EFFECT OF USE OF SWIRL FLOW DEVICES TO IMPROVE HEAT TRANSFER RATE IN HEAT EXCHANGERS

P.S.Desale[1], Prof. N.C.Ghuge[2]

[1] *PG Student, ME (Heat Power), MCERC, Nasik, (India)*

[2] *Associate Prof., Department of Mechanical Engineering, MCERC, Nasik, (India)*

ABSTRACT

Heat Exchangers are always associated with their performance improvement in context of heat transfer rate and pressure drop. All are conversant with passive techniques, of which swirl flow devices are very favorite. The thermohydraulic behavior of these inserts in laminar, transition and turbulent flow has been experimentally studied science last decade. This paper presents an extensive survey on three wire coils of different pitch inserted in a smooth tube. The inserts are tested by many researchers in laminar and transition regimes. Many of them have performed heat transfer experiments and Isothermal pressure drop tests. These all experimentations are conducted under uniform heat flux conditions. The heat exchangers are inserted with helical wire coils and steady heat transfer enhancement is studied. The heat exchangers with corrugated tube surface are also taken under consideration. This corrugation induces additional swirling motion of fluid flow. The researchers have examined different geometrical parameters by numerical calculations also the impact of flow and thermal boundary conditions for the heat transfer rate in laminar and transitional flow regimes are studied. All of the researchers have compared calculated results to existing empirical formulas. Comparison of the flow and temperature fields in case of common helical tube and the coil with spirally corrugated wall configuration are discussed. Also many have performed experimental tests to investigate the validity of the numerical results in case of common helical tube heat exchanger and additionally results of the numerical computation of corrugated straight tubes for laminar and transition flow have been validated with experimental tests available in the literature.

Keywords-Heat transfer enhancement; Wire coil inserts; Heat exchangers; Spirally corrugated helical pipe

I. INTRODUCTION

Wire coils are a type of inserted elements which present some advantages compared to other enhancement techniques, such as artificial roughness by mechanical deformation. They may be installed in an existing smooth tube heat exchanger. They keep the mechanical strength of the smooth tube. Their installation is easy and their cost is very low. The insertion of a device such as a wire coil inside a smooth tube produces an increase in the heat transfer due to one or more of the following phenomena. The first one can be turbulence promotion. Wires attached to the wall cause separation in the flow that increases its turbulence level. They act also as roughness elements mixing up the flow in the viscous sublayer. Many inserted devices induce secondary flows which can favor thermal exchange. Helical wire coils produce a helicoidal flow at the periphery superimposed on the main axial flow. Due to the flow velocity increase and to the appearance of centrifugal forces, convection increases. This favors the convection in heating processes. Any inserted element in a smooth tube will reduce the cross-sectional area increasing the average flow velocity. The wetted perimeter also increases and the hydraulic diameter decreases. Evidence suggests that depending on the wire coil geometry and on the Reynolds number, two different types of flows can occur: rotating flow and separated flow. The first one occurs at the tube periphery due to the helix angle and affects to a greater or lesser extent the thickness of the flow. A separated flow can occur due to the fluid crossover through the wire. Most of the experimental works on wire coils focus on the turbulent regime and pay little attention to their behavior in laminar and transition regimes. In the last decades, significant effort has been made to develop heat transfer enhancement techniques in order to improve the overall performance of heat exchangers. The interest in these techniques is closely tied to energy prices and, with the present increase in energy cost, it is expected that the heat transfer enhancement field will go through a new growth phase. Although there is need to develop novel technologies, experimental work on the older ones is still necessary. The knowledge of its performance shows a large degree of uncertainty which makes their industrial implementation difficult. Tube side enhancement techniques can be classified according to the following criteria: (1) additional devices which are incorporated into a plain round tube (twisted tapes, wire coils) and (2) non-plain round tube techniques such as surface modification of a plain tube (corrugated and dimpled tubes) or manufacturing of special tube geometries (internally finned tubes). In applications like petrochemical industry where specifications codes are required, insert devices can be used since they do not modify round tube mechanical properties as integral roughness does. They can be used when it is required to increase the heat transfer rate of an existing heat exchanger: there is no need to replace the tube bundle and they can be installed in a routine maintenance stoppage. Wire coil inserts are currently used in applications as oil cooling devices, preheaters or fire boilers. They show several advantages in relation to other enhancement techniques:

(1) Low cost.

