LAMINAR FLOW THROUGH A CIRCULAR TUBE HAVING TRANSVERSE RIBS AND TWISTED TAPES

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ABSTRACT

The experimental friction factor and Nusselt number data for laminar flow of viscous oil through a circular duct having integral transverse rib roughness and fitted with twisted tapes with oblique teeth are presented. Predictive friction factor and Nusselt number correlations have been developed. The thermohydraulic performance has been evaluated. The major findings of this experimental investigation are that the twisted tapes with oblique teeth in combination with integral transverse rib roughness perform significantly better than the individual enhancement technique acting alone for laminar flow through a circular duct up to a certain value of fin parameter.

Keywords: Heat Transfer Enhancement, Integral Transverse Rib Roughness, Laminar Forced Convection, Swirl Flow, Twisted Tapes with Oblique Teeth.

I. INTRODUCTION

Laminar flow situations are often encountered in food, oil and process industries. Improving heat transfer under such flow condition is quite challenging because there is major thermal resistance in the bulk flow in addition to the dominant thermal resistance in the thin boundary layer adjacent to the flow. Integral rib-roughness [1-2] has been used for the enhancement of tube-side heat transfer coefficient in low-flow automotive radiators and needless to say that twisted tape inserts [3] have gained popularity as heat transfer enhancer. Compounding of enhancement techniques [4] is an emerging trend to augment heat transfer. It has been observed from the literature review that the combined effect of integral transverse rib roughness and twisted-tape with oblique teeth has not been studied in the past. The spiral fluid flow due to integral transverse rib roughness coupled with twisted-tape with oblique teeth-generated swirl flow is likely to give larger swirl intensity and vortex in the flow; the present study deals with this.

II. EXPERIMENTAL SET-UP, OPERATING PROCEDURE AND DATA REDUCTION

The Schematic Diagram of the Experimental Rig is shown in Fig. 1. The heat transfer and pressure drop measurements were taken in a 19 mm ID (D), 20 mm OD and 2m long circular brass duct. Porcelain-beaded Nicrome heater wire was wrapped uniformly along the test section to ensure uniform wall heat flux boundary condition. Asbestos rope and glass wool insulated the heat transfer test section after the heater wire. Finally the test section was covered with jute bag for further thermal insulation. Transverse rib roughness was incorporated inside the tube by the method described in [2]. Twisted-tape inserts were placed at the centre of the duct crosssection by SS lugs. Servotherm oil (medium type), supplied by Indian Oil Corporation was used as the working fluid. Instrumentations included rotameters, U- tube mercury manometer for measuring mass flow rate and the pressure drop across the test section, respectively. Copper-constantan thermocouples and digital multimeter were used to measure test section outer wall temperatures at seven axial locations. Tube inside wall temperature was found by calculating temperature drop across tube wall thickness using one-dimensional radial heat conduction equation. Thermocouples embedded at calming section and mixing chamber enabled measurement of oil bulk-mean temperatures at inlet and outlet of the test section. Oil temperature at other locations was found using linear interpolation because of the fact that the fluid bulk-mean temperature in the fully developed section increases linearly for the uniform wall heat flux boundary condition. Peripherally local temperatures in an axial station were arithmetically averaged to get axially local temperature and Nusselt number. Then axially local Nusselt numbers were averaged by trapezoidal rule. Experimental uncertainty was determined by the method of Kline and McClintock [5] and the uncertainty in Reynolds number, friction factor and Nusselt number were found $\pm$ 4.24 percent, $\pm$ 6.89 percent and $\pm$ 8.22 percent, respectively.

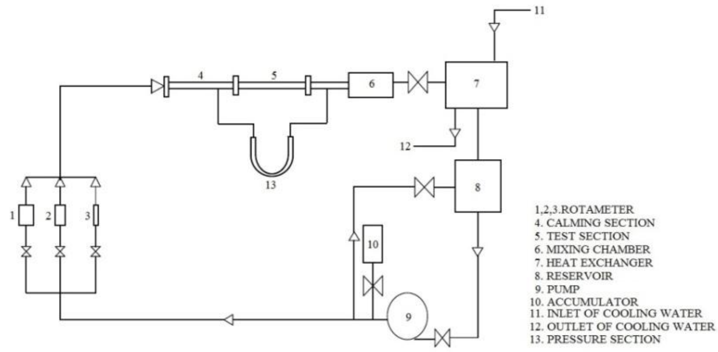

Figure 1: Schematic Diagram of the Experimental Rig

III. RESULTS AND DISCUSSION

Data have been generated for the following geometrical parameters of transverse rib and twisted tape:

