Advances in Passive Heat Transfer Augmentation-A review

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Abstract— Heat transfer augmentation methods can increase the heat transfer rate. They are widely used in process industries, power plants, air conditioning equipments automobiles etc. Many efforts have been done to improve the performance of the thermal equipment such as heat exchanger etc. There are basically two techniques, active and passive techniques for improving the heat transfer rate. Inserting baffles on heat transfer surface is widely employed to enhance heat transfer inside the thermal equipment which is a passive technique. This paper discusses the various types of passive heat transfer enhancement techniques and various characteristics of heat transfer.

Key words: Baffles, Heat Transfer Enhancement, Laminar Flow, Turbulent Flow

I. INTRODUCTION

Nowadays more stress has been given on developing the new techniques which can increase the heat transfer rate. In present scenario more emphasis is given to the energy, material and space saving options in heat transfer. Many efforts have been done to advance the performance of heat exchanger. Sometimes there is need for miniaturization of heat exchanger for some application like space applications. It is also observed that as heat exchanger becomes older heat transfer decreases because of fouling and scaling. These problems are common when heat exchangers are used for marine application. Such problems can be solved by incorporating the turbulence in the flow of fluid which augments heat-transfer rate. Several techniques have been developed in recent years.

A. *Heat Transfer Enhancement Methods*

1) *Active Techniques:*

In active techniques external power is provided to get the desired flow and to enhance heat-transfer rate for examples induced pulsation by cam and reciprocating plungers etc. These techniques are more complex and find limited applications.

2) *Passive Techniques:*

In passive techniques there is no need to give input external power. They use from the system itself like by making the surface rough, by using insert and by using fins. In order to improve heat transfer rate in this technique surface area is increased. In passive method swirl is generated in the bulk of fluid which disturbs the boundary layer which results in increase the surface area, resident time, turbulence and hence increase the heat transfer.

Methods generally used in passive heat transfer augmentation are inserts, extended surfaces, modification in the surfaces adding the additives.

3) *Compound Techniques:*

It is the combination active and passive methods.

B. *Inserts:*

Inserts are the arrangements which are designed in order to disturb the fluid flow. Inserts act as an obstacle in the fluid flow. Insert can be twisted tapes, wire coils, helical coils, baffles, ribs and plates etc. In this paper review of heat transfer augmentation using insert is discussed.

II. LITERATURE REVIEW

M. Siddique et al. [1] reviewed various types of enhancers like fins and microfins, porous media, large particles suspensions, nanofluids, phase-change devices, flexible seals, flexible complex seals, vortex generators, protrusions, and ultra high thermal conductivity composite materials. This paper describes most of passive heat transfer enhancement methods.

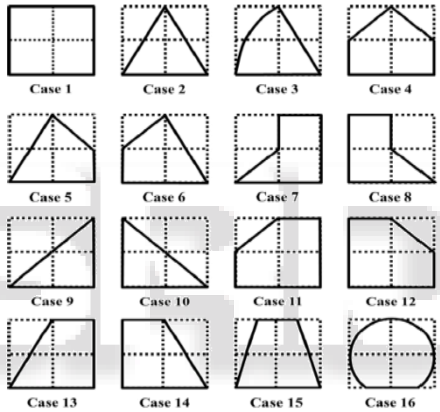

Fig. 1: Various cross-sectional rib shapes [2]

Mi-Ae Moon et al. [2] performed numerical simulations on rib roughened rectangular cooling channel having number of ribs. Sixteen types of ribs like squares, isosceles triangular, fan shaped, house shaped, river cut trapezoidal and boot shaped etc. They used Reynold stress model with the speziale-Sarkar-Gatski pressure strain model to study the turbulence. They studied the effect of Reynolds-number and rib pitch –to width ratio on performance of various ribs by keeping the Reynolds number range from 5000 to 50,000. It was founded that boot shaped rib (case 7) design has best heat transfer performance with least pressure drop.

