Heat transfer enhancement in heat exchangers with V-cut twisted tape inserts: A review

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ABSTRACT

Improving heat transfer in the heat exchangers can be achieved by infringement of the laminar sub-layer or generating forced convection by employing twisted tape inserts as turbulence promoters. Significantly less research has been carried out on V type with combined cut twisted tape inserts in heat exchangers. This mini-review paper discusses the influence of various shapes V type with combined cut in twisted tape inserts by a few researchers in improving the performance of heat exchangers. V type with combined cut twisted tape design, shapes used, the influence of forced convection, and thermal and hydraulic performance have been discussed.

1. Introduction

Devices for transferring heat are widely used in various thermal engineering and manufacturing sectors, such as the biochemical industry, gas turbines, air and refrigeration, and thermal power generation [1]. Utilizing swirl flow generators is one of the most promising passive strategies that has recently gained importance for improving the heat transfer rate and increasing the effectiveness of thermal devices for various applications. As equipment to promote heat transfer, swirl flow generators are efficient and cost-effective because they provide excellent flow mixing [2]

Numerous studies have examined the use of twisted tape in heat exchangers. For example, using quad-channel twisted tapes (QCTT) increased the friction factor more than using typically twisted tapes [3], conducting combined research on twisted tape and nanofluid [4], using a spiral pipe with twisted tape [5] and Fig.1 represents the spiral pipe heat exchanger used by [5]. For the validation of experimental correlation and CFD methodology, the results for conical-shaped heat exchangers have been investigated using the proposed techniques reported by Chen et al. [6], also Fig.2 conical-shaped heat exchangers used by Chen et al. [6].

The supplement of twisted tapes can reduce the coke deposition, subsequently slowing the growth of the total flow friction investigated by twisted-tape insertion can reduce coke deposition, which slows the progression of the overall flow friction studied by [7]. Evaluation and discussion of stream behavior and overall heat transfer performance in a spiral pipe with a twisted tape insert subjected to a constant wall temperature [8]. This work compared the heat transfer and flow friction of a dual-twisted tape turbulator-equipped double-pipe heat exchanger with and without air bubble injection [9].

The overall performance parameters of the circular pipe with and without V-cut inserts have been measured at varied flow rates under constant heat flux circumstances

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[10]. Fig. 3 depicts the twisted tape inserts (turbulence promoters) used in round pipe heat exchangers [10]. Fig. 4 signifies the twisted tape inserts in heat exchangers[11].

Turbulence generators have been identified as one of the most promising ways to increase fin-and-round pipe heat exchangers' air-side heat transfer capacity [12]. The heat transfer and flow friction of a novel form of micro-fin helically coiled pipe (MF-HCT) are compared to those of conventional smooth helically spiral round pipe [13].

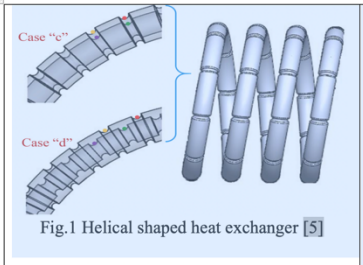


Fig.1 Helical shaped heat exchanger [5]

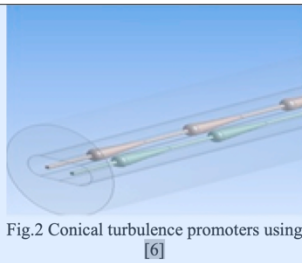


Fig.2 Conical turbulence promoters using [6]

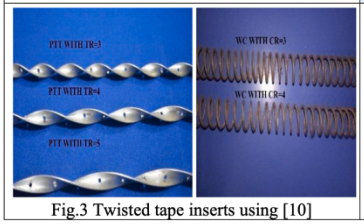


Fig.3 Twisted tape inserts using [10]

