HEAT TRANSFER ENHANCEMENT WITH CENTRALLY HOLLOW TWISTED TAPE AND AL_2O_3 WATER BASED NANOFLUID IN TUBULAR HEAT EXCHANGER

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ABSTRACT:

Twisted tape is widely used passive augmentation technique in tubular heat exchanger for heat transfer enhancement. In this study, a new tube insert is made, named centrally hallow twisted tape and its effect on the heat transfer enhancement of a tube under laminar flow condition is experimentally studied. Experimentation is carried out at constant wall heat flux boundary condition with variations of Reynolds number from 600- 1600 with step size 200. In experimentation mainly two parameters varied 1) central hollow width of centrally hollow twisted tape 2) Volume concentration of Al_2O_3 Water based nanofluid. As centrally hallow width increase heat transfer enhancement increases and maximum enhancement when hollow width of 8 mm. Also enhancement increased as nanofluid concentration increase. The optimum overall heat transfer enhancement of the centrally hollow twisted tape increase by 22.4% compared to conventional twisted tape. The results shows that the centrally hallow twisted tape is a very good high performance tube inserts also increase in friction factor is less compared to rise in heat transfer.

KEYWORDS: Al_2O_3 Nanofluid, Centrally hollow twisted tape, Friction factor

INTRODUCTION:

Tubular heat exchangers used in various fields such as refrigeration, air-conditioning, metallurgy, electric power, chemical engineering, and widely used in these fields. High rate of heat transfer performance is very crucial for the use of heat exchangers in these fields because it is relates to the energy saving benefits. Therefore it is necessary to improve the performance of the heat exchangers. Increase the heat transfer in the tube side is the main way to enhance the performance of heat exchangers. Also using working fluid of high heat transfer performance characteristics will increase heat transfer rate. For more than a decade, researchers had carried many studies in the past to show enhanced properties of nanofluids. Nanofluids are made by mixing Nano-sized particles in basefluid such as water, oils and ethylene glycol.

Choi [I] was the first person to do so and he named the solution "nanofluid". Further research more than decade revealed that nanofluids have enhanced thermo physical properties compared to their basefluid. Wen and Deng [II] carried experiment on Al_2O_3 water based nanofluids under laminar flow conditions and constant heat flux. They observed an enhancement in heat transfer coefficient with an increase of nanoparticle concentration and Reynolds number. Yung et al. [III] experimented on the convective heat transfer coefficient and friction factor in rectangular micro channels using Al_2O_3 water/ethylene glycol (50:50) nanofluid with different concentrations. Their results had shown increase in convective heat transfer with increase in Reynolds number of flow and enhanced by 32% at 1.8% volume concentration. Choi et al.[IV] Their results has shown 160% heat transfer enhancement by adding carbon nanotubes to traditional motor oil, as basefluid, with 1% volume concentration. Kolade et al. [V] carried experiment convective heat transfer performance in laminar thermally developing flow with Al_2O_3 water and Silicone oil/MWCNT nanofluids. They observed that augmentation factor for water - Al_2O_3 nanofluid is very less compared to silicone oil with MWCNT. Anoop et al.[VI]carried experiments in the developing region tube flow with Al_2O_3/water nanofluid. They found that nanoparticles with 45 nm diameter have higher heat transfer coefficient than particles with 150 nm diameter. Asirvatham et al. [VII] performed experimentation on the heat transfer properties of CuO/water nanofluids inside the tube under laminar flow conditions, and they observed a significant increase in heat transfer with an increase in Reynolds number.

There are mainly three techniques to improve heat transfer rate, namely 1) Passive technique 2) Active technique and 3) Compound technique. Among the three techniques passive technique mostly used because that does not need external energy source. Twisted tapes, as one of the passive technique, have been extensively studied due to their advantages of good performance, easily installed or replaced for cleaning purposes and easy to manufacture. Twisted tape enhance heat transfer due to the partition and block the flow, reduction of hydraulic diameter, elongate the flow path and generate fin effect [VIII-IX]. However the heat transfer improvements are accompanied by increase in friction factor.

