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Single Phase Laminar Flow Heat Transfer Enhancement A Review: (a) Combined Transverse Ribs and Twisted Tapes and (b) Combined Helical Screw Tape Inserts and Wire Coil Inserts

Manvendra Tiwari, Sarbendu Roy and Sujoy Kumar Saha[1]

Mechanical Engineering Department, IIEST Shibpur, Howrah India

***Abstract*:** *Passive heat transfer enhancement is the most widely adopted technique in industries due to low implementation cost. This paper presents state of the art reviews of two very popular passive techniques namely, wall roughness (ribs and wire coils) and swirl generators (twisted tapes and helical screw tapes). This paper concludes that ribbed surfaces and wire coils have potential to improve the performance of heat exchangers at low pumping power penalty and when coupled with twisted tapes/helical screw tapes, more compact and high performance heat exchangers may be developed with considerable saving of materials and energy.*

Keywords: *Heat transfer enhancement, wall roughness, swirl flow, wire coil inserts, helical screw tape inserts, twisted tape inserts.*

1. Introduction

For heat transfer enhancement, wall roughness (integral and non-integral) and swirl flow insert devices are the most commonly used passive methods in industries. Needless to say, the choice of enhancement technique is based on the constraints prevailing. For example, in food industries, due to hygiene problem, usage of wire coils for heat transfer augmentation is discouraged while mechanically deformed tubes such as corrugated and dimpled tubes are readily adopted. But on the other hand, in petrochemical industries, deformed tubes are not used for safety reasons. The fact that laminar flow conditions have poor heat transfer characteristics due to lack of fluid mixings, swirl generators, such as twisted tapes and helical screw tapes are being widely opted due to their potential to mix the gross flow. For this, review of selected experimental/numerical works pertaining to wall roughness (rib and wire coils) and swirl generators (twisted tapes and helical screw tapes) has been done and presented in the subsequent sections.

2. Ribs and Twisted Tape Inserts

Ribbed surfaces are used to mix fluid near the heat transfer walls only. The mechanism of heat transfer enhancement by the conventional ribs is based on the flow separation and reattachment. This technique is attractive for the heat transfer enhancement in single phase flow as the pressure drop penalty is quite low. The twisted tapes, on other hand, are popular because they give scope of improving the performance of existing heat exchangers, thus preventing the major modification cost. Further easy removal for inspection /maintenance/replacement makes preferred.

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2.1. Recent Experimental Works

Large number of experimental works has been carried out by researchers to investigate the thermohydraulic performance of various ribs and twisted tapes. S. Wang et al. [1] investigated heat transfer and friction factor of Therminol 55 liquid phase heat transfer fluid experimentally and numerically in a ribbed tube (Figure 1) with the outer and inner diameters of 19.0 mm and 15.0 mm, and pitch and height of the rib being 4.5 and 1.0 mm, respectively. They concluded that, for laminar flow through ribbed tube, the increase in heat transfer and friction factors in comparison to the plain tube were 3.3–4.6 times and 2.0–3.1 times respectively, while for turbulent case, the values increased 1.9–3.8 times and 3.0–3.9 times, respectively. They also calculated thermal enhancement factor and reported that in laminar flow, the thermal enhancement factor increased, reached maximum, and then decreased with increase in Reynolds number. While it decreased with the increase of Reynolds number in turbulent flow, indicating that the Nusselt number of Therminol 55 liquid phase heat transfer fluid is enhanced in convective heat transfer process and the rib effect is more effective in laminar flow region.