Lin Guang-yi et al. [3] had done theoretical and experimental analysis for heat exchanger whose tube was mounted with 19-100 specification (rotor outer diameter 19 mm and lead 100 mm) and 19-400 specification (rotor outer diameter 19 mm and lead is 100 mm) respectively. In the experiment heat exchanger was used and tube was fitted with rotor. Cold water flows by the tube side and hot water flows in the shell side. A comparison of result was done in which it was founded that heat exchanger whose tube was fitted with 19-400 specification had better heat transfer characteristics because with the increasing lead the rotors kinetic moment and rotating speed decreases which ultimately causes the low flow resistance in the tube. In the experiment it was seen that when water velocity exceeds the critical velocity, the performance of tube inserted with 19-100 specification rotor was better than smooth tube. In the experiment it was also found that when hot water inlet temperature of is kept constant and water flow velocity is greater than critical velocity, it is not necessary that coefficient of heat transfer will also be higher i.e. there should be optimum flow rate at which the heat transfer coefficient is maximum.

Fig. 2: Twisted tape with rectangular cut insert [4]

Bodius Salam et al. [4] performed experiment to find out tube side coefficient of heat transfer, factor of friction and heat transfer enhancement efficiency of a tube having twisted tape insert. Water was taken as working fluid. Test section was a copper tube of 26.6 mm internal diameter, 30 mm outer diameter and length of test section 900 mm. For uniform heat flux nichrome wire was used. Constant heating flux was provided throughout the test length. Reynolds number was kept in the range of 10000-19000, for smooth tube heat flux was varied from 14 to22 kW/m^2 and for tube with insert heat flux varied from 23 to 40kW/m^2. Results were compared with the smooth tube results. It was observed that tube having rectangular-cut twisted tape insert has 68% more heat flux than smooth tube. In the experiment it was noticed that tube having insert had 39% to 80% more friction factor than that of smooth tube.

S.S Joshi [5] conducted experimental investigation of various types of twisted tapes like short length twisted tape in tube, full length tape in tube, tape with gradually decreasing pitch, tape with holes, short tape connected with rod, tape with attached baffles. In this study various parameters are studied like effectiveness, overall heat transfer coefficient, friction factor etc. From the experiment it was concluded that by using insert heat transfer rate increases. If we use annular insert we can get higher coefficient of heat transfer and heat exchanger effectiveness. It was also studied that turns in twisted tape create the turbulence because of which heat transfer rate enhances so as number of turns increases heat transfer rate also increases. But more number of turns more will lead to increase in the factor of friction. The results were compared with the results of smooth tube. Effect of increasing the Reynolds number on overall heat transfer coefficient, effectiveness was studied for different types of twisted tape insert.

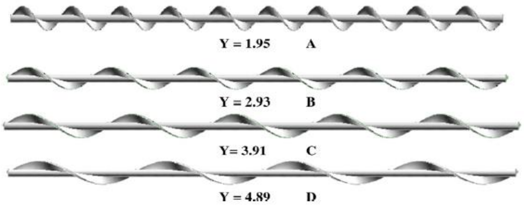

Fig. 3: Helical screw inserts having different twist ratio [6].

P. Sivashanmugam [6] studied heat transfer and factor of friction variation inside a circular tube having full length helical screw insert with dissimilar twist ratios(length of one twist/diameter of the twist) studied. Twist ratio of increasing and decreasing order have also studied. Uniform heat flux was provided across the tube. Dimension of the test section is 1800 mm length with 25.25 mm internal diameter and 33.33 mm outer diameter. Experimental data were compared with the result obtained from published data of plane tube. From the experiment it was concluded that both coefficient of heat transfer and factor of friction increases with twist ratio. There was slight change in the value of coefficient of heat transfer with reducing twist ratio and with the increasing twist ratio. This occurs because the strength of swirl generated at inlet and or at the outlet was same for both conditions.

P. Bharadwaj et al. [7] investigated pressure-drop and heat-transfer rate of spirally grooved tube with insert twisted tape. Analysis was carried out for Reynolds number ranges in laminar and turbulent region. The grooves are designed such that they are clockwise to the direction of fluid flow. Further the study is done on various twist ratios After comparing the results of spirally grooved tube with insert twisted tape, results showed maximum heat transfer enrichment of 60 0% in laminar range and 140% in turbulent range. Experimental results have showed that heat transfer and in a spirally grooved tube are affected by complex interactions that occurs between momentum and heat transfer near the grooved wall. The three twist ratio (Y = 10.15, 7.95 and 3.4) which were experimentally tested and heat transfer characteristics of clockwise twisted tape with Y = 7.95 was observed to be the highest at Pr = 5.4 in all the three flows i.e. laminar, transitional and turbulent ranges of Reynolds number.

