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(Research Article)

Study of the flow characteristics and augmentation of heat performance in a horizontal tube with and without spring inserts

Saad Obied Esmaiel and Dhamyaa Saad Khudhur *

Department of Mechanical Engineering, College of Engineering, Mustansiriyah University, Baghdad, Iraq.

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Abstract

In this project, heat transfer and thermal performance factor characteristics in a tube fitted with coil wire and twisted tape inserts, using air as working fluid are investigated experimentally. Enhancement forced convection heat transfer characteristics is studying for air Reynolds number range from 10.328×10^3 to 11.769×10^3 and 10.927×10^3 to 12.029×10^3 in the tube without and with coil wire inserts. Effects of various hydrostatics parameters on the heat transfer are considered in this work with heat flux are constant conditions of 600 W/m^2 and 800 W/m^2 with using the coil wire and twisted tapes with three ratios (y/w = 3, 4 and 5). The test section is a horizontal annular passage with outer diameter 10 cm. The results indicated that the enhancement of heat transfer coefficient factors in tube with coil wire inserts provide local heat transfer coefficient percentages of (5.1% to 7.8%) for heat fluxes (600) W/m^2 and (800) W/m^2 respectively. While tube with swirl inserts provide local heat transfer coefficient percentages of (3.6% to 6.1%) for heat fluxes (600) W/m^2 and (800) W/m^2 respectively. The obtained results show that mean Nusselt number and heat transfer coefficient in the tube with twisted tape and coil wire increase with decreasing twisted ratio (y/w). It is also observed that the percentage of heat transfer coefficient for the coil wire when compared with that of swirl inserts tube were ranged between (10.6%) to (16.5%) and (11.5%) to (17.3%) for the heat flux (600) W/m^2.

Keywords: Enhancement; Convection heat transfer; Inserts; Heat performance

1. Introduction

Heat transfer enhancement techniques have been extensively developed to improve the thermal performance of heat exchanger systems with a view to reducing the size and cost of the systems. Swirl/vortex flow is the one of the enhancement techniques widely applied to heating/cooling systems in many engineering applications. The vortex flows can be classified into two types: continuous swirl and decaying swirl flows. The former represents the swirling motion that persists over the entire length of the duct for example helical/twisted tape and coiled wires inserts while the latter means the swirl created at the duct entrance and then decays along the flow path. Swirl flow has been used in a wide range of applications from various engineering areas such as chemical and mechanical mixing and separation devices, combustion chambers, turbo machinery to pollution control devices. It is commonly known that the swirl flow enhances the heat transfer mainly due to the increased velocity in the swirl tube and the circulation of the fluid by forced convection.

S. Eiamsa-ard et al. (2010) [1] investigated experimentally heat transfer, flow friction and thermal performance factor characteristics in a tube fitted with twisted tape, using water as working fluid. The experiments are conducted using the tapes with three twist ratios (y/w = 3, 4 and 5) and three depth of wing cut ratios (DR = d/w = 0.11, 0.21 and 0.32) over a Reynolds number range of 3000–27,000 in a uniform wall heat flux tube. The obtained results show that mean Nusselt number and mean friction factor in the tube with the delta-winglet twisted tape increase with decreasing twisted ratio (y/w) and increasing depth of wing cut ratio (DR). It is also observed that the twisted tape is more effective turbulator

