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Experimental Augmentation of Heat Transfer in a Shell and Tube Heat Exchanger using Twisted Tape with baffles and hiTrain Wire Matrix Inserts – A Comparative Study

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Abstract. Heat transfer, a mere process of exchange of heat due to a temperature gradient, plays a vital role in industries and domestic applications. Among all the heat exchangers, Shell and Tube Exchanger are used predominantly due to their compact and robust design. For a given design to increase the heat transfer characteristics needs a research investigation. Among all augmentation techniques, a passive method found widely used as it avoids mechanical modification of the existing heat exchanger and addresses only on flow geometry. Twisted tape inserts are extensively used to change the flow geometry of fluid on the tube side. The present research work intended on utilising twisted tape, twisted tape with baffles and hiTrain wire matrix inserts. Experimental investigation reveals that inserts efficiently disturb the tube side fluid flow, in turn, increases pressure drop which increases the fluid wall shear and hence enhances the substantial increase in tube side heat transfer rate. At lower Reynolds number twisted tape with baffles has comparatively higher heat transfer coefficient, and at higher Reynolds, number hiTrain wire has comparatively higher heat transfer coefficient. Friction factor decreases linearly from twisted tape with baffles to hiTrain wire matrix as Reynolds number increases.

1. Introduction:

Heat is a type of energy which exchanges due to the difference in the temperature between a framework and its encompassing. In nature heat energy always flow from the high-temperature source to the low-temperature source until thermal equilibrium attains. Heat transfer happens in different modes like conduction, convection and radiation. In solids transfer of heat takes place by conduction either by electromagnetic conduction or phonon conduction. In convection, the heat transfer is through bulk movement of matter. Here the heat is carried by the particles as they move from one location to another and is mainly in fluids. In radiation, transfer of energy is by electromagnetic waves.(1)

The heat transfer process is very significant in many industries as it serves as the primary mode of energy transfer. Heat transfer system enhancement leads to increase in heat transfer characteristics and in turn reduces size and cost. Increased heat transfer characteristic increases second law efficiency by reducing the temperature driving force and reduces entropy. (2)

Enhancement of heat transfer rate results in turbulence by interrupting boundary layer increases heat transfer area and generates swirls and secondary flows due to treated or rough surfaces(3). Enhancement techniques popularly known as augmentation techniques, commonly used swirl generators like twisted tapes and hiTrain wire matrix belongs to passive augmentation method(4)(5)(6). Many researchers and scientist have contributed to processing and devising heat transfer enhancement through various techniques(7)(8)(9).

1.1. Conventional Twisted Tapes:

The effect of twisted tape in a dimpled tube on friction factor and heat transfer behaviours are investigated using air. The results concluded that friction factor and heat transfer coefficient increase as pitch and twist ratio decreases. An empirical co-relation is derived from experimentation results to predict heat transfer rate (Nusselt Number) and friction factor(3). Short length twisted tape inserts are experimented under turbulence condition with air as working fluid. The heat transfer coefficient and friction factor performed lower in short length tape than in full-length tape. Correlated and experimentally measured values of Nusselt number deviated in the order of ±7%(10)(11). Effect of clearance ratio on the Nusselt number, friction factor and thermal performance are numerically simulated for circular tube fitted with twisted tapes of two different twist ratios. The physical behaviour of simulated flow reveals that friction factor has been increased from 160% - 330% (12).

