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Double-Sided Semi-Circular-Wing Tape Inserts to Enhance Thermal Performance of a Double-Pipe Heat Exchanger

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Abstract: **In this study, the effects of the wing-width ratio (0.31, 0.47, and 0.63) on the heat transfer and fluid flow characteristics of the heat exchanger and the results were compared with those obtained for a plain tube and tube with longitudinal strip (L-S) insert. The comparison was also done among the thermal performance of plain tube, tube with longitudinal strip (L-S) insert, T-W tape semi-circular insert. At last the results of the Nusselt numbers and friction factors with those predicted by standard correlations for a plain tube were validated. The results reveal that the wing-width ratio of the T-Ws significantly affects the flow characteristics and the effect of the wing-width ratio on the friction factor is dependent on the Reynolds number. It was found that lowest thermal performance factor is obtained for the tube with L-S insert.**

Keywords: **wing-width ratio, heat exchanger, thermal performance, Nusselt numbers, friction factor.**

1. INTRODUCTION

Heat transfer is a discipline of thermal engineering that concerns the generation, use, conversion, and exchange of thermal energy and heat between physical systems. Heat transfer is classified into various mechanisms, such as thermal conduction, thermal convection, thermal radiation, and transfer of energy by phase changes. Engineers also consider the transfer of mass of differing chemical species, either cold or hot, to achieve heat transfer. While these mechanisms have distinct characteristics, they often occur simultaneously in the same system. To improve the performance of heat exchanging devices for reducing material cost and surface area and decreasing the difference for heat transfer thereby for reducing external irreversibility, lot of techniques have been used.

Enhancing the thermal performance of heat exchange affects directly on energy, material and cost savings. Consequently, improving the heat exchange can significantly improve the thermal efficiency in applications involving heat transfer processes as well as the economics of their design and operation [1]. DPHEs are primarily adapted to high temperature and high-pressure applications due to their small diameters. They are low cost, but the space they occupy is relatively high compared to the other types. To achieve the desired heat transfer rate in the given design and length of the heat exchanger at an economic pumping power, numerous techniques have been used. These improvement techniques are classified as active and passive techniques [2, 3]. The thermal performance of heat exchangers can be increased by heat transfer enhancement methods. Tape insert is one of the passive heat transfer enhancement method and used in most heat transfer application, for example, air conditioning and refrigeration systems food processes.

A majority of heat exchangers used in thermal power plants, chemical processing plants, air conditioning equipment, and refrigerators, petrochemical, biomedical and food processing plants serve to heat and cool different types of fluids. Both the mass and overall dimensions of heat exchangers employed are continuously increasing with the unit power and the volume of production. This involves huge investments annually for both operation and capital costs. Hence it is an urgent problem to reduce the overall dimension characteristics of heat exchangers.

2. LITERATURE REVIEW

One of the earliest researches done on DPHEs was the one by Mozley (1956) who both numerically and experimentally made a case for the study and prediction of dynamic characteristics of a special DPHE using two automatic control methods. These methods were based on simple mathematical models and also passive electrical network analogs. He also compared the frequency responses which were based on basic analog results and concluded that the numerical results were in a good agreement with experimental results.

In the same year, Cohen and Johnson (1956) also studied dynamic characteristics of DPHEs. This numerical and experimental work shaped some thinking for years to come. In this study, equations of dynamic characteristics were obtained for a simple system and it was reported that the characteristics of DPHE's components could be easily determined by frequency responses of the data. They also observed that these data were so close to experimental results.

Agung Tri Wijayanta et al (2018) double-sided delta-wing (T-W) tape inserts were designed to enhance convective heat transfer of a double-pipe heat exchanger. The effects of the wing-width ratio (0.31, 0.47, and 0.63) on the heat transfer and fluid flow characteristics of the heat exchanger were investigated by experiments where water was used as the working fluid and the Reynolds number was varied from 5,300–14,500.

