# Heat Transfer Enhancement of Shell-And-Coiled Tube Heat Exchanger Utilizing Helical Wire Turbulator

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**Abstract**— *in present study, a shell and coiled tube heat exchanger is experimentally studied in which a helical wire has been placed inside the helically coiled tube as a turbulator. The fabrication method of helically coiled tube which contains turbulator and also the effects of turbulator on thermal and frictional characteristics of heat exchanger are presented in this paper. Experiments were performed in two main modes. In first mode, the fluid of coiled tube was water and in second mode the fluid of coiled tube was air. Each mode was studied for both empty coiled tube (without turbulator) and with turbulator under different fluid flow rates. The fluid of shell side was hot water for all cases. Findings showed that this type of turbulator can be employed in coiled tubes which significantly increased the overall heat transfer coefficient and obviously pressure drop. Overall heat transfer coefficient, pressure drop, effectiveness and NTU are evaluated and discussed.*

**Keywords**— shell-coiled tube heat exchanger; experimental investigation; pressure drop; turbulator; heat transfer coefficient.

## Introduction

In recents years, researchers have tried to reduce the size and weight of heat exchangers without reduction of heat transfer rate. Related to this point of view, helical tubes are considered as one of the most appropriate tubes because of their smaller size and higher performance. Nonetheless, other heat transfer enhancement techniques such as nano-fluids, conical tubes and bubble injection etc. These are employed in order to enhance the thermal performance of coiled tubes. However, turbulators were not extensively employed as heat transfer improvement method for helical tubes (shell-coiled tube heat exchanger) in previous studies. Thus, in this paper, helical wire was used as a turbulator for helical tube through a shell-coiled tube heat exchanger. The main studies on coiled tubes are summarized as below.

These are studied on heat transfer and pressure drop of a heat exchanger which is constructed by placing spring-shaped wires with varying pitch within a helical pipe. They observed that the helical spring elements placed inside the helical pipes improve heat transfer but cause an appreciable increase in pressure losses.[The best heat transfer was achieved with the smallest pitch/wire diameter ratio] Experimentally and numerically evaluated the performance of helical coiled tube heat exchanger with different curvature ratio and coil pitch. The performance of heat transfer in helical coiled tube heat exchanger with wire coil inserts was evaluated. Coiled wire of different pitches and same diameter were fabricated and used as tube inserts in copper helical coiled heat exchanger. An average increase of 120% in the coil side inside heat transfer coefficient was observed for coil tubes with 3mm pitch spring inserts. The effect of alumina/water nano-fluid with five different weight concentrations (from 0.78% wt. to 7.04% wt.) on convective heat transfer characteristics was experimentally studied by Wu et al. for a double-pipe helically coiled heat exchanger.

## Principle

When nano-particles on the critical Reynolds number is negligible. Moreover, the heat transfer enhancement of the nano-fluids compared to water was from 0.37% to 3.43% according to the constant flow velocity basis. Numerical investigation on heat transfer characteristics in double tube helical heat exchangers have already been taken. Also there have been experiments on condensation heat transfer of R-134A in horizontal straight helically coiled tube-in-tube heat exchangers. Evaporation heat transfer and condensation heat transfer of HFC-134a in a helically coiled concentric tube-in-tube heat exchanger. Experimental studied on thermal characteristics of a double-pipe helical heat exchanger. The effect of cold and hot fluid flow rates on overall heat transfer coefficient, inner tube Nusselt number and annulus Nusselt number were discussed. Their findings showed that, said parameters increases with the increase of hot or cold fluids flow rates. Recently, there have been focused on exergetic behaviour of coiled tubes. They studied on the effect of different geometrical, thermodynamic and fluid flow characteristics on exergetic behaviour of coiled tubes. Most recently, Mashoofi et al. investigated the effect of helical wire of thermal behaviour of tube-in-tube helically coiled tube heat exchangers. In this paper an especial method are presented to insert a turbulator (helical wire) inside a coiled tube of shell-coiled tube heat exchanger. Heat transfer rate, pressure drop, effectiveness and NTU are studied. Memorable behaviours were observed for effectiveness. The reasons which improve the heat transfer rate and increase the pressure drop were discussed from new point of view.

## Components

### A. *Turbulator*

Helical wire is employed as a turbulator in this paper as shown in Fig. 1. There is an important point related to inserting a helical wire into a helical tube. Helical wire should be inserted into the tube before coiling operation (when the tube is straight tube). Indeed, in this paper, the helical wire was inserted inside a straight tube (with length of 1.8 m) and then the straight tube was transformed into a helical tube via a special machine which can be seen in Fig. 2. Geometric specifications of turbulator are presented in Table 1.

