Conical Spring Inserts Effect on the Thermo- hydraulic Characteristics in Circular Copper Tube

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Abstract: Experimental and numerical investigation was conducted to study the thermo-hydraulic characteristics in circular tube fitted with conical spring inserts. The dimensions of circular copper tube are 100cm, 2.2cm and 2.4 cm which represent the length, inner and outer diameters respectively. The length of insert was 15cm, while the conical spring has 16mm diameter gradually decreases to 6mm with the length and the pitch between the coils was 20mm. The diameter of wire used to fabricate the conical spring insert was 4mm. Those inserts were arranged into eight categories (A1 to A8). In the numerical part, the governing equations were solved by using commercial ANSYS-Fluent package (2019 R3) with the assistance of solid works and Gambit software program. The finite volume approach was used in solving the equations to predict the pressure flow, heat transfer and temperature distribution along the tube. Experimental work included design and built a test platform for the experimental measurements. The aim of experimental study was to predict the behavior of heat transfer and pressure in the tube with two cases, plain tube and inserted tube at the effect of different parameters. All experimental tests were conducted at turbulent flow fully developed. The range of Reynolds number and heat flux were (3542-7522) (4549-10576 W/m²) respectively. The results showed that the best augmentation in heat transfer was by using a category A5 of conical spring insert compared with plain tube. Results show good agreement between the numerical and experimental results with an error of 8%. Also results showed that the Nusselt number increases as the Reynolds number increasing.

1. Introduction
Heat transfer augmentation in a thermal system can be achieved by adding swirl flow devices. Conical spring insert is one of these devices utilized to improve the heat transfer without addition any external power. Experimental and numerical studies were conducted to predict the augmentation in heat transfer by using swirl flow devices contain a tube inserts. Gurveer et al. [1] studied experimentally the thermal performance of a flat-plate solar collector using insert devices. The range of Reynolds number and Prandtl number were (200–8000) (5–8) respectively. In the study different insert configurations were used such as; twisted-tape, wire coil and wire mesh. Results showed increases in Nusselt number when using all insert devices. Also results show that the mesh insert and wire coil are best than others in laminar and turbulent flow respectively. Sahiti et. al. [2] conducted an experimental study of the effect of adding pin fins on heat transfer. The simple relationships of heat transfer by convection and conduction were used to derive an equation explaining the factors influencing the improvement of heat transfer. The results showed a significant improvement using small cylindrical pins on the surface of the heat exchanger. Kapatkar et al. [3] studied experimentally the heat transfer inserts for Reynolds
number range laminar flow (20-2000), range of mass flow rate (2gm/s - 20gm/s) under uniform wall heat flux condition and friction factor of a smooth tube fitted with full length twisted tape. An enhancement in average Nusselt number for the flow in smooth tubes was resulted with full-length twisted tapes and it increases with the increase in Reynolds number and mass flow rate. Kannan et al. [4] conducted experimental study the heat transfer characteristics and friction factor within a circular tube fitted with perforated twisted tape for Reynolds number range (21,000 – 50,000). The results show that Nusselt number varies inversely with the twist ratio. Shuai and Chang [5] performed numerical simulations on a compact tubular heat exchanger using fluent software. They have verified that the software is fluent in digital simulation method of integrated fin tube is possible. The superior software has proven to be feasible for numerical simulation on a built-in fin tube and to be effective for developing and designing heat exchange tubes. Burse et al. [6] conducted experimental research to understand the effect of twisted tape with different torsion ratios on the heat transfer properties of a round tube. The twisted tapes used are of three different winding ratios such as 1.78, 2.32 and 2.77. Initially the experiment was performed