

# Thermodynamic and Hydrodynamic Performance of Double Pipe Heat Exchanger with Bended Strips

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## Abstract

The various techniques for achieving improved heat transfer are usually referred to as "heat transfer augmentation" or "heat transfer enhancement" and the heat exchanger provided with heat transfer enhancement techniques as "Augmented Heat Exchanger". The objective is to reduce as many of the factors as possible: Capital Cost, Power Cost, Maintenance Cost, Space and Weight, Consistent with safety and reliability. Present work describes the principal techniques of industrial importance for the augmentation of single phase heat transfer on the inside of tubes namely "Bended strip". So Bended strips should be used in heat exchanger when high heat transfer rate is required and pressure drop is of no significance. This study investigates the heat transfer characteristics of a horizontal tube-in-tube heat exchanger for single phase heat transfer with water as the working fluid. The material used for the construction of heat exchanger is copper, owing to its high thermal conductivity. Bended strips of varying pitches ranging from 10mm, 15mm, 20mm and 25mm respectively inserted in the inner tube. Experiments were carried out for plain tube with/without Bended strip insert at constant wall heat flux and different mass flow rates. The Reynolds number varied from 500 to 6000. Both heat transfer coefficient and pressure drop are calculated and the results are compared with those of plain tube

## 1. Introduction

Tube in tube heat exchangers are one of the most common equipment found in many industrial applications ranging from chemical and food industries, power production, electronics, environmental engineering, air-conditioning, waste heat recovery and cryogenic processes[2]. Heat exchangers are devices that facilitate the exchange of heat between two fluids that are at different temperatures while keeping them from mixing with each other. Heat exchangers are commonly used in practice in a wide range of applications, from heating and air-conditioning systems in a household, to chemical processing and power production in large plants. Ru Yang [1] presents the experimental studies of double pipe heat exchanger

with the curves inner tube. Curved-pipe curvature induces a secondary flow across the main stream that may enhance heat transfer rate significantly. Therefore, it should receive much attention in the heat transfer enhancement applications. Mainly, the study is for periodically varying curvature curved-pipes (e.g., wavy curved-pipe) is comparatively very little. N. Shahiti et.al [2] presents the experimental study of heat transfer and pressure drop characteristics of a double-pipe pin fin heat exchanger. Pin fins are used in heat exchangers as very effective elements for heat transfer enhancement. Li Zhang [4] presents the study on double-pipe heat exchanger with helical fins and pin fins. LDA measurements are performed on the flow in helical shell sides of double-pipe heat exchanger with and without pin fins under the cylindrical coordinate system. Pongjet Promvong et.al [5] experimentally investigated the turbulent convective heat transfer characteristics in a helical-ribbed tube fitted with twin twisted tapes. The work has been conducted in the turbulent flow regime, Re from 6000 to 60,000 using water as the test fluid. The experiment was carried out in a double tube heat exchanger using the helical-ribbed tube having a single rib-height to tube-diameter ratio,  $e/DH = 0.06$  and rib-pitch to diameter ratio,  $P/DH = 0.27$  as the tested section. Chii-Dong Ho [6] presents the work on efficiency improvement in heat transfer through double-pass concentric circular tubes with an impermeable sheet of negligible thermal resistance to divide a circular tube into two sub channels with uniform wall temperature and external refluxes at the ends. The introduction of reflux has position effects on the heat transfer for large Graetz number and the outlet temperature as well as transfer coefficient increases with increasing reflux ratio. Z. Iqbal [7] presents the optimal configurations of finned annulus with parabolic fins have been investigated for maximum convection by employing trust-region and genetic algorithms. Prabhata K. Swamee [8] presents the optimal design of the exchanger has been formulated as a geometric programming with a single degree of difficulty. M. A. Akhavan Behabadi et.al [9] presents the experimental investigation has been carried out to study the enhancement in heat transfer coefficient by coiled

wire inserts during heating of engine oil inside a horizontal tube in a laminar flow heat exchanger. In present experimentation two different coiled wire insert of 2.0 mm and 3.5 mm wire thickness are used and results are carried out. The test-section was a double pipe counter-flow heat exchanger. The engine oil flowed inside the internal copper tube; while saturated steam, used for heating the oil, flowed in the annulus. The effects of Reynolds number and coiled wire geometry on the heat transfer augmentation and fanning friction factor were studied. In present work, the bended strips are used in the inner pipe having a hot water region. Therefore the design and manufacture the bended strip and study of heat transfer through them have been a problem of great interest for designer of different disciplines. The proposed study is concerned with experimental investigation of convective heat transfer from tube in tube heat exchanger with and without various bended strips.

