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Heat Exchanger Experimental Investigation Using Trapezoidal Cut Twisted Tape Insert

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Abstract: *The objective of present research was to evaluate the "heat transfer characteristics, efficiency ratio and friction factor" of a twin tube heat exchanger for the rounded bare tube and with the complete length perverted tape with trapezoidal twist cut for fractions of 6.0 and 4.4, individually. For the "Reynolds Number" assortment of 2000-12000, experimental evaluations were directed to assess the "friction factor and heat transfer characteristics" for a rounded tube. The experimental recorded data from a rounded bare tube were likened to the regular correlation to ensure the authentication of investigational outcomes. The outcomes of the trapezoidal-cut twisted tape-fitted tube was tested to those of the rounded bare tube. The consequences validate that the twisted tape with trapezoidal-cut has a large increase in "Heat Transfer and Friction Factor Coefficient" and furthermore the Heat Transfer growth was also discovered to be rational, since the resulting output ratio is greater than unity.*

Keywords: *Twist Ratio, Trapezoidal-Cut, Performance Ratio, Friction Factor, Heat Transfer Estimation.*

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I. OUTLINE

In a number of trials, twisted tape inserts were altered to increase heat transmission and thermal efficiency when compared to smooth tubes. It has been demonstrated that using twisted tape inserts as a flow turbulator improves heat transfer efficiency in a number of conditions, notably at low Reynolds Numbers [1-3]. The advantages of adopting a twisted tape insert over a smooth tube include enhanced test fluid mixing along the cross-section of the tube [4-6] and a smaller boundary layer thickness [7,8]. The use of twisted tape inserts, on the other hand, is typically linked with a bigger drop in pressure [9, 10], which has motivated additional scientific study to improve heat exchanger thermal performance. [11].

Passive heat transfer enhancement solutions have greater advantages than active heat transfer improvement strategies, and they may be utilized directly in heat exchangers with no additional pumping power required. Previously, numerous research on passive heat transfer augmentation strategies have been published. Tu et.al [12] investigated the functioning of a tiny pipe insert inserted within a circular tube for heat transfer improvement at a constant heat flux. Researchers discovered that using a tape insert improved heat transmission and friction factor by 2.09–2.67 and 1.59–1.85, respectively, as compared to using a smooth tube. Bhuiya et al. [13] evaluated "the heat transfer performance and friction factor characteristics of a circular tube equipped with a twisted wire brush insert." When compared to a simple tube, they observed a 2.15-fold increase in heat transfer [14].

Sarma et al. [15] forecasted the friction factor and convective heat transfer coefficient for a wide range of "Reynolds and Prandtl Numbers" using generalized correlations in a tube fitted with twisted tapes. Ferroni et al. [16] carried out experiments in circular tubes with a large number of physically separated twisted short-length tapes. Sarma et al. [17] looked into using "twisted tapes" inside a tube to improve laminar convective heat transmission. Researchers studied the thermal efficacy of "twisted tape inserts" using modified tube rather than smooth tube in some studies. Thianpong et al. [18] investigated the improvement in heat transfer by means of a "dimpled tube" injected with a swirl generator "twisted tape insert." Based on the investigative findings of some study, the researchers additionally offered the experiential correlations across a "Reynolds Number" range of 12,000-44,000 to estimate the "Nusselt Number and friction factor." Bharadwaj et al. [19] investigated the heat transmission and pressure drop characteristics of water in a 75-start spiral pattern grooved tube using ordinary twisted tapes. Some studies also changed traditional twisted tape geometries [20]. Murugesan et al. [21] examined the heat transmission and pressure fall properties of V-cut twisted tapes in a circular tube [22].