* Corresponding author: Dhamyaa Saad Khudhur

giving higher heat transfer coefficient than smooth tube. S. Naga Sarada et al. (2010) [2] presented the study an experimental investigation of the potential of reduced width twisted tape inserts to enhance the rate of heat transfer in a horizontal circular tube with inside diameter 27.5mm with air as working fluid. The twisted tapes were of three different twist ratios (3, 4 and 5) each with five different widths (26-full width, 22, 18, 14 and 10 mm) respectively. The Reynolds number varied from 6000 to 13500. The percentage increase in Nusselt numbers for reduced width tapes compared to plain tube were about 11–22%, 16–31%, 24–34% and 39–44% respectively for tape widths of 10, 14, 18 and 22 mm respectively for twist ratio =3. Shashank S. Choudhari and S.G. Tajiv (2013) [3] have been studied the experimental investigation of the heat transfer and friction factor characteristics of a double pipe heat exchanger fitted with coil wire insert made up of three different material as copper, aluminum and stainless steel and different pitches for Reynolds number in range of 4000-13000. Cu tube causes higher heat transfer enhancement about 1.58, and aluminum and stainless steel causes heat transfer rate enhancement up to 1.41 and 1.31 respectively. Overall heat transfer coefficient was higher for copper coil wire insert than aluminum, stainless steel inserts and plain tube. The friction factor of aluminum coil wire insert of 5 mm pitch was 5.4 to 6.7 times of the plane tube. Stainless steel tube insert causes friction factor of 4.8 to 5.9 times to plane tube and copper insert has friction factor of 4.3 to 5.4 times plane tube. Dr. A. G. Matani, Swapnil A. Dahake (2013) [4] the influences of twisted tapes and wire coil on pressure drop, friction factor (f), heat transfer and thermal enhancement index are experimentally determined. The twisted tapes are used as swirl flow generators also double twisted tapes are act as counter/co-swirl generator while wire coil along with twisted tapes used as co-swirl flow generators in a test section. The tests are conducted using the twisted with three different twist ratios (y/w = 3.5, 2.66 and 2.25), double twisted tape (y/w=3.5 and 2.66) and pitch ratio of 0.88 for Reynolds numbers range between 5000 and 18,000 under uniform heat flux conditions. The experiments using the twisted tape and with wire coil performed under similar operation test conditions, for comparison. The experimental results indicate that the tube with the various inserts provides considerable improvement of the heat transfer rate over the plain tube. The experimental results demonstrate that friction factor (f) and thermal enhancement index increase with decreasing twist ratio (y/w). The results also show that the wire coils along with twisted tapes are more efficient than the TT for heat transfer enhancement. P. B. Malwadkar, et al. (2014) [5] investigated experimental of the augmentation of turbulent flow heat transfer in a horizontal tube by means of Matrix coil wire inserts with air as the working fluid. Experiments were carried out for plain tube with/without Matrix coil wire insert at constant wall heat flux and different mass flow rates. The Matrix coil wire inserts are of same pitch but three different density of 8, 10, 12 no of turns per pitch and different material. The Reynolds number varied from 6000 to 13000. Both heat transfer coefficient and pressure drop are calculated and the results are compared with those of plain tube. It was found that the enhancement of heat transfer with Matrix coil wire inserts as compared to plain tube varied from 42% to 179 % for various inserts. Anil Kumar and Man-Hoe Kim (2016) [6] presented heat transfer and fluid flow characteristics in a solar air heater channel with multi V-type perforated baffles. The flow passage has an aspect ratio of 10. The relative baffle height, relative pitch, relative baffle hole position, flow attack angle, and baffle open area ratio are 0.6, 8.0, 0.42, 60_, and 12%, respectively. The Reynolds numbers considered in the study was in the range of 3000–10,000. The turbulence model has been used for numerical analysis, and the optimum relative baffle width has been investigated considering relative baffle widths of 1.0–7.0.The numerical results are in good agreement with the experimental data for the range considered in the study. Multi V-type perforated baffles are shown to have better thermal performance as compared to other baffle shapes in a rectangular passage. The overall thermal hydraulic performance shows the maximum value at the relative baffle width of 5.0.

The impact of using spring inserts within a horizontal condenser on condensation heat transfer enhancement of R-600a was investigated by Hadi Ahmadi Moghaddam, et al. (2019) [7]. A copper tube of 8.1 mm in internal diameter, 0.71 mm in wall thickness, and 1000 mm in length served as the condenser. Five coiled wires were employed inside the test pipe, with different wire diameters of 0.5, 1, and 1.5 mm and coil pitches of 10, 20, and 30 mm. The findings showed that coiled wires are useful tools for improving the condenser's heat transfer. Regarding this, out of all the inserts, the coiled wire with a wire diameter of 1.5 mm and a coil pitch of 10 mm performed the best, with a heat transfer coefficient increase of up to 107% over the smooth tube. Additionally, the usage of springs was shown to influence the flow pattern's transition from annular to intermittent, and the annular regime was discernible at a lower vapor quality than the smooth tube.

A numerical simulation of the airflow of heat exchange elements, which are springs positioned at 45° and 90° angles, was shown by Olga Soloveva, et al. (2022) [8]. The element packaging has several porosities, ranging from 0.75 ε= to 0.8 ε=, 0.85 ε= to 0.9 ε= to 0.95 ε=.ANSYS Fluent (v. 19.2) was used to perform numerical simulations for a range of airflow velocities. An analysis was conducted to determine how heat exchange elements and air velocity parameters affected the energy efficiency rating.

In a transition flow regime, forced convection tests were performed by Devendra Kumar Vishwakarma , et al. (2023) [9] to examine the changes in pressure drop and heat transfer inside a circular duct that was heated uniformly and included full-length spring tape inserts with different spring ratios. To cover all three flow regimes, experiments were carried out for three constant heat fluxes of 2, 3, and 4 kW/m2, with Reynolds numbers ranging from 502 to 10936. The Reynolds number width of the transition for a plain channel heated by 2 kW/m2 is 886. The transition starts at a Reynolds number of 2897 and ends at a Reynolds number of 3783. When a channel with spring tape and a spring ratio of 3 experiences the same heat flux, the transition starts at Reynolds number 661 and ends at 1734; however, when a channel with a spring ratio of 5, the transition starts at 1305 and finishes at 2226.