(2) Easy installation and removal.

(3) Preservation of original plain tube mechanical strength.

(4) Possibility of installation in an existing smooth tube heat exchanger.

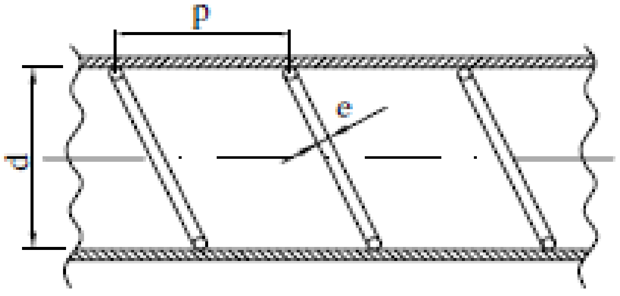

Fig. 1 Sketch of a helical-wire-coil fitted inside a smooth tube.

Fig. 1 shows a sketch of a wire coil inserted in close contact with the inner tube wall, where p stands for helical pitch, e for the wire-diameter and d is the tube inner diameter. These parameters can be arranged to define the wire geometry in non-dimensional form: dimensionless pitch p/d, dimensionless wire-diameter e/d and pitch to wire-diameter ratio p/e. The tube side flow pattern is modified by the presence of a helically coiled wire as follows: (1) If the wire coil acts as a swirl flow generator, a helical flow at the periphery is produced. This rotating flow is superimposed upon the axially directed central core flow and causes centrifugal forces. In most of liquids, where density decreases with temperature, centrifugal forces produce a movement of the heated fluid from the boundary layer towards the tube axis, which produces a heat transfer augmentation. (2) If the wire coil acts as a turbulence promoter, flow turbulence level is increased by a separation and reattachment mechanism. Besides, whenever wire coils are in contact with the tube wall, they act as roughness elements and disturb the existing laminar sublayer. Depending on flow conditions and wire coil geometry, the heat transfer rate will increase through one or both of the mechanisms mentioned earlier. However, it is expected that wire coils will act as artificial roughness at high Reynolds numbers. Many of researchers consider that in turbulent regime, wire coils disturb the flow in a similar way that corrugated or ribbed tubes do. Experimental works which focus on wire coil inserts are few in comparison to those that study twisted tapes. Wire coils are interesting insert devices, and therefore predictable correlations are needed to extend the use of this technique. Twisted tapes may not necessarily be the best insert devices, but they are more used than wire coils because design correlations are well established in laminar, transition and turbulent flows.

II. EXPERIMENTATION

The facility depicted in fig.2 was built in order to study the flow pattern induced by a wire coil inserted in a tube. The main section consists of a 32 mm diameter acrylic tube installed between two reservoir tanks, that stabilize the flow. In the upper reservoir tank the flow temperature is regulated by an electric heater and a thermostat. The flow is impelled from the lower calm deposit to the upper one by a gear pump, which is regulated by a frequency converter. By using mixtures of water and propyleneglycol at temperatures from 20 ^{0}C to 50 ^{0}C, Reynolds numbers between 100 and 20 000 can be obtained. The tests presented in this work were carried out employing a mixture of 50% water and propyleneglycol at temperatures from 25 ^{0}C to 40 ^{0}C, yielding Reynolds number in the range from 200 to 3000. Heat losses in the vertical tube were calculated and it was confirmed that the velocity field was not modified by buoyancy forces in any test.

