International Journal of Research in Engineering, Science and Management
Volume 4, Issue 9, September 2021
https://www.ijresm.com | ISSN (Online): 2581-5792

Determination of Thermal Performance of Perforated Variable Pitch Twisted Tape Inserts

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***Abstract*: In the past few years, a number of trials and studies are being done to improve heat transfer techniques to reduce the thermal resistance, by increasing the effective heat transfer surface area or by generating turbulence into the heat exchangers. The effectiveness of a heat transfer enhancement technique is determined by the Thermal Performance Factor which is a ratio of the change in the heat transfer rate to change in friction factor. To achieve this, in a tube in tube heat exchangers, a variety of tube inserts such as swirl flow generator, wire coil, twisted tape, etc. are used. In this research work, different types of twisted tape tube insert with different geometries like twisted tape with perforations; winglets, variable twist pitch of twisted tapes, etc. are studied in order to understand the current mechanism of fluid flow and heat transfer. Suitably, an attempt has been made to explore the new geometry of twisted tape having perforations with variable pitch. This new geometry will be studied to clarify the fluid flow behavior that controls the heat transfer rates across the thermal boundary layer attached to the tube wall.**

***Keywords*: Heat exchanger, thermal performance factor, tube inserts, twisted tape.**

1. Introduction

Heat exchangers are used to exchange the heat between two fluids, in various industrial, commercial, domestic applications. Some examples include steam generation in steam power plant, sensible heating and cooling in thermal processing, fluid heating in manufacturing and waste heat recovery etc. Improvement in Heat exchanger's performance can lead to more economical design of heat exchanger which can help to make energy, material and cost savings related to a heat exchange process.

For long time, efforts were made to improve heat transfer, reduction in the heat transfer time, reduction of size of heat exchangers. These efforts include passive and active methods, are also termed as Heat transfer Augmentation or referred as Heat transfer Enhancement. So, when we design a heat exchanger using any of these techniques, analysis of pressure drop and heat transfer rate has to be done.

In Literature review, it is found that, to improve heat transfer rate, variable configurations of twisted tape as tube inserts are used. Variable pitch twisted tape & uniform pitch twisted tape with perforations are calculated individually. Variable pitch with twisted tape with perforation are not investigated yet. Hence in this paper some efforts are made to investigate and correlate the heat transfer rate of perforated variable pitch twisted tape with other simple uniform pitch and variable pitch with twisted tapes.

2. Literature Review

Morteza Khoshvaght-Aliabadi et. al. [1] Heat transfer, pressure drop, and thermal performance enhancement of the twisted-tape inserts with variable twist lengths are experimentally investigated. The experiments are performed in turbulent flow regime. Twisted-tape inserts with the non-uniform twist lengths, i.e. Low–High, High–Low, Low–High–Low, and High–Low–High were tested. The results disclose that all the twisted tape inserts yield higher heat transfer coefficient and Nusselt number values than the uniform one. The tube fitted with the uniform, Low High, High Low, Low High Low, and High Low High twisted-tape inserts provides the pressure drop higher than the plain tube. Overall thermal Enhancement Ratio values for the tube equipped with the tape having Low-High twist pitch are higher.

Nemat Mashoofi et. al. [2] Heat transfer, pressure drop, and thermal performance enhancement numerically analyzed in a double tube heat exchanger equipped with simple twisted tape (STT) and perforated twisted tapes (PTTs). By using perforated twisted tapes instead of simple twisted tape, friction factor and effectiveness of heat exchanger decreases depending on Reynolds number and hole diameter of perforated twisted tapes value. Also study found that, for large values of perforation hole diameters of twisted tap, TEF increases as compared to STT. Despite that, for small hole diameters the obtained values of TEF is close to the data suggested by the simple twisted tape. Maximum enhancement of TEF occurred when perforated twisted tape with the higher hole diameter depending upon Reynolds number value.