The effect of various geometries on performance characteristics of double pipe heat exchanger such as heat transfer, friction factor and pressure drop.

## 2. Objectives:

- i. Experimentally investigated the double pipe heat exchanger with bended strips having angles 15, 30, 45 and 60° with the central axis of the inner tube.
- ii. To study thermodynamic and hydrodynamic performance of the double pipe heat exchanger.

## 3. Experimental Set-Up

The experimental set up of double pipe heat exchanger with bended strips was reported and this topic presents the detailed information of apparatus, working procedure, operating parameters and geometries of bended strip. Four different patterns of bended strips are manufactured and tested under various operating conditions. Geometry of strip and manufacturing process of strip patterns is explained in following subtopic-

### 3.1 Experimental Apparatus

Figure 1 illustrates the experimental set-up used in the present study. The test section is a tube in tube heat exchanger. An experimental apparatus is conducted to study the heat transfer performance and friction factor in a tube with bended strips inserts. It is composed of cold water tank, hot water tank, temperature sensors, flow control valve, temperature display, monoblock pump, thermostatic water heater, annulus and four different geometries of bended strips.

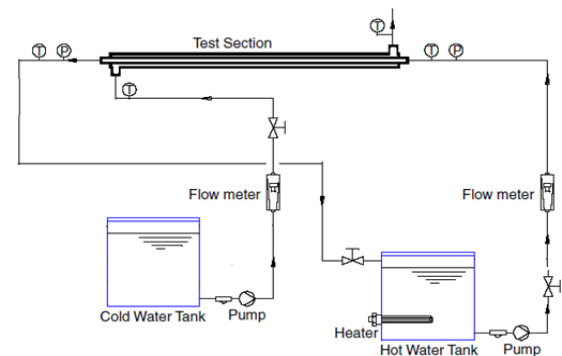


Fig.1 experimental setup of double pipe heat exchanger

A double pipe heat exchanger is utilized as the main heat transfer test section which is insulated using asbestos to minimize heat loss to the surrounding. It consists of two concentric tubes in which hot water flows through the inner tube and cold water flows in counter flow through annulus. The outer tube made of a stainless steel having inside and outside diameters of 23 mm and 24.5 mm respectively. The inner tube made of a copper having inside and outside diameters of 11.2 mm and 12.6 mm respectively. It has a heat transfer section of a length of 1.25m. In the experimentation, the various bended strips having different pitch 10, 15, 20, 25 and plain tube with the central axis of the inner tube are inserted inside the inner tube. The inserted strips create turbulence inside the inner pipe which enhances the heat transfer rate.

The two flow meters are used to maintain shell side and tube side mass flow rates of water. The working range of flow meter is from 0.003kg/sec to 0.024kg/sec. The two FCV is used to controlled tube side and annulus side mass flow rate. One flow meter used to measure hot water mass flow rate and another flow meter is to measure annulus side cold-water mass flow rates. A PT100 type temperature sensor is directly inserted into inner and outer tube to measure inlet and outlet temperatures of both the fluids. Temperature data was recorded using data acquisition/switch unit.

