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Forced Convective Heat Transfer Enhancement by Using Conical Ring Inserts- A Review

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Abstract: In the recent years, heat transfer augmentation techniques plays an important role for improving the rate of heat transfer without affecting the overall performance of the system. Enhanced heat transfer surfaces are mostly used in heat exchanger, air conditioner, refrigeration system, chemical reactor. The high cost of energy and material has resulted in an increased effort aimed at producing more efficient heat exchange equipment. Augmentation techniques increase forced convective heat transfer by reducing the thermal resistance in a heat exchanger. These techniques are broadly classified as passive, active and compound techniques. Passive techniques, where inserts are used in the flow path to intensify the heat transfer, are advantageous when compared with active techniques, because the insert manufacturing process is simple and these techniques can be easily employed in an existing heat exchanger. In this paper, emphasis is given to work dealing with round pipe conical ring inserts. Conical ring inserts are generally more efficient in the turbulent flow compared to the laminar flow.

Keywords: Augmentation techniques, forced convective heat transfer, conical ring insert, heat transfer coefficient.

I. INTRODUCTION

Heat exchanger is equipment built for efficient heat transfer from one medium to another. They facilitate the exchange of heat between two fluids that are at different temperatures while keeping them from mixing with each other. In recent years, the high cost of energy and material results in an increased effort for producing more efficient heat exchange equipment. Therefore, heat transfer enhancement techniques comes into play for enhance heat transfer and improve the thermal performance of heat exchanger system. These augmentation techniques increases convective heat transfer by reducing the thermal resistance in a heat exchanger. The difficulties in manufacturing finned surfaces, constant director fins and increasing heat exchanger dimensions and the difficulties in their maintenance.

Now a days, more consideration is given to attachable turbulators to use in heat transfer enhancement. Several methods are applied to improve the thermal performance of heat transfer devices such as treated surfaces, rough surfaces as well as incorporations of inserts (such as turbulators and swirl flow devices). Among the passive techniques, insertion of conical turbulators is one of the most promising techniques. By inserting the conical turbulators (or strips, fins, and any corrugation) in any direction creates a turbulent flow, which enhances the heat transfer coefficient. Whenever inserts technologies are used for the heat transfer enhancement, along with the improvement in the heat transfer rate, the pressure drop also increases, which induces the higher pumping cost.

Therefore any augmentation device or methods utilized into the heat exchanger should be optimized between the benefits of heat transfer coefficient and the higher pumping cost owing to the increased frictional losses.

In general, heat transfer enhancement techniques are broadly classified into three categories:

1. Passive techniques.
2. Active techniques.
3. Compound techniques.

A. Passive Techniques:
These techniques does not require any direct input of external power. They use power itself form the system which ultimately increases in fluid pressure drop. Passive techniques are incorporating inserts or additional devices in the flow channel with the help of surface or geometrical modification. These inserts promotes higher heat transfer coefficient by altering or disturbing the flow behavior.

a. Treated surface: In this techniques heat transfer area consist of pits, cavities or scratches like alteration in the surface which may be continuous or discontinuous. Primarily used for boiling and condensing duties.
b. Rough surface: This type of surface modification creates the turbulence in the viscous sub-layer region. These techniques are applicable primarily in single phase turbulent flows, without increase in heat transfer area.
c. Extended surface: conventional fin (plane fin) are the types of extended surfaces used extensively in many heat exchanger. The recent modified fin surfaces which improves the heat transfer coefficient by disturbing the flow field in addition to the increase in surface area.
d. Displaced enhancement device: These are the insert techniques which improves the heat transfer coefficient. Inserts refers to the additional arrangements made as on obstacle to fluid flow so as to augment heat transfer. These techniques primarily used in forced convection duties.

