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A Study on the Use of Helical Twisted Tape with Perforations to Improve Heat Transfer in an Intra-Tube Heat Exchanger

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Abstract— This study is consist of the experimental investigation of the heat transfer enhancement along with pressure drop for counter flow heat exchanger consisting perforated twisted tape as insert. The study is conducted for various Reynolds number. The parameters investigated were the hole diameter ratio (d/W = 0.2, 0.4 and 0.6) and depth ratio (w/W = y/w=2.5, 3.5 and 4.5). Twisted tape without perforation is also tested for comparison. Compared to the plain tube, the tubes with TT and PTT heat transfer enhancement up to 168% and 226%, respectively. The evaluation of overall performance under the same pumping power reveal that the PTT with d/W = 0.4 and y/W = 4.5, gave the maximum thermal performance factor of 1.62, as compare to plain tube.

INTRODUCTION

The efficient use of energy is a pressing requirement in the modern world. Clearly, this calls for the creation of equipment that works well. A heat exchanger is a device that allows for the transfer of heat from one medium to another. There is a wide range of uses for heat exchangers. Automobiles, air conditioners, oil refineries, and other industrial-scale chemical processes often use heat exchangers. More cost-effective heat exchanger design may enhance heat exchange performance. By taking the material cost, energy type, and other factors into account, a more cost-effective heat exchanger design may be developed.

A heat exchanger's optimum performance is affected by a number of design characteristics and operating circumstances. Prior research has shown that shape has a significant impact on heat exchanger flow. Modifying the geometrical features

By taking design constraints into account, the heat exchanger is able to achieve its maximum heat transfer coefficient. The primary objective in developing a heat exchanger with a minimal area is to maximize heat energy transmission, allowing for an increase in heat flux. Improvements in heat exchanger thermal performance may lead to significant savings in energy, materials, and money when achieved via the use of heat transfer augmentation methods. Intensification and Heat Transfer Enhancement refer to the methods used to increase the rate of heat transfer. Convective heat transfer is enhanced in augmentation methods by decreasing the heat exchanger's thermal resistance. Some examples of these augmentation methods include surfaces that have been artificially roughened or expanded, surfaces that have been vibrated, the use of electrostatic fields, inlet vortex generators, and the insertion of materials like twisted tapes or wire matrix coils into tubes. An augmentative approach may be used to enhance existing systems in many cases, but in others, like designing heat exchangers for space shuttles, it may be necessary to adopt an augmentative strategy to ensure the system works as intended and fits within the size constraints. It is important for the designer to do thorough research to ascertain the net improvement that may be achieved with a particular augmentative technology, since these methods often come with increased weight, expense, and pumping power.

A. Methods for Enhancing Heat Transfer

"Heat transfer Augmentation" describes the method utilized to boost the heat exchanger's heat transfer rate. With the use of these methods, the heat exchanger's heat transfer performance may be enhanced via augmentation. Because of this, additional inexpensive design of heat exchanger. There are three main categories of augmentation methods: passive, active, and compound.

Active methods: These methods make use of some kind of external power in order to improve heat transfer.

Passive methods: These methods aim to increase the heat transfer rate by altering the geometry or surface in

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a certain manner. One way to do this is by adding devices or inserts into the flow channel.
Compound approaches: To further improve a heat exchanger's thermo-hydraulic performance, this method uses one or more of the aforementioned techniques in combination.

Article I. Review of Relevant Literature

The heat exchanger is a crucial component in the process sector and almost every mechanical business. A wide variety of processes involving the use, conversion, and recovery of thermal energy make use of heat exchangers. Common examples are sensible cooling and heating in different thermal processes, steam production, condensation in power and cogeneration facilities, and so on. Therefore, several researchers in this field have been diligently striving to enhance the efficiency of these heat exchangers for quite some time, all while limiting the pressure loss. It is common practice to use heat transfer augmentation methods to boost heat transfer and the heat exchangers' thermal performance. Saving money, energy, and materials is possible via improved heat exchanger performance, which in turn allows for more efficient heat exchanger design. Improving heat exchanger thermal performance is of paramount importance nowadays. The discovery and implementation of several methods referred to as Heat Transfer Augmentation have resulted in significant energy, material, and cost reductions. Active, passive, and compound procedures are the three main categories into which these methods fall.