Table No 3.1 Dimensions of Double heat exchanger

Dimensions	Outer Tube	Inner Tube
Outer Diameter (m)	0.025	0.0125
Wall Thickness (m)	0.0015	0.0015
Length of tube (m)	1.25	1.25
Reynolds No ranges	500-6000	500-6000
Prandtl Number	3-5	3-5
Bended strip Pitch (m)		10,15, 20, 25 and No pitch

Material of Construction	SS	Cu
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Table 3.2 Range of operating parameters

Parameters	Range
Tube side water flow rate	0.003–0.024 kg/s
Shell side water flow rate	0.004–0.025 kg/s
Tube inlet temperature	55–59 °C
Tube outlet temperature	42–50 °C
Shell inlet temperature	35–37 °C
Shell outlet temperature	49–44 °C

A schematic diagram of the experimental apparatus is shown in Fig. 1. It consists of a test section, hot water tank, and cold water tank and data acquisition system. The close-loops of hot and cold water consist of the electric heaters controlled by adjusting the temperature. Water is used as the medium for cooling the hot water. The hot water is adjusted to the desired level and controlled by a temperature controller. The temperatures of the cold and hot water are adjusted to achieve the desired level. The water and tube wall temperatures at the inlet, middle and outlet sections are measured by four K type thermocouples.

### 3.2 Test procedure

Experiments were performed with various inlet temperatures and flow rates of hot water entering the test section. In the experiments, the hot water flow rate was increased in inner tube, while the cold water flow rate, and were kept constant. The inlet hot water temperatures were adjusted to achieve the desired level of temperature by using electric heaters controlled by temperature controllers and kept cold water temperature constant. Before any data were recorded, the system was allowed to approach the steady state. The flow rates of the water are controlled by adjusting the valve and measured by two calibrated flow meters with a range of 0–0.020 kg/s. The four heat exchangers made with different portions of the bended strip inside the inner tube. The inclination angles are 15, 30, 45 and 60° with the central axis of the inner tube. For various bended strips we take inlet/outlet temperatures of inner tube and outer

tube. Also we will take hydrodynamic performance of the bended strip.

Experimental Procedure is as follows,

- First filled water in hot water tank up to certain level, and switch ON electric supply to water heater.
- After 15 minutes thermostatic water heater heat the water up to 60°C. Thermostatic valve maintain the constant 60°C water temperature.
- Start monoblock to pump hot water from hot water tank and circulate in inner tube. The mass flow rate of hot water is controlled by the flow control valve (FCV) and flow measured by the Rotameter.
- For same time mass flow rate of cold water or annulus side flow is controlled by the flow control valve and flow measured by the shell side Rotameter. The annulus side cold water received from the large cold-water reservoir.
- The test was conducted for counter-flow configuration.
- Inner tube inlet-outlet and annulus side inlet-outlet temperature measured by temperature indicator in steady state condition of the temperatures.
- Initially both side mass flow rate varies and taken the observations.
- For first observation, keep tube side mass flow rate is 15 LPH and Shell side mass flow rate maintained 30 LPH. Likewise vary the tube side mass flow rate and keep shell side mass flow rates is constant. Take inlet-outlet temperatures, pressure drop (mercury difference) and mass flow rates in observation table.
- For next observation, likewise vary the tube side mass flow rate and keep annulus side mass flow rate is constant. Take inlet-outlet temperatures, mass flow rates and head loss due to friction in observation table. This procedure is continuous for all readings.
- Hot water outlet again circulates to hot water tank, so that water heater conserves the energy.
- Next, change heat exchanger, repeat it above procedure for various mass flow rates, and take observations.

### 3.3 Calculation of tube side heat transfer coefficients

In present investigation, the heat transfer coefficient was determined based on the measured temperature data. The operating parameter range is given in Table 1,

Tube Side Heat transfer

$$Q = m_t C_{p_t} (T_{hi} - T_{ho}) \quad (1)$$

Shell Side Heat Transfer

$$Q = m_s C_{p_s} (T_{co} - T_{ci}) \quad (2)$$

The physical properties of taken on average temperature

$$T_m = (T_{in} + T_{out})/2 \quad (3)$$

The heat transfer coefficient was calculated with,

$$U_o = \frac{Q}{A_o \Delta T_{LMTD}} \quad (4)$$

The overall heat transfer surface area was determined based on the tube diameter and developed area of tube diameter,  $A_{total} = \pi L d_o$  is the total convective area of the tube ( $\pi L d$ ) constant for various geometries of inserted bended strips heat exchanger.