Lachi et al. (2018) studied time constant of a DPHE and a shell and tube heat exchanger. The particular purpose of this investigation was to classify the characteristics of these heat exchangers in a transient condition, especially the time when abrupt changes in inlet velocities are considered.

Aicher and Kim (2018) investigated the effect of counter flow in nozzle section of a DPHE which were mounted on the wall of the shell side. It turned out that the counter flow in nozzle section had a significant effect on heat transfer and pressure drop. It was also concluded that the very effect would be more conspicuous, if the heat exchanger were small and also the ratio of free cross section areas were low enough. They also presented experimental correlations to predict heat transfer rate in turbulent flow.

Ma et al. (2018) experimentally investigated the effects of supercritical carbon dioxide (SCO_2) in a DPHE in which the effects of pressure, mass flux and buoyancy force of the SCO_2-side were broadly studied. On one hand, it was observed that pressure increase of the gas-side conspicuously caused both the overall and the gas-side heat transfer rates to be decreased.

Raghavan (2018) investigated a double pipe helical heat exchanger for both parallel and counter flow configurations. The corresponding heat transfer rates of inner tube and the annulus were calculated using Wilson plots. It is well worth noting that the performance evaluation criterion of both configurations was identical, while surely the heat transfer regarding to the counter flow configuration was higher than its counterpart which was due to a higher temperature difference.

Dizaji et al. (2018) did an experimental study of heat transfer and pressure drop of corrugated tubes in a DPHE which turned out to perceive much importance in the field (Fig. 2.1). Both inner and outer tubes were corrugated in concave and convex shapes. Working fluids in the experiments were hot and cold water which flowed in the inner and outer tube of the heat exchanger, respectively

Bhadouriya et al. (2018) investigated heat transfer and pressure drop of a DPHE both experimentally and numerically in which the major objective was the effect of twist ratio of the inner tube on the flow characteristics. The results of the present paper will help the engineers design more compact heat exchangers. It was also concluded that, unlike smooth tube, Nusselt number in the laminar flow regime was dependent on the flow characteristics and physical parameters such as Reynolds number and twist ratio.

Tang et al. (2018) investigated the effects of twisted inner tube of a DPHE which was carried out experimentally and numerically. In the experimental process, the inner tube had three different cross section shapes which were circular, oval and tri-lobed; while the outer tube was a simple cylindrical tube. Upon having a higher performance evaluation criterion, an intense concentration was shown to the above-mentioned tri-lobed cross section along with the simple outer tube. Moreover, a broad range of studies were carried out in numerical process of the study, especially in different cross-section shapes.

Dewangan (2018) made helical ribs on the tube surface by machining the surface on the lathe So that artificial roughness can be created The artificial roughness that results in an undesirable increase in the pressure drop due to the increased friction; thus the design of the tubes surface of heat exchanger should be executed with the objectives of high heat transfer rates.

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Reddy N. S (2017) investigated the heat transfer analysis in the horizontal double pipes with helical fins in the annulus side. The material is copper with inner tube internal diameter 10 mm, inner tube thickness 1 mm, outer tube external diameter 40 mm, outer tube thickness 1.5 mm, helical pitch of 50 mm, 75 mm and 100 mm, heat exchanger length 1100 mm. The experimental results of plain tube are validated with numerical results. The results obtained for helical fins in the annulus side provide enhanced heat transfer performance compared to the simple double-pipe exchangers.

Bilawane (2017) presented a review of one of the passive augmentation techniques used in a concentric tube heat exchanger using inner wavy tube. The performance of counter flow heat exchanger will be studied with inner plain tube and inner wavy tube. Then this enhanced performance due to inner wavy tube will be compared with performance of heat exchanger with inner plain tube and percentage of enhancement will be calculated in different hot fluid temperature input and different mass flow rates of hot as well as cold water. Experimentally, Overall heat transfer enhancement will be studied and also, the experimental results will be validated with CFD simulation.

