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Heat Transfer Enhancement by Turbulence Generator inside Heat Receiver

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ABSTRACT

Tubular heat exchanger (THEX), that has been in numerous engineering applications, represents an apparatus that makes heat to be exchanged between two fluids having different changing in temperatures and kept separated by means of a solid wall. In order to enhance the efficiency of the THEX, the rate of heat transfer at the tube side should be improved. Inserting a twisted tape inside the heat exchanger's tube is one of the passive techniques that has been widely used to improve the heat transfer especially in air conditioning and cooling, processes of power recovery, processes for food and dairy, and plants for chemical processing. The heat exchanger enhancement is achieved by means of using a twisted tape inserted with twisting ratios (TR) equal to 3.2, 4.4, and 5.5, independently. The influences of 2-D parameters such as Nusselt number and frictional coefficient on the THEX's effectiveness were investigated. The aim of the study is inserting a twisted tape inside the testing pipe to produced turbulent flow and, therefore, creating large turbulence rate inside the pipe that plays an significant role in improving the transferred heat and increasing the drop in the pressure. In this work, the inserted tape has a width and length equal to 21.5 mm and 1000 mm, respectively. The inner and outer diameters of the used pipes were 23 mm and 22 mm, respectively. The tested sectional length of the THEX was equal to 2000 mm. Reynolds number was changed from 500 to 7000. Results obtained from using twisted inserting tapes with varying TR were compared with result from plain tubes. These results were displayed in the contours show the distribution of the temperature and the trajectory of the flow trajectory by axial velocity for testing the low values of Reynolds number applicability in heat exchanger applications.

1. Introduction

Enhancing heat transfer technique refers to the improvement of thermohydraulic performance of heat exchanger. These techniques have been used in many applications such as heat exchangers, thermal power plant, process industries, refrigerators, air conditioning, automobiles, radars for space vehicles etc... High-performance thermal systems are needed in many engineering applications and, therefore, different methods are developed for improving the heat transfer (HT) [1] in the system. Improved surface can offer a combinations or one of the following situations that are directly affect the increasing rate of heat transfer. Unwelcome friction increase:

- Interruption of the boundary layers development and increasing the turbulence intensity.
- Increasing the area of heat transfer.
- Providing swirling and/or secondary flow.

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Nomenclature

f	Friction Factor	Pt	The Pitch
h	Heat Transfer Coefficient	Re	Reynolds Number
K	Thermal conductivity of the water	SW	Swirl velocity
Nu	Nusselt Number	TT	Twisted Tape
Pr	Prandtl Number	y	Twist Ratio

Heat augmentation techniques are classified generally into the following categories:

1-Active Techniques: concerning the usage and design, these techniques considered as complex techniques because they require external source of the input power to produce the wanted flow and improve the HTR (heat transfer rate). It usage still limited because of the requirement of source of the external power.

2-Passive Techniques: these types of techniques, no external source of input power is required. However, it depends on the system itself and finally leads to increasing the drop in the fluid's pressure. Normally, they utilize changes in geometry of the surface to the flow channel by including additional devices or inserts. Therefore, promoting higher coefficients of heat transfer via altering or disturbing the behavior of existed flow.

3-Compound Techniques: if there are two or more of previous techniques that used together at once for obtaining the increment in rate at which the heat is transfer that is superior than that formed by each individually, they are referred to a compound enhancement technique.

