Thermal Analysis on Hydrothermal Performance of Double Pipe Heat Exchanger with Single and Double Helical Tape

Abhinay Gangwar, Anoop Pathariya, Hitesh Kumar

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Abstract: ***Double pipe heat exchanger has wide applications in industrial process. Thermo-hydro performance plays an important role from the economic point of view. Different enhancement techniques are available for the improvement of heat transfer. In this study the hydrothermal performance of double pipe heat exchanger with single and double HTI on inner pipe of double pipe heat exchanger were experimentally examined. Two types of inner tubes with single and double helical tape was fabricated. Experiments were performed by different mass flow rate of annulus side in the range of 0.072-0.21 kg/s varied. In order to validate the result three dimensional CFD simulations are performed, using Fluent software. CFD simulations analysis was done under turbulent flow conditions. Key design parameters such as heat transfer coefficient and Nusselt number are evaluated in order to predict the performance of DPHE. Findings from this study shows that hydrothermal performance of double pipe heat exchanger with double helical tape is better than single HTI. Moreover both the results of CFD simulation & experimental one are in good agreement. Therefore, the present study will help the manufacturers in providing the better thermal performance of DPHE.***

Keywords: Thermal performance, Double pipe heat exchanger (DPHE), Helical tape insert (HTI), Nusselt number (Nu), heat transfer, CFD Fluent

I. INTRODUCTION

Double pipe heat exchanger are commonly used in many industries application [1]. Hence improvement of hydrothermal performance of DPHE is the main concern. Moreover there are various techniques available for the enhancement in heat transfer rate and thermal performance of double pipe heat exchanger. Among the various techniques inserting of helical tape is popular one [2]. In past decades many attempts have been made towards the enhancement of heat transfer DPHE with numerous type of inserts [3]. In the literature, Salem et al. [4] studied experimentally the hydrothermal performance of double pipe heat exchanger with and without single helical tape insert. The result shows that inserting a helical tape significantly improve the heat transfer rate as compare to double pipe heat exchanger without helical tape. Zhang et al. [4] had done similar study towards the performance of double pipe heat exchanger. Result indicates that by varying pitch of helical tape significantly improved the heat transfer performance. Kumar et al.

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[5] reported that by using parabolic fins among rectangular and triangular fins influence pressure drop by 38% and 68%. However, Iqbal et al.
[6] argued that no single fin shape was best in all situation among the parabolic, trapezoidal and triangular fins. In the another study of Al-Kayiem [7] and Al-Habeeb [8] they studied the effect of ribs and its height on inner tube of double pipe heat exchanger. Results shows that with the provision of ribs heat transfer rate increase significantly. Maakoul et. al. [9] simulated DPHE with helical baffle. Result indicate that the thermal performance of DPHE with helical baffle was found significantly higher than DPHE with plain baffle. Omidi et al. [10] recently presented a review on different techniques for heat transfer enhancement in DPHE. In another study of Zhang et al. [11] helical fins with different spacing was considered in DPHE. Promvonge [12] found that optimum fin spacing ratio was 0.5 is sufficient for optimal heat transfer. Guo [13] explored the thermal performance of DPHE with twisted tape. Results indicate that Nusselt number improves significantly as compared to DPHE without twisted tape.

Since DPHE is used in many industrial applications including chemical processing plants, food processing plants etc. Further with increase in production causes a huge investment with change in dimension of heat exchanger. Therefore there is a need to cope up the investment without compromising heat transfer. Hence inserting such helical tape would definitely increase the heat transfer enhancement.

From the past studies various authors use different type of inserts for heat transfer enhancement. Moreover no such studies was found to investigate the thermal performance of DPHE with double helical tape.

II. EXPERIMENTAL APPARATUS

The experimental study has been carried out on a DPHE having the tube side outer diameter (12 mm) and annulus side outer diameter (76 mm) and heat transfer length is 800 mm. The test section of DPHE is in horizontal section where hot water is allowed to flow in inner tube of DPHE while cold water is allowed to flow in annulus side. Fig. 1 shows a schematic diagram of setup, while Fig. 2(a) & (b) shows a single and double helical tape. For measuring the flow rate of hot and cold water, flowmeter is used. Four thermocouples was installed to measure temperatures at different section for measuring temperatures of hot and cold water. The installed thermocouples were directly attached to a digital thermometer indicator having resolution ± 0.1° C to display the temperature of cold and hot water. All four thermocouples were calibrated in a laboratory.

Fig. 1: Experimental setup of DPHE

(a) Single helical tape insert

(b) Double helical tape insert

Fig. 2: Schematic diagram of the Tape used

III. EXPERIMENTAL PROCEDURE

Total, a series of five experimental runs were accomplished on the DPHE with single and double helical tape with varying mass flow rate of cold water in annulus side. After each experimental run cold and hot water temperature was measured. Readings is measured once the steady-state condition was achieved. The operating range of parameters is given in table 1.