Twist ratio: y = 2.5, 5.0; Tooth horizontal length: t_{hl} = 0.01052, 0.01578, 0.02105, 0.03157, 0.04210

Tooth angle: $\Theta = 30^o, 45^o, 60^o$

Rib height e: (e/D) = 0.0526, 0.07894, 0.10526

Rib pitch P: (P/e) = 20, 13.33, 10

Effect of geometrical parameters of transverse rib and twisted tape on frictional losses and heat transfer are depicted in Fig. 2-7. It is observed that both friction factor and Nusselt number decrease (Fig. 2 and Fig. 5, respectively) with decrease in the value of t_{hl}, Θ, increase in rib pitch and decrease in rib height initially; however, after that, with further changes of the values of parameters, no appreciable changes in friction factor occur; however, Nusselt number further decreases to some extent. Further, friction factor increases 54-92 percent with combined use of integral transverse rib roughness and twisted-tape with oblique teeth as compared to the separate cases of integral transverse rib roughness and twisted-tape with oblique teeth. Approximately 158 percent increase in Nusselt number is observed.

These results are explained by the fact that both pressure drop associated with momentum loss and heat transfer depend on the extent to which the hydrodynamic and thermal boundary layers are disturbed, flow recirculation and separation, chaotic mixing, extent of flow stratification in the horizontal test section, relative positions of insert devices, Reynolds number, Prandtl number, Graetz number and Grashoff number.

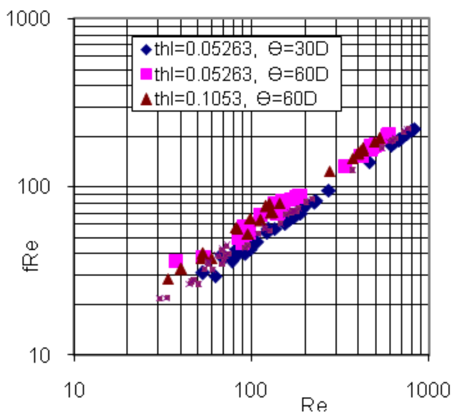

Figure 2: Effect of tooth horizontal length and the tooth angle of the twisted-tape oblique teeth; y = 2.5, P/e = 2.0437, e/D_h = 0.07692

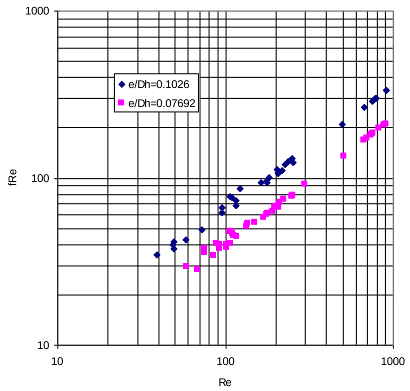

Figure 3: Effect of rib pitch, y = 2.5, t_{hl} = 0.05263, Θ = 30^o , e/D_h = 0.07692