for a normal tube at constant wall heat flux and different mass flow rates. Second, the experiment was performed with tube insertion with the same working conditions as the normal tube. Dong et al. [7] investigated the effect of the perforated round finned tube on the heat transfer of the circular tube heat exchanger. The heat transfer coefficient \( h \) was increased by (3.31%, 3.55%), the pressure drops increased by (0.68%, 2.08%) for the 2- and 4-holes cases, respectively. Qasim and Ali [8] studied the use of different kinds of tapes that are twisted and fitted through double pipe heat exchanger to increase the fluid mixing property that leads to increase the heat transfer rate with respect to that of the plain-twisted tape. V cut-twisted tape and Horizontal wing cut-twisted tape are two different variant twisted tapes with twist ratios of \( \gamma = 2.0, 4.4 \) and 6.0 are used. The main conclusion has been reached that the Nusselt number, thermal enhancement factors and friction factor of different twisted tapes are higher than that of plain twisted tape for the twist ratios of 2.0, 6.0 and 4.4 respectively. Yu and Tao [9] conducted a study on the heat transfer and pressure drop in toroidal wave-like finned tubes. The results showed an enhancement in heat transfer for finned tube when the flow was turbulent. Dhirajkumar et al. [10] offered review of researches work of modern techniques in heat transfer enhancement. Many researchers have used different techniques to enhance heat transfer. Worldwide energy utilize is expected to increase by almost 1.6 times, from 4.03 x 1020 J in 1999 to 6.4 x 1020 J in 2020. Thus, if the efficiency of energy usage could improve by 10 per cent, by means of different heat transfer enhancement techniques, this will result in 6.4 x 1019 J of advantage in terms of energy utilization to the society. Special importance in this study is given on different techniques of heat transfer enhancement, developed in recent times. Iqbal et al. [11] investigated the optimal longitudinal fins on the outer surface of the inner tube inside the closed outer tube concentric in the developer laminar flow in full uniform heat flow. The results showed that the optimal shape of the fin depends on the number of fins, and the proportion of radius, and the number of control points and length characteristic. Kumar. [12] Made a numerical analysis the heat transfer in horizontal tubes having five different types of inserts when the ranges of Reynolds number were (6000-14000). Author concluded that increase in pumping work associated with an increase in heat transfer coefficient in comparison to plain tube. Mon and Gross [13] conducted an analysis of numerical heat transfer characteristics and pressure drop on the side of the heat exchanger tube with fins ring. They have studied the effects of spacing on the fin tubes with fins ringed packs consisting of four rows overlapping arrangements and homogeneous. The findings revealed the point of view of the important characteristics of heat flow and transfer of local heat packs pipe ring fins and supports the development of the boundary layer on the surfaces of the fin and tube spacing to fin height ratio. Sami et al. [14] investigated numerically the characteristics of friction factor and heat transfer for copper-water nanofluid passing through circular tube with constant wall heat flux fitted with two different types of vortex generator, which are classical twisted tape (CTT) and parabolic-cut twisted tape (PCT). The results showed that at lower twisted ration a higher value for Nu and friction factor. Qasim and Noor [15] investigated experimentally the characteristics of heat transfer enhancement and friction factor for completely developed laminar CuO/distilled-water nanofluid flow.
through horizontal tube inserted with various geometries of twisted tapes under constant condition of heat flux ranged from 4483 - 10000 W/m². The results revealed a significant increase of both Nusselt number and convective heat transfer in terms of friction factors with inserting twisted tape and nanofluids as working fluid in comparison to nanofluids in plain tube condition. Kulkarni [16] carry out experimental investigate the heat improvement in a horizontal circular tube with clockwise and counter-clockwise-corrugated twisted tape inserting. They have reported that the using clockwise and anticlockwise- corrugated leads enhancement in heat transfer by 12% and 46% respectively as compared to traditional tube.