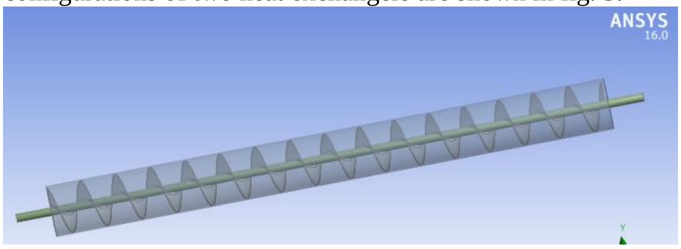
Table 1: Operating conditions

Parameters	Range
Cold side	
Mass flow rate	0.072-0.216 Kg/s
Temperature of cold water	15°C, 20°C, 25°C
Tube side	
Mass flow rate	0.096 Kg/s
Temperature of hot water	50°C

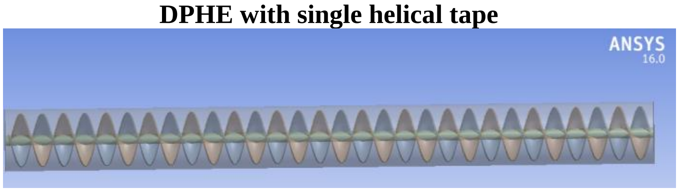
IV. CFD MODELLING

A. Physical model

Two DPHE heat exchangers are modelled in ANSYS CFD Fluent in order to validate the experimental results. The configurations of two heat exchangers are shown in fig. 3.



DPHE with single helical tape



DPHE with double-helical tape

Fig. 4: CFD domain of DPHE with single and double HTI

The dimensions of DPHE with single and double helical tape inserts are same. The materials of helical tape is aluminium.

B. Governing equations

In this work turbulence model was selected using Fluent software. The governing equation based on continuity, momentum and energy equations are given below:

The continuity equation is:

$$\frac{\partial u_i}{\partial x_i} = 0$$

The momentum balance without gravity force equation is:

$$\rho u_i \frac{\partial u_i}{\partial x_i} = -\frac{\partial p}{\partial x_i} + \frac{\partial \tau_{ij}}{\partial x_j}$$

The Energy equation is:

$$\rho c_p \frac{\partial (u_i T)}{\partial x_i} = \frac{\partial}{\partial x}\left(\lambda_{\text{eff}} \frac{\partial T}{\partial x_i}\right)$$

The turbulent kinetic equation is:

$$\rho u_j \frac{\partial k}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\mu_{\text{eff}}\, \alpha_k \frac{\partial k}{\partial x_j}\right] + \tau_{ij}\frac{\partial u_i}{\partial x_j} - \rho\varepsilon + G_k + G_b$$

The turbulent kinetic dissipation equation is:

$$\rho u_j \frac{\partial \varepsilon}{\partial x_j} = \frac{\partial}{\partial x_j}\left[\mu_{\text{eff}}\, \alpha_\varepsilon \frac{\partial \varepsilon}{\partial x_j}\right] + C_{1\varepsilon}\frac{\varepsilon}{k}(G_k + C_{3\varepsilon}G_b) - C_{2\varepsilon}^{*}\rho\frac{\varepsilon^2}{k}$$

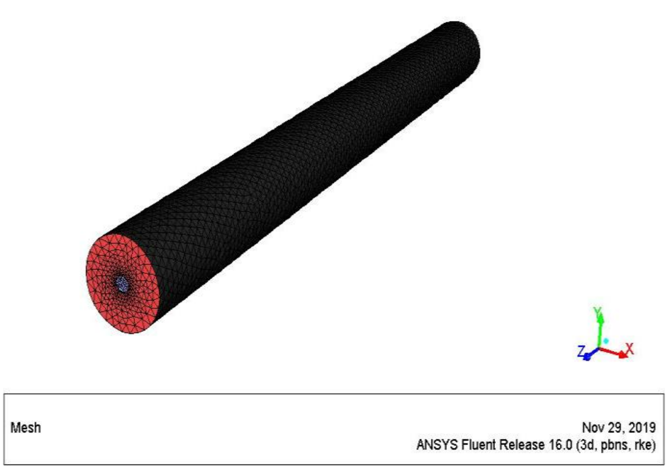


Fig. 5: Mesh model

C. Data deduction

Annulus and tube side heat transfer rate is given by

$$Q_1 = m_1 Cp_1 (Tc_2 - T_{c1})$$

$$Q_2 = m_2 Cp_2 (T_{h1} - T_{h2})$$

Average heat transfer rate is determined by

$$Q_{av} = (Q_1 + Q_2)/2$$

LMTD is determined by

$$\Delta T_{LMTD} = (\Delta T_1 - \Delta T_2)/\ln[\Delta T_1/\Delta T_2]$$

$$\Delta T_{L\text{-}M} = [(T_{h1} - T_{c2}) - (T_{h2} - T_{c1})]/\ \ln[T_{h1} - T_{c2}/\ T_{h2} - T_{c1}]$$

Dittus-Boelter correlation is given by

$$Nu = 0.023\ Re^{0.8}\ Pr^{0.3}$$

Heat transfer coefficient was obtained as follows:

$$h = Nu{*}k/d_h$$

Nusselt number for the annulus-side, Nu, is given by;

$$Nu = h\ d_h/k$$

V. RESULTS AND DISCUSSION

A. Simulation Results of DPHE with Single and Double Helical Tape

Fig. 4-7 shows a CFD simulation results of variation of annulus side heat transfer coefficient and Nu with different range of mass flow rate for DPHE with single and double HTI. Result indicate that by increasing the temperature and mass flow rate, heat transfer increases significantly. This is due to increasing heat transfer area with the provision of single and double helical tape. Another important aspect was a development of swirl flow along with secondary flow to create enough turbulence which causes a heat transfer enhancement.

