Heat Transfer Enhancement on Double Pipe Heat Exchanger using Water based Nano fluid (SiO2) with Twisted Tape inserts

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Abstract*- This project report deals with the use of plain twisted tape inserts in a double pipe heat exchanger as Passive Heat transfer augmentation device. Experiments are conducted to see the effect of twisted tape inserts (PTT) on heat transfer with water as the working fluid. And also conduct analysis on ANSYS FLUENT 15.0 Nano fluid SiO2 as the working fluid. Experiments are also conducted with plain twisted tape (PTT) and plain tube for comparison. Computational fluid dynamic (CFD) studies were carried out by using the ANSYS FLUENT 15.0 to numerically predict the flow structure through the twisted tape inserts in a double pipe heat exchanger. Based on constant flow rate, the heat transfer coefficient values were found to be plain tube with water, plain tube with Nano fluid, plain twisted tape (PTT) with water and plain twisted tape (PTT) with Nano fluid respectively.*

The simulation results with the effect of having twisted tape reveals that, there is an increase in the velocity near the walls of the inner pipe along with the increase in turbulence which mixes the fluid well. Apart from the swirl flow generated due to the presence of twisted tape, this analysis shows the combined effect of the presence of twisted tape along with Nano fluid SiO2 Concentration. Finally plain twisted tape (PTT) with Nano fluid increases overall heat transfer co-efficient and effectiveness compare to plain tube and plain twisted tape (PTT) with water as working fluid.

Keywords- Double pipe heat exchanger, plain twisted tape, Nano fluid (SiO2)

I. CLASSIFICATION OF ENHANCEMENT TECHNIQUES

Heat transfer augmentation or enhancement techniques improve the thermal and hydraulic performance of the heat exchange surface. Existing Augmentation methods are mainly classified into three groups:

ACTIVE TECHNIQUES:

Active techniques are found to give high heat transfer coefficient values and were recognized in the literature, although practical applications have been limited because the enhancement is due to the application of external power. The heat transfer enhancement can be achieved by some of the active strategies like surface or fluid vibration, electrostatic fluids, or mechanical stirrers. It finds out a constrained application because of the requirement of external power in many practical applications. So, let's focus more on the passive techniques which are based on a modification of the heat transfer surface and do not require any external power.

PASSIVE TECHNIQUES:

Passive techniques regularly utilize the modification of heat transfer surface to increase the heat transfer coefficient between the surface and a fluid or by fitting in inserts inside a flow channel that produce a swirl flow. These techniques produce higher heat transfer coefficients by creating disturbance in the existing fluid flow behavior except for the case of extended surfaces.

In the case of extended surfaces, the effective heat transfer area increases on the extended surface side. Passive techniques are more advantageous than the active techniques as they don't require any external power for enhancing.

Heat transfer enhancement can be accomplished by utilizing these techniques:

- **Treated Surfaces**
- **Rough surfaces**
- **Extended surfaces**
- **Swirl flow devices**

SWIRL FLOW DEVICES:

Swirl flow devices or tabulators inserted into the flow channel are designed to induce a swirl flow motion about an axis parallel to the flow direction. Even the duct geometry modification can be generating a swirl flow or turbulence. Some of the examples of duct geometry adjustments are dimples, ribs and helically twisted tubes. Tube inserts comprise of twisted-tape inserts, louvered strip and wire coil inserts. Twisted-tape swirl flow device which is used in many advanced shell and tube heat exchangers is shown in Figure.

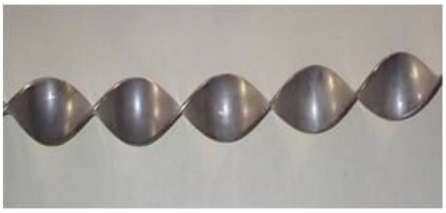

Fig: Twisted Tape

The enhancement arises due to increased flow velocity; secondary flows generated by the swirl, or increased flow path length in the flow channel. Swirl flow devices are used for single-phase forced flow and in flow boiling.

II. LITERATURE SURVEY

Twisted tape enhances the heat transfer coefficient with the increase in the pressure drop as well. Different geometrical configurations of twisted tapes like full-length, short length twisted tape, twisted tape with different twist ratio) and twisted tapes with different clearance ratio inside the tube have been studied widely by many researchers.