Fig.1: Ribbed tube

Tiwari and Saha [2] experimentally investigated the thermo-hydraulic performance of laminar flow through circular tube having integral transverse rib roughness (Figure 2) (rib height = 0.0526, 0.07894, 0.10526 and rib pitch = 20, 13.33, 10) and fitted with twisted tapes with oblique teeth (twist ratio = 2.5, 5.0; tooth horizontal length = 0.01052, 0.01578, 0.02105, 0.03157, 0.04210 and oblique). Servotherm oil (medium type) was used as a working fluid which gave the advantage of wide Prandtl number range (187-573). They reported that the friction factor increased 54–92% and Nusselt number increased approximately 158% with combined use of integral transverse rib roughness and twisted-tape with oblique teeth as compared to the individual cases. The performance evaluation revealed that, depending on rib height and pitch parameters, for constant pumping power, there was 35-75% increase in the heat transfer while there was 26-51% reduction in pumping power for constant heat duty. Finally it was concluded that the twisted-tape with oblique teeth inserts in combination with integral transverse rib roughness performed significantly better than the individual enhancement technique acting alone up to a certain value of fin parameter. This was so, because in case of combined enhancement techniques, the hydrodynamic boundary layer was more disturbed than the thermal boundary layer by integral transverse rib roughness in the duct and the thermal boundary layer separation and reattachment were more frequent than the hydrodynamic boundary layer. Therefore, the increase in heat transfer was more than the increase in pressure drop.

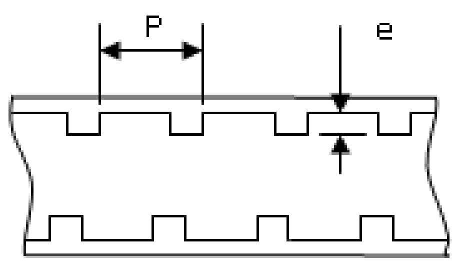

Fig. 2: Transverse ribs

Zhang et al. [3] performed numerical studies on heat transfer and flow characteristics for laminar flow in a tube (0.02m diameter) with multiple regularly spaced twisted tapes (thickness 0.001m and width 0.004m) with different clearance ratio. The simulation was conducted for the tube fitted with triple and quadruple twisted tapes (Figure 3) and Reynolds number varying from 300 to 1800. Numerical results revealed that, compared to the plain tube, there was 162%, 164% and 171%, increment in heat transfer coefficient of the tube fitted with triple twisted tapes for the clearance ratio of 0.25, 0.3 and 0.35 respectively while there was increment of 180%, 182% and 189%, respectively for the case of the tube fitted with quadruple twisted tapes. Further, corresponding friction factor values compared to the plain tube were reported as 4.06-4.74, 4.36-5.06 and 4.45-5.19 times higher for the case of triple twisted tapes and for the case of quadruple twisted tapes, 5.33-6.27, 5.84-6.76 and 5.99-7.02 times higher friction factor values were recorded compared to the plain tube. The tubes fitted with twisted tapes of the clearance ratio 0.35 gave better overall heat transfer performance than the tubes with twisted tapes of other clearance ratios and the tubes fitted with quadruple twisted tapes gave better overall heat transfer performance than the tubes with triple twisted tapes when Reynolds number is from 900 to 1800. They explained that the tubes fitted with more twisted tapes make the temperature in core flow more uniform, and thus the temperature gradient near the tube side is larger which means the heat transfer enhancement is greater.

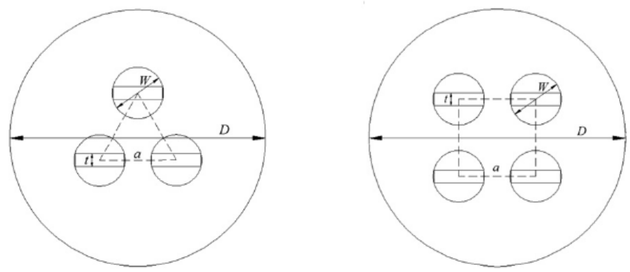

Fig. 3: Sectional view of tube fitted with triple and quadruple twisted tapes

Murugesan et al. [4] compared V-cut twisted tape insert (Figure 4) with plain twisted tape on the basis of heat transfer, friction factor and thermal performance factor characteristics. They reported that the V-cut twisted tape offered a higher heat transfer rate, friction factor and also thermal performance factor rather than the plain twisted tape; in addition, the impact of the depth ratio was more dominant than that of the width ratio for all Reynolds number; the thermal performance factors for all the cases were more than one and from this it may be concluded that the heat transfer enhancement is more dominant than the rising friction factor.