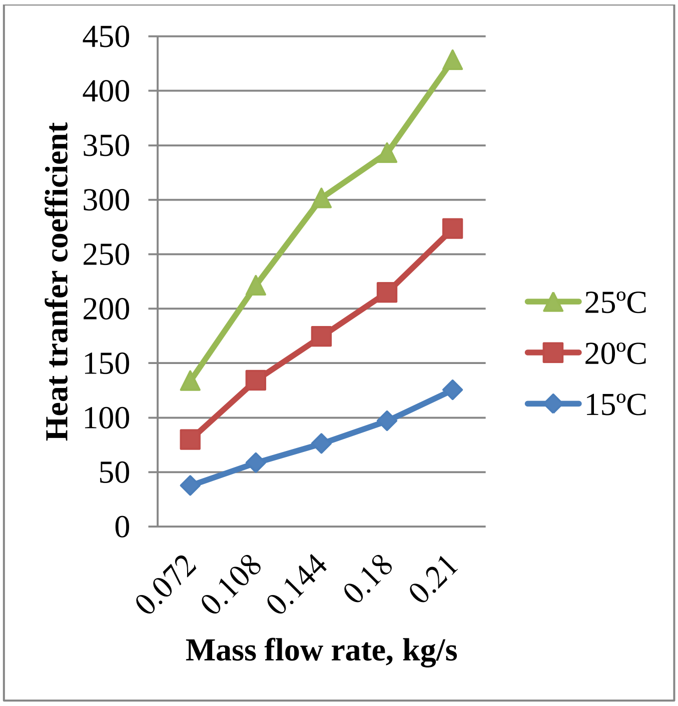


Fig. 6: Plot of mass flow rate versus heat transfer coefficient for DPHE with single HTI

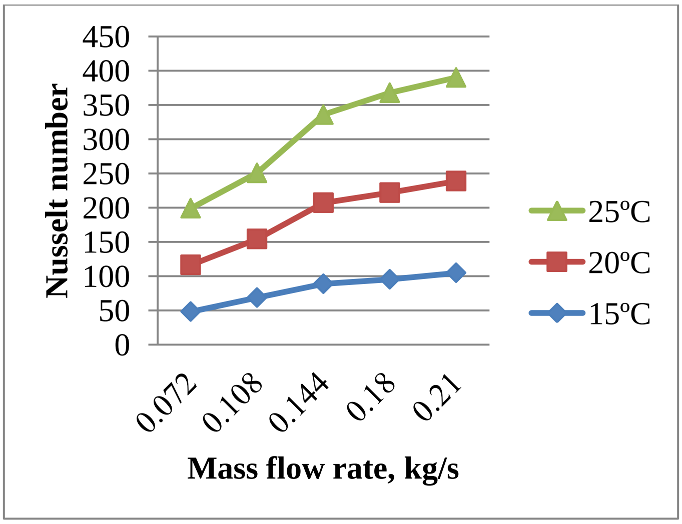


Fig. 7: Plot of mass flow rate versus Nusselt number for DPHE with single HTI

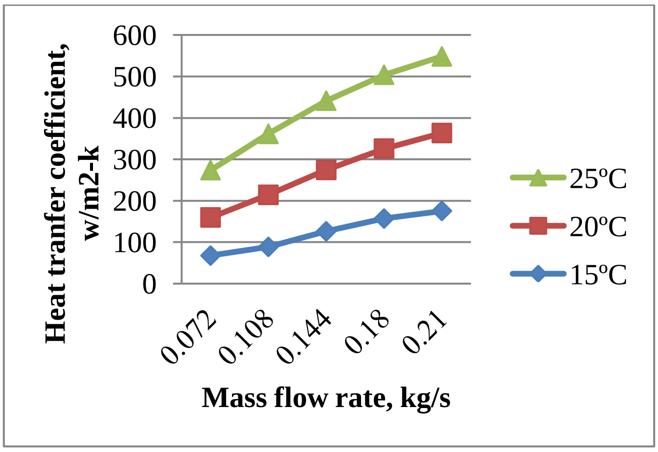


Fig. 8: Plot of mass flow rate versus heat transfer coefficient for DPHE with double HTI

