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Heat Transfer Enhancement in Tube-in-Tube Heat Exchanger using Passive Techniques

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Abstract*— The heat exchanger is an important device in almost all of the mechanical industries as in case of process industries it is key element. Thus from long time many researchers in this area are working to improve the performance of these heat exchangers in terms of heat transfer rate, keeping pressure drop in limit. This paper is a review of such techniques keeping focus on passive augmentation techniques used in heat exchangers. The thermal performance behavior for tube in tube heat exchanger is studies for wire coil inserts, twisted tape inserts and their combination. The research was carried for constant/periodically varying wire coil pitch ratio. Some of them have varied three coil pitch ratios. The twisted tapes were also been tested by many of them for different twist ratios. These inserts are tested individually and in combine form and results were compared. The wide range of Reynolds number is selected for allowing the inserts to be tested for different flow conditions from laminar to turbulent. The improved performance was found in the increasing order for wire coil inserts, twisted tapes and combined inserts. Also few of researchers have developed correlations for these inserts for Nusselt number as a function of Reynolds number.

Keywords*— Heat Exchanger, Wire Coil Inserts, Twisted Tape Inserts, Enhancement Efficiency, Pressure Drop.

I. INTRODUCTION

In order to augment heat transfer and to increase thermal performance of the heat exchangers heat transfer enhancement techniques are widely used. These techniques are classified in two groups, active and passive techniques. For active techniques heat transfer rate is improved by supplying extra energy to the system while in passive techniques the purpose is solved with out use of any extra energy. The passive techniques include surface area extension (extended surfaces: fins), rough surfaces, inserts, turbulators also called swirl flow devices and coated surfaces. The turbulators are of different types like wire coil inserts, twisted tapes and their combination. Out of all inserts are most popular devices used for improving heat transfer performance of heat exchangers used in industries. The purpose of inserting these swirl flow devices is to improve heat transfer rate by decreasing the thickness of thermal boundary layer, disturbing velocity boundary layer and allowing core fluid to mix with peripheral fluid. The wire coil inserts and twisted tape inserts are easy to manufacture and install, their cost is too less.

The literature survey in this area shows that a lot of research work has been carried out on passive techniques, specially wire coil inserts and twisted tapes. They have done experimental investigation on wire coil inserts acting alone and by varying wire thickness, coil pitch, coil separation from tube wall, wire cross section and have developed correlations for Nusselt number with different variables listed. The same kind of experimentation is also been performed to study heat transfer and pressure drop for twisted tape inserts by varying tape thickness, twist ratio. S. Eiamsa-ard and team [3] in their paper, have made the comparison of the heat transfer rate, pressure drop behavior and thermal performance between wire coil inserts of varying pitch ratios, twisted tape and their combination inserted in a test tube and also developed correlations of the Nusselt number and friction factor for all parameters studied. They end up with the conclusion that at low Reynolds number, the compound devices of the Twisted Tape with twist ratio=3 provide the highest thermal performance.

Wand and Suden [6] also have discussed the comparison of wire coil inserts and twisted tape in their work. It was observed and noted that to disturb the central core flow the twisted tapes are the solution but if peripheral annular flow is to be mixed with core flow the wire coil inserts perform better. In context with heat transfer rate they have concluded that twisted tape perform better than the wire coil inserts. In process industries the fluids used have high density because of high viscosity and dirt and thus they need high pumping power. In such cases the pumping power is the important element and is drive to put constraints on selection of passive device. When pumping power is an issue pressure drop adds limitation on type of insert, as twisted tape cause more pressure drop than wire coil inserts. To analyze such involvement of pressure drop in the heat transfer enhancement many of researchers have introduced a term ‘Overall enhancement efficiency’ to predict the performance of an insert. It counts positive effect of heat transfer improvement and negative effect of pressure drop rise.

Sibel Gunes, Veysel Ozceyhan, Orhan Buyukalaca,[1] in their first paper investigated experimentally, the heat transfer and pressure drop in a tube with wire coil insert in turbulent flow regime. The coiled wire they used had equilateral triangular cross section and was inserted separately from the tube wall. The experiments were carried out with three different pitch ratios (P/D = 1, 2 and 3) and two different ratio of equilateral triangle length side to tube diameter (a/D = 0.0714 and 0.0892) at a distance (s) of 1 mm from the tube wall in the range of Reynolds number from 3500 to 27,000. The use of coiled wire inserts leads to a considerable increase in heat transfer and pressure drop over the smooth tube.

