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The Effect of insertion of different geometries on heat transfer performance in circular pipe- A review

Amol P. Yadav[1], Pranit M. Patil[2], Dr. P. A. Patil[3]

[1]P.G. Student, M.E. Heat Power, J.S.C.O.E, Hadapsar, Pune(M.S.) India

[2]Assistant Professor, Department of Mechanical Engineering, G.I.T, Lavel, Khed (M.S.) India

[3]Professor, Department of Mechanical Engineering, J.S.C.O.E, Hadapsar, Pune (M.S.) India

Abstract: *Under turbulent flow conditions, the increase in heat transfer rate is more significant than that under laminar flow conditions. The turbulent effects become a dominant factor over secondary flow at higher Reynolds number. The turbulent flow can be produced by inserting different geometries in the circular pipe. This study focuses on the various methods or geometries used to produce turbulent geometries and its effect on the heat transfer. The turbulent generators with different geometrical configurations have been used as one of the passive heat transfer enhancement techniques and are the most widely used in tubes in several heat transfer applications. Insertion of such geometries may lead to increase the friction factor and pressure drop which directly enhances the heat transfer characteristics.*

Keywords: *Heat transfer characteristics, Turbulent flow, Reynolds number, Friction factor.*

I. Introduction

When turbulent flow is considered, many techniques were investigated for augmentation of heat transfer rates inside circular tubes using wide range of inserts. The inserts studied included coil wire inserts, brush inserts, mesh inserts, strip inserts, twisted tape inserts etc. Heat exchangers have many industrial applications for example, heat recovery processes, air conditioning and refrigeration systems, chemical reactors, and food and dairy processes. For better performance and economic aspects of the equipment, the design of heat exchanger needs exact analysis of heat transfer rate and pressure drop. Garc et al. [1] investigated the laminar–transition–turbulent heat transfer enhancement and flow patterns in the tube with wire coil inserts. Hsieh et al. [2] experimentally studied the turbulent heat transfer and flow characteristics in a horizontal circular tube with strip-type inserts. Bhuiya et al. [3] studied the heat transfer performance and friction factor characteristics in a circular tube fitted with twisted wire brush inserts were investigated experimentally. Halit bas [4] Flow friction and heat transfer behavior in a twisted tape swirl generator inserted tube are investigated experimentally Bhuiya et al. [5] have done the experimental investigation on Nusselt number, friction factor and thermal performance factor in a circular tube equipped with perforated twisted tape inserts with four different porosities of Rp = 1.6, 4.5, 8.9 and 14.7%. M.M.K. Bhuiya [6] explored the effects of the double counter twisted tapes on heat transfer and fluid friction characteristics in a heat exchanger tube. The double counter twisted tapes used as counter-swirl flow generators in the test section. Pankaj N. Shrirao et.al [7] Experimental investigation of heat transfer and friction factor characteristics of horizontal circular pipe using internal threads of pitch 100mm, 120mm and 160mm with air as the working fluid. Bodius Salam et.al [8] have carried an experimental investigation for measuring tube-side heat transfer coefficient, friction factor, heat transfer enhancement efficiency of water for turbulent flow in a circular tube fitted with rectangular-cut twisted tape insert.

In the above literature review, the numerous research articles were reported on heat transfer enhancement and pressure drop characteristics in tubes with various geometrical configurations of turbulence creator. Hence this study gives the overview of different techniques to enhance the heat transfer characteristics by producing turbulent flow in circular pipe with insertions of different types of inserts or geometries.

1. Twisted wire brush inserts
2. Twisted tape
3. Perforated twisted tapes
4. Double counter twisted tapes
5. Pipe with internal threads.

