

Experimental Investigations on Heat Transfer Enhancement in Double Pipe Heat Exchanger Using PT-SCA and PTT-SCA Twisted Insert Profile



A. P. Sivasubramaniam, K. Mayilsamy, and P. Murugesan

1 Introduction

All processing industries that require heat energy use heat exchanging devices. Over the years it was found that there is lot of scope for energy saving and size reduction to make them compact through research works. As these heat exchanging devices involve convective transfer, enlarging the heat transferring surface has become one of the main criteria. This can be noticed from the continuous rise in literature available world-wide on heat transfer enhancing devices, a growing number of patents and also hundreds of companies are marketing thermal products ranging from enhanced tubes to complete set of thermal systems with integrated improved technology. The considerations for the saving of energy, materials, and space in the design along with cost incentives have led to producing heat exchanger equipment with more efficiency.

2 Literature Review

Dittus and Boelter [1] experimented using nano-fluids in heat exchanger and found that it improves the heat transfer rate and also reduces fuel consumption and weight. To further enhance the heat transfer process in the tube a twisted ribbon inclusion

A. P. Sivasubramaniam (✉)

Department of Mechanical Engineering, Paavai Engineering College, Namakkal, Tamil Nadu, India

K. Mayilsamy

Department of Mechanical Engineering, PSG College of Technology, Coimbatore, Tamil Nadu, India

P. Murugesan

Department of Mechanical Engineering, K.S.R Institute for Engineering and Technology, Namakkal, Tamil Nadu, India

was used JFE/1991 [2]. The editorial states that uncertainty in the measurements of fluid pressure, temperature, etc. may lead to error in the final outcome/efficiency of experimental methods ANSI/AMSE [3] provides procedural standards to conduct experiments in thermal devices. Moffat [4] showed that uncertainty could be calculated using either the single-sample or multiple-sample methodology, which are conventional methods generally followed to calculate error. Manglik and Bergles [5] studied correlation between friction factor and Nusselt number for laminar flow using twisted tape as inserts for heat exchange between water and ethylene glycol. A swirl parameter was estimated to obtain the inter-relation between centrifugal force, convective inertia force, and viscous force during operation.

Cengel [6] has stated methods for heat transfer calculations and input variables that could help improve heat transfer in various modes. Eiamsa-Ard et al. [7] examined the influence of twisted tapes of different geometries (variation in twist ratio and free space ratio) on heat transfer and friction characteristics of a DPHE. It was noted that increase in twist ratio increased the heat transfer coefficient whereas increase in space ratio increased both friction factor and heat transfer coefficient.

Eiamsa-Ard et al. [8] investigated the impact of twin-counter twisted tapes and twin co-twisted tapes on heat transfer characteristics of a heat exchanger. The twin-counter twist tapes produced higher heat energy transfer compared to twin co-twist which also provided considerable improvement.

Murugesan et al. [9] conducted experiments by inserting twisted tapes with square cuts in the fluid carrying tubes of a DPHE. The heat transfer enhancement was considerably high compared to the friction factor which increased to a moderate level.

Murugesan et al. [10] used twisted tapes and twisted tape containing wire nails as insertion into DPHE to conduct experiments and compare the heat transfer enhancement. The twist ratios employed were: 2, 4.4, and 6. The insert of the twisted tape containing wire nails performed better (higher Nusselt number, friction factor, and thermal enhancement factor) due to swirling effect produced by twists and the extra turbulence created by the nails.

3 Objectives

The literature study reveals that experimentations have been carried out using a variety of inserts which include plain tape, twisted tape, and making small cuts of various profiles (square cuts, step-cut arc, etc.) to be fitted longitudinally in the plain tube of the heat exchanger for thermal enhancement. Though experimental studies are large in number, numerical works are very few on topics related to heat exchanger performance analysis. Hence, the objective of the present work is to carry out numerical investigations on heat energy transfer improvement in turbulent zones of the tube inserted with PT-SCA of 165 mm pitch and PTT-SCA of twist ratio $\gamma = 7$ for which trial test runs are conducted in an experimental setup. Heat transfer

as well as friction factor characteristics of the heat exchanger after insertion of the above inserts would be investigated separately for comparison.