One study by P. Eiamsa-ard and colleagues This study compares regularly spaced twisted tape against both full length twisted tape and plain tape in order to analyze its impact. A variety of twisted tapes are used. pitches. Numerical simulation is used to visualize the flow. The experiment results show that heat transfer rate and friction increased with decreasing twist ratio and space ratio. The full length twisted tapes found to be more useful than regularly spaced tapes from the thermal performance point of view.

A.Rahul kumar et. al. [2]The objective of this paper is to investigate the swirl flow behavior and the laminar convective heat transfer in a circular tube with twisted-tape inserts. The fluid flow and thermal fields are simulated computationally in an effort to characterize their structure. Apart from this, issues like long term performance & detailed economic analysis of heat exchanger has to be studied to achieve high heat transfer rate in an existing or new heat exchanger while taking care of the increased pumping power. It was concluded from the experiment that for same twist ratio, twisted tape shows higher heat transfer coefficient & friction factor increase because of higher degree of turbulence created.

W.H.Azmi et. al. [3] This paper covers the experimental determination of heat transfer coefficients of SiO2/water and TiO2/water nanofluid up to 3% volume concentration flowing in a circular tube. The investigations are conducted in the Reynolds number range of 5000 to 25000 at a bulk temperature of 30 Deg C. The experiments are undertaken for flow in a circular tube with twisted tapes of different twist ratios in the range of 5< H/D<
93. It was found that the heat transfer enhancement is inversely increased with twist ratio. The heat transfer coefficient of SiO2/water nanofluid at 3.0% volume concentration is 27.9% higher than water flow for the same twist ratio of five. However, the value of heat transfer coefficient of TiO2/water nanofluid evaluated at the same concentration is 11.4% greater than water for twist ratio five. Regression equations for Nusselt number estimation are developed valid for water and nanofluid flow with twisted tape inserts under turbulent flow conditions.

A. E. Zohir [4] In this paper, heat transfer characteristics and pressure drop are studied for turbulent flow in a sudden expansion pipe equipped with propeller swirl generator. The experiments are performed for vaying Reynolds number for three locations for the propeller fan upstream the sudden expansion and three locations downstream the sudden expansion. Use of propeller at downstream gives

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better result than at upstream. Correlations for Nusselt number and thermal performance are fan locations and different Reynolds number.S Eiamsa-ard et. al. [5] Here the combination of twisted tape and helical screw tape is used for generating swirl flow. The two tapes are arranged in co-swirl and counter swirl arrangement. Initially both the tapes are testes alone for benchmark analysis and then combination of these two tapes is studied. The results show the combined tapes method gives 10% higher thermal performance than the single tape < 30000 and 2.5 < t < 12. Screw knurling can be performed with different numbers of threads, which is determined by the requirements of the heat-transfer and pressure drop growth rates.Many researchers have been carried out experimental studies for improvement in heat transfer by using twisted tapes insert. Agrawal et. al. [7] conducted an experiment study to determine the characteristic of friction and heat transfer for heating and cooling of Servotherm oil under uniform wall temperature with twisted tapes inserts. In experiment two double pipe heat exchangers is used, one pipe for hot and other is for cold in series. The prediction of isothermal friction factor and Nusselt number is given by new correlation for uniform wall temperature of viscous

presented for different

method.Yu. A. Kuzma-Kichta et. al. [6] In this paper, the results of investigation of heat-transfer enhancement in tubes with two-thread screw knurling are presented. The analysis of heat-transfer enhancement in tubes with double-thread screw knurling leads to the following ranges of parameters, in which optimal intensification of heat transfer is ensured: 7000 < Re

liquids when twisted tapes of twist ratio is less than or equal to 5. The results showed a growth in isothermal friction factor which was 3.13–9.71 times the values of plain tubes whereas at constant pumping power and constant flow rate increase in Nusselt number were found to be 1.21–3.70 and 2.28–5.35 respectively times the plain tube values. The relationship was developed to predict isothermal friction factor for (Re/y) ¼ 9-1000.Al-Fahed et. al. [8]carried out an experimental investigation to study the effect of clearance between tube and tape on heat transfer characteristics for fully developed turbulent flow through a horizontal isothermal tube. The experimentation is conducted

