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OPTIMIZING HEAT TRANSFER EFFICIENCY: EXPERIMENTAL ANALYSIS OF WIRE-COIL INSERTS IN RECTANGULAR TUBES UNDER NON-UNIFORM HEAT FLUX CONDITIONS

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1. ABSTRACT

This experimental study analyzes heat transfer and friction factor in a rectangular duct utilizing coiled wire inserts. The experimental setup involved water as the working fluid, with Reynolds numbers spanning from 500 to 10000, covering laminar, transition, and turbulent flow regimes. A comparative study was conducted between experimental pressure drop data and existing correlations from open literature for an empty duct, demonstrating a notable agreement. Furthermore, the study delves into the impact of employing wire coil inserts on heat transfer enhancement. The results revealed that the utilization of coiled wire inserts led to significative increase in both heat transfer and friction factor within the channel.

2. INTRODUCTION

Efficient thermal management and cooling applications in industrial processes necessitate the optimization of heat transfer. Among various heat transfer enhancement techniques, the utilization of tube inserts, such as coiled wires, ribs, and twisted tapes, has been extensively explored for their ability to promote turbulence, enhance fluid mixing, and augment convective heat transfer [1] in addition to their simplicity in manufacturing, cost-effectiveness, ease of assembly/disassembly, and maintenance [2]. However, there has been limited research conducted to examine the effective convective heat transfer coefficient under non-uniform heat flux or non-uniform wall temperature thermal boundary conditions in ducts, commonly encountered in applications such as solar collectors. Additionally, there is a lack of reported research on rectangular cross-section tubes in open literature. This study delves into the realm of heat transfer enhancement using three wire coil inserts in a rectangular duct under a non-uniform heat flux, aiming to evaluate their effectiveness and potential for industrial applications. By analyzing heat transfer and pressure drop characteristics, this research aims to contribute valuable insights into optimizing heat transfer performance in channels.

3. METHDOLOGY (LENGTH AND LAYOUT)

The experimental setup comprised a closed water loop that supplied water at preselected temperatures (40-50-60 °C) to an electrically heated test section. Temperature stability was ensured using a storage tank controlled by a thermostat and connected to a chiller unit. Water was pumped through the test line at predetermined mass flow rates using a pump. A Coriolis mass flow meter determined water mass flow rates. The main objective of this study was to investigate the effects of non-uniform heat flux boundary conditions. To achieve this, two metal strips, each measuring 1000x6x0.6 mm, were placed in the middle of the upper surface of the duct and powered by a 1-3 kW DC power supply

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to generate heat flux of 16700-25000 W/m^2. Temperature probes and mass flow meters were connected to data acquisition systems using National Instruments LabVIEW software and MATLAB scripts.

The test section consisted of a rectangular tube measuring 25x10x2500 mm. Six different test sections were designed, each equipped with 8 thermocouples to monitor temperature variations across the tube's cross-section. Additionally, three interconnected wire coils were introduced through the duct, with dimensions of 10.6/7.5/0.8mm (pitch/diameter/thickness) each.

4. RESULTS

Pressure drop test

The pressure drop results in the test geometry are presented. The experiments were carried out at room temperature (25°C). The range of flow rates tested has allowed covering a range of 100 < Re < 10000.

To validate the experimental procedure, isothermal flow tests were conducted to determine the friction factor for a smooth tube across Reynolds numbers ranging from 50 to 8000, encompassing laminar, transition, and low turbulent flow regimes. The experimental results were compared against analytical solutions: for laminar and turbulent flow, the theoretical friction factor is given by modified Hagen–Poiseuille and Blasius equations[3]. Figure 1 illustrates the Fanning friction factor for the wire-coil configuration under study, compared to the experimentally obtained friction factor for a smooth tube. A significant increase in pressure drop compared to the smooth tube is observed. The most notable characteristic is the presence of turbulent flow characteristics even at very low Reynolds numbers, with no significant changes in the friction factor trend, resulting in an almost linear evolution on a logarithmic scale with Reynolds number.

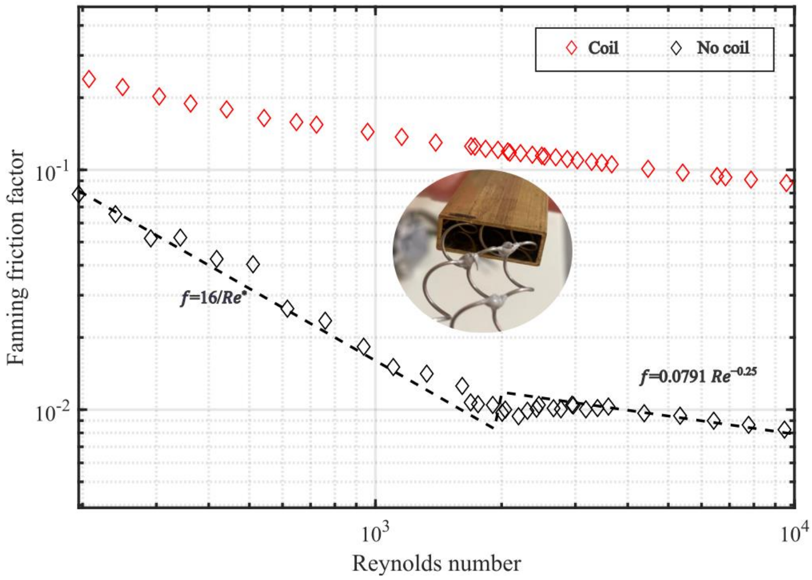

Fig. 1 Fanning friction factor results in tubes with and without wire-coil inserts.

