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Development of Correlations for Heat Transfer and Friction Factor in Double Pipe Heat Exchanger due to V-Cut Twisted Tape

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ABSTRACT:

The study focuses on enhancing the heat transfer performance of double pipe heat exchangers (DPHE) by employing twisted tape inserts with varying V-cut angles. Experimentation was conducted using single-phase forced convective flow with water as the testing fluid across a range of Reynolds numbers (10,000 to 5,500).The investigation involved comparing heat transfer rates, Nusselt numbers, and friction factors with and without twisted tape inserts. Results indicate that while twisted tape inserts improve heat transfer characteristics, they also increase frictional resistance. The maximum enhancement in heat transfer rate was observed with a 45° V-cut angle, showing a significant improvement over plain tubes and other V-cut angles. Similarly, the maximum friction factor was recorded with a 45° V-cut angle.A correlation was developed using regression analysis, incorporating V-cut angle, Reynolds number, and Prandtl number, to predict heat transfer and friction factor. These findings contribute to optimizing the design and performance of DPHEs for various industrial applications, facilitating sustainable energy growth.

Keywords: Heat Transfer, Correction , Calculation.

INTRODUCTION:

Heat transfer is an inevitable phenomenon and is the fundamental concept behind a large number of applications such as refrigeration, air-conditioning, thermal power generation, food processing, feedstock processing, etc. The exchange of heat between two fluids different temperatures and separated by a solid surface has widespread applications; the device that enables effective heat exchange is called a heat exchanger. Among the various heat exchangers available, DPHE is the most basic in design, construction and required comparatively less maintenance, and is therefore most widely adopted. Owing to its simple design and low cost, it is commonly used in small-scale industries like food, oil, chemical, reheating, preheating, effluent heating process, etc. The performance of a DPHE is vital vis-à-vis system economics and efficiency.

Thus, the improvement in the heat transfer ability of DPHES can be a significant step towards sustainable energy growth. In present work, experimental investigation on heat transfer and friction characteristics of double pipe heat exchanger for single-phase forced convective flow in clockwise twisted tape of pitch 75mm and length 2500mm inserted in the inner tube, has been carried out.

A comparative study was done to evaluate the effects of variable V-cut angle on twisted tape inserts while depth of cut is constant (2mm) and compared with without insert heat exchanger on the values of heat transfer rate, Nusselt Number and friction factor through a circular tube using water as testing fluid with a range of Reynolds number between 10000 and 5500. In the double pipe heat exchanger (DPHE), hot water was cooled in the inner tube and cold water was used as cooling fluid between the inner tube and the outer tube.

The results showed that the heat transfer characteristics of DPHE were enhanced with twisted tape while frictional resistance also increases at the same time. The maximum increase in heat transfer rate was found for 45° V-cut (i.e. 73.92 at Re-10000) and it is 44.95%, 15.30%, 11.84%, and 2.52% greater than the plain tube, without V-cut, 15° V-cut, and 30° V-cut respectively.

The maximum value of the friction factor was found for 45° V-cut (i.e. 0.0529 at Re-5500) and it is 26.25%, 20.22%, 12.31%, and 6.8% greater than the plain tube, without V-cut, 15° V-cut, and 30° V-cut respectively. The maximum value of PEC was found for 45° V-cut angle twisted tape (i.e. 1.2639 at Re-5500) and it is 6.6%, 2.68%, and 1.24% greater than twisted tape without V-cut, twisted tape with 15° V-cut angle, and twisted tape with 30° V-cut angle respectively. The following correlation has been developed by using regression analysis in terms of simple geometry (v-cut angle, 0), Reynolds number (Re), and Prandtl number (Pr).

Heat transfer: Nu = 0.002279 x Re^1.1289 (Pr)^0.0466 (0)^0.0781 Exp[0.0018(In(0))]

Friction factor: f = 2.479 x Re^-0.5260 (Pr)^0.6939 (0)^0.211 Exp[0.0668(In(0))^2]

METHODOLOGY :

Classification of Heat Exchangers:- Heat exchangers are classified on the basis of following terminology and on the basis of application.

