Experimental Analysis of Heat Transfer Augmentation by Using Twisted Tapes of Different Twist Ratio as Flow Arrangement inside the Tubes

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Abstract: *The objective of this thesis is to investigate the swirl flow behavior and the laminar convective heat transfer in a circular tube with twisted-tape inserts. The fluid flow and thermal fields are simulated computationally in an effort to characterize their structure. Apart from this, issues like long term performance & detailed economic analysis of heat exchanger has to be studied. To achieve high heat transfer rate in an existing or new heat exchanger while taking care of the increased pumping power.*

Keywords**:** *Twisted tapes, pumping power, friction factor, enhancement techniques*

I. Introduction

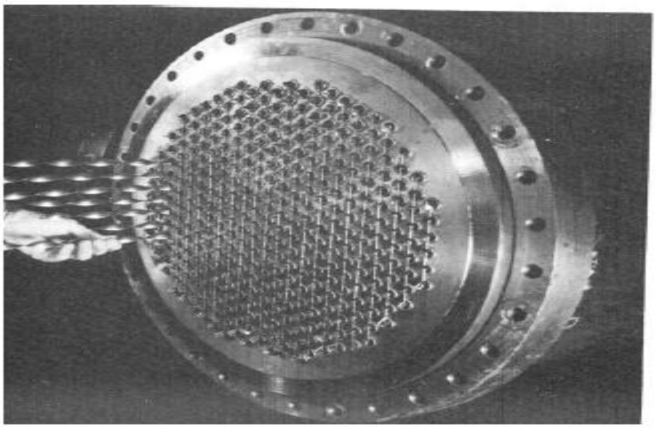
Heat exchangers are used in different processes ranging from conversion, utilization & recovery of thermal energy in various industrial, commercial & domestic applications. Some common examples include steam generation & condensation in power & cogeneration plants; sensible heating & cooling in thermal processing of chemical, pharmaceutical & agricultural products; fluid heating in manufacturing & waste heat recovery etc. Increase in Heat exchanger's performance can lead to more economical design of heat exchanger which can help to make energy, material & cost savings related to a heat exchange process. The need to increase the thermal performance of heat exchangers, thereby effecting energy, material & cost savings have led to development & use of many techniques termed as―Heat transfer Augmentation. These techniques are also referred as―Heat transfer Enhancement or―Intensification. Augmentation techniques increase convective heat transfer by reducing the thermal resistance in a heat exchanger. Use of Heat transfer enhancement techniques lead to increase in heat transfer coefficient but at the cost of increase in pressure drop. So, while designing a heat exchanger using any of these techniques, analysis of heat transfer rate & pressure drop has to be done.

II. Twisted-Tape Flow and Heat Transfer

It is well known that energy transport is considerably improved if the flow is stirred and mixed well. This has been the underlying principle in the development of enhancement techniques that generate swirl flows. Among the techniques that promote secondary flows, twisted-tape inserts are perhaps the most convenient and effective (Manglik and Bergles, 2002).They are relatively easy to fabricate and fit in the tubes of shell-and-tube or tube-fin type heat exchangers. A typical usage in the multi-tube bundle of a shell-and-tube heat exchanger.

The geometrical features of a twisted tape, as depicted in Fig. 2.1, are described by its 180º twist pitch H, the thickness δ, and the width w. In most usage, where snug-to-tight-fitting tapes are used, $w \cong d$, and the severity of the tape twist is characterized by the dimensionless ratio $y = (H / d)$.

The helical twisting nature of the tape, besides providing the fluid a longer flow path or a greater residence time, imposes a helical force on the bulk flow that promotes the generation of secondary circulation. The consequent well-mixed helical swirl flow significantly enhances the convective heat transfer (Manglik and Bergles, 2002, 1993a, 1993b). In most cases, depending on how tightly the tape fits at the tube wall and what material it is made of, there may be some tape-fin effects as well. The enhanced heat transfer due to twisted-tape inserts, is also accompanied by an increase in pressure drop and suitable trade-offs must be considered by designers to optimize their thermal-hydraulic performance ratio $y = (H / d)$. The helical twisting nature of the tape, besides providing the fluid a longer flow path or a greater residence time, imposes a helical force on the bulk flow that promotes the generation of secondary circulation. The consequent well-mixed helical swirl flow significantly enhances the convective heat transfer (Manglik and Bergles, 2002, 1993a, 1993b). In most cases, depending on how tightly the tape fits at the tube wall and what material it is made of, there may be some tape-fin effects as well. The enhanced heat transfer due to twisted-tape inserts, is also accompanied by an increase in pressure drop and suitable trade-offs must be considered by designers to optimize their thermal-hydraulic performance.