Sivashanmugam and Suresh[X-XI] experimentally studied heat transfer and pressure drop characteristics of laminar flow through a tube fitted with full length helical screw inserts with different twist ratios. They reported that heat transfer coefficient and friction factor increase as twist ratio increase. Guo et al.[XII] studied numerically the heat transfer behaviour in a tube with a centre-cleared twisted tape, short-width twisted tape, and conventional twisted tape separately for laminar flow. They found that the short-width twisted tape reduced not only the resistance but also the heat transfer coefficient, because of the weakening of the disturbance in the flow boundary layer. For centre-cleared twisted tapes the thermal performance factor are 7-20% greater than the conventional twisted tape. Pengxiao Li et al. [XIII] studied a new tube insert, named centrally hollow twisted tape, is developed and its effect on the heat transfer enhancement performance of a tube under laminar flow conditions is numerically simulated. Chandrasekar et al. [XIV] studied the heat transfer properties and pressure drop of Al_2O_3 water based nanofluid with 0.1% volume concentration inside a tube fitted with wire coil under laminar flow conditions. They found a 12.24% increase in Nusselt number at Re-2275 compared to water in plain tube. Sharma et al. [XVI, XIX] have investigated convective heat transfer of Al_2O_3 nanofluids in plain tube with twisted tape insert under turbulent flow conditions. Their results indicated enhancement of Nusselt number compared to the plain tube at the same flow conditions. Eiamsa-ard et al.[XVIII] studied the heat transfer and pressure drop behavior in a double pipe heat exchanger fitted with regularly-spaced twisted tapes with different twist ratios.

According to the literature in recent years, nanofluids enhance heat transfer compared to regular fluid, moreover, the use of inserts can further increase the heat transfer. So, in recent years many studies have been carried out in order to find an optimum geometry that produce maximum heat transfer enhancement with nanofluids. These efforts include the use of short length twisted tapes [18], tapes with alternate axes [19,20], and many more. Results from above studies it indicate that centrally hollow twisted tapes have low flow resistance and better heat transfer performance. Hence in this study we manufactured a centrally hollow twisted tape and studied it experimentally that not found in complete literature. In this experimental investigation, the effect of different central hollow width studied at various Reynolds number in laminar flow. Five different width of centrally hollow were studied also two volume concentrations are studied.

NANOFLUID PREPARATION:

The nanofluid was made by mixing in distilled water. Al_2O_3/water nanofluid with 0.25% and 0.5% volume concentrations were prepared as working fluids. Surfactant addition method used for preparing nanofluid to this experimentation. Sodium Lauryl Sulphate (SLS) is used as surfactant. The method used for stabilizing the working fluid was magnetic stirring at 1500 rpm and ultra-sonication (20 KHz) for 1 hour period to 1 liter fluid.

EXPERIMENTAL SETUP AND PROCEDURE:

The Schematic diagram of the proposed experimental setup is shown in Figure 1.The experimental setup consists of a 1 m long copper tube, a cooler, a storage tank, and a variable displacement pump with a by-pass valve arrangement. The test section of the tube is wrapped with nichrome wire heater to give a constant heat flux input to the test section. The outer surface of the test section is well insulated to minimize heat loss to the surrounding.

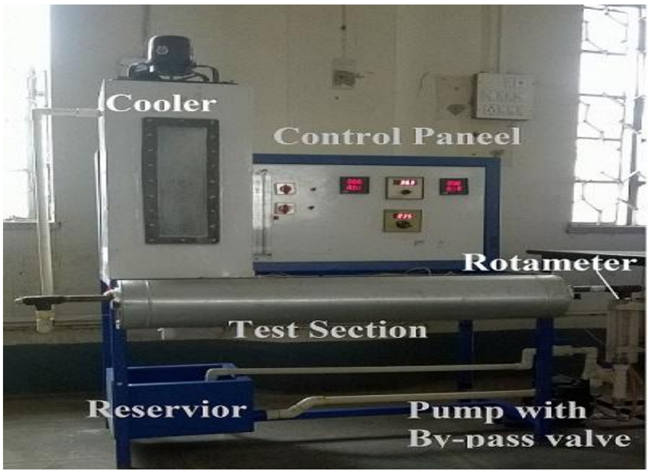


Figure 1 Photographic image of experimental setup

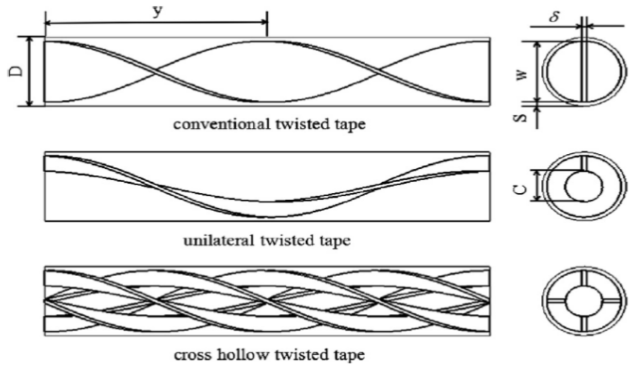


Figure 2 Tube fitted with conventional, unilateral, and centrally hollow twisted tape.