$$A_{total \text{ convective area}} = \pi L d_o = 0.01 \text{ mm}^2$$

LMTD is the log mean temperature difference, based on the inlet temperature difference  $\Delta T_1$ , and outlet temperature difference  $\Delta T_2$  [18, 19],

$$LMTD = \frac{(\Delta T_2 - \Delta T_1)}{\ln(\Delta T_2 / \Delta T_1)} \quad (5)$$

The flow rate in shell side was varying with combination to tube side flow rate. The overall heat transfer coefficient can be related to the inner and outer heat transfer coefficient from following equation [4, 5],

$$\frac{1}{U_o} = \frac{A_o}{A_i h_i} + \frac{A_o \ln(d_o/d_i)}{2\pi k L} + \frac{1}{h_o} \quad (6)$$

Where,  $d_i$  and  $d_o$  are inner and outer diameters of the tube respectively.  $k$  is thermal conductivity of wall material and  $L$ , length of tube (stretch length) of heat exchanger. After calculating overall heat transfer coefficient, only unknown variables are  $h_i$

and  $h_o$  convective heat transfer coefficient inner and outer side respectively, by keeping mass flow rate in annulus side is constant and tube side mass flow rate varying.

$$h_i = C V_i^n \quad (7)$$

Where  $V_i$  are the tube side fluid velocity m/sec. Substituting Equation 4.7 into Equation 4.6, the values for the constant,  $C$ , and the exponent,  $n$ , were determined through curve fitting. The inner heat transfer could be calculated for both circular and square coil by using Wilson plot method. This procedure is repeated for tube side and annulus side for each mass flow rate on both helical coils

### Result and Discussion

The results obtained from the experimental investigation of heat exchanger operated at various operating conditions are studied in detail and presented.

#### 4. Thermal Performance

The thermal performance of the double pipe heat exchanger is evaluated in heat transfer rate, overall heat transfer coefficients and Nusselt numbers. The tube side flow rate is varied from the 0.008 kg/s to 0.023 Kg/s, same time annulus side flow rate is maintained constant. The test is conducted for only the counterflow configuration. For each strip geometries, five annulus side flow rates taken i.e. 30, 60, 90, 120, and 150 LPH.

The nusselt number of the plain tube is matches with the Detus Bolter equation. The experimental nusselt number of the plain tube is closely matches with the available literature. Detus Bolter equation is referred from the literature and compared the the present data and it found 9% variation shown in figure 2.

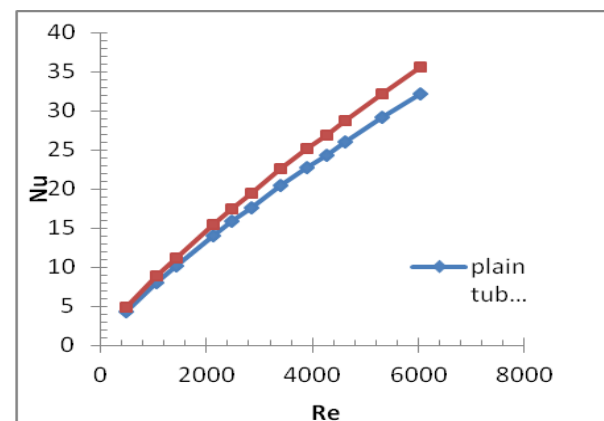


Fig. 2 Comparison of the plain tube Nusselt number and Detus Bolter equation

Figure 3 shows the overall heat transfer coefficients changes with the tube side hot water flow rate. The convective heat transfer area is constant for all the inserts geometries. In presents study found that the overall heat transfer coefficient increases with increase in the tube side flow rate.