Accordingly, most researchers preferred using the passive techniques over others owing to their applicability and simplicity to apply in many applications. In this research, the passive technique is under consideration. The passive technique is applied for producing the swirl flow and in turn disturbing the regions rich of the boundary layer close to the HT surface.[2] The passive technique can be achieved via installing the swirl turbulators/generators within the heating system. Several researchers have studied the effect of different geometries on HT rate for several twisted tapes and how that enhance HT efficiency and affect the pressure drop.[3] Few of them are as follows: Manglik and Bergles [4] formed a connection between the friction factor and the Nusselt number Suresh Kumar et al. [5] reported thermo-hydraulic output due to using twisted tape inserts inside a large annulus with a hydraulic diameter. Withada Jedsdara Tanchai, Amnart Boomloi [6] performed the numerical study on the influence of twisting ratios (TR) on the thermal improvement and HT of the flow structure in a circle with single twisted tape, the result show that HT in tube with twisted tape is more effective than that without twisted tape and Reynold number decrease with increase twist ratio. Patil et al.[7] achieved the experimental test of an inventive water-heating system with the aid of CFD, the result showed that high HT could be obtained at high twist tape rotating. Yangium W. [8] studied numerically the optimized configuration of a regularly spaced short-length twisted tape inserted inside a circular tube to produce turbulence in the transferred heat in air utilizing CFD modeling for the Reynolds number between 10000-20000. The results exhibited that the larger angle of twisting produced a higher value of HT along with a higher resistance in the flow. Promvonge and Eiamsa-ard [9] simulated the 3-D CFD modeling for several inserted tape shapes inside the tubes of the heat exchanger. Three different types of different twisted tapes were used, namely plain, jagged V-cut, and V-cut along with utilizing two TRs that equal to 2 and 4. Friction factor and Nu increased in inverse.

manner with twist and width ratios at small depth ratio value the results shows that the HT rate in term of Nusselt number, Nu increase with the increase in depth ratio but decrease with increase in the width ratio of the TT. Salman et al. [10] used the CFD technique for simulating the twisted tape inserted inside the tube having circular cross section with different locations and ratios. The hydraulic characteristics and the transferred heat increased when decreasing the TR. Padalkar and Yadav [11] simulated the B.Cs of the exposed hot regions along with the configurations for generating swirl influence with TRs. Range. Fazlay Rubbi et al. [12] performed the numerical study to research HT performance increasing and flow behavior in a circular tube using twisted tape insert fitted with HES. The results show that for twisted tape insert with hemispherical extrude surface lead to increase in heat transfer rate above 69.4% compared to plain pipe due to effective vortex flow and best mixing caused by the TT insert.

In this paper, a review of HT enhancement using twisted tape with different twist ratios. This paper is also giving performance criteria for different twist ratios of twisted tapes.

2. The Numerical Analysis and grid sensitivity

In this study, CFD solid work software is used to investigate the turbulent swirl flow induced by twisted tape inserts. The solutions were completed with the multi physics commercial software solid work which can be used to model fluid flow, heat, and mass transfer for a big range of flow fields. CFD solvers (including solid work) help to discretize the flow field and solve the governing equations numerically. Solid work is used to investigate fluid and HT problems by solving the governing equations over a particular region of interest. Solid work is used to investigate fluid and HT problems by solving the governing equations over a particular region of interest. [13] Viscous flow is administrated by the conservation of mass, energy, and momentum equations as follows:

$$\vec{\nabla} \cdot \vec{V} = 0 \tag{1}$$

$$\rho \frac{D\vec{V}}{Dt} = \rho \vec{g} + \vec{\nabla} \cdot \tau'_{ij} - \vec{\nabla} p \tag{2}$$

$$\tau'_{ij} = \mu \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) + \delta_{ij} \lambda \vec{\nabla} \cdot \vec{V} \tag{3}$$

$$\rho \frac{Dh}{Dt} = \frac{Dp}{Dt} + \vec{\nabla} \cdot (k \vec{\nabla} T) + \tau'_{ij} \frac{\partial u_i}{\partial x_j} \tag{4}$$

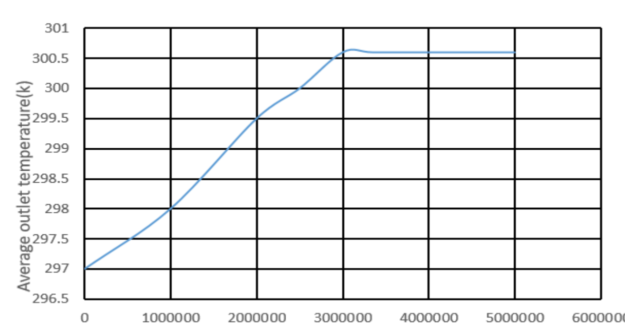

Figure 1. Grid sensitive.

Many grid sensitivity tests to ensure that the results are grid independent and 3350,000 cells number was selected for all the computations done in the present work.

