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Investigation of Heat Transfer Enhancement in Laminar Flow through Circular Tube by using Combined Wire Coil and Wavy Strip with Central Clearance

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***Abstract:** The experimental friction factor and Nusselt number data for a laminar flow in a circular pipe having wire coil and wavy strip insertion are presented. Thermal boundary layer is the primary hindrance to the heat transfer. That is why to destroy it or at least to disturb it the insertions are used. The thermohydraulic phenomenon has been analyzed. The objective of this work is to find out the combined effect of wire coil and wavy strip on the heat transfer and whether it can enhance it. Nusselt number and friction factor are measured for different Prandtl number and Reynolds number. The findings of this work are useful in automobile and air-conditioning industries to reduce the size of the heat exchanger.*

***Index Terms:** friction factor, heat transfer, Nusselt number, wavy strip, wire coil*

I. INTRODUCTION

Heat transfer enhancement has a widespread application in power plants, automobile, air-conditioning industries. Zimparov [1] has presented experimental result of Heat transfer and isothermal friction pressure-drop for two three-start spirally corrugated tubes combined with five twisted-tape inserts with different relative pitches in the range of Reynolds number 3×10^3 - 6×10^4. Garcia et al [2] analyzed the thermal hydraulic behavior of three types of enhancement technique based on artificial roughness: corrugated tubes, dimpled tubes and wire coils. Sarma et al [3] presented a new method to predict heat transfer coefficients with twisted tape inserts in a tube, in which the wall-shear and temperature-gradients are properly modified through friction coefficient correlation leading to heat transfer augmentation from the tube wall. Rainieri and Pagliarini [4] aimed to the analysis of the thermal performances of corrugated wall tubes employed in a broad variety of industrial applications in order to intensify the convective heat transfer. Patil [5] has presented experimental result of heat transfer and flow friction of a generalized power-law fluid in tape-generated swirl flow inside a 25.0 mm inner diameter circular tube. Laohalertdecha and Wongwises [6] presented presents the condensation heat transfer and flow characteristics of R-134a flowing through corrugated tubes experimentally. Shauib et al [7] has presented the numerical studies on heat transfer and pressure drop characteristics of copper–water nano-fluid flow through isothermally heated corrugated channel. Agarwal and Raja Rao [8] has experimentally determined the isothermal and non-isothermal friction-factors and mean Nusselt numbers for uniform wall-temperature heating and cooling of Servotherm oil for their flow in a circular tube with twisted-tape inserts.

It has been observed from the literature survey that combined effect of wire coil and wavy strip insertions were not studied in the past. The swirl flow induced due to the wire coil coupled with wavy strip with central clearance may enhance the heat transfer. The material for the wavy strip used in the present study is brass metal with 60^0 wave angle and non-dimensional central clearance is 0.4.The material of the wire coil is stainless steel with 1mm wire diameter, 19mm coil diameter and 60^0 helix angle.

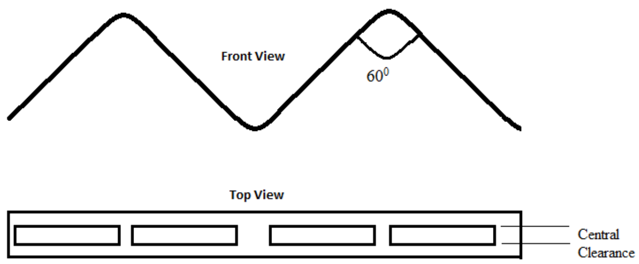

Fig. 1. Wavy Strip Sketch

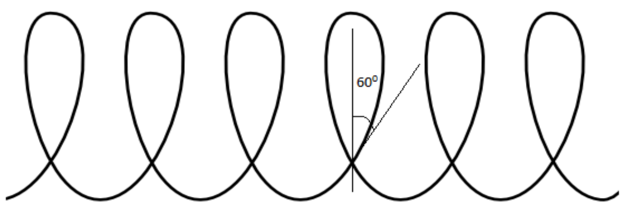

Fig. 2. Wire Coil Sketch

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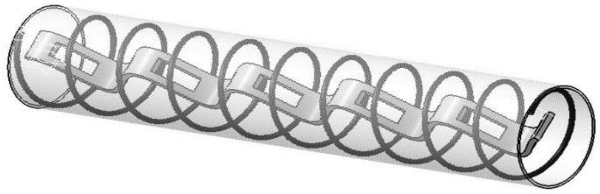