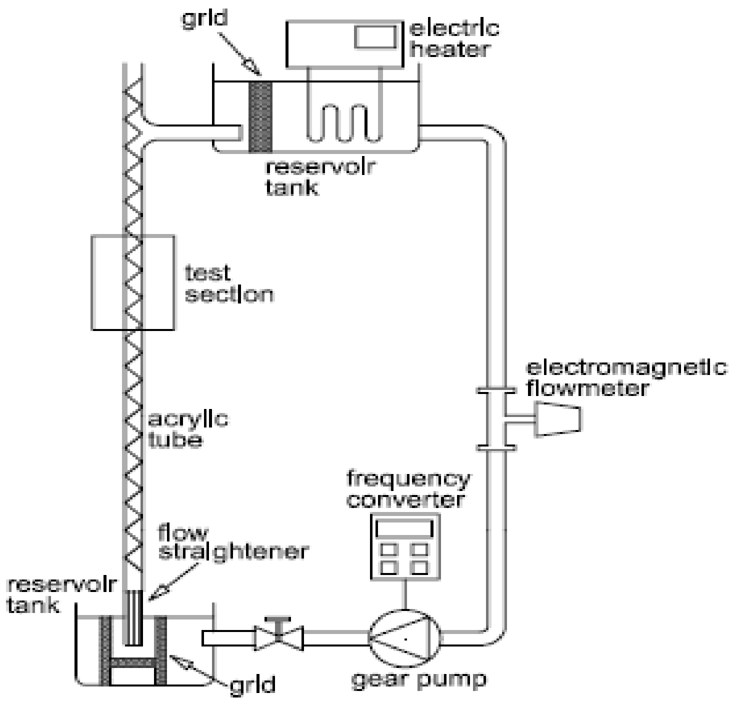

Fig.2 Experimental Set Up

III. EXPERIMENTAL RESULTS

An experimental study in three wire coils with the same wire diameter and different non-dimensional pitch has been carried out. Wire coils were produced from a stainless steel coil covered by an ulterior plastic sheet. Table 2 shows the wire coils that have been used in the visualization tests. Since the tube used in the visualization facility has a diameter of 32 mm and the one used in the installation of the pressure drop facility has a diameter of 18 mm, the three wire coils are geometrically similar (Table 1). Therefore, the visualization results can be compared to the pressure drop results. Tests have allowed the description of different flow patterns and have established with accuracy the Reynolds number at which transition to turbulent flow occurs. The flow will be described in two different areas: the central region, which is defined as the tube region and the peripheral region.

	d (mm)	p/d	e/d	p/e	α (deg)
Wire Coil W01	18	1.25	0.076	16.4	68.3
Wire Coil W02	18	1.72	0.076	22.6	61.3
Wire Coil W03	18	3.37	0.076	44.3	43.0

Table.1 Coil tested specification

	d (mm)	p/d	e/d	p/e	α (deg)
Wire Coil W01	32	1.21	0.073	16.6	68.9
Wire Coil W02	32	1.65	0.073	22.6	62.3
Wire Coil W03	32	3.66	0.073	50.1	40.6

Table.2 Coil tested specification

Smooth tube:

hydrogen bubbles allows one to establish when the flow starts to become unstable and how the transition to the turbulent regime is produced. Experimental results in laminar regime are compared with the analytical solution and results in turbulent regime are compared with the Blasius equation. Deviations were lower than 4% for the 95% of the experimental data. These tests served to the adjustment and verification of the experimental installation. Next the results obtained from the hydrogen bubbles
visualization along with the pressure drop results are commented:

I. Reynolds number range from 100 to 1800. Stable laminar flow, parabolic velocity profile. Friction factor results adjust perfectly to the curve fs = 16/Re.

II. Reynolds number range from 1800 to 2100. Laminar flow with light flow oscillations. At Re = 2000 the presence of turbulence outbreaks is appreciated.

III. Reynolds number range higher than 2100. Turbulence is clearly established. From the flow visualization by means of the hydrogen bubbles, the break point at Re = 2100 was established. In the friction factor curve a minimum at 2100 is observed. Moreover, a quite sudden friction factor increment due to the transition from laminar to turbulent flow is found.

Wire coil short-pitch:

The flow characterization in the wire coil has been carried out using the fluid visualization by means of hydrogen bubbles and the velocity profile measurement by the PIV technique. On a qualitative level, images have served to show the flow pattern based on the Reynolds number and to establish the point where transition occurs.