Saha et al. concluded that the short length twisted tape inserts placed regularly perform better than the full length twisted tapes because the swirl flow is generated with minimum pressure drop compared to full length twisted tape and decays downstream slowly with an enhanced heat transfer coefficient. So, Regularly spaced short length twisted tapes are decreasing the friction factor and the heat transfer coefficient values when compared to full length twisted tape inserts but the reduction in heat transfer coefficient is not much high because the spacing of the twisted tape inserts also disturbs the swirl flow and turbulence is created.

Manglik and Bergles carried out investigation on finding out the heat transfer enhancement and variation in friction factor with twisted tapes of different twist ratio for an isothermal tube. They developed a correlation between the friction factor and Nusselt number for laminar flows including the swirl parameter.

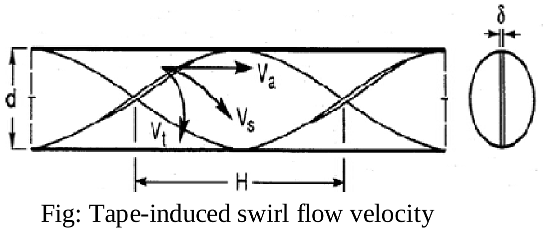

Fig: Tape-induced swirl flow velocity

The correlation introduces a swirl parameter S_w which is defined as

$S_w = Re_s/Y^{0.5}$

Where Res is the swirl Reynolds number which depends on the swirl velocity and Y is the twist ratio Res = $\rho v_s d/\mu$

V_s is the swirl velocity and V_a is the axial velocity

$v_s = va[1+(\pi / 2 y)2]1/2$

$v_a = m/ \rho A$

In laminar flow, the thermal resistance exists entirely all over the cross section. But in turbulent flow the thermal resistance exists near the wall region. So, twisted tape in laminar flow disturbs the boundary layer more than in the turbulent flow regime. Lokanath has conducted experiments in a horizontal tube with full length and half-length twisted tape inserts on unit pressure drop basis and on unit pumping power basis and found that half-length twisted tape is more effective than full-length twisted tape both for unit pressure drop basis and on unit pumping power basis.

Bhuiya et al. Carried out experimentally to find the effect of perforated twisted tape inserts in a circular tube on heat transfer, friction factor and the thermal performance factor. So, four twisted tapes having different porosities of (Rp=1.6, 4.5, 8.9, 14.7) are taken and are investigated in a turbulent flow Reynolds number range of 7200-49500. The working fluid used is air with uniform heat flux boundary condition applied to the circular tube. The results show that both the heat transfer rate and the friction factor increase with perforated twisted tape when compared to the plain tube. The Nusselt number, friction factor and thermal performance factor are 110-340, 110-360 and 28-59% higher than those of the plain tube, respectively.

Murugesan et al. investigated experimentally the effect of square cut twisted tape inserts (STT) and plain twisted tape inserts (PTT) with water as the working fluid in a double pipe heat exchanger. The range of the Reynolds number is 2000 to 12000. Three different twisted tapes having twist ratios of (Y = 2.0, 4.4, 6.0) are investigated. The values of heat transfer coefficient for the case of STT are higher than that of the PTT. The Nu, friction factor and thermal enhancement factor with STT are 1.03 to 1.14, 1.05 to 1.25 and 1.02 to 1.06 times of those in the tube with PTT respectively.

Murugesan et al. investigated experimentally the effect wire-nailed twisted tape insert (WN-TT) and plain twisted tape inserts (PTT) with water as the working fluid in a double pipe heat exchanger. Al-Fahed et al. [20] carried out experiments to see the effect on pressure drop and heat transfer coefficient with the plain, micro fin and twisted tape inserts of different twist ratio and width ratio in a single shell and tube heat exchanger. The experiments are conducted in the laminar flow regime with oil as the working fluid and steam as the heat source to obtain a uniform wall temperature of the tube. The results show that as the twist ratio decreases, the performance of the twisted tape by enhancing the heat transfer is more. The loose-fit having width ratio of (W = 10.8 mm) is best performed and recommended to be used in the situations where low twist ratios (Y = 5.4, and Y = 3.6) producing high pressure drops in design of the heat exchanger and it is also easy to install and remove for cleaning purposes.

Bhattacharyya et al. carried out experimentally to find the Nu and friction factor characteristics in a circular duct having integral transverse ribs with a centre-cleared twisted tape. Correlations are developed to predict the values using the data obtained from the experimental study. The results show that the combined effect of having integral transverse ribs and a centre-cleared twisted tape has shown good performance when compared with one enhancement technique acting alone in a circular duct for a laminar flow. Through this study it suggested this result is recommended in the design of solar thermal heaters and heat exchangers.