1. According To Nature of Heat Exchange Process: –
   - Open Heat Exchanger/Direct Contact Type
   - Contact Heat Exchanger
2. According To Constructional Design Features: -
   - Concentric Tubes
   - Shell and Tube
   - Multiple Shell and Tube Passes
3. According To Relative Directions Of The Flow Arrangement:-
   - Parallel Flow
   - Counter Flow
   - Cross Flow
4. According To Physical State Of Fluids: -
   - Condenser
   - Evaporator

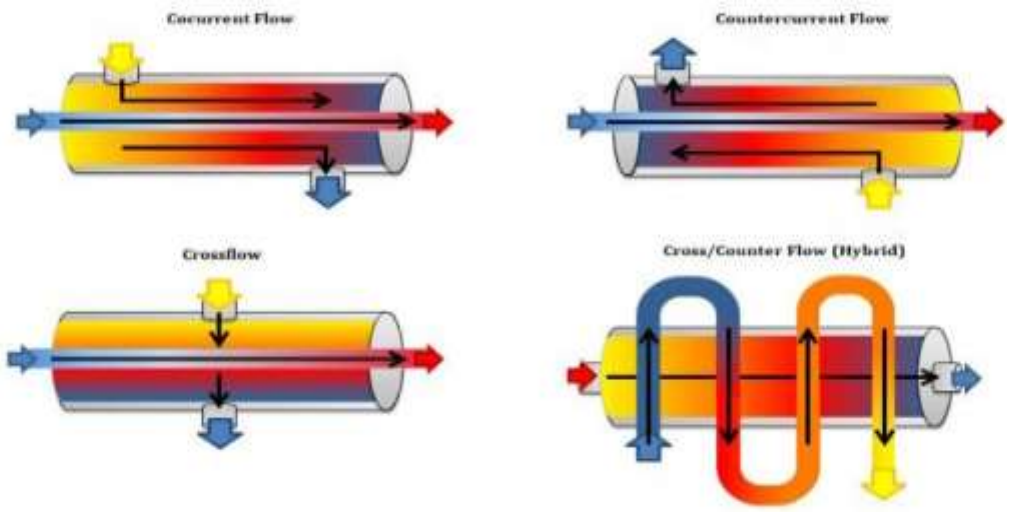


Fig.1 Heat Exchanger Flow Configurations [Ref no. 1]

Goal of Heat Exchanger :-

The goal of any heat exchanger is to allow two flows to interact at some conductive barrier, where this barrier physically separates the flows but allows for thermal energy transfer. One of the simplest and most applicable type heat exchangers is double pipe heat exchanger (DPHE). In the double pipe heat exchanger one pipe held concentrically inside of a larger pipe (thus the name "double pipe"). The inner pipe acts as the conductive barrier, where one fluid flows inside pipe and other flows around it through the outer pipe, forming an annulus shape. The outside flow passes over the inside which will cause heat exchange through the inner tube's walls between these fluids. These type of heat exchangers are also referred as hairpin, jacketed pipe, jacketed u-tube and pipe-in-pipe exchangers. The double pipe heat exchanger is often used in counter-flow, where cold fluid and hot fluid move in opposite directions. True counter-flow arrangement can be achieved in double pipe exchangers because of the concentric tube(s), and designers take advantage of this to increase the system's heat transfer coefficient. They can also be used in parallel flow where both fluids move in the same direction, but counter-flow arrangement is often used and most thermally efficient regime. This kind of heat exchanger is excessively used in chemical, food, oil and gas industries. Due to having a relatively small diameter this type of heat exchanger can be used in high-pressure applications. They are also of great importance where a wide range of temperature is demanded. It is also well- known that this kind of heat exchanger makes a significant contribution to pasteurizing, reheating, preheating, and digester heating and in effluent heating processes. It is also believed that having a high and appropriate rate of heat transfer in devices such as computers, electric power systems, automobile engines and many other examples is inevitable.

Terms Used In Heat Exchanger

• Overall Heat Transfer Coefficient [U]

• Effectiveness [s]

• LMTD (Logarithmic Mean Temperature Difference)

• NTU (Number of Transfer Unit)

• Heat Transfer Rate (Q)

• Reynolds Number (Re)

• Nusselt Number (Nu)

•Prandtl Number

•Twist Ratio

LITERATURE REVIEW & PROBLEM IDENTIFICATION :

Literature Survey: -

This survey focuses on the reviewing of the recent investigations about the heat transfer enhancement with twisted tape inserts which are widely used as a passive technique in tubular flow. The twisted tape inserts intensify the disturbance of viscous sublayer and promote redevelopment of the thermal and hydrodynamic boundary layers in the tube flow effectively. Also, twisted tape inserts are used commonly on heat transfer process due to its simple design and easy installation. These methods are widely preferred to generate swirl flow and increase the turbulence rate in the flow. Additionally, they are used extensively over decades in scientific research as well as industrial applications.