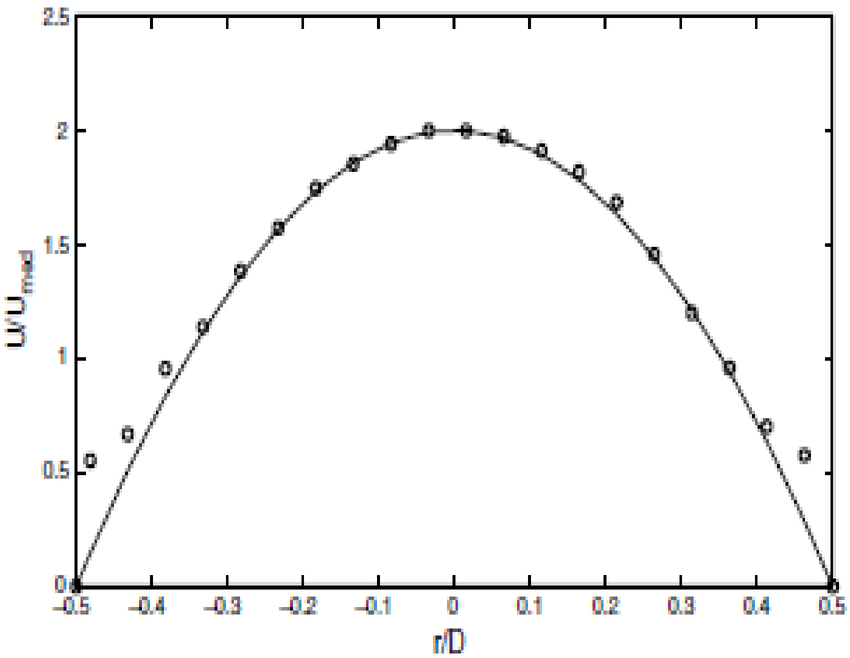

Fig.3 Velocity Profile In Smooth Tube

The general flow topology is similar to that of region II, except that the central flow becomes oscillatory. At Re = 500, it is observed that the central flow oscillates and seems to be a laminar undulating flow. At Re = 600 flashes of turbulent flow are observed. These are turbulence outbreaks. At Re = 650 the central flow is in a turbulent transitional regime. At Re = 700 the flow is fully turbulent. Friction factor becomes almost constant. This means that the pressure drop is proportional to the mean square velocity (a typical solution of turbulent flows). Given the flow structure in the transitional region to turbulence, this is produced smoothly without any kind of discontinuity. In

fact, in the pressure drop tests, the transitional point cannot be established (just as occurs in the smooth tube tests).

Heat Transfer-

Heat transfer tests under uniform heat flux condition were carried out in a smooth empty tube and in the same tube with 6 wire coil inserts. A wide range of flow conditions was covered: Re = 80000 to 90,000 and Pr = 2.8 to 150. The set of tests started with the empty smooth tube. These experiments allowed to check the experimental setup, to verify the procedure and to con. rm the calculated uncertainties. In laminar flow, heat transfer was produced under mixed convection. Local Nusselt numbers were measured in the fully developed region and therefore they depend only on Rayleigh number. Results at Reynolds number below 2300 are compared with Petukhov and Polyakov equation,