Shell-and-tube heat exchanges with twisted-tape inserts

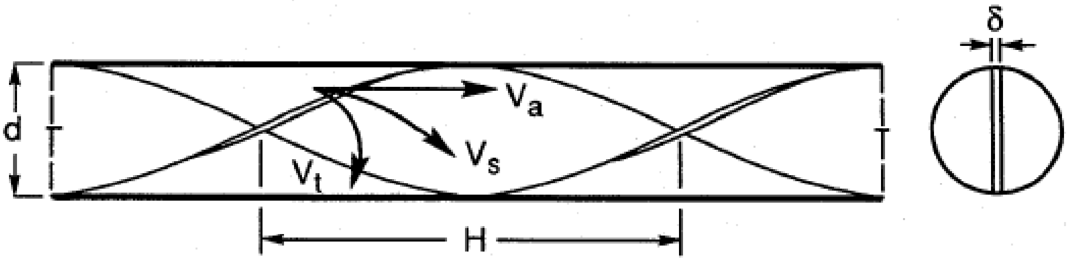


Fig.2.1 Twisted-tape geometry

III. Clasification Of Enhancement Techniques

Heat transfer enhancement or augmentation techniques refer to the improvement of thermo-hydraulic performance of heat exchangers. Existing enhancement techniques can be broadly classified into three different categories:

1. Passive Techniques
2. Active Techniques
3. Compound Techniques.

III.I.PASSIVE TECHNIQUES: These techniques generally use surface or geometrical modifications to the flow channel by incorporating inserts or additional devices. They promote higher heat transfer coefficients by disturbing or altering the existing flow behavior (except for extended surfaces) which also leads to increase in the pressure drop. In case of extended surfaces, effective heat transfer area on the side of the extended surface is increased. Passive techniques hold the advantage over the active techniques as they do not require any direct input of external power. Heat transfer augmentation by these techniques can be achieved by using:

1. Treated Surfaces
2. Rough surfaces
3. Extended surfaces
4. Swirl flow devices
5. Coiled tubes

III.II.ACTIVE TECHNIQUES: These techniques are more complex from the use and design point of view as the method requires some external power input to cause the desired flow modification and improvement in the rate of heat transfer. It finds limited application because of the need of external power in many practical applications. In comparison to the passive techniques, these techniques have not shown much potential as it is difficult to provide external power input in many cases. Various active techniques are as follows:

1. Mechanical Aids
2. Surface vibration
3. Fluid vibration.
4. Electrostatic fields.
5. Injection
6. Suction

III.III.COMPOUND TECHNIQUES: A compound augmentation technique is the one where more than one of the above mentioned techniques is used in combination with the purpose of further improving the thermo-hydraulic performance of a heat exchanger.

IV. Performance Evaluation Criteria

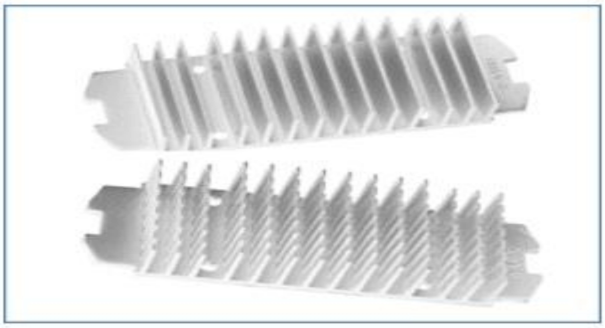
In most practical applications of enhancement techniques, the following performance objectives, along with a set of operating constraints and conditions, are usually considered for optimizing the use of a heat exchanger:

1. Increase the heat duty of an existing heat exchanger without altering the pumping power (or pressure drop) or flow rate requirements.
2. Reduce the approach temperature difference between the two heat-exchanging fluid streams for a specified heat load and size of exchanger.
3. Reduce the size or heat transfer surface area requirements for a specified heat duty and pressure drop or pumping power.
4. Reduce the process stream's pumping power requirements for a given heat load and exchanger surface area.