This studies broadly support the concept that this type of heat exchanger is navigating towards a considerable progress. Through these years, a series of researches have been carried out which falls into different categories. In some cases, just the characteristics of working fluids and their modifications were studied, some analysis done under active methods, passive methods, compound methods, geometry change and the various heat transfer methods.

Suvanjan Bhattacharyya, Devendra Kumar Vishwakarma et al. 2021 used a Circular Tube with Novel Hybrid Grooved Tape Inserts for Turbulent Flow Heat Transfer. The Nusselt number deviates only 5% with Dittus-Boelter correlation and 4% with Meyer and Everts correlation while friction factor differs only 6% with data obtained using Blasius Correlation.

Indri yaningsih, Agungtri Wijayanta, Takahiko Miyazaki et al. 2018 used V cut twisted tape insert and found that effect are best in low Reynolds number and thermos-hydraulic performance tends to decrease With rise of Reynolds number. Nusselt number, friction factor and thermal performance factor are falls under 3% each.

Man et al. carried out an experimental investigation on heat transfer and friction characteristics of dual-pipe heat exchanger for single-phase forced convective flow with alternate clockwise and counter-clockwise twisted tape and typically twisted tape for the Reynolds number ranging from 3000 to 9000. They reported that the maximum values of performance evaluation criteria with the full-length alternate clockwise and counter-clockwise twisted tape insert reached in experimental flowing conditions.

Zhang et al. in 2012 Used helical fins and vortex generator in outer surface of the inner tube and found Synchronous use of helical fins and vortex generators Led to an efficient case with greater heat transfer.

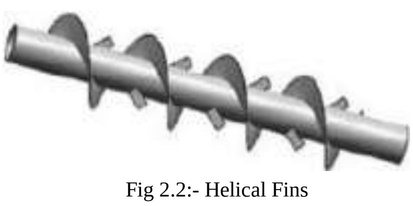


Fig 2.2:- Helical Fins

Moawed et al. in 2011 used Helical screw tapes with varied strips and found that the average Nusselt no. Nu increases with in Heat transfer-coefficient-enhancement for Right-Left helical screw inserts is higher than that for plain helical twist for a given twist ratio.

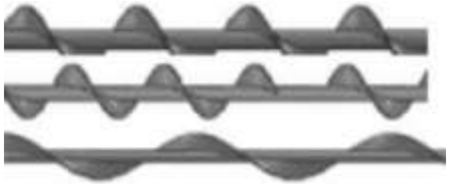


Fig 2.3:- Helical Screw Tapes

Problem Identification: -

However, literature does not reveal any investigation on heat transfer and friction characteristics in circular tube fitted with typical twisted tape configuration having V-cut angle. Present work involves a novel configuration of twisted tape to comparatively study turbulence, heat transfer and friction characteristics of double pipe heat exchanger. Heat transfer data pertaining to proposed configuration will be collected and compared with plain tube and twisted insert. To justify the proposed configuration heat transfer data and friction characteristics are plotted and discussed.

The aim of this study is to analyse effect of turbulence due to v cut twisted tape inside the tube on the heat transfer effectiveness. V cut is provided with Variable angle (15 degree, 30 degree and 45 degree respectively) at a certain distance on twisted tape and compared data with twisted tape insert without any V-cut angle and without insert observed data.

Problem Formulation:-

The aim of this work is to investigate the heat transfer and friction characteristics in a horizontal DPHE using twisted tape with different V- groove angles of same depth. Specific objectives include:

1. To examine the effect of geometrical factor such as the V-groove angles of twisted tape on the heat transfer rate and friction factor in a double heat exchanger (DPHE).
2. To compare all the obtained experimental results with plain tube.
3. To evaluate performance evaluation criterion (PEC).
4. To develop correlations for Nu and f as a function of geometrical and flow parameters.

