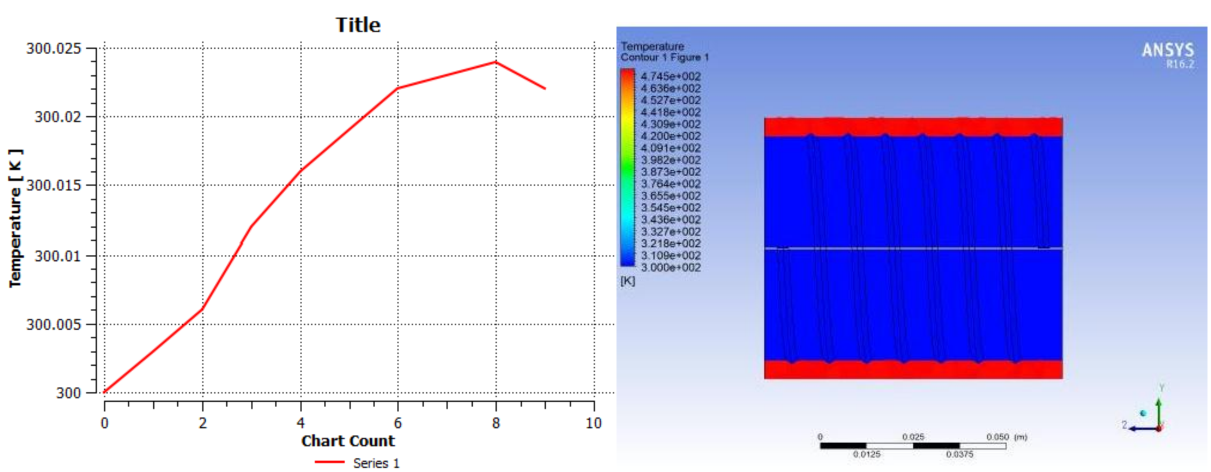

Figure 2. Distilled Water (a) Temperature v/s Length (b) ANSYS model

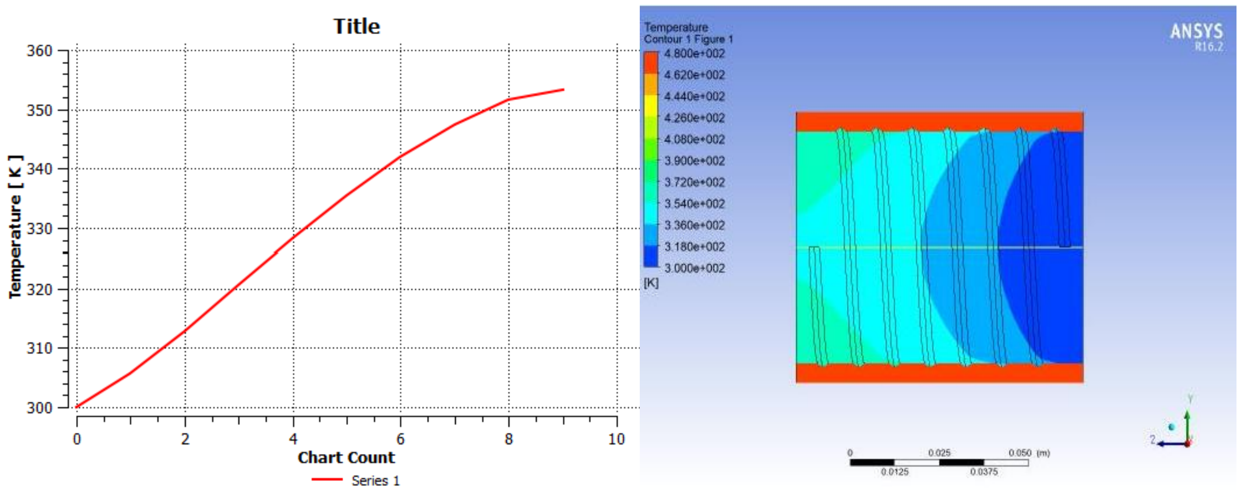

Figure 3.Therminol - 55 (a) Temperature v/s Length (b) ANSYS model

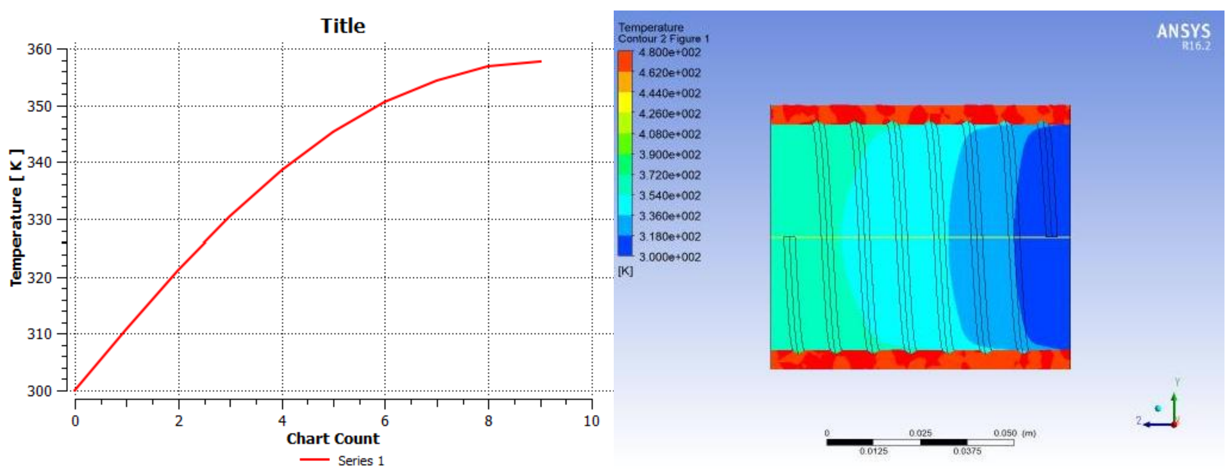

Figure 4.Therminol - 66 (a) Temperature v/s Length (b) ANSYS model

CASE 2

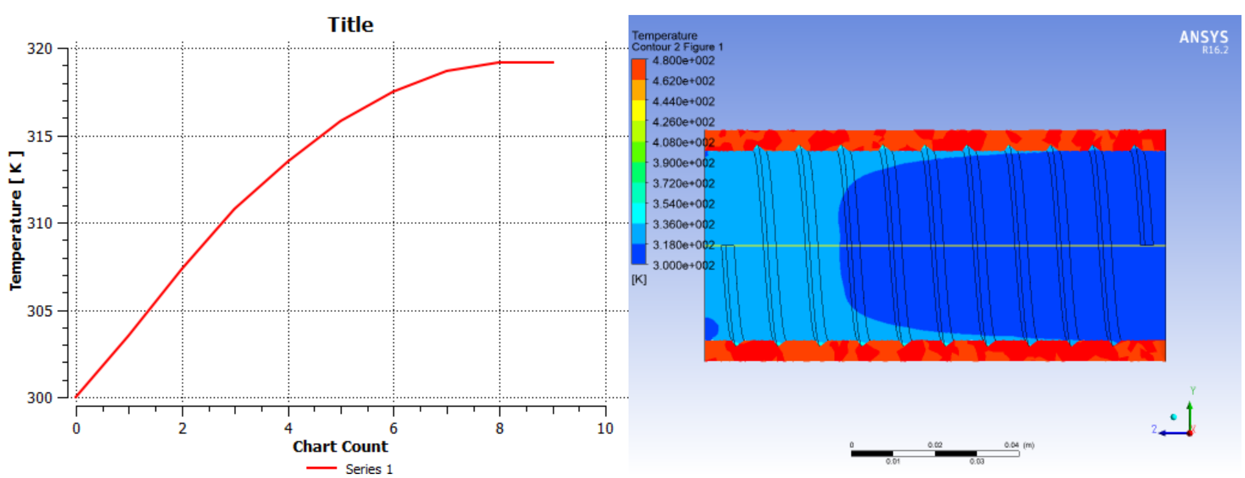

Figure 5. Water + water vapour (a) Temperature v/s Length (b) ANSYS model

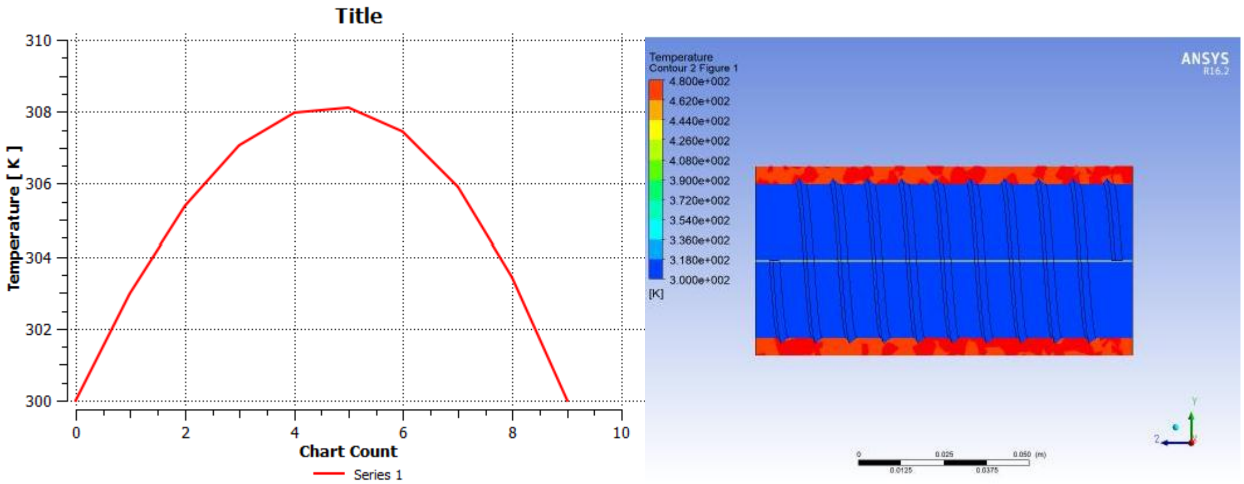

Figure 6. Distilled Water (a) Temperature v/s Length (b) ANSYS model