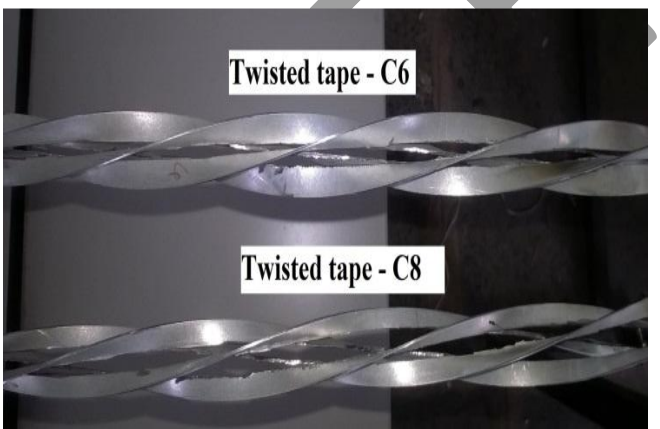


Figure 3 Photographic image of centrally hollow twisted tape for C at 6 and 8 mm.

Seven thermocouples are provided, in which two are used to record the inlet, outlet temperatures of the working fluids and the remaining thermocouples are brazed on the outer periphery of the test section of the tube, to measure the average surface temperature of the tube. Pressure drop across the test section is measured by providing pressure transducers. Flow meter is incorporated in order to measure flow rate of working fluid.. The working fluid under investigation is forced through the test section with pump connected to the sufficient capacity of storage tank. The fluid is heated by receiving heat from the test section and is allowed to cool by passing it through a cooler. By recirculation, the cooler in the flow loop helps in achieving steady state condition faster.

NANOFLUID PROPERTIES AND DATA ANALYSIS:

The nanofluid effective thermal conductivity was calculated using the Yu and Choi equation (1). Specific heat of nanofluid was calculated by Xuan and Roetzel's equation (2)

$$\frac{K_{nf}}{K_w} = \frac{K_p + 2K_w - 2\varphi(K_w - K_p)}{K_p + 2K_w + \varphi(K_w - K_p)} \qquad (1)$$

$$(\rho C_p)_{nf} = (1-\varphi)(\rho C_p)_{bf} + \varphi(\rho C_p)_p \qquad (2)$$

Viscosity of nanofluid was estimated by Einstein's equation (3) .The equation (4) was used to calculate the nanofluid density.

$$\mu_{nf} = (1 + 2.5\varphi)\mu_{nf} \qquad (3)$$

$$\rho_{nf} = (1-\varphi)\rho_{bf} + \varphi\rho_p \qquad (4)$$

The Pr number and Re number were calculated by equations (5) and (6)

$$\mathrm{Pr}_{nf} = \frac{\mu_{nf} c_p}{K} \qquad (5)$$

$$\mathrm{Re}_{nf} = \frac{\rho_{nf} v D}{\mu_{nf}} \qquad (6)$$

In the experiments conducted under constant heat flux boundary condition. The heat transfer coefficient is calculated with Newton's law of cooling. The energy supplied by pipe inner surface to the fluid is equal to heat absorbed by flowing fluid is established by using equations (8) and (9). The deviation between values obtained from equation (7) and (8) is less than 3-5 % and heat loss to the atmosphere is negligible so it is neglected.

$$Q = VI \quad (7) \qquad Q = mC_p(T_{Out} - T_{in}) \quad (8)$$

$$Q = hA_{Surf}(T_{surf} - T_m) \qquad (9)$$

The value obtained of heat transfer coefficient by Newton's law of cooling used to calculate Nusselt number from equation (10). Also the Nusselt number can be determined for plain tube from well-known Sider-

Tate correlation for thermally developing flow condition given by equation (11).