The Nusselt number rises with the increase of Reynolds number and wire thickness and the decrease of pitch ratio. The highest overall enhancement efficiency of 36.5% is achieved for the wire with a/D = 0.0892 and P/D = 1 at Reynolds number of 3858. Consequently, the experimental results reveal that the best operating regime of all coiled wire inserts is detected at low Reynolds number, leading to more compact heat exchanger.

Sibel Gunes, Veysel Ozceyhan, Orhan Buyukalaca,[2] in their second paper performed experimental study with same setup as in [1]. But in this paper they focused on coil separation from tube wall. The experiments were performed with a constant wire thickness of a = 6 mm, three different pitch ratios (P/D= 1, P/D= 2 and P/D=3) and two different distances (s = 1 mm, s = 2 mm) at which the coiled wire inserts were placed separately from the tube wall. They varied Reynolds numbers from 4105 to 26400 in these experiments. They found that Nusselt number and friction factor increase with decreasing pitch ratio (P/D) and distance(s) for coiled wire inserts. The highest overall enhancement efficiency of 50%was achieved for the coiled wire with P/D = 1 and s = 1 mm at Reynolds number of 4220. As a result, it was found to them that using these coiled wire inserts are thermodynamically advantageous at all Reynolds numbers.

Mr.Kumbhar D.G., Dr. Sane N.K. [4] both investigated Heat transfer, friction factor and enhancement efficiency characteristics in a horizontal circular tube fitted with conical wire coil tabulators experimentally. In this work two enhancement heat transfer devices were applied. They used conical coil inserts and full length wire coil inserts, placed in test tube, through which air was working fluid. The coiled wire inserts of 6mm, 9mm and 12mm spring pitches were introduced in each run. In addition, the conical wire inserts of pitch ratio 2.5mm and 3.5mm were also tested. The Reynolds number was varied from 2000 to 10000. Their experimental results revel that the tube fitted with the conical coil inserts and full length wire coil inserts provides Nusselt number values of around 5% to 12% and enhancement efficiency varies between 0.78 to O. 98 compared with the plain tube.

Er. Pardeep Kumar, Manoj Sain, Shweta Tripathi [5] performed experimental work on five wire coils of different pitch, inserted in a smooth tube in laminar and transition regimes. They also carried Isothermal pressure drop tests and heat transfer experiments under uniform heat flux conditions. They studied the air flow friction and heat transfer characteristics in a round tube fitted with coiled wire turbulators. They worked in turbulent regime with Re = 2000 – 10,000 and Pr = 0.7. It was found that use of coiled circular wire causes a high pressure drop increase, which depends mainly on spring pitches and wire thickness. The heat transfer in case of the conical coil was highest as compare to the plain pipe and the pipe containing the coil of different pitches. The outcome of their study says that the enhancement efficiency increases with the decreasing pitches and found highest in the conical sets and at a Reynolds number 2200-3000, the friction factor was highest.

Prof.Mathew V Karvinkoppa [7] in his paper worked over horizontal concentric tube in tube heat exchanger for its heat transfer enhancement using wire coil inserts. Till his study investigation was carried out for only one coil, which usually placed in the inner tube of the exchanger and its outer surface mates to inner surface of the tube. He says that the case that contains more than one spring and location of the spring in the tube had not been focused. In an experimental investigation into effects of numbers (n= 4, 5, 6), incline angles (θ =0 deg, 7 deg, 10 deg etc.), and outer diameters of the springs (Ds=7.2mm, 9.5mm, 12mm, etc) for heat transfer and pressure drop by using spring coils as turbulators in a heat exchanger whose inner tube is heated by constant temperature water vapor on all surfaces.