EXPERIMENTAL SETUP

This section of study describes the devices and components used in the experiment and how the experiment was done. It also includes the procedure that was followed to collect important data. The experimental setup consisted of a double pipe heat exchanger with water as the flowing fluid. Hot water coming from boiler is flowing through the inner tube whereas cold water from water tank is flowing through the annulus (around inner tube). Hot water Circuit consisted of hot water storage tank of capacity 200 litres equipped with SSR with 0.1-degree Celsius control. Stirrer of capacity 25 litres, 0.5HP centrifugal pump, a rota-meter of governing range from 50LPH to 500LPH and a piping system with adjustable valves is attached in hot water circuit and suitable thickness insulation is provided. Cold water circuit consisted of a cold-water reservoir of capacity 200 litres, 0.5 HP centrifugal pump, a rota-meter of governing range from 50LPH to 500 LPH, a piping system with suitable valves. Inner diameter of inner copper tube is 16mm and thickness is 2mm and length of 2500mm whereas thickness of outer tube is 3mm, inner diameter 30mm and length is 2500mm. The temperature of hot water inside the boiler is maintained at 70 degree whereas inlet temperature of cold water is at room temperature (28-32°C). Twisted tape used in experiment is made up of aluminium of rectangular cross-section and twisted with one direction of pitch 75mm. Thickness of aluminium (T cross-section) is 1 mm, length 2500 mm and width are 14mm. Ten K-type thermocouples calibrated by thermal resistances with a measurement error of 0.1°C are attached within the piping (Hot water as well as cold water) and connected to a data logger. Pressure drop of hot water flowing in test piece is measured by U-tube manometer to consider frictional losses. Values of temperature, pressure drop and flow rate were recorded for calculation when system reached steady state condition.

The Practical set-up used for mentioned investigation is illustrated in figure (a) and (b) The set-up consisted of the following components:

1. AC power supply.
2. Hot water Reservoir with SSR control (Boiler).
3. Stirrer.
4. 0.5 HP centrifugal Pump for hot water.
5. Flow Control Valves.
6. Rotameter from 50LPH to 500LPH.
7. Plane Steel Tube.
8. Concentric Double Pipe (inner pipe of copper and outer steel pipe)
9. Thermocouples
10. Cold water Storage

11. 0.5HP Centrifugal pump for cold water
12. U-Tube Manometer
13. Data Logger
14. Twisted tape
15. Insulating Material - Glass wool (Jain Dori)

Fig 3.1:- Experimental set-up for Double Pipe Type Heat-exchanger available in HMT Lab

RESULTS AND DISCUSSION

Experimental set-up is validated against standard correlations suggested by the researchers in order to justify the heat transfer data obtained through the experimentation. Result reveals that the experimental values are within the justify range. Total deviation is found 13.90% for Nusselt number and 13.03% for friction factor.

The values of Nusselt number and friction factor of inserted twisted tape of constant depth of 2mm at variable angle (15, 30 and 45) degree are compared with no twisted tapes and with inserted twisted tapes to validate the heat transfer system. Observation and calculation table are pasted below**.**

Table No. 1:- Temperature Readings (Without Twisted Insert)

S.No	Hot Water			Cold Water			Surface Temperature						Average Surface Temperature
	Inlet Temperature t_{hi}	Outlet Temperature t_{ho}	Bulk (Mean Film) Temperature t_h	Inlet Temperature t_{ci}	Outlet Temperature t_{co}	Bulk (Mean Film) Temperature t_c	t_1	t_2	t_3	t_4	t_5	t_6	t_s (Or, t_w)
1	73.2	58.7	65.95	34.4	59.9	47.15	55.5	55	55	55.2	55.2	55.2	55.18333
2	73	59.1	66.05	34	53.5	43.75	56.2	55.6	55.6	55.9	55.9	55.8	55.83333
3	73.2	59.4	66.3	33.9	53.9	43.9	57	56.4	56.4	56.6	56.6	56.5	56.58333
4	73.1	59.9	66.5	33.9	54.4	44.15	57.8	57.1	57.1	57.5	57.5	57.4	57.4
5	73.1	60.3	66.7	33.6	54.8	44.2	58.2	57.6	57.7	57.9	57.9	57.9	57.86667
6	73.2	60.8	67	33.5	55.3	44.4	58.7	58.1	58.2	58.4	58.4	58.3	58.35
7	73.9	61.7	67.8	33.2	56.3	44.75	60	59.3	59.6	59.6	59.6	59.5	59.6
8	73.8	62.3	68.05	33.1	56.4	44.75	60.7	60	60.2	60.4	60.4	60.3	60.33333
9	73.9	62.6	68.25	32.5	57	44.75	61	60.4	60.6	60.7	60.8	60.6	60.68333
10	73.8	63	68.4	32.5	57.3	44.9	61.4	60.8	61	61	61.1	61	61.05

