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CFD Analysis of Heat Pipe with Helical Rings on the Inner Surface

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ABSTRACT

A heat exchanger is a device used to transfer thermal energy between two or more fluids at different temperatures. They are used in both, cooling and heating processes. This work is to conduct a numerical study on the effect of different heat transfer coefficients on shell and tube heat exchangers, to demonstrate the laws of different coefficients depending on the flow regime. Heat exchangers are used in many heating and cooling processes within various industries. The performance of a heat exchanger depends in part on the flow and heat transfer characteristics of the fluids within the heat exchanger. The objective is to study flow characteristics such as temperature drop and pressure drop for one, two and three helical rings on the inner surface of a heat pipe using ANSYS software.

Keywords- heat transfer; numerical study; twisted-tape inserts; Helical Rings.

1 INTRODUCTION

Ibrahim et al. 2014, reported the thermohydraulic performance of a tube equipped with cone ring bundles of three different shapes: convergent, convergent–divergent and divergent cone rings. They observed that the ideal temperature of these tubes were 3.3, 4.19 and 7.65 times higher than the temperature of the empty tube. Furthermore, the highest thermo-hydraulic efficiency index, 1.29, was obtained at a Reynolds number (Re) of 6000 using different conic rings with d/D = 0.4 and PR = 2.0. They report that a circular-type turbulator with a ratio (PR) of 2.0 and an angle ratio of 0.125 resulted in an increase in the heat transfer rate and friction factor, which were 4.16 and 5.11 times that of the hollow tube, respectively, while the thermo-hydraulic efficiency index was 2.9 times higher. Yadav and Sahu 2015, investigated the influence of helical surface disk turbulator on thermo-hydraulic performance characteristics. The diameter ratios of the turbulators used in this work were 0.42, 0.475 and 0.54, and the helix angles were 20◦ , 30◦ and 40◦ . The turbulator with the smallest diameter ratio (0.42) and the largest helix angle (40◦) gives the highest heat transfer ratio. All tubes with helical surface disc turbulators had thermohydraulic efficiency factors greater than unity, indicating energy saving potential.Nalavade et al. 2015, reported the heat transfer rate of heat tubes with flow divider-type turbulators installed. The results for pitch ratios (0.54, 0.72 and 1.09) and bend angles (45◦, 30◦ and 90◦) were evaluated. They found that turbulators with bending angles of 30◦ and 45◦ increased the bare tube heat transfer by 1.6 and 1.46 times, respectively. Vesey etc. 2015, studied the heat transfer behavior of tubes equipped with continuous and discontinuous twisted turbulators. They reported that discontinuous turbulator has better heat transfer enhancement with less pressure loss than continuous turbulator.

Ranat Musbakhov et al. in 2015, the strengthening of heat transfer research with numerical methods was reported, investigating the numerical modeling of shell and tube heat exchangers with helical, dimple, ring, and semi-ring breaks. The use of an intensifier results in an increase in heat flux across the flow range of the heater. The greatest effect of intensifiers is seen in color intensifiers, but they also increase hydraulic resistance. The increase in heat flux is almost the same for helical, dimple, and semi-ring intensifiers. Alimoradi et al. 2016, reported improved heat transfer in rectangular channels where curved turbulators were installed. They found that 90◦ turbulators give thermo-hydraulic efficiency factors of up to 1.62. SheikhoIslami etc. 2016, investigated heat transfer rates in a circular tube embedded with multiple helical tapes. In this study, tapes helped to reduce thermal irreversibility by 90% with an impedance ratio of 0.098. Keklikcioglu et al. 2016 analyzed the entropy production of a diverging/converging-diverging/converging wire-equipped heat exchanger tube using a mixture of ethylene glycol and water as the test flow. Their results showed that the heat exchanger tube equipped with flexible coiled wires gave higher values of entropy generation than other coiled wires. They also reported that a low entropy generation number of 0.42 was obtained using pure water as the test fluid in a heat exchanger tube mounted on a coiled deflector wire. Mangarolkar et al. 2017 reported the development and improvement of thermal performance of flow heat exchanger by combining vortex generator (VG), fin embedding and tube cross-section modification. Lu et al. 2017 investigated the effect of surface roughness on the heat transfer characteristic and flow structure in a micro channel with different types of wavy, square and dimple channels. They reported that the dimple channel results in higher heat transfer and pressure loss than other types of channels. Outocash etc. 2017, conducted experiments to study the heat transfer and thermal efficiency of a circular tube connected by curved tapes of different lengths. Their results showed that the highest thermal efficiency of 28% was for the curved tape with a 5 mm curve operating at a Reynolds number of 20,000.

Masood Otokash, et al. 2020, reported a numerical evaluation of the effect of using a twisted tape with a curved profile as a turbulator on the improvement of heat transfer in a pipe, a study of turbulent fluid flow and heating through a circular tube was carried out to investigate the thermal efficiency of the transfer with curved tape. The geometric parameters considered are the length-to-height ratio and the curvature of the curved tapes. It was observed that by increasing the height of the bend, the swirl flow increases the strength of the tube, and the heat transfer increases. Increasing the pitch ratio increases heat transfer but pressure drop is a problem. Greater curvature is preferred for better heat transfer. M. Pamsan et al. 2021, studied heat transfer, friction factor, and thermohydraulic performance index for varying Re, Pr, and serrated-diagonal ring angles using a serrated ring turbulator in tube heat exchangers. Tubes with small bevel angles produce better heat transfer with serrated rings. As the liquid enters the heated test section, the friction coefficients decrease with higher values of Re due to its higher velocity. Ring piles with smaller skew angles result in higher friction factors.Zhiqiang Sun et al. 2021, reported an experimental and numerical study of turbulent heat transfer in a circular duct with curved fin vortex generators, a study of turbulent fluid flow characteristics within a duct with vortex generators of different diameters and PR. In the same dynamic aircraft, wide fins greatly aid in fluid mixing resulting in greater mass and power transfer. As the PR decreases, the regions of high turbulence kinetic energy gradually shift to the smooth flow region and the TKE in both the smooth flow region and the near-wall region becomes stronger, which means that the better mass and energy transportation. Ahmed Ramadan Al-Obeidi and others in 2021 reported a study of flow characteristics, pressure drop, and thermal conductivity in a horizontal pipe with and without bend tape. A study was conducted to compare the flow characteristics of three cross-sectional area twisted tapes with and without the use of twisted tapes. Twisted tape installation caused flow and swinging and cross-mixing in the pipe. The pressure drop through the pipe with the insert was greater than the pipe without the insert. The temperature drop was more pronounced in the wider section tape.