for fifteen different twisted tapes. 3.6, 5.4 and 7.1 these three different twist ratios were selected with five different widths of 10.8 mm, 11.4 mm, 12.0 mm,
12.6 mm and 13.2 mm. The results showed that with decrease in tube- tape clearance the enhancement of heat transfer rate increases. Result Also shows that, for twist ratio 3.6 and tape width 10.8 mm, heat transfer enhancement was nearly equal to 13.2 mm width of same twist ratio. Almost 17% difference in heat transfer enhancement was obtained from different widths with twisted tape of twist ratio 3.6, and same difference in heat transfer improvement for twisted tapes of twist ratio 5.4 and 7.1 was 9% and 5% respectively. The study concluded that with small twist ratio and tight fit tape are desirable to achieve high heat transfer improvement for turbulent flow in practical design of thermal systems.

Al-Fahed and Chamra L.M. [9]conducted an experimental study to study and compare heat transfer coefficients and pressure drop for a plain, twisted tape inserts and microfin in laminar flow
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region. By using a single shell and tube heat exchanger tThe experiments were performed, were steam as a heating source and oil was used as a working fluid. The twisted tapes of three different twist ratios 3.6, 5.4 and 7.1 for and two widths ratio
0.95 and 0.77 were selected in the study. The study shows that from the results that the use of twisted tapes is most effective method to improve heat transfer rate. It was also found that heat transfer rate increases with decreasing twist ratio. Higher values of heat transfer were obtained by using tight fit tapes for twist ratios 3.6 and 5.4 than loose fit tapes. But the high heat transfer rate was obtained by loose fit tapes than tight fit tapes for twist ratio of 7.1. The comparison of friction factor of microfin tube with that of plain tube was done using Friction Loss Ratio. The friction loss ratio of microfin tube was approximately unity due to which pressure drop in microfin tube was almost same as that of plain tube. A small increase in heat transfer and pressure drop coefficients was obtained by using microfin tubes over the plain tubes therefore, the studied microfin tubes were not found useful for laminar flow

tubes with three dimensional internal extended surfaces and copper continuous or segmented twisted tape inserts. On three copper, continuous twisted tapes insert the experiments were conducted with twist ratio 5, 10 and15 along with two copper segmented twisted tape inserts with a twist ratio of 10 and 15. The range of Prandtl number (Pr) and Reynolds number (Re) was 5.5–590 and 80–50,000

. Thianpong et. al [11] conducted an experimental investigation for heat transfer and pressure drop analysis for turbulent flow with perforated twisted tapes in heat exchanger. The experimentation is carried out for perforated twisted tapes of having hole diameter ration d/W is 0.11, 0.33 and 0.55 with wing depth ratio w/W is 0.11. 0.22 and 0.33. Experimental result shows that the heat transfer enhancement in

Sombat Tamna et. al. [12] conducted an experimental work on heat transfer enhancement in a round tube by insertion of 300 V-shaped ribs on twisted tapes. The working fluid is air in test tube having a constant wall heat-flux with Reynolds number varies between 5300

angle is investigated. The experimental results shows that pressure drop and heat transfer enhancement in terms of friction factor and Nusselt number in V-ribbed twisted tapes increases as increase in Reynolds number and Blockage ratio

respectively. The results showed that by using 3 DIEST tubes technique with twisted tape inserts to increase heat transfer rate is suitable for laminar flow of highly viscous fluid flowing through tube. Also, there was found a small increase in heat transfer for transitional and turbulent flow but friction factor increasesconsiderably

perforated twisted tube and twisted tube is be up to 208% and 190% as compared to plain tubes. Perforated twisted tube with same pumping power having d/W ratio 0.11 and 0.33 gave the maximum thermal performance factor of 1.33 at Reynolds number of 5500. The empirical relations for friction factor, heat transfer and thermal performance for perforated twisted tube were also developed.

to 24000. Thermal characteristics of V-ribs parameter such as relative rib height having dimensions BR= b/D= 0.07, 0.09, 0.14 and 0.19 along with relative rib pitch PR=P/D=1.9. at 300 attack

BR). the highest heat transfer and friction factor occurs for BR=0.19, but the maximum thermal enhancement is about 1.4 for the V-ribbed twisted tape having BR=0.09 as compared to no rib tapes which having thermal enhancement 1.09.

