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Investigation of exergy efficiency in shell and helically coiled tube heat exchangers

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ABSTRACT

This study presents exergy analysis for forced convection heat transfer in shell and helically coiled tube heat exchangers. The effect of operational and geometrical parameters on the exergy efficiency was investigated. Water is selected as the working fluid of both sides. Results show that, the efficiency decreases linearly with the increase of the fluids dimensionless inlet temperature difference. Based on the results, a correlation was developed to predict the efficiency for wide range of mass flow rates ratio ($0.1 < R_m < 4$), fluids dimensionless inlet temperature difference ($0 < R_T < 0.8$), product of Reynolds numbers ($3.31E+8 < (Re_c.\ Re_{sh}) < 1.32E+9$) and dimensionless geometrical parameters. According to this equation it was found that, the coil which has the maximum number of turns and minimum diameter is more efficient than other coils which have the same length and pitch.

1. Introduction

As we know many countries reexamine their energy policies and take serious measures in eliminating waste because the world's energy resources are limited.

Exergy is a powerful tool in the optimization of complex thermodynamic systems and engineering devices.

Shell and helically coiled tube heat exchangers are one of the most important heat exchangers used in industrial applications. The common applications are: domestic hot water heat exchangers, pump-seal coolers, steam jet vacuum condensers and tank-vent condensers. The study of the thermal performance of these types of heat exchangers was extensively performed in the past years. Many researchers [1–12] have studied thermal performance and frictional characteristics of these types of heat exchangers and proposed various correlations for Nusselt numbers and friction factors of both sides.P. Naphon [13] investigated the thermal performance and pressure drop of a helical coil heat exchanger with and without helical crimped fins. The heat exchanger was formed from a shell and a helically coiled tube unit with two different coil diameters. The experiments were done at the cold and hot water mass flow rates ranging between 0.10 and 0.22 kg/s, and between 0.02 and 0.12 kg/s, respectively. The inlet temperatures of cold and hot water are between 15 and 25 °C, and between 35 and 45 °C, respectively. Results show that, hot and cold water inlet mass flow rates and hot water inlet temperature have significant effect on the heat exchanger effectiveness. Dizaji *et al.* [14] experimentally studied the effect of operational (flow rates and inlet temperatures) and geometrical parameters (coil diameter and pitch) on the exergetic characteristics in shell and helically coiled tube heat exchangers. They found that, exergy loss increases with the increase of shell or coil side flow rate but dimensionless exergy loss can increase or decrease with the increase of flow rates (It depends on C_{min}). Furthermore, they found that, both exergy loss and dimensionless exergy loss increase with the increase of coil side (hot fluid) inlet temperature and decrease of shell side (cold fluid) inlet temperature. Ko [15] proposed a correlation to obtain the optimal curvature ratio for steady, laminar, fully developed forced convection in a helical coiled tube with constant wall heat flux

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Nomenclature		*Greek symbols*	
d	Diameter (m)	η	Exergy efficiency
E	Rate of exergy (W)		
f	Distance between inlet and outlet of the shell (m)	*Subscripts*	
g	Gravitational acceleration (m^2/s)		
H	Height (m)	0	Ambient state
l	Length of the coil (m)	c	Coil
m°	Flow rate (kg/s)	cr	Critical
N	Numbet of the turns	i	Inner
p	Pitch (m)	in	Inlet
R_m	Relative mass flow rate ($m°_c/m°_{sh}$)	o	Outer
R_T	Fluids dimensionless inlet temperature difference ($\|T_{in,c}-T_{in,\ sh}\|/\|T_{in,c}+T_{in,\ sh}\|$)	out	Outlet
		sh	Shell
Re	Reynolds number	t	Tube
s	Specific entropy (J/kg K)	v	Shell's inlet
T	Temperature (K or °C)		
z	Height from the ground (m)		

by thermodynamic second law based on the minimal entropy generation principle. The optimal curvature ratio is a function of Reynolds number and two dimensionless duty parameters. Sasmito et al.[16] evaluated heat transfer performance and entropy generation of laminar flow in coiled tubes with various cross sections geometries (i.e. circular, ellipse and square), relatives to the straight tubes of similar cross-sections. A computational fluid dynamics model was developed and validated against empirical correlations. The results indicate that coiled tubes provide higher heat transfer rate. In addition, it was found to be more efficient as reflected by lower entropy generation as compared to straight tubes. Among the studied cross-section, square cross-section generates the highest entropy, followed by ellipse and circular counterpart. Dizaji et al.[17] experimentally investigated the effects of flow, thermodynamic and geometrical parameters on exergetic characteristics (exergy loss, dimensionless exergy loss and second law efficiency) for tube-in-tube helically coiled heat exchangers. It was found that enhancement of hot or cold water flow rates, hot water inlet temperature and coil diameter increase the amount of exergy loss while, the effect of pitch size is negligible. Also it was found that, higher hot water flow rate with lower inlet temperature and lower cold water flow rate with higher inlet temperature can enhance the second law efficiency of heat exchanger.

In this study first, the effect of operational parameters (i.e. product of Reynolds numbers, relative mass flow rate and relative fluids inlet temperature) and geometrical parameters (i.e. dimensionless pitch, diameters of coil and shell, heights of coil and shell, and the distance between the inlet and outlet of the shell) on the exergy efficiency will be obtained. Then the optimal dimensionless pitch and coil diameter will be obtained based on minimal exergy destruction (or maximum exergy efficiency). According to the literature review, it can be found that the effect of many of these parameters has not been studied in previous works.

2. Geometry and parameters of the heat exchanger

The typical heat exchanger with its geometrical parameters is shown in Fig. 1. Furthermore, its dimensions are shown in Table 1. The length of the coil can be obtained from the following equation:

$$l = N\,(p^2+9.87d_c^2)^{0.5} \tag{1}$$

Water was used as the working fluids of both sides. The critical Reynolds number of the coil side can be calculated from the Schmidet [18] correlation. This correlation is as follows:

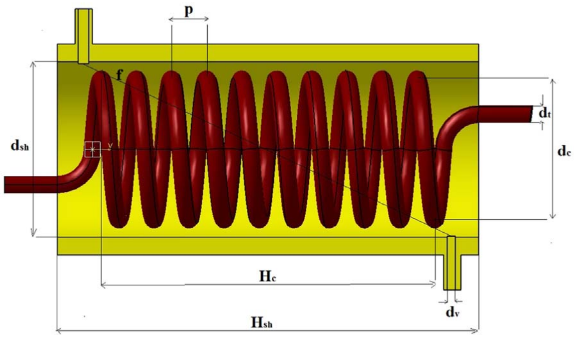

Fig. 1. Typical heat exchanger and its geometrical parameters.