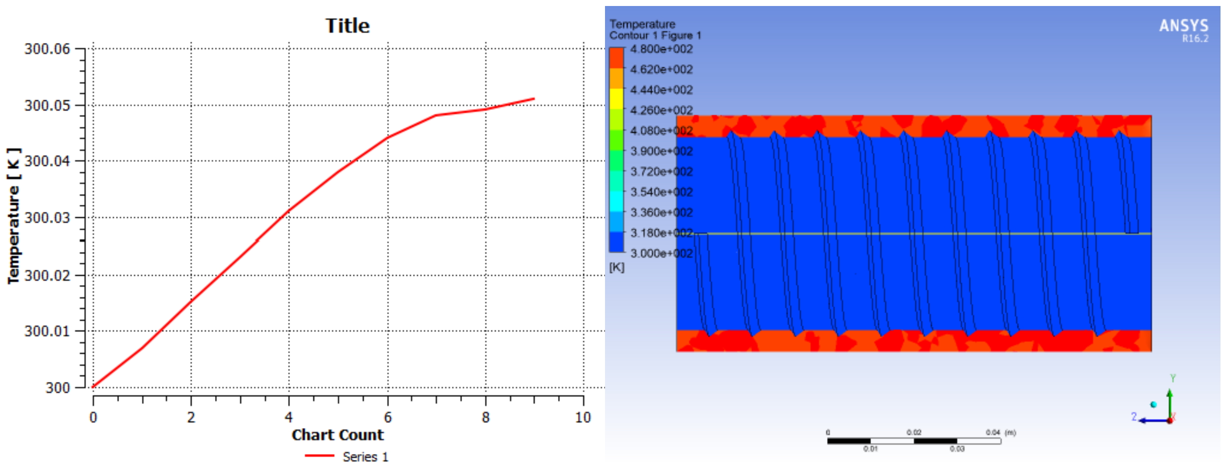

Figure 7.Therminol 55 (a) Temperature v/s Length (b) ANSYS model

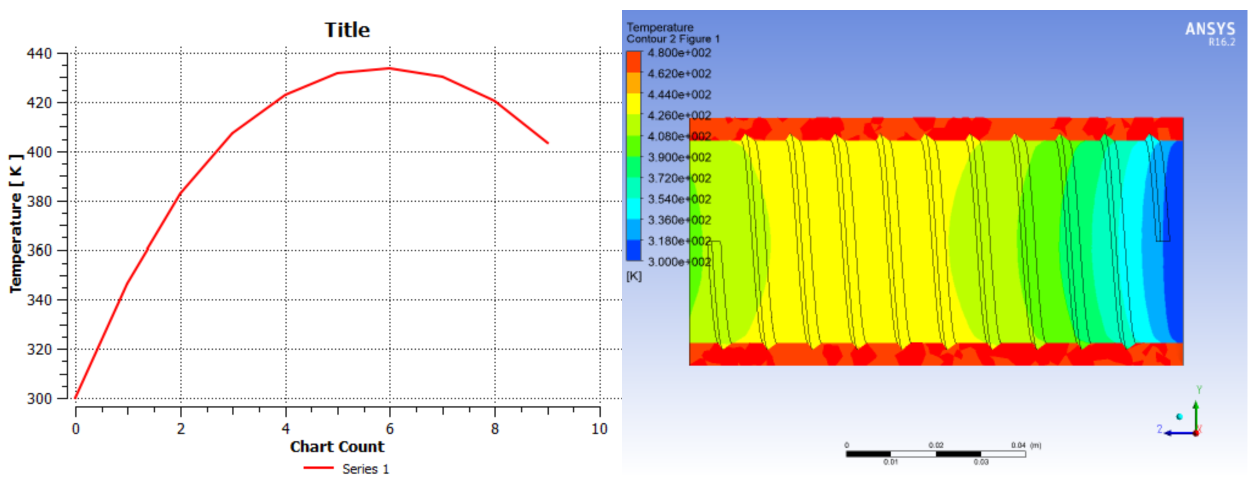

Figure 8.Therminol 66 (a) Temperature v/s Length (b) ANSYS model

CASE 3

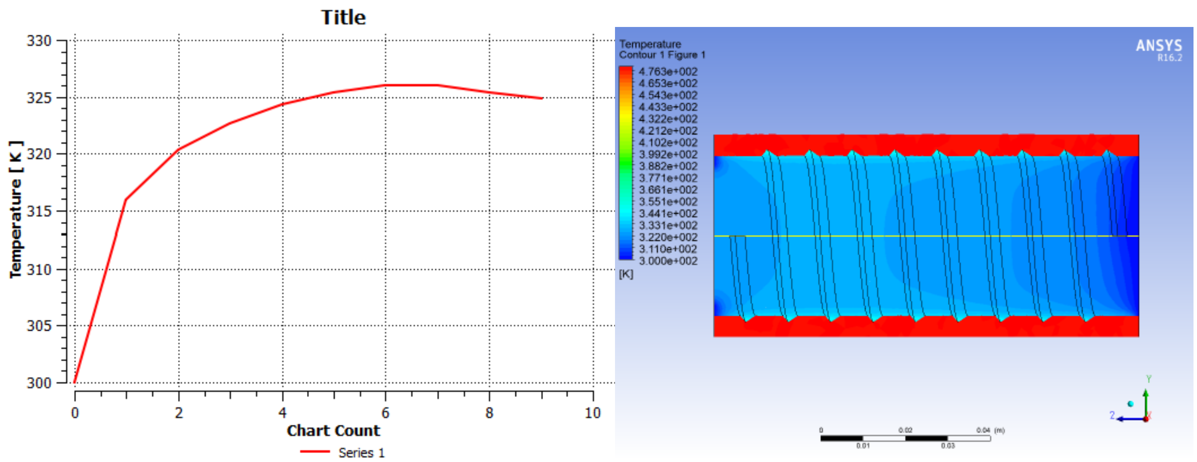

Figure 9. Water + water vapour (a) Temperature v/s Length (b) ANSYS model

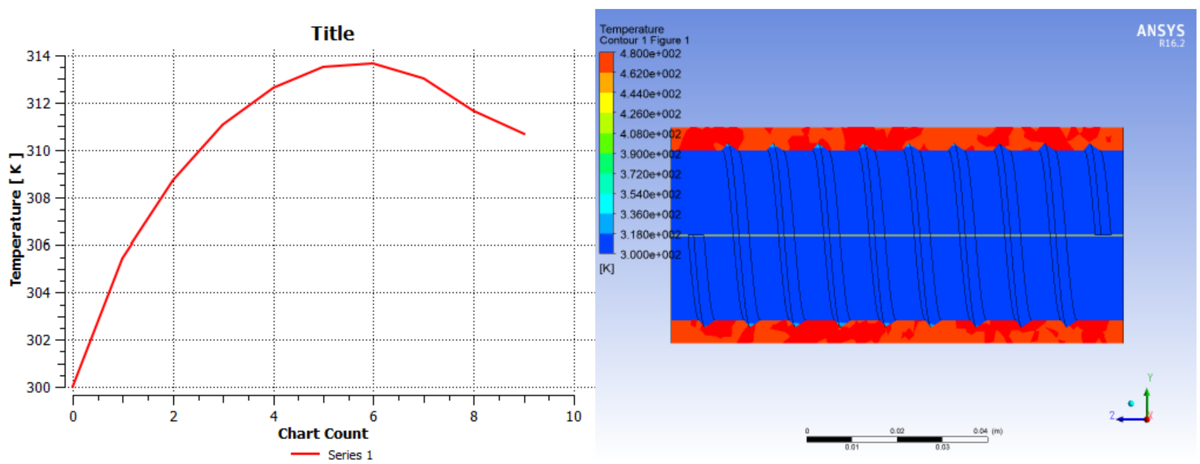

Figure 10. Distilled Water (a) Temperature v/s Length (b) ANSYS model

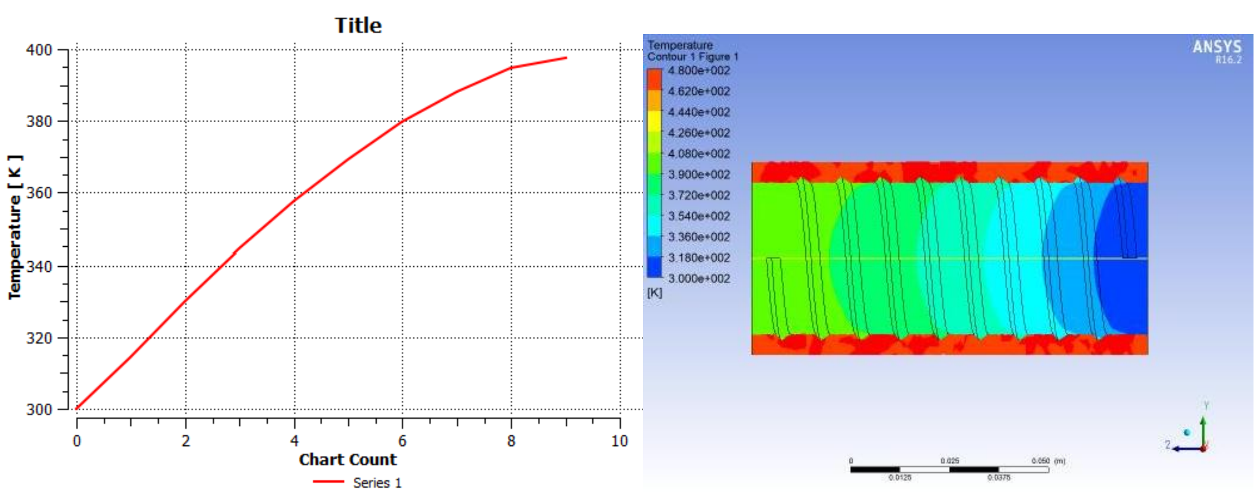

