HEAT TRANSFER ENHANCEMENT IN A HEAT EXCHANGER TUBE WITH OVERLAPPED DUAL TWISTED TAPE INSERTS AND NANO FLUIDS

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Abstract:

The compactness of a tube Heat exchanger improves the performance and reduces the space by incorporating various inserts and Nanofluids. Experimental investigations and modeling analysis is carried out in this paper to enhance the heat transfer rate for the same operating parameters with and without inserts as well as Nanofluids. Overlapped dual twisted tape (ODTTs) inserts play a vital role to increase the heat transfer rate by increasing the heat transfer coefficient. The impact can be prevailed by changing twisting ratios in between 1.5 to 2.5. Concerning manufacturing constraint, three possible ratios have been identified as 1.5. 2.0 And 2.5. The thermal performance can be increased further by introducing Al_2O_3 nanoparticles by changing its volume. Here nanofluid concentrations of 1% and 2% are chosen and mixed with plain water. The experiment has been carried out initially with plain tube and water without inserts and compared the performance against inserts with different twist ratios and nanofluid concentrations. These results are compared with Numerical simulation with ANSYS Fluent. The tube with 1% nanofluid concentration by volume and twisting ratio of 2 yielded better performance. The heat transfer coefficient is improved by 8% with 3 % accuracy between experimental results and numerical study.

Keywords: Overlapped dual twisted tapes (ODTTs) , Al2O3 nanoparticles, Nanofluids, ANSYS fluent, Thermal performance factor.

Nomenclature

W Width of the tape insert, m
ϕ Nanofluid concentration, % by volume
Cp(np) Specific heat of nanoparticles, J/kg K
ρnp Density of nanoparticles, kg/m3
ρw Density of water, kg/m3
A Heat transfer surface area, m2
D Diameter of the pipe
k Thermal conductivity of nanofluid, W/mK
m Mass of nanofluid, kg/s
Cp Specific heat of nanofluid, J/kg K
Ti Temperature at the inlet, °C
To Temperature at an outlet, °C
Tw Wall temperature, °C
Tb Average bulk fluid temperature, °C
Yo Overlapped pitch length of the tape insert, m
Y Pitch of the twisted tape insert, m
Yo/Y Overlapped twist ratio
U Average velocity, m/s
μ Dynamic viscosity, kg/s m

1. Introduction:

Space management is the primary concern for any kind of Industry. Indirectly it influences the cost and performance of the system. With this concern, an attempt has been made to minimize the size of the existing equipment without compromising operating conditions. Concerning various engineering applications like Chemical processing industries, nuclear reactors, power plants, automobile cooling systems, etc, it is very essential to enhance the heat transfer rate. The main idea behind this is to modify the flow pattern to carry and dissipate the maximum amount of heat. This can be achieved by creating turbulence in fluid flow by incorporating various inserts in the form of obstacles without affecting much in the pressure drop.

The generation of secondary recirculation by incorporating swirlers resulted in enhanced radial and tangential fluctuations in the intensity of turbulence which lead to a reduction in boundary layer thickness and greater fluid mixing inside the tubes of a heat exchanger. The inserts block the fluid partially that provides enough time for fluid with nano-additives to absorb heat resulting in heat transfer enhancement.