Table No. 2:- Temperature Readings (With Twisted Insert)

S.No	Hot Water			Cold Water			Surface Temperature						Average Surface Temperature
	Inlet Temperature t_{hi}	Outlet Temperature t_{ho}	Bulk (Mean Film) Temperature t_h	Inlet Temperature t_{ci}	Outlet Temperature t_{co}	Bulk (Mean Film) Temperature t_c	t_1	t_2	t_3	t_4	t_5	t_6	t_w (Or, t_{av})
1	73.8	56.1	64.95	34.1	56.2	45.15	59.4	58.6	59	58.8	58.7	58.8	58.88333
2	73.8	57.3	65.55	33.7	56.4	45.05	59.5	58.8	59.2	59.1	59	59.1	59.11667
3	73.8	58.6	66.2	33.8	57.4	45.6	60.3	59.6	60	59.9	59.8	59.9	59.91667
4	73.8	58.6	66.2	33.5	56.6	45.05	60.2	59.6	59.9	59.8	59.7	59.8	59.83333
5	73.8	59.8	66.8	33.4	57.8	45.6	61.2	60.6	60.9	60.8	60.7	60.7	60.81667
6	73.7	59.6	66.65	33.2	57.2	45.2	61	60.4	60.7	60.5	60.4	60.5	60.58333
7	73.8	60.6	67.2	33.2	58	45.6	61.8	61.2	61.5	61.4	61.3	61.4	61.43333
8	73.8	60.8	67.3	33	57.8	45.4	62.1	61.5	61.8	61.7	61.6	61.7	61.73333
9	73.8	61.5	67.65	33	58.6	45.8	62.6	62	62.2	62.2	62.1	62.2	62.21667
10	73.6	61.7	67.65	32.8	58.4	45.6	62.6	62.1	62.4	62.3	62.1	62.2	62.28333

Table No. 3:- Temperature Readings (V-Cut Angle= 15º, Constant Depth= 2mm)

S.No	Hot Water			Cold Water			Surface Temperature						Average Surface Temperature
	Inlet Temperature t_{hi}	Outlet Temperature t_{ho}	Bulk (Mean Film) Temperature t_h	Inlet Temperature t_{ci}	Outlet Temperature t_{co}	Bulk (Mean Film) Temperature t_c	t_1	t_2	t_3	t_4	t_5	t_6	t_w (Or, t_{av})
1	75.1	55.4	65.25	26.7	54.9	40.8	54	54	54	54	54	54	54
2	74.9	56.2	65.55	26.6	55.5	41.05	54.2	54.4	54.5	54.4	54.4	54.6	54.4
3	74.9	56.9	65.9	26.5	55.8	41.15	55.4	55.9	55.8	55.9	55.9	55.9	55.8
4	74.6	57.8	66.2	26.3	56.4	41.35	56.3	56.5	56.6	56.5	56.5	56.6	56.5
5	74.4	58.4	66.4	26.4	57	41.7	57	57.1	57.1	57.1	57.1	57.2	57.1
6	74.5	59.2	66.85	26.6	57.5	42.05	57.6	57.9	57.9	58	58	58	57.9
7	74.4	59.9	67.15	26.8	58.2	42.5	58.5	58.6	58.8	58.8	58.9	58.9	58.8
8	74.5	60.6	67.55	26.9	58.9	42.9	59.5	59.5	59.5	59.5	59.5	59.5	59.5
9	74.8	61.8	68.3	27.9	59.7	43.8	60.8	60.8	60.8	60.8	60.8	60.8	60.8
10	74.8	61.8	68.3	27.9	59.7	43.8	60.8	60.8	60.8	60.8	60.8	60.8	60.8

