Passive Heat Transfer Augmentation Methods in Circular Tube

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Abstract: The present paper is a review of the passive heat transfer augmentation in circular tubes used in the recent past and these techniques will be useful to designers while implementing in heat exchangers. In passive techniques, where inserts are used in the flow passage to increase the heat transfer rate, are advantageous compared with active techniques, because the insert manufacturing process is simple and cheap and these techniques can be easily employed in an existing heat exchanger.

Keywords: ***circular tube, inserts, Passive heat transfer.***

I. INTRODUCTION

Heat exchangers have several industrial and engineering applications. The design procedure of heat exchangers is quite complicated, as it needs exact analysis of heat transfer rate and pressure drop estimations apart from issues such as long-term performance and the economic aspect of the equipment. The major challenge in designing a heat exchanger is to make the equipment compact and achieve a high heat transfer rate using minimum pumping power. Techniques for heat transfer augmentation are relevant to several engineering applications. In recent years, the high cost of energy and material has resulted in an increased effort aimed at producing more efficient heat exchange equipment. Furthermore, sometimes there is a need for miniaturization of a heat exchanger in specific applications, such as space application, through an augmentation of heat transfer. Furthermore, as a heat exchanger becomes older, the resistance to heat transfer increases owing to fouling or scaling. These problems are more common for heat exchangers used in marine applications and in chemical industries. In some specific applications, such as heat exchangers dealing with fluids of low thermal conductivity (gases and oils) and desalination plants, there is a need to increase the heat transfer rate. The heat transfer rate can be improved by introducing a disturbance in the fluid flow (breaking the viscous and thermal boundary layers), but in the process pumping power may increase significantly and ultimately the pumping cost becomes high. Therefore, to achieve a desired heat transfer rate in an existing heat exchanger at an economic pumping power, several techniques have been proposed in recent years.

II. CLASSIFICATION OF AUGMENTATION TECHNIQUES

Generally, heat transfer augmentation techniques are classified in three broad categories:

A. Active method:

This method involves some external power input for the enhance- ment of heat transfer. Some examples of active methods include induced pulsation by cams and reciprocating plungers, the use of a magnetic field to disturb the seeded light particles in a flowing stream, mechanicals aids, surface vibration, fluid vibration, electro-static fields, suction or injection and jet impingement requires an external activator/power supply to bring about the enhancement.

B. Passive method:

This method generally uses surface or geometrical modifications to the flow channel by incorporating inserts or additional devices. For example, inserts extra component, swirl flow devices, treated surface, rough surfaces, extended surfaces, displaced enhancement devices, coiled tubes, surface tension devices and additives for fluids.

C. Compound method:

Combination of the above two methods, such as rough surface with a twisted tape swirl flow device or rough surface with fluid vibration, rough surface with twisted tapes.

III. LITERATURE REVIEW:

An extensive literature review of all types of heat transfer augmentation technique in circular tube with inserts has been discussed in this section. In the following subsections, literature involving recent work on passive heat transfer augmentation techniques by employing twisted tapes, wire coils, dimples, ribs and fins as an insert has been reviewed.

A. Twisted tape:

Twisted tapes are the metallic strips twisted with some suitable techniques at desired shape and dimension, inserted in the flow. The twisted tape inserts are popular and widely used in heat exchangers for heat transfer augmentation besides twisted tape inserts promote heat transfer rates with less friction factor penalty on pumping power.

Insertion of twisted tapes in a tube provides a simple passive technique for enhancing the convective heat transfer by introducing swirl into the bulk flow and disrupting the boundary layer at the tube surface due to repeated changes in the surface geometry. That is to say such tapes induce turbulence and superimposed vortex motion (swirl flow) which induces a thinner boundary layer and consequently results in a better heat transfer coefficient and higher Nusselt number due to the changes in the twisted tape geometry. However, the pressure drop inside the tube will be increased by introducing the twisted-tape to insert. Hence a lot of researches have been carried out experimentally and numerically to investigate the optimal design and achieve the best thermal performance with less frication loss.