**Fig. 1:** Helical wire

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**Table 1.** Geometric specifications of turbulator (helical wire)

| Pitch (mm) | Helical diameter (mm) | Wire diameter (mm) |
|---|---|---|
| 5 | 4 | **0.9** |

### B. *Stimulation*:

**Fig. 2:**

In this paper, stimulations were performed in two main modes. In first mode, the fluid of coiled tube was water and in second mode the fluid of helical tube was air; (shell side fluid was always hot water). Each mode was tested for both with turbulator and without turbulator. Thus, totally four modes were investigated. Experiments procedure including hot water flow rate (shell side), cold water rate or air flow rate (coil side) and inlet temperatures are presented in Table 2 for main modes. All procedures shown in Table 2 were carried out for both empty coiled tube and coiled tube with turbulator.

**Table 2: Temperature specifications**

| First mode (fluid of coiled tube is water) | | | |
|---|---|---|---|
| Coil side inlet temperature ($^0$C) ± 0.7 | Shell side inlet temperature ($^0$C) | Coil side water flow rate (LPM) | Shell side water flow ate (LPM) |
| 16 | 40 | 1, 1.5, 2, 2.5, 3 | 1 |
| 16 | 40 | 1, 1.5, 2, 2.5, 3 | 2 |
| 16 | 40 | 1, 1.5, 2, 2.5, 3 | 3 |
| 16 | 40 | 1, 1.5, 2, 2.5, 3 | 4 |
| 16 | 40 | 1, 1.5, 2, 2.5, 3 | 5 |
| **Second mode (fluid of coiled tube is air)** | | | |
| **Coil side inlet temperature ($^0$C)** | **Shell side inlet temperature ($^0$C)** | **Coil side air flow rate (LPM)** | **Shell side water flow ate (LPM)** |
| 18 | 40 | 1, 2, 3, 4, 5 | 2 |

### C. *Coiled tube:*

**Table 3**. Geometric specifications of coiled tube

| Turns | Pitch (mm) | Coil diameter (mm) | Tube inner diameter (mm) |
|---|---|---|---|
| 9.5 | 30 | 60 | 6 |

**Table 4**. Geometric specifications of shell

| Length (mm) | Thickness (mm) | Inner diametei |
|---|---|---|
| 400 | 2 | 110 |

## Calculations method

Overall heat transfer coefficient, pressure drop, effectiveness and also NTU effectiveness curves are four main parameters which are evaluated and discussed in present paper for different conditions. The average heat transfer rate (qave) can be calculated with:

**(qh + qc) (2)**

**= m h cph (Th,in – Th,out) (3)**

**= m c cpc (Tc,out – Tc,in) (4)**

The shell side surface was isolated during the stimulation and the difference between qh
and qc was less than 2%.

Overall heat transfer coefficient (Ui) is calculated by:

$$U_i = \frac{q_{ave}}{A\,\Delta T_{LMTD}} \quad (5)$$

$$\Delta T_{LMTD} = \frac{(T_{h,out} - T_{c,out}) - (T_{h,in} - T_{c,in})}{\mathrm{Ln}\left(\frac{T_{h\,out} - T_{c\,out}}{T_{h,in} - T_{c,in}}\right)} \quad (6)$$

$$\varepsilon = \frac{\text{actual heat transfer}}{\text{maximum possible heat transfer}} \quad (7)$$

In which maximum possible heat transfer is evaluated by:

**m.c(Th, inlet – Tc, inlet) (8)**

$(m\,.c)_{min}$ is evaluated using of cold fluid or hot fluid mass flow rate (minimum flow rate).

Hence, depending on $(m\,c)_{min}$ two different correlations are obtained for calculating of ε.