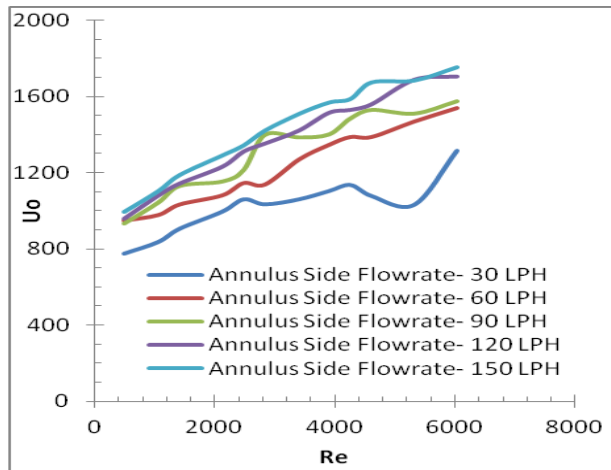


Fig. 3 Variation of overall heat transfer coefficient with Reynolds Number for 10mm pitch

The overall heat transfer coefficient variation with respect to the Reynolds number are presented in the figure 4. Heat transfer rate and heat duty also increasing with reducing the pitch length. The inserted strip manufactured in the workshop and maintained the uniform pitch throughout the strip. From the one end inserts the strip and conducted the experiment on the various geometries.

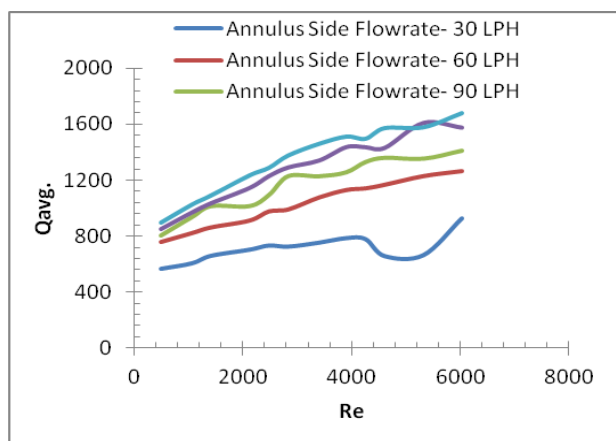


Fig. 4 Variation of heat transfer rate with Reynolds Number for 10mm pitch

It is found that, the value of Nusselt number is maximum for 10 mm pitch per 120 LPH with increase in Reynold number. The value of Nusselt Number is minimum for Plain Tube. In experimental results shows that, as increases the flow obstruction, its affect on the flow pattern. The

flow obstacles generate turbulence inside the inner tube. The turbulence plays important role in the heat transfer enhancement. This is a one of the passive heat transfer technique.

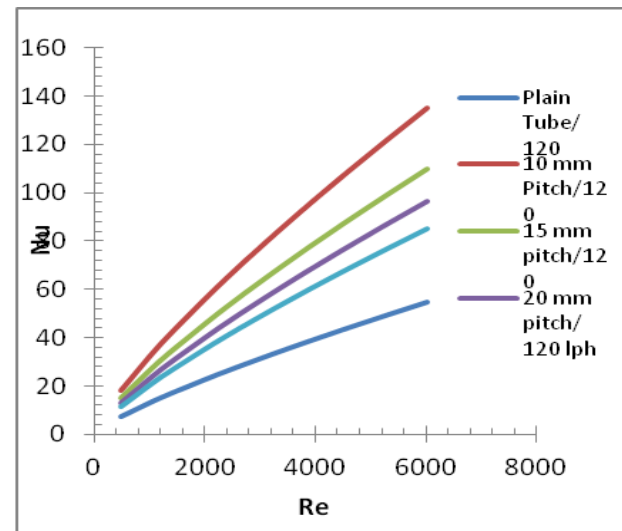


Fig. 5 Variation of inner Nusselt Number with Reynolds Number for 120 LPH constant annulus flow rate

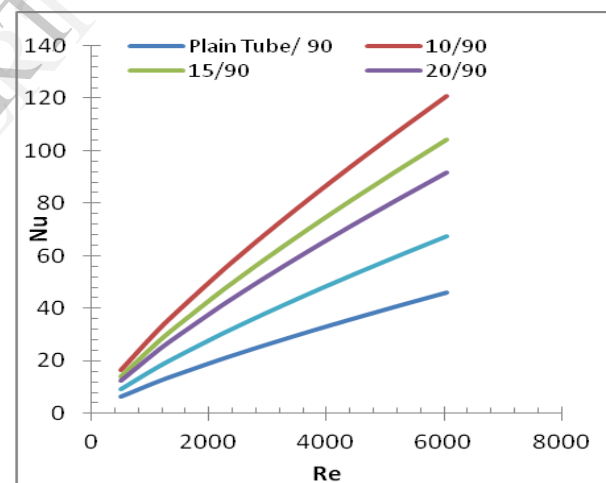


Fig. 6 Variation of inner Nusselt Number with Reynolds Number for 90 LPH constant annulus flow rate