Sarada et al. [1], investigated the augmentations of turbulent flow heat transfer in a horizontal tube by varying the width of the twisted tape inserts as shown in fig 3.1(a) using air as the working fluid. When the widths changed from 10mm to 22 mm, the heat transfer rate are improved by 36% to 48% for the full width =26 mm. This is because of that the centrifugal forces generate the spiral motion of the fluid and heat transfer enhancement with twisted tape inserts is greater as compared to plain tube.

Fig:3.1(a)Twisted tape with various twist widths.

Noothong et al. [2], Investigated the typical twisted tape (TT) insertion with a twist ratio regarding the influences of the twisted tape insertion with a twist ratio of 5.0 and 7.0 in a in a concentric double pipe heat exchanger using water as working fluid as shown in fig 3.1(b) with the Reynolds no. ranging from 2000 to 12000. The result s revealed that the twisted tape inserts induced the swirl or vortex motions which decrease the boundary layer thickness and enhance the heat transfer rate. The enhancement efficiency, Nusselt number (Nu) and friction factor all are reduced with the decreasing of the twist ratio.

Fig:3.1(b)Twisted tape with various twist ratios

Eiamsa-ard et al. [3],Investigated the effect of dual and multiple twisted tape impacts on the heat transfer enhancement as shown in fig 3.1(c) using air as working fluid,with reynold number ranging from 4000to 19000. The heat transfer rate for the dual twisted tapes is increased by 12% to 29% in comparison with the single tape at the twist ratios from 3.0 to 5.0 by generating strongly dual swirling flow inside side the test tube.Depending on the flow conditions and twist ratio y, the increases in heat transfer rate over the plain tube are about 146%, 135% and 128% for y=3.0, 4.0and5.0, respectively.The smaller space ratio of the dual twisted tapes in tandem is more attractive in heat transfer application due to the higher enhancement efficiency than the single one.

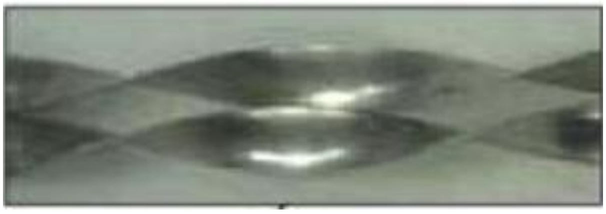

Fig:3.1(c)Dual twisted tapes.

Saha[4],investigated the twisted-tape inserts with and without oblique teeth with air as working fluid as shown in fig3.1(d), ranging Reynolds no. from 10000 to 10,0000.The axial corrugations in combination with twisted-tapes of all types with oblique teeth have been found performing better than those without oblique teeth in combination with axial corrugations.

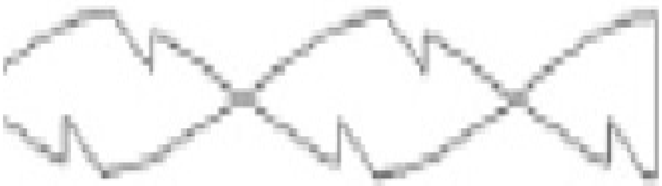

Fig:3.1(d)Twisted-tape with oblique teeth.

Veeresh Fuskele and Dr. R. M. sarviya [5], investigated heat transfer enhancement in Double heat exchanger using Twisted dense wire mesh inserts, using air as working fluid Twisted wire mesh having different twist ratios have been compared with values for smooth tubes for heat transfer coefficient varied from 2.09 to 1.69 times and friction factor increased to 4.3 to 4.0 times smooth tube values. Also higher heat transfer rates can be achieved using porous inserts.

B. Wire coil:

Wire coil is the helical inserts which are new addition to the family of inserts for enhancement of heat transfer. For the helical taps, the swirl moves in one direction along the helical and induce swirl in the flow, which increase the retention time of the flow and consequently provide better heat transfer performance over twisted tape insets. Wire coil inserts are currently used in the applications such as oil cooling devices, pre heaters or fire boilers.