1.2. Modified Twisted Tapes:

Helically corrugated tubes have been experimentally augmented under turbulent conditions with water as working fluid. Heat transfer rate increased to 123% - 232% depending on Reynold's number and height pitch ratios (13). Peripherally cut twisted tapes create more turbulence intensity near the tube wall compared to that induced by twisted tapes. Overall heat transfer, thermal performance and friction factor increases in the case of peripherally cut twisted tapes as depth ratio increases (14). Triple twisted tapes swirl flow generator investigated with four different twist ratio and for different Reynold's number under constant heat flux condition. The decrease in twist ratio increases friction factor (4.2 times), thermal efficiency (1.4 times) and Nusselt number (3.85 times) (15). Tube fitted with double counter twisted tape with air as working fluid in a turbulent region, for different twist ratios, the heat transfer rate varies from 60% - 40% and friction factor varies from 91% - 86% compared with plain tubes. At constant blower power, the maximum thermal efficiency found 1.34 times in double counter twisted tape (16). Three different twist ratios of twisted tape with square edge geometry under transitional flow is performed at three different heat flux rate. For the same heat flux, the twist ratio decreases and Colburn j-factor increases, the effect of constant twist ratio on varying heat fluxes delays transitional flow. The increase of heat flux and decrease of friction factor were noted for constant Reynolds number and twist ratio (17). A comparative numerical study between square cut twisted tapes and the conventional twisted tape is studied in a circular tube under turbulent flow conditions. The five different ratios of perforated width to tape width and three different perforated lengths to tape width show that heat transfer, pressure drop and thermal enhancement factor increases for the decrease in perforated width to tape width ratio and perforated length to tape width ratio (18). Effect of multiple channels, clearance ratio in a loose fit twisted tape for different Reynolds number is studied numerically on heat transfer rate and friction coefficient. Loose fit twisted tapes performed better rate compared to plain twisted tapes (19). Effect of tape width ratio for single helical twisted tape, dual helical twisted tape, and triple helical twisted tapes on friction factor, Nusselt number, and heat transfer are studied. For double and triple helical twisted tapes, the Nusselt number increased up to 23.4%, and friction factor increased up to 206%, and thermal performance factor decreased up to 26.2% compared with single helical twisted tape (20).

1.3. Helical, Conical, Circular and wire coil swirl generators:

Correlation of turbulent flow at higher Reynolds number is predicted in a tube with helical tape inserts of five different twist ratios. For decreasing twist ratio, an increment is seen on the physical behaviour of Nusselt number (260%), thermal performance factor (144%) and friction factor (285%). Based on the result a correlation was proposed for different twist ratios (21). Helical screw tape inserts in the core flow of tube are used to reduce flow resistance with four different widths for different flow rates is simulated. The heat transfer coefficient increased from 212% - 351% and friction factor surged to 33%

- 1020%. Entropy generation analysis helps to state optimum helical screw tape from first principle (22). Double pipe water to air heat exchanger fitted with discontinuous helical turbulator with different pitch ratio, Reynolds number is studied. Optical designs of high efficiency were found using non dominated sorting genetic algorithm II; results show an increase in open air ratio and pitch ratio decreases friction factor and Nusselt number whereas thermal performance increases with open air ratio and decreases with pitch ratio (23). Combined Application of circular rings and twisted tape shows increased thermal performance (6.3%), heat transfer rate (25.8%) and friction factor (82.8%) than circular rings alone. Heat transfer rate increases with a decrease in pitch/twist ratio and increases the Nusselt number. By employing compound enhancement devices, shows higher heat transfer rate than with single insert. (24). An air to water double pipe heat exchanger fitted with perforated circular ring in annular pipe is experimentally investigated for different Reynolds number, pitch ratio and number of perforated holes. From the experimental data a correlation is developed (25).Vortex flows generated due to modified conical ring into hexagonal conical ring turbulators provides lower friction factor and increase in heat transfer characteristics. The friction factor increased to 188-345 in the hexagonal conical ring, thermal enhancement factor is 1.65 for 30º V-shaped hexagonal conical rings fitted to the plain tube(26). Experimental, numerical studies on air to water heat exchanger is carried out by varying pitch ratio, Reynolds number and open area ratio. Results indicate that thermal performance increases as open area ratio increases and attenuation of temperature gradient as open area ratio increases. The empirical relation developed between variables and compared experimentally with numerical simulation (27). Conical nozzle inserts and swirl generators with snail are experimentally augmented with air as working fluid by varying pitch ratio. Heat transfer rate increased by 278% for the conical nozzle and by 206% for the snail, the combined effect of the conical nozzle and snail increases the heat transfer 316% (28). The wire coil inserts fitted in double pipe heat exchanger is simulated using computational fluid dynamics to study the behaviour of Nusselt number, overall efficiency and friction coefficient for varying Reynolds number. The Nusselt number improved by 1.77 times with these results a correlation is proposed for coil wired inserts with different geometric conditions under laminar flow (29). Experimental augmentation of wire rod bundles on heat transfer, friction factor and thermal performance is carried out in a constant wall heat flux condition using turbulent flow. Nusselt number (3.5% - 68.8%) and friction factor (156% - 353%) increases with increase in wire rod number per bundle and Reynolds number and decreasing pitch ratio (30).