C_p	specific heat at constant pressure [J/(kg K)]	k	thermal conductivity [W/(m K)]
d	core-rod diameter [m]	L	tube length [m]
Di	tube inside diameter [m]	η	thermal performance factor, dimensionless
Do	tube outer diameter [m]	ηp	predicted thermal performance factor, dimensionless
d_w	wire diameter [m]	Re	Reynolds number, dimensionless
f	friction factor, dimensionless	Nu	Nusselt number, dimensionless
fp	predicted friction factor, dimensionless		

II. WIRE BRUSH INSERTS

Bhuiya et al. [3] the twisted wire brush inserts fabricated with four different twisted wire densities of 100, 150, 200, and 250 wires per centimeter by winding a 1 mm diameter of the copper wire over a 5 mm diameter of two twisted iron core-rods used for experimentation as shown in figure 1.

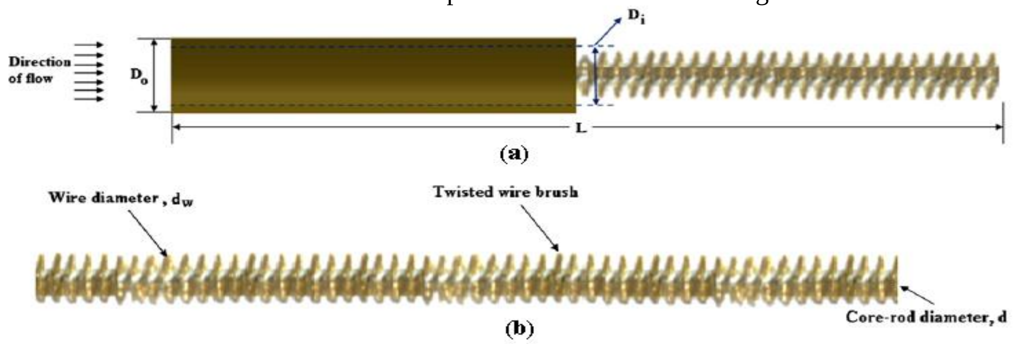

Figure 1. (a) Geometry of the test section fitted with the twisted wire brush insert. (b) Geometric parameters of the twisted wire brush insert.

By examining heat transfer and friction factor data in tubes for Reynolds number ranging from 7,200 to 50,200, it is found that the heat transfer performance and friction factor characteristics for turbulent flow through a tube are affected by means of twisted wire brush inserts. The twisted wire brush inserts provided significant enhancement of heat transfer with the corresponding increase in friction factor. The friction factor achieved for the tube with twisted wire brush inserts varied from 1.35 to 2.0 times than those of the plain tube values at the comparable Reynolds number. It was found that the Nusselt number, friction factor, and thermal performance factor increased with the increase of twisted wire densities. The thermal performance factor (η) obtained for the tube with twisted wire brush inserts varied from 1.1 to 1.85 times than those of the plain tube values at constant blower power as shown in Figure 2.

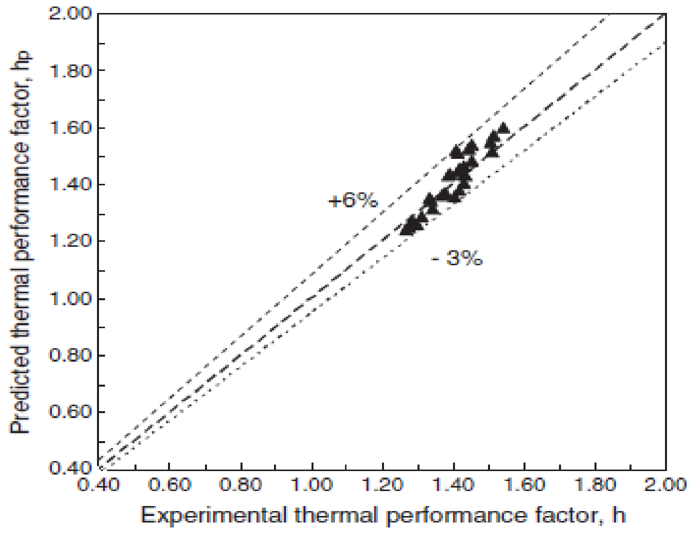

Figure 2. Comparison between the predicted and experimental thermal performance factor, η_p and experimental thermal performance factor η. [3]