Heat transfer test

Wire coil inserts enhance convective heat transfer by disrupting the thermal boundary layer, generating secondary flow, and increasing turbulence intensity. This leads to higher convective heat transfer compared to a smooth tube, as illustrated in Figure 2. The results were presented for two mass flow rates out of a total of 8 tested, specifically 30 and 556 kg/h, representing the highest and lowest flow rates, respectively. Both the water temperature and the wall temperature along the duct were measured and compared to those of an empty tube. The wall temperature was plotted for position 2, which corresponds to the location where the heat flux is applied.

Results demonstrate that the use of wire coil inserts results in a decrease in wall temperature demonstrating the effectiveness of wire coil inserts in enhancing heat transfer within the studied system. The fluid temperature remains the same for both cases, with or without the coil, as indicated by the superimposed squared symbols in the graph.

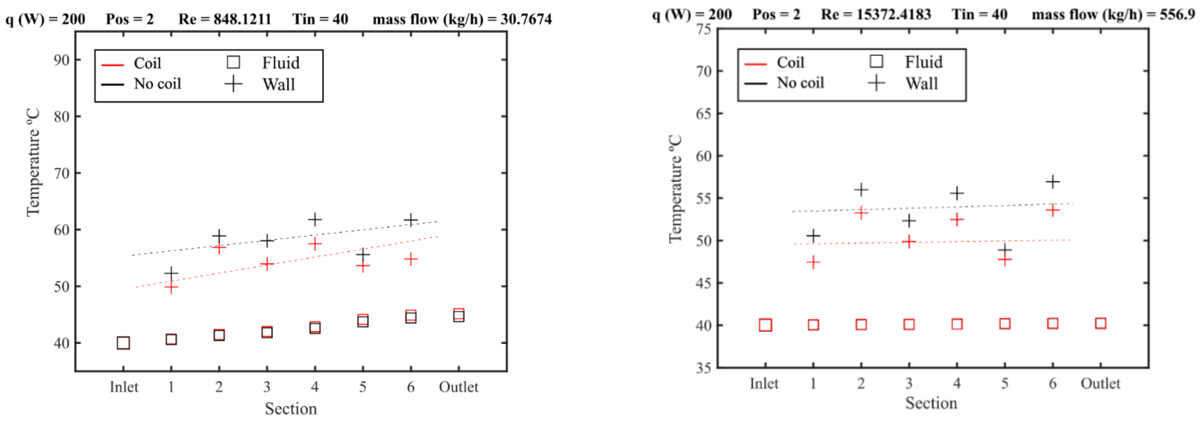

Fig. 2 Temperature Variation at Various Sections of the Duct: With and Without Coil Inserts.

5. CONCLUSIONS

This research has addressed the gap in literature regarding the effective convective heat transfer coefficient under non-uniform heat flux or non-uniform wall temperature thermal boundary conditions in ducts, with a particular emphasis on rectangular cross-section tubes. Through our experimental investigation, we have evaluated the effectiveness of three wire coil inserts in a rectangular duct subjected to non-uniform heat flux for a large range of Reynolds number covering laminar transition and turbulent flow. Our findings suggest that these inserts contribute significantly to heat transfer enhancement, leading to a decrease in wall temperature and improved thermal performance in the system. These results hold promising implications for industrial applications where efficient heat transfer is crucial.

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REFERENCES

[1] L. Shijie, Q. Zuoqin, and W. Qiang, “Optimization of thermohydraulic performance of tube heat exchanger with L twisted tape,” *International Communications in Heat and Mass Transfer*, vol. 145, Jun. 2023, doi: 10.1016/j.icheatmasstransfer.2023.106842.

[2] A. H. Altun, S. Ors, and S. Dogan, “Investigation of effects on turbulent heat transfer of twisted wavy tape elements in the tube,” *International Journal of Thermal Sciences*, vol. 185, Mar. 2023, doi: 10.1016/j.ijthermalsci.2022.108068.

[3] S. Osman, M. Sharifpur, and J. P. Meyer, “Experimental investigation of convection heat transfer in the transition flow regime of aluminium oxide-water nanofluids in a rectangular channel,” *Int J Heat Mass Transf*, vol. 133, pp. 895–902, Apr. 2019, doi: 10.1016/j.ijheatmasstransfer.2018.12.169.