Fig. 3. 3D view of Combined Wire Coil and Wavy Strip

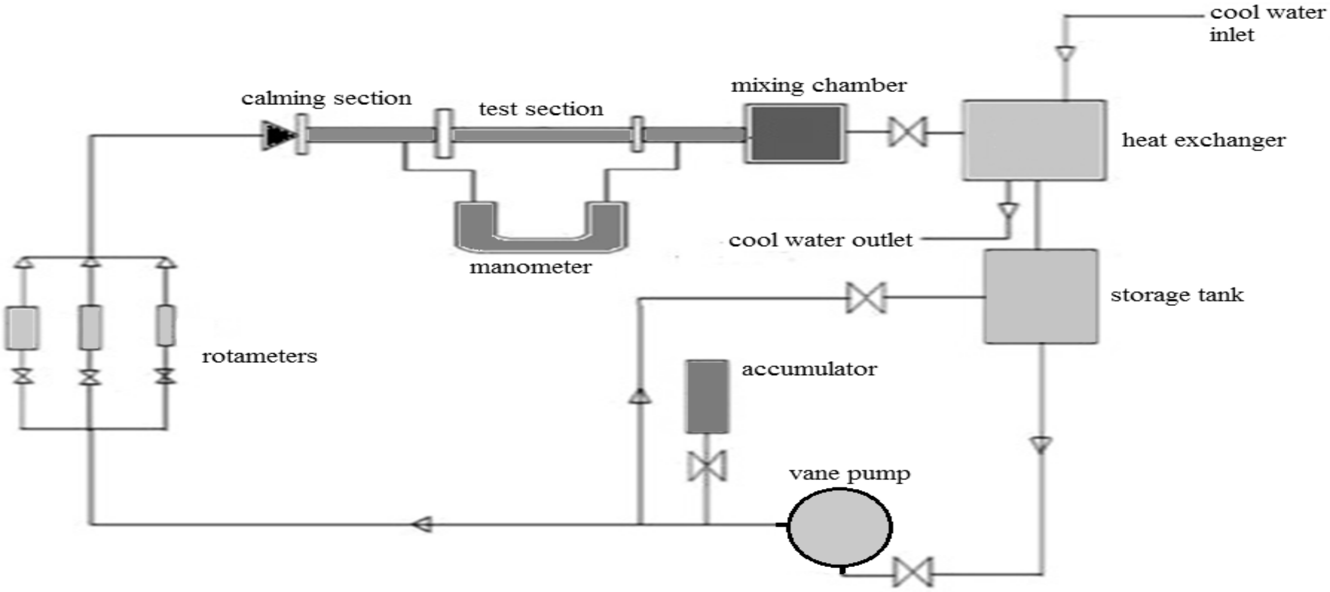

Fig. 4. Schematic of the Experimental Setup

II. EXPERIMENTAL SETUP

A vane pump of 2kW power pumps the working fluid from the storage tank. The fluid passes through one of the three rotameters. There is a bypass line for excess fluid that goes back to the storage tank. The accumulator is used to reduce the turbulence and pressure fluctuations and also the oil hammering. The rotameters can be controlled and it can measure the flow rate with the adjustment of the valve. The rotameters' ranges are- (i) 0.07-0.7 kg/s (ii) 0.0115-0.115 kg/s (iii) 0.00175-0.0175 kg/s. After the rotameters oil enters into the calming section. It is easily conceivable from the name that the turbulence gets further reduced in this section and velocity profile gets fully developed. Then it enters the test section. After the test section the fluid enters the mixing chamber. The fluid gets thoroughly mixed by serpentine motion in this section. Thermocouples were used to measure the uniform fluid outlet temperature. The axial locations of the thermocouples were 0.05, 0.5, 1, 1.25, 1.5, 1.75 and 1.95m. The bulk mean temperature of the fluid at the inlet and outlet of the test section were measured by copper-constantan thermocouples. Then the fluid enters a closed type heat exchanger and then it gets cooled here. Finally, the working fluid returns to the reservoir at ambient temperature. The vertical mercury manometer was used to measure the pressure drop across the test section. Then the cycle repeats.

Fig. 5. The Actual Experimental Setup

Fig. 6. shows the longitudinal cross section of the test section. It is made of a 2 m long, 20mm of outer diameter and 19 mm inner diameter brass tube. Then it is wrapped by two nichrome heater wires of equal length which is used to heat it up electrically. Two autotransformers power the test section which is measured by digital voltmeter and ammeter. The duct of the test section is first wrapped up with glass fiber tape, upon which nichrome heater wire with porcelain beads on them are wound. After that, it gets wrapped up by asbestos rope cover and later a glass wool is used upon it to minimize the heat loss to outside. The thermal conductivity of the duct wall material is high enough and the duct wall thickness is sufficient to ensure uniform wall heat flux. Finally, the test section is wrapped by jute bag to keep the insulation in its place. The wavy strips are generally located in the center of the duct cross section.