Li et al. numerically simulated the effect of a new tube insert named centrally hollow narrow twisted tape on the heat transfer performance in a laminar flow conditions. Two study variables hollow width and clearance are considered in the analysis.

The Enhancement with the new twisted tape i.e., the hollow narrow twisted tape has found to be 28.1% higher than the conventional twisted tape.

OBJECTIVES:

Based on the literature closure, the following objectives have been framed for the research work:

- To study the effect on heat transfer using plain twisted tape inserts as the augmentation device inside the inner pipe of a double pipe heat exchanger.
- To determine the enhancement of heat transfer rate, effectiveness, and overall heat transfer co-efficient for plain twisted tape and compare those with that of plain twisted tape and plain tube under constant flow rate and constant pumping power criteria.
- To perform CFD analysis of the flow structure in the double pipe heat exchanger with plain twisted tape inserts with Nano fluid (SiO2).

III. EXPERIMENTAL WORK

In the current work, experiments are carried out on a double pipe heat exchanger without twisted tape insert, with twisted tape insert and with baffled twisted tape inserts inside the inner tube to analyze the performance of the baffled twisted tape inserts.

EXPERIMENTAL SETUP:

The experimental setup has been fabricated according to the design and the fabrication includes:

DOUBLE-PIPE-HEAT-EXCHANGER:

- Specifications of the double pipe heat exchanger are:
- Inner diameter of inner pipe = 12.5mm
- Outer shell diameter =40 mm
- Material used: Inner pipe - copper
  Outer pipe – G.I
- Length of the test section = 1.5
- Geyser capacity = 1ltr, 3kw

a) Hot water (set at 60°C) was pumped through the inner pipe while water at room temperature flows through the annulus side in the counter flow direction.

ORIGINAL EXPERIMENTAL SETUP:

Fig: Double pipe Heat exchanger

Fig: Twisted Tape Inserts into Heat Exchanger

TYPES OF TAPE INSERTS USED:

For experimentation, one type of twisted tape inserts made from aluminium strips of thickness 1mm was used.

Plain twisted tape (PTT): Twisted tapes of width 6mm, thickness 1mm and of length 1.5m were used in the inner pipe of ID 12.5mm as shown in Fig4.5 one tape is inserted to cover the whole heat transfer length.

Fig: Plain twisted tapes (PTT)

NUMERICAL SIMULATION

Computational Domain:

Numerical simulations to analyze the flow structure with plain twisted tape(water as working fluid) in a double pipe heat exchanger is carried out using the commercial CFD analysis software ANSYS-Fluent15.0. In Fig the computational domain of double-pipe-heat-exchanger with different twisted-tape inserts and of the plain tube are presented. ANSYS-Design Modeler was used to create the domain. The 3D geometry of twisted tape insert inside a plain tube created by using ANSYS 15.0 software.

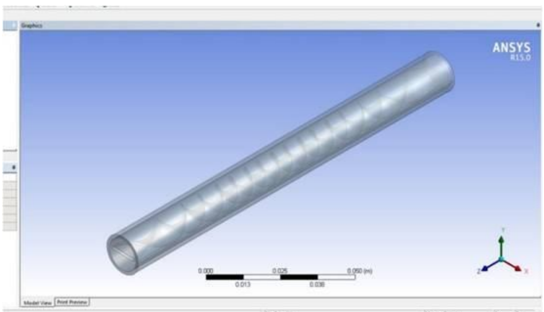

Fig gives the front view and side view of the computational domain of double pipe heat exchanger with twisted tape insert.

GEOMETRY CREATION AND MESH GENERATION:

The geometry of the double pipe heat exchanger and twisted tapes are modeled with the same dimensions used in the experimental setup. The twisted tapes are modeled with the use of sweep option in the design modeler where we can give the required number of turns to maintain a certain twist ratio. The twisted tape having same twist ratio of 6.67. Twisted tape with thickness (δ) of 1mm are fitted full length inside the inner tube. The inner diameter (D) and length (L) of the tube are 12.5 mm and 1500 mm. tetrahedral meshing method is used for meshing the geometry.