There has been a lot of research done on how to increase heat transmission by utilizing twisted tapes in the laminar zone. Manglik and Bergles [23, 24] presented dimensionless parameter for pressure drop and heat transmission correlations. Hong and Bergles [25] correlated "heat transfer and pressure drop" data of a tube fitted with twisted tape inserts under conditions of undeviating wall temperature using "water and ethylene glycol" as working fluids. Agarwal and Raja Rao [26] observed swirl flow behavior in a twisted tape-lined circular tube. Chakroun and Al-Fahed [27] studied the influence of tape width on the heat transfer and pressure drop characteristics of a fully evolved flow. Patil [28] investigated the effects of full-length twisted tape of varying widths inside a circular tube for friction factor and heat transfer features in laminar swirl flow. In terms of thermo-hydraulic performance, Saha et al. [29] evaluated the heat transfer and friction factor characteristic features of regularly spaced twisted tape elements fitted in a circular tube under the laminar swirl flow regime and indicated that pinched tapes are a best alternative than a rod to connect the tape components [30]. The main objectives of present research are to investigate the friction factor characteristics, heat transfer, and output ratio of double pipe heat exchangers fitted with full lengths of trapezoidal-cut twisted tape with twist ratios of 6.0 and 4.4, respectively. Finally, correspondences for calculating the friction factor and heat transfer rate will be developed.

II. SETUP FOR EXPERIMENTATION

Figure 1 shows the conceptual framework, which is depicted in two distinct colours: blue represents "cold water" parameters, while red represents "hot water" parameters. The configuration is made up of two concentric tubes, one within the other. Hot water runs through a copper tube with an internal diameter of 28.5 mm and a length of 2000 mm, whereas cold water flows in the reverse direction through the annulus. The outside wall of the tube is insulated with wool and asbestos rope to reduce heat loss and improve the overall heat transfer performance of the tube.

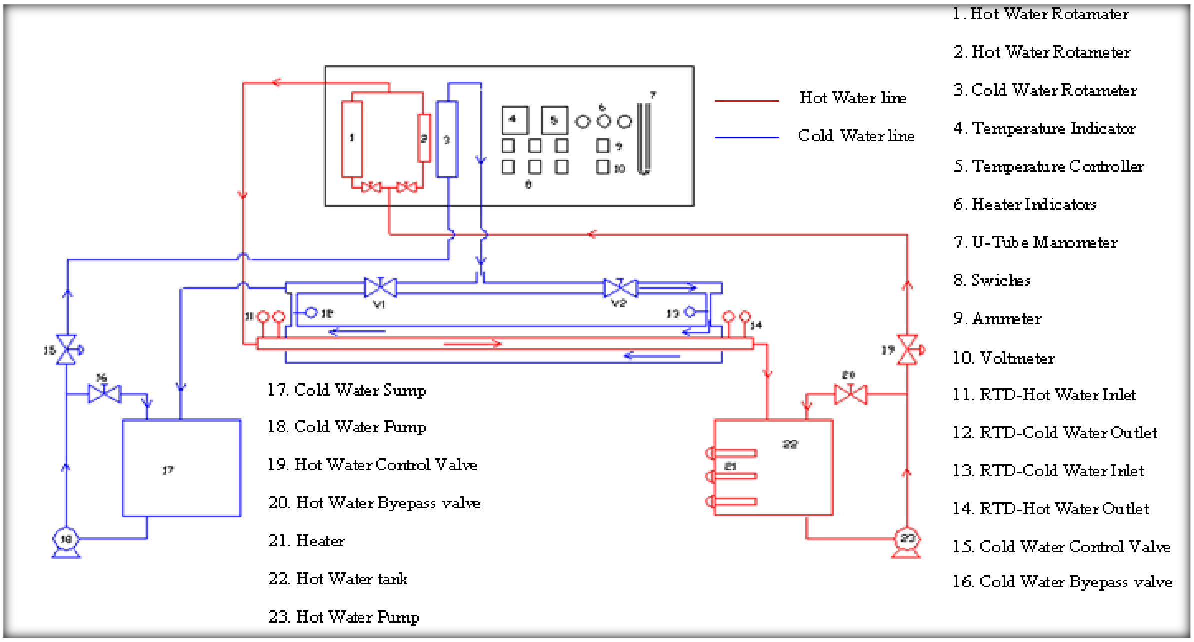


Figure 1 Setup for Experimentation

The experimental set-up comprises of two rota-meters that measure cold and hot water flow rates with a flow range of 0-15 LPM (Liter per Meter) and a ±10% accuracy. The temperature at the entrance and output of cold and hot water is measured using temperature sensors (PT 100) with a precision of ±10%. As shown in Figure 1, four temperature sensor devices (02 on each side) sense the temperature of hot water at the outlet and inlet, whereas two (01 on each side) measure the temperature of cold water at the outlet and inlet flow. Three 1 KW of water heaters is utilized to heat water within a water tank. The temperatures upon that panel is displayed by temperature sensor, which is regulated by a temperature controller. The input temperature of hot water is maintained consistent at 55°C, and that of "cold water" is maintained fixed at 28°C. To preserve the Reynolds number throughout a range of 2000-12000, the "cold water flow rate" is consistently kept at 10 LPM, whereas the "hot water flow rate" is altered from 2-7 LPM with a 0.5 LPM increments. When steady state settings were established in the instance of a plain tube, a U tube manometer monitored the drop in pressure and an RTD (Resistance Temperature Detector) recorded the temperatures of hot and cold water at the intake and output.