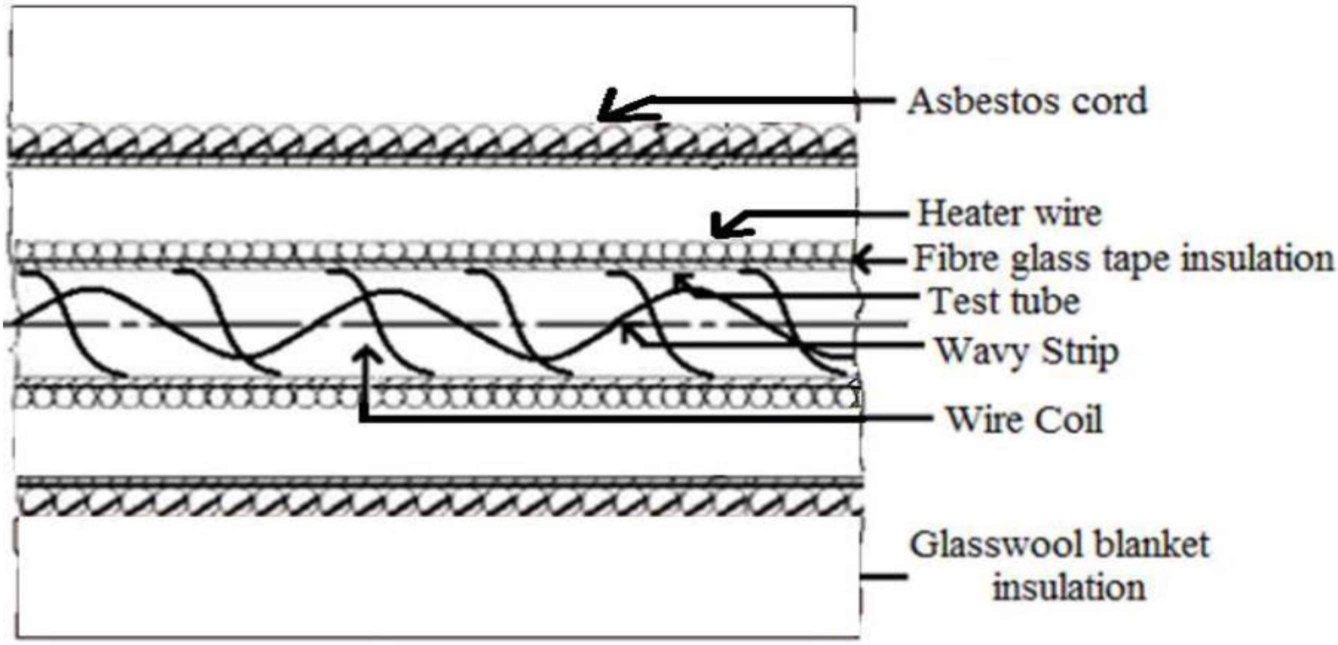

Fig. 6. Longitudinal cross Section of the test section

List 1. Nomenclature of different parameters

NOMENCLATURE		
Re	Reynolds Number	$Re = UD_i/\nu$
T_{wi}	Temperature of the inner Wall of the pipe	
T_{bj}	Bulk Mean Temperature of the fluid at a section	
f	Friction Factor	
Pr	Prandtl Number	$Pr = \mu_b C_p / k_f$
Nu	Nusselt Number	$Nu = hD_i/k_f$

III. RESULT AND DISCUSSION

A. Axial variation of the Temperature of the Fluid

The bulk mean temperature at a section increases linearly along the length of the duct after the developing length in the downstream direction of the flow as the duct wall was subjected to the uniform heat flux. For various Reynolds and Prandtl number the increment in bulk mean temperature of the fluid at a particular section is shown in the Fig. 7, 8 & 9 respectively.

B. Axial variation of the inner wall Temperature

The inner wall temperature is expected to increase continuously along the length of the duct. But in the present case, the plot does not behave like that. This is due to the heat loss in the axial direction as well as in the radial direction through the insulation due to the circulatory motion, flow separation and reattachment and thermal and hydrodynamic boundary layer disturbances, thermal and hydrodynamic entrance effect. The plots are shown for Fig. 10, 11 & 12.

C. Variation of Nusselt number in the axial direction

Nusselt number is dependent on several flow parameters like Reynolds no., Prandtl no., Swirl in the flow and geometric parameters like center-clearance ratio of the wavy strip and wire coil diameter ratio of the wire coil. There is anomaly in the behavior of downstream end Nusselt number. This is perhaps due to the end conduction heat losses which were out of control. The axial variation of Nusselt number for various Reynolds number and Prandtl number are shown in Fig. 13, 14 & 15.

D. Variation of friction factor with Reynolds number

It is observed from the Fig. 16 that as Reynolds number increases, the fRe also increases. So, it can be implied that increase in inertia force is far greater than decrease in friction. And, the value of fRe signifies the amount of pumping power needed. For higher Reynolds number heat transfer is also more but with the penalty of pumping power.

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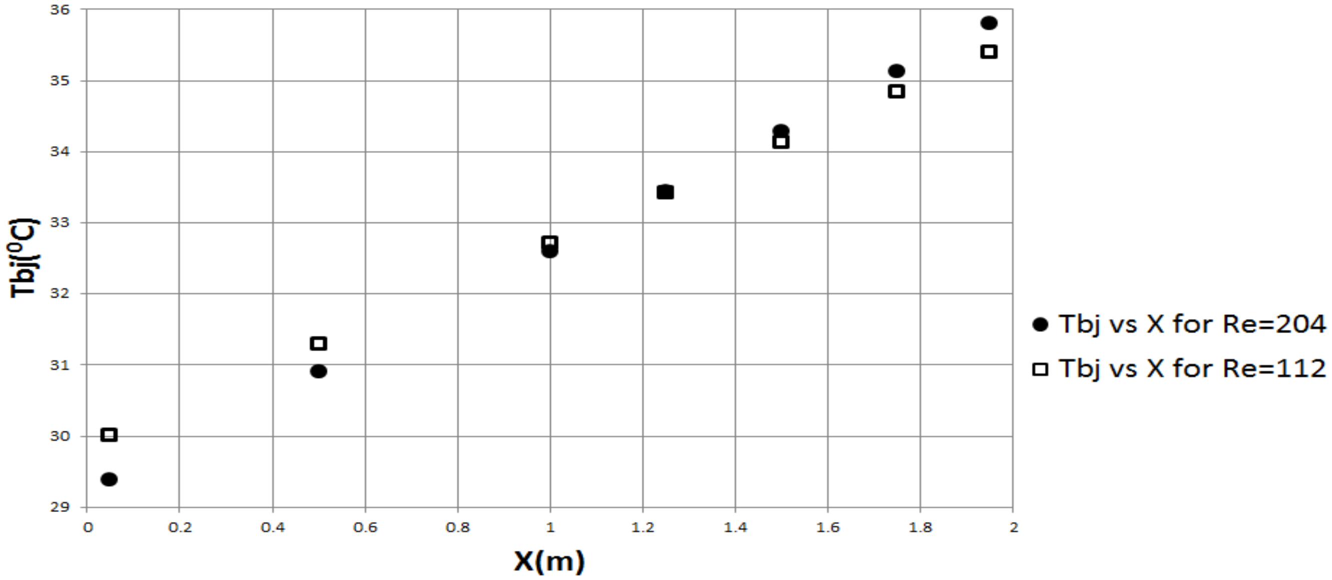