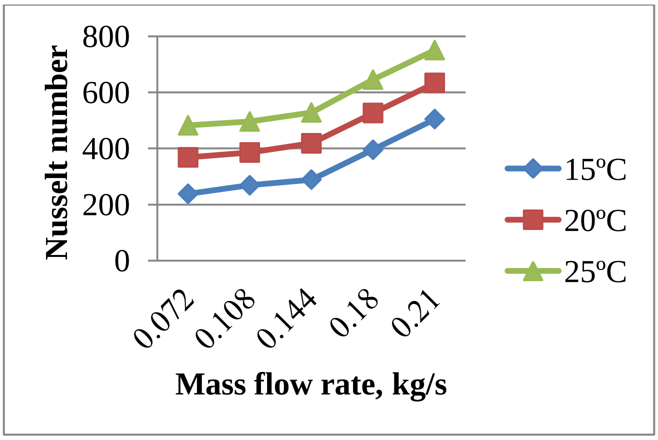


Fig. 9: Plot of mass flow rate versus Nusselt number for DPHE with double HTI

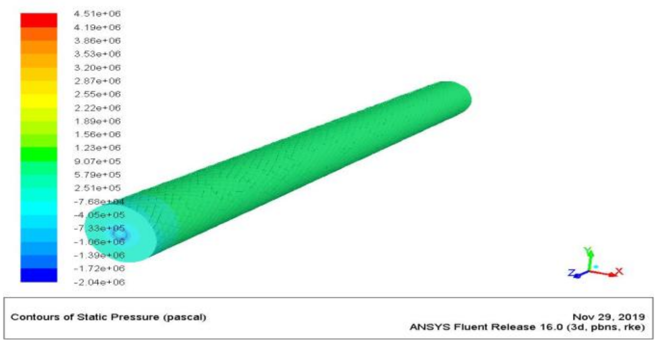


Fig. 10: Pressure contour

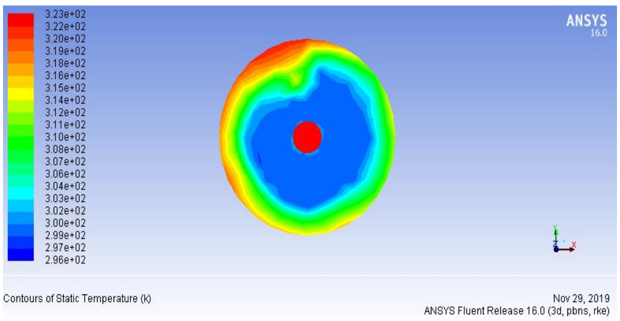


Fig. 11: Temperature contour

Higher thermal performance of DPHE with single and double helical tape was achieved at high temperature of cold water (25°C). Also the thermal performance of DPHE with double helical tape was higher than DPHE with single helical tape.

B. Validation of numerical code

Validation of experimental results was done by using Ansys CFD Fluent using realizable (RKE) turbulence model. Fig. 8-19, reported a validation graph between annulus side heat transfer coefficient and Nu associated with simulation and experimental results for DPHE with single and double helical tape. This shows that a good agreement exist between experimental and simulation results.

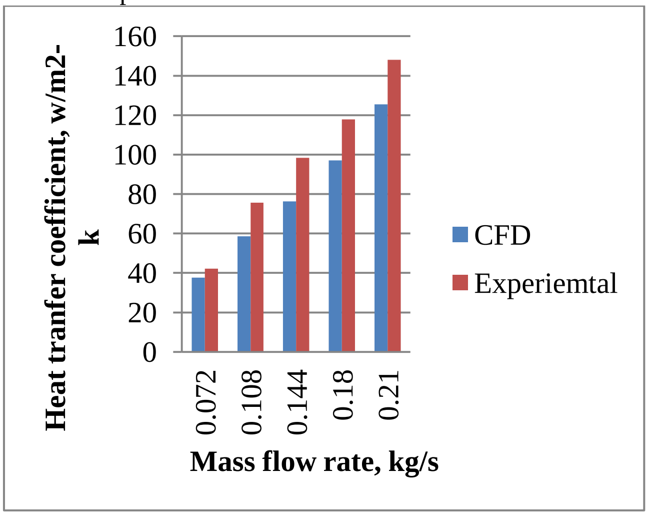


Fig. 12: CFD validation results for DPHE with single HTI at water inlet temperature = 15ºC

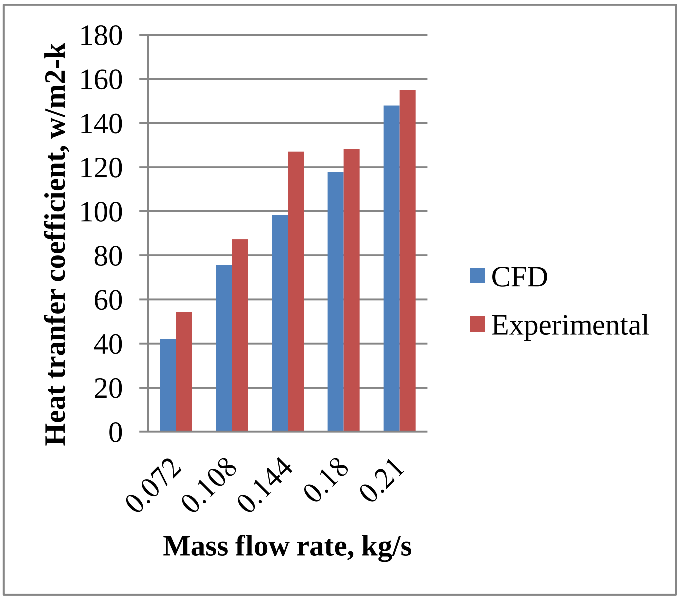


Fig. 13: CFD validation results for DPHE with single HTI at water inlet temperature = 20ºC