2.1. Problem and Boundary Conditions Description

CFD have used to examine effect of several ratios of the tape placed inside a long pipeof a half-length on the rate of HT. A specific pipe of 2m in length and 2.2 cm in diameter is used. In the current work, the wall of The pipe is assumed to be maintained at temperature of 310 K. while the temperature of the inlet water is maintained constant at 290 K. Three values of the diameter/pitch ratio (TT) are set as 3.2, 4.4, and 5.5. Each one of the TRs has studied for Reynolds number within the range of (500 to 7000).

Figure 2. Twisted tape insert.

Y=3.2

Y=4.4

Y=5.5

Plain pipe

Figure 3. Plain pipe and pipe include twist tapes with three twist ratios.

Table 1: Explain the pitch of three twist ratios and the number of twist for each ratio.

Twisted tape(TT)	Pitch(Pt)	Pt/ dt	Number of twists
TT1	70mm	3.2	15
TT2	90mm	4.4	11
TT3	125mm	5.5	7

3. Theoretical Calculation

Manglik and Bergles have developed the theoretical calculation based on their well-accepted correlation of the twisted tape.[14], [15] They developed empirical relations for swirl flow as follows:

$$\text{sw} = \mathbf{Re_x}/\sqrt{\mathbf{y}} \tag{5}$$

$$(\mathbf{fRe}) = \frac{15.76}{\mathrm{Re}}\left[\frac{\pi+2-2\delta/d}{\pi-4\delta/d}\right]\left(1+10^{-6}\mathbf{sw}^{2.55}\right)^{1/6} \tag{6}$$

For uniformly heated (UHF) tubes, the older Hong and Bergles [16]correlation given below:

$$\boldsymbol{Nu} = 5.172[1+5.484\times10^{-3}\boldsymbol{Pr}^{0.7}(\boldsymbol{Re}/\boldsymbol{y})^{1.25}]^{1/2} \tag{7}$$

For smooth tube:

The theoretical friction factor

$$\mathbf{f} = 0.046\times\mathbf{Re}^{-0.2} \tag{8}$$

The theoretical Nusslet number for smooth tube:

$$\mathbf{Nu} = 0.023\times\mathbf{Re}^{0.8}\times\mathbf{Pr}^{1/3} \tag{9}$$

$$\boldsymbol{h} = \frac{0.023\times\boldsymbol{k}}{\boldsymbol{d}}\times\boldsymbol{Re}^{0.8}\times\boldsymbol{Pr}^{1/3} \tag{10}$$

4. Results and Discussions

In this numerical and theoretical study, the results obtained of twisted tape effect on heat transfer cofficient and pressure drop and compare this result with the plain.

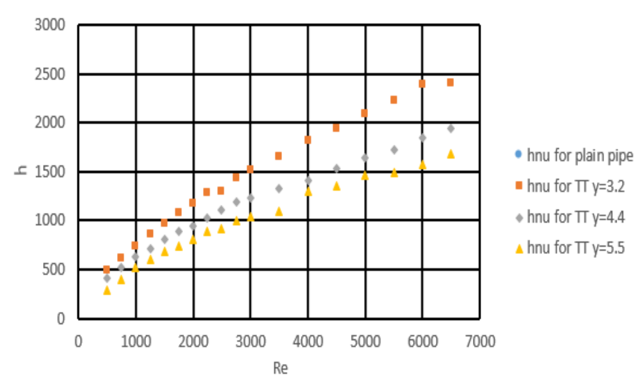

Figure 4. Numerical solution of heat transfer coefficient vs. Reynolds Number for plain pipe, y=3.2, y=4.4 & y=5.5.

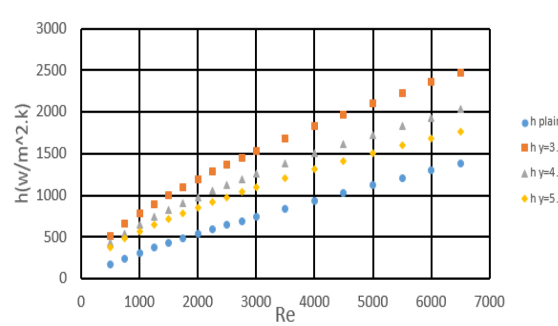

Figure 5. Theoretical solution of heat transfer cofficient and Reynold number.