1.4. Next generation swirl generators:

Concentric tube heat exchanger fitted with louvered strip inserts were experimentally investigated with water as working fluid. Heat transfer rate increased to 284% - 413% in forwarding louvered strips and 233% - 263% in backward louvered strips. (31). Numerical simulation of a circular tube fitted with louvered strip inserts with turbulent air flow shown outstanding overall thermohydraulic performance due to more significant slant angle and small pitch. Friction factor and Nusselt number are more sensitive to slant angle than the pitch. The combined effect of average slant angle and small pitch increases overall thermohydraulic performance in steady state by four times and performance evaluation criteria by 1.6 - 2.05 (32). Reynold's number, tail length ratio and the cone angle are varied for diamond shaped tabulators in tandem arrangements, heat transfer rate decreases for tail length ratio and increase with increasing included cone angle and Reynold's number, this is because of increase in pressure loss and enhancing the convective heat transfer due to the mixing of fluid in the boundary layer. (33). Numerical simulation swirl vanes in a shell and tube heat exchanger are carried out for different tube diameter and blade angle using computational fluid dynamics. The maximum heat transfer rate, friction factor and heat transfer enhancement is found for six swirl vanes of 19 mm diameter pipe and 45º blade angle (34). Tube heat exchanger fitted with winglet vortex generators for varying turbulent air flow in a uniform wall heat flux tube and Reynolds number is carried out. The results show that heat transfer and friction loss are enhanced (35). Thermal characterisation of a circular tube fitted with inclined (20º) horseshoe baffles with three different baffle pitch ratio by varying turbulent air flow is carried out. Heat transfer rate improved up to 208% and friction factor increased up to 6.37 times (36). An elliptic shaped 26 turbulators with 45º or 60º ellipses is studied in three different tube diameters of a heat exchanger. The heat transfer rate increases up to 900% with an ellipse angle of 45º with a considerable pressure drop; this pressure drop is compensated by 30% modification of turbulators geometrically decreases friction factor by 50% while the compensation of Nusselt number decreases only by 20% (37).

2. Research Statement:

From section 1.1 its evident that extensive work has been done on twisted tape and in section 1.2 possible modification of twisted tapes are experimentally investigated. In section 1.3 an extensive work has done on conical, helical circular and wire coil inserts. In section 1.4 we have seen less work has taken on next-generation swirl generators. In all the cases, it was found that heat transfer, friction factor, pressure drop has notably increased. The increasing pressures drop, and friction factor due to the application of inserts has been addressed by some of the works. So, in general, it has seen that the heat transfer characteristics increases by different swirl generators an adverse that friction factor also increases. Conventional twisted tape and modified twisted tape are the popular swirl generators as they are easy to fabricate and to derive empirical relations. In this regard, the twisted tape is considered in work adding baffles to the twist. As hiTrain wire matrix creates higher turbulence resulting in higher heat transfer coefficient as stated by section 1.4, a comparative experimental study is carried out using twisted tape, twisted tape with baffles and hiTrain wire matrix as swirl generators.

3. Experimental setup:

Experimental investigation of heat transfer characteristics is carried out by using a well-insulated water to water shell and tube heat exchanger as shown in figure 1. Single shell, 16 tubes and two pass heat exchanger is used for the experiment; the hot water is supplied in tube side via flow meter using a hydraulic pump, similarly cold water on the shell side.

