HEAT TRANSFER ENHANCEMENT OF HEAT PIPE EXCHANGER BY INCORPORATING PERFORATED CONICAL NOZZLE RINGS

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ABSTRACT
Numerical analysis of the air flow characteristics has been experimentally studied and conducted by equipping a simple plain heat pipe with perforated conical rings (PCR’s) under constant wall temperature conditions. The air is taken as working fluid and the pitch ratio of the conical rings is assumed to be 4. Dimensionless quantities like Reynolds number and Nusselt number are used in calculations to study the flow of the fluid and the rate of heat transfer coefficient. The work is aimed at enhancing heat transfer rate of the heat pipe exchanger for which experimental investigation is carried out which are further supported by CFD simulations. The results showed increased heat enhancement where the losses in kinetic energy for a flow through heat pipe are compensated by equally spaced conical rings. In addition, the perforations over the nozzle rings enhanced heat transfer rate by creating turbulence thus enabling flow to form vortices that increases heat pipe effectiveness to some more extent. These tubes with conical nozzle inserts are suitable for industrial cooling and heating equipment’s where increase in heat pipe effectiveness improves the overall efficiency of the power plant.

KEYWORDS: Heat pipe exchanger, Perforated conical rings (PCR’s), CFD analysis & Conical nozzle inserts

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NOMENCLATURE

- \( h \): Convective heat transfer coefficient W/m²K
- \( Q \): Convection Heat Transfer (W)
- \( q \): Heat transfer rate
- \( Nu \): Nusselt Number
- \( Re \): Reynolds Number
- \( T \): Temperature
- \( T_m \): Mean Surface Temperature
- \( Gr \): Grashof Number
- \( T_{am} \): Ambient Temperature
- \( T_m \): Mean Temperature
- \( \mu \): Dynamic Viscosity
- \( \nu \): Kinematic Viscosity
- \( k \): Thermal Conductivity
- \( D \): Diameter of Pipe

INTRODUCTION
Heat exchangers in industries have got greater importance due to the need for continuous circulation of cooling or heating fluids which effects the overall plant efficiency if not properly maintained. Many researchers are carrying
out experimental investigations on how to enhance the heat transfer rate without creating complications in the plant design especially in chemical processing plants, transportation power systems, steam power plants, etc. A number of investigations have been carried out by incorporating various types of inserts in heat pipes which showed significant improvement in heat transfer rate. Conical rings are one of such type which can be used as inserts for increasing the flow velocity thus compensating kinetic energy losses obtained in heat pipes due to molecular friction. They are also used to increase thermal performance to a considerable extent.

Considerable heat enhancement is observed by employing compound perforated conical nozzle rings [1] and perforated vortex generators (PVG’s) were later developed in order to improve heat transfer rate by creating vortices [2]. Experimental investigation is done to study heat transfer characteristics in a uniform heat flux tube incorporated with conical rings where they are employed as reverse flow generators through which air is allowed to pass on [3]. Another similar investigation is carried out where friction factor and efficiency parameters are studied by fitting conical ring tubulators and also a twisted tape type swirl generator [4]. Using a passive method, a study of convective heat transfer coefficient is done over a uniform heat flux tube over which a number of conical rings are mounted over the test tube[5]. Entropy generation evaluation for fluid through a wavy channel is investigated where simulation is carried out by finite volume technique. All governing equations which involves the role of continuity, momentum and energy equations are solved in this work [6]. Eccentrical helical type screw tapes are tried in the next attempt where a significant rise in thermal and frictional entropy generations are observed with increase in eccentricity [7]. A heat pipe at the entrance of which if grooved surfaces are fitted, then the local heat transfer changes are studied and noted [8]. A numerical study is done where performance evaluation is done by studying the effects due to changes in eccentricity between centers of helical shaped screw tapes [9]. Then the work is extended for nanofluids where Cu-water fluid is tested by incorporating cross-cut twisted tapes alternate axis (CCTA) [10]. Various experimentations have been done to produce a swirl motion inside the heat pipe exchanger to increase their effectiveness to advanced standards.