Yogeshwari (2017) discussed analytical solution of the compartment based double pipe heat exchanger model obtained using Differential Transform Method for parallel flow with theoretical varying initial and boundary condition. The working fluid is transformer oil i.e. hot fluid and water act as coolant. Convergence analysis of solution is also discussed.

3. METHODOLOGY

In this study, double-sided delta-wing (T-W) tape inserts were designed to enhance convective heat transfer of a double-pipe heat exchanger. The effects of the wing-width ratio (0.31, 0.47, and 0.63) on the heat transfer and fluid flow characteristics of the heat exchanger were investigated by experiments where water was used as the working fluid and the Reynolds number was varied from 5,300–14,500.

To investigate the heat transfer and fluid flow characteristics of the system, hot water was used as the working fluid whereas cold water was used as the coolant. The mass flow rate of the hot water was varied from 0.033 to 0.082 kg/s, which results in different flow velocities. The Reynolds number was varied from 5,500 to 14,500 and the values were determined based on the flow velocity, fluid properties at the bulk mean temperature, and inner diameter of the inner tube in the test section.

Five test cases were investigated in this study: (1) plain tube, (2) tube with L-S insert, (3) tube with T-W tape insert (w/W: 0.31), (4) tube with T-W tape insert (w/W: 0.47), and (5) tube with T-W tape insert (w/W: 0.63). A plain tube was used in the first test case, where there were no inserts installed in the inner tube of the test section. This test case was used as the baseline case in order to validate the test results.

4. RESULTS AND DISCUSSION

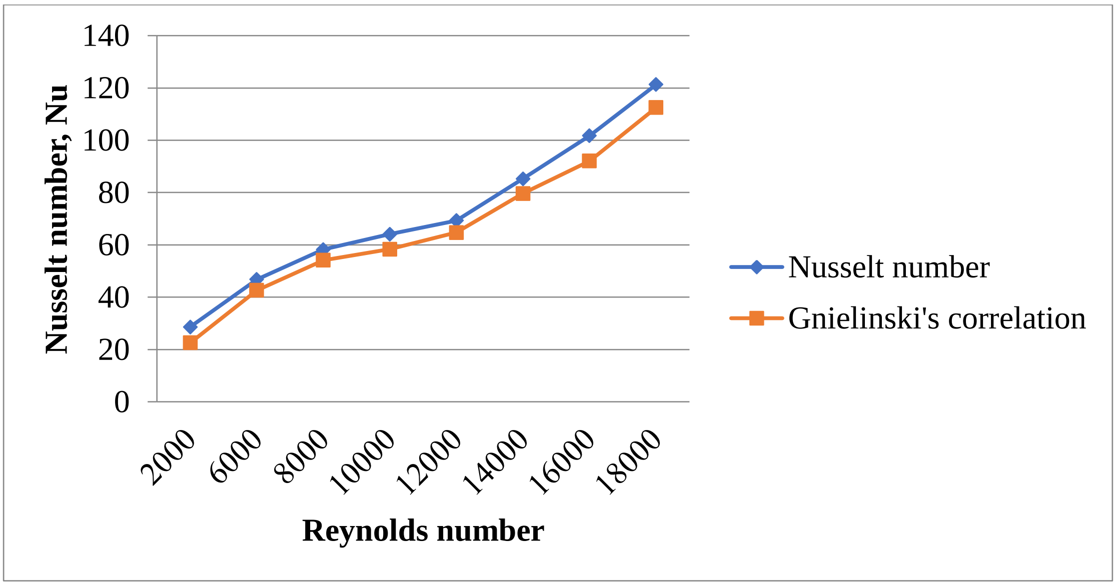

Fig. 4.1: Comparison between the Nusselt numbers determined from simulation and those predicted using Gnielinski's correlation for a plain tube