K. Nanan [13] studied the impact of perforated helical twisted-tapes (P-HTTs) on the thermal performance characteristics, friction loss and heat transfer under a uniform heat flux condition is reported. The P-HTTs were obtained by punching typical helical twisted-tapes (HTTs) with a prospect to reduce the friction loss of fluid flow. The P-HTTs' having three different diameter ratios (d/w) of 0.2,
0.4 and 0.6 were used for experiments, along with three different perforation pitch ratios (s/w) of 1, 1.5 and 2. The ratio of helical pitch and twist were fixed at P/D = 2 and y/w = 3. The experiment is carried out for Reynolds number ranging between 6000 and 20,000. The experiments for comparison is carried out using the plain tube and the tubes with HTTs for assessment. The experimental results shows that the use of P-HTTs leads to the decreases the friction loss as compare to that of HTT. Heat transfer, friction loss and thermal performance factor increase as d/w decreases and s/w increases. The maximum thermal performance factor of 1.28 is obtained by using the P-HTT with d/w = 0.2 and s/w = 2.0 at the Reynolds number of 6000. The empirical correlations for thermal performance factor, friction factor and Nusselt number give accurate predictions within ±3%, ±6% and ±4%, respectively.

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I. EXPERIMENTATION

A. Experimental Setup:

A schematic drawing of the facility used for heat transfer measurements is shown in Fig. The average heat transfer coefficient on the circular tube was measured for various rates of hot and cold-water flow through the inner tube and outer tube. It consists of an open loop flow circuit having two centrifugal pump units fitted with a circular tube, which is connected to the test tube located in horizontal orientation. The test tube which is of copper material, 26 mm ID, 1 mm thickness and 1.5 m length is used for experimentation.

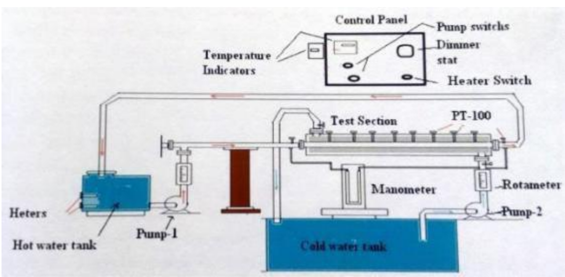

Figure 1 Schematic diagram of experimental Setup

Four thermo-couples at the inlet and outlet of cold and hot water flow are embedded. The measurement of surface temperature across the fluid flow five thermocouple is attached at equal distance. The digital device temperature indicator is used to display the temperature measured by thermocouple at various position.

Figure 2: Experimental Setup

A U tube manometer is used to measure the pressure drop across the test section. Typically, the pipe system consists of a valve, which controls the water flow rate through it and two rotameters to find the volume flow rate of water through the system. The two pressure tapings of the test section are connected to a U-tube manometer to indicate the pressure difference between them.

The insulation is provided to reduce the heat flow through the surface to atmosphere air. The PUF insulation is used to avoid the heat transfer to the atmospheric air. The thickness of insulation is 8 mm.

II. RESULT AND DISCUSSION

The experimental procedure and sample calculation is discussed in previous chapter. This chapter deals with the obtained results and its interpretation. The

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effect of Reynolds number on Nusselt's number, pressure drop, and performance evaluation criteria