M. M. K. Bhuiya et. al. [3] In this paper, the study is completed to explore the consequences of perforated double counter twisted tapes on heat transfer and fluid friction characteristics in a heat exchanger tube. The twisted tapes with four different porosities percentage were used as counter swirl flow generators in the test portion. The experimental results found that the friction factor, Nusselt number and thermal

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enhancement efficiency were found increased at particular mid-range porosity percentage than at lower & higher porosity percentage.

Yan He, et.al. [4] This paper experimentally confronts the heat transfer and friction factor characteristics of a tube fitted with cross hollow twisted tape inserts of hollow widths under uniform heat flux. Experimental data of a plain tube are correlated to the standard correlations for validation. Results show that the Nusselt number and friction factor decrease and then increase as the hollow width increases.

A. Hasanpour et.al. [5] In this paper, heat transfer, pressure drop, and thermal performance improvement by experimentally and numerically has been studied in a corrugated tube heat exchanger which equipped with numerous types of twisted tapes. There are perforated, conventional, U-cut and V-cut twisted tapes. The basic results displayed that Nusselt number and friction factor of corrugated tube equipped with modified twisted tapes are higher than typical tapes apart from perforated types, which directs to lower friction factor and lower Nusselt number. Also the optimization disclosed that the V-cut tapes give highest Nusselt ratio that is twice to the empty corrugated tube and twice to corrugated tube with typical twisted tapes. The lowest values of friction factor ratio belong to perforated type.

Anucha Saylroy et.al. [6] This paper reports a numerical study of improving heat transfer and thermal performance of in a circular tube inserted by square cut twisted-tapes in comparison with that inserted by classical twisted tapes. The highest thermal enhancement factor is achieved by using square cut twisted tapes at the smallest perforated length to tape width ratio and the largest perforated width to tape width ratio.

A. Objective

Various configurations of perforated twisted tape with variable twist pitch as tube inserts will be analyzed through CFD, numerically & experimentally.

Analysis will be done to proove/achieve below,

- To increase the heat transfer rate with less friction factor.
- To make the equipment compact.
- To minimize the operating cost.
- To Increase efficiency of process and system.
- To reduce heat exchanger size.
- To transfer required amount of heat with high effectiveness.

3. Computational Fluid Dynamics Procedure

A. Computational Fluid Domain

Computational fluid domain of heat exchanger is created as per the selected parameters

B. Grid Formation

Three dimensional model is divided using tetrahedral mesh elements. Fine mesh size are selected with nodes of 213485 and 971101 elements.

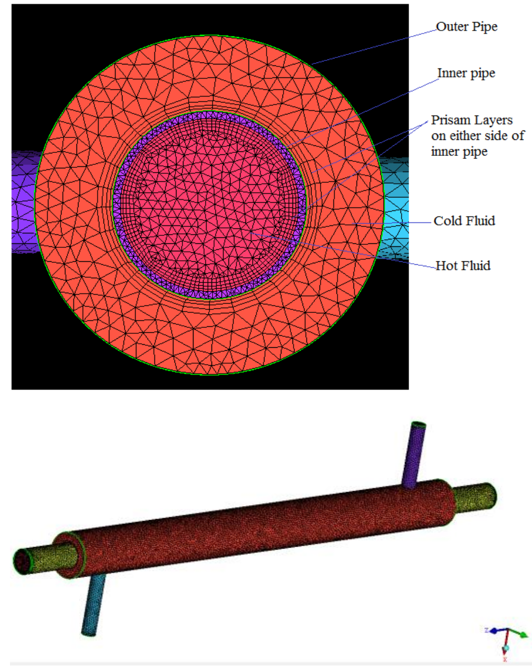

Fig. 1. Discretized domain

C. Mathematical Foundation

Numerical model is developed with assumptions given below,

- Steady fluid flow and heat transfer
- Constant fluid properties
- Fluid in single phase
- Outer wall is Adiabatic

D. Boundary Conditions

Table 1
Boundary conditions

Quantities	Boundary Conditions	
Working Fluid	Water	
Inner Pipe	Hot Inlet	
	Mass Flow Rate	Temperature
	0.1329 Kg/s	25 ˚C
Outer Pipe	Cold Inlet	
	Mass Flow Rate	Temperature
	0.0830Kg/s	75 ˚C

E. Result

Velocity, Temperature and Pressure distribution plots in tube without twisted tape insert double pipe heat exchanger are shown.

