Review of Heat Transfer Augmentation in a Tube Heat Exchanger Using Passive Methods

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Abstract – There is a need to increase efficiency of existing heat exchangers by increasing the heat transfer area. It is possible with introducing passive methods of heat transfer. Heat transfer augmentation methods are employed in existing heat exchangers to increase heat transfer rate and decrease the size, weight there by cost of the system. It is proved that on adapting these methods, the overall thermal performance increases substantially. This paper reviews the work done on the use of passive techniques like swirl flow devices, surface roughness, coiled tubes, etc. in heat exchangers. It is found that a number of researches used different types of turbulators and these helped to continuously enhance the heat exchanger efficiency. In laminar regime, the twisted tape gives good results than in turbulent regime.

Keywords— Twisted Tape, Passive Techniques, Heat Exchanger, Wire Coil, Turbulators.

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INTRODUCTION

A. Role of Heat Exchangers

Heat exchangers are used in many practical applications to reuse the thermal energy from the thermal systems.Design of heat exchangers is very problematic because it needs correct estimation of pressure drop and heat transfer rate. The applications of heat exchangers include fluid heating in manufacturing, refrigeration, air conditioning, chemical processing plants. Economy of heat exchanger depends on its efficiency which includes minimum use of material, low operating cost and high performance of the system using minimum power. To achieve enhanced heat transfer rate in existing heat exchanger it require to increase the pumping power which increases the operating cost. So to deal with this problem, there has to be some techniques which increases heat transfer rate considerably in existing exchanger with slightly increasing pumping power. These techniques increase the thermal characteristics of heat exchanger by minimizing the thermal resistance of the system. To make reasonable heat transfer rate by taking care of increasing operating power, number of passive technique presented in recent years. The aim of presenting this paper is to propose different methods of increasing heat transfer rate of heat exchanger by inserting passive techniques.

B. Important Terms

The common terms used throughout this paper are thermal performance factor (η), heat transfer rate and pressure drop introduced in this part. Thermal performance factor is used to check the performance of the turbulators inserted inside the tube. These parameters are expressed as follow,

Nusselt number = $Nu = \frac{h\,d}{K}$ .... (I)

Friction factor = $f = \frac{2 \times d \times \Delta P}{L \times \rho \times V^2}$ .... (II)

$\eta = \frac{\frac{Nu_w}{Nu_p}}{\left(\frac{f_w}{f_p}\right)^{1/3}}$ .... (III)

Where i, p are subscripts used for insert and plain tube respectively. d and L are diameter and length of the test section. h, k and ρ are convective heat transfer coefficient, thermal conductivity and density of water respectively.

CLASSIFICATION OF AUGMENTATION TECHNIQUES

The augmentation techniques for heat transfer are categorised as passive methods, active methods and compound methods [1]. For difficult designs, the compound methods are used and has selective applications.

A. Active Methods

The method which uses any external source as power input to augment the heat transfer called as active method. Some of these methods are surface vibration, disturbance in the flow field, mechanical aids, injection or suction, jet impingement, electrostatic field.

B. Passive Methods

These methods do not use any external power as input source. They generally use some modifications in existing test section like change in geometrical or surface structure of the flow field, insertion of turbulators, materials or the additional instruments.

C. Some Important Passive Methods

1) Rough Surfaces (Corrugated Surfaces): There are some modifications on the inner or outer surface of the test section. Reference [2] made a study on three types of artificial roughness namely corrugated tubes, wire coils and dimpled tubes. The heat transfer and friction factor are investigated in all flow regimes. These results shows that greater impact on friction factor rather than heat transfer rate. It is concluded that for turbulent flow above 2000 Reynolds number corrugated and dimpled tubes shows good results. For flow regime having Reynolds number ranging 200 to 2000, wire coils showing good enhancement results. For flow having small Reynolds number below 200, the plain tube is recommended. Thermal performance variation of a tube with corrugated surfaces are studied in [3] (Fig. 1). Result shows that there is no much change in heat transfer at low Reynolds number.