It may be noted that objective 1 accounts for increase in heat transfer rate, objective 2 and 4 yield savings in operating (or energy) costs, and objective 3 leads to material savings and reduced capital costs.

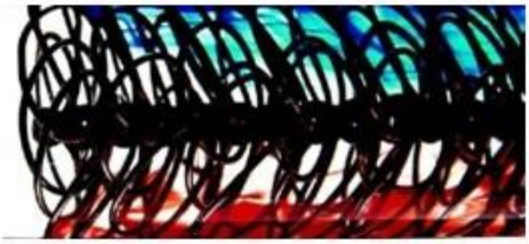
		Criterion number							
		R1	R2	R3	R4	R5	R6	R7	R8
Fixed	Basic Geometry	×	×	×	×				
	Flow Rate	×						×	×
	Pressure Drop		×				×		×
	Pumping Power			×					
	Heat Duty				×	×	×	×	×
Objective	Increase Heat Transfer	×	×	×					
	Reduce pumping power				×				
	Reduce Exchange Size					×	×	×	×

EXTENDED SURFACES: Extended or finned surfaces increase the heat transfer area which could be very effective in case of fluids with low heat transfer coefficients. This technique includes finned tube for shell & tube exchangers, plate fins for compact heat exchanger and finned heat sinks for electronic cooling.



DISPLACED ENHANCEMENT DEVICES: Displaced enhancement devices displace the fluid elements from the core of the channel to heated or cooled surfaces and vice versa .Displaced enhancement devices include inserts like static mixer elements (e.g. Kenics, Sulzer), metallic mesh, and discs, wire matrix inserts, rings or balls.

Heatex wire matrix tube insert is one of the commercially available new displaced enhancement devices



SWIRL FLOW DEVICES: Swirl flow devices causes swirl flow or secondary flow in the fluid .A variety of devices can be employed to cause this effect which includes tube inserts, altered tube flow arrangements, and duct geometry modifications

TWISTED TAPE IN LAMINAR FLOW: Twisted tape increases the heat transfer coefficient with an increase in the pressure drop. Different configurations of twisted tapes, like full-length twisted tape, short length twisted tape, full length twisted tape with varying pitch, reduced width twisted tape and regularly spaced twisted tapes have been some impact on heat transfer process.

TWISTED TAPE IN TURBULENT FLOW: Unlike laminar flows where thermal resistance exist entirely over the cross section, it is limited to the thin viscous sub layer. So the main objective of the twisted tape in the turbulent region is to reduce that resistance near the wall to promote better heat transfer. Besides, a tube inserted with a twisted tape produces swirl and cause intermixing of the fluid which leads to better performance than a plain tube. Heat transfer rate is improved effectively with the increase in the frictional losses

FABRICATION OF TWISTED TAPES: The stainless steel strip of length 125cm, width 16mm and thickness 1.80mm were taken. Holes were drilled at both ends of every tape so that the two ends could be fixed to the metallic clamps. Desired twist was obtained using a Lathe machine. One end was kept fixed on the tool post of the lathe while the other end was given a slow rotatory motion by rotating the chuck side. During the whole operation the tape was kept under tension by applying a mild pressure on the tool post side to avoid its distortion. Three tapes with varying twist ratios were fabricated (y_w=5.25, y_w =4.39, y_w =3.69) as shown in fig