Figure 5 and 6 presents the Nusselt number variation for the annulus side flow rate i.e. 120 and 90 LPH respectively. The test procedure is same for all the five annulus side flow rates. Change the bended strip from the other end of the inner tube of the heat exchanger. Tube side Reynolds number is varied from the 400 to 7000 and operating hot and cold water temperature is ranges from the 50°C to 61°C and 25°C to 30°C respectively. The tube side flow rate is varied by using flow control valve. The Rotameter is used to measure the tube side flow rate and annulus side flow rate.



#### 4.1 Hydrodynamic Performance

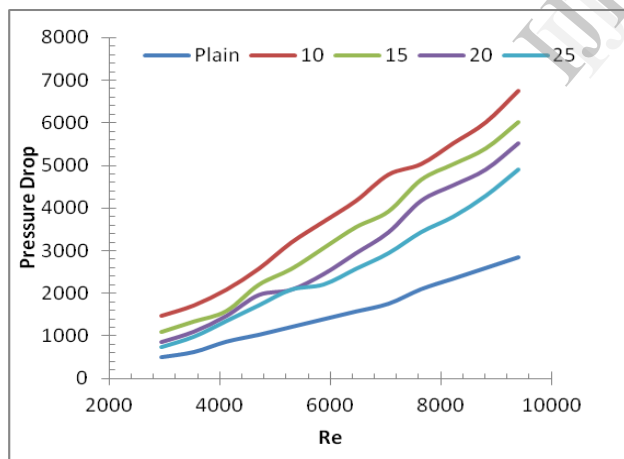
The tube side friction factor can be calculated by using the formula,

$$f = \frac{\Delta P d_h}{2 \rho v^2 L}$$

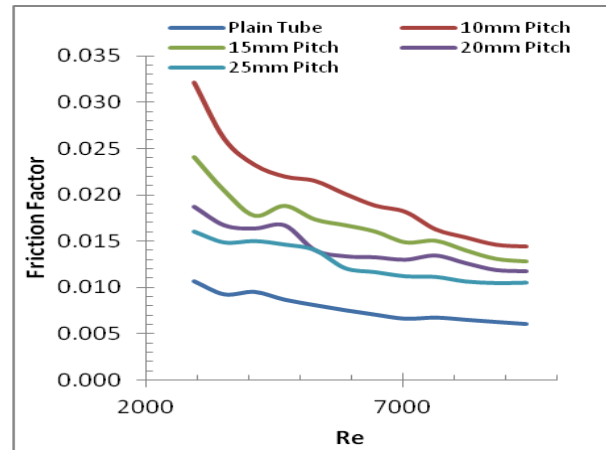
(5.1)

Where,  $d_h$  is the hydraulic diameter in mm,  $L$ , length of heat exchanger in mm,  $v$ , velocity of the flowing fluid. As changes the geometry of the strip it directly affect on the hydraulic diameter because the volume of material required is more for the 10 mm pitch strip and volume of material required is less for the 25 mm pitch strip.

For measurement of the pressure drop U tube manometer is used having the range 150-0-150 mm. The mercury is an media used in the U tube manometer to measure the height of mercury across the heat exchanger. Pressure drop and friction factor is calculated for the various strips geometries, for various mass flow rates. Pressure drop is increases with increase in the velocity of the flow. The pressure drop reduces with increasing strip pitch and very less pressure drop found in the plain tube. The height and length of the inserted strip is same. The effect of bended strip on the pressure drop and friction factor is given in the figure 5.9 and 5.10.