From previous studies, we have observed that there are a variety of ways to improve the heat transfer process. With a slight study of the use of a conical spring insert. The purpose of the current study is to investigate the thermo-hydraulic characteristics in circular tube fitted with conical spring insert at different factors experimentally and numerically. Hence, this study is conducted in order to enhance the thermal performance of the heat exchanger that is used in many applications.

2. Numerical Simulation

ANSYS FLUENT (2019 R3) commercial software is employed to simulate the physical phenomena of heat transfer and fluid flow in plain and inserted tube. Solid works Software (2016) is used to draw the geometry models in present study. Figure 1 shows the Computational domain of the copper tube and the conical spring insert with dimensions. The conical springs were distributed inside the tube with eight types of distributions (A1-A8). We are looking for the best type to improve heat transfer with minimal pressure loss. In the current study, the continuity, Navier-Stokes, and energy equations have been used to solve the flow field three dimension.

![Computational domain in the present study.](a) Computational domain in the present study.

![Conical spring insert with dimensions.](b) Conical spring insert with dimensions.

**Figure 1.** (a) Geometrical domain in the current study; (b) Conical spring insert with dimensions.

2.1. Mesh Generation

GAMBIT software was utilized modeling the mesh. Currently, in this work, triangular and tetrahedron element types were involved for surface mesh and three-dimensional geometry respectively. Figure 2 shows the present model mesh. Various grid sizes were tested and now transported to software program fluent (2019 R3). The temperature distributions of the tested grids were compared to select the optimal grid size in the study. In this investigation, an average of (1.25) million cells are utilized and it is representing the highest number of iterations done to achieve the solver terminates. As shown in figure 3, (1600) iterations are required in this work.
3. Experimental description

3.1 Experimental set-up

Figure 4 depicts a diagram of the experimental set-up under study. The experimental set-up involved of a centrifugal pump, flow meter to measure flow rate of water, U- tube manometer, and the heat transfer test sector. In the eclectically heated unit, a copper tube having an inside diameter of (Di) 22 mm, an outside diameter of (Do) 24 mm, and length of L=1000 mm is wound with electrical heating wire (L=3 m, d= 1.5 mm, power =1.2 kW) covered with ceramic beads. The terminals of the wire are connected to a variac AC transformer, which is used to vary the voltage of the AC current passing through the heating coil. In order to reduces convective heat loss to ambient and to prevent leakages from the experimental rig, well insulate has been used. The inlet and outlet temperatures of the water and three stations on the outer surface of the test tube were measured by multi-channel type-k thermocouples.

In the experiments, the conical-spring insert in eight category utilized in the current study are showed in figure 5. The conical-spring was made of copper with15cm in length, while the conical spring has 16mm diameter gradually decreases to 6mm with the length and the pitch between the coils was 20mm. The diameter of wire used to fabricate the conical spring insert was 4mm. Those inserts were arranged into eight categories (A1 to A8).
3.2 Experimental procedure
In the present work, the pressure drop was measured by utilizing in U-tube manometers. Also both the inlet and outlet temperatures of the water and three stations on the outer surface of the test tube were measured by multi-channel type-K thermocouples for finding out the average Nusselt number. For each test, temperature, volumetric flow rate and pressure drop of the water were record the data of under steady state conditions. All tests were conducted under a fully developed turbulent flow with range of Reynolds number (3542-7522) and heat flux (4549-10576 W/m²).

3.3 The data reduction
In this study, the water used as a working fluid that flowed through a uniform heat flux and insulated tube. The steady state of the heat transfer rate is assumed to be equal to the heat loss from the test section. to estimate the electrical power applied at the external surface of the tube, can be used equation (1) [18]:

\[ Q_{heater} = I \cdot V \]  

where:
I and V are representing the electric current (A), and the electric voltage (V) respectively.

Equation (2) can be used to calculate the heat transferred amount to the distilled water from the heating wire:

\[ Q_{fluid} = m_w \cdot C_p \cdot (T_i - T_o) \]  

where:
\( m_w \), \( C_p \), \( T_i \) and \( T_o \) are representing the water mass flow rate (kg/s), specific heat of the water (kJ/kg\( \cdot \)°C), inlet and outlet temperature of the water (°C) respectively.

One of the most important parameters that should know is the heat transfer coefficient of the water, it can be calculated by using equation (3):

\[ h(z) = \frac{q_w}{(\Delta T)_e} \]  

where: \((\Delta T)_e\) is the difference between the inner wall temperature of the tube \( T_{wi} \) \( (z) \) and the temperature of the water \( T(z) \) at distance \( Z \) from the entrance of the tube.

The local Nusselt Number has been calculated from the equation (4):

\[ Nu(z) = \frac{h(z)D}{k_w} \]
where:
\( k_w \): Thermal conductivity of water (W/m.K).

While, Reynolds number can be estimated by equation (5)

\[
\text{Re}_w = \frac{4m}{\pi \mu d_i}
\]  

(5)

where:
\( m_w \), \( \mu_w \) and \( d_i \) are depict the water mass flow rate (kg/s), dynamic viscosity of water (kg/m.s) and internal tube diameter (m) respectively.

4. Results and Discussion

4.1. Model Validation
A comparison has been conducted to authorize the current numerical simulation according to the former numerical results, achieved by Qasim and Noor [15]. In figure 6 shows good agreement has been found between these results which indicate the acceptable validations of the present simulation. Figure 7 shows a comparison between the numerical and practical results of the temperature distribution along the tube within conditions (Reynolds number 3500 and thermal flux 4500). The figure shows that there is a clear convergence of the results, and the highest percentage for the plan is 8%.