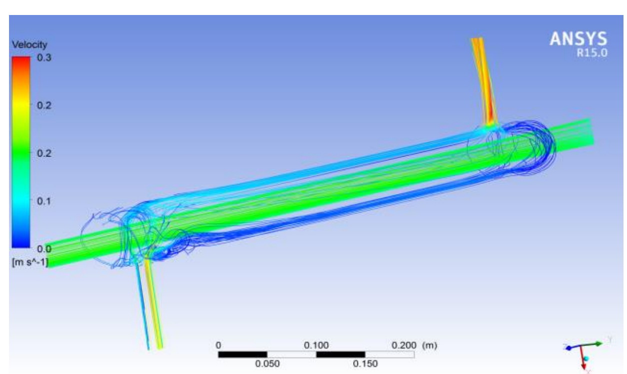

Fig. 2. Velocity Distribution pattern across DPHE

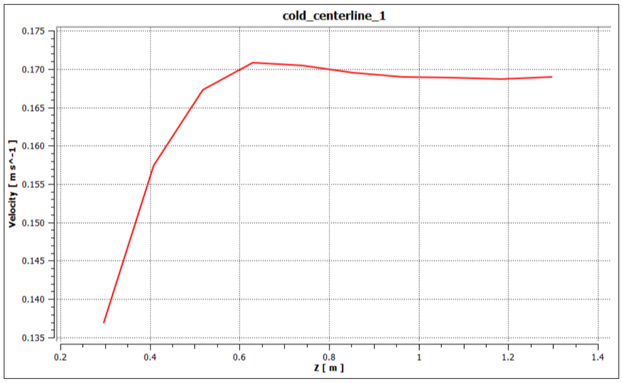

Fig. 3. Graph of velocity variation of cold fluid

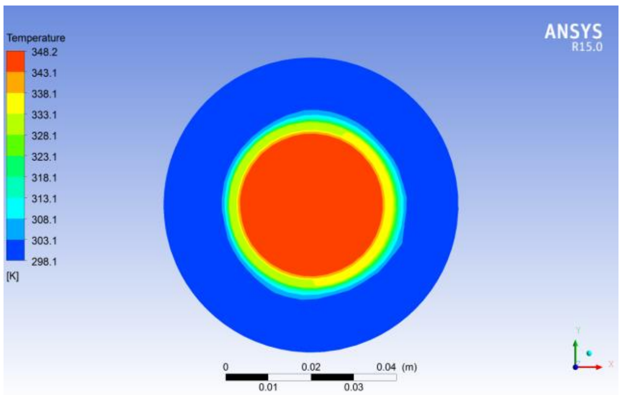

Fig. 4. Temperature distribution across DPHE cross section

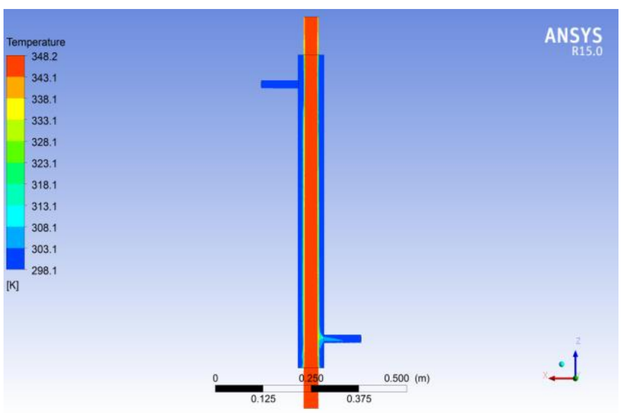

Fig. 5. Temperature distribution across DPHE

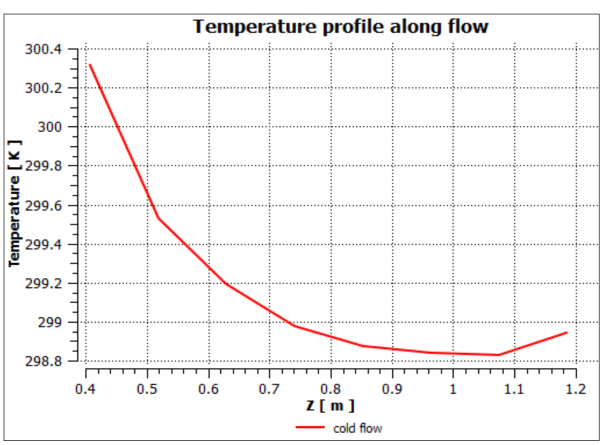