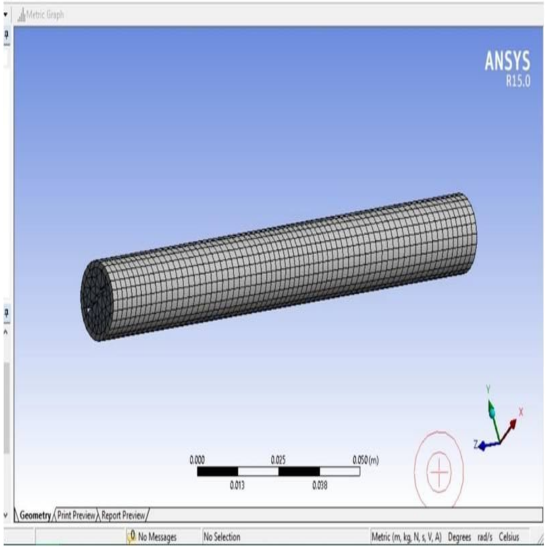

Fig: Meshing

FLUENT SETUP:

Numerical simulations were performed by using the Commercial CFD software package ANSYS FLUENT 15.0. The first step is to import the meshed geometry into FLUENT which checks the mesh or grids for any errors. Once the Grid/mesh was set, the type of solver was chosen and the boundary conditions were given for different cases and were run and analyzed.

The setup contains the options for the materials to be chosen under the define materials section. Water is selected as the fluid used and solid materials selected are copper, and aluminium in the current work. In the cell zone conditions section, give the material of inner pipe, outer pipe and twisted tape as copper, steel and aluminium respectively

BOUNDARY CONDITION:

Hot Inlet – Mass flow option is taken from drop down and Temperature is 350 K and mass flow rate is 0.15kg/s given as per the experimental results.

Cold Inlet – Mass flow option is taken from drop down and Temperature is 300 K and mass flow rate is 0.08 kg/s given as per the experimental results.

Hot Outlet & Cold Outlet – Pressure outlet is being taken.

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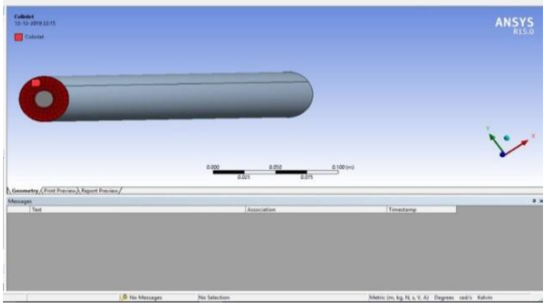