Fig.7. Variation of Bulk mean temperature at particular section (Tbj) in the axial direction (X) for Pr=573

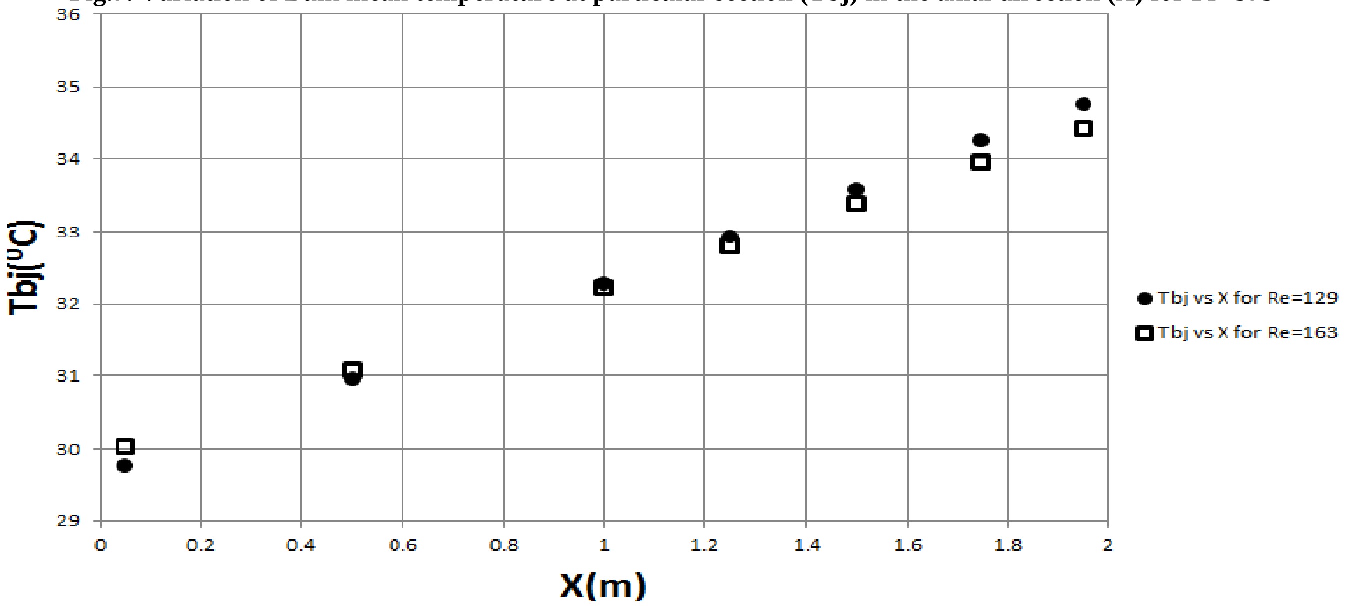

Fig.8. Variation of Bulk mean temperature at particular section (Tbj) in the axial direction (X) for Pr=582