Table No. 4:- Temperature Readings (V-Cut Angle= 300, Constant Depth= 2mm)

S.No	Hot Water			Cold Water			Surface Temperature						Average Surface Temperature
	Inlet Temperature t_{hi}	Outlet Temperature t_{ho}	Bulk (Mean Film) Temperature t_h	Inlet Temperature t_{ci}	Outlet Temperature t_{co}	Bulk (Mean Film) Temperature t_c	t_1	t_2	t_3	t_4	t_5	t_6	t_w (Or, t_{av})
1	74.8	54.5	64.65	27.7	53.8	40.75	53.4	53.4	53.4	53.4	53.4	53.4	53.4
2	74.6	55.6	65.1	27.2	54.3	40.75	54.3	54.3	54.32	54.3	54.3	54.3	54.3
3	75.3	58.5	66.9	25.4	56.1	40.75	56.6	56.6	56.6	56.6	56.6	56.6	56.6
4	74.6	59.4	67	25.2	56.3	40.75	57.9	57.9	57.9	57.9	57.9	57.9	57.9
5	74.5	57.9	66.2	26.2	55.5	40.85	57	57	57	57	57	57	57
6	74.7	59.2	66.95	25.6	56.3	40.95	58	58	58	58.1	58	58	58
7	74.4	56.4	65.4	27.3	54.8	41.05	56.1	56.2	56.1	56.1	56.1	56.1	56.1
8	74.8	60.2	67.5	25.6	57.3	41.45	58.9	58.9	58.9	58.8	58.9	58.9	58.9
9	74.5	57.6	66.05	27.5	55.6	41.55	57.4	57.4	57.4	57.4	57.4	57.4	57.4
10	74.5	57.6	66.05	27.5	55.6	41.55	57.1	57.1	57.1	57.2	57.1	57.1	57.1

Table No. 5:- Temperature Readings (V-Cut Angle= 450, Constant Depth= 2mm)

S.No	Hot Water			Cold Water			Surface Temperature						Average Surface Temperature
	Inlet Temperature	Outlet Temperature	Bulk (Mean Film) Temperature	Inlet Temperature	Outlet Temperature	Bulk (Mean Film) Temperature	t_1	t_2	t_3	t_4	t_5	t_6	
	t_{hi}	t_{ho}	t_h	t_{ci}	t_{co}	t_c							t_w (*Or*, t_{av})
1	74.4	54.7	64.55	29.7	53.5	41.6	53.5	53.4	53.5	53.5	53.5	53.6	53.5
2	74.6	55.9	65.25	29.7	54.4	42.05	54.9	54.9	54.9	54.9	54.9	54.9	54.9
3	74.4	58.4	66.4	29.2	55.8	42.5	55.8	55.8	55.8	55.8	55.8	55.8	55.8
4	74.5	56.9	65.7	29.7	55.7	42.7	56.1	56.1	56.1	56.1	56.1	56.1	56.1
5	74.5	59	66.75	29.3	56.3	42.8	57.9	57.9	57.9	57.9	57.9	57.9	57.9
6	74.5	57.7	66.1	29.6	56.1	42.85	57	57	57	57	57	57	57
7	74.4	60	67.2	29.2	57.6	43.4	59	59	59	59	59	59	59
8	74.6	60.7	67.65	29.3	58.3	43.8	60	60	60	60	60	60	60
9	74.5	61.5	68	28.8	58.8	43.8	60.2	60.2	60.2	60.2	60.2	60.2	60.2
10	74.7	61.4	68.05	28.9	58.9	43.9	60	60	60	60	60	60	60

DEVELOPMENT OF CORRELATIONS FOR NUSSELT NUMBER AND FRICTION FACTOR

The data collected after rigorous experimentation in the form of Nusselt number (Nu) and friction factor (f) is used to build the correlations for the range of operating and the geometrical parameters under investigation. 'Nu' and 'f' have been chosen for evaluation in current study because these are important parameters. The functional relationship for 'Nu' and 'f' with the system and operating parameters such as Reynolds number (Re), Prandtl number (Pr) and angle of V-cut (θ) can be expressed as:

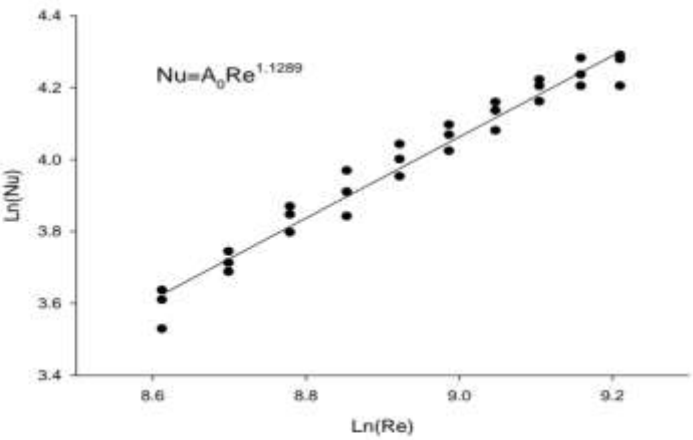
$Nu = f\ \{Re, Pr, \theta\}$

$f = f\ \{Re, Pr, \theta\}$ (5.2)

All the experimental data collected for the 'Nu' using the V-cut twisted tape geometry is plotted against the range of Reynolds numbers . It is observed from the that there exists linear relation among the 'Nu' and 'Re'.

The regression analysis has been done for the plotted data and curve fitting to determine the average slope of all the lines. The data for logarithmic value of Nusselt number 'ln(Nu)' and Reynolds number 'ln(Re)' varies linearly and the line generated by the curve fitting is represented as:

$Nu = AoRe1.1289$



Plot of Ln(Nu) vs Ln(Re)

Fig. 5.1. Plot of $\log_e$ (Nu) vs $\log_e$ (Re) for the experimental data

The coefficient Aoin the generated equation (5.3) is a function of other influencing parameters. The next step is to consider the parameter Pr for regression analysis and plot a graph between ln (Ao) and $ln(Pr)$. The data for logarithmic value of Ao 'ln(Ao)' and Prandtl Number 'ln(Pr)' varies linearly as shown in Fig. 5.2 and the line generated by the curve fitting is represented as:

$ln(Ao)$ = ln $B0$ + $A11ln(Pr)$

CONCLUSIONS

Experiments on heat transfer characteristics and friction factor in double pipe heat exchanger for single phase forced convective flow with and without twisted tape inserts have been carried out in this investigation. Effect of twisted tape insert on heat transfer enhancement and friction factor was studied after calculation. Following conclusions can be drawn from obtained data:

- Heat transfer rate(Nu) of DPHE is found to be enhanced with twisted tape insert with increase in V-cut angle while frictional resistance also increases at the same time.
- The maximum increase in heat transfer rate was found for45º V-cut(i.e 73.92 at Re=10000) and it is 44.95%, 15.30%,11.84% and 2.52% greater than the plain tube, without V-cut,15º V-cut and 30º V-cut respectively.
- The maximum value of friction factor was found at for45º V-cut(i.e 0.0529 at Re=5500) and it is 26.25%, 20.22%,12.31% and 6.8% greater than the plain tube, without V-cut,15º V-cut and 30º V-cut respectively.
- The maximum value of PEC was found for 450 V-cut angle twisted tape (i.e 1.2639 at Re=5500)and it is 6.6%,2.68% and 1.24% greater than twisted tape without V-cut, twisted tape with 150 V-cut angle and twisted tape with 300 V-cut angle respectively.
- It can be emphatically deduced that the performance evaluation criteria decreases with an increase in Reynolds number for all cases which reflects when Reynolds number increases, the impact of friction factor becomes more and more significant in comparison to Nusselt number.
- It can be emphatically deduced from the Figure that the performance evaluation criteria decreases with an increase in Reynolds number for all cases which reflects when Reynolds number increases, the impact of friction factor becomes more and more significant in comparison to Nusselt number.
- Correlations have been established for Nu and f using the results.

(a) Correlation for Nu in terms of Re, Pr and θ is given as.

$Nu = 0.002279 \times Re1.1289(Pr)0.0466(\theta)0.0781Exp[0.0018(\ln(\theta))2]$

(b) Correlation for f in terms of Re, Pr and θ is given as.

$f = 2.479 \times Re{-}0.5260(Pr)0.6939(\theta)0.211Exp[0.0668(\ln(\theta))2]$

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