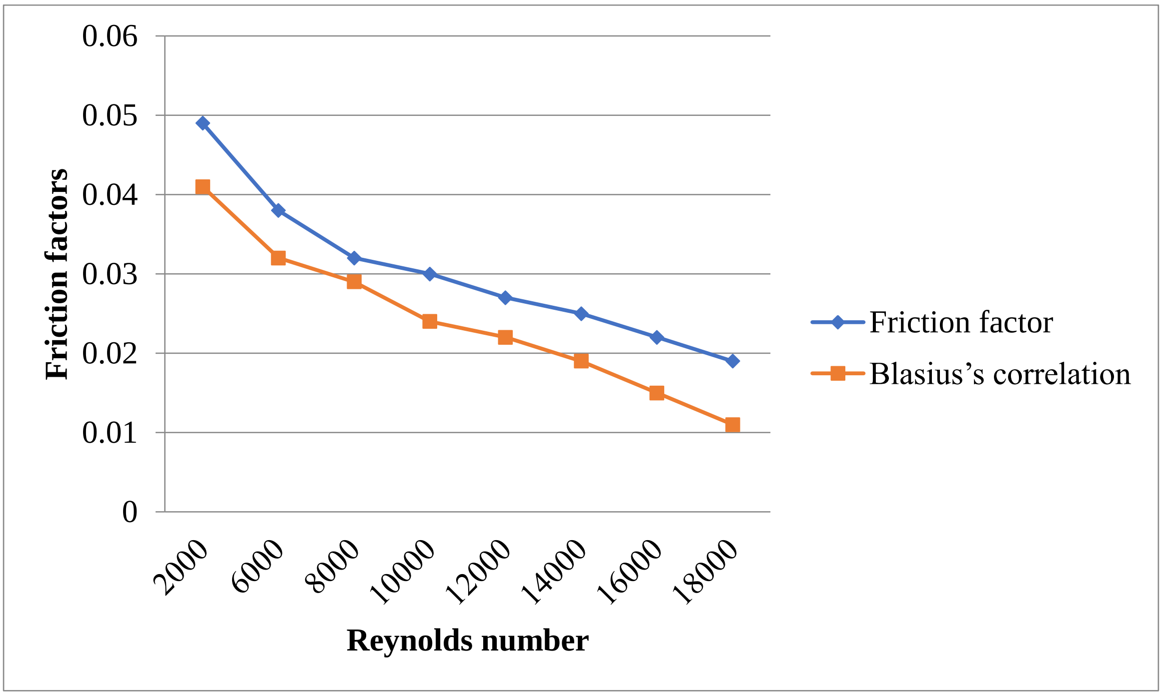

Fig. 4.2: Comparison between the friction factors determined from simulation and those predicted using Blasius's correlation for a plain tube

In order to examine the heat transfer enhancement of the horizontal heated circular tube provided by the L-S insert and T-W tape inserts, the Nusselt numbers of the tube with L-S and T-W inserts (w/W: 0.31, 0.47, and 0.63) were compared with those for the plain tube, as shown in Fig. 4.3.