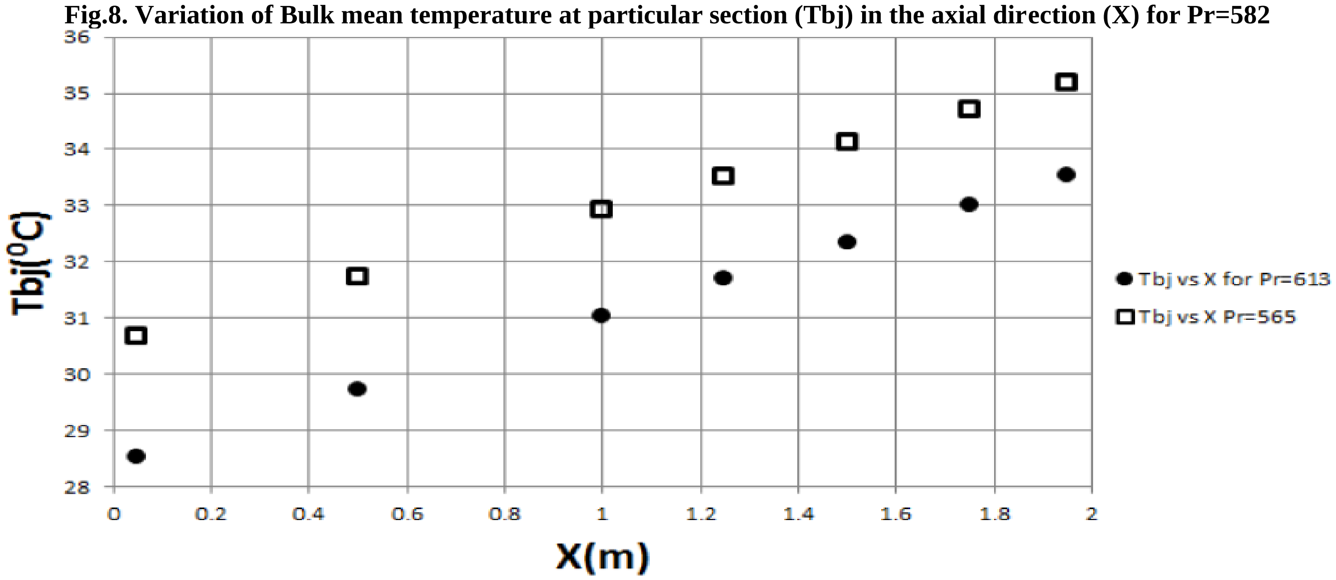

Fig. 9. Variation of Bulk mean temperature at particular section (Tbj) in the axial direction (X) for Re = 120

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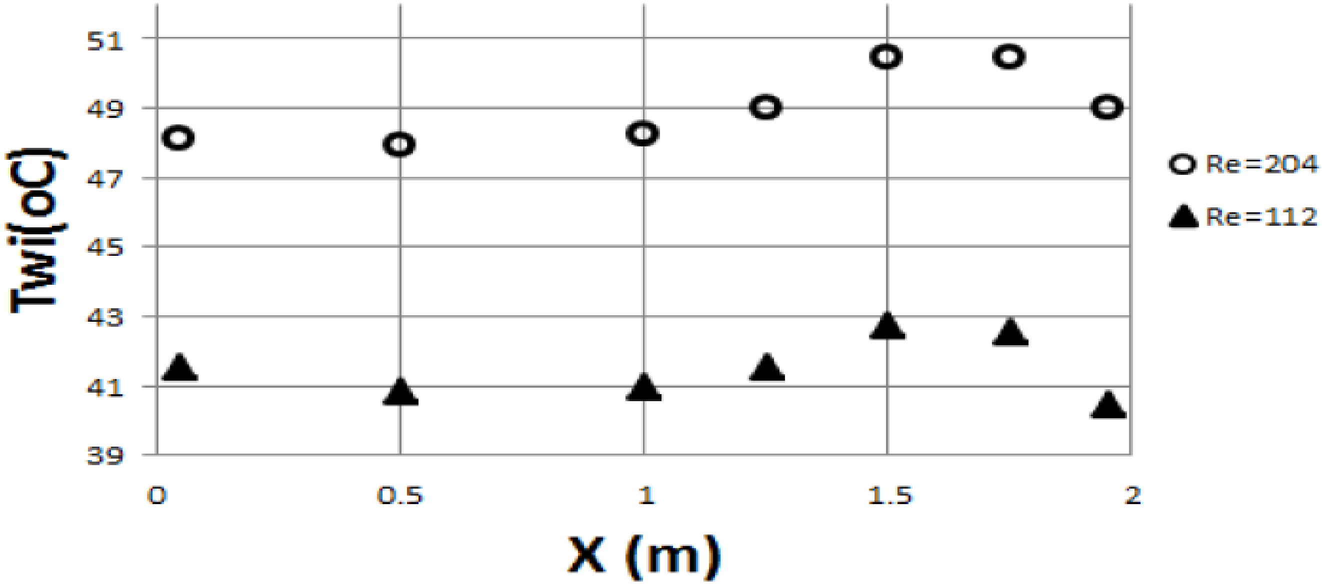

Fig.10. Variation of inner wall temperature of pipe (Twi) in the axial direction (X) for Pr = 573