Fig. 4 and **Fig. 5** show coefficient of heat transfer (h) variation as a function to the Reynolds number for a smooth tube at different values of twist tape. One can notice that decreasing the twist ratio lead to develop swirls with higher degree. The presence of these swirls increases the flow turbulence, thereby, increase the coefficient of HT. In other words, HT rate increase as twist ratio decrease. The higher value of the coefficient of HT is noticed at the presence of the secondary flow, which develop the higher disturbance in the flow and the thermal boundary layer close the wall. That in turns, leads to increase the rate at which the heat is transferred.

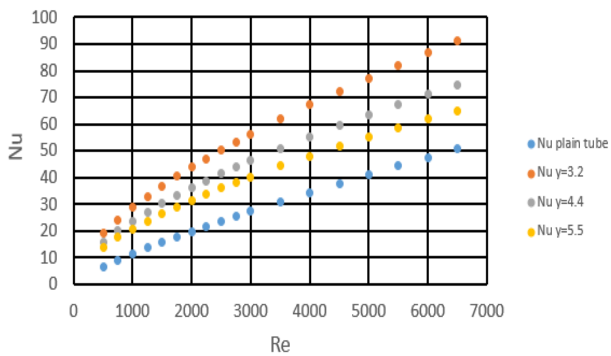

Figure 6. Theoretical solution of Nusslet number for plain tube and the three twist ratios.

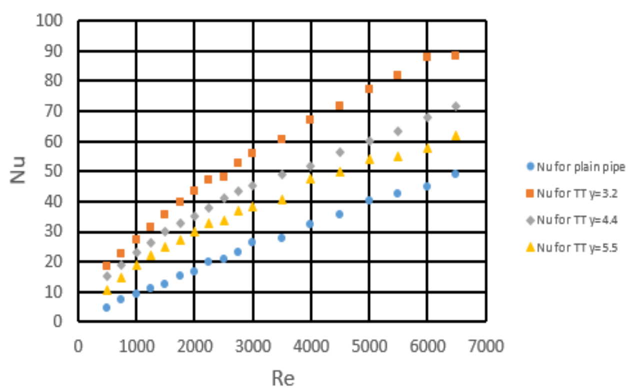

Figure 7. Numerical solution of Nusslet number for three twist ratios and plain pipe.

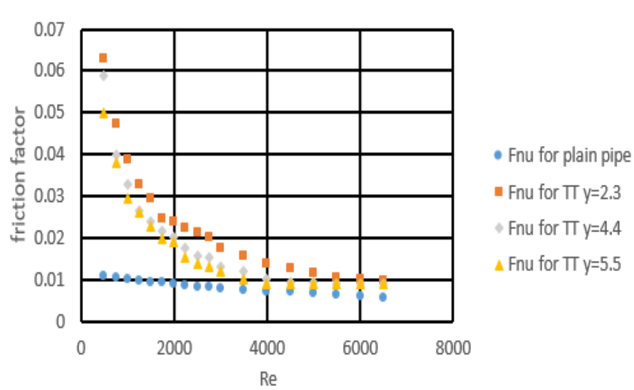

Figure 8. Numerical solution of friction factor for three twist ratios and plain pipe.

Fig. 8 shows the variation of (f) with Re number for plain pipe, and pipe with twist ratios (y=3.2, 4.4, 5.5). When twist ratios decreases, a high degree of vortex is created which leads to high friction cofficient. High friction factor is noted with twist ratio=3.2 due to increase in degree of swirl created by the inserted tapes.