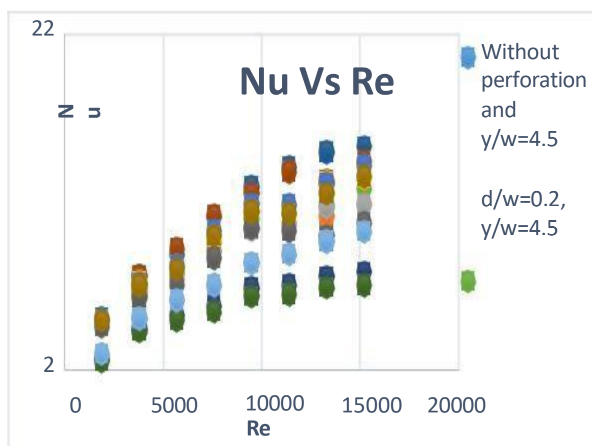
A. Nusselt's Number

The Graph 1 shows the variation of Nusselt's number on Reynold's number for plain tube and the tube equipped with Perforated Twisted Tapes (PTT) inserts. As the Reynold's number is increased the value for Nusselt's number is also increasing. The values of Nusselt's number is low for plain tube and insert without perforation, as compared to the Nusselt's number of inserts having perforation. At a given Reynolds number, the use of twisted tape inserts leads to considerable increase

R1 is studied. This parameter is studied for without

of Nusselt number as compared to that of the plain tube. This can be explained that the thermal boundary becomes thicker as Reynolds number decreases, thus the effect of boundary destruction by inserts turns out to be more prominent. The Nusselt numbers for the tubes with tape inserts are enhanced between 158.4% and 183.46%, over that for the plain tube. This is primarily attributed to the effect swirl flow induced by the tape inserts which leads to stronger turbulent intensity and tangential contact between the fluid flow and tube wall.

Graph 1 Effect of Nusselt's number over Reynold's Number



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At the given Reynolds number, the Nusselt number is consistently increasing with decrease in d/w. This is occurring due to the smaller perforation create stronger turbulence in fluid. Also, it gives longer flowing path which leads to longer residence time and thus more effectively heat transfer takes place.

The twisted tape having pitch ratio 4.5 will give more Nusselt value as compared to pitch ratio 2.5 for same Reynolds number. The value of Nusselts number is increased by 138.4 % for same Reynolds number with change in pitch ratio only.

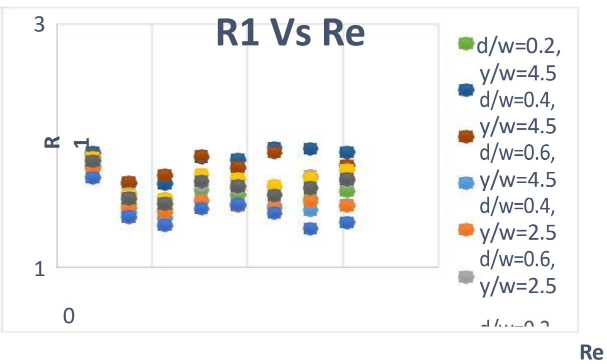
Considering the effect of twist ratio on Nusselt number it is found that with increase in y/w up to certain condition along with d/w the values is going to increase and letter on it will get decrease. This is because of the turbulence intensity generated in fluid.

B. Performance evaluation criteria R1:

The various criteria are available to evaluate the performance of the heat transfer enhancement device. Bergles [15] have also suggested several criteria for the evaluation of performance. The performance of the heat transfer enhancement device is evaluated on the basis of constant mass flow rate.

R1= (hptt)/(hwtt) , Where, hptt – Heat transfer coefficient for perforated twisted tape