III. TWISTED TAPE

The Use of twisted tape swirl generator in tube is one of the technique to enhance flow friction and heat transfer behavior. The twisted tapes are inserted separately from the tube wall. The effects of twist ratios (y/D = 2, 2.5, 3, 3.5 and 4) and clearance ratios (c/D = 0.0178 and 0.0357) are discussed in the range of Reynolds number from 5132 to 24,989, and the typical one (c/D = 0) is also tested for comparison by Halit bas [4]. He used SS304 seamless steel test and calming tube with 56 mm inner diameter (D1), 60 mm outer diameter (D2), and 2 mm thickness (t). The twisted tapes tested in experiments, with five different twist ratios (y/D = 2.0, 2.5, 3.0, 3.5 and 4.0) and two different clearance ratios (c/D = 0.0178 and 0.0357) are considered in this experimental study, are fabricated from steel. The schematic figure of the test tube with twisted tape insert is given in Figure 3.

Figure 3. Schematic view of the twisted tape inserted tube separated from the tube inner surface with teflon rings.

The twisted tapes are placed separately from the tube wall to obtain only heat transfer increase depending on laminar sub layer destruction near the tube wall. So, the effect of increased heat transfer surface area is eliminated. It is showed that the twist ratio (y/D) has major effect when compared with the clearance ratio (c/D) on heat transfer in twisted tape inserted tube. The heat transfer enhancement decreases, while Reynolds number increases and it is nearly constant at Reynolds number is higher than 15,000 and twist ratios are lower than 3. The highest heat transfer enhancements are obtained as 1.756 for c/D = 0.0178, as 1.744 for c/D = 0.0357 and as 1.789 for the typical twisted tape (c/D = 0) at y/D = 2 of all twist ratios. Heat transfer enhancement is higher in the tube with twisted tape inserted which has c/D = 0.0178 than c/D = 0.0357 for all cases as shown in figure 4 and 5.

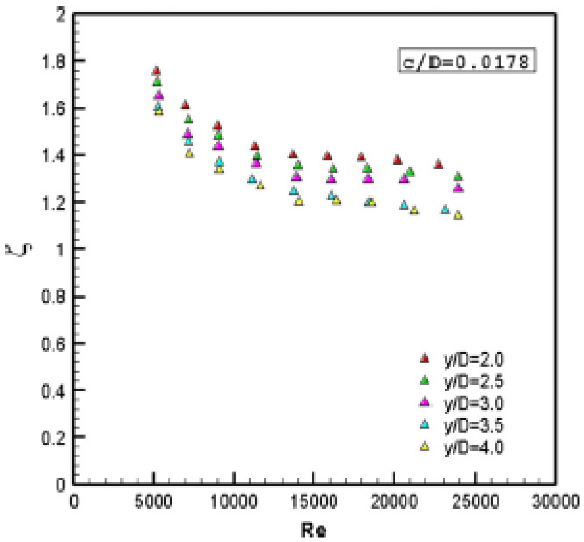

Figure 4. Variation of heat transfer enhancement with Reynolds number for different y/D ratios (c/D = 0.0178).

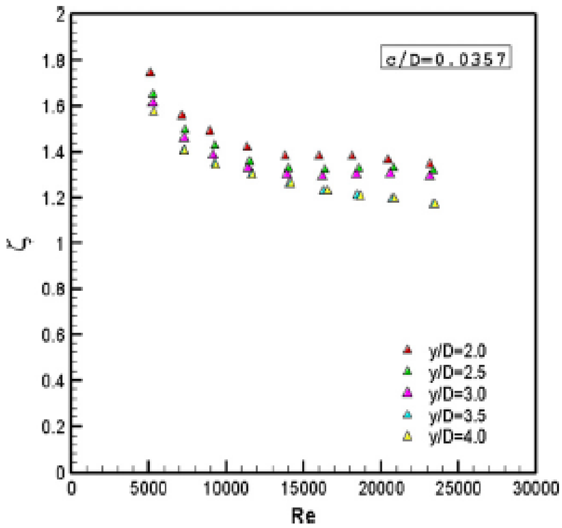

Fig. 5. Variation of heat transfer enhancement with Reynolds number for different y/D ratios (c/D = 0.0357).