$$Nu = \frac{hD}{K} \qquad (10)$$

$$Nu = 1.86\left[\mathrm{Re}\,\mathrm{Pr}\frac{D}{L}\right]^{1/3}\left[\mu_m/\mu_w\right]^{0.14} \qquad (11)$$

Friction factor is calculated from equation (12) and practically friction factor for plain tube is calculated from equation (13).

$$f = \frac{\Delta P}{\left(\frac{1}{2}\rho v^2\right)\left(\frac{L}{D}\right)} \qquad (12) \qquad f = \frac{64}{\mathrm{Re}} \qquad (13)$$

Thermal performance factor is calculated from equation (14). It indicates overall performance of different configuration of twisted tapes and nanofluid. Higher the performance factor means having high rate of heat transfer with minimum pressure drop.

$$\eta = \frac{Nu/Nu_o}{\left(f/f_o\right)^{1/3}} \qquad (14)$$

EXPERIMENTAL RESULTS AND DISCUSSION:

5.1. VALIDATION TEST:

Experimental Nusselt number and friction factor results of the thermally developing flow in plain tube were confirmed by existing correlations for Nusselt number and pressure drop, respectively.

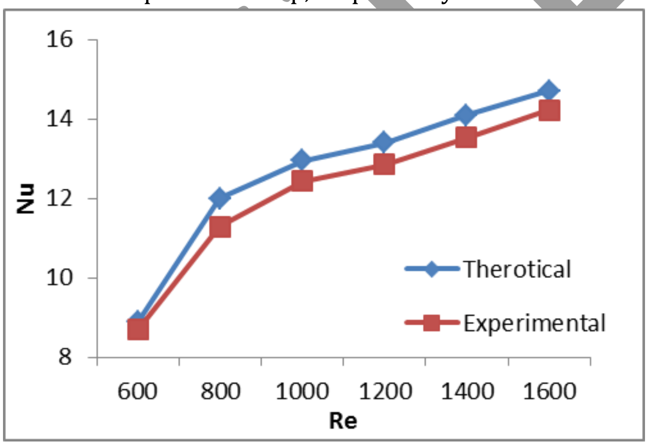


Figure 3 Comparison of the experimental results and the theoretical data of Nusselt number (Nu)

Results obtained for Nusselt number are compared with those predicted by Sider-Tate correlation in Figure 3. As it is evident, the deviation of experimental data and Sider-Tate data Equation is in the range of 2.3%-5.9%. Moreover, Figure 4 indicates that maximum deviation between the Blasius Equation (21) and experimental results is about 15.1%, for friction factor validation. As both figure show the experimental data have good agreement with exiting equations. The deviation of present experimental values compared to experimental data of literature is found to be less than 8% hence validating the experimental setup.

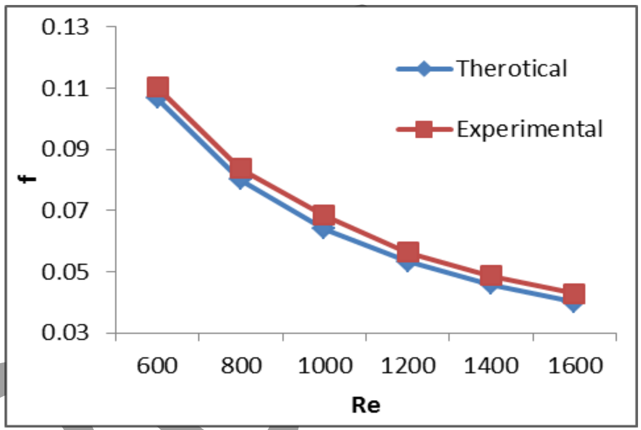


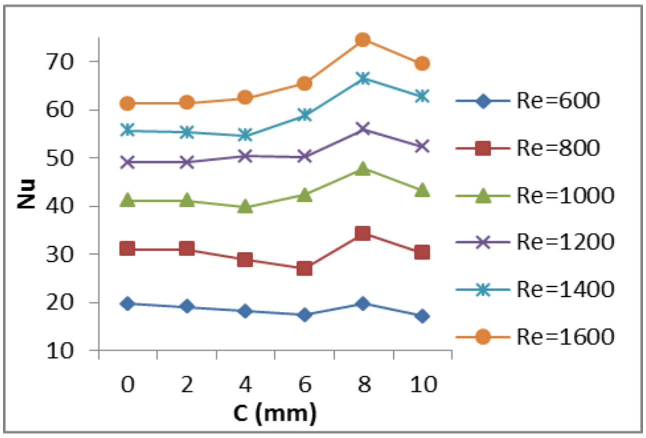
Figure 4 Comparison of the experimental results and the theoretical data of friction factor (*f*)

