A REVIEW ON ENHANCEMENT OF HEAT TRANSFER AND FRICTION FACTOR CHARACTERISCTICS IN HEAT EXCHANGER TUBE HAVING INSERTS

Shweta Negi,
Department of Mechanical Engineering, student of thermal engineering, Faculty of Technology, UTU, Dehradun,
Rahul Bahuguna
Department of Mechanical Engineering, Assistant Proffesor, Faculty of Technology, UTU, Dehradun,
Lokesh Pandey
Department of Mechanical Engineering, Assistant Professor, DIT Rishikesh, Uttarakhand

ABSTRACT

Heat transfer and friction factor can be enhanced by many ways either by changing the surface of exchanger tube or by changing the fluids used in heat exchanger or by using some techniques which are active, passive and compound techniques. The passive techniques have been found very effective as it does not require any direct input of external power. The passive techniques generally use surface or geometrical modifications to the channel of flow by introducing inserts or additional devices due to which a disturbance is created in fluid flow which enhances the heat transfer. This paper includes the different types of geometries of inserts used in the heat exchanger and its comparison in enhanced results. The different types of geometries used in this paper are varying width twisted tape, baffle, perforated helical tape, mesh cylinder, circular tube with drainage and so on.

Keywords: Friction factor, Heat transfer enhancement, Inserts Nusselt number, Reynolds number and Thermal performance factor.

I. INTRODUCTION

Heat exchanger is an essential element which transfers the energy from one medium to another by virtue of temperature difference. The transfer of heat is between a solid object and a fluid, or between two or more fluids. The fluids may be separated by a solid wall or may be in direct contact. The transfer of energy should be as quickly as possible. Therefore, the designers are taking a step ahead to transfer the desired amount of energy quickly by making the heat exchangers compact and efficient in low investment and running cost. To enhance the heat transfer the three types of techniques can be used named as: active, passive and compound techniques.

1.1 Active Techniques: The active techniques use the external power source for enhancement. Therefore, it is more complex to use and design. It has limited application because of external power need in many practical applications. Various active techniques are:

1. Mechanical aids
2. Surface vibration
3. Fluid vibration
4. Electrostatic fields
5. Injection
6. Suction
7. Jet impingement

1.2 Passive Techniques: The passive techniques does not require any external power source and uses the surface or geometrical modifications to the flow channel by introducing inserts or additional devices. Due to the disturbance in flow behavior at exit which increases the pressure drop which promotes the higher heat transfer coefficients. Various passive techniques are:

1. Treated surfaces
2. Extended surfaces
3. Rough surfaces
4. Displacement enhancement devices
5. Swirl flow devices
6. Coiled tubes
7. Surface tension devices
8. Additives for liquids

1.3 Compound Techniques: The compound techniques are the techniques which use the both active and passive techniques with the purpose of improving more thermo-hydraulic performance of heat exchanger **[1]**.

To achieve an optimal result in enhancement of heat transfer the passive techniques are used because it does not require any external power source. As well as the passive techniques are simple and cheap and easy to employ. As one of the passive method techniques, tube inserts technology has been widely used in the heat exchanger such as twisted tape, wire coil, helical, etc. The tube inserts can be divided into two broad categories: stationary and self-rotating. The stationary inserts have relatively fixed position in plain tube. The self-rotating inserts can automatically rotate while the fluid flows through the tube and can strengthen the heat transfer efficiency and achieve the on-line anti-scaling and de-scaling effect **[2]**.

Different types of geometries of inserts are used with different types of parameters which create a huge turbulence inside the heat exchanger tubes and researchers used them to calculate the outcomes of augmentation. The twisted tape inserts are mainly used to enhance the heat transfer because it creates a swirl motion due to which centrifugal forces are generated which enhances the heat transfer.

II. LITERATURE REVIEW

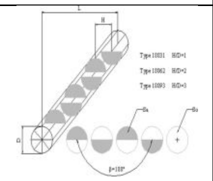
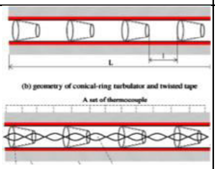
Many researchers had done experiments to enhance the heat transfer by taking many different types of inserts or tubes or tube surface and calculated the results. These types of researches are discussed below:

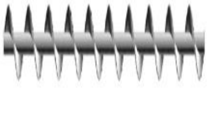
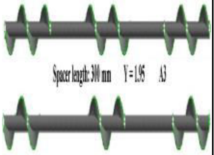
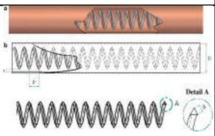
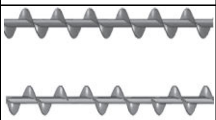
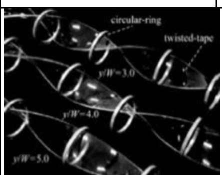
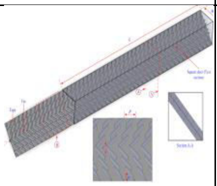
P. Promvong and S. Eiamsa-ard [4] used conical ring with twisted tape and record the heat transfer behavior and found that the maximum heat transfer and enhancement efficiency is achieved at lowest twist ratio and the enhancement efficiency decreases with the increasing Reynolds number and is uniform over 16,000. **P. Sivashanmugam and P.K. Nagarajan [5], P. Sivashanmugam and S. Suresh [6,7] and E. Z. Ibrahim [10]** used right and left helical screw tape, helical screw tape inserts, regularly spaced helical screw tape in circular tube and helical screw tape in flat tube respectively and found that the heat transfer coefficient and friction factor increases with the decrease in twist ratios. They also found that the helical screw inserts with spacer can only be used for the enhancement of heat in turbulent flow with less reduction in pumping power and the enhancement of heat transfer coefficient is higher than that for straight helical twist.

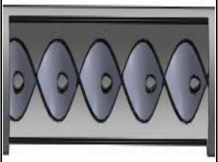
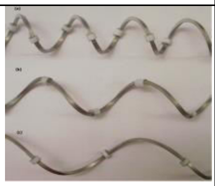
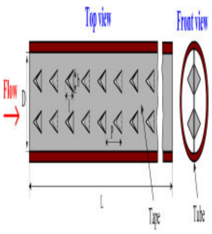
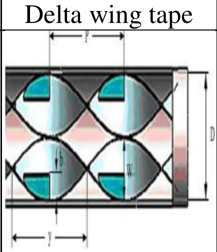
S. Eiamsa-ard et al. [11] used circular rings with twisted tape and found the maximum heat transfer rate, friction factor and thermal performance factor with the use of circular ring with twisted tape as compared to the circular ring tape only and the highest thermal performance factor are found at lowest pitch ratio and lowest twist ratio.**K. Nanan et al. [12]** used perforated helical twisted tapes and found that with the use of perforated helical twisted tapes the reduction in heat transfer and friction factor occurs as compared to helical twisted tapes. They also found an increase in heat transfer, friction factor and thermal performance factor with decreasing diameter ratios and with increase in perforation pitch ratios. **A. Kumar et al. [15]** used circular perforated ring with circular cylindrical tube and found that the heat transfer is enhanced about 4 times for lowest perforation index and diameter ratio and thermal performance factor is improved about 1.4 times for highest perforation index and diameter ratio.**M. Kh. Abdolbaqi et al. [16]** done experimental analysis of turbulent heat transfer in a flat tube fitted with twin counter twisted tape and twin co twisted tape and found that the Nusselt number, the friction factor and the thermal enhancement index increases as the twist ratio decreases and the twin co twisted tape is less efficient than the twin counter twisted tape for enhancement of heat transfer. **O. Keklikcioglu and V. Ozceyhan [17]** used coiled-wire with the separation from tube wall with the help of Teflon rings and found the considerable increase in Nusselt number and friction factor and observed the maximum thermal performance with lowest separation and pitch to diameter ratio.

S. Tamna et al. [19]used double V-ribbed twisted tapes and found that with increasing blockage ratio the Nusselt number and friction factor increases and the maximum thermal enhancement factor is achieved at lowest blockage ratio.**V. Singh et al. [20]** used multiple twisted tapes and solid rings and found the highest thermal performance factor at the lowest pitch ratio and twist ratio for solid ring tubular and the Nusselt number, friction factor and thermal performance factor is maximum at quadruple co-twisted tape insert.**P. Li et al [22]** used drainage inserts fitted in a circular tube and found the increase in Nusselt number and friction factor with the decrease in pitch ratio. In this paper twenty-one works are presented in tabular form for the ease and to get future prospect. Table 1 represents the different insert geometries and its parameters and fluids used for experiments with their outcomes. Table 2 represents the correlations developed for Nusselt number, friction factor and thermal performance factor.