Fig. 6. Graph of temperature variation of cold fluid

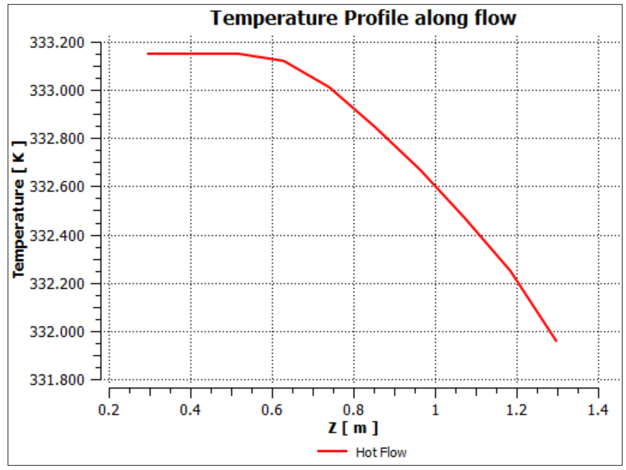

Fig. 7. Graph of temperature variation of hot fluid

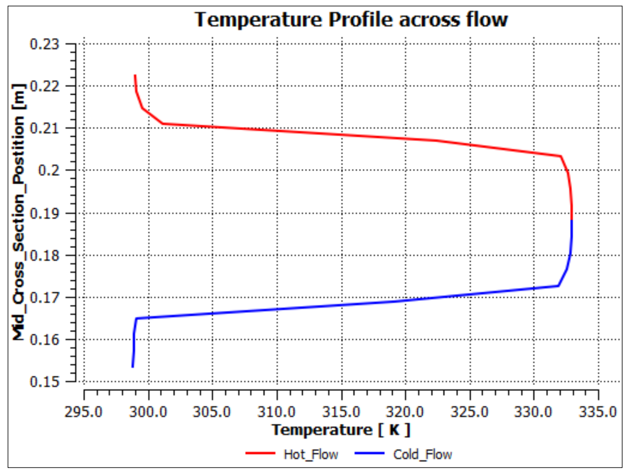

Fig. 8. Graph of temperature variation of cold & hot fluid across the heat exchanger cross section

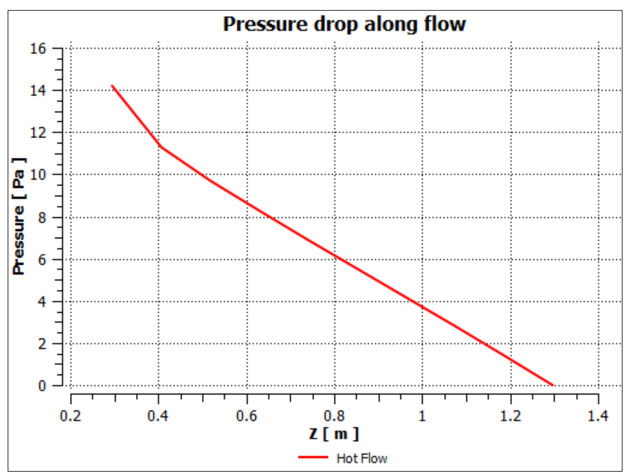

Fig. 9. Graph of pressure drop of hot fluid along the pipe length

Temperatures at outlets are as below.