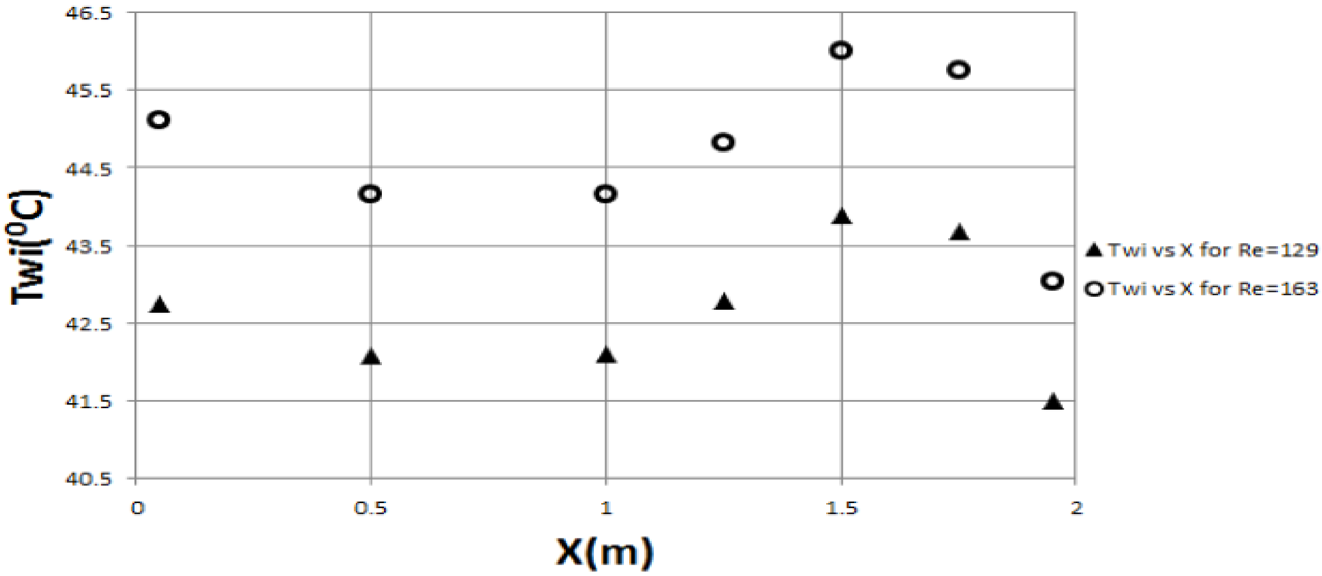

Fig. 11. Variation of inner wall temperature of pipe (Twi) in the axial direction (X) for Pr = 582

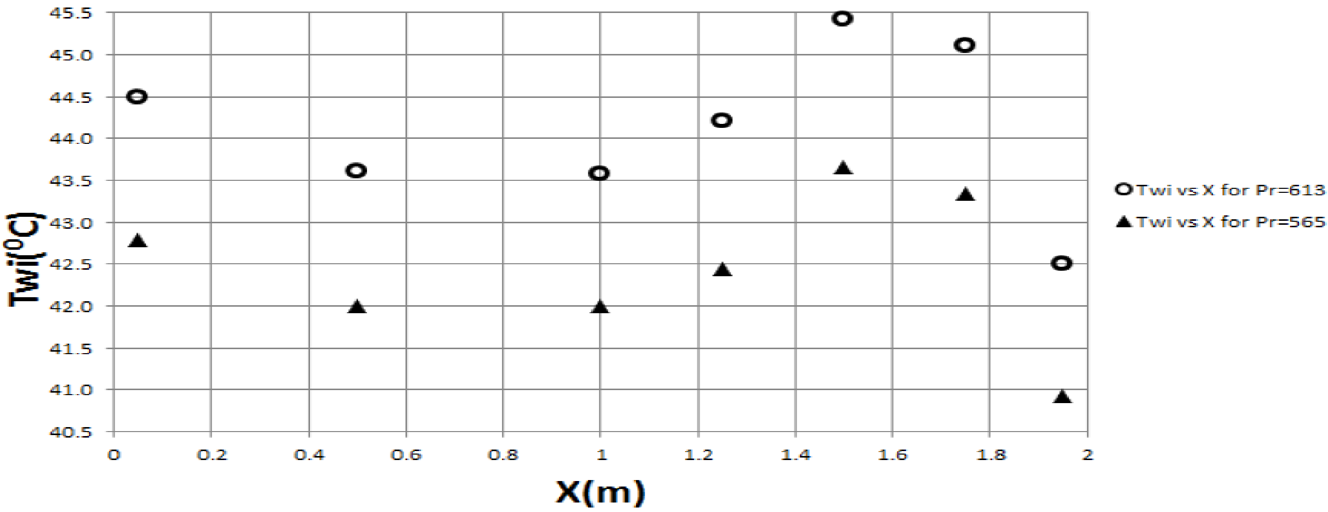

Fig. 12. Variation of inner wall temperature of pipe (Twi) in the axial direction (X) for Re = 120

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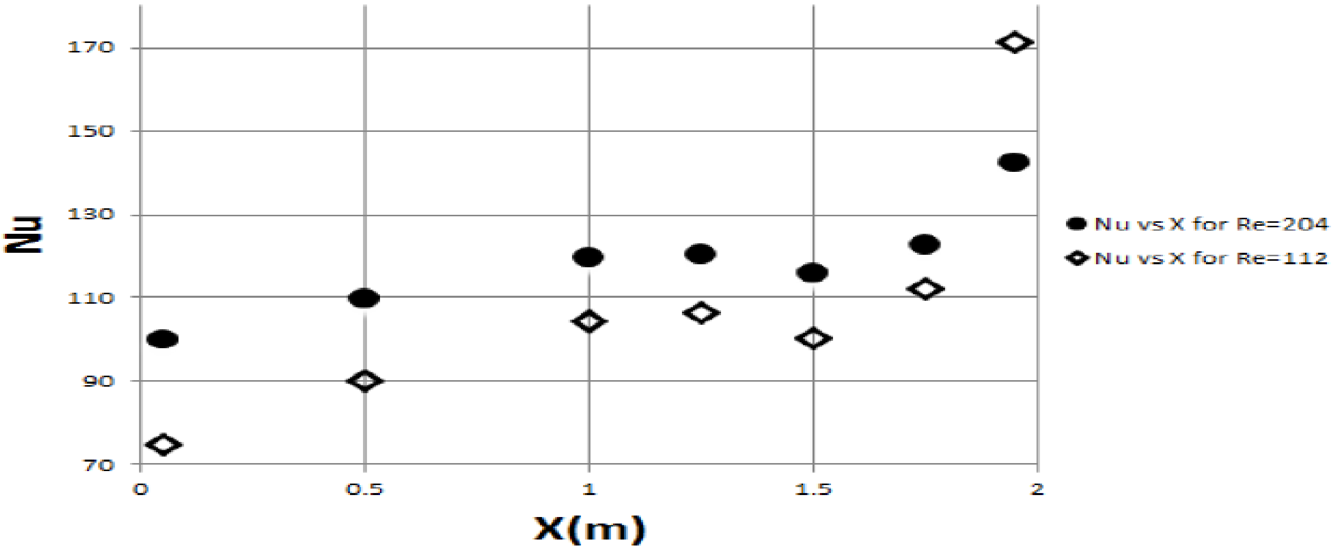