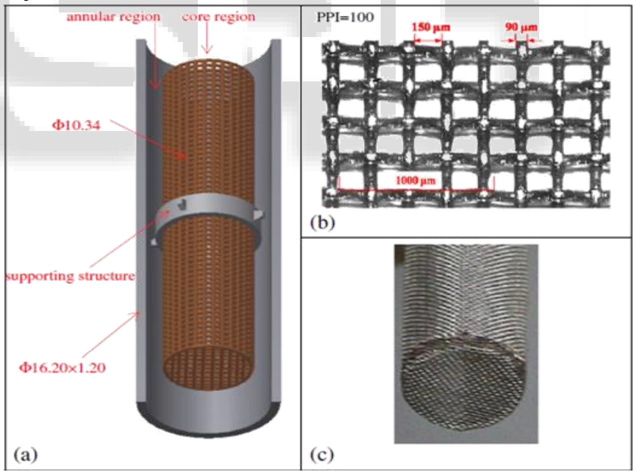

Fig. 4: The enhanced heat transfer tube with mesh cylinder inserted (a) photo of mesh screen (b) and the fabricated mesh cylinder (c) [8]

Feng Xing et al. [8] had experimentally analyzed a circular tube in which a mesh cylinder is suspended. They inserted a mesh cylinder into a hollow cylinder due to which the cross section is divided into an annular and core region consequently the flow also divided. Most of the flow takes place through the annular region which results in maximum velocity gradient near the wall than those of bare tube region .Velocity gradient was major reason of significant heat transfer enhancement. Water was used as operational fluid. It was founded that heat transfer enhancement ratios ranges from 1.21 to 1.8.

Naga Sarada S. et al. [9] performed experiments to find out maximum heat transfer enhancement through mesh inserts in a tube. For this he performed experiment with sixteen types of insert of different diameter whose porosity ranges from 99.73 to 99.98. It was found that rate of heat transfer for equal mass flow rate is 2 times as that of plane tube. They also concluded that for smaller porosity of constant diameter we can get maximum heat transfer rate.

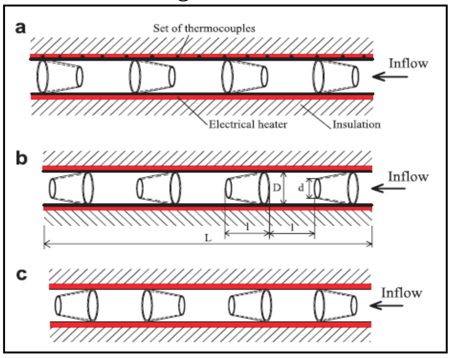

Fig. 5: Test tube fitted with various conical ring arrays, (a) DR array, (b) CR array and (c) CDR array [10].

P. Promvonge [10] predicted the behavior of heat transfer through a circular tube having number of conical ring insert. Conical rings having three different diameter ratios of ring to tube diameter (d/D=05, 0.6 and 0.7) are introduced .For each diameter ratios three arrangements are used i.e. converging ring array (CR), diverging ring array (DR) and converging and diverging ring array (CDR).In the experimental setup cold air at atmospheric condition with Reynolds number in range of 5000 to 26000 was allowed to flow through circular tube on which uniform heat flux was maintained. Results showed that 197%, 333% and 237% increase in Nusselt number in turbulent flow for converging ring (CR), diverging ring (DR) and converging diverging ring(CDR) respectively .It was also observed that in all the cases of insert conical ring, heat transfer rate enhances but at the expense of high friction losses .

Aberto Garcia et al. [11] studied effect on the heat transfer after inserting wire coil insert inside a circular tube. Numbers of wire coils were mounted within the tube and constant heat flux was given. Reynolds number was kept within the range of 10 to 2500. Comparison is carried out between wire coil insert and twisted tube insert. It was founded that wire coil insert have slightly better heat enhancement performance.

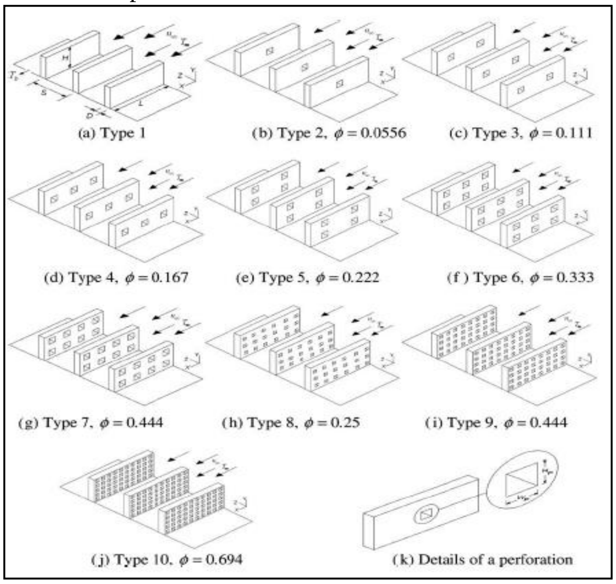

Fig. 6: Arrays of perforated fins [12]