Paisarn Naphon [8]& Parkpoom Sriromruln[9] presented papers for micro fin tubes with coiled wire inserts. The heat transfer characteristics and the pressure drop of the horizontal double pipes with and without coiled wire insert were investigated. The inner and outer diameters of the micro-fin tube were 8.92 and 9.52 mm, respectively. The coiled wire was fabricated by bending a 1-mm-diameter iron wire into the coil wire with coil diameter of 7.80 mm. Cold and hot water were used as working fluids in shell side and tube side, respectively. The test runs were performed at the cold and hot water mass flow rates ranging between 0.01 and 0.07 kg/s and between 0.04 and 0.08 kg/s, respectively. The inlet cold and hot water temperatures were between 15 and 20 °C and between 40 and 45 °C, respectively. The results obtained from the micro-fin tube with coiled wire insert were compared with those obtained from the smooth and micro-fin tubes.

They found that the coiled wire insert had a significant effect on the enhancement of heat transfer. However, the friction factor of the tube with the coiled wire insert also increases. And the very important, they stated that wire coil effectiveness is in inverse proportion with Reynolds Number.

Alberto Garcı a, Pedro G. Vicente, Antonio Viedma [10] all together studied helical-wire-coils fitted inside a round tube in order to characterize their thermo-hydraulic behavior in laminar, transition and turbulent flow. In laminar flow, results show that wire coils behave mainly as a smooth tube. Transition to turbulent flow takes place at low Reynolds numbers (Re = 700) and in a gradual way. Wire coils have a predictable behavior within the transition region since they show continuous curves of friction factor and Nusselt number, which involves a considerable advantage over other enhancement techniques. In turbulent flow, wire coils cause a high pressure drop increase which depends mainly on pitch to wire-diameter ratio p/e. These show considerable heat transfer augmentations: at Re = 10,000, depending mainly on dimensionless pitch p/d.

II. EXPERIMENTATION

There are two main classes of experimental setups available to study effect of turbulators on heat transfer and pressure drop, one working under water as working fluid and other air as working fluid. The setup constructed for study of water as working fluid face a major problem to store water; it needs storage tanks which in term increases its weight. This paper is to study effect of wire coil on heat transfer enhancement under air as working fluid and thus setup with water as working fluid is not focused. The general open loop experimental facility used by all researchers in the experiments is schematically shown in Fig. 1.

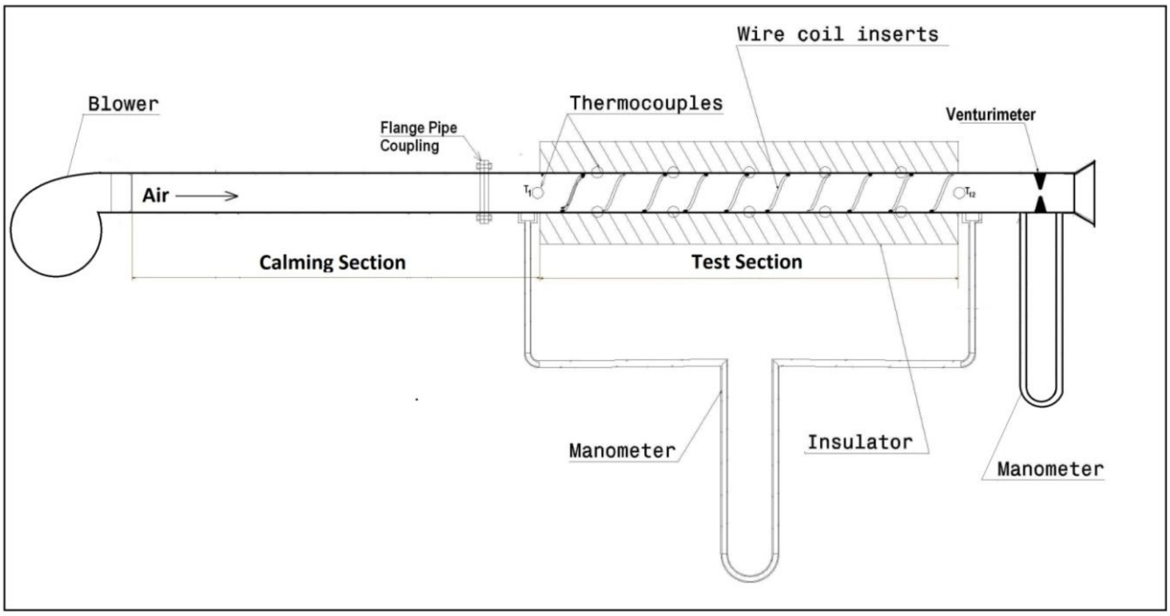

Fig. 1 A General Experimental Facility used by all of the Researchers.