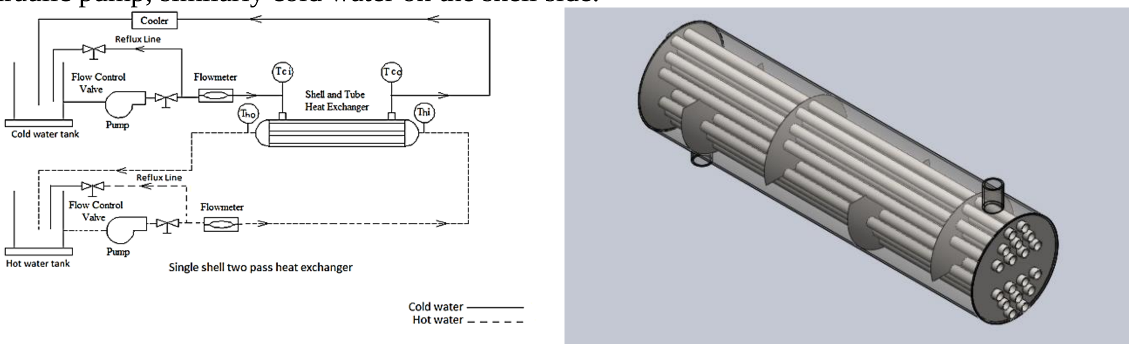

Figure 1: Schematic representation of Shell and Tube Heat Exchanger

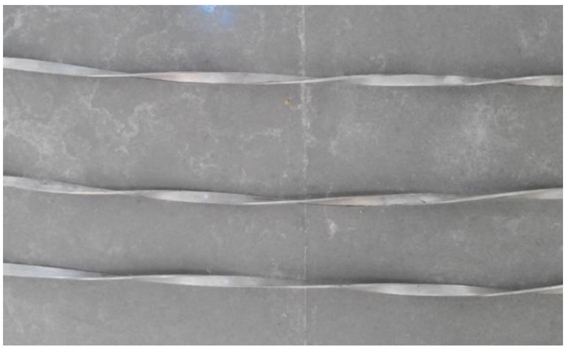

Figure 2: Twisted tapes of width 12mm, twist ratio 2.2 and length 825mm

Figure 3: Baffled twisted tapes of width 12mm, twist ratio 2.2 and length 825mm

The heat exchanger of shell and tube type has a shell with ID 0.2 meter and of tubes with ID and OD are 0.016 meters and 0.1924 meters respectively. The tubes are made up of stainless steel which has length 0.825 meters with the triangular pitch of 0.03 meter. The heat exchanger is provided with equally spaced four baffles with baffle cut of 35%.

The swirl generators used in present work is shown in Figure2, 3, 4 and 5 with caption specification. The material used for twisted tape, twisted tape with baffles and hiTrain wire matrix is stainless steel. Flow rates are varied in the range of 0.02 to 0.08 kg/s, while maintaining constant tube side hot fluid temperature (T1) value of 50^0C. The accuracy of the results is confirmed by ascertaining the readings obtained using instruments calibrated for known values of the temperatures and flow rates measured through data acquisition system using lab view platform.

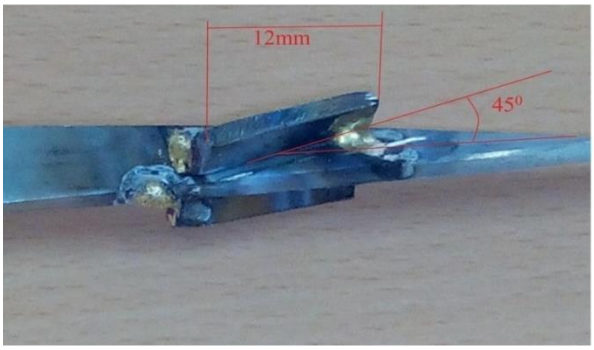

Figure 4: Details of Twisted Tape with Baffles

Figure 5: hiTrain wire matrix with 14 mm outer diameter, 1.2-1.6mm centre wire diameter, 190-210 loops per foot and length 825mm

4. Results:

The plot of heat transfer coefficient, pressure drop, Nusselt number and friction factor versus Reynolds number are drawn for different mass flow rates as shown below. Twisted tape with baffles and hiTrain wire matrix with baffles shows lesser heat transfer coefficient compared to twisted tape at lower Reynolds number. As Reynolds number increases the transition of increase of heat transfer coefficient takes place from twisted tape with baffles to hiTrain wire matrix due to bundle loop of hiTrain wire matrix as shown in figure 6. Twisted tape and hiTrain wire matrix show lesser pressure drop compared to twisted tape with baffles at lower Reynolds number. At higher Reynolds number, the hiTrain wire matrix and twisted tape show the same behaviour as in low Reynolds number, whereas twisted tape shows a drastic increase in pressure drop. The reason for twisted tape with baffles to show higher pressure drop is due to baffles which obstruct the fluid flow as shown in figure 7.