IV. PERFORATED TWISTED TAPE

To obtain better heat transfer perforated twisted tapes are also used. Bhuiya [5] worked on Nusselt number, friction factor and thermal performance factor in a circular tube equipped with perforated twisted tape inserts with four different porosities of Rp = 1.6, 4.5, 8.9 and 14.7%. He conducted experiments in a turbulent flow regime with Reynolds number ranging from 7200 to 49,800 using air as the working fluid under uniform wall heat flux boundary condition.

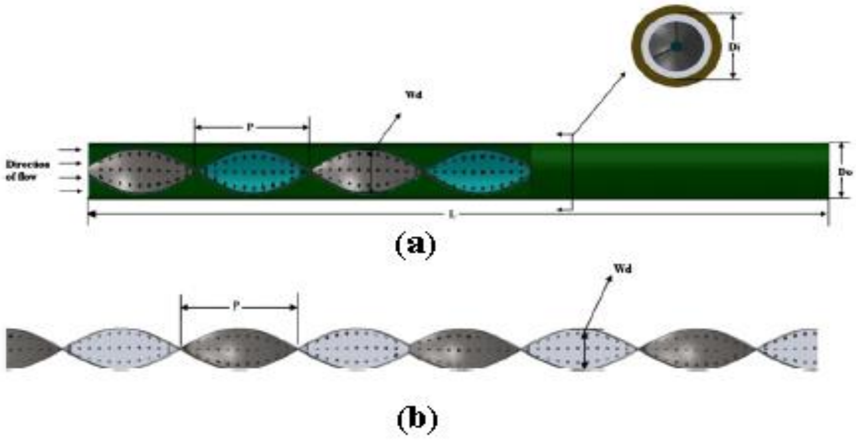

Figure 6. Geometry of test section fitted with perforated twisted tape insert; (b) Geometric parameters of the perforated twisted tape insert

The perforated twisted tape offered a higher heat transfer rate, friction factor and thermal performance factor compared to that of the plain tube. The Nusselt number (shown in Figure 8) friction factor and thermal performance factor obtained from the tube with perforated twisted tape inserts was 340%, 360% and 59% higher than those of the plain tube values, respectively. In addition, the influence of porosity 4.5% was more dominant than that of the other porosities of 1.6, 8.9 and 14.7% for all the Reynolds number. Figure 7 shows the performance factors for all twisted tapes tended to decrease with increasing Reynolds number. The thermal performance factors for all the cases were more than one indicated that the effect of heat transfer enhancement due to the enhancing tool was more dominant than the effect of the rising friction factor and vice versa as shown in figure 9.