5.2. EFFECT OF CENTRAL CLEARANCE WIDTH:

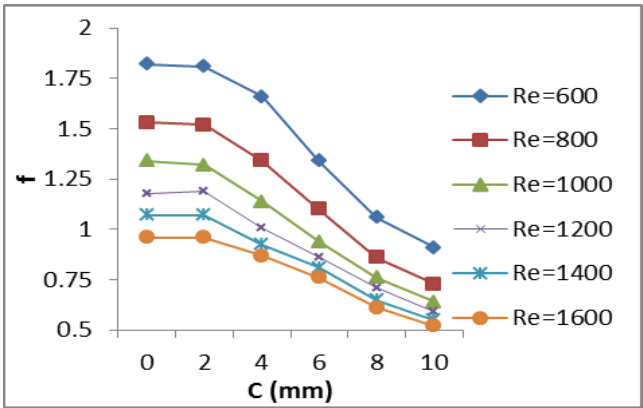
As can be seen from Figure 5 (a), when the Reynolds number increases, the Nusselt number also increases. We can find as hollow width increase the heat transfer capability. The heat transfer enhancement mechanism transfer of the centre-cleared twisted tape consists of two parts. (1) The twisted tape generates swirls, which enhance the heat transfer capability. The enhancement capability is weakened as the hollow width increases. (2) The hollow part generates irregular disturbance [12] so as the hollow width increase the irregular disturbance makes mixing of fluid between boundary region and core region, it results to increase in the heat transfer. However, when the hollow width increases beyond certain value, the irregular disturbance decreases and it affects heat transfer mechanism.

These two factors mentioned above affects each other, as Nu number little increases from 0 to 6 mm. When central hollow width increase to 8 mm the effect of irregular disturbance play's important role and heat transfer increases as result. Irregular disturbance increase mixing of core flow and boundary flow. When central hollow width increases beyond 8 mm irregular disturbance is reduced, thereby reducing heat transfer capability. So, further increase in central hollow width reduces heat transfer coefficient.

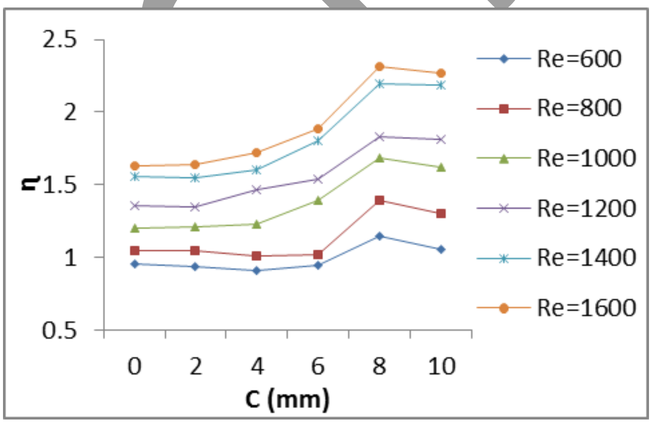
Figure 5 (b) indicates that when hollow width increases, the friction factor decreases significantly. The f of centrally hollow twisted tape decreases by 33.7-40.6 % compared with plain twisted tape. The friction factor is greater for plain twisted because of the larger surface area is in contact with the fluid. So, as hollow width increases contact area between fluid and tape decreases it results into decrease in friction factor. As shown in fig. the thermal performance factor of the centrally hollow width is greater when the centre hollow width (C) is 8 mm.