Figure 11.Therminol 55 (a) Temperature v/s Length (b) ANSYS model

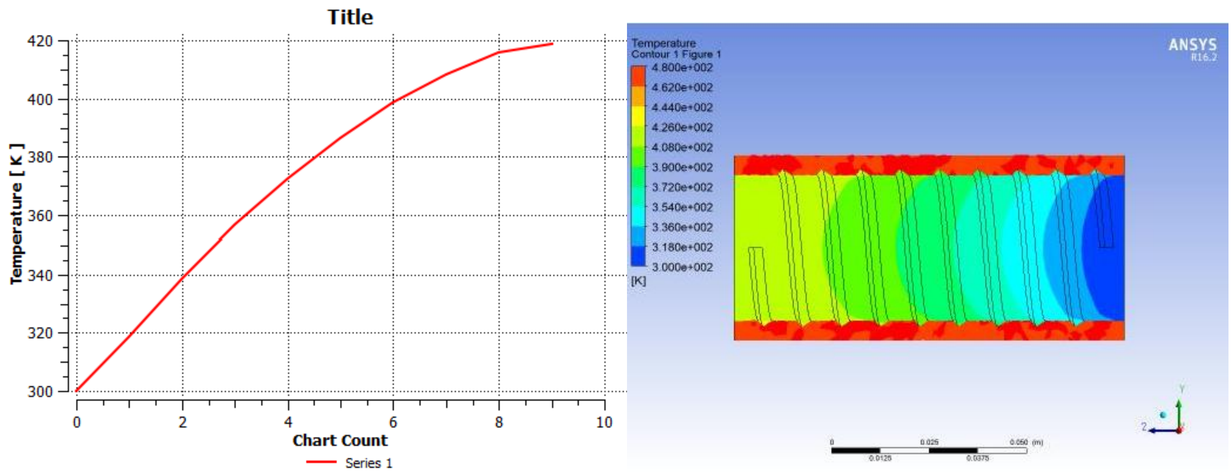

Figure 12.Therminol 66 (a) Temperature v/s Length (b) ANSYS model

CASE 4

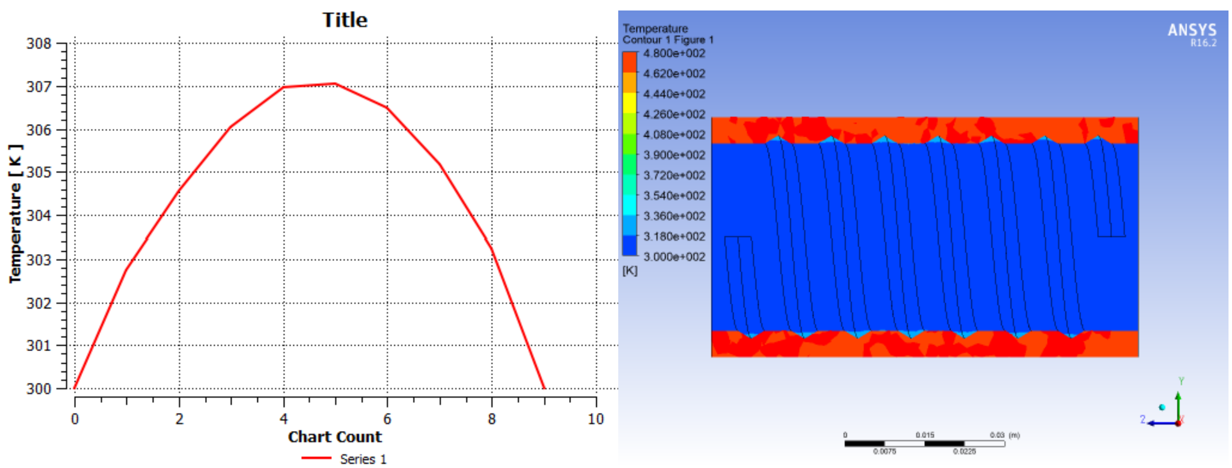

Figure 13. Water + water vapour (a) Temperature v/s Length (b) ANSYS model

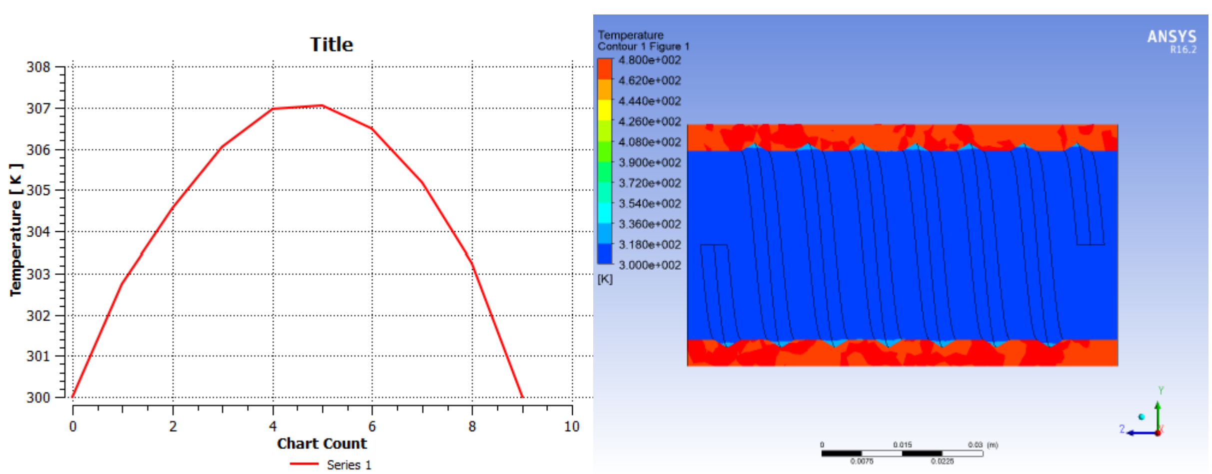

Figure 14. Distilled Water (a) Temperature v/s Length (b) ANSYS model

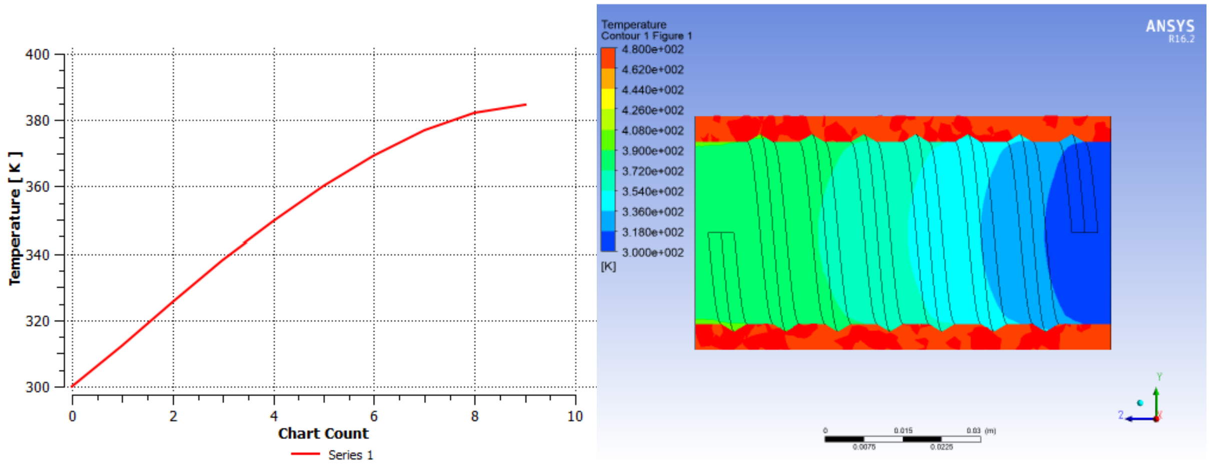

Figure 15. Therminol 55 (a) Temperature v/s Length (b) ANSYS model

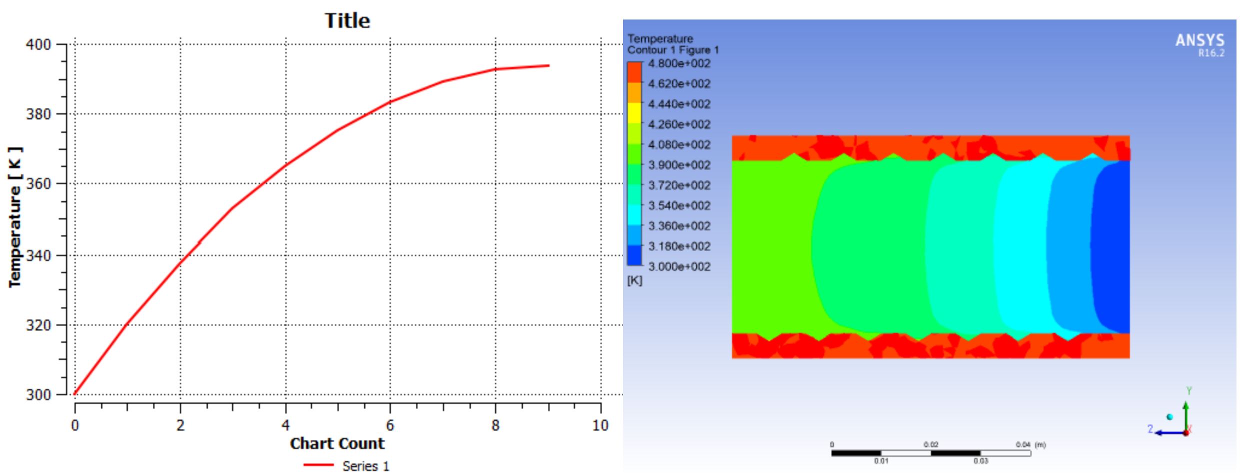