hwtt – Heat transfer coefficient for without twisted tape

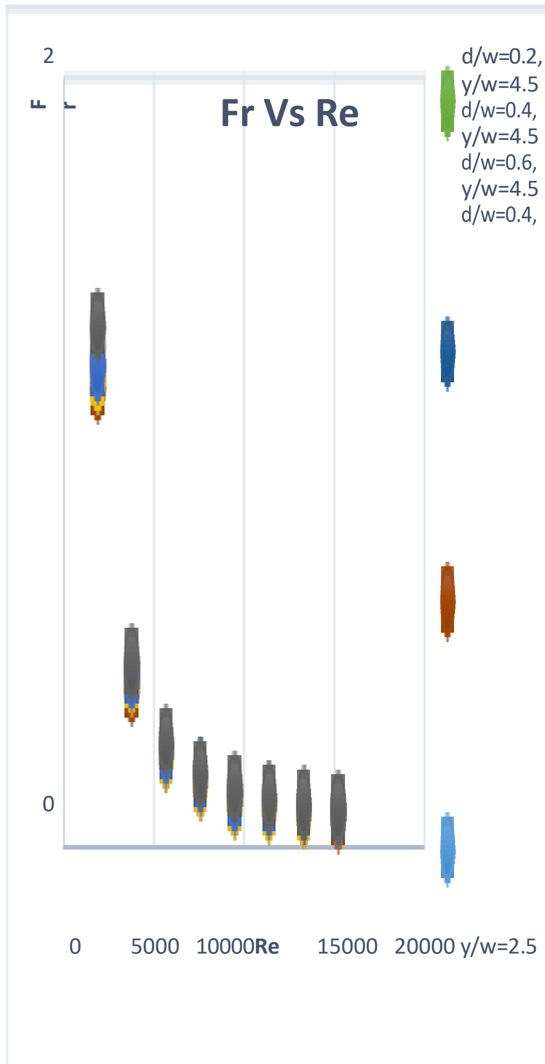


Graph 2 Performance Evaluation Criteria (R1) Vs Reynolds number for all cases

In Graph 2 the effect of performance evaluation criteria (R1) over the different values of Reynolds number is shown for all type of perforated twisted tapes. The maximum performance is shown by the d/w=0.4 and y/w=4.5. from this result, we can say that this will be the best arrangement out of all tested arrangement in these experimentations.

The results indicate that the PTT with moderate perforation performance factor increases as perforation diameter ratio (d/w) decreases and perforation pitch ratio (s/w) increases. The PTTs with s/w = 4.5 enhance thermal performance factor around 4.3% to 5.5% and 0.5% to 1.3% over those given by the PTTs with s/w = 3.5 and 2.5, respectively. The maximum thermal performance factor of 1.93 is obtained by using the PTT with the perforation diameter (d/w = 0.4) and the largest perforation pitch (s/w = 4.5) at the lowest Reynolds number of 1902.

C. Friction Factor



Graph 3 Friction factor Vs Reynolds number for all studied arrangement

In design of Heat exchanger, pressure drop is one of the important parameter as it decides the pumping power require to circulate fluid through the exchanger. The good heat exchanger should have high thermo hydraulic efficiency. It means the device has to provide larger surface area for heat transfer and lower pumping power. Hence it is essential to study the effect of different inserts on the pressure drop. It is comparatively studied by calculating the friction factor for all arrangements.

The results of Friction factor (FR) with respected to Reynolds number is shown in Graph 3 for various pitch ratio and perforation ratio (i.e. y/w= 2.5, 3.5& 4.5 and d/w=0.2, 0.4 and 0.6). The friction factor value will get decrease with respect to the increase in Reynolds number. The results show that the value for friction factor will get increase by decreasing the d/w ratio. Because twisted tape with shorter twist length provides longer flowing path, resulting in larger tangential contact between the flowing stream and tube surface. Therefore, loss due to the friction increases. The larger pressure drop is not desirable. Hence to select the proper insert for heat transfer enhancement, one has to determine the