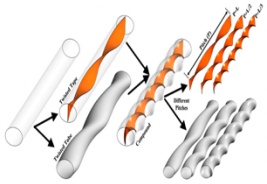


Fig.4 twisted tape inserts using [11]

2. Heat Transfer characteristics in V type with combined cut twisted tape inserts heat exchangers

Investigated the consequence of a V with combined cut twisted tape inserts on overall efficiency performance appearances in a round pipe for dissimilar twist ratios and dissimilar depth and breadth ratio combinations. The consequences show that reducing V-cut twist ratios (y), V-cut width ratios (WR), and increasing V-cut depth ratios (DR) improve the thermal performance and flow friction in the pipe with V with combined cut twisted tape [14]. Hydrodynamic and thermal performance are examined experimentally in a round pipe heat exchanger with an innermost corrugated pipe filled with numerous twisted tapes ranging from conservative to adjusted types such as perforated, V type with combined cut, and U-cut. The critical metrics on heat transmission and flow friction demonstrate that the heat transfer and flow friction are more significant than the empty corrugated pipe in all twisted tape corrugated pipes [15], various researchers have investigated other similar studies in a round pipe with V-cut twisted tape inserts [16], [17] and [18].

The heat transmission and friction properties of a heat exchanger pipe equipped with a twisted perforated tape insert with V type with combined cuts are investigated. V-type with combined cuts are added, and the V type

with combined cut relative pitch ratio is altered from 1 to 2. 1.58 is shown to be the highest hydraulic as well as thermal performance parameter [19].

Experimentally examined the hydrodynamic-thermal performance of turbulent tube flow through V with combined cut twisted tapes and indicated that the V-cut twisted tape performance is better than compared to plain wall round pipe heat exchangers [20]. Inserts significantly improve the overall efficiency of a heat exchanger. The current work explores the hydraulic and thermal performance of solid twisted tape, twisted perforated tape, and twisted perforated tape with double V type combined cuts for the range of 2000-25000 [21].

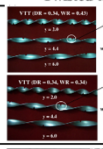
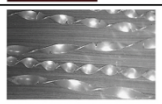
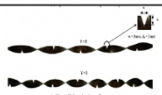
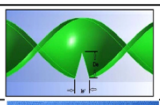
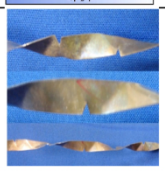
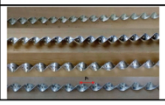
Other similar experimental and numerical analyses on overall thermal performance in round tube pipe fitted with unique V type with combined cut twisted tape [22], [23], and [24]. Similarly, the suggested inserts are installed in the internal pipe of the double pipe heat exchanger to generate a swirl motion and raise the intensity of turbulence in the fluid flow [25]. Table.1 represents the previous investigations on V type with combined cut twisted tape inserts heat transfer and flow friction correlations developed by researchers.

Table.2 represents the previous investigations on V type with combined cut twisted tape insert heat exchangers.

Table.1 V type with combined cut twisted tape inserts heat transfer and flow friction correlations developed by researchers

Ref.	Nusselt number correlation	friction factor correlation
Murugesan et al. [14]	$Nu = 0.0296Re^{0.853}Pr^{0.33}y^{-0.222}(1+[d_e/W$	$f = 08.632Re^{-0.615}y^{-0.269}(1+[d_e/W)^2$
Saravanan et al. [16]	$Nu_{HSC} = 0.005Re^{1.002}y^{-0.127}Pr^{1.045}$ $Nu_{HVC} = 0.018Re^{0.861}y^{-0.158}Pr^{0.853}$	$f_{HSC} = 0.382Re^{-0.174}y^{-0.079}$ $f_{HVC} = 0.382Re^{-0.165}y^{-0.109}$
Langeroudi and Javaherdeh [20]	$Nu = 0.04125Re^{0.8615}(W_c/W)^{-0.0891}$ $(D_c/W)^{0.082}y^{-0.2106}Pr^{0.4}$	$f = 013152Re^{-1.23}(W_c/W)^{-0.1117}$ $(D_c/W)^{0.1725}y^{-0.2998}$
Kumar et al .[21]	$Nu = 0.0678Re^{0.78}y^{-0.37}$ $Nu = 0.08Re^{0.77}y^{-0.36}$ $Nu = 0.1126Re^{0.75}y^{-0.39}$ $Nu = 0.11Re^{0.76}y^{-0.43}$	$f = 114.89Re^{-0.63}y^{-0.75}$ $f = 74.18Re^{-0.6}y^{-0.68}$ $f = 66.57Re^{-0.53}y^{-0.68}$ $f = 88.89Re^{-0.6}y^{-0.73}$