2 CLASSIFICATION OF HEAT EXCHANGER

Heat exchangers are devices used to transfer thermal energy from one fluid to another with or without mixing the two fluids. Fluids are usually separated by a solid wall (with high thermal conductivity) to prevent mixing or they may be directly mixed. A classic example of a heat exchanger is found in an internal combustion engine where engine coolant passes through radiator coils and air passes through the coils, cooling the coolant and heating the incoming air. In power engineering, common applications of heat exchangers include steam generators, fan coolers, cooling water heat exchangers, and condensers. For example, a steam generator is used to convert feed water into steam from the heat generated in the core of a nuclear reactor. The steam generated drives a turbine.

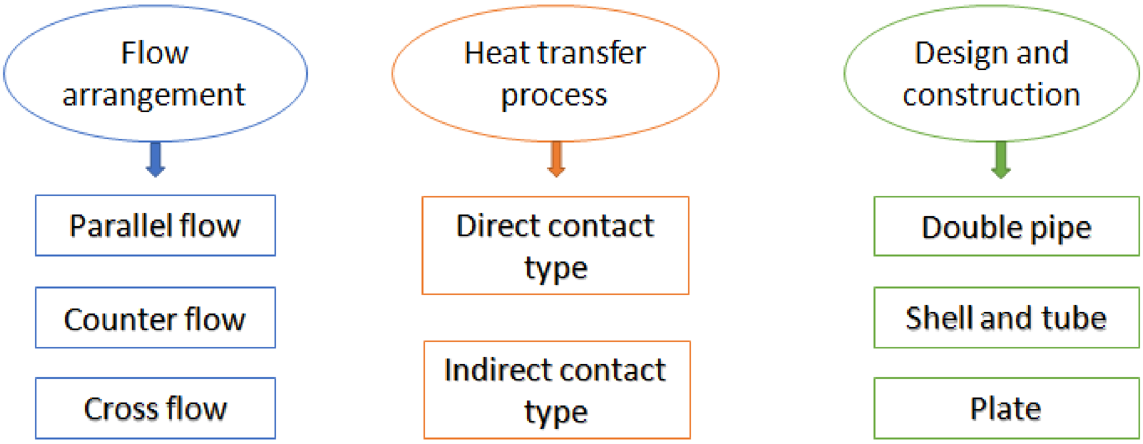

Figure 1 Classification of heat exchanger

2.1 DOUBLE PIPE HEAT EXCHANGERS

Two-pipe heat exchangers are inexpensive in both design and maintenance, making them a good choice for small industries. In these heat exchangers, one fluid flows inside the tube and the other fluid flows outside. Although they are simple and cheap, their low efficiency as well as the large space taken up has forced modern industries to use high efficiency heat exchangers such as shell and tube heat exchangers.

2.2 SHELL AND TUBE HEAT EXCHANGERS

Shell and tube heat exchangers in their various construction configurations are probably the most commonly used primary heat exchangers in industries. Shell and tube heat exchangers are further classified according to the number of shells and tubes. Shell and tube heat exchangers are typically used for high-pressure applications (with pressures greater than 30 bar and temperatures greater than 260 °C). This is because shell and tube heat exchangers can withstand higher pressures due to their shape. In this type of heat exchanger, small bore pipes are placed between two tube plates and the main fluid flows through these tubes. The tube bundle is placed inside the shell and the secondary fluid flows through the shell and over the tubes. In nuclear engineering, this design of heat exchangers is widely used as a steam generator, which is used to convert feed water into steam from the heat generated in the core of a nuclear reactor. To increase the amount of heat transferred and the energy produced, the area of the heat exchanger must be increased. This is achieved by using tubes. Each steam generator can have anywhere from 3,000 to 16,000 tubes, each about 19 mm in diameter.

2.3 PLATE HEAT EXCHANGERS

A plate heat exchanger is a type of heat exchanger that uses metal plates to transfer heat between two fluids. This system is popular for variables using air or gas and low velocity fluid flow. A classic example of a heat exchanger is found in an internal combustion engine where engine coolant passes through radiator coils and air flows through the coils, cooling the coolant and heating the incoming air.

3 TURBULATORS AND INTENSIFIERS

Various types of devices are used to enhance the flow rate and for better mixing of fluid in heat pipe known as tabulators and intensifiers which are shown below :-

Figure 2 Tabulators, intensifiers and components

4 METHODOLOGIES

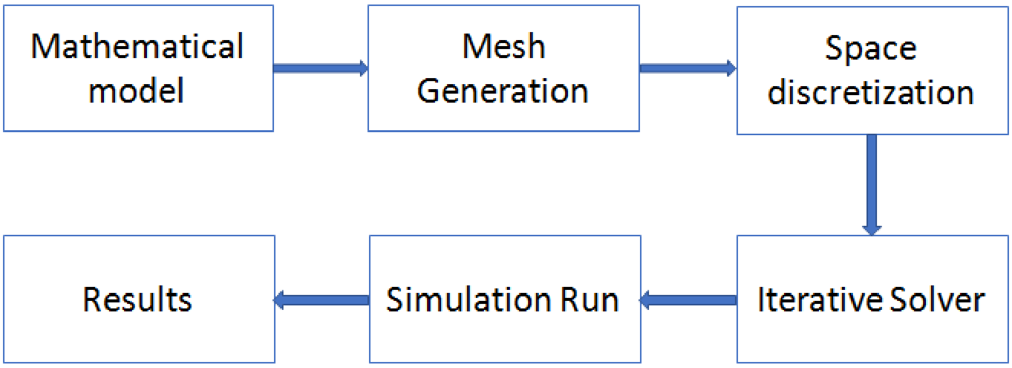

Figure 3 ANSYS Methodology

5 VALIDATIONS

The result of the base paper is validated for the following parameters
*Pipe Length = 1920 mm

*Pipe Diameter = 11.08 mm
*Twisted tape cross-section = 1 x 3 mm

Table 1 shows the different volume flow rates (0.56, 3.15 and 5.74 lit/min) with temperature drop (K) as previous study and present study and also shows the percentage error between the previous study and the present study. The minimum percentage error was 0.035 in the volume flow rate (5.74 lit/min) and the maximum percentage error was 1.729 in the volume flow rate (3.15 lit/min).