EXPERIMENTATION

A thermal evaluation of heat exchanger tubes to find the Reynolds number and rate of heat transfer and overall heat transfer coefficient by equipping it with perforated conical rings (nozzles) is carried out.

The test Session is placement of conical rings (nozzles) which are placed inside a heat exchanger tube and an air is passed through them. The voltage is supplied and heat is applied to the air using heater. Thermocouples are placed at different positions to make a note of readings. This experimental setup is designed to check the increase in the rate of heat transfer and Reynolds number and a comparison is done with those of theoretically obtained results.

![Figure 1: Schematic Representation of Heat Pipe Equipped with Perforated Conical Rings(PCR’s)](image-url)
The fig. 1 shows the Schematic diagram of heat exchanger tube equipped with perforated conical rings. As the hot air enters the perforated rings the pressure of the air is decreased and velocity is increased. Due to the perforated holes present on the nozzle (fig. 2) the fluid becomes turbulent and the Reynolds number obtained will be very high which results in the increase of heat transfer coefficient.

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of copper tube</td>
<td>500mm</td>
</tr>
<tr>
<td>Thickness of copper tube</td>
<td>6mm</td>
</tr>
<tr>
<td>Internal diameter of copper tube</td>
<td>42mm</td>
</tr>
<tr>
<td>External diameter of copper tube</td>
<td>44mm</td>
</tr>
<tr>
<td>No. of nozzles</td>
<td>4</td>
</tr>
<tr>
<td>Thickness of nozzle</td>
<td>3mm</td>
</tr>
<tr>
<td>Type of thermocouples</td>
<td>K-type</td>
</tr>
<tr>
<td>Blower capacity</td>
<td>1.5 m³/min</td>
</tr>
</tbody>
</table>

Fig. 3 shows the experimental setup made to carry out the experimentation by inserting conical nozzle rings. The specifications of the setup made are given in Table 1. Initially when the equipment is in off condition, a nozzle is inserted in the copper tube and the heater is connected to it and the whole set up is connected to the blower. The setup is made ready and the mains are turned on. Heater is turned on and the power input is set to 65 W. The equipment is left until it reaches the steady state and blower is turned on. The temperature readings are noted carefully and the mains are turned off. The second nozzle is inserted in the copper tube and the above procedure is repeated again until the 4 nozzles are inserted.
Then the required calculations are done and thermal analysis is performed in the simulation tool.

**THEORY/BACKGROUND**

When a heat exchanger tube is equipped with conical perforated nozzles generally turbulence is created and velocity of the fluid also increases which results in the increase of the rate of heat transfer coefficient.

The heat transfer coefficient is given by:

\[ h = \frac{q}{A_s(T_s - T_a)} \]

Where,

\[ T_s = \frac{T_1 + T_2 + T_3 + T_4}{A_s(T_s - T_a)} \]

The dependence of ‘h’ on all the above-mentioned parameters is generally expressed in terms of non-dimensional groups, as follows:

\[ Re = \frac{\text{inertial forces/viscous forces.}}{\text{Reynolds Number}} \]

\[ Re = \frac{\rho V D}{\mu} \]

\[ \text{Density of fluid} \]

\[ \text{Velocity of fluid} \]

\[ \text{Diameter of pipe} \]

\[ \text{Dynamic Viscosity of fluid} \]

**RESULTS AND DISCUSSIONS**

A CFD analysis is carried out for heat pipe exchanger equipped with perforated conical rings (PCR’s). Initially simulation is carried out for single PCR to study the gain in kinetic energy and thermal performance. Again the experiment is repeated for multiple nozzles by adding each extra ring everytime. The velocity contours clearly representing the rise in kinetic energies are clearly shown in the figs 4-7.

