Thermal analysis of the helical and shell heat exchanger

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ABSTRACT

The most important engineering devices used to transfer heat between fluids to are heat exchangers. Heat exchanger are applied in a wide range of applications: heat regeneration systems, nuclear reactors, power stations, refrigeration systems and air-conditioning, mechanical and biomedical, petrochemical industries. In certain industries, heat exchangers are typically developed and evaluated in a way that reduces costs, materials and energy and maximizes heat transmission. The main problem in the design is to make them small and provide maximal heat transfer in a required amount. This research focuses on the design and thermal analysis via counterflow configuration of shell and helical coil thermal exchange. The thermal analysis takes into account the different factors such as Reynolds number, Dean Number, Nusselt number, and coefficient of heat transfer, flow rate of cold and hot water, temperature and heat transfer coefficient.

KEYWORDS

Helical coil, heat exchanger, Reynolds number, Shell, Dean Number, Nusselt number, and coefficient of heat transfer.

INTRODUCTION

A heat exchanger is a system that transfers energy between fluids at various temperatures. Most heat exchanger fluids are separated by a heat transfer surface and, ideally, do not mix. Heat exchangers are utilized in a wide variety of industries, including power, process, transportation, air conditioning, petroleum, alternative fuels, cryogenic, heat storage, refrigeration, among others. Air preheaters, automobile radiators, condensers, evaporators, and oil coolers are examples of heat exchangers in usage [1]. The compactness and good heat transfer coefficient distinguish the Helical coil. The curvature of the coil provides a centrifugal force, causing the secondary flow to occur if the fluid is moving through a helical coil[2]. A curved pipe flow attracted a lot of interest as helical coiled pipes are commonly utilized as chemical reactors and heat exchangers in practice. The flow of fluid via curved tubes causes in the tube secondary flow. This second flow in the tube might improve the heat transfer owing to fluid mixing. The secondary flow intensity [1, 2] created in the tube is based on coil diameter and tube diameter. The study of heat transfer properties and flow in the curved tube is significant because of higher heat transfer in the helically coiled structure [3].

THEORETICAL WORK

The helical coil heat exchanger's basic design incorporates calculations of:

The helical is analyzed using the procedure [4][5]:

$$L = \pi \times D_c \times N \tag{1}$$

Shell side equivalent diameter or Hydraulic diameter:

$$D_h = \frac{D_o^2 - \pi D_c d_o^2 \gamma^{-1}}{D_o + \pi D_c d_o \gamma^{-1}} \tag{2}$$

The heat transfer [6]:

$$Q_h = \dot{m}_h \times Cp_h \times \Delta T_h \tag{3}$$

$$Q_c = \dot{m}_c \times Cp_c \times \Delta T_c \tag{4}$$

The average heat transfer value (Q_{avg}) may be utilized as an exchanger heating charge [7]:

$$Q_{avg} = \frac{Q_c + Q_h}{2} \tag{5}$$

$$Q_{max} = \dot{m}_{min} \times Cp_{min} \times (Th_i - Tc_i) \tag{6}$$

As indicated below, the heat load of the heat exchanger (Q_{avg}) was used to compute the coiled side fluid Nusselt number (Nu_c), and coefficient heat transfer (h_c):

$$h_c = \frac{Q_{avg}}{(Ai(Th - Tw))} \tag{7}$$

$$Nu_c = \frac{h_c d_{c,i}}{K_c} \tag{8}$$

Heat Exchanger effectiveness

$$\varepsilon = \frac{Q_{avg}}{Q_{max}} \tag{9}$$

The overall coefficient of heat transfer (Uo) calculated for the shell side using the formulas below

$$U_o = \frac{Q_{avg}}{A_o LMTD} \tag{10}$$

The Nusselt number (Nu_{sh}) and coefficient of heat transfer(h_{sh}) for the shell are computed as follows[7]:

$$\frac{1}{U_oA_o} = \frac{1}{A_oh_{sh}} + \frac{1}{hcAc} \tag{11}$$

$$Nu_{sh} = \frac{h_{sh}Dh}{K_{sh}} \tag{12}$$

The number of Reynolds on the coil and shell is obtained by:

$$Re_{sh} = \frac{4m_c}{\pi\mu D_h} \tag{13}$$

$$Re_c = \frac{4m_h}{\pi\mu h_{c,i}} \tag{14}$$

The friction factor is the most important element in determining the degree of flow loss in helical tubing, although secondary flow causes loss in flow is calculated from the recorded pressure drop using the equation below [7]:

$$f = \frac{\Delta p_c d_{c,i}}{2L_c pu^2} \tag{15}$$

The logarithmic mean temperature difference can be calculated [7]:

$$LMTD = \frac{(Th_i - Tc_0) - (Th_o - Tc_i)}{Ln(\frac{Th_i - Tc_o}{Th_o - Tc_i})} \tag{16}$$

Dean Number (*De*) is calculated as [7]:

$$D_e = R_e \times \left(\frac{d}{D}\right)^{0.5} \tag{17}$$

The constant velocity inlet to the shell is 0.35 m/s, while to the helical is (0.922) m/s. the mesh of the helical coil is shown in figure1.