Pongjet Promvonge[6], experimentally investigated effects of wires with square cross section forming a coil used as a turbulator on the heat transfer and turbulent flow friction characteristics in a uniform heat flux, circular tube as shown in fig 3.2 (a).The experiments are performed for flows with Reynolds numbers ranging from 5000 to 25,000. Two different spring coiled wire pitches are introduced. The results are also compared with those obtained from using a typical coiled circular wire, apart from the smooth tube. The experimental results reveal that the use of coiled square wire turbulators leads to a considerable increase in heat transfer and friction loss over those of a smooth wall tube.

The use of coiled square wire causes a high pressure drop increase, which depends mainly on spring pitches and wire thickness, and also provides considerable heat transfer augmentations. However, the Nusselt number augmentation tends to decrease rapidly with the rise of Reynolds number. If wire coils are compared with a smooth tube at constant pumping power, an increase in heat transfer is obtained, especially at low Reynolds number. The coiled square wire should be applied instead of the round one to obtain higher heat transfer and performance, leading to more compact heat exchanger.

Fig 3.2(a): Coiled square wires

Pongjet Promvonge [7],Experimentally investigated Influences the insertion of wire coils in conjunction with twisted tapes on heat transfer and turbulent flow friction characteristics in a uniform heat-flux, circular tube using air as the test fluid, as shown in fig3.2(b). The wire coil used as a turbulator is placed inside the test tube while the twisted tape is inserted into the wire coil to create a continuous impinging swirl flow along the tube wall. The effects of insertion of the two turbulators with different coil pitch and twist ratios on heat transfer and friction loss in the tube are examined for Reynolds number ranging from 3000 to 18,000. The use of the wire coil and the twisted tape inserts causes a high pressure drop increase and also provides considerable heat transfer augmentations, Nu/Nus = 3–6. However, Nusselt number augmentation tends to decrease with the rise of Reynolds number. If the combined wire coil and twisted tape turbulators are compared with a smooth tube at a constant pumping power, a double increase in heat transfer performance is obtained especially at low Reynolds number. Therefore, the combined wire coil and twisted tape should be applied instead of using a single one only to obtain the highest heat transfer and performance of about 200–350%, leading to more compact heat exchanger.

Fig:3.2(c)Twisted tape and wire coil

Munoz-Esparza et al.[8**]**,Employing the computational fluid dynamics(CFD) simulation package investigated the heat transfer and fluid flow performance inside around pipe with the helical wire coils inserts as shown in fig3.2(d).They found that the friction factor becomes constant in the Reynolds no. range of 600–850.The effect of the pitch on the friction factor has been addressed by performing a parametrical study with a pitch-periodic computational domain for wire coils within the dimensionless pitch range(p/d), 1.50<p/d<4.50, and dimensionless wire diameter, e/d=0.074, showing that the increase of p/ d, decreases the friction factor.

Fig:3.2(d)Wire coil in pipe

C. Swirl generators:

Swirl flows have wide range of applications in various engineering areas such as chemical and mechanical mixing and separation devices, combustion chambers, turbo machinery, rocketry, fusion reactors, pollution control devices, etc. The utilization of swirl flows may lead to the heat and mass transfer enhancements. Problems of heat and mass transfer in swirl pipe flows are the practical importance in designing different heat exchangers, submerged burners, heat transfer promoters and chemical reactors. Swirl flows result from an application of a spiral motion, a swirl velocity component (also called as ‘tangential’ or ‘azimuthal’ velocity component) being imparted to the flow by the use of various swirl-generating methods.