Table.2 Previous investigations on V type with combined cut twisted tape insert heat exchangers

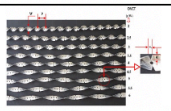
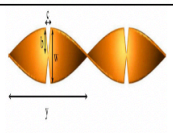
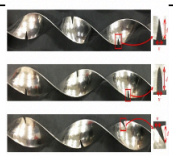
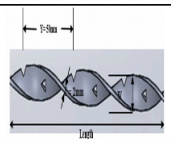
Authors	Twisted tape	Parameters	Major findings
Murugesan et al. [14]		y=2.0, 4.4 and 6.0 DR=0.34 and WR=0.43, Re=2000-12000	All situations have multiple thermal performance factors, showing that the influence of overall efficiency due to the improving tool (V-cut twisted tape) is more dominating than the effect of growing friction factor, and vice versa.
Hasanpour et al. [15]		Twist ratios=3-7, Hole diameter ratio= 0.11-0.33, Width and depth ratio of the cuts vary from 0.3 to 0.6 and Re=5000 to 15,000	The significant outcome is that the influence of V type with combined cut increases the efficiency; however, this assumption is additional evident at lower twist ratios than at higher twist ratios.
Saravanan et al. [16]		Twist ratio = 3-5, Re=200-1200	Heat transfer with twist ratio 3.0 has the most outstanding overall efficiency due to the fluid's increased swirl flow and larger contact surface area.
Abed et al. [17]		Re=4000-9000, Twisted ratio=4.0-6.0, Heat flux=5000-10000W/m².	The (V type with combined cut) twisted tape delivers superior overall performance with each twisted ratio value than the (P-TT).
Arunachalam and Edwin [18]		0.01% Cu + 0.4% Alumina, 8 mm square segment V type with combined cut twisted tape insert round pipe produced from 23.5 mm tape, width (W) above a 10 mm width (w) of V type with combined cut and 8 mm depth	Overall performance for 0.1% Al_2O_3/H_2O based nanofluid and 0.4% Al_2O_3/H_2O based nanofluid are 2.5% and 20.8% greater than for pure water, respectively. It is 13.6% and 35.9% more remarkable with a tape insert than with water in a standard pipe.
Kumar et al. [19]		Twist ratio=2-6, Reynolds number=2,700–23,400, Pitch ratio=1-2.	The overall efficiency of twisted tape improves with decreasing twist ratio for all twisted tape geometries.

3. Comparative Analysis

This section contained a comparative investigation of several types of V type with combined cut twisted tape inserts for heat transfer enhancement. The comparison results without V type with combined cut twisted tape insert versus V type with combined cut twisted tape insert are shown in Fig.5.

It is apparent that V type with combined cut twisted tape inserts outperforms non-V type with combined cut twisted tape inserts because the depth and width of isosceles V type with combined cuts, significantly impact the flow stream, raise the flow friction, and raise the heat transfer rate. The correlations obtained by applying geometrical corrections based on the plain pipe are strongly advised.