Whitham et al. [1] have worked extensively in this area by incorporating twisted inserts and reported improved results in the majority of the heat exchangers. Rahim et al.[2] showed heat transfer enhancement by carrying out a numerical study with notch twisted tapes and jagged perforated modified shapes. Sivashanmugam et al.[3,4] proved the right-left helical form of screw inserts showed extraordinary heat transfer improvement over straight format. Nagarajan et al.[4,5] concluded that left-right sided geometries have a great impact on thermal performance, friction factor, and heat transfer enhancement. Eiamsa-ard et al.[6] gave a fitting conclusion stating the heat transfer improvement alongside friction factor for varying twist angles, i.e 30^0, 60^0, and 90^0 for varying twist ratios. Chang et al.[7] investigated the pressure drop and heat enhancement characteristics in the Reynolds range carrying from 3000 to 14,000 where he observed reduced fanning factors for increased Reynolds number. Eiamsa-ard et al.[8] studies the behavior of pressure changes and heat transfer rates by varying three different space ratios which exhibited better characteristics at instances. Zhang et al.[9] have shown a significant rise in Nusselt number by almost 171 % and 182% for heat exchangers with triple and quadruple inserts, respectively. M Chandrasekhar et al. [10] validated experimental correlations to determine the properties of nanofluids. Rokkala Rudrabhiramu et al.[11] have been developed numerical simulation on Heat Transfer Enhancement Using Overlapped Dual Twisted Tape Inserts with Nanofluids”

Nanotechnology plays a vital role in enhancing the heat transfer rate by adding nanoparticles such as Al_2o_3, Tio_2, Cuo, etc, to the basic working fluids. Out of which Al_2o_3 gives better performance parameters, which increases the thermal conductivity tremendously even for small changes in volume fractions. A suitable particle loading depending upon the type of application yielded for better heat enhancement characteristics which emerged as a promising approach to carry out this work.

2. Experimentation:

2.1 Preparation of Alumina:

Crystalline nano-alumina powder (Al2O3) was prepared from an aqueous solution of aluminum chloride using a chemical precipitation method with the help of a microwave. The solution was dissolved with water for 20 minutes, and the resulting solution was neutralized with an ammonia solution. The precipitate formed is washed with distilled water and dried. The mixture is then continuously sounded for 180 minutes in an ultrasonic bath under ultrasound pulses to disperse the uniform particles. This process improves the stability of the suspension.

2.2 Overlapped dual twisted tapes:

Fig. 2.1 Overlapped dual twisted tapes (ODTTs) and its nomenclature

Figure 2.1 shows the geometry of overlapped dual twisted tapes. The tapes are made of 0.6mm thin aluminum foil and the 8mm width tape. Each twisted is made by wrapping a straight strip around its longitudinal axis. Twisted tapes are wrapped in four different lengths. The overlapping double braided tapes were formed by attaching each of the three bars with a twist length of 24 mm (r) with each of the other three straps of different twisted lengths (y0 = 36.48 and 60 mm). Therefore, three pairs of double-twisted cross straps were obtained with y0 / y = 1.5, 2.0, and 2.5.

2.3 Apparatus and procedure:

The experimental preparation for the study is shown in Figure 2.2. It mainly consists of a wound heat exchanger tube with a heating coil, which provides a constant wall heat flow limit condition, data logger, thermocouple assembly, centrifugal pump, spindle, multi-scale, and variable. The tube is made of copper with a diameter (D) وط "and length (L) 1000 mm and a thickness of (t) 1.5 mm. The outer surface of the test tube is well insulated to reduce heat loss by convection in the surrounding areas.

During the experiments, the fluid inlet temperatures were set at 300 K, transported via a Rotameter, and then to a heat transfer test tube. The bulk fluid was heated using an adjustable electric heater that wraps the test tube. Data on temperature, volume flow, and pressure drop for bulk liquids were recorded in constant condition. Experiments were performed with (in three different rates of torsion) and without inclusion against Reynolds numbers ranging from 7,000 to 16,000, with water, 1%, and 2% of the nano-liquid concentration per volume.