## Results and discussions:

### *Verification of empty tube (without turbulator)*

Validation was performed for empty tube (without turbulator). However, Nusselt number should be calculated in order to compare with other correlations. Hence, Wilson plots method was used to evaluate the amounts of Nusselt numbers as described below. Indeed, Wilson plots method is an appropriate technique for experiments in which only inlet and outlet temperatures have been recorded (temperature distribution on tube surface is not 2 required). hi is related to the overall heat transfer coefficient (Ui) by the flowing equation.

$$\frac{1}{U_i} = \frac{1}{h_i} + \frac{A_i \ln(\frac{d_o}{d_i})}{2KL\pi} + \frac{A_i}{A_o h_o} \quad (11)$$

Shell side Reynolds number is a constant value for set of coil side flow rates (see each row 5 of table 2). Thus, it can be assumed that ho and thereupon the last two terms on the right hand side of Eq. (11) are constants. The coil side heat transfer coefficient is assumed to behave in the following manner with the coil side Reynolds number:

$$\mathbf{h_o = B\ Re\ m\ (12)}$$

Eq. (12) is substituted into Eq. (11) and the values of constant B and the exponent m are obtained through curve fitting. The coil side heat transfer coefficients (hi) could then be calculated. Hence, the experimental Nusselt number can be evaluated by :

$$Nu_{exp} = \frac{h_i\, d}{K}$$

The range of De and Pr for present experiments (air fluid) is 71 < De < 357 and Pr=0.71.

Hence, validation was performed by Kalb and Seader equation.

## Heat transfer analysis

### *A. First mode (fluid of coiled tube is water):*

The amounts of overall heat transfer coefficient are presented in Fig. 3. Fig. 3 (a) is related to empty coiled tube (without turbulator) and Fig. 3 (b) is related to coiled tube which contains turbulator.

As seen in Fig. 3, employment of turbulator causes improvement of overall heat transfer coefficient. Moreover, the amount of U is increased with increment of cold or hot fluid flow rate too. The reasons of heat transfer enhancement due to using of turbulator (helical wire) can be explained as below.

The key roles of turbulator are increment of turbulence level of fluid flow and mixing thermal boundary layer. In present study, fluid of coiled tube is strongly mixed due to contact with helical wire (turbulator) through the helical tube which increases the heat transfer rate and subsequently overall heat transfer coefficient. For first mode, turbulator increased the heat transfer rate between 59 and 78 % (depending on flow rate). Maximum improvement is observed in 3 LPM of coil side and 5 LPM of shell side.

In addition to key role of turbulators, there is another significant reason which causes enhancement of U as described below. Obviously, turbulator reduces the effective inner volume of coiled tube. On the other hand, each turbulator causes reduction of effective diameter of tube. Hence, a hydraulic diameter is defined and the effective cross section are of coiled tube is calculated using of hydraulic diameter. The amount of hydraulic diameter is always less than tube diameter. Thus, the amount of cross section area from which the coil side fluid passes is reduced for coiled tube which contains turbulator. Hence, for a constant water flow rate, the water mean velocity (and obviously Reynolds number) of empty tube is less that the coiled tube which contains turbulator. Higher Reynolds number means higher heat transfer rate. Fig.  shows the amounts of Reynolds number for empty coiled tube and coiled tube with turbulator. Reynolds number was calculated with flowing equations. For coiled tube with turbulator, hydraulic diameter was placed instead of tube diameter. "d" is tube diameter of coiled tube (inner diameter). It should be noted that, "rc", "e" and "b" are related to turbulator (helical wire). "rc" is curvature ratio of helical wire (turbulator), "e" is wire diameter and "b" is the pitch of helical wire. Tube diameter of coiled tube is around 6 mm however the amount of hydraulic diameter (after inserting the turbulator) is around 3.51 mm. In most studies related to turbulators, the effect of hydraulic diameter is ignored which seems is incorrect. Indeed, for this type of turbulator (helical wire), evaluation of hydraulic diameter (due to turbulator) is important because this type of turbulator occupies a significant volume of inside of tube.