Fig.6 compares water (V type with combined cut twisted tape inserts) and nanofluid (V type with combined cut twisted tape inserts), with nanofluid significantly outperforming water. According to a literature review, nanoparticles, which are often metallic or metal oxide, considerably improve the thermal properties of the nanofluid, raising conduction and convection coefficients and permitting a more significant overall heat transfer. The comparative examination of different cut twisted tape inserts in Fig.7 demonstrates that the obtuse V type with combined cut configuration exhibits a considerably noticeable enhancement compared to the isosceles V type with combined cut design.

Langeroudi and Javaherdeh [20]		y = 4.5-6.07, depth and Width ratios =0.285–0.5, Reynolds number=5300 to 25,700	The overall efficiency rises with increasing flow parameter value in the turbulent domain, and the overall efficiency is better than V-cut twisted tape than that simple twisted tape.
Kumar et al [21]		V type with combined cuts are different in the range of 0.2–0.27, Re=2000–25000	The size of the V type with combined cuts is shown to effect both heat transmission and friction, albeit it appears to provide somewhat better performance.
Nakhchia, J.A. Esfahani [22]		Cut ratios=0.6-1.8, Twisted tape cut= 0.6, 1, 1.4, 1.8, Re=5000 to 15,000	Twisted tape with bigger slits can provide an additional recirculation flow (on top of the basic swirl flow) that promotes fluid mixing between the pipe walls and the core area.
Chu et al. [23]		Re=4000 to 10,000, Twist ratios= 4-8	Average heat transfer with Y = 4, 6, and 8 may be enhanced 1.5 times, while the flow friction is raised by 2.7 times compared to the smooth pipe.
Singh & Jahar Sarkar [24]		DR = 1/2 and 1/3, WR = 1/2 and 1/3, Twist ratios=5-15	PCM nanofluid outperforms all other working fluids at low flow rates. The significant parameter indicates the most outstanding data at a small mass flow rate for PCM nanofluid employing V type with combined cut twisted tape of TR = 5 within the examined ranges.
Kumar et al. [25]		Pitch=100-120, Re=1000-15000	The Nusselt number changes significantly in the laminar case compared to the turbulent situation. However, employing the perforated-peripheral cut insert produces better results than using no inert or plain insert.

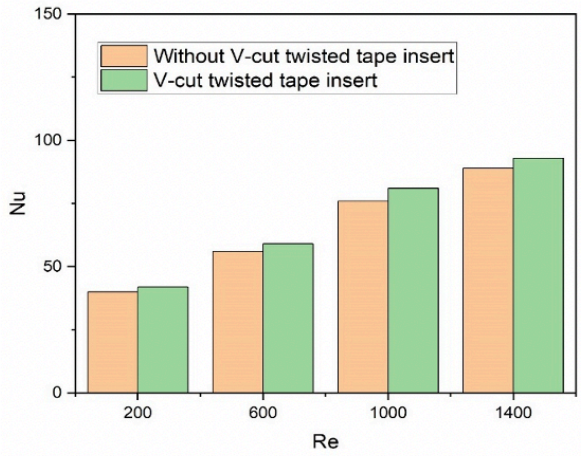


Fig.5 Comparison results of without V type with combined cut twisted tape insert vs V type with combined cut twisted tape insert.

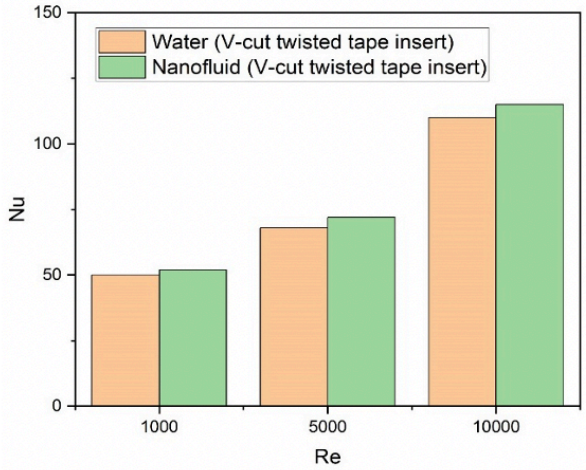


Fig.6 Comparison results from water vs nanofluid

4. Conclusions

Present article a review of the use of V type with combined cut in turbulence promoters (twisted tape inserts) to improve overall efficiency. As per the literature review, the following are the paper's findings.