(a)



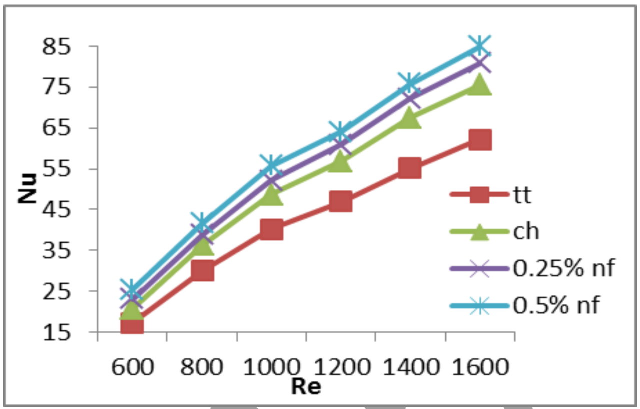
(b)



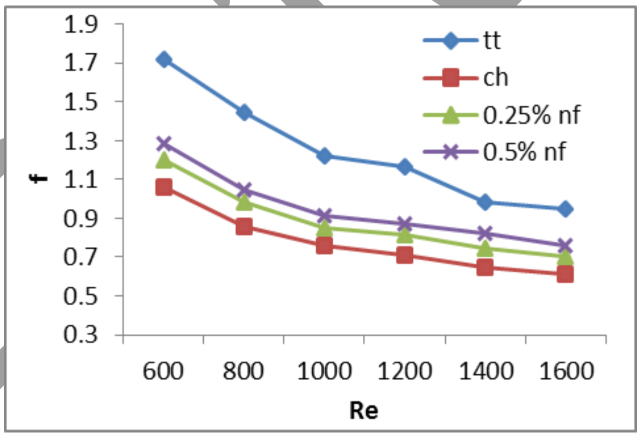
(c)

Figure 5 Variation of the (a) Nusselt number (Nu), (b) friction factor (*f*), (c) Thermal performance factor for tube fitted with centrally hollow twisted tape.

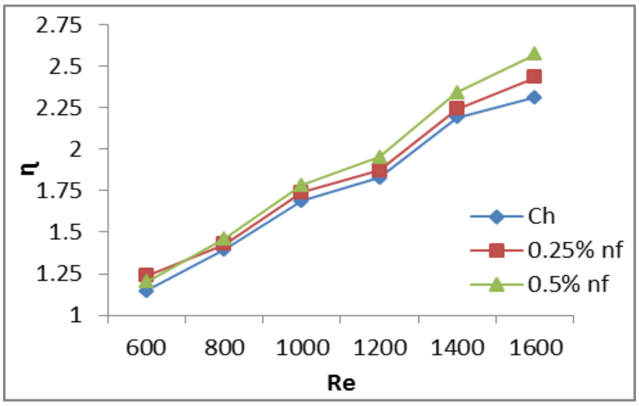
5.3. EFFECT OF VOLUME CONCENTRATION OF AL2O3 WATER BASED NANOFLUID:



(a)



(b)



(c)

Figure 6 Variation of (a) Nusselt number (Nu) and (b) friction factor (f), (c) thermal performance factor for water and nanofluid to centrally hollow twisted tape of C= 6 mm.

The use of Al_2O_3 nanoparticles as the dispersed phase in water can significantly enhance the convective heat transfer in the laminar flow, and the enhancement increases with increase in Reynolds number, as well as particle concentration which can be observed from figure 5 (a). The concentration of nanoparticles increases thermal conductivity (k) of nanofluid increases. The enhancement of the 'h' is a better indicator than the enhancement of thermal conductivity (k).

The physical properties are different than the base fluid, density, specific heat and dynamic viscosity also changed which enhance the heat transfer coefficient. It can be observed that for increasing volume concentration the friction factor is increasing while for increasing Reynolds number the friction factor decreases. The variation of friction factor for different nanofluids to plain twisted tape and centrally hollow twisted is presented in Figure 6 (b). The optimum enhancement is achieved at central width of 8 mm and higher volume concentration of nanoparticle.

CONCLUSION:

The experiments were conducted in a pipe under low Reynolds number range using water and nanofluids. The Nusselt number and friction factor for nanofluid in flow path enhanced compared to water.

a) The centrally hollow twisted tape enhances the heat transfer coefficient by 1.27-22.4 % compared to the plain twisted tape of same pitch.

b) Nanoparticle of 0.25-0.5 % volume concentration increase the heat transfer 6.84-12.8 % compared to centrally hollow twisted tape of 8 mm hollow width.

c) Friction factor of centrally hollow twisted tape at central width 8 mm has 33.7-40.6 % less by friction factor of plain twisted tape.

d) Nanoparticle of 0.25-0.5 % concentration increase friction factor by 8.23-25 % with respect to friction factor getting from water.

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