Table 2
Temperatures at outlets

Area Weighted Average	
Cold Inlet	298.9 K
Cold Outlet	300.3 K
Hot Inlet	333.1 K
Hot Outlet	331.9 K

4. Calculation steps for Theoretical Evaluation of Overall Heat Transfer Coefficient

1. The area averaged convective heat transfer coefficient of the test channels is calculated by,

$$h = \frac{Q_{net}}{A_{heat}\Delta T_{im}}$$

$$Q_{conv} = \dot{m}C_p(T_o - T_i)$$

Here Q_{net} is the net heating power, which is equal to the total electrical heating power.

2. Temperature difference between the cooling flow and the heating wall.

$$\Delta T_{im} = \frac{(T_w - T_{in}) - (T_w - T_{out})}{ln(\frac{(T_w - T_{in})}{(T_w - T_{out})})}$$

Here Tw is the average temperature of the surface of the heating wall.

3. Averaged Nusselt number is defined by,

$$Nu = \frac{hDh}{K}$$

4. The Reynolds number is given by,

$$Re = \frac{\rho u_{in} dh}{\eta}$$

Where u_{in} is the inlet average velocity.

5. The calculation of friction factor is given as,

$$f = \frac{2}{(L/D_h)}\frac{\Delta P}{\rho U^2}$$

Considering, DP is the pressure drop across the test duct and U is the mean air velocity in the duct.

6. The thermal enhancement factor (n) defined as the ratio of the heat transfer coefficient of an augmented surface; h to that of a smooth surface ho, at a constant pumping power is given by,

$$\eta = \left.\frac{h}{h_0}\right|_{pp} = \left.\frac{Nu}{Nu_0}\right|_{pp} = \left(\frac{Nu}{Nu_0}\right)\left(\frac{f}{f_0}\right)^{-1/3}$$

5. Experimentation

A. Instrument Specification

Heat Exchanger type is Pipe in pipe heat exchanger.

Hot and cold fluid used is Water, Heat exchanger outer pipe outer diameter is 75 mm and inner diameter is 69 mm. Material of outer pipe is M.S. Inner pipe outer diameter is 38 mm and inner diameter is 35 mm. Material of inner pipe is Copper. Heat Exchanger length is 1 m (1000mm). Temperature Indicator type is digital indicator. Fluid Heater capacity is 1000watt immersion heater (230 volt). Cold & Hot water tank capacity is 20 liters. Flow meter selected is of 0 to 9 lpm Capacity. By using the above instrumentation set up & flow parameters, experimentation to be carried out to check thermal performance of various twisted tapes.