Inserts: Inserts are used to create the swirl or turbulence in the flow passage. Hence, the type and number of insert are critical factors in governing the heat transfer characteristics and pressure loss of the flow passage. Insert is located at the entrance of the flow passage where the swirl flow or redevelopment of boundary layer occur and subsequently after passing the insert, the flow is freely developed.

e. Swirl flow devices: They produce swirl flow or secondary circulation in the axial flow channel. Helical tape and various forms of altered (tangential to axial direction) are common examples of swirl flow devices. They can be used for both single and two phase flow.

f. Coiled tubes: In this devices secondary flows or vortices are generated due to the shape of conical coiled tubes. Which promotes higher heat transfer coefficient in single phase flows and in most regions of boiling. This leads to relatively more compact Hear Exchanger.

g. Surface tension devices: These devices are most used for heat exchanger occurring phase transformation. These consist of wicking or grooved surfaces, which directly improve the boiling and condensing surface.

h. Additives for liquid: These include the addition of solid particles, soluble trace additives and gas bubbles into single phase flows. This addition to the liquid reduces the drag resistance of flow. In case of boiling systems, trace additives are added to reduce the surface tension of the liquids.

B. Active techniques:

These techniques are more complex from the use and design point of view. As the method requires some external power input to cause the desired flow modification and improvement in the rate of heat transfer. This techniques have limited application due to need of external power input. Various active techniques are as follows:

a. Mechanical aids: These devices stir the fluid by mechanical means or by rotating the surface. These include rotating tube heat exchangers and scrapped surface heat and mass exchangers.

b. Surface vibration: A low or high frequency is applied to facilitate the surface vibrations which results in higher convective heat transfer coefficients. They have been used primarily in single phase flows.

c. Fluid vibration: These are primarily used in single phase flows. Instead of applying vibrations to the surface, pulsations are created in the fluid itself.

d. Electrostatic field: Electrostatic field like electric or magnetic fields or a combination of the two from DC or AC sources is applied in heat exchanger systems, which can be applied in heat exchange systems involving dielectric fluids. To enhance heat transfer it can produce greater bulk mixing and induce forced convection or electromagnetic pumping.

e. Injection: Such techniques are primarily used for single phase heat transfer process. In this technique, same or other fluid is injected into the main bulk fluid through a porous heat transfer interface or upstream of the heat transfer section.

f. Suction: This technique is applicable for both two phase and single phase heat transfer processes. Two phase nucleate boiling involves the vapour removal through a porous heated surface whereas, in single phase flows fluid is withdrawn through the porous heated surface.

g. Jet impingement: This technique is used for both two phase heat transfer and single phase heat transfer process. In this method, fluid is heated or cooled perpendicularly or obliquely to the heat transfer surface.

C. Compound techniques:

A compound augmentation technique is the one where more than one of the above mentioned techniques is used in combination with the purpose of further improving the thermo-hydraulic performance of a heat exchanger. This technique involves complex design and hence has limited applications.

II. LITERATURE REVIEW

Durmus A. [1] studied the effects of disordering the flow area of air by placing conical type turbulators of different dimensions on the improvements in heat transfer with a passive method in classical coaxial heat exchanger. In this study the air was passed through the exchanger tube, the outer surface of which was heated with saturated water vapor. Eight turbulators were placed in the inner pipe at 50 mm equal distances. The conical angles of the four different types of turbulators were 50, 100, 150 and 200. The edges of the conical turbulators were cut in equal size in a way of one full and one empty to obtain four brushes in the tips of the turbulators. The analysis were conducted for air flow rates in the range of $15,000 < Re < 60,000$. Heat transfer, pressure loss and exergy analysis were made for the conditions with and without turbulators and compared to each other. The heat transfer rates increase with turbulator angles too, as well as friction coefficients and also exergy loss decreases with increasing conical angle. The pressure drop in the tube also increases with the heat transfer rates and conical angles. For this reason, the conical angle may need to be limited. However, it was found from the experimental results that the upper limit should be less than 20^{O}.