Eiamsa-ard et al. [9],studying the heat transfer, friction loss and enhancement efficiency behaviours in a heat exchanger tube equipped with propeller type swirl generators at several pitch ratios,using air as working fluid with reynold nu.ranging from 4000 to 21000,as shown in fig 3.3(a) with different blade angles (30^0,45^0,60^0). Swirl generator is used to create a decaying swirl in the tube flow. The results indicate that the use of the propeller leads to maximum enhancement efficiency up to 1.2. Thus, because of strong swirl or rotating flow, the propellers and their blade numbers become influential upon the heat transfer enhancement. The increase in friction factor from using the propeller is found to be 3–18 times over the plain tube.

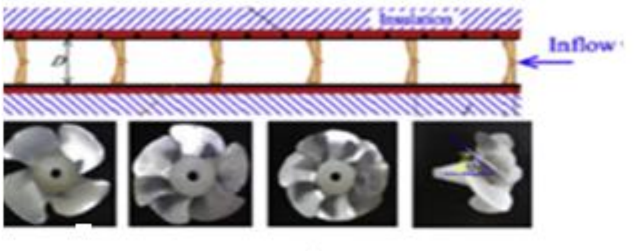

Fig:3.3(a)Propeller swirl generator

Yang et al. [10],studied the heat transfer process of swirling flow issued into a heated convergent pipe with a convergent angle of 5^0 with respect to the pipe axis as shown in fig 3.3(b). A flat vanes wirler situated at the entrance of the pipe is used to generate the swirling flow. There results show that the convergence of the pipe can accelerate the flow which has an effect to suppress the turbulence generated in the flow and reduce the heat transfer. However, in the region of weak swirl(S=0–0.65), the Nusselt numbers increase with the increase of swirl numbers until (S>0.65), where the turbulence intensity is expected to be large enough and not suppressible.

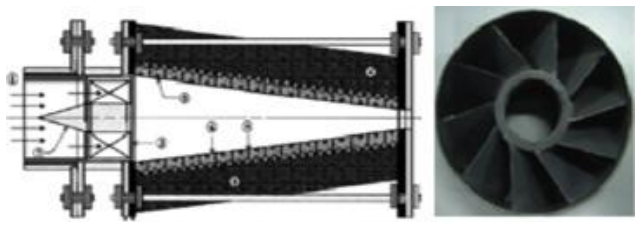

Fig: 3.3 (b)Typical swirler

Yilmaz et al. [11], studied the effect of the geometry of the deflecting element in the radial guide vane swirl generator on the heat transfer and fluid friction characteristics in decaying swirl flow as shown in fig 3.3(c),using air as working fluid with Reynolds number ranging from 32000-111000.The results show that an augmentation up to 150% in Nusselt number relative to that of the fully developed axial flow was obtained with a constant heat flux boundary condition. The exact segmentation depends upon the vane angles, Reynolds numbers and types of the swirl generators. They observed that the swirl generator with no deflecting element presented the highest Nusselt numbers and also the highest pressure drop in both the swirl generator and the tested pipe.

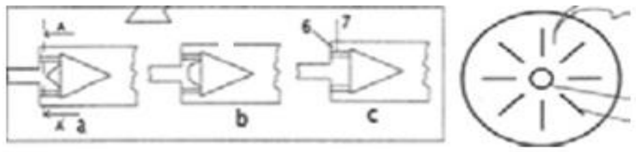

Fig:3.3(c)Radial guide vane swirl generator.

D. Conical ring:

Anvari et al. [12], studied the impact of conical ring inserts in transient regime as shown in fig.3.4(a) using water as working fluid with reynold number ranging from 2500 to9500.The insertion of turbulators has significant effect on the enhancement of heat transfer, especially the DR (Divergent rings) arrangement, and also increase the pressure drop. So tabulators can be used in places where the compact size is more significant than pumping power.

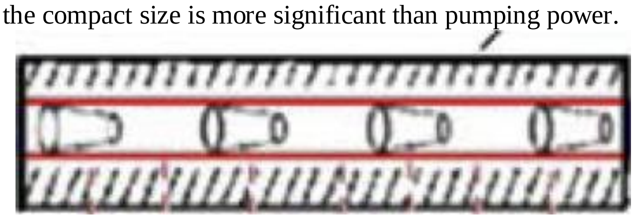

Fig:3.3(a)Conical tube insert.