Fig. 13. Variation of Nusselt's number (Nu) in the axial direction (X) for Pr = 573

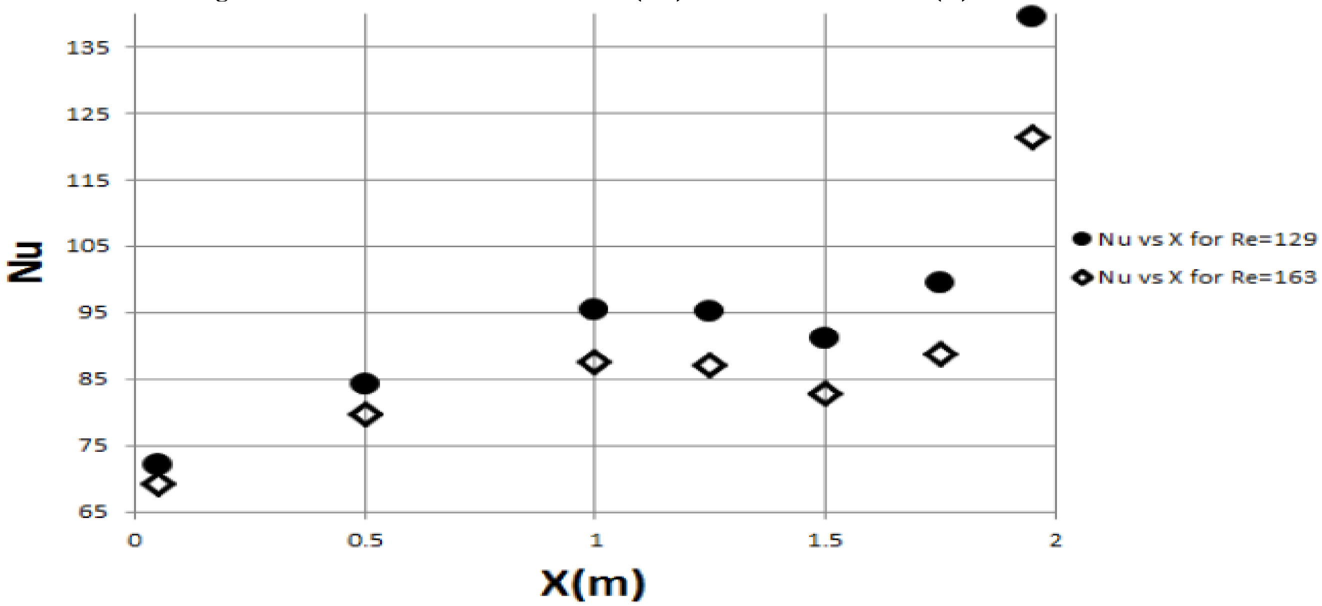

Fig. 14. Variation of Nusselt's number (Nu) in the axial direction (X) for Pr = 582