In the present study, experimental and theoretical study the problem of turbulent forced convection heat transfer enhancement in a horizontal circular duct with wire coil and swirl tape inserts.

The experiments are performed using the tape with three different twist ratios (y/w = 3, 4 and 5) a Reynolds number range from 10.328×10^3 to 11.769×10^3 and 10.927×10^3 to 12.029×10^3 in the tube without and with spring inserts. While Reynolds number ranges from 11.077×10^3 to 11.963×10^3 and 11.637×10^3 to 12.153×10^3 in the tube without and with swirl inserts. The flow is steady, turbulent, incompressible and one dimension. The experiments were conducted to examine the effect of using inserts on heat transfer and fluid flow characteristics of air flow in a tube.

2. Experimental Rig

The apparatus consists of a blower unit fitted with a pipe, which is connected to the test section located in a horizontal orientation. A nichrome bend heater encloses the test section to a length of a 40 cm. Four thermocouples, $T2$, $T3$, $T4$ and $T5$, at a distance of 5 cm, 15 cm, 25 cm and 35 cm from the origin of the heating zone are embedded along the walls of the tube, and two thermocouples are placed in the air stream, one at the entrance ($T1$) and the other at the exit ($T6$) of the test section, to measure the temperature. The experiments were conducted to examine the effect of using Sinusoidal corrugated sheet plate on heat transfer and fluid flow characteristics of air flow in a tube. The geometry and coordinate system is shown in Fig. 1.

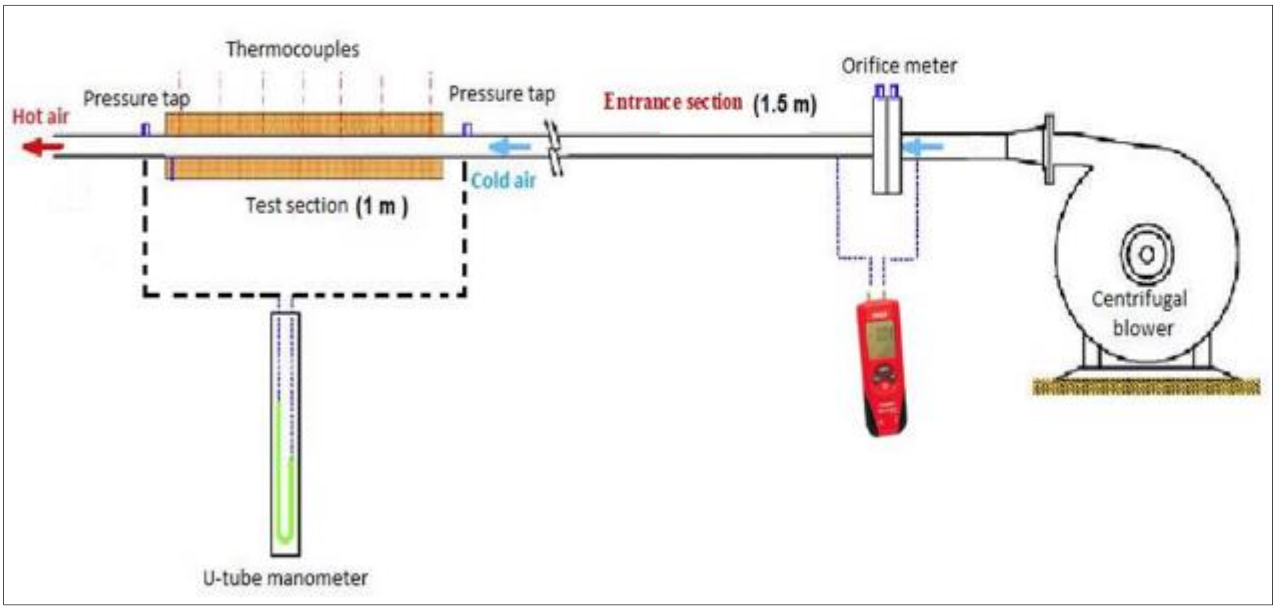

Figure 1 Schematic diagram of experimental setup

2.1. Test section

The air is passed to the test section which is circular tube outer diameter OD (2.7) cm, inner diameter ID (2.2) cm with length as 1 m as shown in figure 2. The entrance section is used cylindrical tube with outer diameter OD (2.7) cm, inner diameter ID (2.2) cm with length as 1.5 m to obtain a fully developed to the flow. To minimize the heat loss from test section to the ambient, the duct is insulated with 5 mm thick coated fiberglass standard sheet.