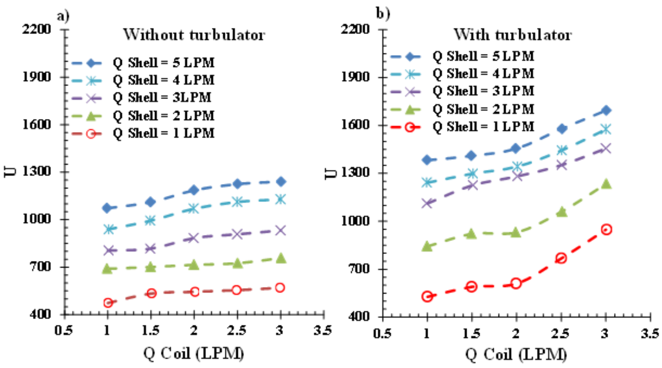


**Fig. 3:** Overall heat transfer coefficient for first mode (a) without turbulator b) with turbulator

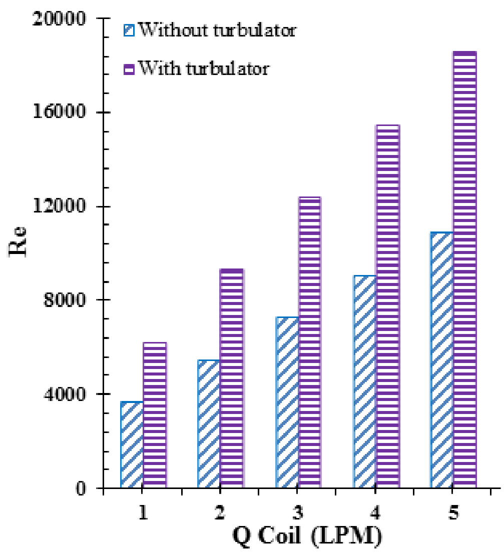


**Fig. 4:** Reynolds number of each flow rate for with and without turbulator

## *B. Second mode (fluid of coiled tube is air)*

The amounts of overall heat transfer coefficient are presented in Fig. 5 for second mode. Fig. 5 (a) is related to empty coiled tube (without turbulator) and Fig. 5 (b) is related to coiled tube which contains turbulator. Depending on air flow rate, turbulator increases the amount of heat transfer rate between 26 and 52%. Maximum enhancement was observed at 5 LPM. In addition to two reasons of heat transfer enhancement due to turbulator which was described for first mode, there is another memorable reason for second mode (air fluid). Indeed, as described in first mode, the main reason is mixing behavior of turbulator and the next reason is related to hydraulic diameter and increment of Reynolds number. However, for air fluid another reason can be explained as below. Obviously, using of turbulator causes increment of requirement air inlet pressure (for a defined air volumetric flow rate). Increment of air inlet pressure increases the numerator of Eq. (18). Hence, subsequently air inlet density is increased. And according to increment of air inlet density increases the air inlet mass flow rate (Kg/s). It should be noted that air volumetric flow rate (Qa) which is measured by Rota-meter (LPM) does not change. And finally according to increment of mass flow rate (m ) increases the amount of heat transfer rate. Indeed, although the values of volumetric air flow rate are the same (for example 2 LPM) for both empty tube and coiled tube with turbulator, their mass flow rates are different. It should be noted that, this event is occurred only for gas fluids (because of compressibility) and not for liquids. Indeed, for liquids (water), inlet pressure does not have effect on inlet water density (or it is very negligible). Fig. (6) shows the amounts of 2 air mass flow rates for each volumetric air flow rate (with and without turbulator).