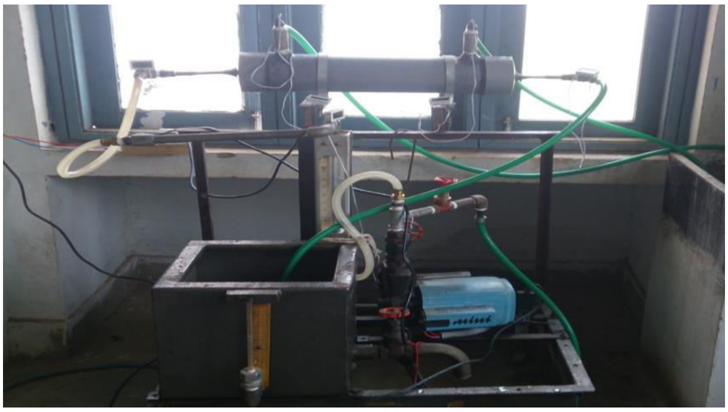

Fig.2.2 Experimental setup of twisted cum helical heat exchanger with apparatus rig

3. **Modeling and Analysis:**

Geometric shapes or tubes with dual twisted tapes interfering with CFX grids are imported. The mesh field is chosen for the best results as a total of 16,415 knots and 80,033 elements are taken with a growth rate of 1.2, as shown in Figure 2.3. Aspect ratio 1.89. The range is then formed with boundary conditions that include a smooth non-slip wall along with negligible backpressure. The input speed ranges from 0.15 m / s, which represents a change in the Reynolds number.

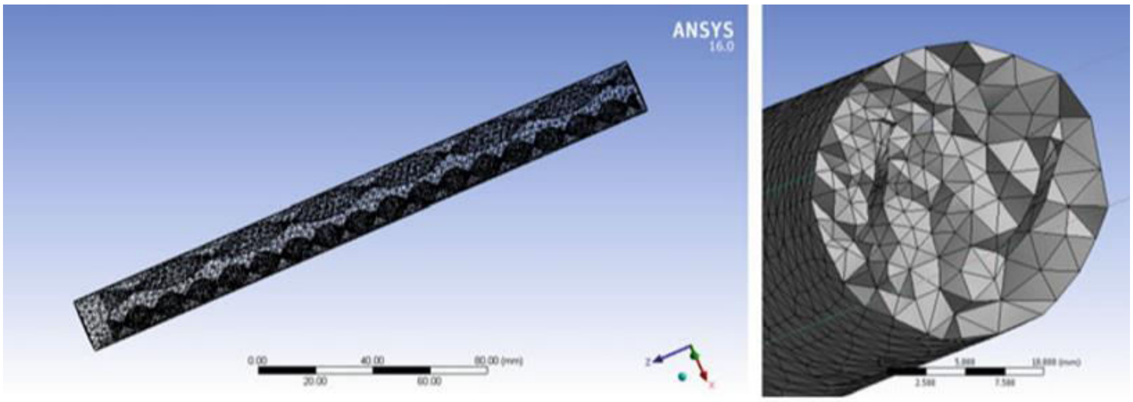

Fig.2.3 Meshed domain and a cut section showing tetra elements

Table 1. Details of the test tube and experimental conditions:

S.No	Description	Quantity / Remarks
1	Tube inner diameter	19mm
2	Tube wall thickness	1.5mm
3	Tube length	1000 mm
4	Material	Copper
5	Wall condition	Constant heat flux
6	Inlet temperature	299 K
7	Reynolds Number, Re	7,000 – 16,000
8	Type of base fluid	Water
9	The concentration of nanoparticles	1 and 2 % by volume
10	Type of nanoparticle	Alumina (Al_2O_3)
11	Thermal conductivity of nanoparticle	0.661 W/mk
12	Dynamic viscosity	0.000612 kg/ms
13	The density of nanoparticles	1007.4 kg / m^3
14	Specific heat of nanoparticles	4154.7 J/kg-K

4. **Calculation of heat transfer coefficient:**

In the present work, the heat transfer rate of working fluid was calculated by using the difference between inlet and outlet working fluid temperatures as,

$Q_{Fluid} = M.C_p.(T_0 – T_i)$.----- (1)

At the steady-state condition, the heat transfer taken by the fluid is equal to the convective heat transfer from the test section which can be expressed as, $Q_{Fluid} = Q_{conv}$, Where

$Q_{conv} = hA(T_w-T_b)$.---- (2)

Here, Q_{conv} = Conventional heat transfer from the test section.