![Velocity Contours for Heat Pipe with 1 PCR](image-url)
Heat Transfer Enhancement Of Heat Pipe Exchanger By Incorporating Perforated Conical Nozzle Rings

Figure 5: Velocity Contours for Heat Pipe with 2 PCR’s

Figure 6: Velocity Contours for Heat Pipe with 3 PCR’s

Figure 7: Velocity Contours for Heat Pipe with 4 PCR’s
The figs 4-7 clearly indicate that there is a significant gain in kinetic energy as the flow is progressing through each individual nozzle. The kinetic energy drop when no conical rings are incorporated is compensated by adding these inserts thus improving Reynolds no and enhancing thermal performance to a considerable extent.

![Figure 8: Variation of Temperature across the Heat Pipe with PCR’s](image)

Fig 8 shows the variation of temperature along the length of the heat pipe where the heat pipe is observed to generate higher heat rate with increase in number of conical nozzle rings. This is a clear indication that adding equally spaced rings can enhance the thermal performance of the heat pipe to a considerable extent. The maximum temperature obtained is 80°C for four nozzles whereas it is 70°C for pipe with single nozzle. At every location of 10 cm apart, the region is found to generate higher amounts of heat for increased number of equally spaced conical rings. However, as we navigate away from the heater, the curves converge accounting smaller heat rate difference.

![Figure 9: Variation of Nusselt No. with Reynolds No. for Heat Pipe](image)
Fig 9 shows the improvement in Nusselt number with increasing Reynolds number. When the fluid is passing through the nozzle it’s pressure decreases and velocity increases. A turbulence will also be generated due to the perforation of the nozzle and therefore results in the increase of Reynolds number. The values of Reynolds number and Nusselt number varies due to the number of nozzles equipped in the tube. The Reynolds number and Nusselt number obtained for 1st nozzle is 16837 and 43.1 respectively and for the 4th nozzle is 16975 and 43.75 respectively which is very high compared to the other nozzles. These values are obtained by substituting the observation values obtained in the formulas carefully. The increase in both of these dimensionless numbers is a significance of rise in thermal performance of the equipment.

This graph clearly shows the advantage of equipping the heat exchanger tube with more number of nozzles.

Figure 10: Variation of Heat ($Q_{conv}$) with No. of PCR’s
Fig. 10 shows the variation of convective heat transfer rate with increasing number of perforated nozzles. A significant rise can be observed through the plot due to increase in no of conical inserts. The value obtained is found to be 58.23J for 4 nozzles whereas it is as low as 45.28J for heat pipe incorporated with single conical insert. Fig. 11 is a graphical representation of theoretical and experimental heat transfer coefficients. The plot clearly shows that the $h_{\text{exp}}$ value of first PCR is 62.1 W/m²K and $h_{\text{th}}$ is 18.09 W/m²K. The $h_{\text{exp}}$ of fourth PCR is 64.6 W/m²K and 19.01 W/m²K which is high compared to the other PCR’s.

Fig. 12: Variation of Velocity with Increasing PCR’s

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Fig. 12 shows the variation of velocities by increasing the number of PCR’s where velocity at each PCR are shown here. The velocity is increasing by the time the air is reaching towards end due to PCR inserts which are positioned at equal interval distance. The maximum velocity is found to 32 m/s at the exit of fourth PCR whereas it is as low as 24 m/s at the exit of first PCR.

CONCLUSIONS

A detailed investigation of effect of incorporating PCR’s inside heat pipe exchanger is carried out where a number of positive conclusions are drawn. It was observed that the loss in kinetic energy of the fluid due to internal molecular friction and with that of inner surface of the pipe can be easily overcome by fitting PCR’s at equally spaced positions. The addition of perforations over the conical PCR’s also accounted for increase in turbulence factor which accounted for improvement of overall thermal performance of the heat pipe. The convective heat transfer rate (Q) is found to rise drastically which is a good sign. In addition, increased velocities at the PCR exit and good agreement of results so obtained theoretically and experimentally have strengthened the output to an extent. The overall thermal performance deciding factor is represented by Nusselt number (Nu) which also showed a drastic rise and also leading the case with high number of PCR’s thus concluding the work with a solid evidence. The work can further be extended to nano fluids or supercritical fluids which can show a significant improvement in result.

REFERENCES