Fig: 1. Test tube having helical and transverse corrugated surface [3]

2) *Extended surfaces (Louvered strip, Fins, Baffles):*These extended surfaces creates the swirl flow turbulence. In rectangular channel, the effect of baffles as turbulators on heat transfer enhancement is presented in [4]. It is found that there is a significant effect of with and without using baffles on friction factor and heat transfer augmentation (Figs. 2 and 3). It is observed that out-phase 45˚ Z- baffles are showing considerably lower friction factor, thermal performance factor and Nusselt number than those of in-phase 45˚ Z-baffle at same operating condition. The heat transfer rate with 45 inline baffles on both opposite walls of a square pipe is studied in [5]. The higher thermal performance factor was found as 2.6 times more than plain tube. The values of performance factor of all baffles found to be nearly same and greater than unity (Fig. 4).

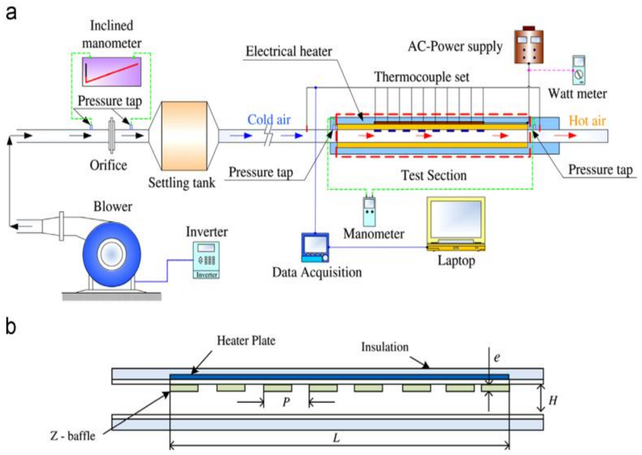

Fig. 2 Diagrams of experimental setup (b) test tube [4]

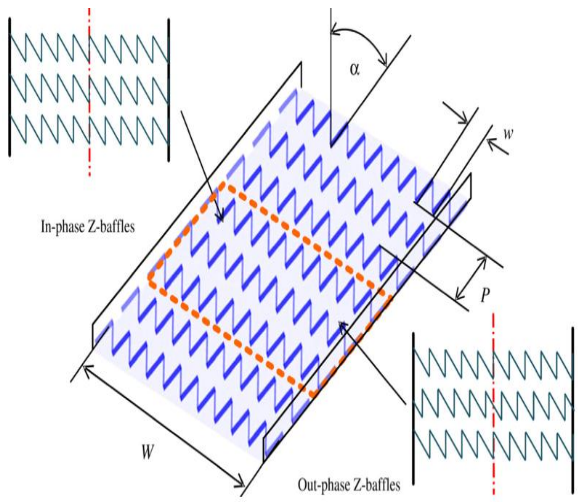

Fig. 3 Test section with out-phase and in-phase Z-baffle arrangements [4]

3) Coiled tubes: These are the wire coils inserted directly inside the tube which enhances the turbulence of working fluid. A numerical study is made in [6] (Fig. 5) to investigate the pressure drop and heat transfer performance of Al_2O_3/water nanofluid. It is found the pressure drop nearly remains unchanged up to 2% concentration of nanofluid. As the curvature ratio increases the pressure drop increases. The heat transfer characteristics of engine oil in a shell and coiled tube type heat exchanger is studied in [7]. It is found that the heat transfer rate of coiled tubes with smaller pitches are greater than larger pitches.

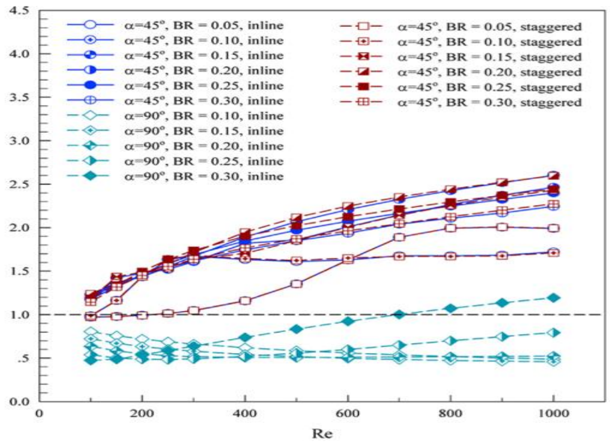

Fig. 4 Thermal performance factor of baffles at various BRs [5]