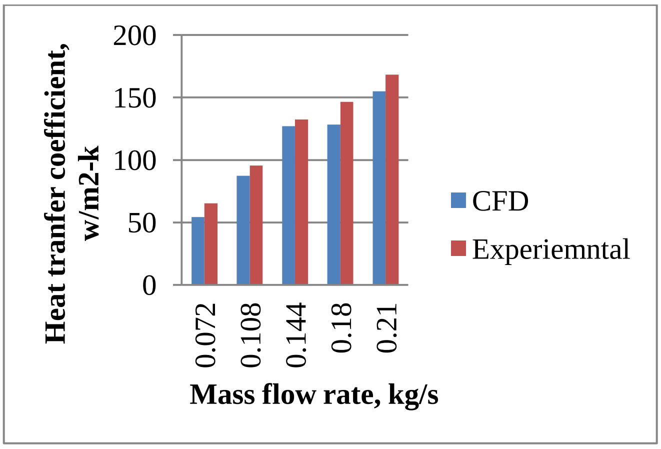


Fig. 14: CFD validation results for DPHE with single HTI at water inlet temperature = 25°C

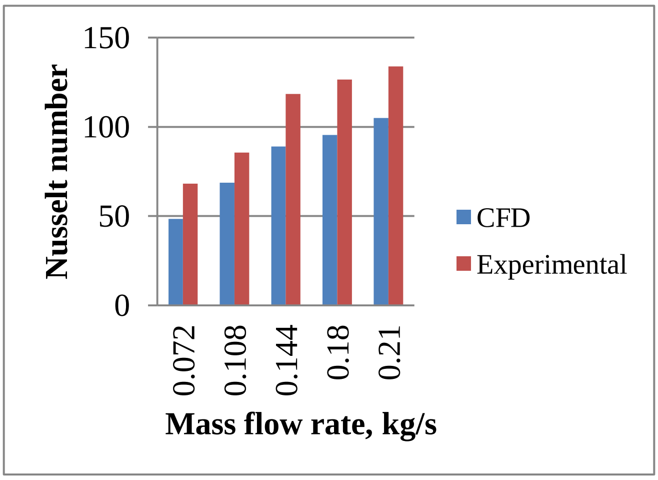


Fig. 15: CFD validation results for DPHE with single HTI at water inlet temperature = 15°C

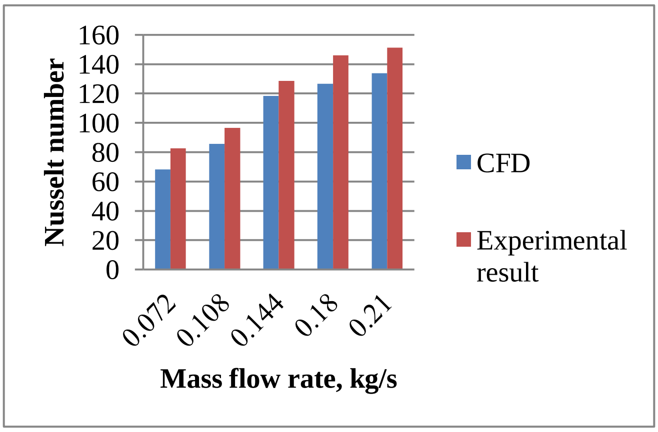


Fig. 16: CFD validation results for DPHE with single HTI at water inlet temperature = 20°C

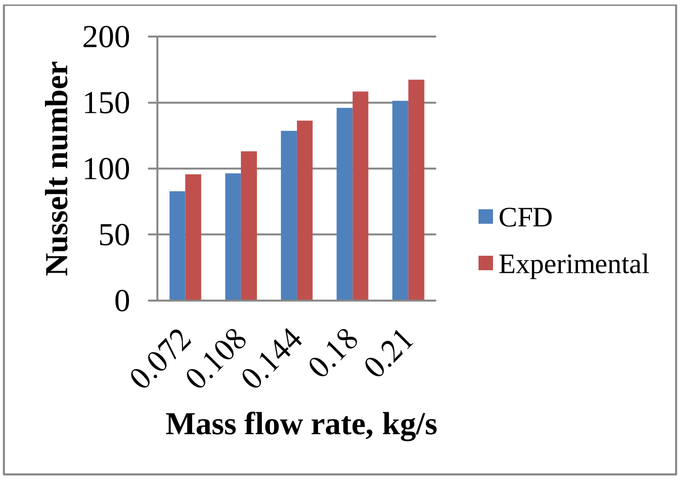


Fig. 17: CFD validation results for DPHE with single HTI at water inlet temperature = 25°C