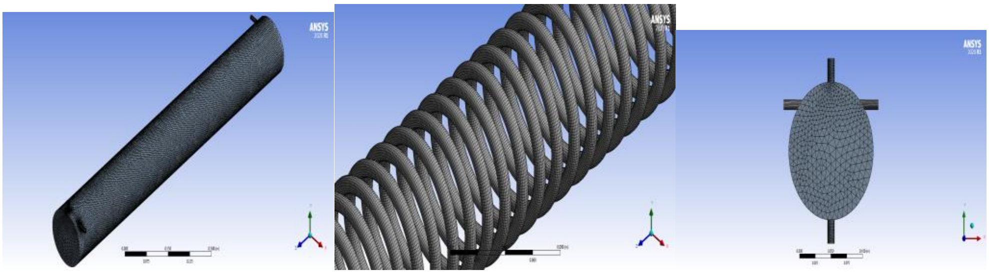

Figure1. mesh of helical coil

EXPERIMENTAL WORK

A heat exchanger was designed according to the dimensions in Table 1 and shown in figure2.

Table1. Helical and Shell dimensions

Parameters	Dimensions
D_c	0.09
D_o	0.14
d_i	8.31×10^{-3}
d_o	9.53×10^{-3}
N	48
b	0.02

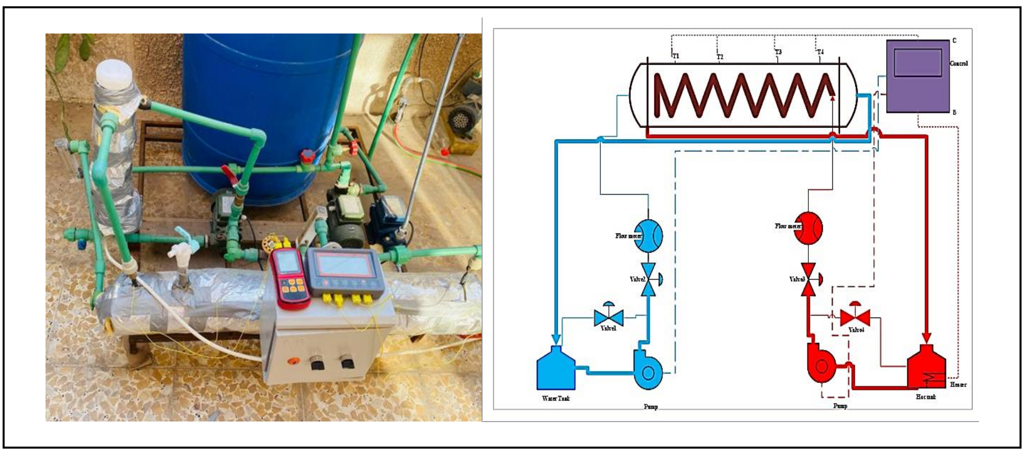

Figure2. Heat exchanger

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Table 2. Characteristics of the cold and hot fluids in a tube heat exchanger

Characteristics	Hot water	Cold water
Thermal conductivity	0.6352	0.6216
Density	990.688	994.629
Viscosity	0.000620	0.000753
Specific heat	4179.2	4178
Pr	4.08	5.06

RESULTS AND DISCUSSION

A helical type was manufactured and many experiments were carried out utilizing distilled water at different flow rates (2,3,4) L/min, where the results were represented by graphics and graphical statistics to compare the results obtained from distilled water. The temperature distribution throughout the turns of a helical coil at various volumetric flow rates and curvature

ratios, as shown in figure3. This chart clearly shows that the largest temperature gradients emerge during the first forty turns and thereafter decrease