4 Methodology and Experimental Setup

4.1 Plain and Twisted Tape Inserts

The inserts (PT-SCA and PTT-SCA) are fitted into the copper tube to enhance the temperature in the heat exchanger. The plain tape inserts have plain tape without any. The inserts (PT-SCA and PTT-SCA) are fitted into the copper tube to enhance the temperature in the heat exchanger. The plain tape inserts have plain tape without any geometry on the tape and plain tape step-cut arc has a steeped cut arc profile on the plain tape with a pitch of 165 mm and a length of 2000 mm. The tape inserted into the plain tube disrupts the fluid flow creating turbulence force that influences the heat transfer rate to increase.

4.2 Experimental Setup

The experimental setup consists of two tubes (Copper and Galvanized Iron), rotameters, temperature indicators, controllers, flow control valve, voltmeter, ammeter, ON and OFF switches, digital pressure gauge, storage tank, etc. The schematic illustration of the experimental setup is given in Fig. 1. The outer side of steel tube is insulated by glass wool to avoid heat loss to the atmosphere. Heater in the molded tank-1 is used to heat the fluid (water) and the temperature of the inlet hot water is maintained at 53 ± 1 °C through the temperature controller. The hot water is pumped up to the annulus between dual pipes from the tank to the outer pipe. The hot water is circulated from tank-1 and the cold water circulated from tank-2. Both hot and cold water outlet pipes are coupled to the individual rotameter of 20 LPM range. The temperature of cold fluid is maintained at the range of 30 ± 1 °C through ice cubes.

These ice cubes are stored separately in tank-3. If the cold fluid temperature increases, ice cubes are exchanged into the cold water tank (tank-2). Thermocouple is utilized for the measurement of the temperatures of both the tanks (T7, T8), inlet (T3, T4, T5), and outlet (T1, T2, T6) temperatures of hot and cold water. Pressure drop occurring in the tubes is measured by using a digital manometer which is coupled with copper tube outlet. Thus all the required readings could be observed simultaneously for a given flow rate under turbulent flow using the experimental setup.