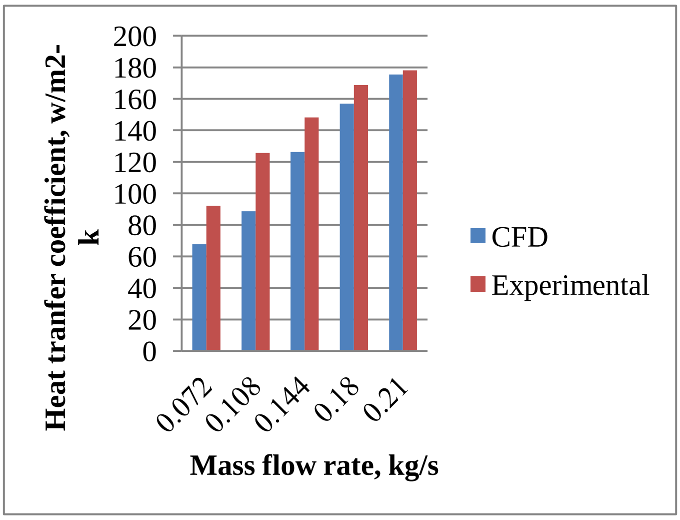


Fig. 18: CFD validation results for DPHE with double HTI at water inlet temperature = 15°C

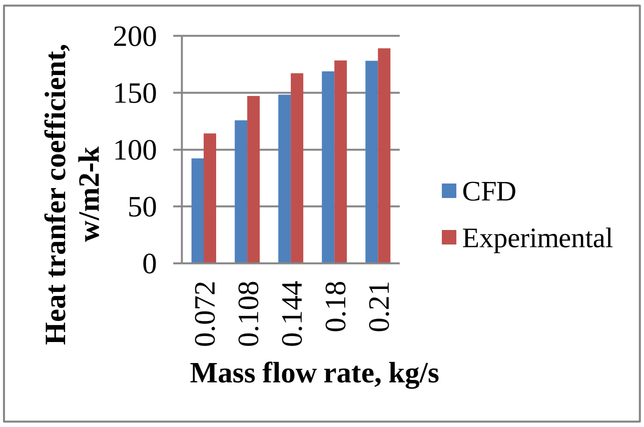


Fig. 19: CFD validation results for DPHE with double HTI at water inlet temperature = 20°C

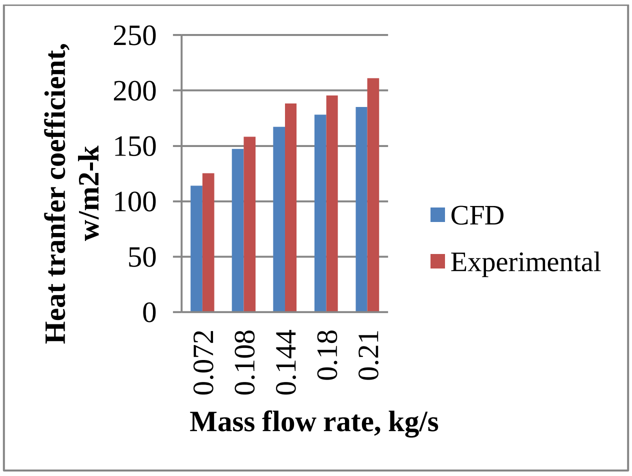


Fig. 20: CFD validation results for DPHE with double HTI at water inlet temperature = 25°C

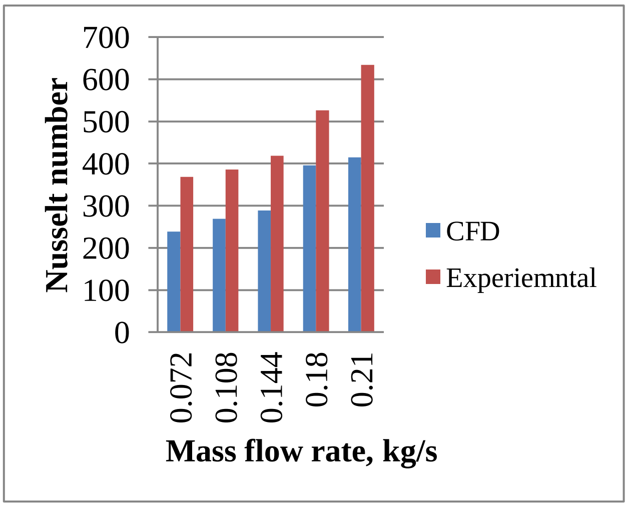


Fig. 21: CFD validation results for Nusselt number for double HTI at water inlet temperature = 15°C

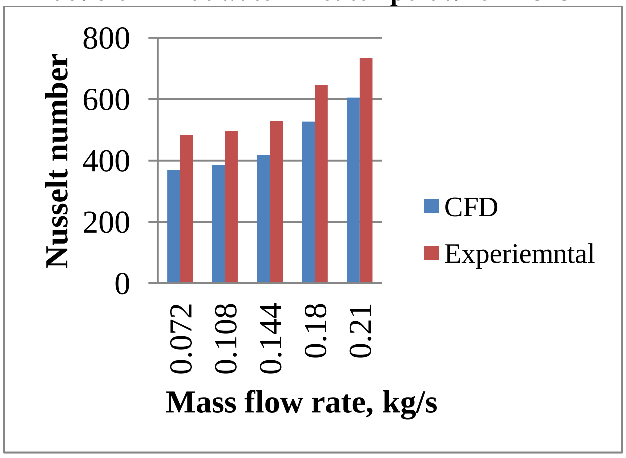


Fig. 22: Plot of CFD validation results versus experimental results for DPHE with double HTI at water inlet temperature = 20°C