A. *Experimental Setup:*

The experimental setup consists of following main components:

1. Blower: The facility includes a blower to provide air velocity, coupled with inverter to vary air velocity. A 3 KW capacity blower is generally used [1]. The delivery side of the blower is usually avoided as it creates eddies and suction side of the blower is generally used to avoid these eddies. A nozzle may be used to allow the air enter in the tube uniformly.
2. Venturimeter & Pressure Transmitter: It is used to measure the mass flow rate of air, and thereby velocity of air. Generally Venturimeter is fitted across the delivery side of the blower to avoid the effect of its back pressure on test section. The Venturimeter should be calibrated as per calibration process available in literature. The volumetric air flow rates from the blower can be adjusted by varying motor speed through an inverter. The pressure drop across the test tube is measured by using a differential pressure transmitter.
3. Test Section: The test section is length of tube in which wire coil inserts are to be placed and is heated from outside. The test tube length selected is 3100 mm with a coiled wire insert. The material used for test tube is SS304 seamless steel test tube and has 56 mm inner diameter (D), 60 mm outer diameter (Do), and 2 mm thickness (t) [1].
4. Calming Tube: The Calming tube section is provided to allow the flow to be hydro-dynamically fully developed. The air vacuumed through the calming tube and then it is directed to test section. Its length as per [1] is 6000 mm. Generally its length is 10 times the hydraulic diameter of the tube.
5. Heater and Insulation: Uniform heat flux is applied to the test tube by heating it with electrical cable. The electrical output power can be controlled by a variac transformer to provide constant heat flux along the entire length of the test section. The outer surface of the test tube is well insulated with glass wool to reduce the convective heat loss to the surroundings.
6. Thermocouples and Data logging System: The surface temperatures of the tube wall is measured by many K-type thermocouples, which are placed on the local wall of the tube and should calibrated within ±0.2 °C deviation by thermostat before being used. The inner and outer temperatures of the bulk air were also measured by K-type thermocouples at certain points. The heated air in the test tube should be removed from the experimental field to the atmosphere by a piping system during the experiments. Therefore, the temperature of experimental field should not change considerably, it is negligible

B. *Wire Coil Geometries Used:*

The coiled wire used in many of the experiments is fabricated from aluminium by extrusion method in different cross sections like circular, square and equilateral triangular with side length of (a). Few researchers have worked on this dimension of cross section and have defined a ratio a/D, where D is the diameter of coil. Sibel Gunes [1] have selected two different a/D ratios of 0.0714 and 0.0892, and three different pitch ratios (P/D = 1, 2 and 3) under consideration in their experimental study. These configurations are shown in fig. 2

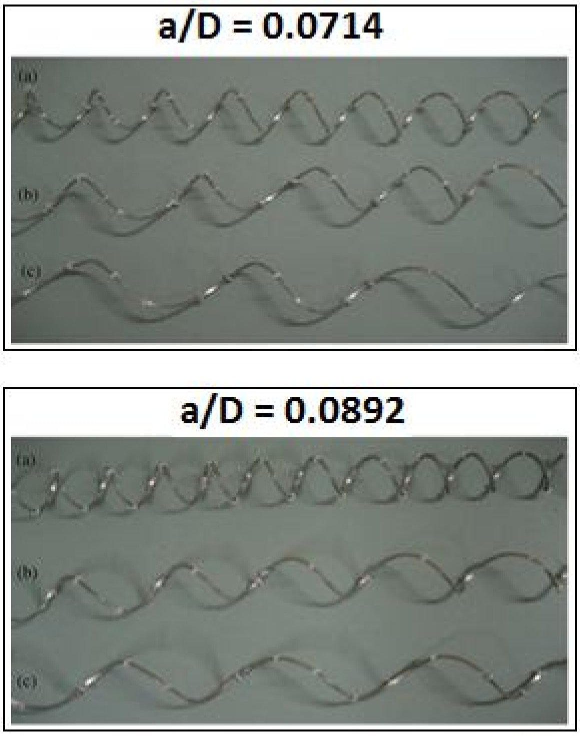

Fig. 2 The coiled wire inserts with Teflon rings (a) P/D = 1, (b) P/D = 2, and (c) P/D = 3.