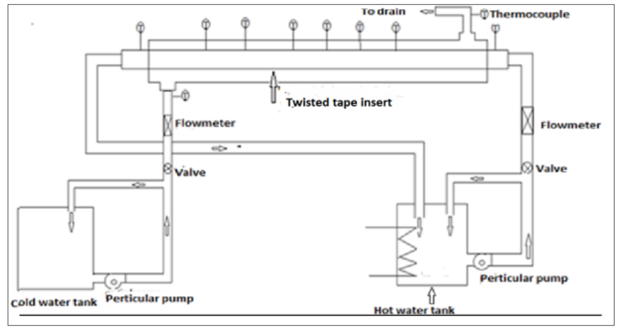

Fig. 10. Diagram for experimental setup

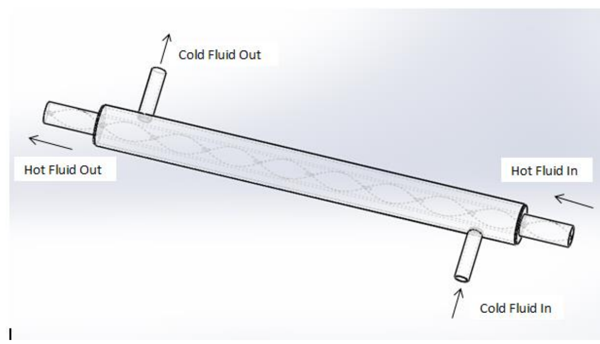

Fig. 11. General set up for heat exchanger device

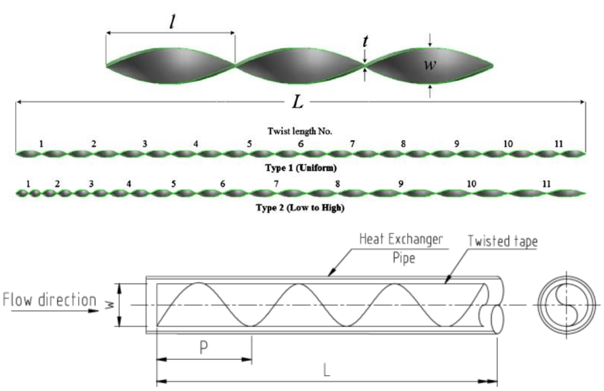

Fig. 12. Twisted tape with uniform twist pitch
Type-1 (Uniform Pitch) L=1000mm, l=50mm, t=1mm, w=32mm

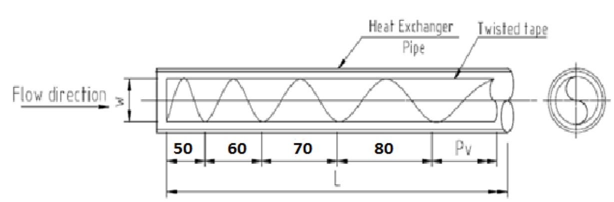

Fig. 13. Twisted tape with uniform twist pitch
Type 2 (Varying Pitch) L=1000mm, l=50-60-70-80-90-100-110-120-130-140-150mm, t=1mm, w=32mm

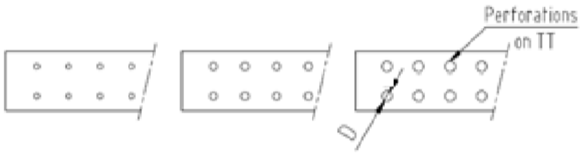

Fig. 14. Twisted tape with varying pitch and perforation
Perforation size=4mm, 6mm, 8mm Peroration row pitch=40mm, Tier pitch=17mm

Table 3
Sample test matrix-1

Sr. No.	Twisted tape configuration	Perforation diameter	Perforation pattern
1	Bare Tube without twisted tape insert	-	-
2	Uniform Pitch Twisted Tape	-	-
3	Variable Pitch Twisted Tape	-	-
4	Variable Pitch Twisted Tape with perforations	4mm	Along Tape Axis
5	Variable Pitch Twisted Tape	6mm	Along Tape Axis
6	Variable Pitch Twisted Tape	8mm	Along Tape Axis

Table 4
Sample test matrix-2

Sr. No.	Flow Rate of Litres/Min	Flow Arrangement	Twisted Tape Configuration
1	7	Counter flow	Configuration-1 to 6
2	8	Counter flow	Configuration-1 to 6
3	9	Counter flow	Configuration-1 to 6

CFD analysis of various configurations of twisted tape was done using inner tube flow of hot water as 7lpm, 8lpm, 9lpm. Corresponding Reynold number values are 8716, 10059, 11347. Outer pipe cold water flow kept laminar of 5lpm.

Below are plots of Re vs. Nu.