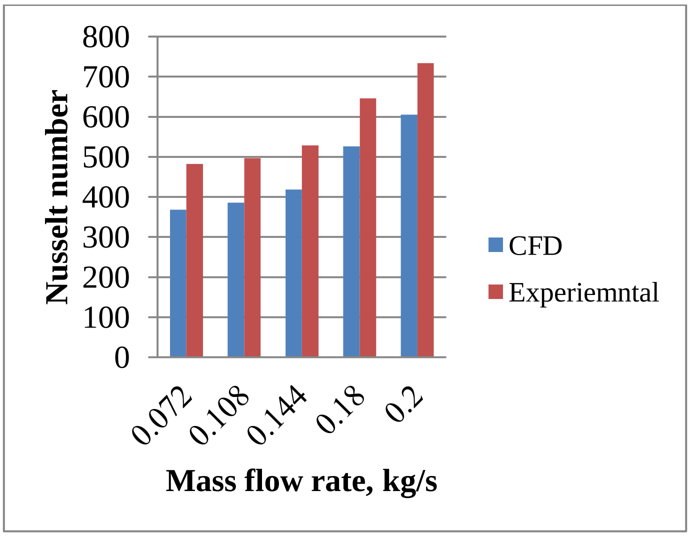


Fig. 23: Plot of CFD validation versus experimental results for Nusselt number for DPHE with double HTI at water inlet temperature = 25°C

C. Comparison of Single and Double Helical Tape

The numerical result of heat transfer characteristics in a DPHE with single and double helical tape are reported in this section.

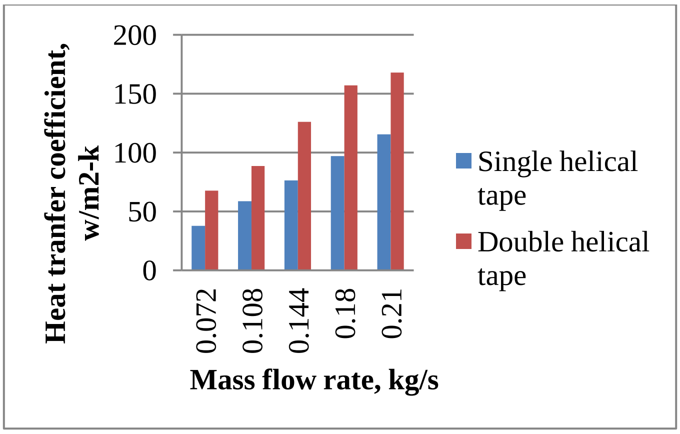


Fig. 24: Plot of heat transfer coefficient versus mass flow rate comparison of single and double helical tape results for HTI at water inlet temperature = 15°C

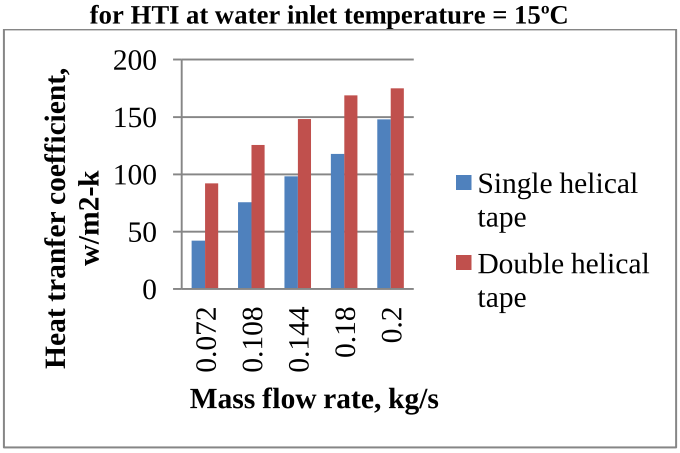


Fig. 25: Plot of heat transfer coefficient versus mass flow rate comparison of single and double helical tape at water inlet temperature = 20°C

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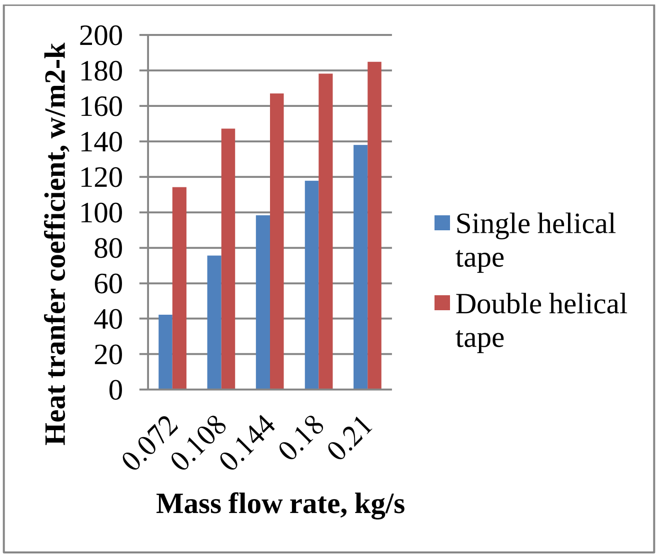