$$Nu_s = 4.36[1 + (Ra/18,000)^4]^{0.045}$$

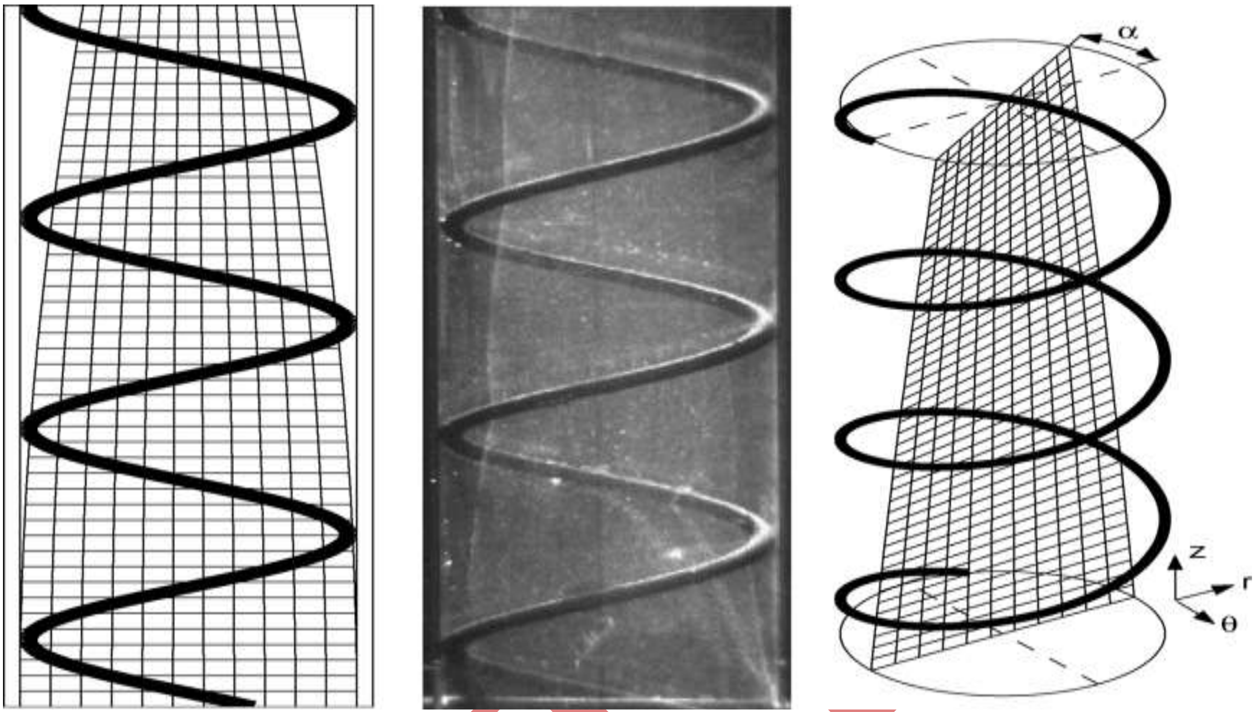

Fig. 4 Central Flow for Wire Coil W01 At Re < 350. Visualization By Hydrogen Bubbles.

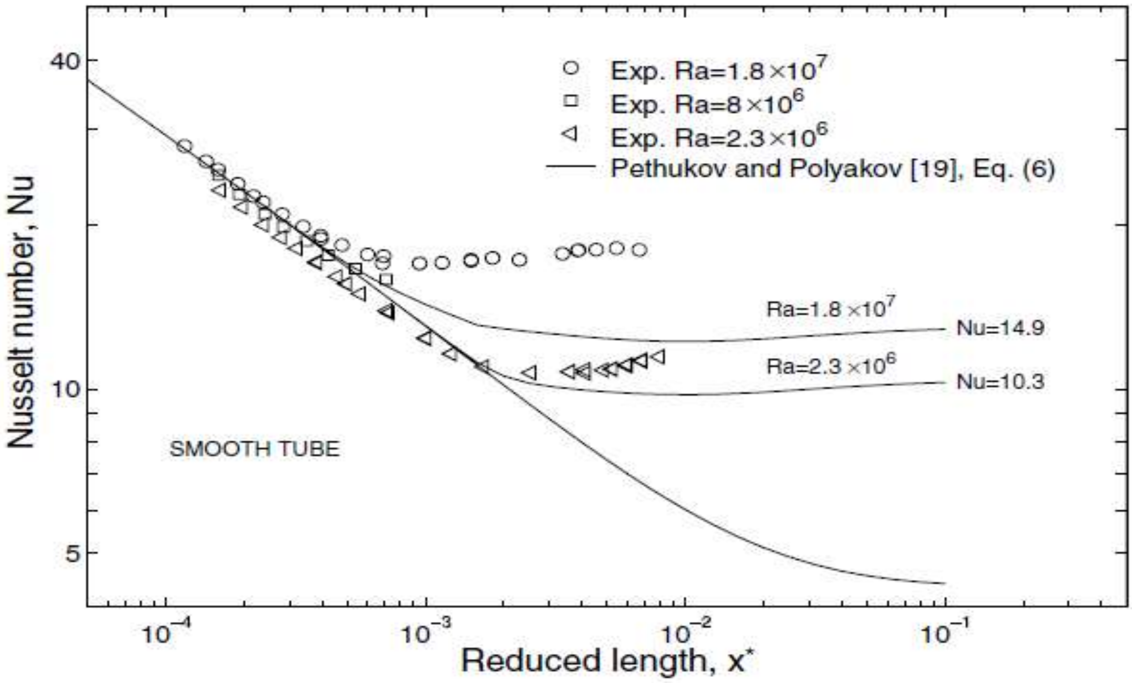

Fig. 5 Experimental results on heat transfer in forced and mixed convection in the smooth tube at xp=d ¼ 55. Local Nusselt number Nux as a function of Rayleigh number Ra and dimensionles length x*. Comparison with the Petukhov and Polyakov correlation