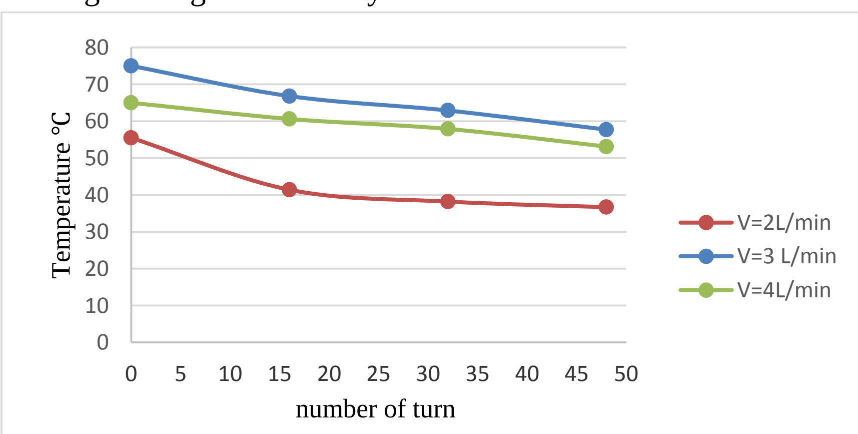

Figure 3. Temperature distribution along with a helical coil at various flow rates

The values of Nu, Re, De, coefficient of heat transfer increases with increasing mass flow rate due to increased velocity intake to the coil tube, which causes a change in the flow pattern inside the coil and a change in the vortex shape that develops in the coil as shown in figure4. The forms of vortex in the coil have a significant effect on less or destroy thermal boundary layer.

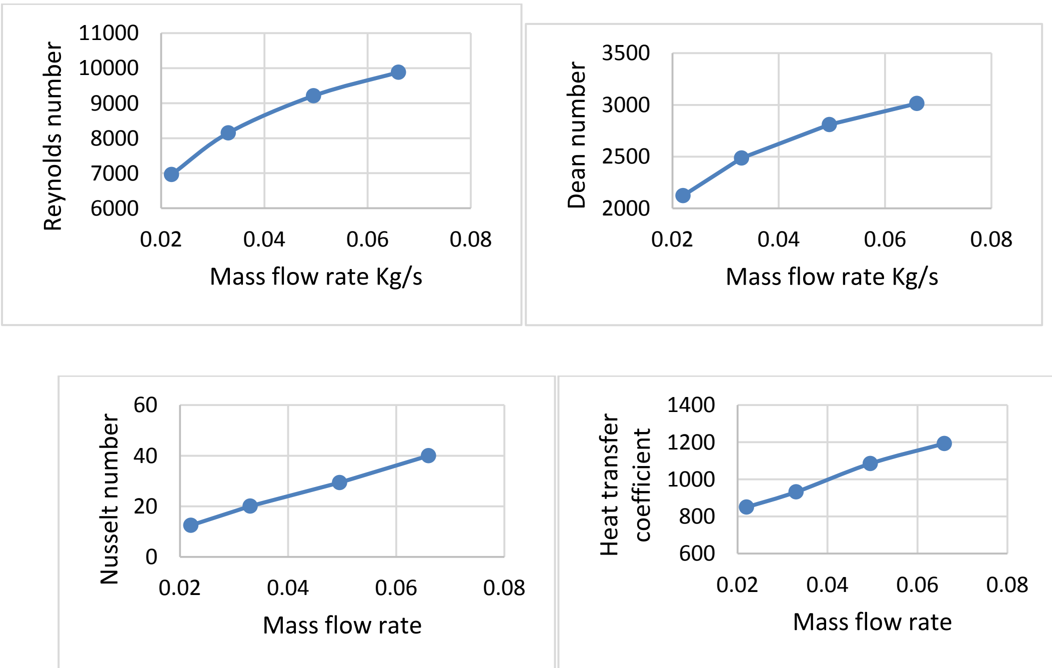

Figure 4. Mass flow rate influence on the Re, Nu, De, coefficient of heat transfer

As shown in figure 5 the increasing Dean number causes the coefficient of thermal transfer and Nusselt to increase because the formation of the vortex can damage the thermal boundary and decrease in temperature between the inside and the outside surface of the coil.