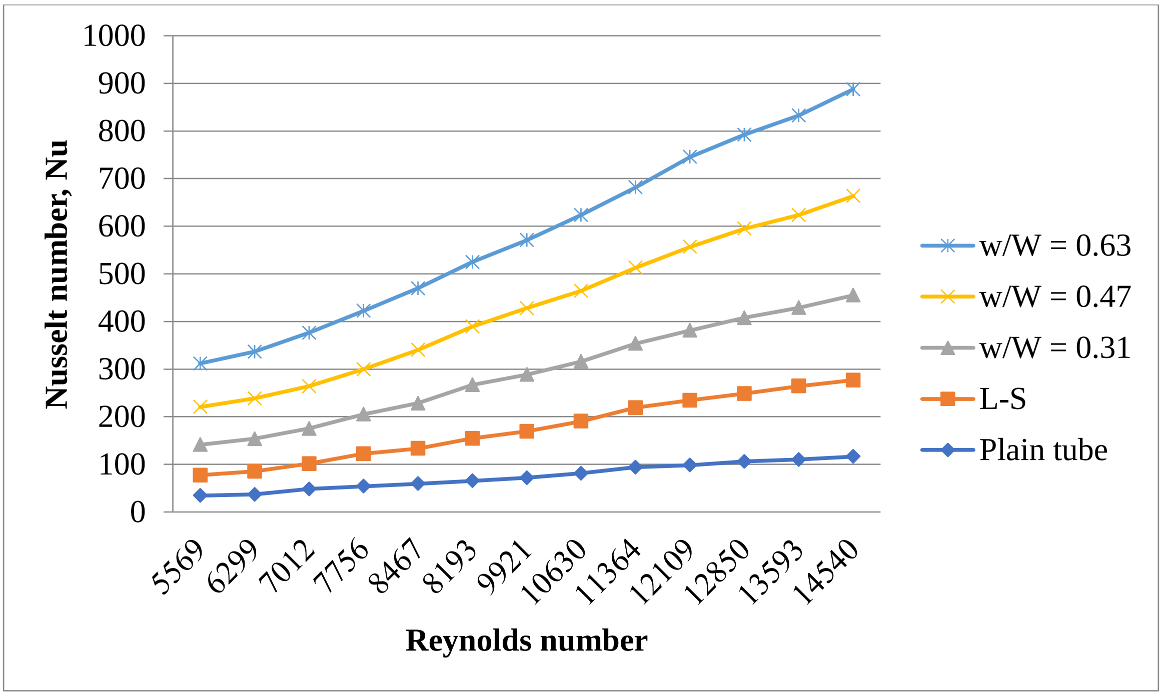

Fig. 4.3: Nusselt number comparison of plain tube, L-S insert and T-W tape inserts (w/W: 0.31, 0.47, and 0.63)

The friction factor was used to evaluate the fluid flow characteristics in this study. Fig. 4.4 shows the variations of the friction factor with the Reynolds number for the plain tube and tube with L-S insert and T-W tape inserts.

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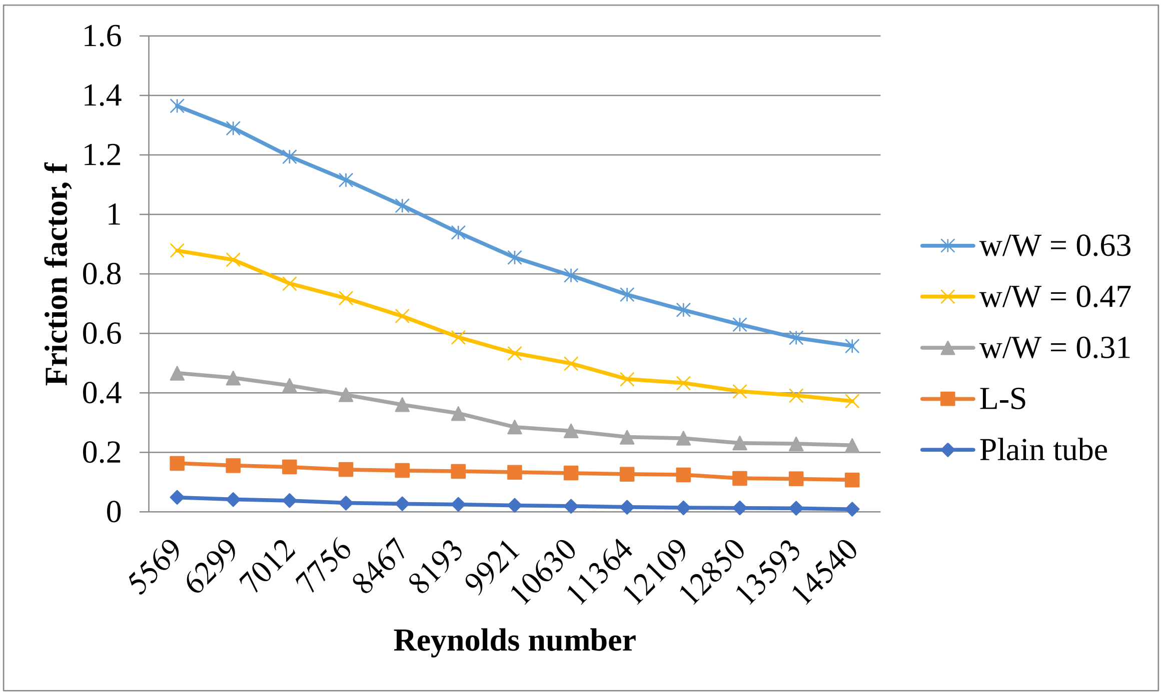