Fig. 3 Details of coiled wire

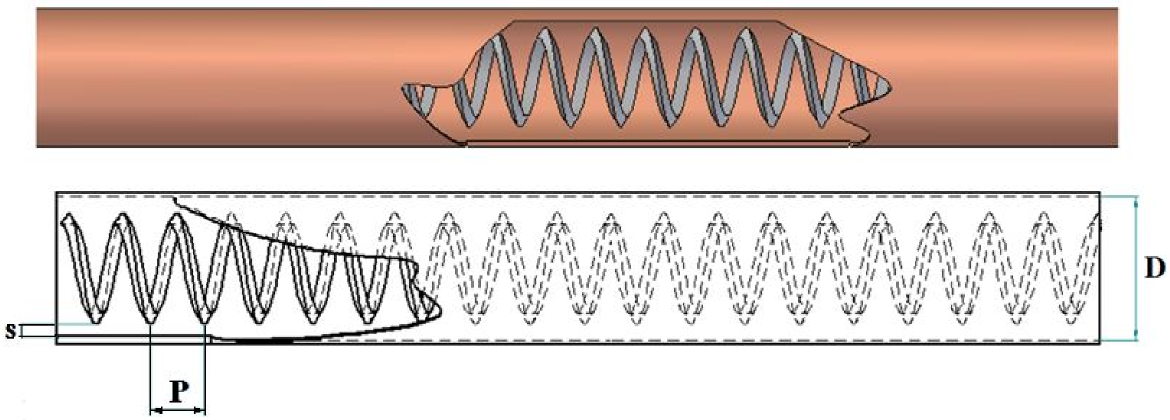

Fig. 4 The equilateral triangle cross sectioned coiled wire inserted in a tube separated from tube wall

The test tube with coiled wire insert and the details are given in Fig. 3 and 4. The separation of wire from tube wall is also been optimized by one of researcher [2]. He has used the Teflon rings which are manufactured according to the wire thickness in order to fix the coiled wire separated from the tube wall. These rings are densely attached onto the inserts, thus the contact of inserts with tube inner wall is prevented. The coiled wire inserts with Teflon rings used in the experimental study are shown in Fig. 2.