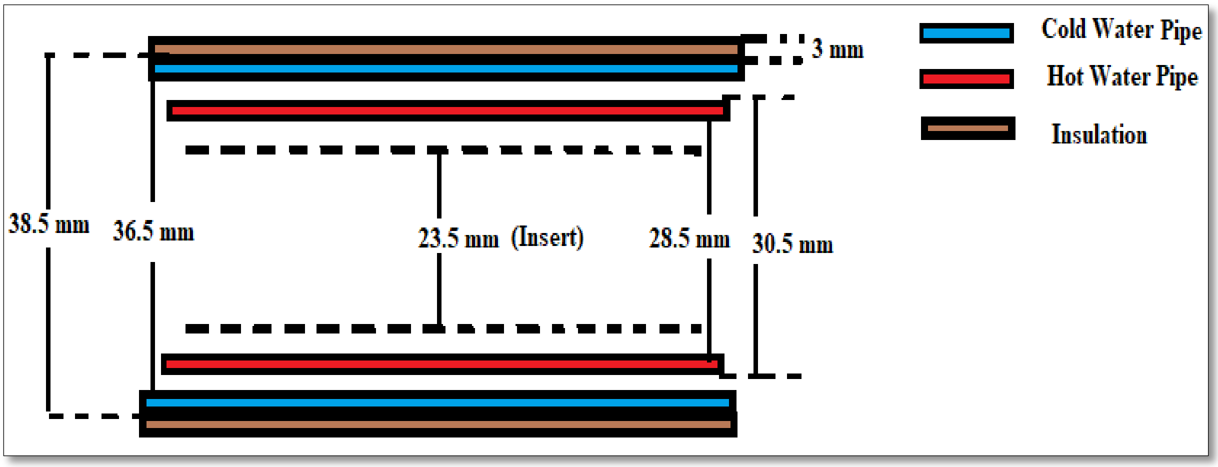
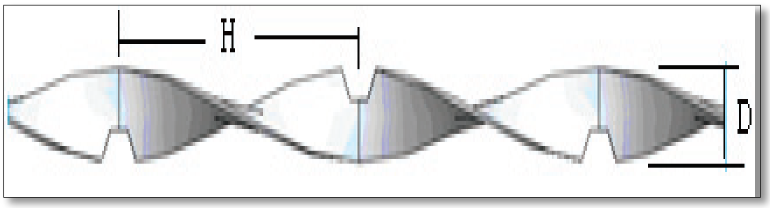
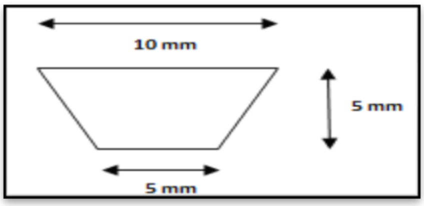


Figure 2 Measurement of Heat Exchanger

Figure 3 depicts a trapezoidal–cut twisted tape insert and is made up of 1.5 mm thick and 23.5 mm wide aluminium strips with twist ratios (y) of 6.0 and 4.4 (y=H/D, where H=108 mm & 79.2 mm and D=18).

(a)





(b)

Figure 3 (a) & (b) Insert of Twisted Tape & Proportions of the Trapezoidal Cut Section

The ratio of twist length to diameter is known as the twist ratio. The experiment uses a full-length twisted tape with trapezoidal-cut dimensions of 5 mm depth, 5 mm base, and 10 mm breadth at the top with trapezoidal-cut to promote fluid mixing nearby the test segment's walls taken alternately on side of the tape. After inserting an insert in the circular tube, the pressure drop is measured again by the U tube manometer, and RTD's measure the temperature of hot and cold water at the intake and outflow, which are related to the plain tube readings.