Figure 2 Test section fitted with insulation

2.2. Inserts

2.2.1. Twisted Tape Inserts and wire coil Inserts

The tapes consist of uniformly long aluminum strips of desired width, which have been twisted about the longitudinal axis. All tapes used in the present work are made of aluminum strip with 0.5 mm thickness (t) and (20 mm) width (w). The length between the two cuts was set equally to the pitch length (y). The taps were prepared with three different twist ratios (y/w) = 3, 4 and 5, and three different depth of wing cut ratios (DR = t/w = 0.025) as shown in figure 3.

Also a wire coil having three different twist ratios (y/w) = 3, 4 and 5, is used to generate co-swirl where twist ratio is defined as twist length (l) to coil width (w). The geometrical configurations of the wire coil are presented in Figure 4. To produce the twisted tape, one end of a straight tape was clamped while another end was carefully twisted to ensure a desired twist length. The details of inserts are shown in table 1.

Table 1 Twisted Tape Inserts and wire coil

Inserts length L (mm)	**Inserts width W (mm)**	**Inserts No. N**	**Pitch Y (mm)**	**twist ratios (y/w)**	**Inserts angle α**
1000	20	17	60	3	33.7˚
1000	20	13	80	4	26.5˚
1000	20	10	100	5	21.8˚

Figure 3 Geometrical configurations of the spring inserts

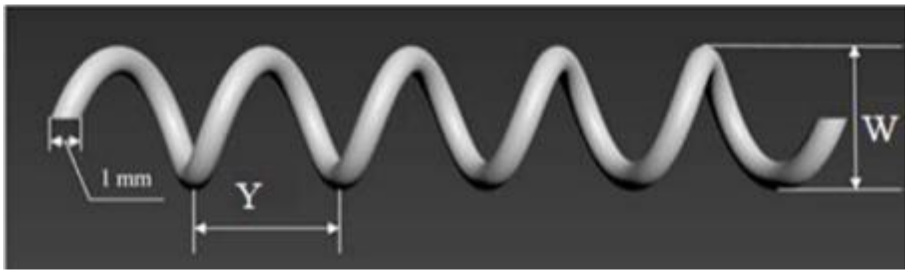

Figure 4 Geometrical configurations of the wire coil

2.3. Test rig instruments

2.3.1. Air Flow Rate

The air flow rate to the test rig was measured by an orifice designed according to B.S.1042, with (1.23) cm diameter. The orifice meter was calibrated using a pitot tube with an accuracy of 2% of full scale are employed to measure the air volumetric.

2.3.2. Temperature

A 12-channals temperature recorder 12 channels model (COMECO-TC800) with SD card to save the data along with time information paperless is used to measure and display the temperatures in seven regions from entrance section. The K-type copper-constantan thermocouples with an accuracy of 0.2% of full scale are used to measure air temperature from entrance section. Seven thermocouples were situated along the test section wall surface to find out the average Nusselt number.

2.3.3. Power Supply

Flexible electrical wire heaters used for heating the test section provided a uniform heat flux. Heaters are placed on the external surface of tube with the same distance from on to the other of the perimeter circular tube. The electrical output power was controlled by a variac transformer type CENH/TDGC-500VA is used to supply the electrical power to the heater wire with constant voltage level, i.e. a constant heat flux. The current is in the range of (0-220) V and (0-0.9) A to obtain a constant heat flux along the length of the test section.

2.3.4. Pressure

There are two pressure taps on wall upstream of the test section and the orifice plate. Carbon tetra-chloride is the working fluid in the U-duct manometer used to measure the pressure drop across the orifice meter with specific gravity (SG) of 1.588.

There are two gauge pressures to measure the pressure drop across the test section with an accuracy of (±0.02).

3. Experimental procedures

In the apparatus setting above

- The inlet bulk air at 20 ˚C from a 7.5 kW blower was directed through the orifice meter and passed to the heat transfer test section
- The volumetric air flow rates from the blower were adjusted by varying motor speed through the inverter, situated before the inlet of test tube.
- The bulk air was heated by an adjustable electrical heater wrapping along the test section.
- Both the inlet and outlet temperatures of the bulk air from the tube were measured.
- For each test run, it was necessary to record the data of temperature, volumetric flow rate and pressure drop of the bulk air at steady state conditions in which the inlet air temperature was maintained at 20 ˚C.

4. Experimental Calculation

The experimental calculations were presented in terms of pressure drop, heat flux, Reynolds number and Nusselt number. In the apparatus setting above, the inlet bulk air at 20 C from a blower and passed to the heat transfer test section.