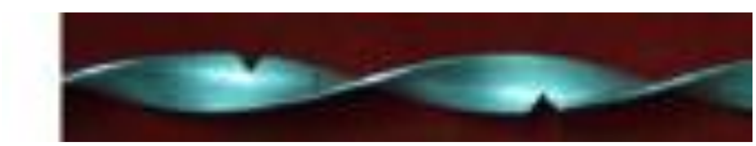
Fig. 4: V-cut twisted tape

3. Wire Coils and Helical Screw Tapes

Wire coils are wall roughness of non-integral type and exhibit several advantages such as easy installation and removal, wall roughness without loss of mechanical strength of original tube and possibility of installation in an existing smooth tube heat exchanger. Wire coil acts as a swirl flow generator and turbulence promoter. Due to these unique features, wire coils are readily adopted for heat transfer augmentation in oil cooling devices, preheaters or fire tube boilers. Nevertheless, twisted tapes are more popular and helical screw tape is a modified form of a twisted tape wound on a single rod giving single way smooth direction of flow like screw motion. Although, both helical screw-tape and twisted-tape generate a similar swirling flow in the circular tube, they have different characteristics of flow. For the helical screw-tape, the swirling flow rotates in single way smooth direction of flow like a screw motion, while the twisted-tape shows the swirling flow in two way directions of parallel flow simultaneously (two parallel flows separated by the twisted-tape).

3.1. Pertinent Research Works

Purandare et al. [5] experimentally investigated heat transfer and pressure drop characteristics of conical coil in shell and tube heat exchanger from spiral to helical coil configuration (Figure 5) at different intermediate cone angles (180o (Spiral), 135o, 90o, 45o, 0o (helical)), varying flow rate of cold and hot fluid (Re – 500 to 5000). It was observed that Nusselt number (Nu) and friction factor are functions of flow rates, tube diameter, curvature ratio and cone angle. Nu increased with increase in tube side flow rate (due to increases in the velocity of tube side fluid, intensity of secondary flow developed in the coiled tube increased and improved the fluid mixing) whereas it reduced with increase in shell side flow rate, reduced with increase in cone angle and reduced with tube diameter. Nu dropped about 48% from helical to spiral coil for constant shell side cold water flow. The friction factor (f) values were found least for helical coil and maximum for the case of spiral coil. Effectiveness (e) of coiled tube heat exchanger is a function of Re inside tube and it reduced with increase in Re. The helical coil had maximum effectiveness whereas this was minimum in case of spiral coil and in conical coil; as cone angle was increased, effectiveness decreased from helical to spiral.

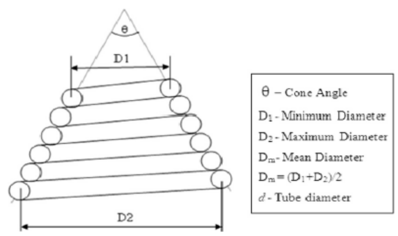

Fig. 5: Conical wire configuration

Martinez et al. [6] carried out experimental study on two wire coils (Figure 6) having different geometrical parameters, inserted in a smooth tube using both Newtonian (propylene glycol) and non-Newtonian fluids (1% of carboxyl-methyl-cellulose solution in water) to characterize their thermohydraulic behavior in laminar and transitional flow. They observed that, for both kinds of fluids, in laminar region, there was no significant heat transfer enhancement, but transition to turbulence was definitely advanced due to the presence of wire coils. For both fluids, maximum Nusselt number was found as 7.5 at around Re = 1900 on the onset of turbulence. However the presence of the wire coil showed a more positive effect on Newtonian fluid than in non-Newtonian ones, advancing the transition to turbulence.