A= Internal heating surface area

T_w = Wall temperature, calculated based upon average thermocouples temperature

T_b = Average fluid bulk temperature= $(T_0 +T_i) /2$

The average heat transfer coefficient (h) was determined by combining equations (1) and (2)

$h= M.C_p.(T_0 – T_i) / A(T_w-T_b)$ ------ (3)

For the local heat transfer coefficient, the fluid temperature and the wall are chosen from a specific local station. The Nussult number is calculated using the following formula, $Nu = h.D /K$ ------ (4)

Where D is the inner test tube diameter and K is the thermal conductivity of the fluid (water/nanofluid).

4.1 Calculation of the Pressure Drop:

The pressure drop (ΔP) across the test section length (L) is calculated from the difference of the levels of manometer fluid. The pressure drop data were subjected to the calculation of friction factor via the following equation;

$f= (D/L)(2\Delta P/\rho U^2)$ ----- (5)

4.2 Calculation of Thermal performance factor:

The thermal performance factor (η) of the tube fitted with overlapped dual twisted tapes under the same pumping power criteria is given by, Thermal performance factor (η) = $(ht / h_p)_{pp}$ ------- (6)

Where h_p and h_t are the heat transfer coefficient for the plain tube, and the tube with inserts respectively.

4.3 Empirical correlations:

4.3 (a) Plain Tube:

Initially, the heat transfer coefficient and pressure drop of the plain tube are validated by comparing the present Nusselt No. with those obtained from the standard correlations of Dittus-Boelter and friction factor with those obtained from petukhov correlation.

Dittus-Boelter correlation: $Nu= 0.023\ Re^{0.8}\ Pr^{0.4}$

petukhov correlation : $f = (0.79 \ln Re - 1.64)^{-2}$.

4.3 (b) Test section with inserts:

The experimental results of the Nusselt number, friction factor, and thermal performance factor were used to develop the empirical correlations by using the least square regression analysis.

$Nu = 0.267\ Re^{0.617}\ Pr^{0.4}\ (y_0 / y)^{-0.213}\ (1+\varnothing)^{0.505}$ ----- (7)

$f= 2.057\ Re^{-0.234}\ (y_0 / y)^{-0.311}\ (1+\varnothing)^{0.886}$ ------ (8)

Thermal performance factor (η) = $5.538\ Re^{-0.179}\ (y_0 / y)^{-0.109}\ (1+\varnothing)^{0.209}$ ----- (9)