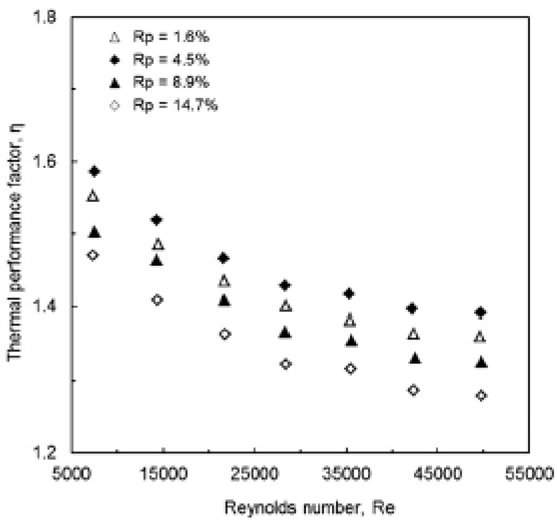

Fig 7 Relationship between the thermal performance factor and Reynolds number

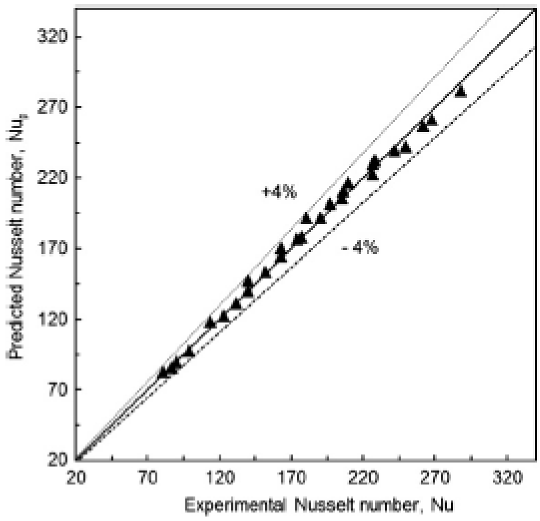

Fig 8 Comparison between the predicted and experimental Nusselt number.

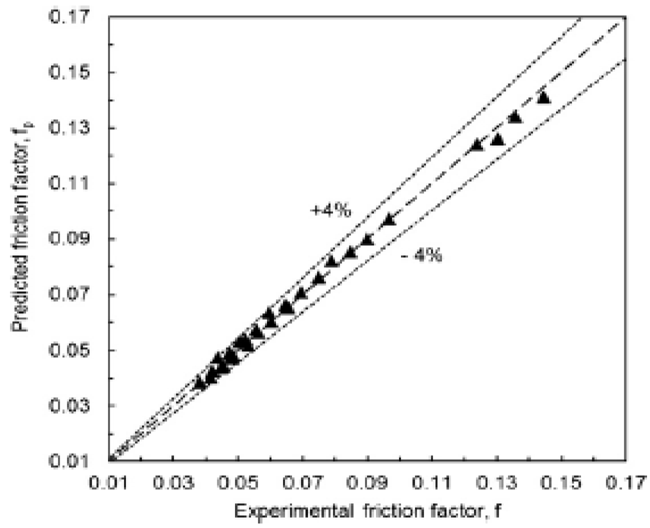

Fig. 9 Comparison between the predicted and experimental friction factor

V. DOUBLE COUNTER TWISTED TAPE

The double counter twisted tapes can be used as counter-swirl flow generators as shown in figure 10. M.M.K. Bhuiya [6] performed experiments with double counter twisted tapes of four different twist ratios (y = 1.95, 3.85, 5.92 and 7.75) using air as the testing fluid in a circular tube turbulent flow regime where the Reynolds number was varied from 6950 to 50,050. The experimental results demonstrated that the Nusselt number, friction factor and thermal enhancement efficiency were increased with decreasing twist ratio. The heat transfer rate in the tube fitted with double counter twisted tape was significantly increased with corresponding increase in pressure drop.