4.1. Air flow rate

The volumetric flow rate in terms of the head differential across the orifice plate Δh, was deduced from the well-known equation presented by **Frank (2003) [10]**:

$$\dot{V}_a = C_d A_o \sqrt{\frac{2g\Delta h_o}{1-\beta^4}} \quad \text{.................. (3)}$$

$$\dot{m}_a = \rho \dot{V}_a \quad \text{.................. (4)}$$

Where: $C_d = 0.72$, $A_o = \frac{\pi}{4} d_o{}^2$, $A_o = 2.826 \times 10^{-5} m^2$

4.2. Heat Transfer

$$Q_a = Q_{conv.} \quad \text{................................ 1}$$

Where

$$Q_a = mCp_a(T_{out} - T_{in}) \quad \text{.......................... 2}$$

Where: $m = mass\ flow rate$

$$m = \rho VA \quad \text{........................... 3}$$

The convection heat transfer from the test section can be written by:

$$Q_{conv} = hA(T_w - T_b) \quad \text{.......................... 4}$$

Where: $T_b = \frac{T_{aout} + T_{ain}}{2}$ 5

Where Tw is the local wall temperature and evaluated at the outer wall surface of the inner tube.

The average wall temperatures are calculated from 6 points, lined between the inlet and the exit of the test pipe.

The heating surface area, a based on the inner tube diameter (D) was used in all calculations for tube with/without tabulators.

The various characteristics of the flow, the Nusselts number, and the Reynolds numbers were based on the average of tube wall temperature and outlet air temperature.

The local wall temperature, inlet and outlet air temperature, and air flow velocity were measured for heat transfer of the heated tube with a disk tape. The average Nusselt numbers were calculated and discussed where all fluid properties were determined at the overall bulk mean temperature. Then we can calculate Nusselt number:

$$Nu = \frac{hD}{K} \quad \text{.................................} \ 6$$

Where:
D = duct diameter

The Reynolds number is given by:

$$\mathrm{Re} = \frac{\rho u_m D}{\mu} \quad \text{..........................} \ 7$$

4.3. Enhancement Evaluation:

The enhancement percentages for the heat transfer coefficient and Nusselt number of wavy plate at the same heat flux can be written as:

$$\eta_{Enh,h} = \frac{h_{Inser} - h_{plain}}{h_{plain}} \quad \text{.............} \ 8$$

$$\eta_{Enh,Nu} = \frac{Nu_{Insert} - Nu_{plain}}{Nu_{plain}} \quad \text{.............} \ 9$$

The pressure drop deterioration, Δp_{Det} at constant pumping power and heat flux is the ratio of the mean pressure drop of the duct with corrugated plate to the flat plain duct which can be written as follows:

$$\Delta P_{Det} = \frac{\Delta P_{baffle}}{\Delta P_{plain}} \quad \text{................} \ 10$$

The deterioration percentage of pressure drop for the corrugated plate when compared with that of flat plain surfaces is expressed as:

$$\eta_{Det,P} = \frac{\Delta P_{baffle} - \Delta P_{plain}}{\Delta P_{plain}} \quad \text{..........................} \ 11$$

5. Results

In this work the analysis was done for inserting baffles into duct that devices promote mixing of coolants and baffles can significantly disturb the air flow.

Experimental results achieved for air Reynolds number range from 10.328×10^3 to 11.769×10^3 and 10.927×10^3 to 12.029×10^3 in the tube without and with coil wire inserts. While Reynolds number range from 11.077×10^3 to 11.963×10^3 and 11.637×10^3 to 12.153×10^3 in the tube without and with swirl inserts. The tests were carried out at constant Prandtl number of 0.71.

Figure 5 and 6 shows a comparison of the local heat transfer coefficient and Nusselt Number with test section distance for both of the coil wire ratio at the same heat flux (600 W/m².C). At the given Reynolds number, the local heat transfer coefficient and local Nusselt number consistently increases with the decrease of twist ratio (y/w). This is due to the fact that, the tape with smaller twist ratio (y/w) induces stronger swirl/turbulent intensity, and also gives longer flowing path, leading to longer residence time and thus more efficient heat transfer compared to that with larger twist ratio (y/w).

The heat transfer coefficient increases at about (38%, 43%) for coil wire ratio (y/w =3) when compared with coil wire ratio (y/w =4) and (y/w =5). Nusselt number increases at about (21% and 32%) when compared with coil wire ratio (y/w =4) and (y/w =5), respectively.