C. Eiamsa-ard, Promvonge P. [13], are investigated experimentally, Flow-induced vibration characteristics of conical-ring turbulators used for heat transfer enhancement in heat exchangers. The conical-rings, having 10,20 and 30mm pitches, are inserted in a model pipe-line through which air is passed as the working fluid as shown in fig 3.4(b). It is observed that as the pitch increases, vortex shedding frequencies also increase and the maximum amplitudes of the vortices produced by conical-ring turbulators occur with small pitches. In addition, the effects of the promoters on the heat transfer and friction factor are investigated experimentally for all the arrangements. It is found that the Nusselt number increases with the increasing Reynolds number and the maximum heat transfer is obtained for the smallest pitch arrangement.

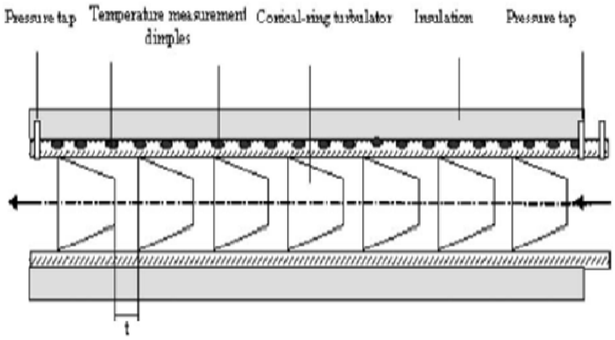

Fig 3.4(b): Arrangement of conical-rings in the test pipe

P. Promvonge and S. Eiamsa-ard [14],an experimental study of the influence of conical-nozzle turbulator inserts on heat transfer and friction characteristics in a circular tube as shown in fig 3.4 (c). In the present work, the turbulators are placed in the test tube section with two different types: (1) diverging nozzle arrangement (D-nozzle turbulator) and (2) converging nozzle arrangement (C-nozzle turbulator). The turbulators are thoroughly inserted inside the tube with various pitch ratios, PR=2.0, 4.0, and 7.0. The Reynolds number based on the bulk average properties of the air is in a range of 8000 to 18,000 and the experimental data obtained are compared with those obtained from the plain tube. The experimental results reveal that increasing the Reynolds number at a given pitch ratio of the turbulators leads to the significant increase in Nusselt number indicating enhanced heat transfer coefficient due to rising convection as the flow increases. However, the friction factor at a given Reynolds number considerably increases with the reduction of pitch ratio and Reynolds number.

E. Rib: Ribs are another technology enhancing the heat transfer rate.

Naphon et al. [15],experimentally studied the heat transfer and pressure drop characteristics in horizontal double pipes with helical ribs in which reynold number ranging from 15000 to 60,000 as shown in fig 3.5 (a).Nine test sections with different characteristic para- meters of: helical rib height to diameter, v/d=0.12, 0.15,0.19,and helical rib pitch to diameter, p/d=1.05, 0.78,0.63 are tested. The results show that the helical ribs have as significant effect on the heat transfer and pressure drop augmentation