III. EXAMINATIONS OF THE RECORDS:

Following are the equations are used to examine the records/data for Heat Exchanger utilizing Trapezoidal Cut Twisted tape Insert:

$$Q_c = m\, C_{water}(T_{out} - T_{in}) \quad \text{.............................. (1)}$$

$$Q_c = h\, A\, (\overline{T_{wall}} - Tx) \quad \text{.............................. (2)}$$

$$h.A\, (\overline{T_{wall}} - Tx) = m\, C_{water}(T_{out} - T_{in}) \quad \text{.............................. (3)}$$

$$h = \frac{m.Cwater(Tout - Tin)}{A\, (\overline{T_{wall}} - Tx)} \quad \text{.............................. (4)}$$

$Nu=\frac{h.Dh}{k}$
…………………………. (5)

$Re= \frac{\rho \upsilon Dh}{\mu}$

…………………………. (6)

$Dh= \frac{4A}{P}$

…………………………. (7)

$Dh = D_{out}-D_{in}$

…………………………. (8)

$f = \frac{\Delta p}{\left(\frac{L}{Dh}\right)\left(\frac{\rho \upsilon^2}{2}\right)}$
…………………………. (9)

$\eta = \frac{[\frac{Nu}{Nup}]}{[\frac{f}{fp}]^{1/3}}$ ………………………….
(10)

$Nu = 0.023*Re^{0.8}*Pr^{0.3}$ ………………………….
(11)

$f = 0.0791*Re^{-0.25}$ ………………………….
(12)

$Nu = 0.1197*Re^{0.82}*Pr^{0.33}*y^{-0.77}$ ………………………….
(13)

$f = 29.93*Re^{-0.6}*y^{-1.15}$ ………………………….
(14)

The Nusselt Number (average) and the Friction Parameter are reliant on the hydraulic diameter (tube). Qc [14] can be expressed in equation (1) as heat absorbed by cold water in a uniform heat flux state.

Heat Transfer Rate through the experimental section for the steady state condition can be investigate by the equation (2).

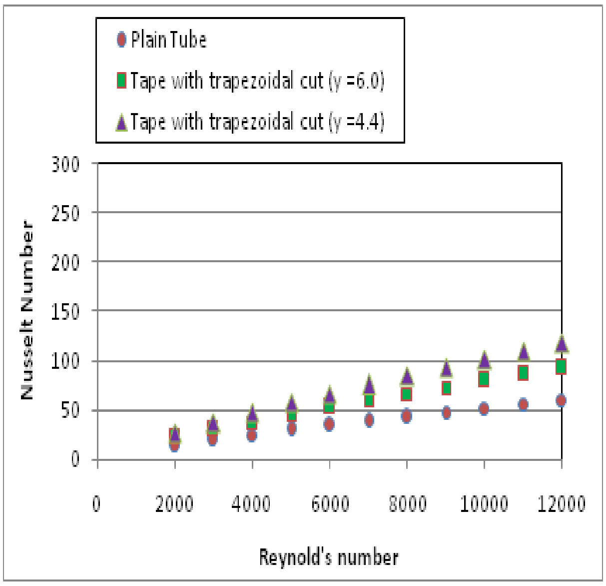
As outcome, the “Average Heat Transfer Coefficient” (h) equation (4) can be expressed by equating the equations (1) & (2) gives the equation (3).

From “Average Heat Transfer Coefficient” the mean “Nusselt Number” can be evaluate as shown in equation (5). Also the “Reynolds Number” for the flow in a tube/pipe calculated by the equation (6). For the internal flow condition the characteristic dimension of the Hydraulic Diameter-Dh” shown in equation (7) and for the circular pipe/tube the magnitude of Dh =D is considered and expressed by equation (8).

The parameter for the Friction and performance ratio/efficiency well-defined by using equations (9) and (10). To obtain the heat transfer and friction factor parameters, for plain tube [31], equations (11) & (12) and the tube with twisted tape insert with trapezoidal-cut [22], equations (13) & (14) were established.