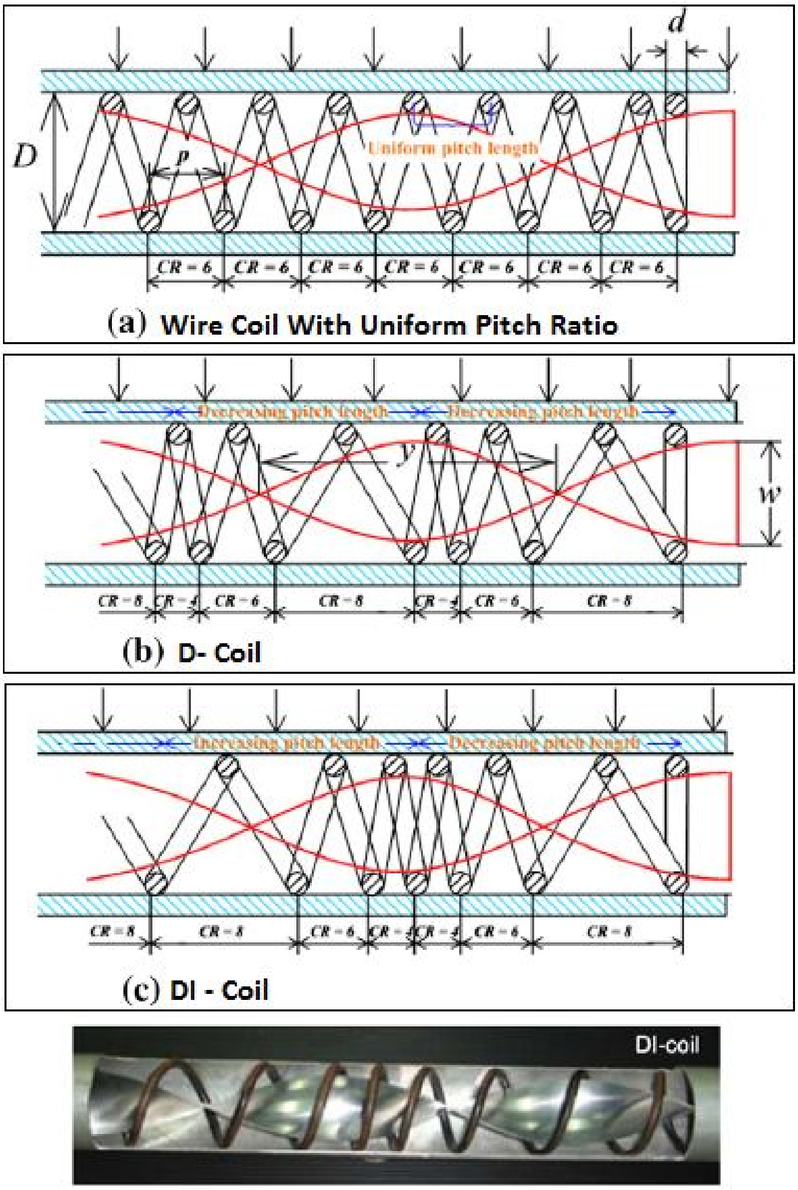

Fig. 5 Test section fitted with wire coil and twisted tape

III. Data Deduction

The obtained data should be interpreted well and should be handled carefully to reach an end. Here the formulation required to analyse the observations and get the results is stated. All the properties of air are taken at the mean fluid temperature.

The radial heat flux cause an increase in the outer surface temperature (TOS) of the test tube and heat is dissipated from outer surface of insulation. Thus, the heat loss can be calculated for test section of the tube in which the thermocouples exist by considering resistance of insulating material.

$$Q_{loss} = \frac{T_s - T_{os}}{R_{ins}} \quad (1)$$

The resistance of insulating material (Rins) in the path of radial heat transfer is given as,

$$R_{ins} = \frac{\ln \frac{r_o}{r_i}}{2\,\pi L K_{ins}} \quad (2)$$

Ideally when electrical heater generates heat on the outer surface of tube, it is taken away by air flowing through the tube. But practically part of it gets lost through insulation. Thus the heat provided by the electrical heater in the test tube is about 5% more than the heat absorbed by the air. Therefore, only the heat transfer rate absorbed by the air is taken into consideration for the convective heat transfer coefficient calculation. Thus rate of steady state heat transfer can be obtained by subtracting heat loss to surrounding through insulation from total heat produced by heater on the surface of test tube. The rate of convection heat transfer is given by,

$$Q_{conv} = VI - Q_{loss} \quad (3)$$

The steady state heat flux applied to the test tube can be computed as;

$$q = \frac{Q_{conv}}{A_s} = \frac{Q_{conv}}{\pi D_o L} \quad (4)$$

The Newton's Law of Cooling states, the convective heat transfer coefficient through the heated test tube in any axial direction is given as;

$$q = h \, x \, [T_s - T_\infty] \quad (5)$$

The Reynolds number depends on the velocity of the air flowing through the duct and is defined as,

$$Re = \frac{V_{air} D_i}{\gamma} \quad (6)$$

The heat transfer coefficient can be calculated from Nusselt number as,

$$h = \frac{K_{air} Nu}{D_i} \quad (7)$$

The enhancement efficiency at constant pumping power is defined as the ratio of heat transfer coefficient of coil wire inserted tube (hc) to heat transfer coefficient of smooth tube without any insert (hs). The same can be defined for Nusselt number as the ratio of Nusselt number of coil wire inserted tube (Nuc) to Nusselt Number of smooth tube without any insert (Nus).

$$\eta = \left.\frac{h_c}{h_s}\right|_{pp} = \left.\frac{Nu_c}{Nu_s}\right|_{pp} \quad (8)$$

IV. Validation And Results

The experimentation and its accuracy itself depends on the reliability of the experimental facility and thus it in did becomes necessary to prove correctness of the setup used. Almost of all the researches have made the comparison between plain tube results and the results obtained from previous correlations which are Petukhov equation for Nusselt number and Blasius equation for friction factor, as shown in Figs. 6.