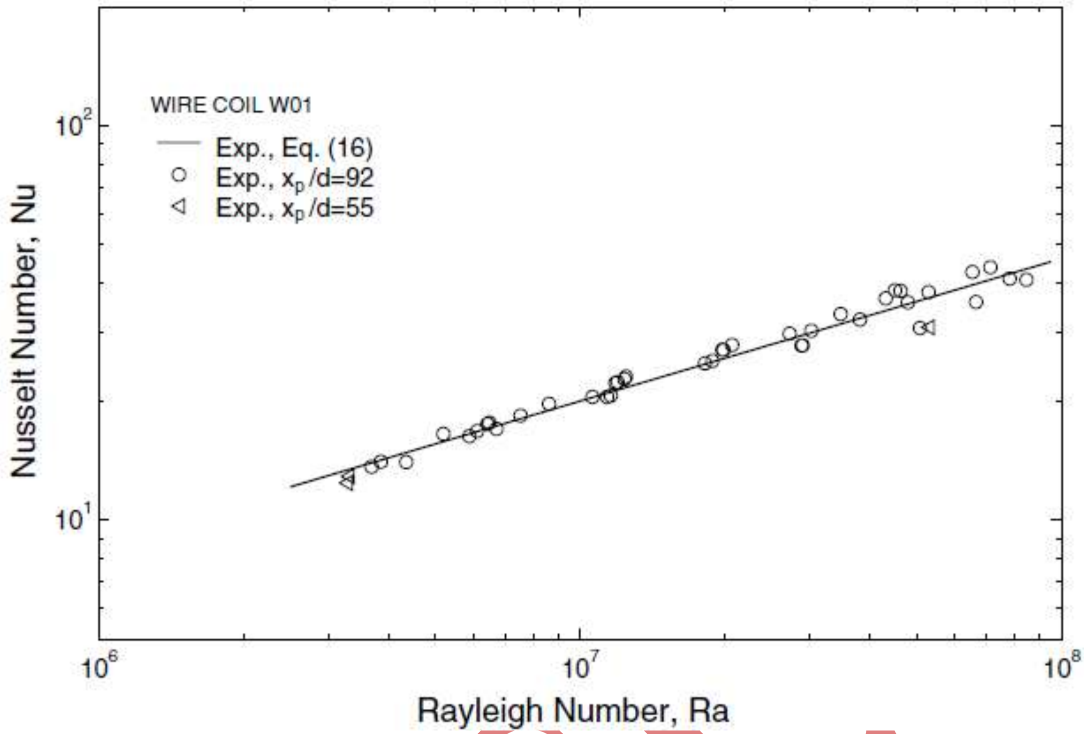

Fig.6 Heat Transfer Experimental Results In Natural Convection In Wire W01. Fully Developed Nusselt Number Nu1 As A Function Of Rayleigh Number Ra.