IV. OUTCOMES/RESULTS

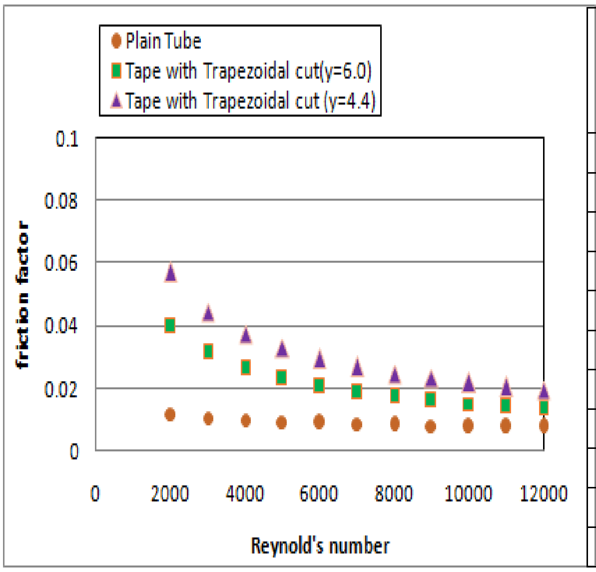
Figure 4 shows the Nusselt Number vs. Reynolds Number variations for plain tube and twisted tape with trapezoidal cut for twist proportions of 6.0 and 4.4, respectively. "Twisted tape with trapezoidal cut" with 4.4 twist ratio has the greatest "Nusselt Number" with rising "Reynolds Number," because the twisted tape causes the flow to swirl along the length of the tube, disturbing the whole flow region, resulting in increased heat transfer rates. Because the lower twist ratio had larger turbulence strength and flow duration than the higher twist ratio, the impact of the lower twist ratio was shown to offer a higher heat transfer rate than the higher twist ratio.



Re	Without Insert	With Insert	
		y =4.4	**y =6.0**
2000	14.34	27.08	21.33
3000	19.84	37.76	29.74
4000	24.97	47.81	37.65
5000	29.85	57.41	45.21
6000	34.55	66.67	52.50
7000	39.06	75.65	59.58
8000	43.47	84.40	66.47
9000	47.77	92.96	73.21
10000	51.97	101.34	79.81
11000	56.08	109.58	86.30
12000	60.13	117.68	92.68

Fig 4 Nussult Number as a function of Reynolds Number **Table 1** Value of Nusselt Number for y=4.4 and y=6

Figure 6 displays the friction parameter divergence with "Reynolds Number" for a straight tube. The friction factor is lowest for the plain tube and highest for the trapezoidal cut twisted tape insert, according to the replies. Though the friction factor reduces with increasing Reynolds Number, increasing the flow of swirls with a lower twist ratio produced the highest friction parameter by employing a twisted tape insert with a twist ratio of 4.4.



Re	Without Insert	With Insert	
		(y =4.4)	**(y =6.0)**
2000	0.0119	0.0569	0.0399
3000	0.0106	0.0446	0.0313
4000	0.0099	0.0375	0.0264
5000	0.0094	0.0328	0.0231
6000	0.0089	0.02946	0.0207
7000	0.0086	0.02685	0.0188
8000	0.0083	0.02479	0.0174
9000	0.0081	0.02309	0.0162
10000	0.0079	0.02168	0.01518
11000	0.0077	0.02047	0.01434
12000	0.0075	0.01943	0.01361

Fig 6 Friction Factor as a function of Reynolds Number **Table 2** Value of Friction Factor for y=4.4 and y=6

The performance ratio determines the consistency of the enhancement principle. Figure 8 depicts the change in performance ratio as a function of Reynolds Number. The performance ratios obtained for trapezoidal-cut twisted tapes with twist ratios of 6.0 and 4.4 fell within the ranges of 1.0-1.23 and 1.07-1.48, respectively. It indicates that the performance ratio is larger than unity in all cases, signaling that implementing modifications for total energy savings is prudent.