Fig: Cold fluid in

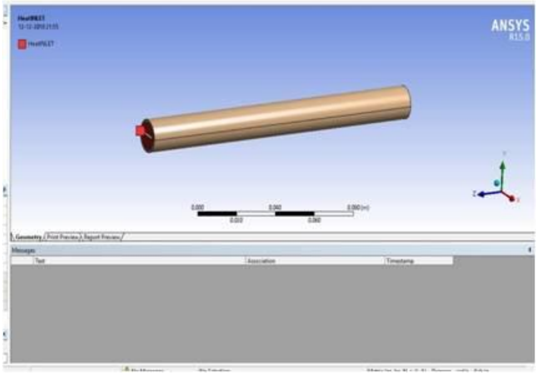


Fig: Hot Fluid in

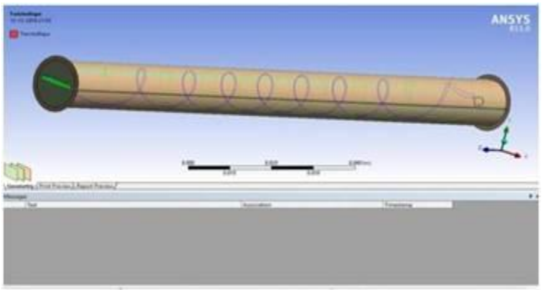


Fig: Twisted tape

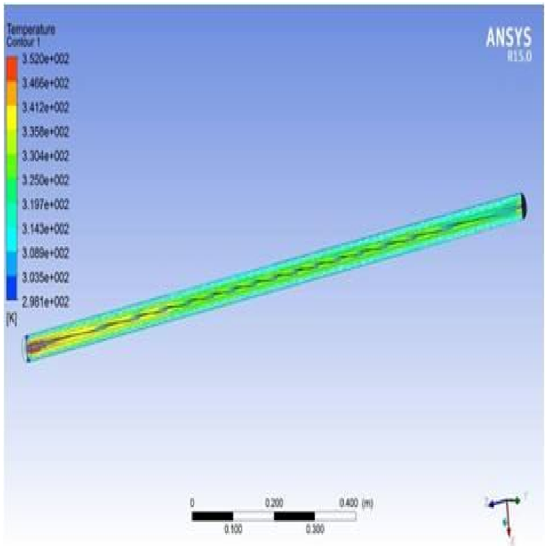


Fig: Hot fluid In- Cold fluid out

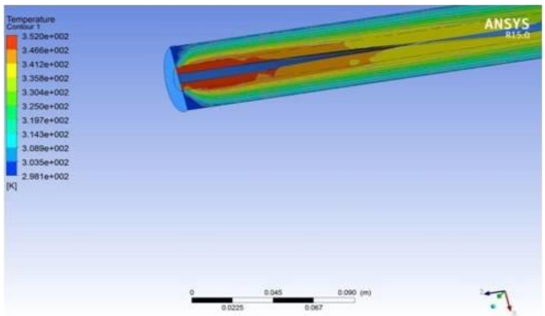


Fig: Hot fluid In-Cold fluid Out (Insight)

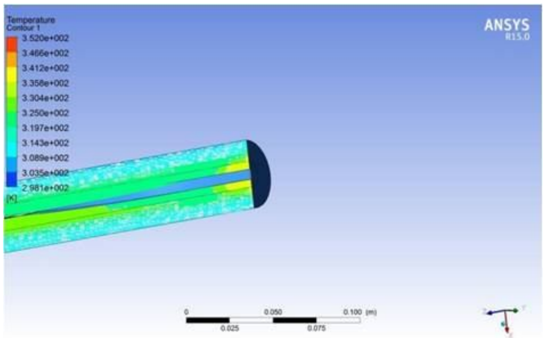


Fig: Hot fluid out

In order to validate the reliability of the numerical methods which were used, the numerical simulation were performed for the double pipe heat exchanger with twisted-tape inserts of same size as used in the experiment work. Tetrahedral meshed model was used to analyze for the case of double pipe heat exchanger with plain twisted tape.

Properties SiO_2 water based Nano fluid

	Volume fraction	Density (kg/m)	Specific heat (J/KgK)	Thermal conductivity (W/mK)
Water	0	998	4182	0.597
Water+SIO_2	0.5	1082.5	3757.71	0.73

(i) EXPERIMENT RESULTS:

The performance of heat exchanger without twisted tape insert and with twisted tape insert was evaluated. The results of the experiment are discussed in this section.

(ii) PLAIN TUBE VALUES:

FLOW	HEAT TRANSFER FROM HOT WATER	HEAT GAIN BY THE COLD FLUID	Q_{AVG}	OVERALL HEAT TRANSFER COEFFICENT (U_0)	LMTD	EFFECTIVENESS
	(WATTS)	(WATTS)	WATTS	$W/M^2.K$	^0K	
PARALLEL	890	4384	2637	2487	17.69	0.206
COUNTER	2207	4722	3460.57	2941.05	21	0.22

WITH TWISTED TAPE VALUES:

FLOW	HEAT TRANSFER FROM HOT WATER	HEAT GAIN BY THE COLD FLUID	Q_{AVG}	OVERALL HEAT TRANSFER COEFFICENT (U_0)	LMTD	EFFECTIVENESS
	(WATTS)	(WATTS)	WATTS	$W/M^2.K$	^0K	
PARALLEL	1867	5240	3553	3175	22	0.28
COUNTER	5552	6735.98	6143	3293	32	0.32

IV. SIMULATION RESULTS

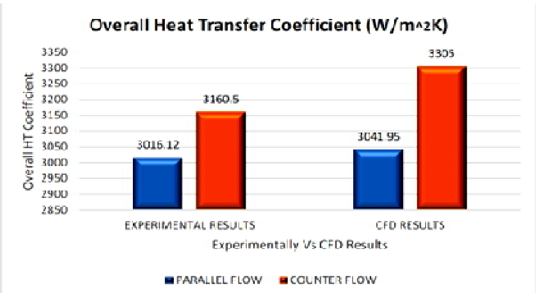
1. WITH TWISTED TAPE VALUES (Water as working fluid):

FLOW	HEAT TRANSFER FROM HOT WATER	HEAT GAIN BY THE COLD FLUID	Q_{AVG}	OVERALL HEAT TRANSFER COEFFICENT (U_0)	LMTD	EFFECTIVENESS
	(WATTS)	(WATTS)	WATTS	$W/M^2.K$	^0K	
PARALLEL	5187.6	3743.13	5713	3041.95	25	0.3
COUNTER	8646.155	6258.13	6154	3305.43	31.9	0.5