Table 1: Different insert geometries and its parameters with their outcomes

S. NO.	AUTHOR	GEOMETRY	PARAMETER	FLUID	OUTCOMES
1.	A. Tandiroglu [2006][3]	 Baffle with circular tube	• Pitch to tube inlet diameter ratio (H/D = 1, 2 and 3) • Baffle orientation angle (β = 45°, 90° and 180°) • Reynolds number from 3000 to 20,000	Air	The proposed empirical correlations were considered to be applicable within the range of Reynolds number 3000 to 20,000 for the case of constant heat flux.
2.	P. Promvong and S. Eiamsa-ard [2007][4]	 Conical ring with twisted tape	• Twist ratios, Y= 3.75 and 7.5 • Reynolds number 6000 to 26,000	Air	For twist ratio of Y= 3.75, A maximum heat transfer rate of 367% and enhancing efficiency of around 1.96 are found.
3.	P. Sivashanmugam and P.K. Nagarajan [2007][5]	 Right and left helical screw-tape	• Twist ratio (Y= 2.93, 3.91 and 4.89) • Reynolds number from 150 to 2500	Water	Heat transfer enhancement for 300 R and 300 L twist set is higher than that for 400 R and 200 L for all twist ratio.

4.	P. Sivashanmugam and S. Suresh [2007][6]	 Helical screw- tape with circular tube	• Reynolds number from 2700 to 13,500 • Twist ratio (Y =1.95, 2.93, 3.91 and 4.89)	Water	The maximum performance ratio of 2.05 was obtained fort wist ratio of 1.95.
5.	P. Sivashanmugam and S. Suresh [2007][7]	 Regularly spaced helical screw-tape	• Spacer length (S= 100, 200, 300, and 400 mm) • Twist ratio (1.95, 2.93, 3.91, and 4.89) • Reynolds number from 6000 to 14,000	Water	The decrease in Nusselt number from twist ratio 1.95 to 4.89 is nearly 30–40% for all Reynolds number for full-length helical screw inserts and helical screw twists with various spacer lengths, whereas the decrease in friction factor is 40–45%.
6.	S. Gunes et al. [2010][8]	 Coiled wire with equilateral triangular cross-section	• Pitch ratios (P/D=1, 2 and 3) • Equilateral triangle length side to tube diameter (a/D= 0.0714 and 0.0892) • Reynolds number from 3500 to 27,000	Air	The highest overall enhanced efficiency of 36.5% is achieved for the wire with a/D= 0.0892 and P/D=1 at Reynolds number 3858.
7.	S. N. Sarada et al. [2010][9]	 Varying width twisted tape	• Twist ratios (Y= 3, 4 and 5) • Reynolds number varied from 6000 to 13500 • Different widths (26-full width, 22, 18, 14 and 10 mm)	Air	Maximum rise in heat transfer, friction factor and over all enhancement ratio was varied from 36 to 48%, 18% and 1.62 resp. for full width of 26mm and 33 to 39%, 17.3% and 1.39 resp. for reduced width of 22 mm inserts compared to plain tube.
8.	E.Z. Ibrahim [2011] [10]	 Helical screw tape with flat tubes	• Reynolds number from 570 to 1310 • Twist ratio (y= 2.17, 3.33, 4.3 and 5) • Spacer length (S= 100, 200, 300 and 400) mm	Water	Nusselt number increases and friction factor decreases with increase in Reynolds number.
9.	S.Eiamsa-ard et al. [2013][11]	 Twisted tape with circular ring	• Pitch ratios (l/D =1.0, 1.5, and 2.0) • Twist ratios (y/W=3, 4, and 5) • Reynolds number from 6000 to 20,000	Air	The increases of mean Nusselt number, friction factor and thermal performance, resp., are 25.8%, 82.8% and 6.3%. Thermal performance factor of 1.42 is found.
10.	K. Nanan et al. [2014][12]	 Perforated helical twisted tape	• Diameter ratios (d/w= 0.2, 0.4 and 0.6) • Pitch ratios (s/w= of 1, 1.5 and 2) • Reynolds number 0from 6000 to 20,000	Air	Heat transfer, friction loss and thermal performance factor increase as d/w decreases and s/w increases. The max thermal performance factor of 1.28 is obtained with d/w = 0.2 and s/w = 2.0 at Reynolds number of 6000
11.	S. Suwannapan et al. [2014][13]	 Square–duct with discrete V–finned	• Reynolds number from 4000 to 25000 • blockage ratio, (R_B= e/H=0.075, 0.1, 0.15 and 0.2) • fin pitch to duct height ratio, (R_P=P/H=0.5, 1.0, 1.5 and 2.0) • fin attack angle, α=45°	Air	The inserted square-duct at R_B=0.2 and R_P=0.5 provides the highest heat transfer and friction factor while the one with R_B=0.1 and R_P=1.5 yields the highest thermal performance.