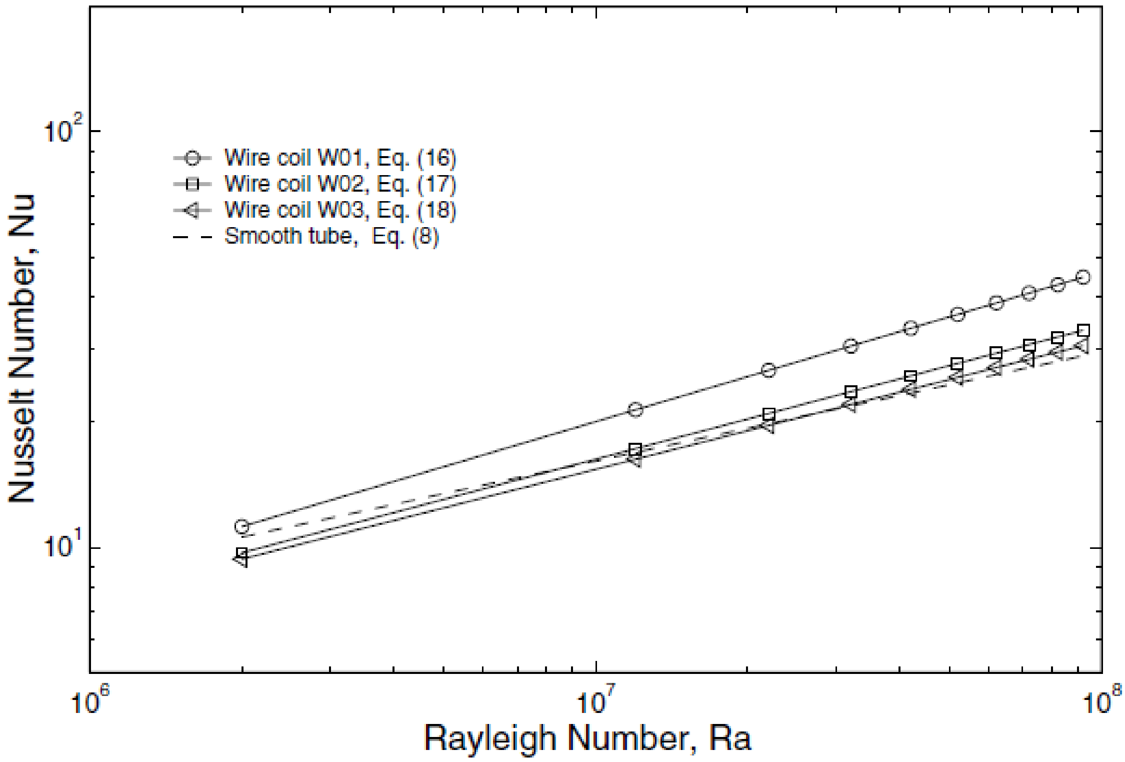

Fig. 7 Fully Developed Nusselt Number Nu1 As A Function Of Rayleigh Number Ra. Comparison Of Results Achieved In Wires W01–03 And In The Smooth Tube.

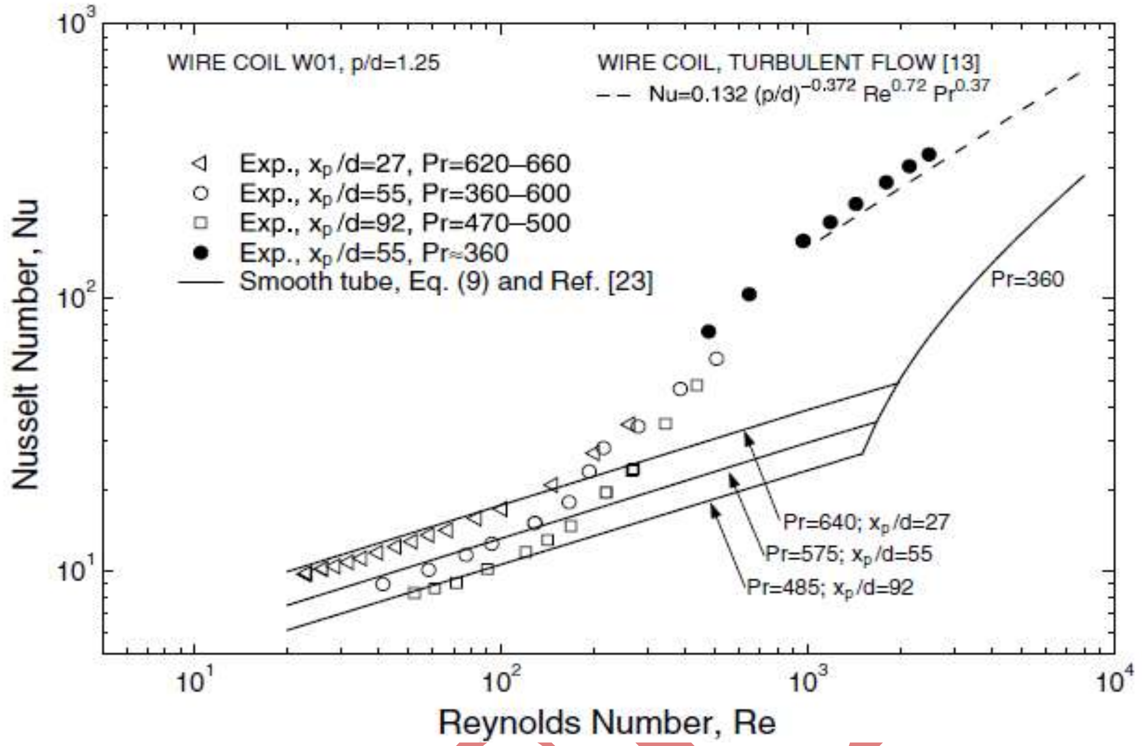

Fig.8 Nusselt Number In Forced Convection Nucf Vs. Reynolds Number Re. Results For Wire W01.