Table 1 Volume flow rate (lit/min) with Temperature Drop (K)

Volume flow rate (lit/min)	**Temperature Drop (K)**		
	Past study	**Present study**	**Percentage error**
V1 = 0.56	12.374	12.385	0.089
V2 = 3.15	4.280	4.354	1.729
V3 = 5.74	2.819	2.818	0.035

6 MODEL DESCRIPTIONS

Table 2 shows the mesh element of Tetrahedrons of size 1 mm, and also shows the models as pipe with 1, 2 and 3 rings having the element number as 2331601, 2304328 and 2262306 respectively.

- The model of heat pipe with inner rings is prepared in Ansys-2020 R1 workbench with analysis system as fluid fluent with Design Modeler.
- k-epsilon (k-ε) model with a SIMPLE algorithm is adopted for numerical investigation.

The Tetrahedrons meshing element of size 1 mm is generated counting to :-

Table 2 Tetrahedrons meshing element of size 1 mm

Model	**No. of Elements**
Pipe with 1 ring	2,331,601
Pipe with 2 rings	2,304,328
Pipe with 3 rings	2,262,306

7 ANALYSES

7.1 PIPE WITH 1 INNER RING

- **Pi**pe Length = 1440 mm
- Pipe Diameter = 15.66 , 19.19, 22.16 mm
- Ring cross-section = 1 x 3 mm

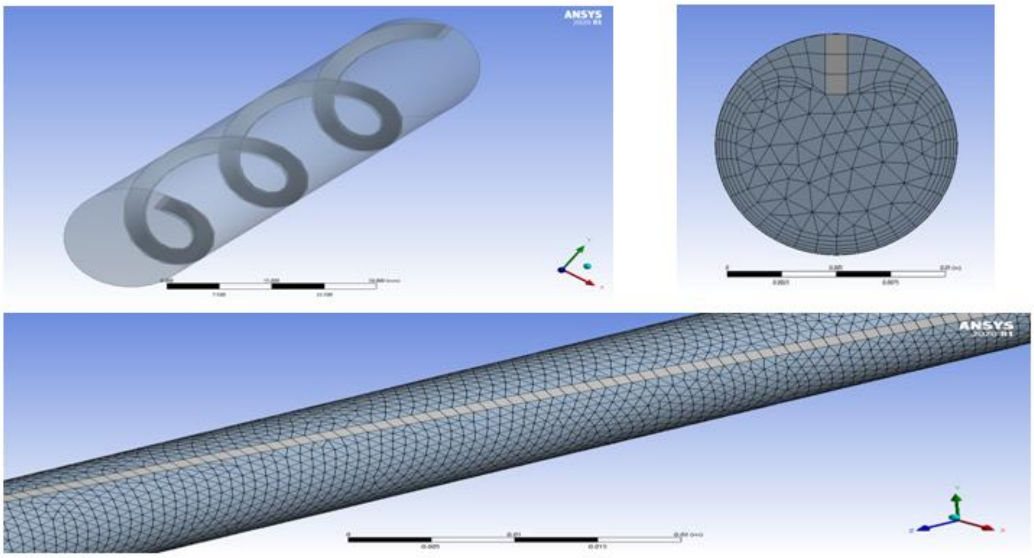

Figure 4 Pipe with 1 inner ring

7.2 PIPE WITH 2 INNER RINGS

- Pipe Length = 1440 mm
- Pipe Diameter = 15.66 , 19.19, 22.16 mm
- Ring cross-section = 1 x 1.5 mm

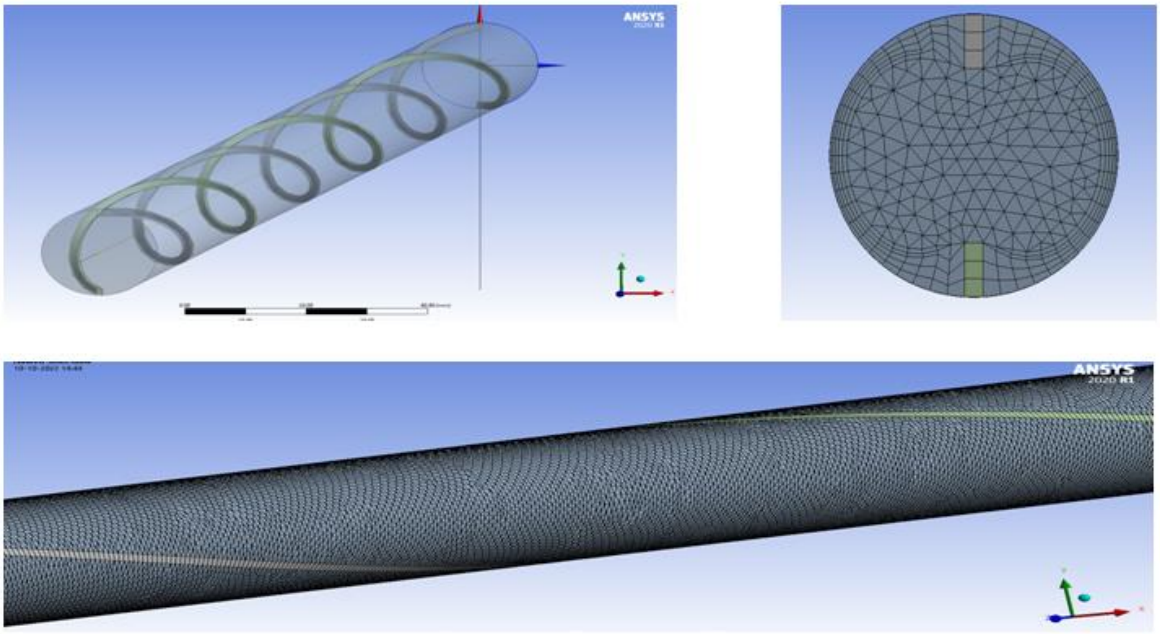

Figure 5 Pipe with 2 inner rings

7.3 PIPE WITH 3 INNER RINGS

- Pipe Length = 1440 mm
- Pipe Diameter = 15.66 , 19.19, 22.16 mm
- Ring cross-section = 1 x 1 mm