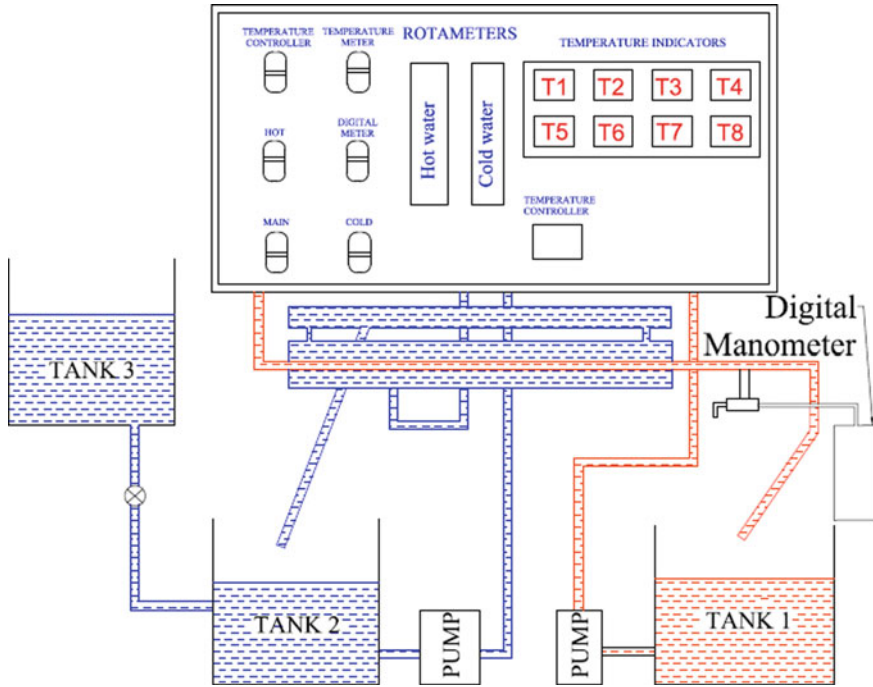


Fig. 1 Schematic diagram for counter-flow double tube heat exchanger

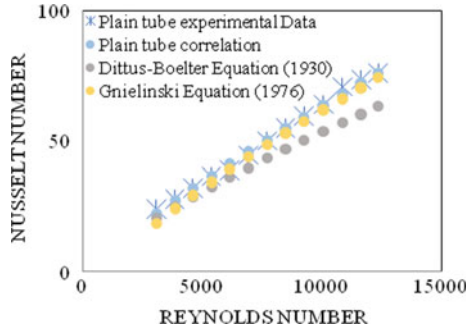
5 Result and Discussion

The performance characteristics such as heat transfer, Re (Reynolds number), friction factor, and thermal enhancement factor of the double pipe heat exchanger fitted with plain tape step-cut arc and plain twisted tape step-cut arc are discussed in this section. The results of the experiments conducted using plain and twisted tapes with inserts (PT-SCA and PTT-SCA) in the range of $Re\ 2000 \leq 14,000$ are conducted as per the procedure followed by and ANSI/ASME [2] and Moffat [4] standard. Various suspicions associated with the experimental investigations are applied in the error analysis.

5.1 Plain Tube Data Verification

Equations. 1, 2, and 3 show the experimental data for turbulent flow which are found to be similar to forced convection correlations for plain tube of Dittus–Boelter (1930) equation and Gnielinski (1976) equation (Cengel 2008). The plain tube correlation with a discrepancy of 20, 20 and 6% for Nusselt number is shown in Fig. 2.

Fig. 2 Data verification of Nusselt number for plain tube under turbulent flow



$$Nu = 0.023Re^{0.8} Pr^{0.3} \tag{1}$$

$$Nu = \frac{\frac{f}{8}(Re - 1000)Pr}{1 + 12.7\left(\frac{f}{8}\right)^{0.5}\left(Pr^{\frac{2}{3}} - 1\right)} \tag{2}$$

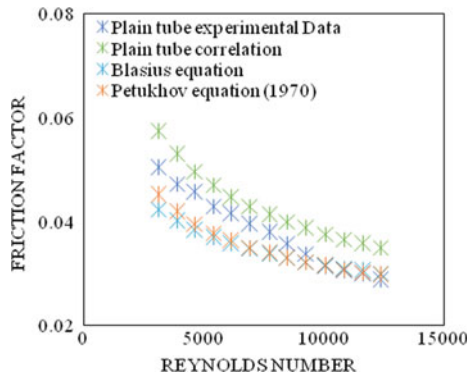
$$Nu = 0.0126Re^{0.879} Pr^{0.33} \tag{3}$$

The variation of friction factor obtained for the plain tube calculated from experimental results is shown in Fig. 3. The data obtained are compared with that of Blasius Equation, Petukhov (1970) Equation (Cengel 2008), and the plain tube correlations are shown in Eqs. 4, 5, and 6. It yields the deviation of 16.25, 13.5 and 18%, respectively, for friction factor.

$$f = 0.316Re^{-0.25} \tag{4}$$

$$f = (0.790 \ln Re - 1.64)^{-2} \tag{5}$$

Fig. 3 Data verification of friction factor for plain tube under turbulent flow



$$f = 0.999\text{Re}^{-0.356} \quad (6)$$

5.2 Heat Transfer Effect of PT-SCA

A comparison of the data obtained from the investigational results of the tube fitted with plain tape step-cut arc with the plain tube is made and the results are confirmed using the correlations of available data [inlet test section turbulent flow experimental data]. The experiment was carried out with a small cut on the plain tape which increases the turbulence in hot water.

From the results, it was revealed that plain tape step-cut arc contributes to create additional disturbance in the tube. The Nusselt number for the plain tape step-cut arc was found to be 1.288 times greater than that of plain tube.