The results of the measurements with using the enhancement devices are also shown in Figure 7. In the figure, shows the variation of the outlet air temperature with for smooth tube and coil wire ratio (y/w =3) at heat fluxes (600) W/m^2 with test section distance. It can be seen that use of the baffle with the increased velocity a higher heat transfer rate than that smooth tube alone. The increase in outlet air temperature with insert can be explained by two mechanisms: firstly, the surface of the inserts tube may be act as extended heat transfer surfaces and secondly, it is due to strong turbulence/swirl flow created by the tape.

Figure 8 shows the variation of the outlet air temperature with test section distance for smooth tube at heat fluxes (600) W/m^2 and (800) W/m^2 respectively. Outlet air temperature tends to increase as heat flux increases due to higher heat transfer rate. The outlet air temperature from tube with inserts tube provides higher temperature by (11 Cº) at heat fluxes (800) W/m^2 than the heat flux (600) W/m^2 due to enhancement heat transfer coefficient.

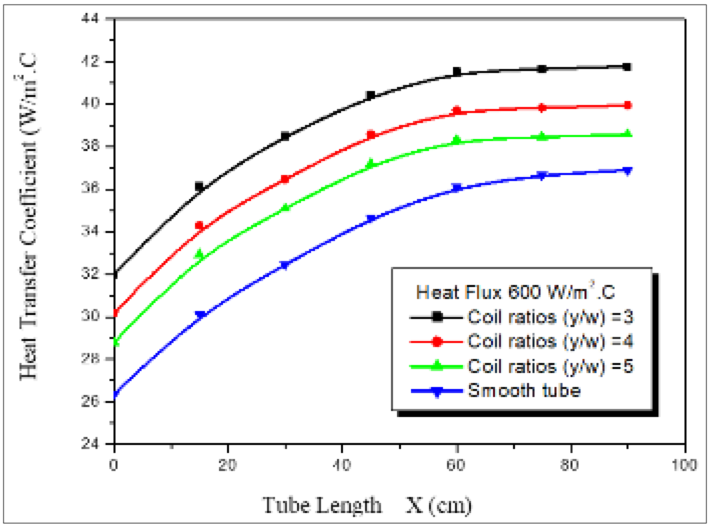

Figure 5 A comparison of the local heat transfer coefficient with test section distance for both of the coil wire ratio at the same heat flux

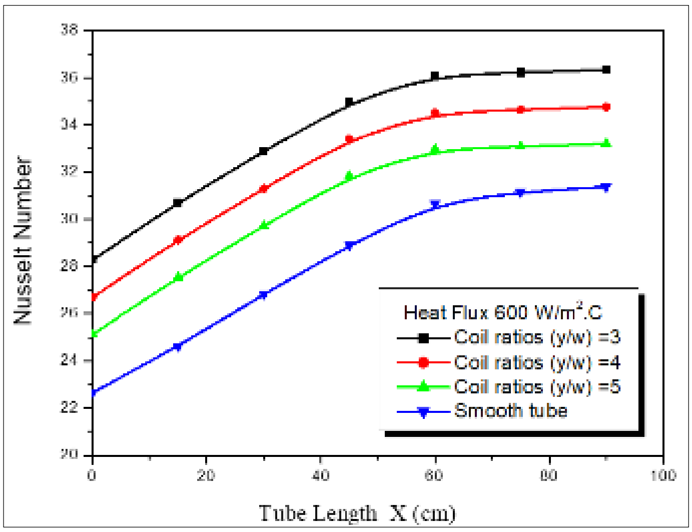

Figure 6 A comparison of the local Nusselt number with test section distance for both of the coil wire ratio at the same heat flux

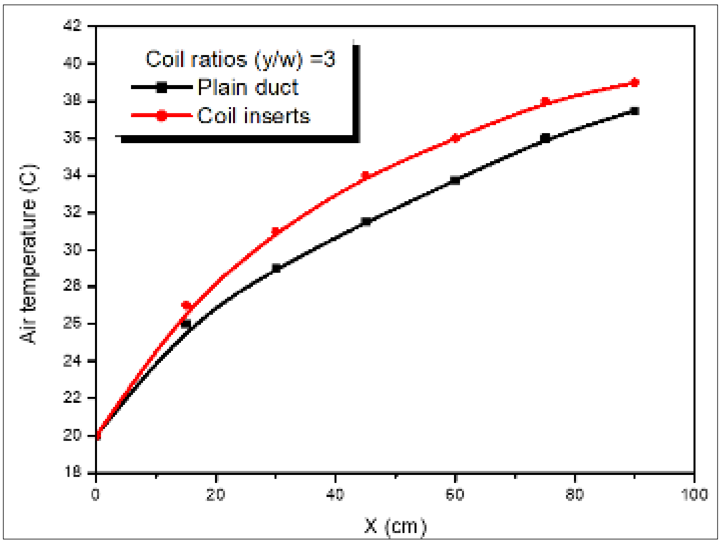

Figure 7 Air temperature with Tube length distance for coil wire (Heat Flux = 600 W/m^2)