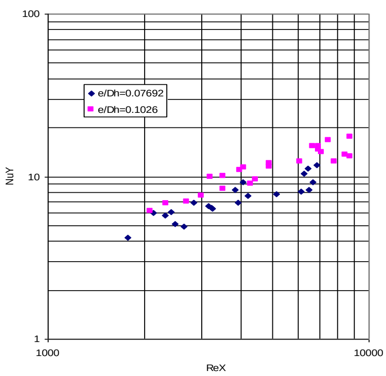

Figure 6: Effect of rib height, y = 2.5, t_{hl} = 0.1053, Θ = 60^o, P/e = 5.6481

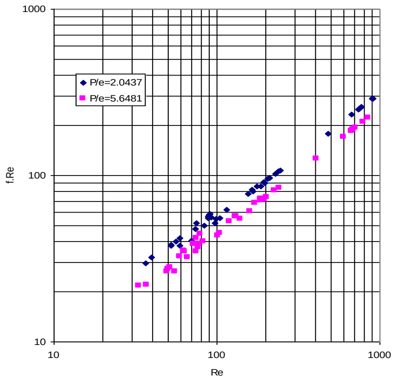

Figure 4: Effect of rib height, y = 2.5, t_{hl} = 0.1053, Θ = 60^o, P/e = 5.6481

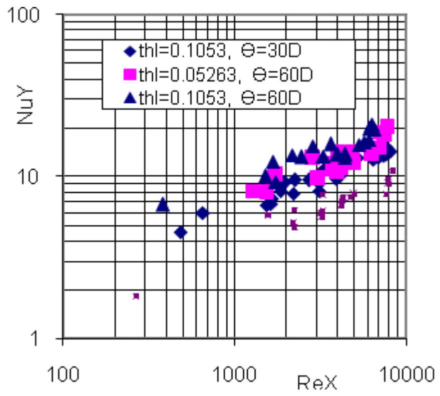

Figure 5: Effect of tooth horizontal length and the tooth angle of the twisted-tape oblique teeth; y = 2.5, P/e = 2.0437, e/D_h = 0.07692

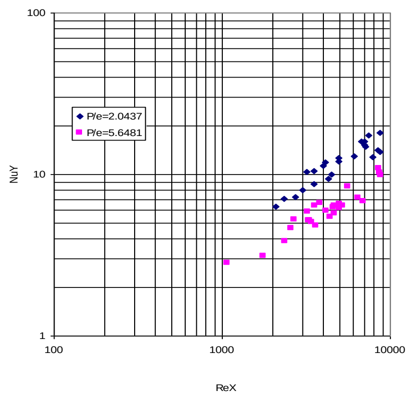

Figure 7: Effect of rib pitch, y = 2.5, t_{hl} = 0.05263, Θ = 30^o , e/D_h = 0.076

IV. CORRELATIONS AND PERFORMANCE EVALUATION

Correlations have been developed by log-linear regression analysis for friction factor and Nusselt number to predict pressure drop and heat transfer coefficient. The correlations predicted the experimental data within $\pm$ 9.71%. For correlations, please see reference [6]. Performance of this fin geometry has been evaluated [6]. This fin geometry with combined techniques performs better than the individual techniques acting alone.

V. CONCLUSIONS

The major findings of this experimental investigation are that the twisted-tape with oblique teeth inserts in combination with integral transverse rib roughness performs significantly better than the individual enhancement technique acting alone for laminar flow through a circular duct up to a certain value of fin parameters.

VI. ACKNOWLEDGEMENTS

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REFERENCES

[1] S. K. Saha, S. Bhattacharyya and P.K. Pal, Thermohydraulics of laminar flow of viscous oil through a circular tube having integral axial rib roughness and fitted with centre-cleared twisted-tape, Exp. Thermal Fluid Science, 41, 121-129 , 2012.

[2] S. K. Saha, P. P. Polley and G. L. Dayanidhi, Laminar flow heat transfer enhancement using transverse ribs and helical screw-tape inserts, AIAA J, Thermophysics and Heat Transfer, 26(3), July-Sept, 464-471, 2012.

[3] S. K. Saha, U. N. Gaitonde and Date, A. W., Heat transfer and pressure drop characteristics of laminar flow in a circular tube fitted with regularly spaced twisted-tape elements, Exp. Thermal Fluid Science, 2, 310-322, 1989.

[4] S. K. Saha, S. Bhattacharyya and G. L. Dayanidhi., Enhancement of heat transfer of laminar flow of viscous oil through a circular tube having integral axial rib roughness and fitted with helical screw-tape inserts, Heat Transfer Research, 43(2), pp. 1-2, 2012.

[5] S. J. Kline and F. A. McClintock, Describing Uncertainties in Single Sample Experiments, Mechanical Engineering, 75 (1), pp 3-8, 1953.

[6] M. Tiwari and S. K. Saha, Laminar Flow Thermal and Friction Characteristics in a Circular Tube with Transverse Ribs and Twisted Tapes, Internal Report, Heat Transfer, Thermodynamics and Thermal Power Laboratory, IIEST Shibpur, Howrah, India, 2015.