2. WITH TWISTED TAPE VALUES: (Nano Fluid is the Working Fluid):

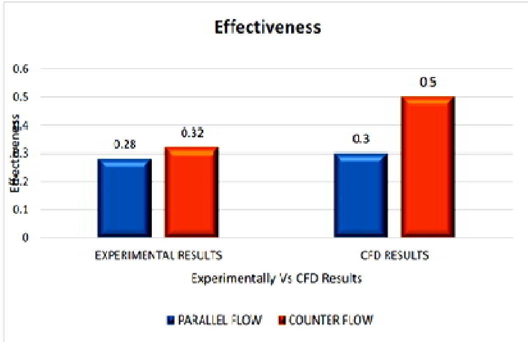
FLOW	HEAT TRANSFER FROM HOT WATER	HEAT GAIN BY THE COLD FLUID	Q_{AVG}	OVERALL HEAT TRANSFER COEFFICENT (U_0)	LMTD	EFFECTIVENESS
	(WATTS)	(WATTS)	WATTS	$W/M^2.K$	^0K	
PARALLEL	6225	11407	8900	5880	27	0.36
COUNTER	6280	12405	9169.9	6227	25	0.6

Validating > Experimental and CFD results - Overall Heat transfer coefficient



Graph: Experimental and CFD - Overall Heat transfer coefficient

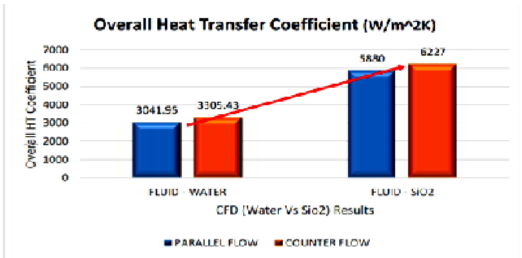
Validating > Experimental and CFD results – Effectiveness



Graph: Experimental and CFD - Effectiveness

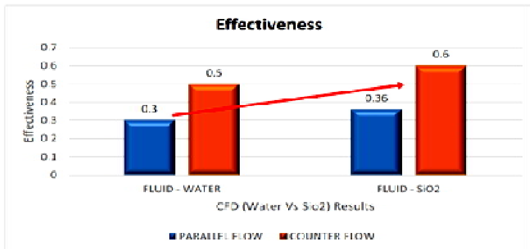
The experimental results for both Overall Heat transfer coefficient and Effectiveness obtained is very near to that of CFD results thus clearly indicating that the approach followed for CFD is matching to the experimental tabulations.

Water Vs SiO_2 - Overall Heat transfer coefficient



By observing the Overall heat transfer coefficient for water and SiO_2 indicating that heat transfer is improving when Nano fluids are in place that of water.

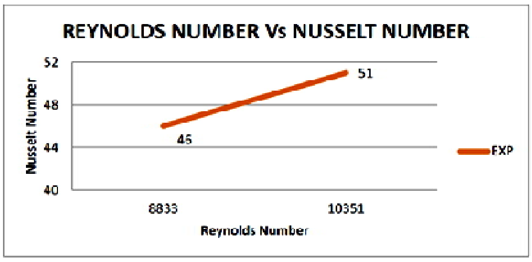
Water Vs SiO_2 -Effectiveness



By observing the Effectiveness for water and SiO2indicating that heat transfer is improving when Nano fluids are in place that of water.

Experimental values:

WITH TWISTED TAPE (Experimental Values)		
Flow rate (Kg/s)	Reynolds Number	Nusselt Number
0.46	8833	46
0.54	10351	51



Graph: Reynolds number Vs. Nusselt number

By viewing the graph shown above, the experimental values we obtain are very near to that of values from the base paper. Hence, the procedure of experiment is validated.

V. CONCLUSION

The present experimental work deals with estimation and comparison of overall heat transfer co-efficient and effectiveness of plain tube, plain twisted tape inserted tube (water as working fluid) and CFD analysis on plain twisted tape inserted tube (SiO_2 as the working fluid).

The results show that the overall heat transfer coefficient value and the effectiveness are more for the plain twisted tape inserted counter flow heat exchanger are 3305.3W/m^2K and 0.5 for the water. The same for the Nano fluid SiO_2 are 6227W/m^2K, and 0.6.

It is concluded that using of the plain twisted tape inserted heat exchanger with counter flow, the overall heat transfer coefficient and effectiveness are increased by 22% and 16.67%.

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