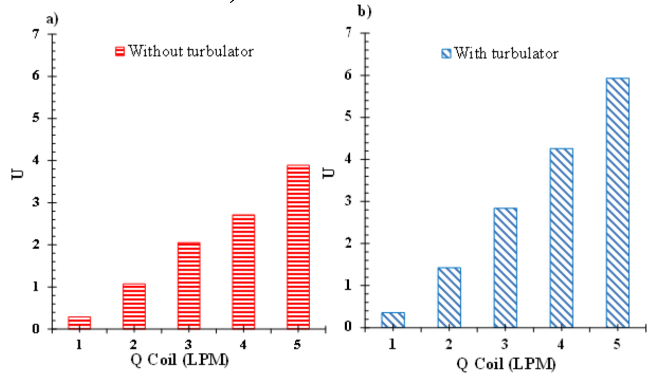


**Fig. 5**: Overall heat transfer coefficient a) without turmulator b) turmulator

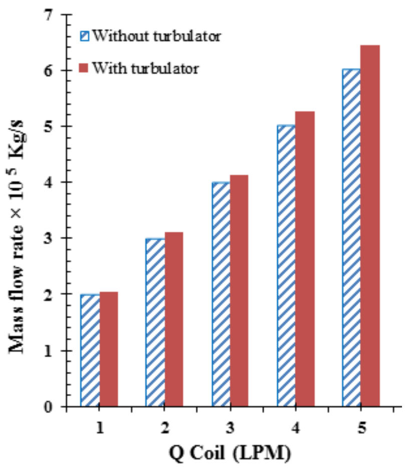


**Fig. 6.** Mass flow rate for each volumetric air flow rate

## Effectiveness

***First mode (fluid of coiled tube is water)*** Effectiveness of empty coiled tube (without turbulator) and with turbulator are presented in Fig. 7(a) and Fig. 7(b) respectively. As seen in Fig. 7, the behavior of effectiveness can be descending or ascending or a combination of both of them. The reason is directly related to the amount of _m c. Indeed, as described in section 4, effectiveness may be calculated with Eq. (9) or Eq. (10). For a constant curve, some points may be evaluated via Eq. (9) and other points are evaluated via Eq. (10). A peak pint is observed for those cases. If al points are calculated with one of the equations, the curves shows a constant behavior (descending or ascending) For example, in Fig. 7(b), the behavior of Qshell = 1LPM is ascending. In this 12 case,_m c is calculated with shell side flow rate (because it is less than coil side flowrate for all points of this case). Hence, denominator of is constant and the amount of nominator increases. Thus, the amount of effectiveness is increased with increment of coil side flow rate. Now consider shell side flow rate of 5 LPM. In this case, both denominator and nominator of are variants. Indeed, the amount of _m c is calculated with coil side flow rate (because coil side flow rate is less than shell side flow rate for all points of this case). The increment rate of denominator is more than the increment rate of nominator and the result is descending behavior of this case. For shell side flow rate of 2 LPM _m c_is evaluated from coil side flow rate for three initial points and is evaluated from shell side flow rate for two final points.As a result, effectiveness curves do not have an absolute behavior and it depends on m c. If in another paper, a constants behavior is observed for all cases, it means that 24 the range of tested flow rates creates a constant value of m c for all points.

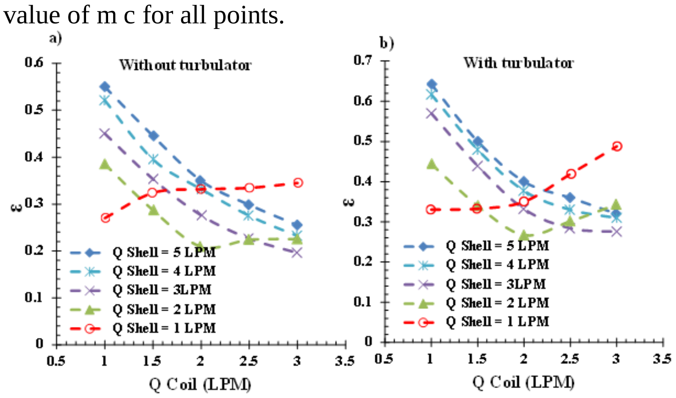


**Fig. 7:** Effectiveness for first mode (a) without turbulator b) with turbulator

### *Second mode (fluid of coiled tube is air)*

The amounts of effectiveness for second mode are presented in Fig. 8. In this mode, mc of air is always less than the amount of mc for water. Hence, effectiveness increases with increment of coil side air flow rate. Although the shell side fluid is water, turbulator plays a key role on enhancement of effectiveness when the fluid of coil side is air. For higher values of coil side air flow rate, the value of effectiveness approaches to 1.

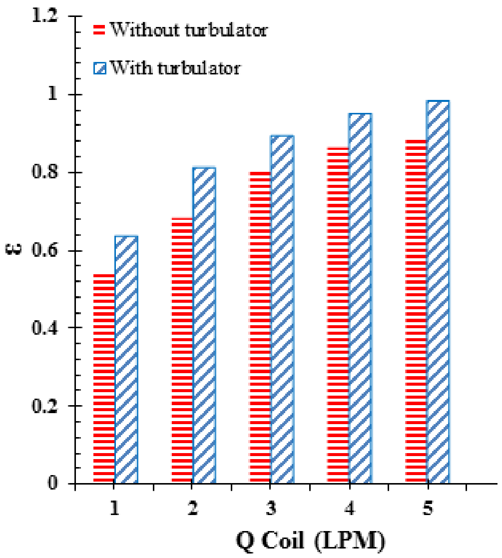


**Fig. 8:** Effectiveness (for second mode)

## Conclusion

In this paper, helical wire was inserted inside a coiled tube (as a turbulator) via an especial method which was described in the paper. No type of turbulator was used for coiled tubes before. Then the thermal, frictional and effectiveness characteristics of tube was compared with empty coiled tube (without turbulator) through a shell-coiled tube heat exchanger. The fluid of shell side was hot water while the fluid of coiled tube was air or cold water. Different shell side and coil side flow rates were performed. The reasons which cause enhancement of thermal of frictional characteristics of coiled tube (due to turbulator) were clearly discussed from new points of view. Three heat transfer improvement mechanisms were explained for air fluid and two mechanisms for water fluid. Memorable and interesting behaviors were observed for effectiveness charts. Generally, this type of turbulator can be used for helical tubes and the result is higher heat transfer rate and obviously extra pressure drop.


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