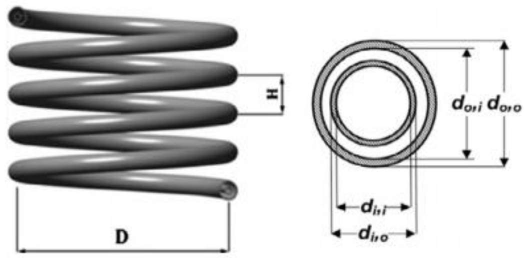

Fig. 5 Diagram and geometry of coiled tube in tube heat exchanger [6]

4) Swirl Flow Devices: Secondary recirculation of flow is produced by using these devices. These devices include twisted tapes, vortex rings, wire coils, conical rings and other turbulators. Effect of γ-Al_2O_3/water nanofluid through a circular tube on friction factor and heat transfer variations with twisted tape of various thicknesses is studied in [8] (Fig. 6). It is found that the friction factor increases and reduces the flow area which produces high swirl flow. The increase in Nusselt number dominates the friction factor thereby thermal performance factor increases.

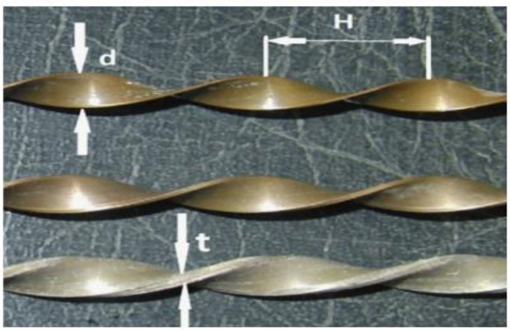

Fig. 6 Twisted tape inserts [8]

Wire coils are the swirl flow devices having advantages like easy to put and remove, low cost, easy manufacturing process. The wire coils placed inside the tube is studied in [9]. It is found that in transition regime the wire coils give good results. The heat transfer coefficient of wire coil wrapped of inner cylinder is numerically studied in [10]. It is found that for wrapped wire annulus the thermal hydraulic performance ratio is higher than unity. Heat transfer and friction factor variations of wire coils in a round tube placed separately from the wall are studied in [11] (Fig. 7). It is found that the friction factor and heat transfer increases considerably as compared to plain tube. The friction factor and Nusselt number increases with decreasing distance (s) and

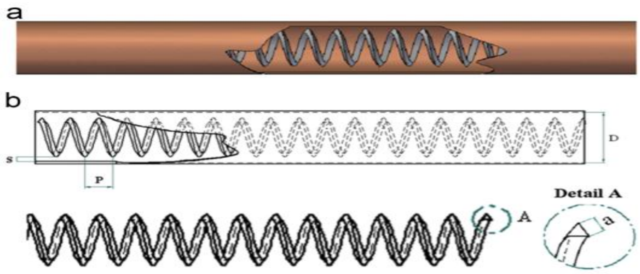

Fig. 7 (a) Wire coil inserts fitted separately from wall (b) The details if wire coil [11]

pitch ratio. In a turbulent flow regime the friction factor and heat transfer variations of a wire coiled inserted tube is investigated in [12]. It is found that the use of wire coils as inserts is good at lower Reynolds number. The helical coil inserts in a double pipe heat exchanger with TiO_2 nanofluid effect on heat transfer and friction factor are investigated in [13]. It is found that for insert having p/d ratio 2.5 and 0.02% nanofluid the friction factor and heat transfer coefficient increased by 10.69% and 13.85% respectively. The effect of square cross section wire coil turbulators on friction factor and heat transfer characteristics under constant heat flux condition is presented in [14] (Fig. 8).

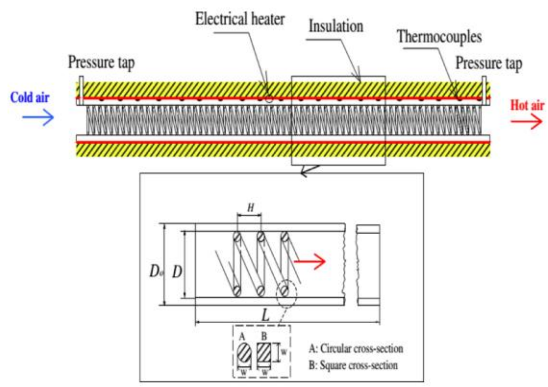

Fig. 8 Test section with wire coil inserts [14]

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The results show that square cross section wire coils increases friction factor and heat transfer rate than that of plain tube (Fig. 9).