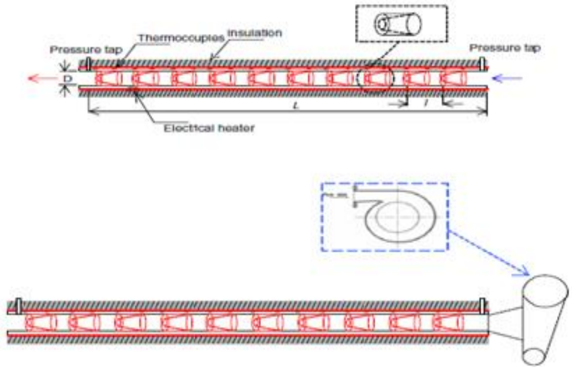

Fig:3.4(c)Conical nozzles combined with a snail

Fig 3.5(a): Helical rib

Eiamsa-ard et al. [16], investigated the louvered strips inserted in a concentric tube heat exchanger in 2008 as shown in fig3.5(b).The louvered strip was inserted into the tube to generate turbulent flow which helped to increase the heat transfer rate of the tube. Experimental results confirmed that the use of louvered strips leads to a higher heat transfer rate over the plain tube. The use of the louvered strip with backward arrangement leads to better overall enhancement ratio than that with forward arrangement around 9% to 24%.

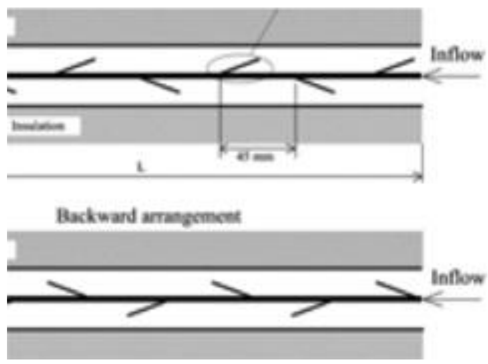

Fig 3.5(b): Louvered strip.

F. Mesh inserts

The utilization of porous Mesh inserts has proved to be very promising in heat transfer augmentation. One of the important porous media characteristics is represented by an extensive contact surface between solid and fluid surfaces. The extensive contact surface enhances the internal heat exchange between the phases and consequently results in an increased thermal diffusivity.

Mehmet Sozen et al [17], numerically studied the enhanced heat transfer in round tubes filled with rolled copper mesh at Reynolds number range of 5000-19,000. With water as the energy transport fluid and the tube being subjected to uniform heat flux, they reported up to ten fold increase in heat transfer coefficient with brazed porous inserts relative to plain tube at the expense of highly increased pressure drop.

Naga Sarada S et al.[18],investigated experimentally of the augmentation of turbulent flow heat transfer in a circular tube by means of mesh inserts with air as the working fluid,as shown in fig 3.6(a)Sixteen types of mesh inserts with screen diameters of 22mm, 18mm, 14mm and 10mm for varying distance between the screens of 50mm, 100mm, 150mm and 200mm in the porosity range of 99.73 to 99.98 are considered for experimentation. It is observed that the enhancement of heat transfer by using mesh inserts when compared to plain tube at the same mass flow rate is more by a factor of 2 times where as the pressure drop is only about a factor of 1.45 times.

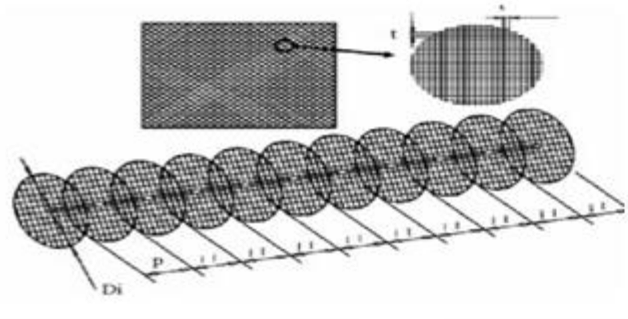

Fig:Porous medium manufactured from copper screens.

IV. CONCLUSIONS

This paper reviews the investigation carried out by various researches in order to enhance the heat transfer, nusselt number, and friction factor by the use of circular tubes with inserts of different shapes, sizes and orientation. Heat transfer rate is increase by using inserts in circular tube as compare to circular plain tube, as these passive techniques increase the turbulence of the air flow in the circular tube. Heat transfer enhancement using passive technique has carried out using inserts such as ribs, conical nozzle, twisted tape, wire coil, different swirl generators, and conical ring. .

REFERENCES

[1] Sarada N, Raju S, Kalyani Radha AV, Shyam K. *“Enhancement of heat transfer using varying width twisted tape inserts”*. International Journal of Engineering, Science and Technology 2010;2(6):107–18.