Fig. 26: Plot of heat transfer coefficient versus mass flow rate comparison of single and double helical tape at water inlet temperature = 25°C

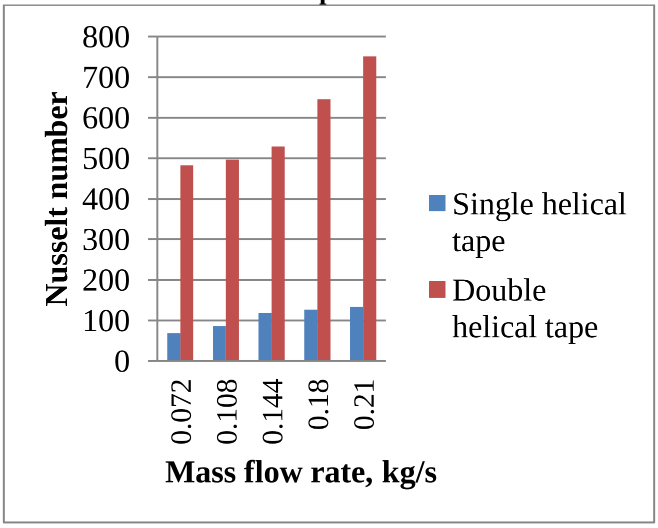

Fig. 27: Plot of Nusselt number versus mass flow rate comparison of single and double helical tape results for HTI at water inlet temperature = 15°C

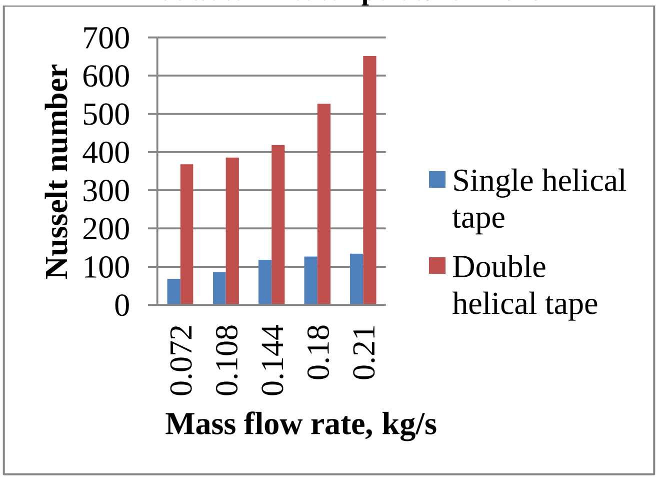

Fig. 28: Plot of Nusselt number versus mass flow rate comparison of single and double helical tape results for at water inlet temperature = 20°C

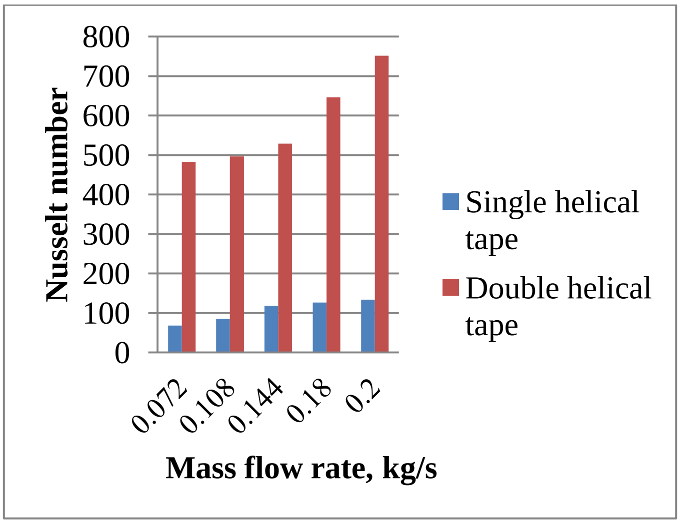

Fig. 29: Plot of Nusselt number versus mass flow rate comparison of single and double helical tape results for HTI at water inlet temperature = 25°C

It is found that annulus side heat transfer coefficient and Nu was found higher in DPHE with double helical tape than single helical tape with varying mass flow rate. This is due to fact that with application of helical tape causes a secondary swirl flow. Therefore it causes a better mixing of fluid and causes a turbulence which results in breakdown of thermal boundary layer.

VI. CONCLUSION

In the present study, the thermohydraulic performance of DPHE with single and double helical tape on inner are experimentally investigated and validated by the adoption of CFD technique with varying mass flow rate of annulus side. The following conclusion can be drawn from the study:-

1. The use of single and double helical tape improves the heat transfer.
2. DPHE with double helical tape has a better thermal performance than DPHE with single helical tape.
3. Heat transfer coefficient and Nusselt number increases with increase in mass flow rate of annulus fluid.
4. Good agreement between CFD and experimental results is present.
5. Finally, double helical tape for DPHE is found effective in enhancing the thermal performance of DPHE.
6. Although, other geometric parameters must be considered for further work such pitch and height of helical tape.

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