IV. CONCLUSION

This paper summarizes work of many researches in the area of swirl flow devices. There are six different wire coils inserted in a smooth tube were mainly under consideration, in which flow conditions were laminar, transition and turbulent regimes. Many of researchers have proposed general correlations as a function of flow situations and coil geometry for Nusselt number and Fanning friction factor. For Reynolds Number below 30000 at constant pumping power the wire coils are compared with a smooth tube and increased heat transfer rate is noticed. There are many differences have been noted out of the six analyzed wire coils. All wire coils have shown predictable nature within the transition region as it can be observed that they show continuous curves of friction factor and Nusselt number. This shows a considerable advantage over other enhancement techniques. Thus the transition region was found best operating regime. Wire coils behave mainly as a smooth tube in laminar flow. For turbulent flow, it is observed that Prandtl number does not show any effect on heat transfer improvement. But on the other hand, within transition region for high Prandtl number, wire coils leads to the maximum heat transfer rise. The transition to turbulent flow is seen at low Reynolds numbers. The high pressure drop is experienced in turbulent flow due to presence of wire coils. This pressure drop mainly is a function of pitch to wire-diameter ratio, and the heat transfer augmentations depending mainly on dimensionless pitch p/d. Also as Reynolds number increases Nusselt number augmentation decreases rapidly.

REFERENCES

[1] Alberto Garcia, Pedro Vicente, Antonio Viedma, Experimental study of heat transfer enhancement with wire coil inserts in laminar-transition-turbulent regimes at different prandtl numbers. International Journal of Heat and Mass Transfer, 48 (2005), 4640-4651.

[2] Alberto Garcıa, Juan P. Solano, Pedro G. Vicente, Antonio Viedma, Enhancement of laminar and transitional flow heat transfer in tubes by means of wire coil inserts, International Journal of Heat and Mass Transfer 50 (2007) 3176–3189.

[3] A. Garcı´a, J.P. Solano, P.G. Vicente, A. Viedma, Flow pattern assessment in tubes with wire coil inserts in laminar and transition regimes. International Journal of Heat and Fluid Flow 28 (2007) 516-525.

[4] M.A. Akhavan-Behabadi, M.R. Salimpour , V.A. Pazouki, Pressure drop increase of forced convective condensation inside horizontal coiled wire inserted tubes, International Communications in Heat and Mass Transfer 35 (2008) 1220–1226.

[5] M.A. Akhavan-Behabadi, Ravi Kumar, M.R. Salimpour c, R. Azimi, Pressure drop and heat transfer augmentation due to coiled wire inserts during laminar flow of oil inside a horizontal tube, International Journal of Thermal Sciences 49 (2010) 373–379.

[6] D. Munoz-Esparza, E. Sanmiguel-Rojas, Numerical simulations of the laminar flow in pipes with wire coil inserts, Computers & Fluids 44 (2011) 169–177.

[7] S. Eiamsa-ard, P. Promvonge, Enhancement of heat transfer in a circular wavy-surfaced tube with a helical-tape insert, International Energy Journal 8 (2007) 29-36

[8] Paisarn Naphon and Tanapon Suchana, Heat transfer enhancement and pressure drop of the horizontal concentric tube with twisted wires brush inserts, International Communications in Heat and Mass Transfer 38 (2011) 236–241

[9] R. Herrero Martin, A. Garcia, J. Perez-Garcia, Influence of wire-coil inserts on the thermo-hydraulic performance of a flat-plate solar collector.

[10] Swaminathan Selvam, Periyakaruppan Thiyagarajan, and Sivan Suresh, Effect of wire coiled coil matrix turbulators with and without bonding on the wall of the test section of concentric tube heat exchanger, Thermal Science, Year 2012, Vol. 16, No. 4, Pp. 1151-1164.

[11] Mohamed A. Abd Raboh, Hesham M. Mostafa, Mostafa A. M. Ali and Amr M. Hassaan, Experimental study for condensation heat transfer inside helical coil.

[12] Ta-Sung Huang, Pai-Hsiang Wang, Yu-Wei Chiu and Jiin-Yuh Jang, Heat and fluid flow analysis over different tube inserts of recuperator, China Steel Technical Report, No. 21, pp. 67－76, (2008)

[13] P. Murugesan, K. Mayilsamy, S. Suresh and P.S.S. Srinivasan, Heat transfer and pressure drop characteristics of turbulent flow in a tube fitted with trapezoidal-cut twisted tape insert, International Journal of Academic Research, Vol. 1. No. 1. September 2009