5. Results:

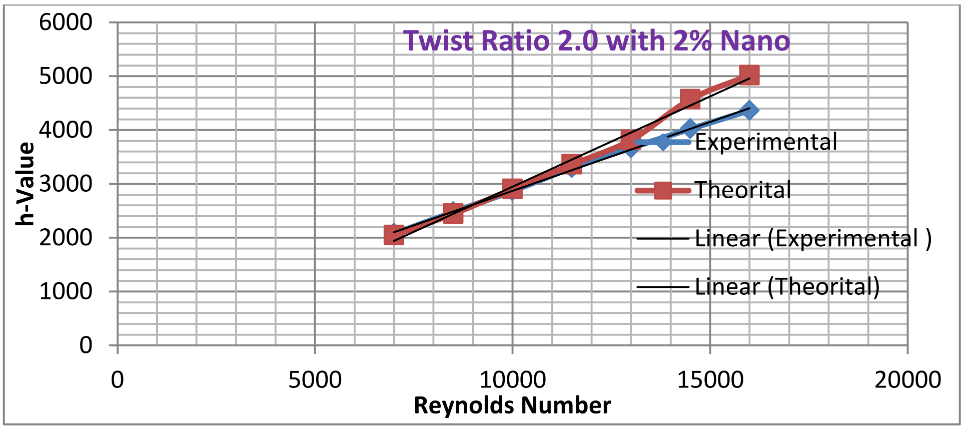

Fig 5.1 h-Value w.r.t to Reynolds number of Twist Ratio 2.0 with 2% Nano

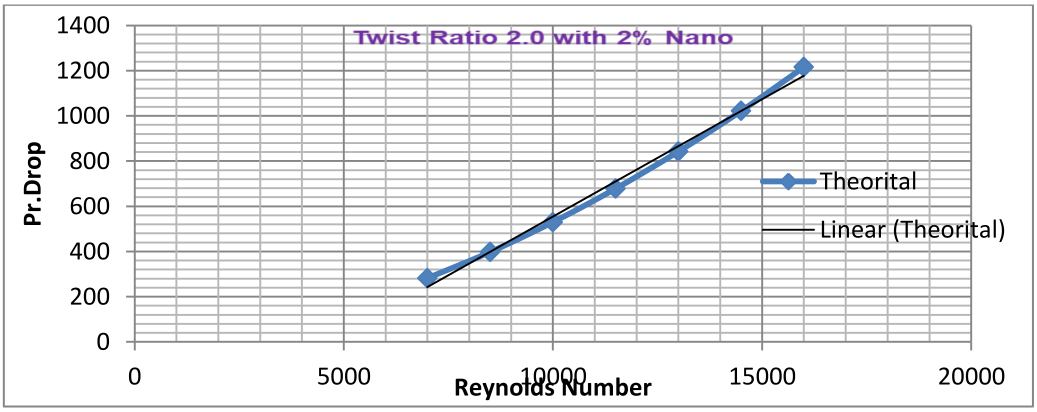

Fig 5.2 Pressure-Drop w.r.t to Reynolds number of Twist Ratio 2.0 with 2% Nano

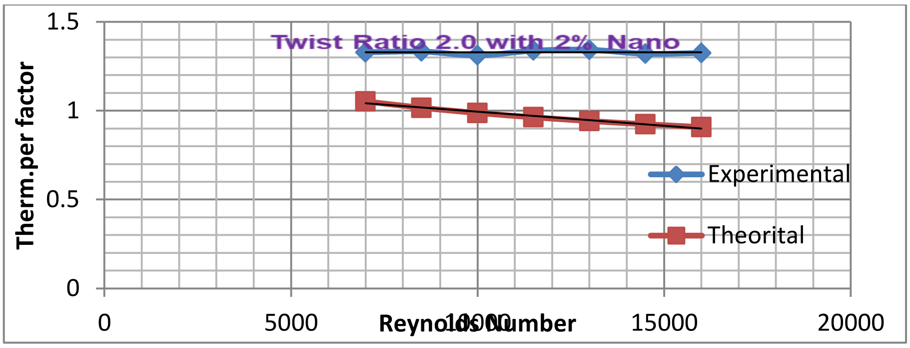

Fig 5.3 Thermal performance factor w.r.t to Reynolds number of Twist Ratio 2.0 with 2% Nano particles

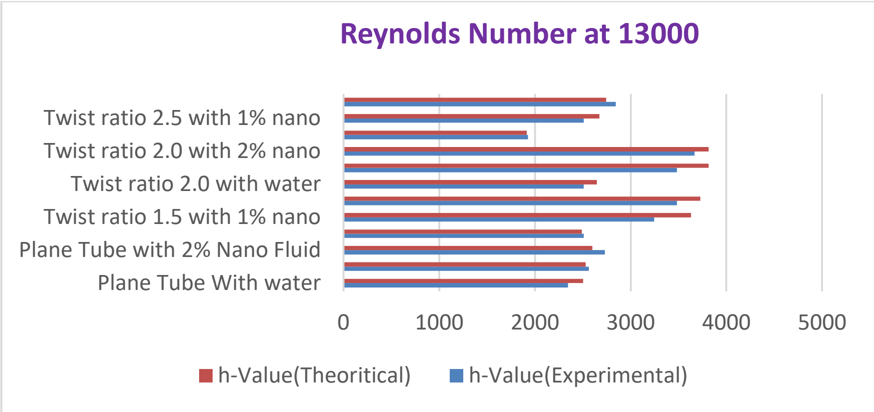

Fig 5.4 Comparison of h-Value for different twisting ratios at Reynolds Number 13000