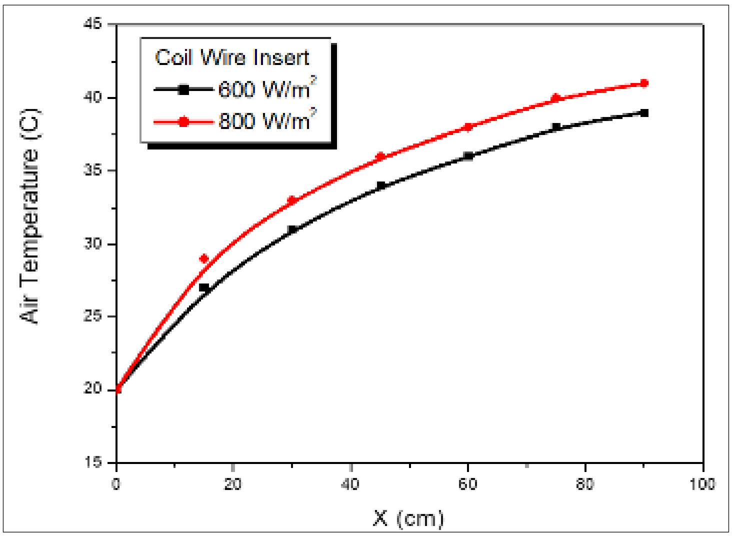

Figure 8 Air temperature with Tube length distance for coil wire (Heat Flux = 600 and 800 W/m^2)

Nomenclature

A: heat transfer surface area of test duct, (m^2)

Cp: Specific heat, (J/ kg.C)

D: Tube diameter , (m)

do: Orifice diameter, (m)

h: Heat transfer coefficient, (W/m^2 K)

I: Current, (A)

K: Thermal conductivity, (W/m K)

L: Tube length, (m)

$\dot{m}$: Mass flow rate , (kg/s)

Nu: Nusselt number, Dimensionless

P: Perimeter, (m)

Δp: pressure drop, (Pa)

Pr: Prandtl number (Dimensionless)

Qair: Air cooling load, (W)

Re: Reynolds number (Dimensionless)

T: Temperature, (̊C)

u: Air velocity, (m/s)

V: Voltage, (V)

Subscript

a: air

Ab: Air bulk

ai: Air inlet

ao: Air outlet

av: Average

Conv: Convection

Enh,m: Mean enhancement

Enh,h: Heat transfer coefficient enhancement

Enh,Nu: Nusselt enhancement

m: Mean

o: Orifice

w: wall

Greek Symbols

Δ: Difference

μ: Air viscosity, (Pa.s)

Ρ: Air density, (kg/m^3)

6. Conclusion

The following findings can be deduced from the present work

- The tube with coil wire inserts provide local heat transfer coefficient percentages of (5.1% to 7.8%) for heat fluxes (600) W/m^2 and (800) W/m^2 respectively.
- The enhancement percentages for the local Nusselt number of coil wire inserts at the same heat flux for heat fluxes (600) W/m^2 are (4.6%) and (6.1 %) than plain tube.
- The percentage of heat transfer coefficient for the coil wire when compared with that of swirl inserts tube were ranged between (10.6%) to (16.5%) and (11.5%) to (17.3%) for the heat flux (600) W/m^2.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

References

[1] Chinaruk Thianpong Experimental investigation of heat transfer and flow friction in a circular tube fitted with regularly spaced twisted tape elements Numerical Heat Transfer, Part A, 37:37-54, 2010.

[2] S. Naga Sarada, A. V. Sita Rama Raju, K. Kalyani Radha, and L. Shyam Sunder, Enhancement of heat transfer using varying width twisted tape inserts, International Journal of Engineering, Science and Technology, vol. 2, pp.107-118, 2010.

[3] S. Choudhari Shashank, and S.G. Taji, Experimental Studies on Effect of Coil Wire Insert On Heat Transfer Enhancement and Friction Factor of Double Pipe Heat Exchanger, International Journal of Computational Engineering Research, vol. 3, pp. 32-39, May. 2013.

[4] Dr. A. G. Matani, Swapnil A. Dahake Experimental Study on Heat Transfer Enhancement in a Tube Using Counter/Co-Swirl Generation, International Journal of Application or Innovation in Engineering & Management (IJAIEM), Volume 2, Issue 3, March 2013.