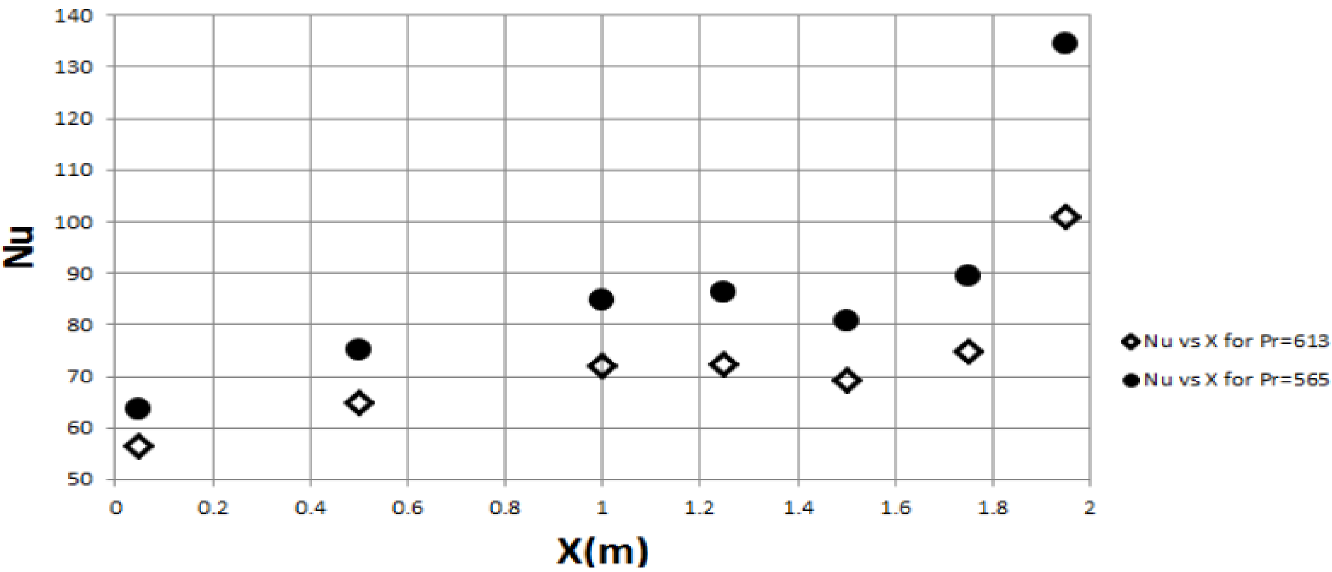

Fig. 15. Variation of Nusselt's number (Nu) in the axial direction (X) for Re = 120

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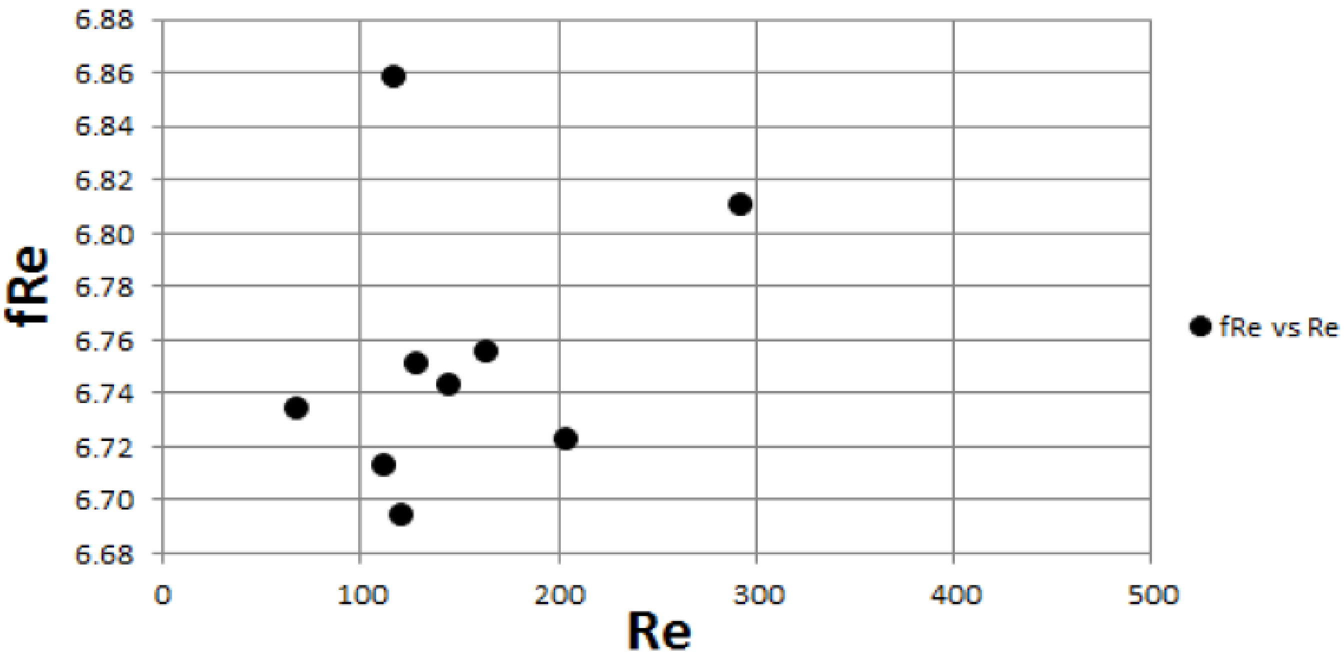

Fig. 16. Variation of scaled friction factor (fRe) with Reynolds number (Re)

IV. CONCLUSION

The major finding of the present work is that, the combined effect of wire coil and wavy strip with central clearance has augmented heat transfer significantly than a clean pipe. Theoretically for constant wall flux condition Nusselt number has the value of 4.36 for a clean pipe. But, using the insertions it has been increased heavily. In the present experiment, Re ranged from 68 to 500 and Pr was varying from 565 to 613, which were not very high. However the measurement were taken within this limited range and because of this the variation of Nu with respect to Re and Pr is not very prominent. Here it can be mentioned that the behavior of the parameters remain to be same irrespective of the Reynolds and Prandtl number range that has been covered in the experiment.

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Dipan Deb, currently am a 2nd year M.Tech student of Aerospace Engineering at Indian Institute of Technology Kanpur. My specialization in Aerospace Engineering is Aerodynamics. My research interest is in experimental aerodynamics and simulation of low Reynolds number flow. Currently I am working on aerodynamic characterization of flow in free oscillation of two rigid plates. I am using different flow visualization techniques, hot wire anemometry, Particle Image Velocimetry to carry out my research. I did my B.E. in Mechanical Engineering in the year of 2015 from Indian Institute of Engineering Science and Technology Shibpur. Till now, I have one research paper published in an international journal.

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