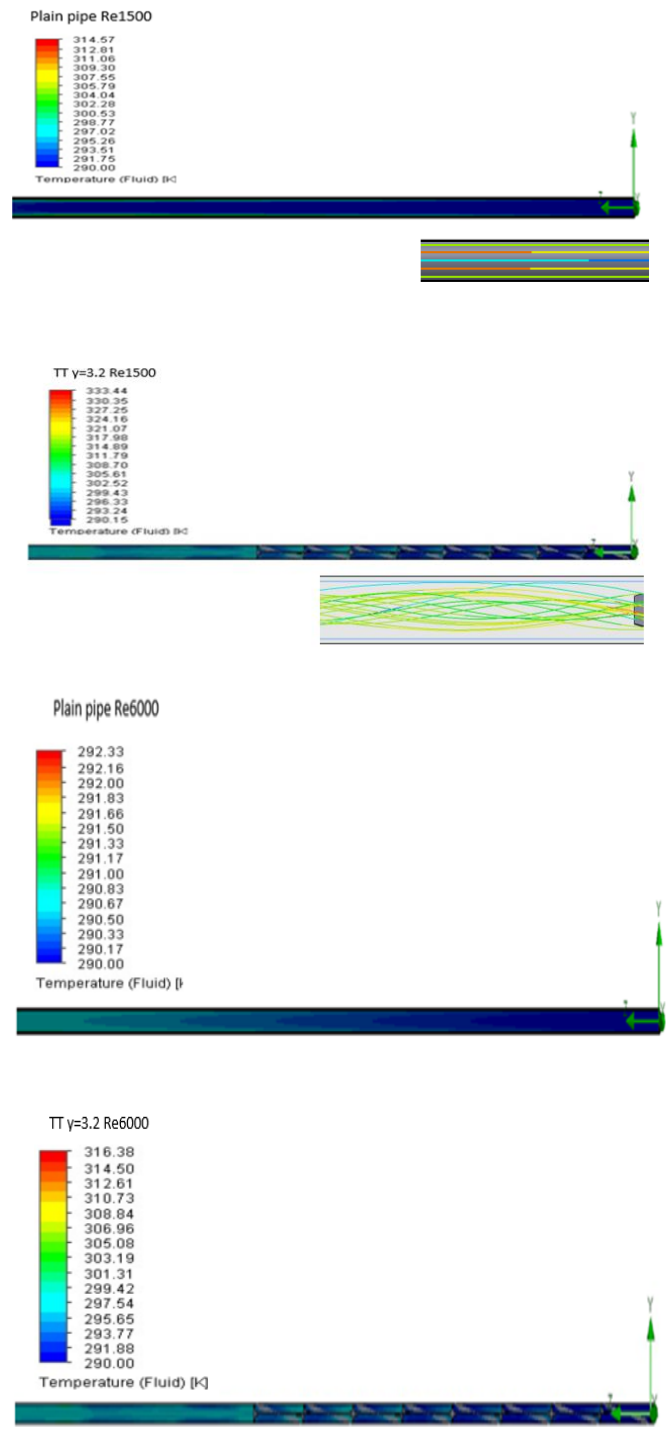

Figure 9. Comparison of the temperature distribution between plain pipe with that corresponding with a twist tape for y=3.2.