[2] Noothong W, Eiamsa-ard S, Promvonge P. *“Effect of twisted-tape inserts on heat transfer in a tube”*. In the 2nd joint international conference on ‘‘Sustainable Energy and Environment (SEE 2006). 21–23 November 2006, Bangkok, Thailand. 1–5.

[3] Eiamsa-ard S, Thianpong C, Eiamsa-ard P, Promvonge P. *“Thermal characteristics in a heat exchanger tube fitted with dual twisted tape elements in tandem”.* International Communications in Heat and Mass Transfer 2010;37:39–46.

[4] Saha SK. *“Thermohydraulics of turbulent flow through rectangular and square ducts with axial corrugation roughness and twisted-tapes with and without oblique teeth”.* Experimental Thermal and Fluid Science 2010;34:744–52.

[5] Veeresh Fuskele and Dr.R.M.sarviya*,”Investigated heat transfer enhancement in double heat exchanger using twisted dense wire mesh insert.”*IJAERS/VOL.I/ISSUEII/January-March,2012/05-09.

[6] Promvonge P. *“Thermal performance in circular tube fitted with coiled square wires”* Energy Conversion and Management 2008;49:980–7.

[7] Promvonge P.*"Thermal augmentation in circular tube with twisted tape and wire coil Turbulators”*.Energy Conversion and Management 2008;49:2949–55.

[8] Mun˜oz-Esparza D,Sanmiguel-RojasE*.”Numerical simulations of the laminar flow in pipes with wire coil inserts”*.Computers & Fluids 2011;44:169–77.

[9] Eiamsa-ard S, Rattanawong S, Promvonge P. *“Turbulent convection in round tube equipped with propeller type swirl generators”.*International Communications in Heat and Mass Transfer 2009;36:357–64.

[10] Yang CS, Jeng DZ, Yang Y, Chen H, Gau C. *“Experimental study of pre-swirl flow effect on the heat transfer process in the entry region of a convergent pipe”* Experimental Thermal and Fluid Science 2011;35:73–81.

[11] Yilmaz M, Comakli O, Yapici S, Sara on. *“Heat transfer and friction characteristics in decaying swirl flow generated by different radial guide vane swirl generators”.* Energy Conversion and Management 2003;44:283–300.

[12] Anvari AR, Lotfi R, Rashidi AM, Sattari S. *“Experimental research on heat transfer of water in tubes with conical ring inserts in transient regime”.* International Communications in Heat and Mass Transfer 2011;38:668–71.

[13] S. Eiamsa-ard , P. Promvonge,”*Experimental investigation of heat transfer and friction*

characteristics in a circular tube fitted with v-nozzle turbulators."

[14] Promvonge P, Eiamsa-ard S.*"Heat transfer enhancement in a tube with combined conical-nozzle inserts and swirl generator"*. Energy Conversion and Management 2006;47:2867–82.

[15] Naphon P, Nuchjapo M, Kurujareon J. *"Investigated Tube side heat transfer coefficient and friction factor characteristics of horizontal tubes with helical rib".* Energy Conversion and Management 2006;47:3031–44.

[16] Eiamsa-ard S, Pethkool S, Thianpong C, Promvonge P. *"InvestigatedTurbulent flow heat transfer and pressure loss in a double pipe heat exchanger with louvered strip inserts"*.International Communications in Heat and Mass Transfer 2008;35:120–9.

[17] Mehmet Sozen and T M Kuzay. 1996*,"Enhanced heat transfer in round tubes with porous inserts"*,International Journal Heat and Fluid Flow. 17: 124-129.

[18] Naga Sarada S., Kalyani K. Radha and A. V. S. Raju,2009 *"Experimental investigations in circular tube to enhance to enhance turbulent heat transfer using mesh insert",* ARPN Journal of Engineering and Applied Sciences, VOL. 4, NO. 5.