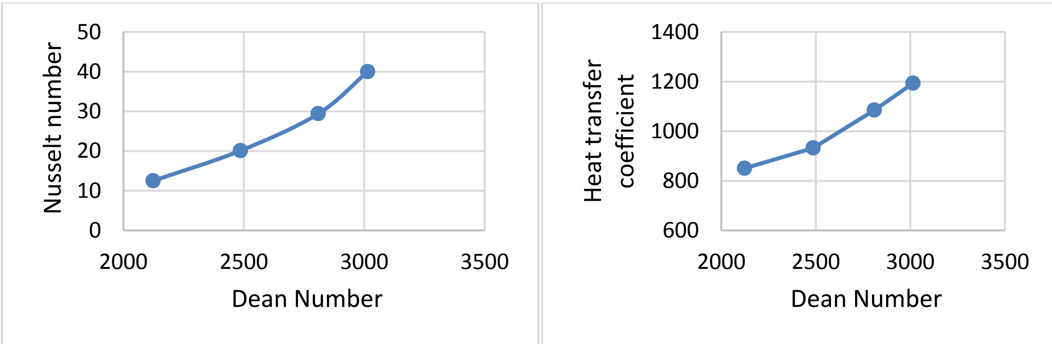

Figure5 Dean Number effect on the Nu and coefficient of heat transfer

The overall coefficient of heat transfer of the heat exchanger increases with the heat transfer rates because of the coefficient of transfer of both shell and coil increases as shown in figure6.

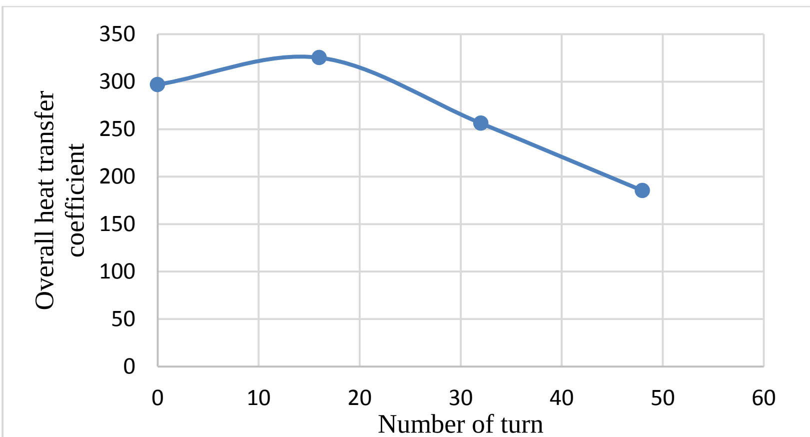

Figure 6. Change the overall coefficient of heat transfer with the number of turns

Figure 7 shows a gradient of the overall heat transfer coefficient along with turns of the helical coil at various curvature ratios and the heat rate increase with increasing mass flow rate.

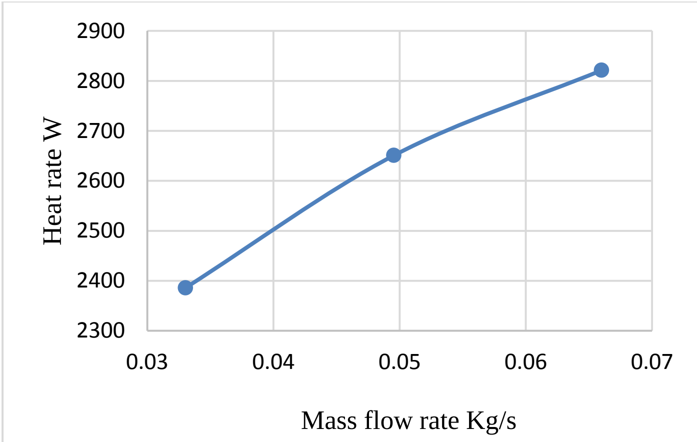

Figure 7. Mass flow rate effect on the heat rate

the overall coefficient of heat transfer increases with increasing heat rate between the coil and shell side as shown in figure8.

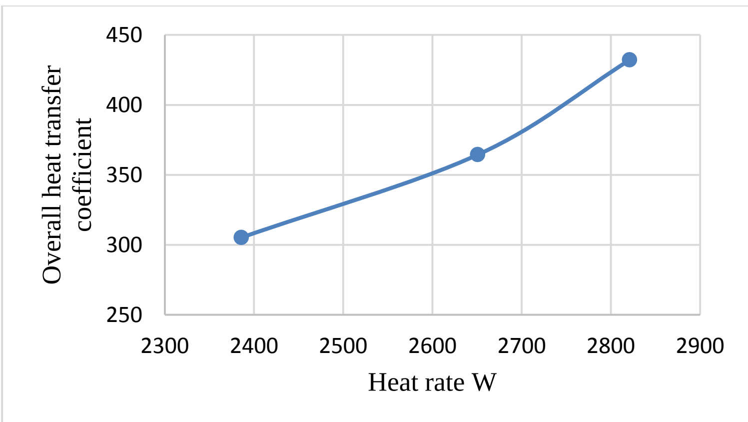

Figure 8. Heat rate effect on the overall coefficient of heat transfer

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Reynolds number and curvature ratios have a significant influence on the value of Dean Number, Nusselt number, and coefficient of heat transfer. At the same inlet condition, these values drop when the ratio is increased. Generally, the heat transfer coefficient decreases as the curvature ratio exceed the optimum ratio because the flow behavior inside the helical coil becomes the same as the flow behavior inside the straight tube, and the flow becomes unable to form secondary flow capable of destroying the thermal boundary layer as shown in figure9.