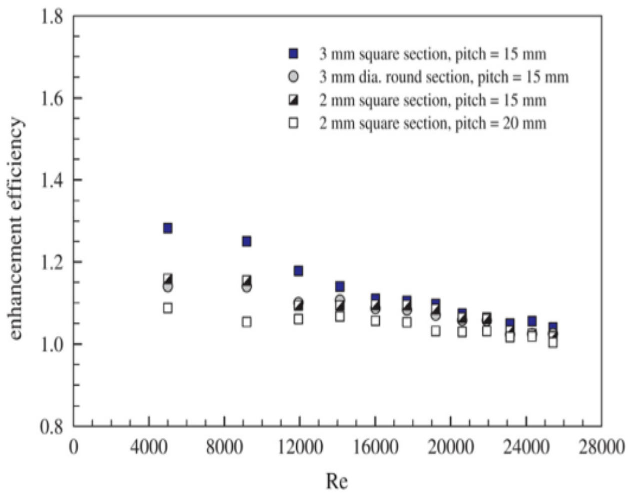

Fig. 9 Enhancement efficiency variation with Reynolds number [14]

Thermal performance variations of a tube placed with wire coil and twisted tape together presented in [15] (Fig. 10). The results show that the use of twisted tapes together with wire coils give double enhancement in heat transfer than that of twisted tape or wire coil alone. The centre wings and alternate axis type twisted tapes (Fig. 11 a and b) effects on thermal performance variations are studied in [16]. It is found that thecentre wings and alternate axis type twisted tape gives good heat transfer augmentation as compared to alternate axis or wing alone.

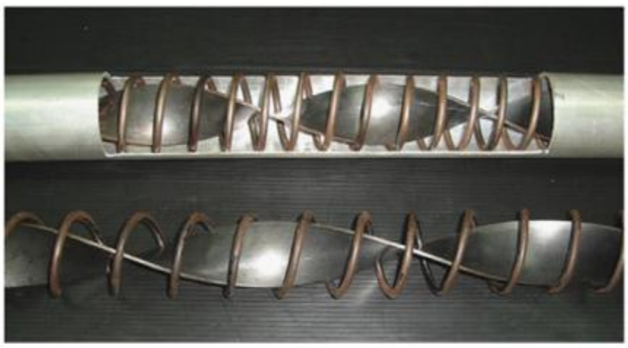

Fig. 10 Test tube with twisted tape and wire coil inserts [15]

CONCLUSIONS

In this paper, effort is taken to report the heat transfer performance of passive techniques used in heat exchangers. Following are the concluding remarks from the literature studied.

- The selection of shape of the turbulators is important in heat exchanging unit.
- Wire coil provides good thermal performance but at the cost of friction factor.
- In laminar regime, the twisted tapes give good results than in turbulent regime.
- The heat transfer rate of coiled tubes with smaller pitches is greater than those with larger pitches.
- There is need to minimize the pressure drop of full length twisted tape by replacing it with some short length twisted tape.
- The square cross section wire coils provides good augmentation of friction factor and heat transfer.

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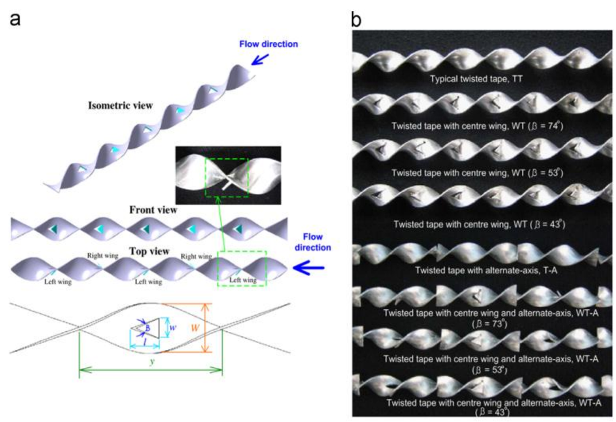

Fig. 11. (a) Twisted tapes geometry (b) Twisted tapes photograph [16]

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