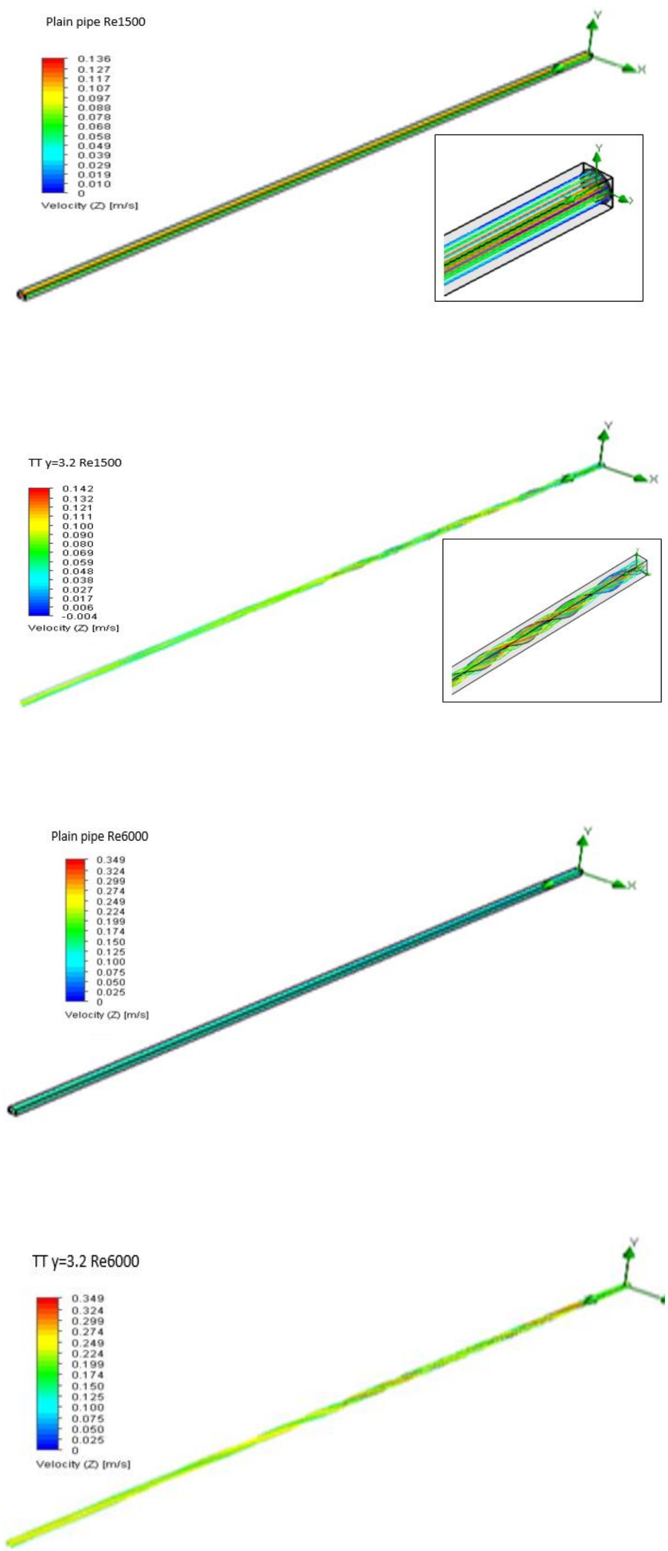

Figure 10. Comparison of trajectory of flow (identified by z-velocity) between plain pipe with that corresponding with a twist tape for y=3.2.

Fig. 9 show the distribution of temperature between fluid flow and the wall for the HT. The results show that the temperature gradient decreases for both cases with increasing the Reynolds number due to higher rate of the flow. The twist tape effect on the temperature distribution is obvious even on the first half of pipe. Especially for low Reynolds number, the variation temperature can be seen on all the length of the pipe. In the twist tape region, the HT increases as the swirl flow increases. The maximum temperature ranges (due to the presence of the twist tape) are 333 K and 316 K for laminar and turbulent flow, respectively.

Fig. 10 shows the demonstration of the motion of the swirl due to the twist tape with z velocity for TR=3.2, which is increasing with the number of Reynolds.

5. Validation test

Comparison between present numerical work and standard correlations (Hong and Bergles correlation [16]) for Nusselt number for plain pipe in **fig. 11** The results of present work reasonably agree within 8.3% error for Nusselt number.

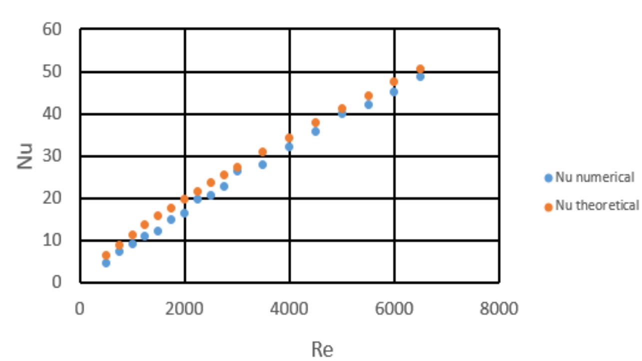

Figure 11. comparison between numerical and theoretical study.

6. Conclusion

The maximum rate HT is achieved by using twisted tape accompanied at 3.2 as a twist ratio. All twisted tape inserts would significantly improve the HT rate compared to the plain tube. The results from this numerical study can be concluded as follows:

- As the twisted ratio decreases, the Nu for twisted tape inserted increases at the specified twist ratios of 3.2, 4.4, and 5.5.
- Friction factor increases as the twist ratios decrease.
- Turbulent intensity considers a useful parameter for analyzing the swirling motion to increase HT.
- The tape presence decreases the hydraulic diameter. This reduction increases the coefficient of HT even when the tape twist is zero.
- The presence of the tape twist develops a tangential component of the velocity and this increases the flow speed specifically close to the wall. The main reasons of the increasing in the HT rate are the increasing in the shear stress at the wall and the secondary flow mixing.
- The higher the wall thermal contact, the higher the rate of the HT from the tape. Little HTs from a loosely fitting tape is however expected.
- By increasing the fluid turbulence in, twisted tape inserts

increases the HT rate of the heat exchanger.