**Fig. 7** Pressure drop for the various strip geometries



**Fig. 8** Friction factor variation for various strip geometries

Pressure drop of the plain tube is less as compared to the other inserted geometries. The plain tube has less obstruction to flow pattern and less turbulence are occurred hence this effect on the heat transfer performance. In tube-in tube heat exchanger various patterns and geometries are inserted for the enhancing heat transfer rate but same time its affect on the pressure drop. Figure 7 and 8 presented the variation of the pressure drop and friction factor with change in inner tube side mass flow rate.

#### 5. Conclusion

Experimental study of tube in tube pipe heat exchanger was performed using various bended strip patterns. The mass flow rates in inner tube and in the annulus were both varied. Single-phase water-to-water heat transfer study performed and tested for counter flow configuration. The heat transfer rates in 10 mm pitch were higher than other bended strip. As increases the strip pitch, reduces the heat transfer rate. In present study found that, very low overall heat transfer in plain tube, tube side heat transfer rate progressively increases with decreasing inserted strip pitch. In hydrodynamic analysis large pressure drop for the minimum pitch i.e. 10mm and very less pressure drop found in the plain tube. In results, various bended strip patterns compared with each other for various operating parameters like heat transfer rate, overall heat transfer coefficients, LMTD and Nusselt number with Varying tube side hot water flow rates. The friction factor is on higher side for the minimum pitch of bended strip.

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## 6. References

- [1] Ru Yang, Fan Pin Chiang, "An experimental heat transfer study for periodically varying-curvature curved-pipe", *International Journal of Heat and Mass Transfer*, 45 (2002), pp. 3199–3204.
- [2] N. Sahiti, F. Krasniqi, Xh. Fejzullahu, J. Bunjaku, A. Muriqi, "Entropy generation minimization of a double-pipe pin fin heat exchanger", *Applied Thermal Engineering*, 28, (2008), pp. 2337–2344.
- [3] Mansoor Siddique, Majed Alhazmy, "Experimental study of turbulent single-phase flow and heat transfer inside a micro-finned tube", *international journal of Refrigeration*, 31, (2008), pp. 234–341.
- [4] Li Zhang, Wenjuan Du, Jianhua Wub, Yaxia Li, Yanwei Xing, "Fluid flow characteristics for shell side of double-pipe heat exchanger with helical fins and pin fins" *Experimental Thermal and Fluid Science*, 36, (2012), pp 30–43.
- [5] Pongjet Promvonge, Somsak Pethkool, Monsak Pimsarn, Chinaruk Thianpong, "Heat transfer augmentation in a helical-ribbed tube with double twisted tape inserts", *International Communications in Heat and Mass Transfer*, 39, (2012), pp 953–959.
- [6] Chii-Dong Ho, Ho-Ming Yeh, Wen-Yi Yang, "Improvement in performance on laminar counter-flow concentric circular heat exchangers with external refluxes" *International Journal of Heat and Mass Transfer*, 45, (2002), pp. 3559–3569.
- [7] Z. Iqbal, K.S. Syed, M. Ishaq, "Optimal convective heat transfer in double pipe with parabolic fins", *International Journal of Heat and Mass Transfer*, 54, (2011), pp 5415–5426.
- [8] Prabhata K. Swamee, Nitin Aggarwal, Vijay Aggarwal, "Optimum design of double pipe heat exchanger" *International Journal of Heat and Mass Transfer* 51 (2008) 2260–2266.
- [9] Smith Eiamsa-ard, Somsak Pethkool, Chinaruk Thianpong, Pongjet Promvonge, "Turbulent flow heat transfer and pressure loss in a double pipe heat exchanger with louvered strip inserts" *International Communications in Heat and Mass Transfer* 35 (2008) 120–129
- [10] M.A. Akhavan-Behabadi, Ravi Kumar, M.R. Salimpour, R. Azimi, "Pressure drop and heat transfer augmentation due to coiled wire inserts during laminar flow of oil inside a horizontal tube" *International Journal of Thermal Sciences* 49 (2010), pp. 373–379
- [11] Paisarn Naphon, Parkpoom Sriromrual, "Single-phase heat transfer and pressure drop in the micro-fin tubes with coiled wire insert" *International Communications in Heat and Mass Transfer*, 33, (2006), pp. 176–183.