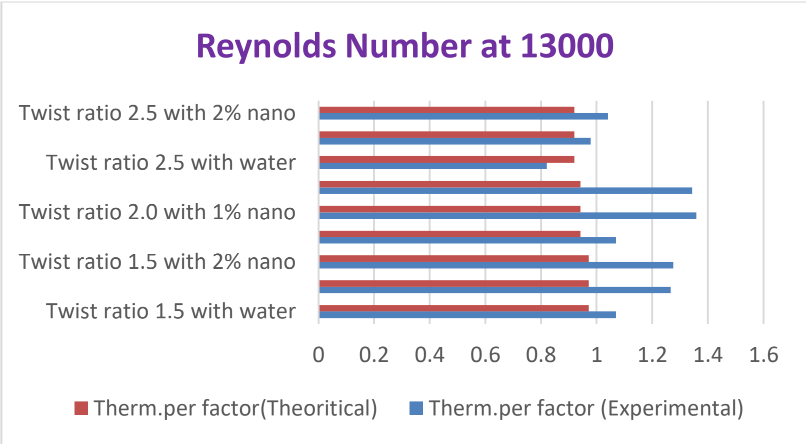

Fig 5.5 Comparison of Thermal.per.factor for different twisting ratios at Reynolds Number 13000

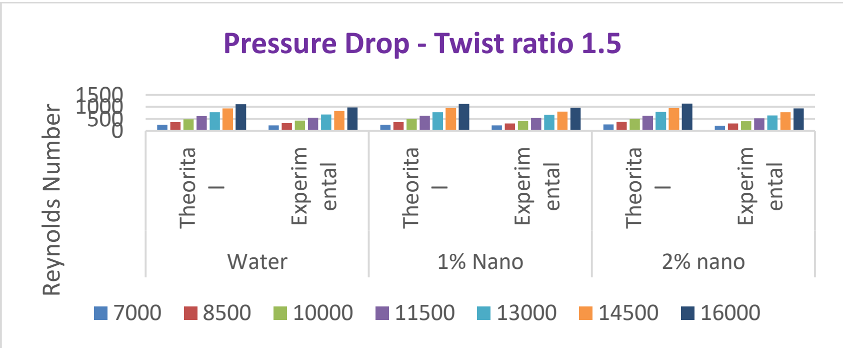

Fig 5.6 Pressure drop for Twist ratio 1.5

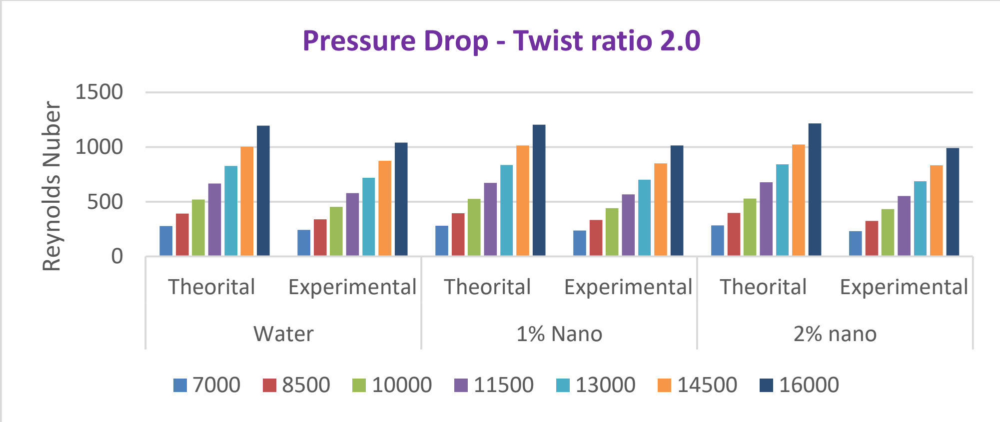

Fig 5.7 Pressure drop for Twist ratio 2.0

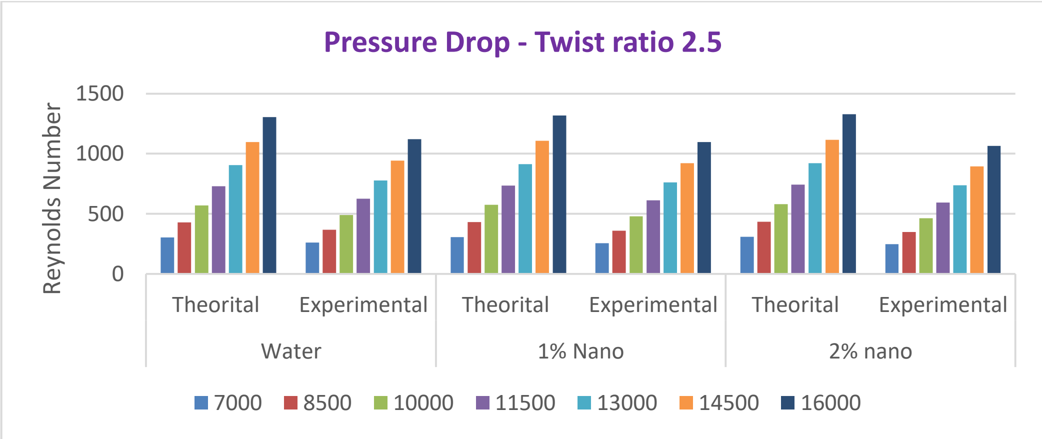

Fig 5.8 Pressure drop for Twist ratio 2.5

(I) Heat transfer rate:

(a) Effect of O-DTs inserts: The heat transfer rate increases with an increase in Reynolds number as well as the Nusselt number. At a given Reynolds number, the tube with inserts had a higher heat transfer rate than the plain tube.

(b) Effect of Al_2O_3 / water nanofluid: For the studied range, Nusselt number increased with increasing alumina concentration by volume, and all alumina/water combination fluid gave higher Nusselt number that base fluid(water).

(II) Pressure Drop:

(a) Effect of O-DTs inserts: Compared to the plain tube, the use of O-DTs increased pressure drop since double swirl flows give stronger flow disturbance than a single swirl flow.

(b) Effect of Al_2O_3 / water nanofluid: At a given Reynolds number, nanofluids caused higher friction factor, this increases pressure drop than plain water.

(III) Thermal performance factor:

(a) Effect of O-DTs inserts: It is evident that the thermal performance factor increases with inserts; this implies that the augmentation of the heat transfer was more pronounced than the pressure drop penalty. The thermal performance factor decreases with the increase of Reynolds Number.

(b) Effect of Al_2O_3 / water nanofluid: Comparatively the use of nanofluids with higher concentration by volume gives higher thermal performance factors than that of base fluids. It is noteworthy that the thermal performance factor was higher at lower Reynolds numbers.

6.Conclusions:

The heat transfer was improved by overlapping the strands of double twisted and Al2O3 / water nanofluids experimentally and numerically. The study covered nested spin ratios (y0 / y) 1.5, 2.0, and 2.5 and nanofluids with Al2O3 volume concentrations (φ) of 1% and 2%. The obtained results indicated that O-DTs caused interfering eddy flows which played an important role in improving fluid mixing and improving heat transfer. From the results obtained, it was observed that the heat transfer coefficient and thermal performance are good in the torsional ratio (y0 / y) 2.0 and

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with the concentration of nanoparticles 2% by volume. Since the torque ratio and the concentration of nanoparticles increase the heat transfer coefficient and the thermal performance also increases, but at a certain value the pressure drop increases dramatically, this is not a desirable condition.

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