Figure 16. Therminol 66 (a) Temperature v/s Length (b) ANSYS model

The temperature variations of the water + water vapour can be observed from the figures 1, 5, 9, 13 for the four cases respectively. The Heat transfer coefficient will be higher for higher temperatures. It can be observed that the temperature for water + water vapour reaches a maximum of 355K for the pipe dimensions considered in case 1 while that for case 2, 3, 4 is around 315K, 326K and 307K respectively.

The temperature variations of distilled water can be observed from the figures 2, 6, 10, 14 for the four cases respectively. It can be observed that the temperature for distilled water reaches a maximum of 313K for the pipe dimensions considered in case 3 while that for case 1, 2 and 4 are around 300K, 308K, and 307K respectively. Thereby it can be inferred that the most ideal dimensions for distilled water is the ones considered in case 3.

The temperature variations of therminol 55 can be observed from the figures 3, 7, 11, 15 for the four cases respectively. It can be observed that the temperature for therminol 55 reaches a maximum of 395K for the pipe dimensions considered in case 3 while that for case 1, 2 and 4 are around 355K, 300K, and

300K respectively. Hence it can be inferred that the most ideal dimensions for therminol 55 is the ones considered in case 3.

The temperature variations of therminol 66 can be observed from the figures 4, 8, 12, 16 for the four cases respectively. It can be observed that the temperature for therminol 66 reaches a maximum of 430K for the pipe dimensions considered in case 2 while that for case 1, 3 and 4 are around 355K, 420K, and 390K respectively. Hence it can be inferred that the most ideal dimensions for therminol 66 is the ones considered in case 2.

5. Conclusion

The heat transfer coefficient of different liquids for different dimensions of the ribbed tube were examined with the through simulations in ANSYS FLUENT. The following conclusions can be observed from this study.

- Dimensions of the ribbed tube considered in case 1 was found to be optimal for water + water vapour since the maximum temperature of 355K was obtained for these dimensions.
- Similarly dimensions of the ribbed tube considered in case 3 was optimum for distilled water as well as therminol 55 with maximum temperatures of 313K and 395K respectively.
- In case of therminol 66 the dimensions of the tube considered in case 2 was the best suited since the maximum temperature of 430K was obtained for these dimensions.
- With higher temperatures the heat transfer coefficient of the liquids also was high implying that they directly proportional to each other.

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