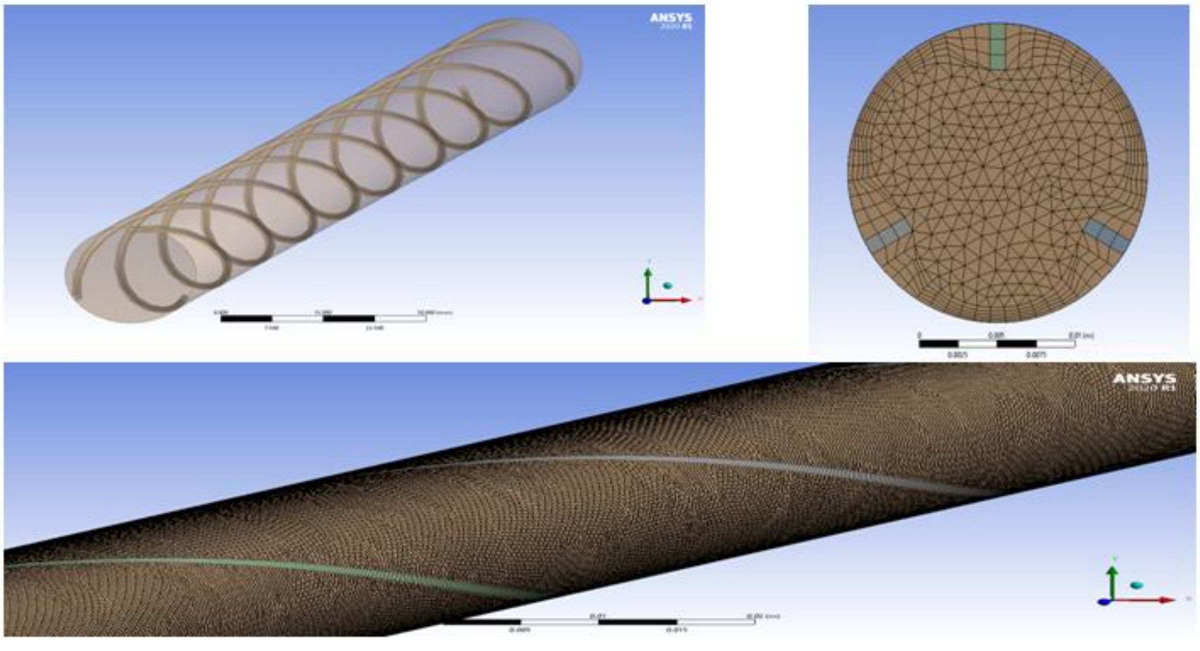

Figure 6 Pipe with 3 inner rings

8 RESULTS AND DISCUSSION

Boundary conditions of fluid (water)

- Properties of water is taken for bulk temperature=293.15 K
- Inlet water temperature = 313.15 K
- Density of water = 992.32 kg/m^3
- Specific heat capacity of water = 4178 J/kg-K
- Thermal conductivity of water = 0.63 W/m-K
- Dynamic viscosity of water = 6.71 x 10^{-04} N/ m^2

8.1 TEMPERATURE DROP VARIATIONS

1. Variation across the cross-sectional area.
2. Variation across the varying volume flow rate.
3. Variations with the constant wall heat fluxes.

Figures 7 to 9 show the temperature drop with variable cross-sectional areas as 192,607, 289,227 and 385,682 mm2, respectively. Figures 10 to 12 show the temperature drop with variable volume flow rate of 1.1, 2.2 and 3.3 lit/min, respectively. Figure 13 to 15 Effect of constant wall heat flux as 4000, 6000 and 8000 W/m2 k respectively on temperature drop. Figure 16 shows the temperature contour profile in the transverse plane.

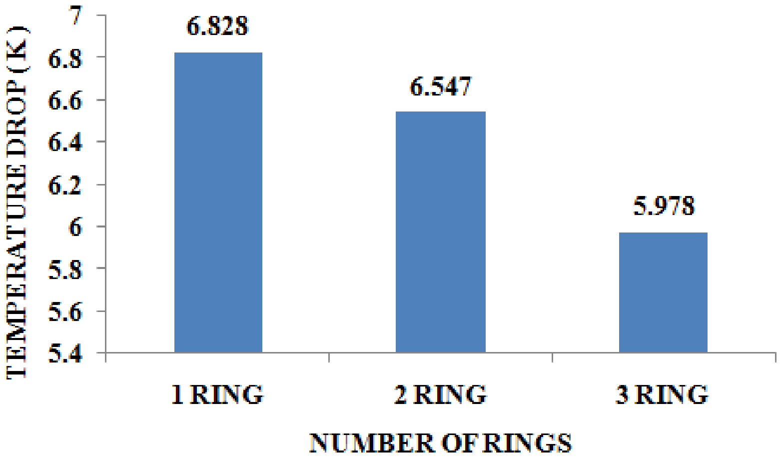

Figure 7 Temperature drop with varying cross-sectional area (192.607 mm^2)