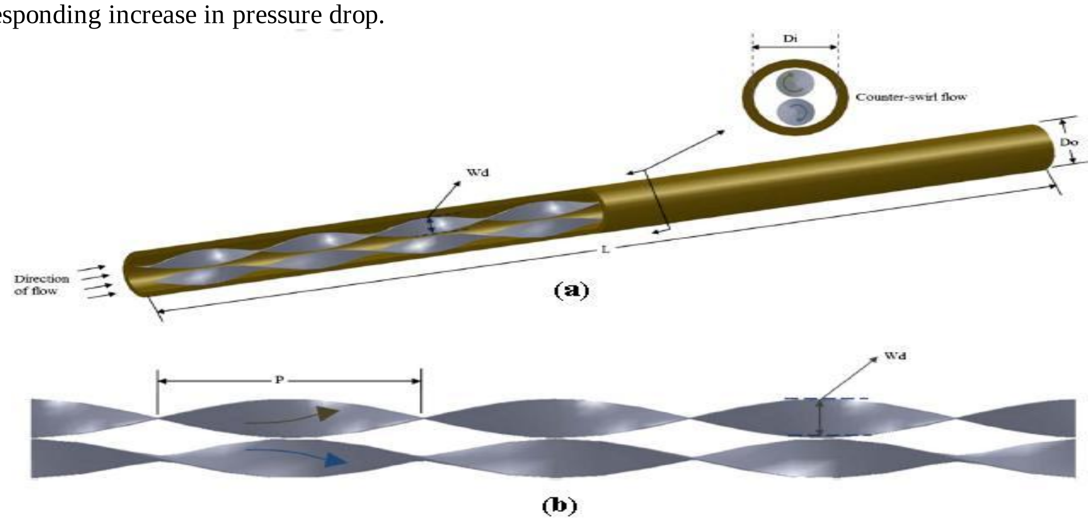

Figure 10. (a) Geometry of test section fitted with double counter twisted tape insert; (b) Geometric parameters of the double counter twisted tape insert. [6]

The double counter twisted tape offered a significant enhancement of heat transfer, friction factor as well as thermal enhancement efficiency compared with the plain tube values as shows in figure 11 and 12. In general observations, it was found that the heat transfer, friction factor and thermal enhancement efficiency increased with decreasing twist ratio. Furthermore, the Nusselt number increased with the increasing Reynolds number while the opposite trends were found for the case of friction factor and thermal enhancement efficiency.

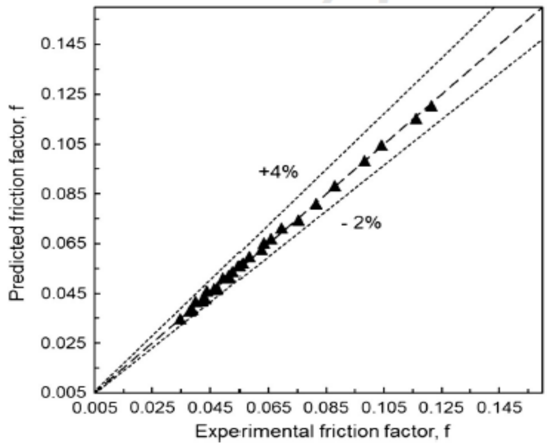

Fig 11 Comparison between the predicted and experimental friction factors

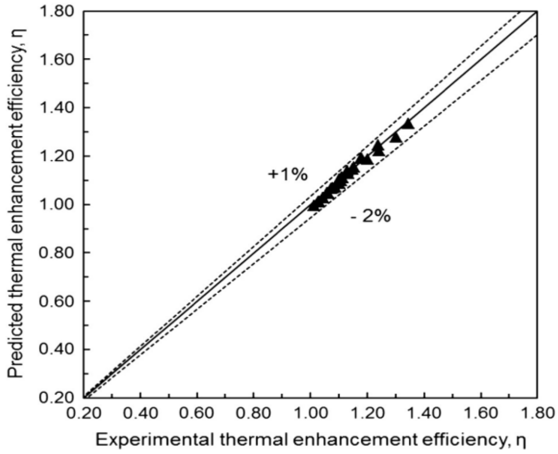

Fig 12 Comparison between the predicted and experimental thermal enhancement Efficiencies.

The thermal enhancement efficiency in the tubes equipped with double counter twisted tapes at constant blower power was achieved to be around 1.01 to 1.34 as shown in figure 12.

VI. PIPE WITH INTERNAL THREADS

To produce the turbulent flow through the pipe for good heat transfer characteristics one of the method used is to use a pipe with internal threads. Shrirao [7] studied heat transfer and friction factor characteristics of horizontal circular pipe using internal threads of pitch 100mm, 120mm and 160mm with air as the working fluid. The transitional flow regime is selected for this study with the Reynolds number range 7,000 to 14,000.