Promvonge P.[2] reported an experimental investigation of the heat transfer and friction factor characteristics of flow of air through horizontal pipe with and without conical turbulators. He used the conical ring with the three different ratios of the ring to tube diameter ($d/D = 0.5, 0.6, 0.7$) are introduced in the tests, and for each ratio, the rings are placed with three different arrangements such as converging conical ring, referred to as CR array, diverging conical ring, DR array and converging–diverging conical ring, CDR array. The boundary layer disruption causes a better chaotic mixing between the core and wall region fluid, thus enhancing the convective process. However, DR array provides higher heat transfer then other array. DR yield higher pressure loss at small Reynolds no. Conical ring turbulator are not feasible in terms of energy saving at higher Reynolds no. The heat transfer enhancement efficiency increases with decreasing the Reynolds number and ratios of diameter for the test.

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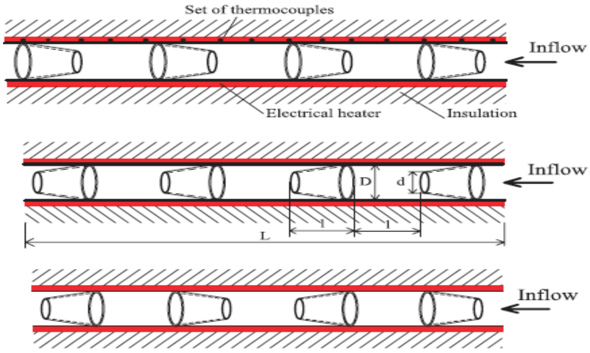

Figure 1. CR, DR, CDR arrangement

Chou Xie Tan. et al. [3] This paper deals with square-cut circular ring insert in tube to promote turbulence and enhance convective heat transfer. The role of insert has been quantified by deriving a new non-dimensional group (characterize the effect of heat transfer enhancement). Significant heat transfer augmentation is observed at low Reynolds number. However, the heat transfer augmentation decreases with increasing Reynolds number, indicating that the role of the insert becomes less significant when Reynolds number is increased. The physical significance of the non-dimensional number which provides a measure of the change of enthalpy relative to the change of flow energy in the flow direction can be used to explain the decrease of heat transfer augmentation in the turbulent flow regime relative to the transitional flow regime. Based on the analysis of the non-dimensional group, it can be deduced that the contribution of the axial pressure drop in the heat transfer augmentation is marginal albeit not negligible compared to the temperature rise in the characterization of the heat transfer augmentation with the incorporation of insert.

Eiamsa-ard, et. al. [4] proposed combined effect of conical-ring turbulators together with a twisted-tape containing in a uniform heat flux tube on heat transfer, flow friction, and enhancement efficiency characteristics using air as the tested fluid. The enhancement efficiency tends to decrease with the rise of Reynolds number and to be nearly uniform for Reynolds number over 16,000. The Nusselt number increases with increasing Reynolds number and reduction of twist ratio. A close examination reveals that the heat transfer rate from using both conical-ring and twisted-tape is higher than that from using conical-ring alone. The average heat transfer rates from using both the conical-ring and twisted-tape for Y=3.75, and 7.5, respectively, are found to be 367% and 350% over the plain tube. However, the friction factor from using both devices also increases considerably.

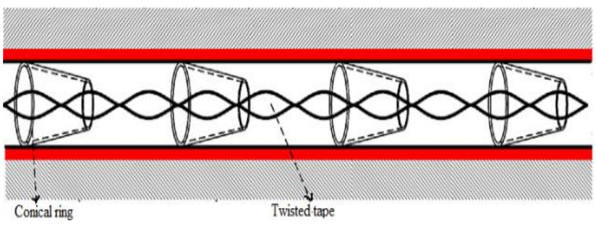

Figure 2. Conical ring with twisted tape inserts.