- Turbulent or swirl flow increases the thermal contact by boundary layer thickness reduction.

REFERENCES

[1] Chaware, P. and C. Sewatkar, *Effects of tangential and radial velocity on the heat transfer for flow through pipe with twisted tape insert-turbulent flow.* International Journal of Heat and Technology, 2017. **35**(4): p. 811-820.

[2] Habeeb, L.J., F.A. Saleh, and B.M. Maajel, *CFD modeling of laminar flow and heat transfer utilizing Al2O3/water nanofluid in a finned-tube with twisted tape.* FME Transactions, 2019. **47**(1): p. 89-100.

[3] Tusar, M., Abdullah, I, Majedul,Y, Prasad,S, Bodius, *CFD study of heat transfer enhancement and fluid flow characteristics of turbulent flow through tube with twisted tape inserts.* Energy Procedia, 2019. **160**: p. 715-722.

[4] Manglik, R.M. and A.E. Bergles, *Heat transfer and pressure drop correlations for twisted-tape inserts in isothermal tubes: part I—laminar flows.* 1993.

[5] Suresh Kumar, P., P. Mahanta, and A. Dewan. *Study of laminar flow in a large diameter annulus with twisted tape inserts*. in *Proceedings of 2nd international conference on heat transfer, fluid mechanics, and thermodynamics, Victoria Falls, Zambia*. 2003.

[6] Jedsadaratanachai, W. and A. Boonloi, *Effect of twisted ratio on flow structure, heat transfer and thermal improvement in a circular tube with single twisted tape.* Journal of Mathematics and Statistics, 2014. **10**(1): p. 80.

[7] Patil, J.V., M.P.P. Patil, and H. Patil, *A review on experimental investigation of an innovative water heating system.* 2016.

[8] Wang, Y., Hou, M., Deng, X., Li, L., Huang, C., Huang, H., Zhang, G., Chen,C., Huang, W., , *Configuration optimization of regularly spaced short-length twisted tape in a circular tube to enhance turbulent heat transfer using CFD modeling.* Applied Thermal Engineering, 2011. **31**(6-7): p. 1141-1149.

[9] Promvonge, P. and S. Eiamsa-ard, *Heat transfer behaviors in a tube with combined conical-ring and twisted-tape insert.* International Communications in Heat and Mass Transfer, 2007. **34**(7): p. 849-859.

[10] Salman, S.D., Kadhum, A.A.H., Takriff, M.S., Mohamad, A.B. *CFD simulation of heat transfer augmentation in a circular tube fitted with alternative axis twisted tape in laminar flow under a constant heat flux.* Heat Transfer—Asian Research, 2014. **43**(4): p. 384-396.

[11] Yadav, R. and A. Padalkar, *CFD analysis for heat transfer enhancement inside a circular tube with half-length upstream and half-length downstream twisted tape.* Journal of Thermodynamics, 2012. **2012**.

[12] Rubbi, F., F K. Habib, M. Tusar, L. Das, and M. T. Rahman, *Numerical Study of Heat Transfer Enhancement of Turbulent Flow Using Twisted Tape Insert Fitted with Hemispherical Extruded Surface.* Journal homepage: http://iieta. org/journals/ijht, 2020. **38**(2): p. 314-320.

[13] Hamzah, D.A. and K. Al-Farhany, *Effect of Twisted Tape Ratio on the Solar Generator Half-length Pipe.* Journal homepage: http://iieta. org/journals/ijht, 2019. **37**(2): p. 407-412.

[14] Manglik, R. and A. Bergles, *Heat transfer enhancement and pressure drop in viscous liquid flows in isothermal tubes with twisted-tape inserts.* Wärme-und Stoffübertragung, 1992. **27**(4): p. 249-257.

[15] Manglik, R.M. and A.E. Bergles, *Heat transfer and pressure drop correlations for twisted-tape inserts in isothermal tubes: part II—transition and turbulent flows.* 1993.

[16] Hong, S. and A. Bergles, *Augmentation of laminar flow heat transfer in tubes by means of twisted-tape inserts.* 1976.