M.R Sharei et al. [12] had performed experimentation on conjugate conduction convective heat transfer through three dimensional array of rectangular perforated fins provided with square perforations. Experimentation was carried out for Reynolds number 2000-5000 based on fin thickness and Prandtl number (Pr)=0.71.Fin material was aluminum and air was used as working fluid. It was found that fins having more perforation showed best performance than solid fin with considerable lower weight and lower drag force.

Se Kyung Oh et al. [13] analyzed heat transfer characteristics of a rectangular channel mounted with various types of perforated baffles.th dimension of test section used was 19.8 cm (width) X 4 cm (height) and a length of 171.8 cm. Upper right and left sides of the channel was made of 5mm thick plexiglass plates and bottom side was made of wood. Heating was provided at the bottom of the channel. Baffles were arranged with inclination of 5°.Study was carried out for four types of baffles namely solid type, 3hole baffle, 6 hole baffle and 9 hole baffle. Reynolds number was set between 25000 to 57000. From the experiment it was analyzed that according to numerical expectation of flow and isotherm, every baffle had its own transport field and isotherm phenomenon. It was also concluded that perforated baffles showed better results than solid one and baffle having three hole showed maximum Nusselt number.

T.Y Chen [14] conducted experiment to see the three dimensional varying velocity effects on heat transfer rate by using wind tunnel in which cylinders were placed in the upstream of test section. They used cylinders of different diameters to form the vertical flow motion with three dimensional velocity fluctuations. A blower was used to maintain the desired flow. Test section consists of a diffuser, honeycombs, screens and a contraction. The flow velocity in test section was adjusted by frequency controller. The experiment showed the velocity fluctuation effect on the heat transfer rate slightly depends on the way it generate and on the boundary layer thickness.

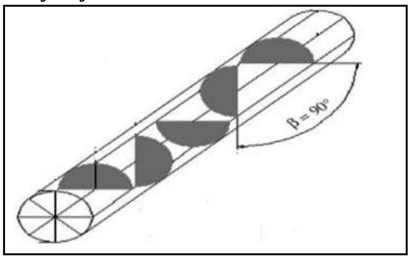

Fig. 7: Schematic of 90^0 baffled tubes [15]

Ahmet Tandiroglu [15] had experimentally analyzed the effect of flow geometrical parameters on convective heat transfer within a circular tube having baffle inserts. He had studied the various orientation angle β=45°, 90° and 180°. He performed the experiment by inserting 9 baffles in the tube which are equally spaced with Reynolds number ranges from 3000 to 20000. He also calculated factor of friction and pressure drop. Experimental results and c empirically predicted correlation data were compared. The results of smooth tube were compared with the results obtained from Dittus and Boelter and Gnieslinski equation.

Correlation from Dittus Boelter

$$Nu = 0.023 \times Re^{0.8} \times Pr^{0.4} \qquad [15]$$

For Re ≥ 10,000

Correlation from Gnielinski

$$Nu = \frac{(f/8) \times Re \times Pr}{1.07 + 12.7 \times (f/8)^{0.5} \times (Pr^{2/3} - 1)} \quad [15]$$

Where, Nu = Nusselt number
Re = Reynolds number
Pr =Prandtl number
F =friction factor

It was concluded that the suggested correlations are satisfactory for the prediction of Nusselt number and pressure drop.

Halit Bas [16] conducted experiment to analyze the coefficient of friction and heat transfer inside a tube having twisted tape swirl generator. The twisted tape was separately placed from tube wall. Three twist ratios (y/D =2,2.5,3.5 and 4) and clearance ratio (c/D= 0.0178 and 0.357) were studied experimentally with Reynolds number in the range of 5132 and 24989.The 'c' was the distance between inner wall of tube and twisted tape insert and 'd' was inner diameter of tube. Also 'y' is the half of the pitch. Working fluid used in the experiment was air. The result showed that the effect of twist ratio is more on heat transfer rate in twisted tape as compared with clearance ratio. It is also observed that as Reynolds number increases, heat transfer enhancement decreases and it remains same for Reynolds number more than 15000 and twist ratio lower than 3.It showed that the twisted tape with c/D=0.0718 has maximum heat transfer enhancement i.e. 1.756 for all cases.