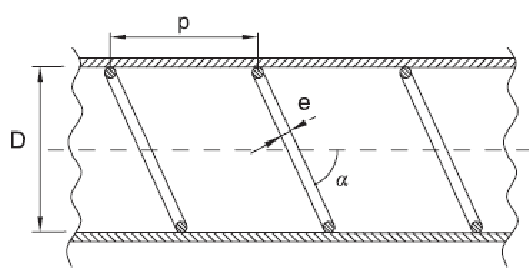

Fig. 6: wire coil fitted in smooth tube

Ibrahim [7] investigated heat transfer and friction factor characteristics of laminar flow through flat shell and tube type arrangement having helical screw tape insert (Figure 7 and Figure 8) with different twist ratios (2.17, 3.33, 4.3, and 5) and different spacer length (100 mm, 200 mm, 300 mm, and 400 mm). Cold and hot water were used as working fluids in tube side and shell side, respectively. The study of effect of twist ratio (y) and spacer length (S) on Nusselt number (Nu) and friction factor (f) revealed that Nu decreases with increases in S and Y. It was explained that the increase in S or Y leads to decrease in turbulence intensity of the flow inside flat tube with the inserted swirl sheet and in turn a decrease in Nu. Further, friction factor also had the same trend as that in case of Nu. Nevertheless, higher Nu and f values were obtained for plain flat tubes compared to plain circular tube.

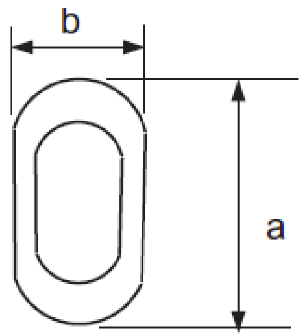

Fig. 7: Cross-sectional area of double flat tubes

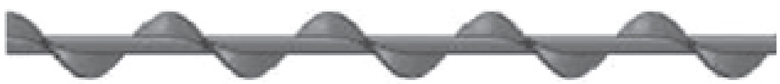

Fig. 8: Helical screw tape

Roy & Saha [8] presented experimental friction factor and Nusselt number data for laminar flow through a circular duct having helical screw-tape with oblique teeth inserts and wire coil inserts. They conducted heat transfer and pressure drop measurements in nine test sections, three each with 13 mm, 16 mm and 19 mm ID brass tubes with 1 mm thickness and 2 m length. They found through experimental investigation that the helical screw-tape with oblique teeth inserts in combination with wire coil inserts performs significantly better than the individual enhancement technique acting alone for laminar flow through a circular duct up to a certain value of fin parameter. They explained that, in case of only helical screw-tapes, there is only swirl flow; whereas there is additional fluid mixing, flow separation, reattachment and recirculation of fluid in presence of wire coil inserts. Also, there is faster momentum and thermal energy diffusion and transport in both molecular and bulk flow levels causing additional pressure loss and faster heat transmission. The inertia force due to swirl flow generated by helical screw-tapes enhances the periodic boundary layer separation and reattachment with temperature and velocity profiles equally flatter, caused by wire coil inserts and hence the enhancement. It has been observed from their work that friction factor increases by 45–132% and approximately 93–235% increase is observed in Nusselt number with combined use of wire coil inserts and helical screw-tape with oblique teeth inserts as compared to those in separate cases of wire coil inserts and helical screw-tape inserts with oblique teeth. They also presented predictive friction factor and Nusselt number correlations. They observed by performance evaluation technique that there is 36–133% increase in heat transfer for constant pumping power and 2–49% reduction in pumping power for constant heat duty. Further references can be obtained from the cross-references of the literature cited here.

Fig. 9: Helical screw tape with oblique teeth

4. Conclusions

A state of the art review of single phase laminar flow heat transfer enhancement for the combined use of transverse ribs and twisted-tape inserts and also the combined use of helical screw-tape inserts and twisted-tape inserts have been done. From the above discussion, following useful inferences may be drawn:

- Ribs and wire coils have potential to improve the performance of heat exchangers at a very reasonable installation cost
- Since ribs and wire coils influence flow patterns near the heat transfer surface, hence their thermo-hydraulic performances are strongly dependent upon their geometrical parameters
- It is possible to replace twisted tapes/helical screw tapes with the wire coils because, like twisted tapes wire coils also generate helical flow at the periphery superimposed upon the axially directed central core flow and induce centrifugal forces. Hence, in liquids where density decreases with temperature, centrifugal forces produce a movement of the heated fluid from the boundary layer towards the tube axis, which produces a heat transfer augmentation.
- It is possible to develop more compact heat exchangers by the combined use of wall roughness (wire coils/ribbed surfaces) and twisted tapes/helical screw tapes, which is quite encouraging from materials cost and energy savings point of view.

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