- Compared to ordinary twisted tape, the V type with combined cut twisted tape had a greater overall efficiency. Furthermore, for all Reynolds numbers, the influence of the depth ratio was more significant than that of the width ratio.
- The primary consequence is that the influence of V type with combined cut increases the Nusselt number, however, this assumption is more obvious at lower twist ratios than at higher twist ratios. The following is an explanation for this improvement. The V type with combined cut creates more turbulence in the fluid along the pipe wall and vorticity behind the cuts, resulting in a more excellent heat transfer value than the standard TT in the corrugated pipe.

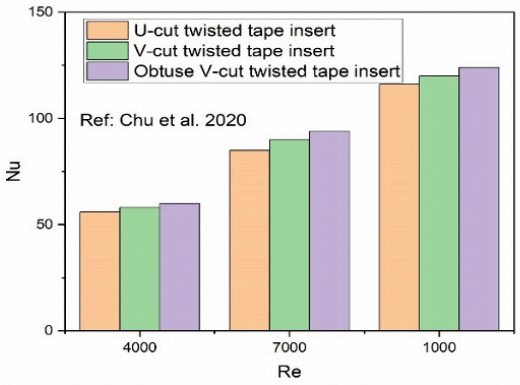


Fig.7 Comparison of different types of shapes with cut twisted tape insert.

- The usage of twisted tape improves heat transmission. The (V type with combined cut) twisted tape improves heat transmission with all twisted ratio values more than the (P-TT).
- Because of the efficient secondary flow and primary swirl flow, the V-TT delivers better overall efficiency than the P-TT. The turbulence strength in this region is increased by a severe collision of the swirl flow created by the TT and the flow stream through the cuts, which promotes heat transmission between the pipe walls and the core region. Twisted tape with bigger slits can provide an additional recirculation flow (on top of the basic swirl flow) that promotes fluid mixing between the pipe walls and the core area.

References

1.Piriyarungrod, N., et al., Intensification of thermo-hydraulic performance in heat exchanger tube inserted with multiple twisted-tapes. Applied Thermal Engineering, 2018. 136: p. 516-530.

2. Bahiraei, M., N. Mazaheri, and F. Aliee, Second law analysis of a hybrid nanofluid in tubes equipped with double twisted tape inserts. Powder Technology, 2019. 345: p. 692-703.

3. Dalkılıç, A.S., et al., Single phase flow heat transfer characteristics of quad-channel twisted tape inserts in tubes. International Communications in Heat and Mass Transfer, 2020. 118.

4. Bahiraei, M. and A. Monavari, Thermohydraulic performance and effectiveness of a mini shell and tube heat exchanger working with a nanofluid regarding effects of fins and nanoparticle shape. Advanced Powder Technology, 2021.

5. Cao, Y., et al., Helical tube-in-tube heat exchanger with corrugated inner tube and corrugated outer tube;

experimental and numerical study. International Journal of Thermal Sciences, 2021. 170.
6. Chen, H., et al., Thermal, hydraulic, exergitic and economic evaluation of a flat tube heat exchanger equipped with a plain and modified conical turbulator. Case Studies in Thermal Engineering, 2021. 28.
7. Cheng, X., S. Feng, and Q. Bi, Surface coke deposition influences on flow and heat transfer of hydrocarbon fuel in circular tubes with twisted-tape inserts. International Communications in Heat and Mass Transfer, 2021. 122.
8. Liaw, K.L., J.C. Kurnia, and A.P. Sasmito, Turbulent convective heat transfer in helical tube with twisted tape insert. International Journal of Heat and Mass Transfer, 2021. 169.
9. Pourahmad, S., et al., Experimental study of heat transfer and pressure drop analysis of the air/water two-phase flow in a double tube heat exchanger equipped with dual twisted tape turbulator: Simultaneous usage of active and passive methods. Journal of Energy Storage, 2021. 44.
10. Ravikiran, B., K. Ramji, and T. Subrahmanyam, Investigation on thermal performance of different wire coil twisted tape inserts in a tube circulated with water. International Communications in Heat and Mass Transfer, 2021. 122.
11. Mashayekhi, R., et al., Hydrothermal performance of twisted elliptical tube equipped with twisted tape insert. International Journal of Thermal Sciences, 2022. 172.