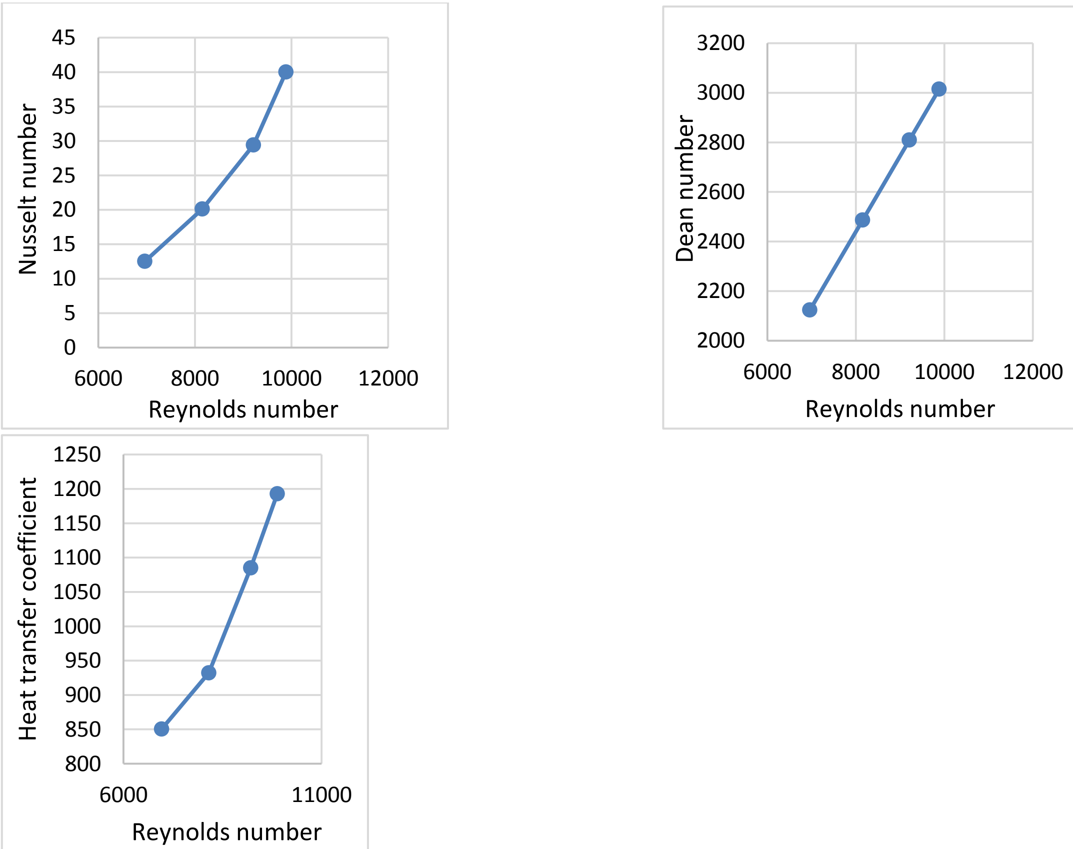

Figure 9. The influence of the Reynolds number on the Nu, De, and heat transfer coefficient

CONCLUSION

The design and thermal analysis of the study under examination has been completed, and the following results have been reached:

- The largest temperature gradients emerge during the first forty turns and thereafter decrease.
- The values Re, Nu, De, and heat transfer coefficient increases with increasing mass flow rate due to increased velocity intake to the coil tube.
- the increasing Dean number causes the coefficient of Nusselt and thermal transfer to increase.

- The overall coefficient of heat transfer of the heat exchanger increases with the heat transfer rates because of the coefficient of transfer of both shell and coil increases.
- the overall coefficient of heat transfer increases with increasing heat rate between the coil and shell side.
- With a rising rate of mass flow coefficient of heat transfer, rate of heat transfer, and the number of Nusselt are all increased.
- The heat transfer coefficient decreases as the curvature ratio exceed the optimum ratio.

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