Fig. 4.4: Friction factor comparison of plain tube, L-S insert and T-W tape inserts (w/W: 0.31, 0.47, and 0.63)

It can be observed that the friction factor decreases with an increase in the Reynolds number. The friction factors are higher for the tube with the L-S insert and T-W tape inserts compared with those for the plain tube, which is likely due to the increase in the contact surface area and reduced free flow, which increases the flow velocity. It is apparent that the friction factors are significantly higher for the tube with T-W inserts (w/W: 0.31, 0.47, and 0.63) compared with those for the plain tube and tube with L-S insert. This is likely because the flow passage in the tube is blocked by the T-Ws and therefore, the stream wise velocity profiles are different from those in the plain tube.

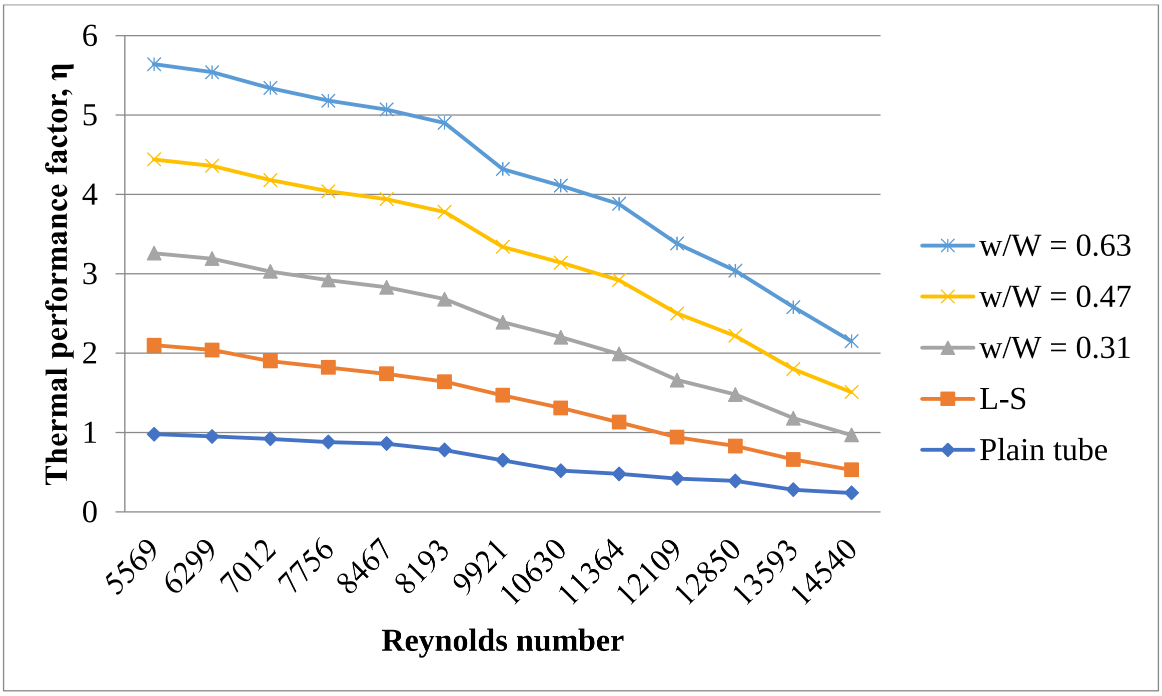

Fig. 4.5: Variations of the thermal performance factor with the Reynolds number for the tube with L-S insert and tube with T-W tape insert at different wing-width ratios

Fig. 4.5 shows the variations of the thermal performance factor with the Reynolds number for the tube with L-S insert and T-W tape inserts (w/W: 0.31, 0.47, and 0.63). It can be observed that the thermal performance factor decreases as the Reynolds number increases, which is likely because the thermal boundary layer thickness increases with an increase in the Reynolds number.