12. Wu, J., et al., Thermo-hydraulic performance and exergy analysis of a fin-and-tube heat exchanger with sinusoidal wavy winglet type vortex generators. International Journal of Thermal Sciences, 2022. 172.

13. Yuan, Y., et al., Economic-effectiveness analysis of micro-fins helically coiled tube heat exchanger and optimization based on multi-objective differential evolution algorithm. Applied Thermal Engineering, 2022. 201.

14. Murugesan, P., et al., Heat transfer and pressure drop characteristics in a circular tube fitted with and without V-cut twisted tape insert. International Communications in Heat and Mass Transfer, 2011. 38(3): p. 329-334.

15.Hasanpour, A., M. Farhadi, and K. Sedighi, Experimental heat transfer and pressure drop study on typical, perforated, V-cut and U-cut twisted tapes in a helically corrugated heat exchanger. International Communications in Heat and Mass Transfer, 2016. 71: p. 126-136.

16.Saravanan, A., J.S. Senthilkumaar, and S. Jaisankar, Performance assessment in V-trough solar water heater fitted with square and V-cut twisted tape inserts. Applied Thermal Engineering, 2016. 102: p. 476-486.

17. Abed, A.M., et al., Numerical analysis of flow and heat transfer enhancement in a horizontal pipe with P-TT and V-Cut twisted tape. Case Studies in Thermal Engineering, 2018. 12: p. 749-758.

18. Arunachalam, U. and M. Edwin, Experimental studies on laminar flow heat transfer in nanofluids flowing through a straight circular tube with and without V-cut twisted tape insert. Heat and Mass Transfer, 2018. 54(3): p. 673-683.

19. Kumar, B., et al., Effect of V cut in perforated twisted tape insert on heat transfer and fluid flow behavior oftube flow: An experimental study. Experimental Heat Transfer, 2018. 32(6): p. 524-544.

20. Langeroudi, H.G. and K. Javaherdeh, Investigation friction factor and heat transfer characteristics of turbulent flow inside the corrugated tube inserted with typical and V-cut twisted tapes. Heat and Mass Transfer, 2018. 54(7): p. 1999-2008.

21. Kumar, B., et al., Effects of Double V Cuts in Perforated Twisted Tape Insert: An Experimental Study. Heat Transfer Engineering, 2019. 41(17): p. 1473-1484

22. Nakhchi, M.E. and J.A. Esfahani, Performance intensification of turbulent flow through heat exchanger tube using double V-cut twisted tape inserts. Chemical Engineering and Processing - Process Intensification, 2019. 141.

23. Chu, W.-X., et al., Experimental investigation on heat transfer enhancement with twisted tape having various V-cut configurations. Applied Thermal Engineering, 2020. 172.

24. Singh, S.K. and J. Sarkar, Experimental hydrothermal characteristics of concentric tube heat exchanger with V-cut twisted tape turbulator using PCM dispersed mono/hybrid nanofluids. Experimental Heat Transfer, 2020. 34(5): p. 421-442.

25. Kumar, R., et al., Modeling of triangular perforated twisted tape with V-Cuts in double pipe heat exchanger. Materials Today: Proceedings, 2021. 46: p. 5389-5395.