[5] P.B.Malwadkar , et al. Experimental Investigation of Heat Transfer Performance of Matrix Coil Wire Inserts using CFD, Journal of Emerging Technologies and Innovative Research (JETIR), Volume 1 Issue 7, Dec 2014.

[6] Anil Kumar and Man-Hoe Kim, Thermal Hydraulic Performance in a Solar Air Heater Channel with Multi V-Type Perforated Baffles, Energies 2016, 9, 564, www.mdpi.com/journal/energies, 2016.

[7] Moghaddam, Hadi Ahmadi, Alireza Sarmadian, and Maziar Shafaee. An experimental study on condensation heat transfer characteristics of R-600a in tubes with coiled wire inserts. Applied Thermal Engineering 159 (2019): 113889.

[8] Soloveva, Olga, et al. Study of the heat transfer efficiency of spring elements for use in transport. Transportation Research Procedia 63 (2022): 1007-1014.

[9] Vishwakarma, Devendra Kumar, et al. Thermo-Hydraulic Performance of Spring Tape Inserts in a Circular Channel in Transitional Flow Regime. Heat Transfer Engineering (2023): 1-15.

[10] Frank M., " Fluid Mechanics", Fourth Edition, NASA/Color-Pic Inc., 2003

[11] Broughton, R. C. & Oliver, A. J. A Numerical Model for Convection in Complex–Dimensional Geometries and it is Application to Buoyancy flow in Power Cable International Heat Transfer Conferences, vol. 2, pp. 447 - 451, 1986.

[12] Focke, W. W., Zachariades, J. & Olivier, I. Augmentation of Turbulent Flow Heat Transfer in A Horizontal Tube With Varying Width Twisted Tape Inserts, Int. J. Automotive and Mechanical Engineering (IJAME). Vol. 6, pp. 797-810, July-December 2012.

[13] INDRAKANT SINGH, DR. NILESH DIWAKAR Heat Transfer Enhancement Using Different Geometry of Twist Tape Tabulator: A Review International Journal of Applied Research in Mechanical Engineering (IJARME) ISSN: 2231 –5950, Vol-3, Iss-2, 2013.

[14] TA-SUNG HUANG, et al. Heat and Fluid Flow Analysis over Different Tube Inserts of Recuperator China Steel Technical Report, No. 21, pp.67-76 , 2008.

[15] Jitendra Kumar PatroExperimental Studies on Heat Transfer Augmentation Using TMT Rods with and without Baffles as Inserts for Tube Side Flow of Liquids, MSc. Thesis, Department of Chemical Engineering National Institute of Technology, Rourkela, 2012.

[16] S. Eiamsa-ard and P. Promvonge Enhancement of Heat Transfer in a Circular Wavy-surfaced Tube with a Helical-tape Insert,International Energy Journal, Volume 8, pp.29-36 , 2007.

[17] Prashanta Dutta, Sandip Dutta, Effect of baffle size, perforation, and orientation on internal heat transfer enhancement , International Journal of Heat and Mass Transfer, Volume 41 , pp. 3005-3013, 1998.

[18] M.B.W. Nabhan, A study of Heat Transfer Enhancement on a Tilted Rectangular Stainless Steel Plate 6th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics 30 June to 2 July 2008 , Pretoria, South Africa.

[19] R. M. Majumdar and V. M. Kriplani Review of internal cooling augmentation using baffles, Journal of Mechanical Engineering Research Vol. 5(2), pp. 26-31, February 2013.

[20] Chii Dong Ho, Hsuan Chang, Rei Chi Wang and Chun Sheng Lin, Analytical and Experimental Study of Recycling Baffled Double-Pass Solar Air Heaters with Attached Fins, Energies, Volume 6, PP.1821-1842, 2013.

[21] Holman, J.P., Heat Transfer ,Tenth Edition, Published by McGraw-Hill, a business unit of The McGraw-Hill Companies, Inc., 2010.

[22] Fahmy Salah, Effect of semi-circular baffle blocks on local scour downstream clear-overfall weirs, Ain Shams Engineering Journal Volume 4, Issue 4, Pages 675–684, December 2013.

[23] Promvonge, P., and Eiamsa, S., Heat Transfer Augmentation in A Circular Duct Using V-nozzle Turbulator Inserts and Snail Entry, in Experimental Thermal and Fluid Science 32, pp. 332–340, 2007.

[24] Oguz Turgut and Erkan Kizillirmak, Effects of Reynolds Number, Baffle Angle, and Baffle Distance on Three-Dimensional Turbulent Flow and Heat Transfer in a Circular Pipe, Department of Mechanical Engineering, Faculty of Engineering, Gazi University, 06570 Maltepe/Ankara, Turkey,2013.