		tape			
12.	T. O. Oni and M. C. Paul [2015][14]	 Divers tape with circular tube	• Reynolds number from 5000 and 20000	Water	Nusselt number, friction factor and TPF are 1.63 – 2.18, 2.60 – 3.15 and 1.35 – 1.43 times respectively that of the tube fitted with plain twisted tape.
13.	A. Kumar et al. [2016][15]	 Circular perforated ring	• Diameter ratios (d/D= 0.6, 0.7 and 0.8) • Perforation index (P_A/T_A=8%, 16% and 24%) • Reynolds number from 6500 to 23,000	Air	For PI= 8% and DR= 0.6 the value of heat transfer is 4 times higher and friction factor is 7.2 times higher.For PI= 24% and DR= 0.8 the TPF is found 1.47 times higher as compared to smooth tube.
14.	M. Kh. Abdolbaqi et al. [2016][16]	 Twin twisted tape with flat tube	• Reynolds number from 7200 to 32,400 • Twist ratio (H/D= 5, 10 and 15)		Heat transfer rates for CTT were around 22.5% higher than CoTT and 61% higher than empty tubes. The maximum thermal enhancement index (η) obtained using CTT with H/D = 5, was 2.52, while using CoTT was 2.26.
15.	O. Keklikcioglu and V.Ozceyhan [2016][17]	 Coiled-wire	• Pitch-to-dia ratios (P/D=1, 2 and 3) • Distance from tube wall (s= 1mm and 2mm) • Reynolds numbers from 3429 to 26,663	Air	Thermo-hydraulic performance was better with s= 1mm. At s= 1mm and P/D= 1, the thermal enhancement efficiency of 82% at Re= 3429 was observed.
16.	S. Skullong et al. [2016][18]	 Delta wing tape	• Inclination angles (α= 30°, 45° and 60°) • Wing-pitch to tube-diameter (P/D= PR= 0.5, 1.0, 1.5, 2.0 and 2.5) • Reynolds number from 4200 to 25,500	Air	With α= 60°, PR= 0.5 the heat transfer rate and friction factor yields up to 505% and 69 times over the plain tube. The 30° DWT at PR = 1.0 provides the highest TEF of about 1.49
17.	S. Tamna et al. [2016][19]	 Double V-ribbed twisted tape	• Reynolds number from 5300 to 24,000 • Twist ratio= 4 • Blockage ratio (B_R)= (b/D= 0.07, 0.09, 0.14 and 0.19) • Angle of attack (α= 30°)	Air	B_R= 0.19 yields highest heat transfer and friction factor and they are in the range of 1.56 to 2.3 times and 2.06 to 4.94 times than smooth tube. Maximum TEF is about 1.4 at B_R= 0.09.
18.	V. Singh et al. [2016][20]	 Solid ring with multile twisted tapes	• Pitch ratios (l/D=1 and 2) • Twist ratios (y/W=2, 3 and 4) • Reynolds number from 6300 to 22,500	Air	At twist ratio (TR= 2) and pitch ratio (PR= 1), Nu is in the range of 107.8– 293.7 while f is 0.93–0.99 times that of the smooth tube. The highest thermal performance factor (h) is found to be about 1.46– 1.61

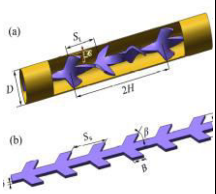
19.	Z. M. Lin et al. [2016][21]	 Twisted tape having parallelogram winglet vortex generators	• Attack angle (α = 27.64°, 21.44°, 17.44° and 14.67°) • Axial spacing (S_t = 0.83D, 1.0D, 1.25D and 1.67D) • Reynolds number ranging from 50 to 600. • Twist ratio (T_r = 3.0, 4.0, 5.0 and 6.0)	Water	Nusselt number and friction factor are increased by 76.4% to 190.9% and 179.9% to 289.1%, respectively, and the corresponding thermal performance factor ranges from 1.25 to 1.85 for α =17.44°, S_t/D =1.25 and Rearranging from 50 to 600.
20.	P. Li et al. [2017][22]	 Circular tube with drainage	• Pitch ratios (P/D=2.5, 3.3, 4.2 and 5) • Slant angles (α=30°, 45° and 60°) • Reynolds number from 6000 to 16,000	Hot water and cold water	For the slant angle of 45°, the heat transfer performance is 0.76–1.05 times and the friction factor is 6.09–6.44 times better than that of smooth tube. The PEC values of experimental results are 0.95–1.13.