It can be seen that the thermal performance factor is more than 1.0 up to Re = 8,000 for the tube with T-W tape inserts and the thermal performance factor decreases to a value less than 1.0 beyond this point. The thermal performance factor is less than 1.0 for the tube with L-S insert, regardless of the Reynolds number.

The highest thermal performance factor is obtained for T-Ws with a wing-width ratio of 0.63, followed by T-Ws with a wing-width ratio of 0.47 and 0.31.

The lowest thermal performance factor is obtained for the tube with L-S insert. The average thermal performance factors are found to be 0.86, 0.93, 1.03, and 1.15 for the tube with L-S insert and T-W tape inserts (w/W: 0.31, 0.47, and 0.63), respectively.

5. CONCLUSION

In this study, the heat transfer and fluid flow characteristics of single-phase turbulent flow in a double-pipe heat exchanger installed with T-W tape inserts (w/W: 0.31, 0.47, and 0.63) were investigated.

1. The percentage difference between the Nusselt numbers determined from simulation and those predicted by Gnielinski's correlation is relatively small, with a value of ±21.1% to ±7.1%. The percentage difference between the friction factors determined from experiments and those predicted by Blasius's correlation is very small, with a value of ±16.32% to ±42.1%.

2. In general, the relative errors are small, indicating that there is good agreement between the simulation and those predicted by the standard correlations for the plain tube. The results prove the reliability of the simulation for heat transfer.

3. Based on the experimental results, the T-W tape inserts significantly enhance the average convective heat transfer coefficient and the convective heat transfer increases with an increase in the wing-width ratio of the T-Ws.

4. The T-W tape insert with the highest wing-width ratio (w/W: 0.63) results in the highest convective heat transfer enhancement.

5. The results reveal that the wing-width ratio of the T-Ws significantly affects the flow characteristics and the effect of the wing-width ratio on the friction factor is dependent on the Reynolds number.

6. Nusselt numbers are significantly higher for the tube with T-W tape inserts compared with those for the tube with L-S insert. The T-Ws generate longitudinal vortices behind them and the fluid from the underside of the wake swirls to the upper side.

7. It is also evident that the Nusselt number increases with an increase in the wing-width ratio of the T-Ws, which is likely because a higher wing-width ratio promotes flow recirculation and separation, which enhances turbulence intensity of the flow.

8. In general, the convective heat transfer enhancement is superior for the tube installed with T-W tape inserts relative to that for the plain tube.

9. It can be observed that the friction factor decreases with an increase in the Reynolds number. The friction factors are higher for the tube with the L-S insert and T-W tape inserts compared with those for the plain tube, which is likely due to the increase in the contact surface area and reduced free flow, which increases the flow velocity. It is apparent that the friction factors are significantly higher for the tube with T-W inserts (w/W: 0.31, 0.47, and 0.63) compared with those for the plain tube and tube with L-S insert.

10. It can be observed that the thermal performance factor decreases as the Reynolds number increases, The highest thermal performance factor is obtained for T-Ws with a wing-width ratio of 0.63, followed by T-Ws with a wing-width ratio of 0.47 and 0.31.

11. The lowest thermal performance factor is obtained for the tube with L-S insert. The average thermal performance factors are found to be 0.86, 0.93, 1.03, and 1.15 for the tube with L-S insert and T-W tape inserts (w/W: 0.31, 0.47, and 0.63), respectively.

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