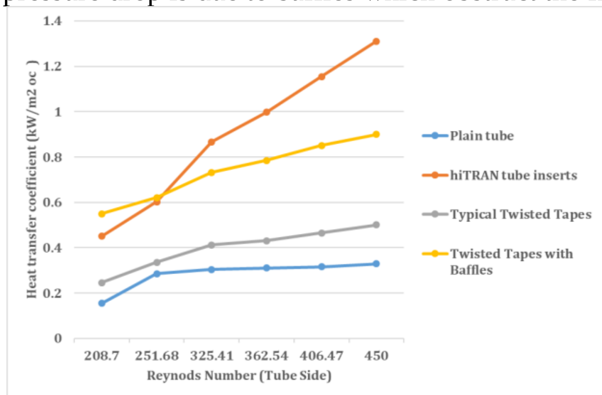

Figure 6: Heat transfer Coefficient versus Reynolds number

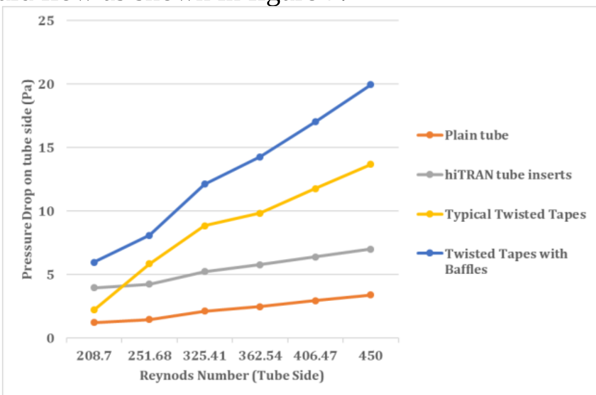

Figure 7: Pressure Drop on tube side versus Reynolds number

The hiTrain wire matrix and twisted tape with baffles show almost similar behaviour for variation of Nusselt number versus Reynolds number and shows higher value compared to twisted tapes and plain tubes as shown in figure 8. Twisted tape and twisted tape with baffles show higher friction factor in all range of Reynolds number compared to hiTrain wire matrix as shown in figure 9. The reason for hiTrain wire matrix to show lesser friction factor is the bundle of loops which helps the fluid to flow smoothly whereas the geometry of twisted tape with baffles obstruct the fluid flow.

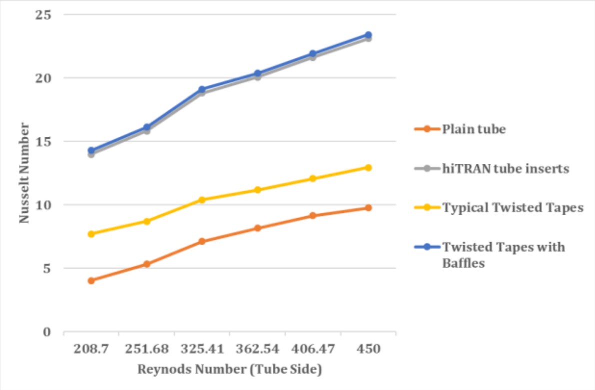

Figure 8: Nusselt Number versus Reynolds Number

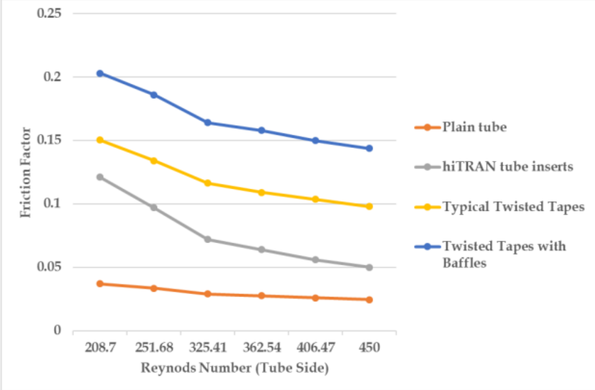

Figure 9: Friction Factor versus Reynolds Number

5. Conclusion:

A good swirl generator should possess a higher heat transfer coefficient, lower pressure drops and lesser friction factor, by experimental results, hiTrain wire matrix meets all these requirements. The reason for extensive application of twisted tape is due to ease of design and fabrication. The different loop density and intensity per foot length makes hiTrain wire matrix more complicated to fabricate. In lower Reynolds number (Laminar flow), the loops in hiTrain wire matrix shear the fluid flow resulting in higher heat transfer coefficient, lesser pressure drop and lesser friction factor. Twisted tape and twisted tape with baffles create swirl and recirculation zones resulting in the building pressure and increased friction factor. Experiments should be extended on the turbulent region to analyse the fluid flow properties of twisted tape baffles and hiTrain wire matrix using nanofluid as additives.

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