4.2. Numerical Results
Figure 8 demonstrate the temperature contours at three locations (Z=0.25, 0.5 and 0.75) for plain tube and all other types of the arrangement of the inserted tube at (Re=3500) and heat flux equal to 10500 W/m². Figure 8 demonstrated that heating of the water passing through the tube is limited for temperature contours in plain tube. So, in order to reach a specific temperature difference, an increase in the length of the tube is needed. The reason behind it is due to the high velocity of water flow through the tube, which holds the possibility of heat transfer as can be seen shown in velocity vector of flow. With the use of conical spring insert, contours show a significant enhancement in the water heating process demonstrating that the heat transfer between the hot tube surface and water has been enhanced.
Figure 8. Temperature contours at (Re=3500) under heat flux equal to 10500 W/m² for (a) Z=0.25, (b) Z=0.5 and (c) Z=0.75.

Figure 9 illustrates the behavior of water during heat transfer by heating the surface of the tube at longitudinal axis. Figure shows that for all type arrangement (A1 to A8), water temperature increases for the tube with conical spring insert. Figure 9 demonstrates that (A5) is the best arrangement, because of the increase in the water temperature. A swirl flow caused by the conical spring inserts disrupting the water boundary at tube surface due to tangential velocities enhancement. The water boundary layer disruption leads to a thinner boundary that improves the heat transfer process. Figure 10 illustrate that the drop in the pressure begins from tube inlet to the downstream of flow along the tube to the exit section due to losses of the friction between the water viscous boundary layer and inner surface of pressure losses through a plain tube is less than losses in the tube with conical spring insert.
This is because of the conical spring insert swirling path is generated by conical spring insert and the additional local vortices. The boundary layer of the viscous nearby the inner surface of tube is destroyed. This caused higher contact between water and the surface then increasing friction losses. Figures 9 and 10 demonstrate that class A5 is the best classification.

4.3. Experimental result
4.3.1. The thermal effect of adding conical springs insert. The relationship between the change in water temperature along the length of the tube at various values of heat flux and Reynolds number 3500 in the eight arrangements of the conical springs inside the tube are shown in figures 11 – 14. In general, we notice that the water temperature rises along the tube length, but in a variable manner due to the effect of the conical springs insert distribution along the tube. Also, the greater the value of the heat flux applied to the tube, the higher the temperature value of the water. Adding the conical springs insert and distributing them inside the tube in different arrangements affect the rate of heat transfer from the tube surface to the water as a result of generating rotational torsion flows that enhance the mixing of water and its contact with the inner walls of the tube and this mixing maintains a high temperature gradient near the tube wall and thus improvement the heat transfer. From these figures, we note that the conical springs insert distribution within the order (A5) gave the best thermal performance among the rest of the arrangements. 11% represents the average of increase in water temperature when using (A5) conical springs insert arrangement compared to a tube without conical springs insert.

![Figure 9](image9.png) **Figure 9.** Heat behavior of water in relation with axial distance.

![Figure 10](image10.png) **Figure 10.** Pressure behavior of water in relation with axial distance.

![Figure 11](image11.png) **Figure 11.** Heat behavior of water in relation with axial distance at heat flux 4549W/m².

![Figure 12](image12.png) **Figure 12.** Heat behavior of water in relation with axial distance at heat flux 6467W/m².
4.3.2. Hydrodynamic effect of adding conical springs insert. The difference in Nusselt number with Reynolds number for normal tube compared to the eight arrangements of conical springs inside the tube are shown in figures 15 - 18 with different heat flux. Generally, for all ranges of the Reynolds number under study, it can be seen clearly that the Nu number increments with increases the Reynolds number. Affected Nusselt number distribution of conical springs inside the tube as a result of the establishment of torsion or rotational flow required which enhances the mixing of water and touching the wall of the inner tube. This confusion maintains a gradient high temperature near the wall of the tube and thus enhances heat transfer.
Figure 17. Relation between Nusselt number with Reynolds number at heat flux $8612 \text{W/m}^2$.

Figure 18. Relation between Nusselt number with Reynolds number at heat flux $10576 \text{W/m}^2$.

5. Conclusions
Experimental and numerical study were conducted to investigate the thermo-hydraulic characteristics in circular tube fitted with conical spring inserts. It is concluded that the best augmentation in heat transfer was by using a category A5 of conical spring insert compared with plain tube. 11% represents the average of increase in water temperature when using (A5) conical springs insert arrangement compared to a tube without conical springs insert. In addition, for all ranges of the Reynolds number under study, Nu number increases with the Reynolds number increases. The main reason behind the enhancement in heat transfer under the current study is that the flow became more turbulent due to insert conical spring insert. In addition, the results shown clear convergence of numerical and experimental results with an error 8%. Future directions of the subject under study is investigation of different types of insert along with various kind of nanofluid.

6. References
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