Table 2.2: Correlations developed for Nusselt number, friction factor and thermal performance factor

Citation	Correlations
[3]	$Nu_{ave(t)} = 14.84\, Re^{1.34}\, (H/D)^{-8.15}\, (L/H)^{-6.9} Pr^{0.4} (S_o = S_a)^{-21.14} \beta^{-0.34}$ $f_{ave(t)} = 12.54\, Re^{0.16}\, (H/D)^{-7.35}\, (L/H)^{-5.7} Pr^{0.4} (S_o = S_a)^{-18.99} \beta^{0.37}$
[4]	$Nu = 1.356\, Re^{0.433} Pr^{0.4} (d/D)^{-1.23} Y^{-0.053}$ $f = 24.87\, Re^{-0.43} (d/D)^{-3.99} Y^{-0.16}$ $\eta = 14.9\, Re^{-0.277} (d/D)^{-0.129} Y^{-0.01}$
[5]	$Nu = 0.196\, Re^{0.608} Pr\, Y^{-0.386} (R_t/L_t)^{-0.118}$ $f = 739.2\, Re^{-1.013} Y^{-0.634} (R_t/L_t)^{-0.234}$
[6]	$Nu = 0.4675\, Re^{0.4774} Pr\, Y^{-0.2138}$ $f = 32.415\, Re^{-0.598} Y^{-0.7986}$
[7]	$Nu = 0.258\, Re^{0.554}\, Pr Y^{-0.242} (1 + S/D_h)^{-0.042}$ $f = Re^{-0.384} Y^{-0.852} (1 + S/D_h)^{0.047}$
[8]	$Nu = 0.598417\, Re^{0.745064}\, (P/D)^{-0.268374}\, (a/D)^{0.813205} Pr^{0.39}$ $f = 83.70924\, Re^{-0.305268}\, (P/D)^{-0.388}\, (a/D)^{1.319018}$
[9]	$Nu = 0.4141 * 10^{-4}\, Re^{0.9591}\, (0.001 + H/w)^{-0.04645}\, (D_h/L)^{-1.411}$ $f = 0.01391\, Re^{-0.1374}\, (0.001 + H/w)^{-0.003}\, (D_e/L)^{-0.2097}$
[10]	$Nu = 6.11\, Re^{0.199}\, (1 + x)^{-0.064} Y^{-0.318}$ $f = 54.41\, Re^{-0.87}\, (1 + x)^{-0.045} Y^{-0.146}$
[11]	For circular ring alone $Nu = 0.0895\, Re^{0.767} Pr^{0.4}\, (l/D)^{-0.418}$ $f = 0.994\, Re^{-0.093}\, (l/D)^{-0.418}$ $\eta = 3.08\, Re^{-0.104}\, (l/D)^{-0.35}$ For compound device $Nu = 0.326\, Re^{0.724} Pr^{0.4}\, (l/D)^{-0.475}\, (y/W)^{-0.406}$ $f = 13.99\, Re^{-0.202}\, (l/D)^{-0.927}\, (y/W)^{-0.619}$ $\eta = 4.63\, Re^{-0.111}\, (l/D)^{-0.166} (y/W)^{-0.199}$
[12]	$Nu = 0.035\, Re^{0.795}\, (d/w)^{-0.068}\, (s/w)^{0.086} Pr^{0.4}$, $f = 1.915\, Re^{-0.299}\, (d/w)^{-0.068}\, (s/w)^{0.094}$ $\eta = 4.058\, Re^{-0.145}\, (d/w)^{-0.045}\, (s/w)^{0.054}$
[13]	$Nu = 0.0701\, Re^{0.7917} R_B^{2.1432} R_P^{-0.2666} Pr^{0.4}$, $f = 1.3766\, Re^{-0.1836} R_B^{8.4569} R_P^{-1.1157}$
[14]	$Nu = 116.961 + Re^{1.323}\, (p/w)^{0.296}\, (y/w)^{-2.645} Pr^{-2.938}$, $f = 20.294\, Re^{-0.522}\, (p/w)^{0.151}\, (\frac{y/w}{(y/w)-1})^{1.462}$
[15]	$Nu = 0.15\, Re^{0.7477}\, (DR)^{-0.5770}\, (PI)^{-0.1915}$, $f = 1.88\, Re^{-0.0916}\, (DR)^{-4.3858}\, (PI)^{-0.7291}$ $\eta = 4.70\, Re^{-0.1027}\, (DR)^{0.8849}\, (PI)^{-0.0347}$
[16]	For twin counter twisted tape: $Nu = 0.268\, Re^{0.7}\, Pr^{0.4} (H/D)^{-0.4}$, $f = 24.96\, Re^{-0.59} (H/D)^{0.1}$ For twin co- twisted tape: $Nu = 0.209\, Re^{0.72}\, Pr^{0.4} (H/D)^{-0.45}$,$f = 66.7\, Re^{-0.6} (H/D)^{-0.54}$