Twist ratio y=3.69

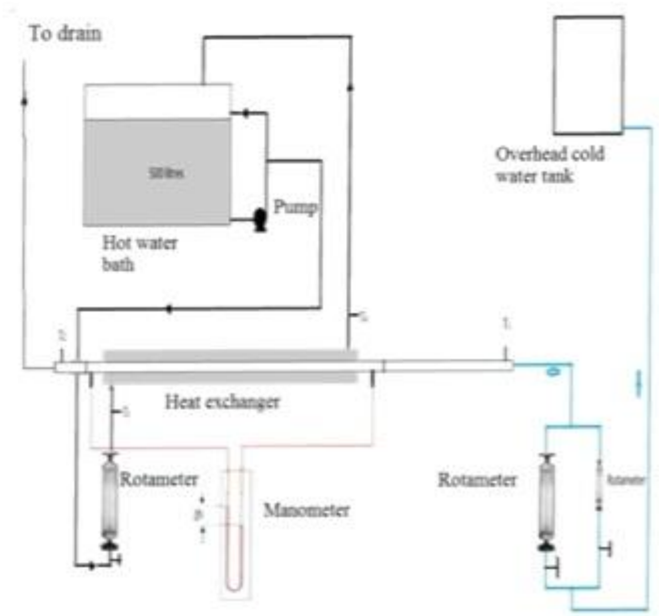
Twist ratio y=4.39

Twist ratio y=5.25

V. Specifications Of Heat Exchanger Used

The experimental study is done in a double pipe heat exchanger having the specifications as listed below:-
Specifications of Heat Exchanger: Inner pipe ID =
20mm
Inner pipe OD=24mm
Outer pipe ID =51mm
Outer pipe OD=58mm
Material of construction= Copper
Heat transfer length= 2.43m
Pressure tapping to pressure tapping length = 2.525m

Water at room temperature was allowed to flow through the inner pipe while hot water (set point 60°C) flowed through the annulus side in the counter current direction.



5.1 Block diagram for double pipe heat exchanger

Standard Equations Used:

I. Friction factor (f_0) calculations:

a. For Re< 2100

$f=16/R_e$

b. For Re>2100

Colburn's Equation:

$f=0.046/R_e^{0.2}$

II. Heat transfer calculations

i. Laminar Flow:

For Re<2100

Nu= f (Gz)

Where Gz= $1/(R_e x L_r x d_i)$

For Gz<100, Hausen Equation is used.

$$Nu = 3.66 + \frac{0.085Gz}{1+0.045Gz^{0.67}} \left(\frac{\mu b}{\mu w}\right)^{0.14}$$

b. For Gz>100, Seider Tate equation is used.

$$Nu = 1.86Gz^{1/3}\left(\frac{\mu_b}{\mu_w}\right)^{0.14}$$

ii. Transition Zone:

For 2100<Re<10000, Hausen equation is used

$$Nu = 0.116\left(Re^{2/3} - 125\right) \times Pr^{1/3} \times \left(1 + \left(\frac{D}{l}\right)^{2/3}\left(\frac{\mu_b}{\mu_w}\right)^{0.14}\right. \quad (3.8)$$

iii. Turbulent Zone:

For Re>10000, Seider-Tate equation is used.

$$Nu = 0.023 \times Re^{0.8} \times Pr^{1/3} \times \left(\frac{\mu_b}{\mu_w}\right)^{0.14} \quad (3.9)$$

Viscosity correction Factor $\left(\frac{\mu_b}{\mu_w}\right)^{0.14}$ is assumed to be equal to 1 for all Calculations as this value for water in present case will be very close to 1 & the data for wall temperatures is not measured.

VI. Results

The below table 5.2 gives correlations for variation of friction factor with Reynolds number for different twisted tapes along with the correlation coefficient, R^2 based on regression analysis. As we can see form the correlations it is quite clear that friction factor is increasing with decrease in twist ratio. As the R^2value is very close to 1, so we can easily make out that the correlation holds true for respective twisted tapes in the given range of Reynolds Number.

Table 5.2 Correlations for Friction Factor for different twisted tapes

SI No.	y_w	Correlation, f_a=	R^2
	TT		
1	3.69	$1.0386\times Re^{-0.380}$	0.9809
2	4.39	$0.5655\times Re^{-0.328}$	0.9916
3	5.25	$0.5226\times Re^{-0.326}$	0.9971

VII. Conclusion

The range of Performance evaluation criteria R_1 (based on constant mass flow rate) & R_3 (based on constant pumping power), & f_a/f_o for different tapes used is given below:

Table Range of R_1, R_3, f_a/f_o for different twisted tapes.

SI No.	Y	Range of R_1	Range of R_3	Range of f_a/f_o
	TT			
1	3.69	1.50-3.66	1.07-1.66	3.70-5.96
2	4.39	1.43-3.35	1.04-1.62	3.43-4.43
3	5.25	1.18-2.75	0.88-1.42	3.23-4.18

For same twist ratio, twisted tape shows higher heat transfer coefficient & friction factor increase because of higher degree of turbulence created.

On the basis of performance evaluation criteria R_1 & R_3, we can say that twisted tape shows better performance than smooth tube.

Twisted tape gives higher heat transfer coefficient than the smooth tube

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