M.M.K. Bhuiya et al. [17] performed an experiment to find the influence of triple helical tape inserted in a tube. The material of triple helical tape used is mild steel with helix angle α=9°, 13°, 17° and 21°.Reynolds numbers are kept in the range of 22000 to 51000. The maximum heat transfer enhancement efficiency was 3.7. New correlations where proposed to find friction factor and heat transfer for turbulent flow.
Correlation for Nusselt number:

$$Nu = C \times Re^{m} \times Pr^{0.33} \quad [17]$$

Where, $C = 0.174(\tan\alpha)^2 - 0.1093(\tan\alpha) + 0.212$ and $m= -2.7013(\tan\alpha)^2 +0.8434$.
Correlation for friction factor:

$$f = C_1 Re^{m1} \quad [17]$$

Where $C_1= -9873.4(\tan \alpha)^2 + 4823(\tan\alpha) + 24.378$ and $m_1 + 1.7736 (\tan\alpha)^2 - 0.923(\tan\alpha) - 0.7792$
α= Helix angle(°)

K. Goodarzi et al. [18] studied the heat transfer in channels carrying different shaped inserts by using computational fluid dynamics (CFD) modeling methods. In the study, RNG k-Ɛ m turbulence model was used to model the turbulent flow regime. Three types of inserts namely starry inserts, coiled wire inserts and classic twisted tape inserts were taken for experimentation in a water heater tube. Coiled wire insert had square cross section with 2mm length of side. Two pitch length 12 mm and 17 mm were considered in the study. Dimensions of classic twisted tapes were 15mm width and 1 mm thickness with two different pitch length 30 mm and 45 mm. Starry inserts had 0.6 mm thickness and consist of holding rod with 2 mm diameter. Experiment was performed for three surface ratios A_{star}/A_{inlet} of 0.31, 0.50 and 0.58. Reynolds number ranges from 5800 to 18500. The results of starry inserts, coiled wire inserts and classic twisted tape tube inserts showed remarkable increase in both pressure drop and heat transfer in comparison with the results of plain tube. It was also founded that the thermal performance factor is maximum for starry insert with surface ratio =0.50

Chayut Nuntdusit et al. [19] conducted experiment in a rectangular wind channel inserted with different types of zigzag cut baffles. Zigzag cut baffles are used so that it will produce 3D flow formation at the back of the baffles in place of vortex flow which increases the heat transfer. Experiment was performed on types of baffles (i) conventional type baffle (Rectangular cross section having no cut), (ii) baffle having rectangular zigzag cut and (iii) baffle having triangle zigzag cut at 45° and at 90°. The channel was constructed with acrylic plates having cross section 200 mm width X 50 mm height and 2780 length. Experiment was performed for a constant Reynolds number 20000. The effect of varying pitch length is also studied at pitch distance P/H = 8, 6and 4(P: pitch of baffle, H: height of baffle).The thermal enhancement factor for rectangular cut baffle was highest in the range of P/H=8, 6 and 4 due to low friction factor and high heat transfer rate.

Aashique Alam Rezwan et al. [20] studied the air process heaters which are used in many industries for packaging, sealing, soldering, shrink fitting and synthetic fabric sewing etc. In the experiment 5 semi circular hollow baffles with 4 cartridge electric heaters with air as working fluid were used. Baffle ensures the uniform heating by producing swirling effect in air. The length of heater section was 0.9 m. The designed and fabricated air process heater had the capability to heat the air up to 147 °C. Velocity of air taken for experimentation was 19 m/s. It was noticed that the temperature ratio (Ambient temperature/Air temperature) was decreased up to 0.72 whereas in many air process heaters the temperature ratio is about 0.9.

III. CONCLUSION

Heat transfer enhancement with various types of insert in a tube is reviewed. In this various parameters like pitch of baffles, number of pores, Reynolds number, flow condition etc are studied. It is founded that porous baffles have maximum heat transfer rate. Heat transfer enhancement also depends on pore size and density, surface area. As surface area increases the heat transfer rate increases. Different research works about each one have been reviewed

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