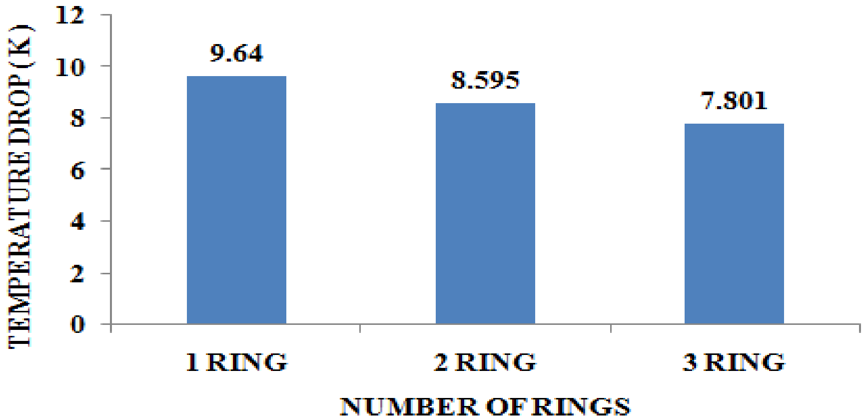

Figure 8 Temperature drop with varying cross-sectional area (289.227mm^2)

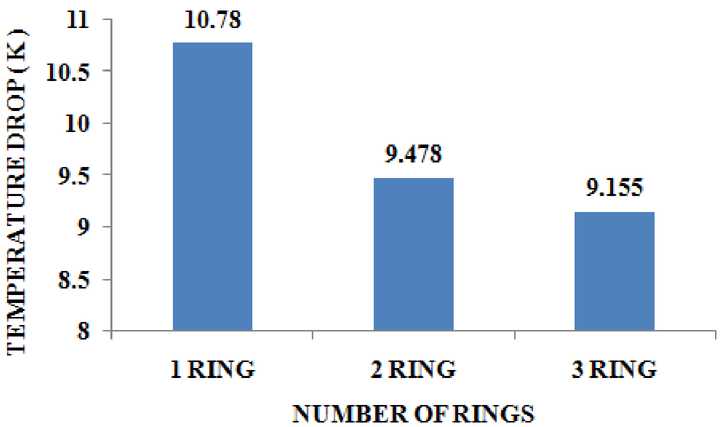

Figure 9 Temperature drop with varying cross-sectional area (385.682 mm^2)