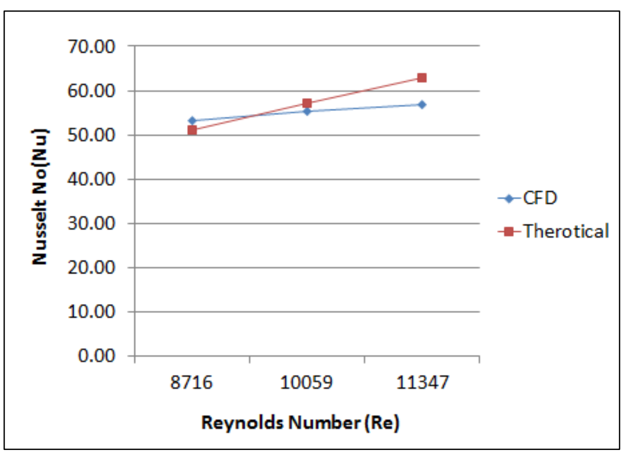

Fig. 15. Graph of Reynolds No(Re) vs. Nusselt No(Nu) for hollow tube

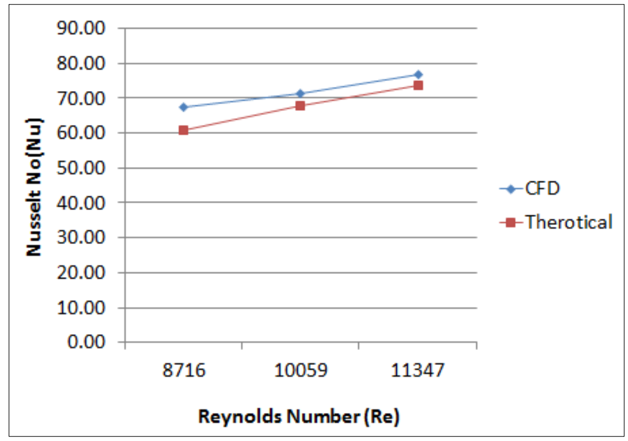

Fig. 16. Graph of Reynolds No (Re) vs. Nusselt No (Nu) for Simple twisted tape with uniform pitch

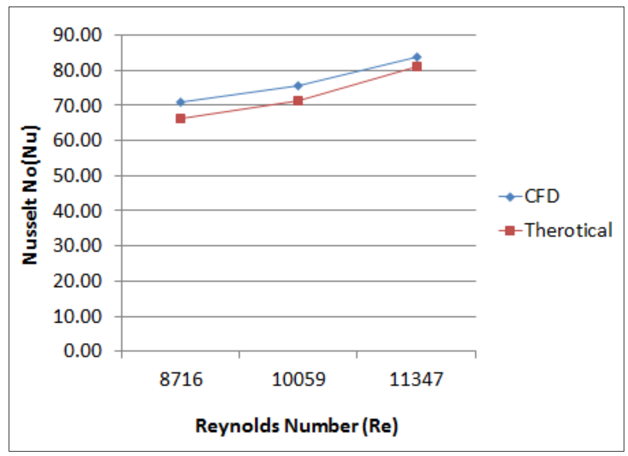

Fig. 17. Graph of Reynolds No(Re) vs. Nusselt No(Nu) for Variable pitch twisted tape

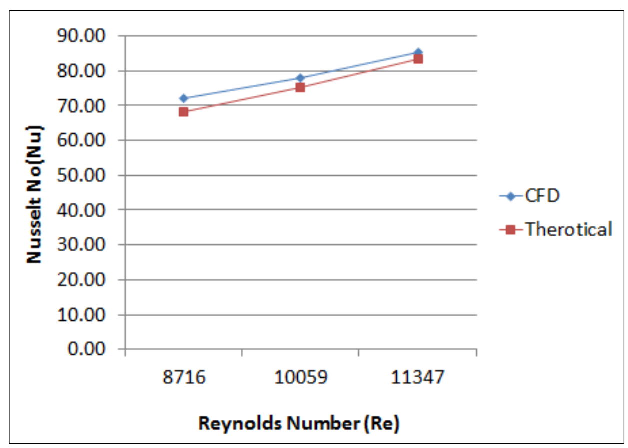

Fig. 18. Graph of Reynolds No(Re) vs. Nusselt No(Nu) for perforated (6mm holes) Variable pitch twisted tape

6. Conclusion and Discussion

Based on CFD study, it is proved that overall heat transfer increases with increase in Reynolds number.

Heat transfer rate for variable pitch and twisted with perforation as tube insert is higher by 1.4 % than hollow pipe, 1.1 % than simple uniform pitch twisted tape and 1.05 % than variable pitch twisted tape.

In perforated twisted tape, heat transfer rate is quite higher in tape having 6 mm perforation diameter than 4 & 8 mm perforation diameters.

Frictional factor for hollow pipe heat exchanger will be low as compared to twisted tapes as tube inserts.

Also, perforated variable pitch twisted tape will have lower frictional factor compared to twisted tape without perforations.

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