The correlations between the Nusselt number (Eq. 7) and friction factors (Eq. 8) are also developed for the tube fitted with plain tape step-cut arc from the experimental outcomes.

$$\text{Nu}_{\text{SCA}} = 0.068\text{Re}^{0.721} \text{Pr}^{0.33} \quad (7)$$

$$f_{\text{SCA}} = 0.999\text{Re}^{-0.2516} \quad (8)$$

The predicted values are in agreement with the experimentally obtained data for Nusselt number and friction factor within variations of 6% and 5%, respectively.

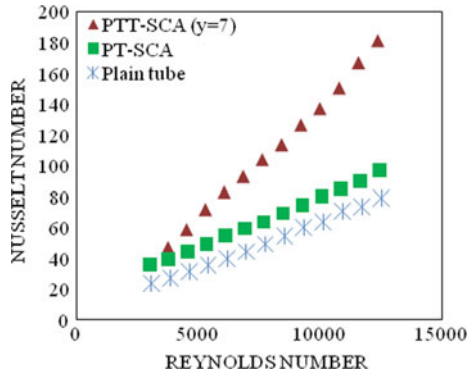
5.3 Effect of Friction Factor on PT-SCA

From observations it is understood that friction factor for tube fitted with plain tape step-cut arc is greater than plain tube but there is decrease in Reynolds number for a specified profile-cut. However, the friction factor rises due to the increasing disturbance offered by the insert for a given Reynolds number. It is also seen that the friction factor for plain tape step-cut arc is about 2.537 times greater than that of plain tube for a given specified profile-cut.

5.4 Comparative Evaluation of PT-SCA with PTT-SCA

The experimental results of plain tape step-cut arc (165 mm of pitch) are evaluated in comparison with the plain twisted tape step-cut arc (twist ratio $\gamma = 7$). Plain twisted

Fig. 4 Evaluation of Nu versus Re for PTT-SCA with PT-SCA and plain tube under turbulent flow

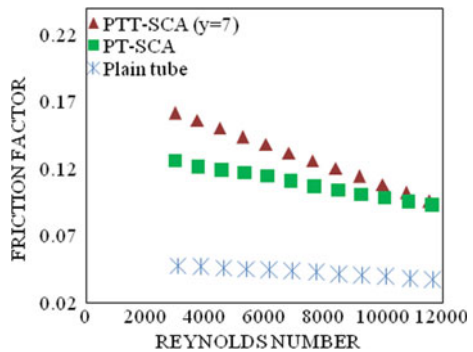


tape step-cut arc raises intensity of turbulence on the wall of the inner tube, and hence it shows comparatively higher heat transfer in the test section. Figure 4 provides the plot of Nusselt number versus Reynolds number for all the test cases. The plot reveals that PTT-SCA’s results are 1.623 and 2.092 times better than plain tube and PT-SCA.

The friction factor versus Reynolds number plot for Plain tube, PT-SCA and PTT-SCA, is presented in Fig. 5.

It has been noted that the friction factor decreases constantly with increase in Reynolds number and the friction factor for PT-SCA. This is significantly larger than that of PTT-SCA due to stronger disturbance in the tube. From the range of study of this investigation the following findings could be made: The mean friction factor for the PTT-SCA is 1.171 times higher than that of the plain tube and 2.971 times higher than that of the PT-SCA. But PTT-SCA is found to have a higher pressure drop than the plain tube as well as the PT-SCA.

Fig. 5 Evaluation of friction factor versus Re for PTT-SCA with PT-SCA and plain tube under turbulent flow



6 Conclusions

Experimental trials are carried out using DPHE setup with PT-SCA and PTT-SCA inserts fitted in the flow tube to compare the heat transfer performance parameters with that of plain tube. The study yielded following main results:

The Nusselt number and friction factor of the PTT-SCA insert are 1.623 and 1.171 times higher than the PT-SCA insert for entire turbulent flow.

Nusselt number increased and friction factor decreased when the PTT-SCA was introduced. It generates high swirl velocity and increases forced convective currents which in turn considerably enhances the heat transfer coefficient.

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