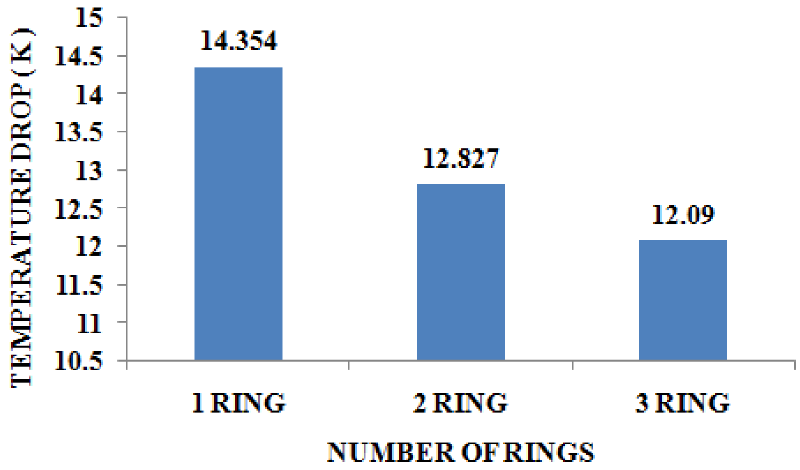

Figure 10 Temperature drop with varying volume flow rate of 1.1 lit/min

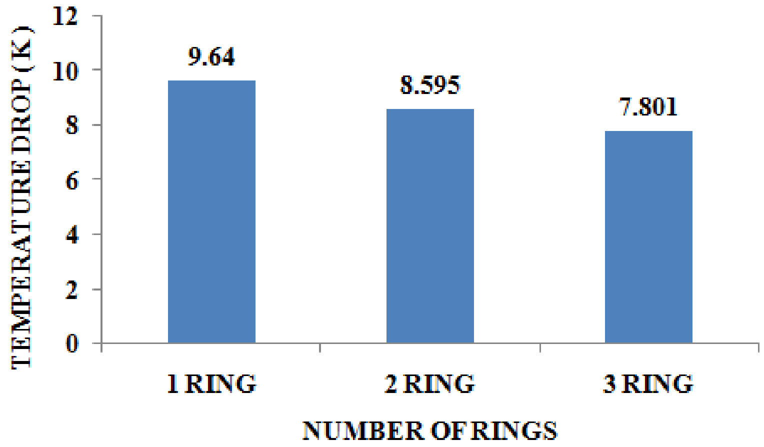

Figure 11 Temperature drop with varying volume flow rate of 2.2 lit/min

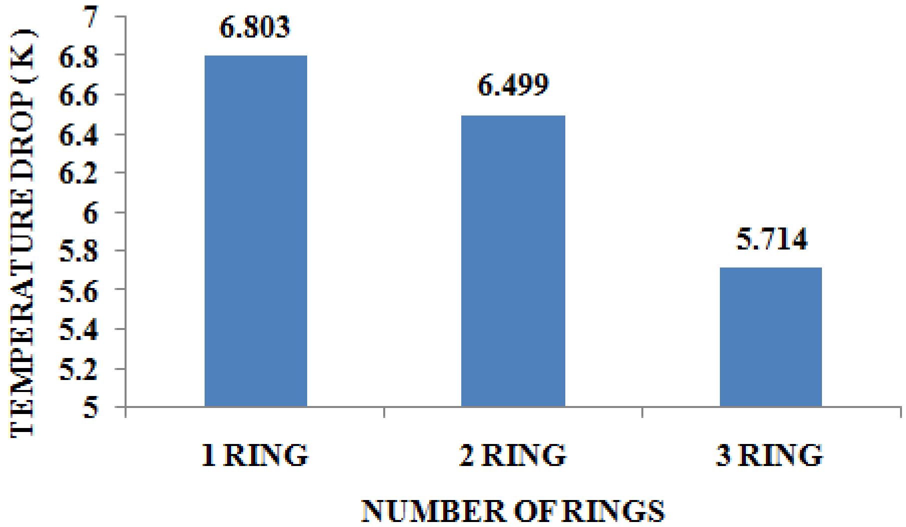

Figure 12 Temperature drop with varying volume flow rate of 3.3 lit/min

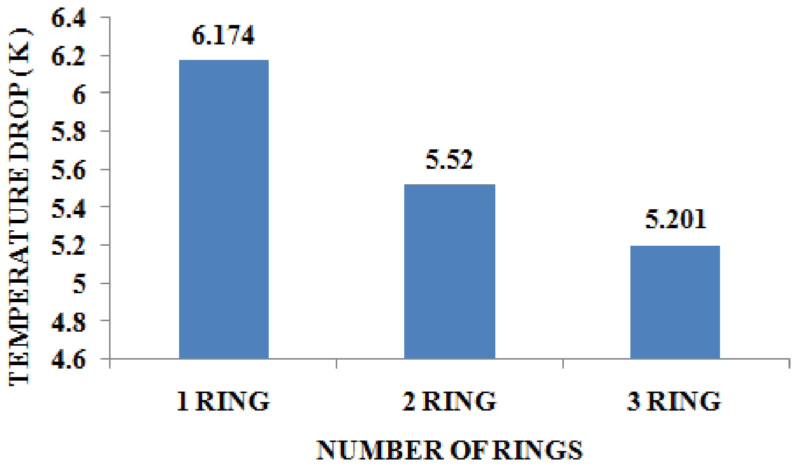

Figure 13 Effect of constant wall heat flux (4000 W/m^2 k) on temperature drop

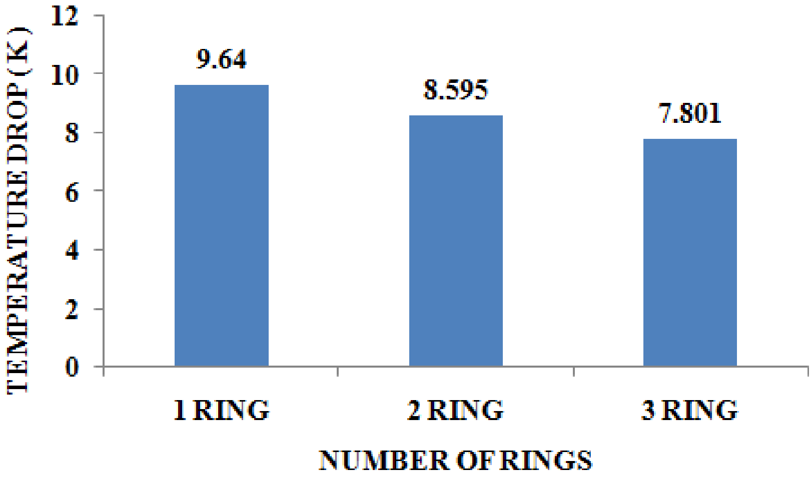

Figure 14 Effect of constant wall heat flux (6000 W/m^2 k) on temperature drop

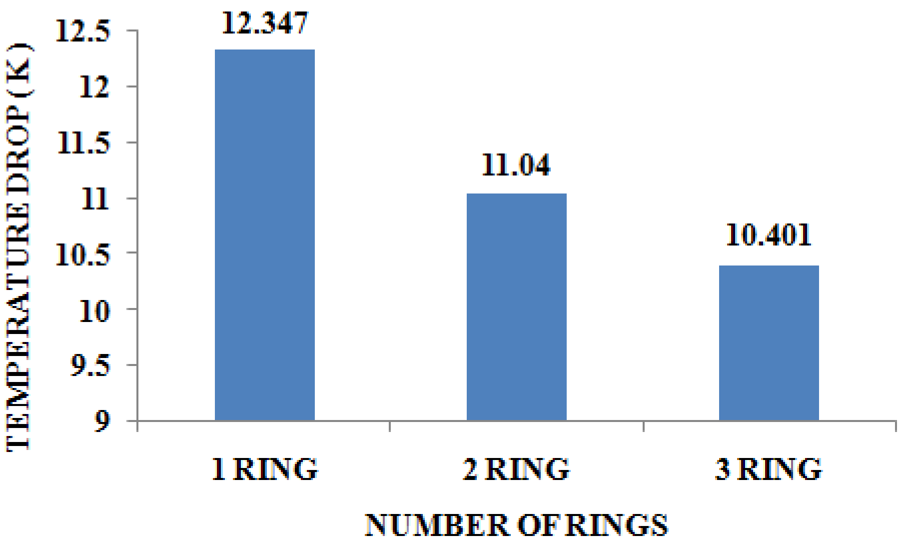

Figure 15 Effect of constant wall heat flux (8000 W/m^2 k) on temperature drop

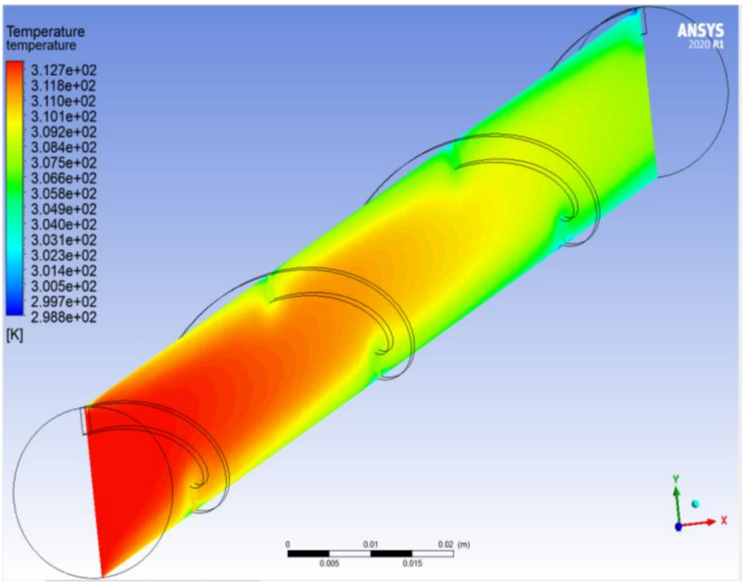

Figure 16 Contour profile of temperature on transverse plane

8.2 PRESSURE DROP VARIATIONS

1. **Variation across the cross-sectional area.**
2. **Variation across the varying volume flow rate.**
3. **Variations with the constant wall heat fluxes.**

Figures 17 to 19 show the pressure drop with a variable cross-sectional area of 192,607, 289,227 and 385,682 mm2, respectively. Figures 20 to 22 show pressure drop with variable volume flow rate as 1.1, 2.2 and 3.3 lit/min respectively. Figure 23 shows the pressure contour profile in the transverse plane.