V. Kongkaitpaiboon et. al. [5] The influences of the Perforated conical rings on the turbulent convective heat transfer (Nu), friction factor (f) and thermal performance factor (η) characteristics have been investigated experimentally. The perforated conical-rings (PCRs) used are of three different pitch ratios (PR=p/D=4, 6 and 12) and three different numbers of perforated holes (N=4, 6 and 8 holes). At the similar test conditions, the PCRs offers lower heat transfer enhancement than the CRs. However, they generate friction factor only around 25% of that produced by the PCRs. Consequently, the thermal performance factor of all PCRs arrangements is higher than those of the CRs over the range studied. The heat transfer rate and friction factor of PCRs increase with decreasing pitch ratio (PR) and decreasing number of perforated hole (N). However, the thermal performance factor increases with increasing number of perforated hole and decreasing pitch ratio.

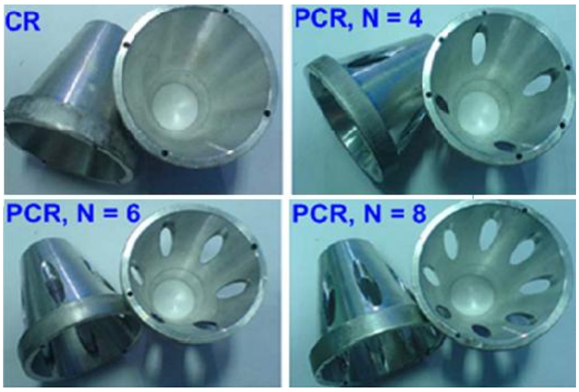

Figure 3. Perforated conical ring inserts.

Gupta R. and Bissa B. [6] This paper deals with experimentation with conical spring in pipe. Converging array, diverging array and converging-diverging array this three arrangement are used. In this study water was used as a working fluid. It is found that the maximum heat transfer is obtained for the smallest pitch arrangement and Nusselt Number increases with the increasing Reynolds Number. The enhancement in the Friction Factor is far greater than the Nusselt Number enhancement. Despite very high friction, the turbulators can be applied effectively in places where pumping power is not significantly taken into account but the compact size including ease of manufacture installation is required.


Figure 4. Conical spring insert.

Anvari A.R. et al. [7] in this paper the experimental investigations was carried out in order to find the role of the conical rings for the heat transfer enhancement and pressure drop change in a pipe with constant heat flux boundary condition. In this work, water used as working fluid. They derived two correlations for the Nusselt number based on the experiment are introduced for practical use. It is found that the insertion of turbulators has significant effect on the enhancement of heat transfer, especially the DR arrangement, and also they increase the pressure drop. So turbulators can be used in places where the compact size is more significant than pumping power.

Shivalingaswamy B.P et. al. [8] Heat transfer enhancement in a tube fitted with circular-ring turbulator (CRT) is reported in this thesis simulated using ANSYS Fluent CFD software. Insertion of turbulators in the flow passage is one of the favorable passive heat transfer augmentation techniques due to their advantages of easy fabrication, operation as well as low maintenance. Influence of the diameter ratio (DR) and pitch ratio (PR) on the heat transfer rate, friction factor and thermal performance factor behaviors was investigated under uniform wall heat flux condition. The CRTs with different diameter ratios (DR=d/D=0.5, 0.6 and 0.7) and pitch ratios (4 and 8) were employed for the Reynolds number ranged between 4000 and 20,000. Over the entire range investigated CRTs propose heat transfer enhancement around 57% to 195% compared to that in the plain tube.

CONCLUSION

From this review, various ways of enhancing heat transfer rate by conical ring inserts is observed. Divergent array has higher rate of heat transfer and pressure drop in comparison with convergent array and convergent-divergent array. Nusselt number and friction factor are dependent on the Reynolds number. Also as the Reynolds number and diameter ratio decreases the enhancement efficiency increases. The enhancement in the friction factor is far greater than the Nusselt number enhancement.

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