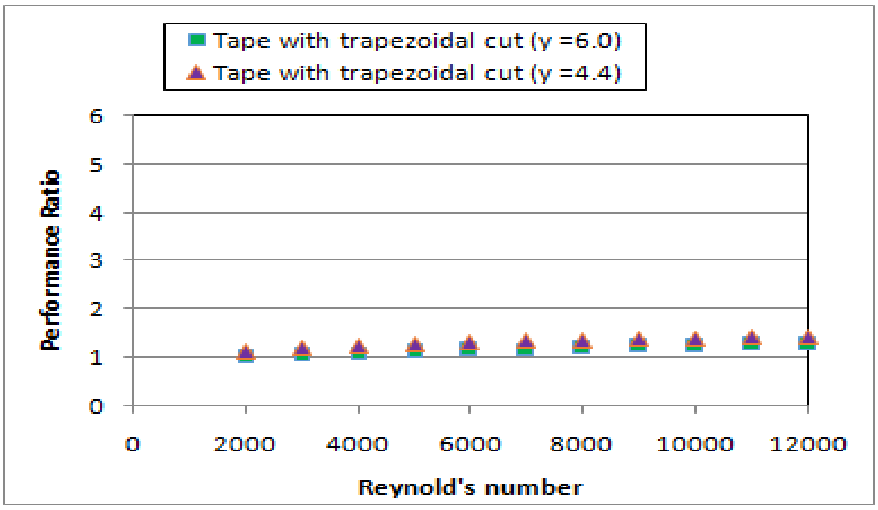


Fig 8 Performance Ratio/Efficiency as a function of Reynolds Number

Re	Nu/Nup		f/fp		Tape with trapezoidal cut	
	y=4.4	y=6.0	y=4.4	y=6.0	y=4.4	y=6.0
2000	1.8884	1.4872	4.81503	3.37051	1.11890	0.99233
3000	1.9037	1.4993	4.17798	2.92458	1.18260	1.04882
4000	1.9147	1.5080	3.77779	2.64444	1.22998	1.09084
5000	1.9233	1.5147	3.49397	2.44577	1.26803	1.12459
6000	1.9303	1.5202	3.27798	2.29458	1.30000	1.15294
7000	1.9363	1.5249	3.10581	2.17406	1.32765	1.17747
8000	1.9415	1.5290	2.96399	2.07479	1.35208	1.19914
9000	1.9460	1.5326	2.84429	1.99100	1.37401	1.21858
10000	1.9501	1.5358	2.74131	1.91891	1.39392	1.23624
11000	1.9539	1.5388	2.65138	1.85596	1.41218	1.25243
12000	1.9573	1.5415	2.57185	1.80029	1.42906	1.26740

Table 3 Performance Ratio/Efficiency for y=4.4 and y=6

V. CONCLUSION:

"Heat transfer and friction factor characteristics" of a trapezoidal-cut tape fitted in a round copper tube were investigated for "twist ratios" of 4.4 and 6.0 separately, for the "Reynolds Numbers" varying from 2000 to 12000 and shows that as the "twist ratio" declines, the "heat transfer coefficient and friction factor" characteristics increase in their value. Trapezoidal-cut twisted tapes boost the "heat transfer rate" by 26 and 40%, respectively, when compared to a plain tube with twist ratios of 6.0 and 4.4. Above importantly, the output ratio produced for trapezoidal-cut twisted tape is larger than unity, indicating that energy savings may be made by this adjustment.

Trapezoidal-cut twisted tapes improve the "heat transfer rate" by 40% and 26%, correspondingly, when compared to a plain tube with twist ratios of 4.4 and 6.0. Furthermore, the output ratio achieved for trapezoidal-cut twisted tape is greater than unity, indicating that energy savings can be achieved through this alteration.

NOMENCLATURE:

m = Water Mass Flow Rate (Kg/sec)
C_{water} = Water Specific Heat (J/kg K)
T_{in} = Water Inlet Temperature (ºC)
T_{out} = Water Outlet Temperature (ºC).
h= Avg-Heat Transfer Coefficient (W/m^2/K)
A= Pipe C/S Area (m^2)
$\overline{T_{wall}}$ = Avg Wall Temperature (expressed as: $\sum_{i=1}^{n} T_{iWall} /n$)
n = Thermocouples Used to Measure Wall Temperature
Tx = Avg Temperature (T_{out}+T_{in}) /2.

Nu= Nusselt Number
k= Thermal Conductivity (W/m-K)
Re= Reynolds Number
ρ = Density of Fluid (kg/m^3)
υ = Mean Velocity of the Fluid (m/s)
Dh= Pipe Hydraulic Diameter (m)
D = Inner Diameter of the Pipe (m)
D_{out} = Outer Diameter of Inner Pipe
D_{in}= Inner Diameter of Outer Pipe.
μ = Dynamic Viscosity of the Fluid (kg/ms)
Pr= Prandtl Number (Value is 3)

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