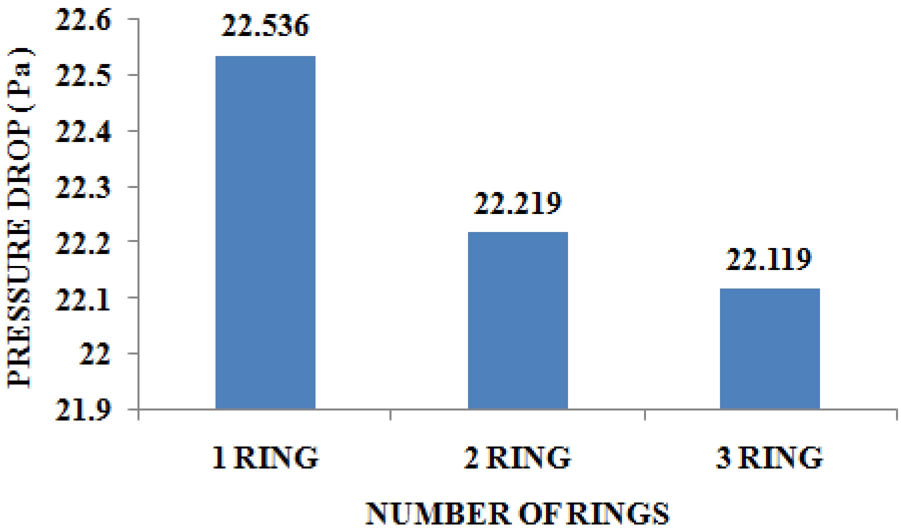

Figure 17 Pressure drop with varying cross-sectional area of 192.607 mm^2

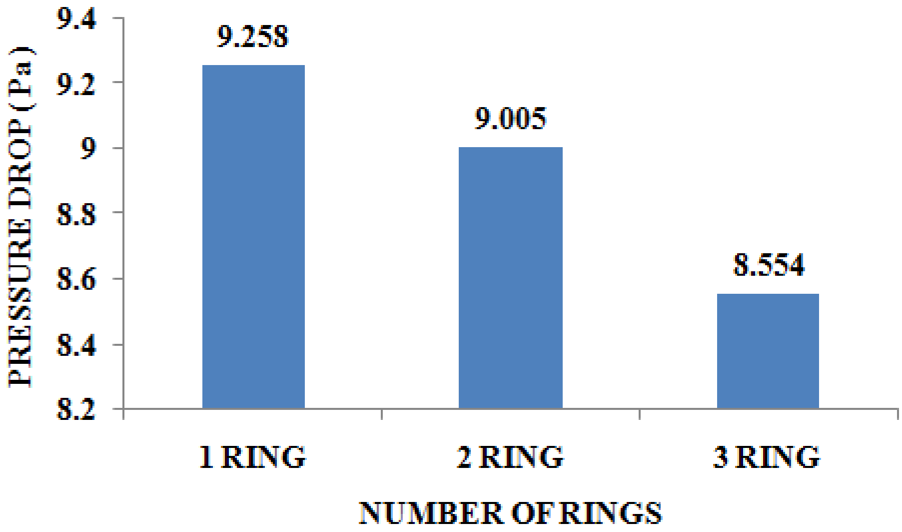

Figure 18 Pressure drop with varying cross-sectional area of 289.227 mm^2

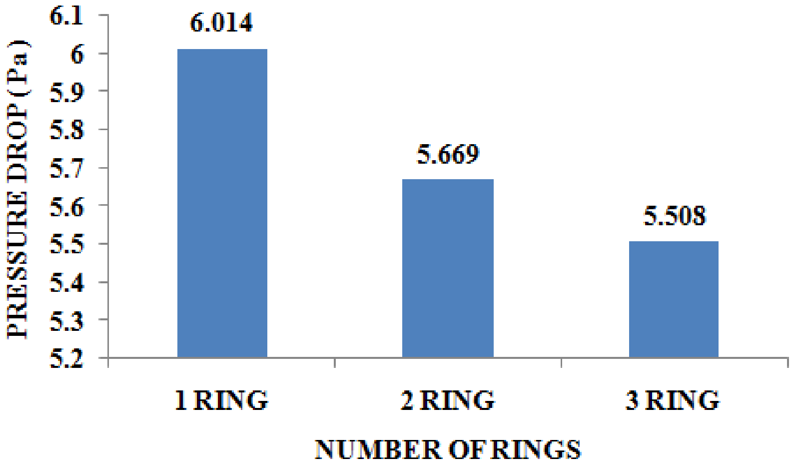

Figure 19 Pressure drop with varying cross-sectional area of 385.682 mm^2

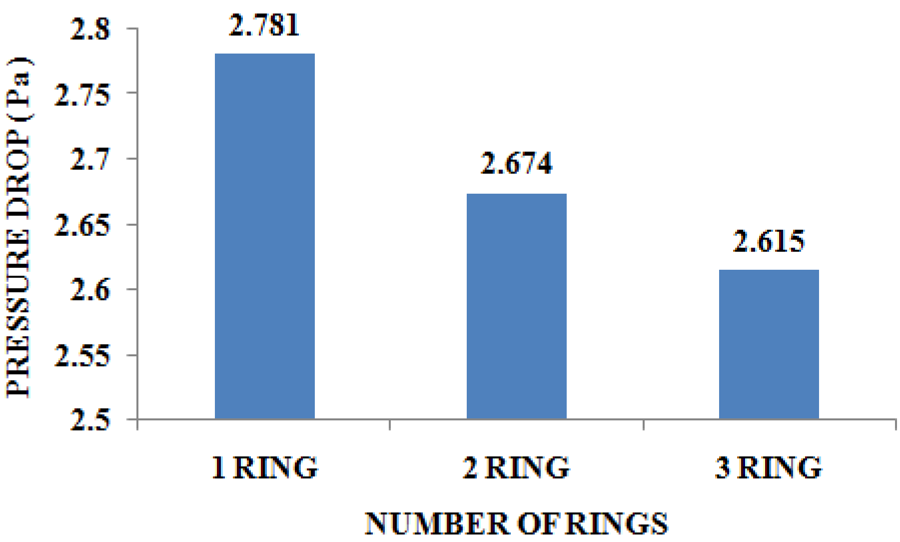

Figure 20 Pressure drop with varying volume flow rate (1.1 lit/min)