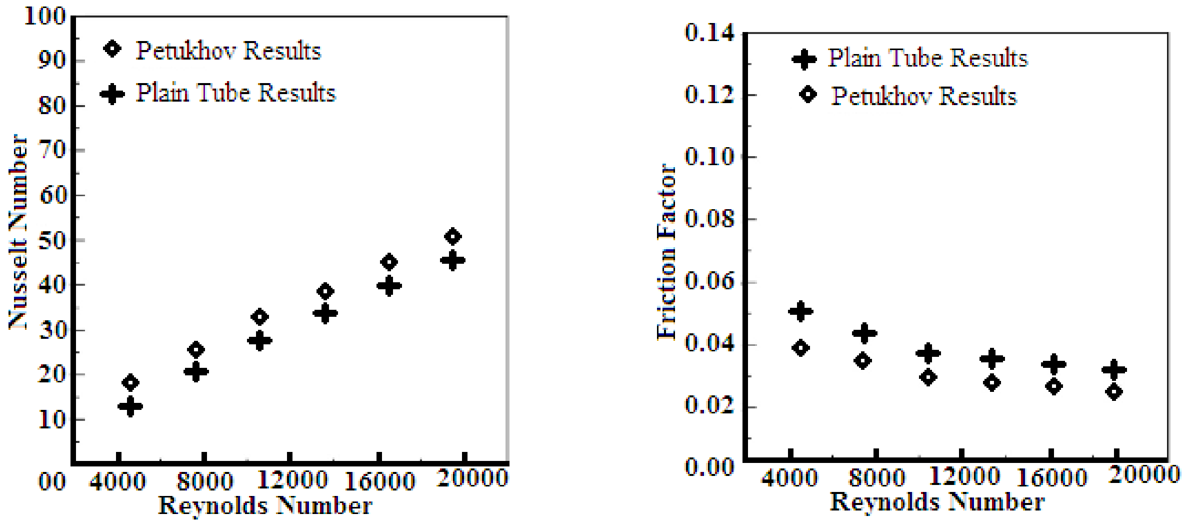

Fig. 6 Verification of Plain tube by Nusselt Number and Friction Factor

To verify that the experimental setup is valid a plain tube test is conducted without inserting any swirl flow device and observations are recorded. Many researchers have examined large range of the Reynolds number and the experimental data of the plain tube are compared with the results from the previous correlations. The good agreement between these two shows that the experimental facility is reliable and can be used for further experimentation.

There are many types of inserts available and experimented for various flow conditions by many researchers stated in the literature. The effects of the combination of twisted tape (TT) and non-uniform wire coil (the wire coil with varying three coil pitch ratio, D-coil/DI-coil) or uniform wire coil (the wire coil with constant coil pitch ratio) on the heat transfer, friction factor and thermal performance factor at various Reynolds numbers, are studied experimentally. The effects of twisted tape alone and wire coil alone were also examined as the references of performance evaluation of the combined devices. A brief comparison can made to get the optimisation. Heat transfer augmentation alone can never be a deciding factor for usefulness of any insert, it should be tested for its pressure drop penalty and then a judgment can be made. Among the researchers studied many have worked on wire coil inserts and recommended these inserts at low Reynolds number regime. The study of Nusselt number variation with respect to Reynolds Number come to a result that use of these inserts at high Reynolds number results in high heat transfer rate, and thus it should be used at high Reynolds number regime. This has other side also and is of pressure drop analysed by friction factor variation.

Also the heat transfer rate given by any insert should be measured with reference to the heat transfer rate without that inserts i.e. at smooth tube. This performance parameter is known as enhancement efficiency and is the ratio of Nusselt number of wire coil inserted tube to the Nusselt number of smooth tube. Thus certainly it must be greater than one. And all inserts must be compared for this enhancement efficiency and then judgment should be made.

V. CONCLUSION

This paper reviews all types of swirl flow devices and made comparison amongst all. The heat transfer augmentation, Pressure drop variation, friction factor and overall thermal performance of a tube inserted with wire coil inserts alone, twisted tape inserts alone and the combined devices between the twisted tape and constant or periodically varying wire coil pitch ratio are studied. Many of researchers have developed The correlations of the Nusselt number and friction factor for all parameters studied are also developed.

The results of smooth tube test are studied and the results from the combined devices are also compared with those from each device alone. Their result shows that twisted tapes are good with heat transfer improvement but are poor with friction factor analysis. But in all for low Reynolds number, the experimental results shows that the compound devices of the Twisted Tape and DI-coil, shows the highest thermal performance which is higher than the wire coil alone, the TT alone, the TT with uniform wire coil, and the TT with D-coil.

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