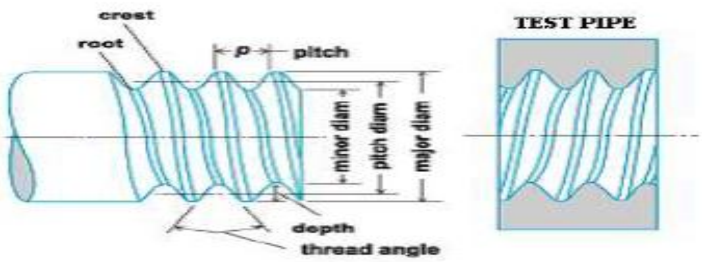

Fig 13 Pipe with internal thread

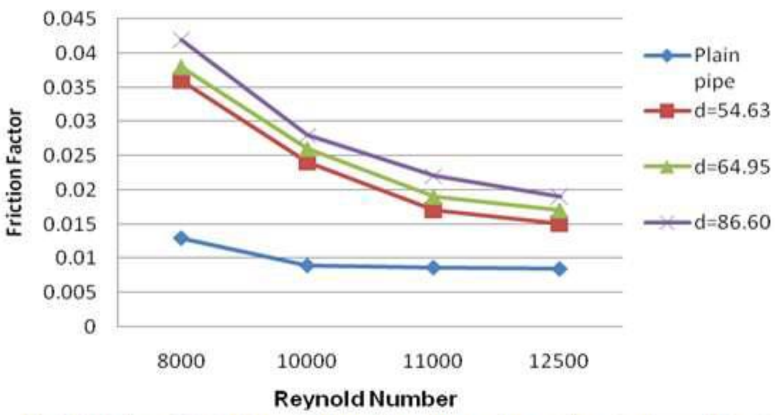

Fig 14 Variation of friction factor vs. Reynolds number for the test pipe using internal threads of varying depth

Figure 14 shows the variation of friction factor Vs Reynolds number for the test pipe using internal threads of varying depth. The friction factor for the test pipe using internal threads of varying depth is more than that for plain test pipe. Friction factor decreases with increase in Reynolds number for a given depth. This shows that the turbulence formation advanced due to artificial turbulence exerted by internal threads. The friction factor is increases with increasing the depth. This is due to more intense swirl flow in case of more depth.

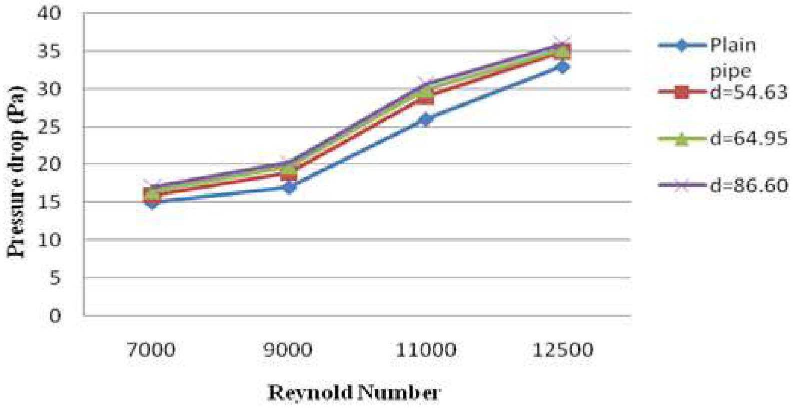

Fig 15 Variation of pressure drop with Reynolds number

Figure 15 shows the variation of pressure drop with Reynolds number. Pressure drop increases with increase in Reynolds number. Maximum pressure drop is observed to be 1.06 times compared to that of plain test pipe for internal thread of depth d = 86.60 mm. The large increase in the pressure drop can be attributed to the plain test pipe for internal thread of depth d = 86.60 mm, and the increased velocity associated more intense swirl flow in case of more depth. The heat transfer enhancement increases with increase in depth of internal threads due to increased turbulence of air. It is due to the swirl flow motion provided by internal threads. The friction factor increases with the increase of depth of internal threads again due to swirl flow exerted by the internal threads.

VII. Conclusion

Laminar flow shows less heat transfer through performance characteristics than that of through turbulent flow. Increase in friction and pressure drop in turbulent flows create dominant effect on heat transfer through the pipe. To produce this turbulent flow various techniques and design strategies are used which are explained in this study. This study shows that turbulent flow increases the Reynolds number. Hence this study helps to design new concept to produce turbulent flow with minimum range of Reynolds number to improve the heat transfer.

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