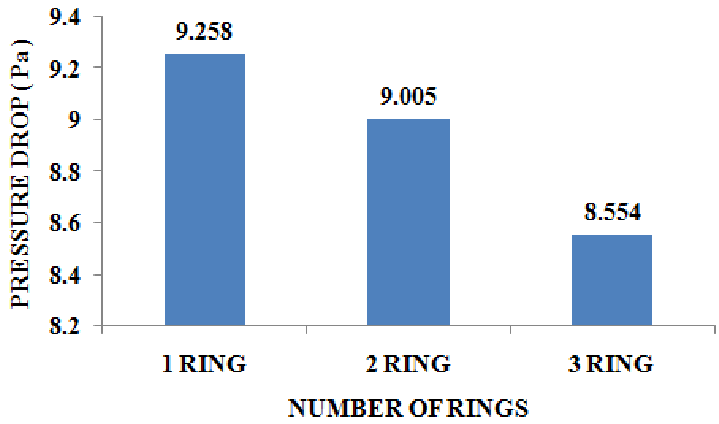

Figure 21 Pressure drop with varying volume flow rate (2.2 lit/min)

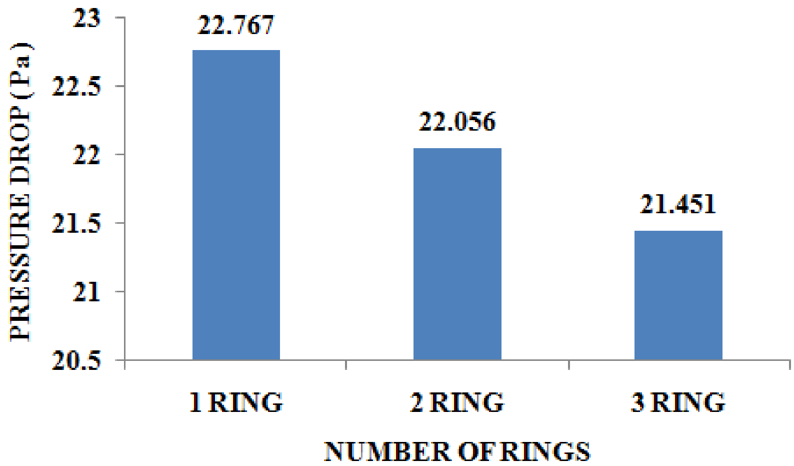

Figure 22 Pressure drop with varying volume flow rate (3.3 lit/min)

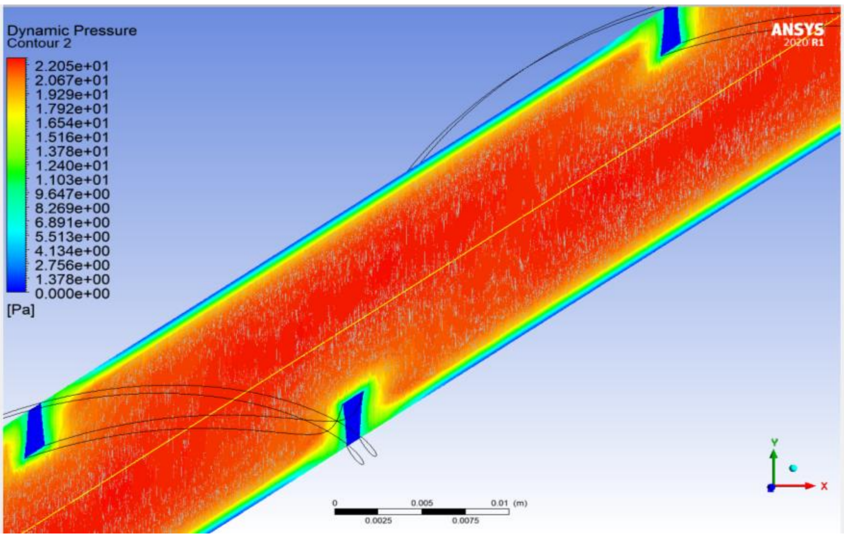

Figure 23 Contour profile of pressure on transverse plane

9 CONCLUSIONS

Heat exchangers are used in heating and cooling processes in various industries. The performance of a heat exchanger depends in part on the flow and heat transfer properties of the fluids within the heat exchanger. Its purpose is to study flow characteristics such as temperature drop and pressure drop on the inner surface of the heat pipe using ANSYS software.From the above results, we came across the following conclusions which are as mentioned below:

Effect of Temperature drop

1. For varying cross-sectional area, better temperature drop is observed i.e. 18.51% in 1 ring and 7.74% in 2 rings as compared to 3 rings.
2. For varying volume flow rate, better temperature drop is observed i.e. 20.27% in 1 ring and 10.01% in 2 rings as compared to 3 rings.
3. For varying constant wall heat flux, better temperature drop is observed i.e. 20.33% in 1 ring and 7.48% in 2 rings as compared to 3 rings.

Effect of pressure drop

1. For varying cross-sectional area, better pressure drop is observed i.e. 6.43% in 1 ring and 2.88% in 2 rings as compared to 3 rings.
2. For varying volume flow rate, better pressure drop is observed i.e. 6.91% in 1 ring and 3.45% in 2 rings as compared to 3 rings.
3. There is no effect of constant wall heat flux on pressure drop for any configuration.

From the above results, we concluded that one helical ring on the inner surface shows better heat transfer than two and three helical rings on the inner surface of the heat pipe.

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