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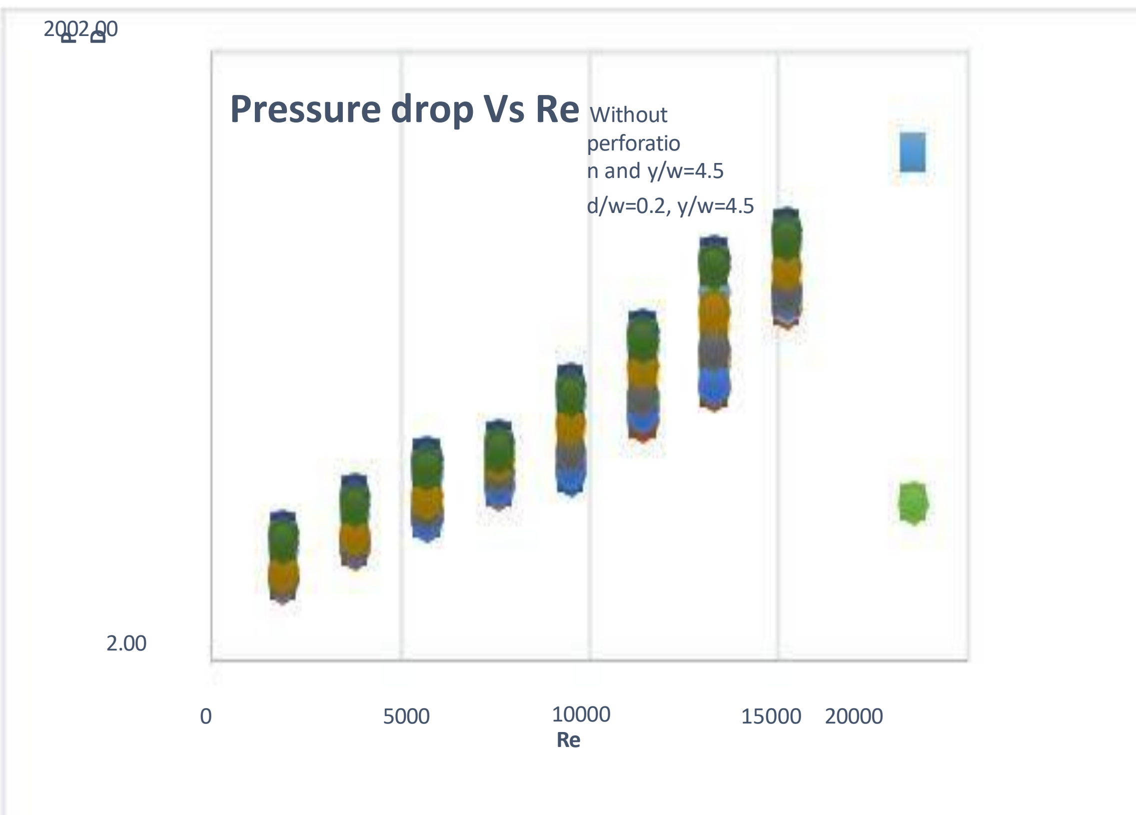
enhancement efficiency which is ratio of Nusselt's number to Friction factor.

The maximum friction factor is obtained at low Reynolds number, this is because the more force is required to overcome the resistance offered by the twisted tape and also the inertia of fluid is very low. As the perforation diameter increased the friction factor is decreased. Also, it gives the decrease in friction factor with increasing the y/w ratio. The minimum friction factor is obtained for y/w=4.5 and d/w=0.6 as this offered less resistance to flow.

D. Pressure Drop

The effect of pressure drop for different arrangement of inserts with Reynolds number is shown in Graph 4. As we use inserts into the tube, it offered the resistance to the fluid motion. Hence the pressure into the system is decreased. For efficient system pressure drop required is minimum but because of resistance by inserts in this study the pressure will get decreased.



Graph 4 Effect of Pressure Drop over the Reynold's Number for different arrangement

The Graph 4 shows the effect of pressure drop with respect to the Reynolds number. As Reynolds number increases the pressure drop is increase because of more turbulence is created and hence pressure drop is occurred. The plain tube having minimum pressure drop as shown in graph. The pressure drop due to twisted tape is increased upto 300%. At lower Reynolds number the pressure drop is minimum as compared to the maximum Reynolds number. The twisted tube without perforation is offer maximum resistance hence pressure drop is more in this study. The minimum pressure drop is obtained into the PTT having d/w=0.6 and y/w=4.5. The more amount of fluid can pass through the perforation and also the pitch size is more hence less resistance can be offered by this type of arrangement. As the pitch

Graph 5 Pressure Drop Vs Heat Transfer Coefficient

CONCLUSION

Augmentation of heat transfer rate in heat exchanger tubes by means of perforated twisted tapes (PTT) inserts is investigated experimentally. The results showed those heat transfer and friction factors were significantly influenced by the presences of holes on PTTs. Both heat transfer and friction increased with the increase of depth ratio (y/W) and the decrease of perforation hole diameter ratio (d/W). Due to the dominant effect of increased heat transfer over that of increased friction factor, the thermal performance factor was found to be increased as depth ratio (w/W) increased and hole diameter ratio (d/W) decreased.

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