[17]	$Nu = 1.087\ Re^{0.569}\ (P/D)^{-0.330}\ (s/D)^{-0.152} Pr^{0.4}$, $f = 6.423\ Re^{-0.301}\ (P/D)^{-0.587}\ (s/D)^{-0.106}$
[18]	$Nu = 0.122\ Re^{0.777} Pr^{0.4}\ (1 + tan \propto)^{0.427}\ (PR + 1)^{-0.6}$ $f = 1.546\ Re^{-0.0726}\ (1 + tan \propto)^{1.605}\ (PR + 1)^{-1.39}$, $TEF = 3.608\ Re^{-0.094}\ (1 + tan \propto)^{-0.108}\ (PR + 1)^{-0.131}$
[19]	$Nu = 0.168\ Re^{0.701} B_R^{0.172} Pr^{0.4}$, $f = 5.494\ Re^{-0.263} B_R^{0.729}$
[20]	For pitch ratio= 1 $Nu = 0.09653\ Re^{0.7834} N^{0.0551}\ exp(0.0256\ lnN^2) TR^{0.2127} exp(-0.1696 \ln TR^2)$ $f = 1.073\ Re^{-0.0786} N^{0.0352}\ exp(0.1094\ lnN^2) TR^{0.4696} exp(-0.3760 \ln TR^2)$ $\eta = 3.033\ Re^{-0.0786} N^{0.0188}\ exp(0.01063\ lnN^2) TR^{0.1304} exp(-0.0968 \ln TR^2)$ For pitch ratio= 2 $Nu = 0.0832\ Re^{0.7899} N^{0.0383}\ exp(0.0355\ lnN^2) TR^{0.23757} exp(-0.2488 \ln TR^2)$ $f = 1.042\ Re^{-0.0539} N^{0.0873}\ exp(0.0772\ lnN^2) TR^{0.0478} exp(-0.3660 \ln TR^2)$ $\eta = 2.94\ Re^{-0.0771} N^{0.0074}\ exp(0.0237\ lnN^2) TR^{0.1097} exp(-0.0814 \ln TR^2)$
[21]	$Nu_m = 4.3543\ Re^{0.2245}\ (\propto/180)^{0.2428}\ (S_t/D)^{-0.2219}$, $f = 47.0429\ Re^{-0.8528}\ (\propto/180)^{0.2764}\ (S_t/D)^{-0.201}$
[22]	$Nu = 0.1628\ Re^{0.7188} p^{-0.5224}\ ((90-\propto)\pi/180)^{-0.1263} Pr^{0.4}$, $f = 4.757\ Re^{-0.2137} p^{-0.9114}\ ((90-\propto)\pi/180)^{-0.3267}$
[23]	$Nu = 1.38\ Re^{0.314}\ (S/D)^{-0.082}\ (L/D)^{-0.108} (ORA)^{-0.052}$ $f = 19.2\ Re^{-0.484}\ (S/D)^{-0.46}\ (L/D)^{-0.228} (ORA)^{-0.44}$

III. CONCLUSION

The paper provides an overview of different types of geometries of inserts. The previous studies on heat exchanger tube with inserts are very efficient in heat transfer augmentation. With the use of different geometries of inserts the Nusselt number, friction factor and thermal performance factor increases sufficiently but there is some effects on surface also occurs.

1. Nusselt number increases and the friction factor decreases with the increase in Reynolds number.
2. Nusselt number and friction factor both decreases with the increase in twist ratio for twisted tape inserts.
3. The thermal enhancement factor (Ƞ) decreases with the increase in Reynolds number.

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