Applied Thermal Engineering 121 (2017) 294–301

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Numerical investigation and optimization of heat transfer and exergy loss in shell and helical tube heat exchanger

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HIGHLIGHTS

- Behavior of the design parameters on heat transfer and exergy loss of the heat exchanger is assessed.
- The helical tube heat exchanger performance is optimized by Taguchi method.
- Significant parameters of exergy loss and heat transfer are evaluated.
- Tube diameter and cold flow rate have the most important effect on heat transfer and exergy loss.

ARTICLE INFO

Article history:
Received 18 January 2017
Revised 31 March 2017
Accepted 18 April 2017
Available online 19 April 2017

Keywords:
Helical tube heat exchanger
Heat transfer
Exergy loss
Taguchi approach
Optimization

ABSTRACT

In this research paper, numerical model of shell and helical tube heat exchanger is investigated to assess heat transfer coefficient and exergy loss. Four design parameters including pitch coil, tube diameter, hot and cold flow rate, which are more significant for the heat exchanger performance, were taken to consideration. Then, Taguchi approach is applied to figure out the optimum levels of the design factors. Sixteen cases with diverse design parameters are modeled and analyzed numerically. The results are indicated that tube diameter and cold flow rate are the most significant design parameters of heat transfer and exergy loss, respectively. Furthermore, the highest Nusselt number are achieved by more both cold and hot flow rates and also, heat transfer coefficient are reduced by increasing of pitch coil as well as by increasing of hot flow rate, the exergy loss increases. The optimum levels for heat transfer coefficient are: pitch 13 mm, tube diameter 12 mm, cold and hot flow rate 4 LPM. Furthermore, the optimum level for exergy loss are: pitch 13 mm, tube diameter 12 mm, cold and hot flow rate 1 LPM.

1. Introduction

Shell and tube heat exchangers are extensively used in industries. Several types of shell and tube heat exchanger are used in different application such as condensers, evaporators, energy conversion, power utility systems as well as heating ventilating and air conditioning engineering. Common straight tube heat exchangers are used are bulky with low efficiency, thus helical tube heat exchanger due to better heat transfer characteristic, higher surface area to volume ratio and removing of the dead-zones caused by helically configuration was proposed. Dravid et al. [1] numerically considered the effect of the secondary flow on laminar regime heat transfer in helical tube both in the fully developed region and in the thermal entrance region to achieve a correlation with the asymptotic Nusselt number. Patankar et al. [2] studied the effect of Dean number on heat transfer and friction factors. They considered the effects in the developing and fully developed regions of the helically coiled tube and compared them results with experimental data. Salimpour et al. [3] experimentally compared the divergent type of flow configuration in helical tube heat exchanger and used Wilson plot to evaluated heat transfer coefficient on tube and shell side. They found that heat transfer coefficient enhanced with the growth of curvature ratio and Reynolds number. Jamshidi et al. [4] investigated on water/Al_2O_3 used in helical tube heat exchanger. They results demonstrate that nanofluids improve the thermal hydraulic efficiency of helical tube heat exchanger.Wu et al. [5] studied experimentally heat transfer and pressure drop of the helical tube in tube heat exchanger in both laminar and turbulent regime with nanofluids. They proposed a novel correlation of asymptotic Nusselt number in laminar regime. Kumar et al. [6] experimentally used water/Al_2O_3 with different volume concentration to analyze heat transfer and pressure

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http://dx.doi.org/10.1016/j.applthermaleng.2017.04.074
1359-4311/

Nomenclature

E	exergy loss
L	length (mm)
k	heat transfer coefficient (W/mK)
Nu	Nusselt number (hd/k)
$\dot{m}$	mass flow rate (kg/s)
p_c	pitch (mm)
$\dot{W}$	work transfer rate
De	Dean number $= Re\sqrt{\frac{D_t}{D_c}}$
D_c	coil diameter (mm)
LPM	liter per minute
Re	Reynolds number $= 4\dot{m}/\pi d\mu$
D_t	tube diameter (mm)
c_p	specific heat capacity (W/kgk)
$\dot{S}_{gen}$	entropy generation rate
s	entropy (kJ/kgk)
SN	signal to noise ratio
T	temperature c^o
u	velocity (m/s)
Y_i	quality characteristic $=\eta + X_i + e_i$
Q_c	cold flow rate (LPM)
Q_h	hot flow rate (LPM)
$\vec{u}$	velocity vector

Symbols

μ	viscosity kg m^{-3}
ρ	density kg/m s

Subscripts

h	hot fluid
c	cold fluid
in	inlet
out	outlet

drop of the helical heat exchanger in the turbulent flow regime. They apprehended that a growth of tube side Reynolds number and volume particles concentration will soar overall heat transfer coefficient. Bahrehmand and Abbassi [7] investigated the numerical performance of heat transfer characteristics of water/Al_2O_3 nanofluid inside the shell and helical tube heat exchanger in turbulence flow regime. They figured out heat transfer rate uplifted when particles volume concentration upraised. On the other hand, reduction of heat transfer rate stems from the growth of flow rate. Sheikholeslami et al. [8] considered heat transfer and pressure drop in the double tube heat exchanger with circular rings on turbulence regime. They compared perforated circular rings and typical circular rings. Other researchers mostly concentrate on consideration of pressure drop, friction factors on heat transfer [9–12]. Whereas, exergy is defined as the maximum shaft work that can be achieved by the system and a specified reference environment. It is a fundamental concept and tool in design and optimization studies in such systems [13]. Exergy analysis takes into account the different thermodynamic values of different energy forms and quantities, for instance, work and heat. The exergy transfer associated with shaft work is equal to the shaft work and heat transfer. Although, it's depends on the temperature at which it occurs in relation to the environment temperature. Since, there is no shaft work in the heat exchanger, so, just effect of heat transfer is considered. Consequently, studies of heat transfer and exergetic characteristics in shell and helical tube heat exchangers are very important [14]. Through past years, thermal and friction factors of SHTHX[1] have been extensively investigated. Since, lack of consideration of exergy loss and heat transfer on SHTHX was felt. So, the main purpose of this research concentrates on exergy loss and heat transfer. Ko[15] proposed optimal coil curvature ratio in helical coil tube with diverse design parameters. The second law of thermodynamic that was based on minimal entropy generation used to analyzed the system for the developed laminar regime and constant wall heat flux. Huminic and Huminic [16] considered three-dimensional entropy generation and heat transfer in helical tube heat exchanger using two different type of nanofluids in laminar regime. Their results portrayed that overall heat transfer coefficient soared with increasing of nanofluids concentration and mass flow rate ratio. Naili et al. [17] considered energy and exergy of horizontal ground heat exchanger in northern of Tunisia. Moreover, the effect of design parameters of the horizontal ground heat exchanger has attended analytically. Jafarmadar et al. [18] studied experimentally effects of flow rate, thermodynamic characteristic and geometry parameters on exergy loss in helical tube heat exchanger. Their results indicate that exergy loss uplifted with surge of hot flow temperature. Some other studies evaluated exergy loss on different type of heat exchanger [19,20]. Besides, Taguchi is a powerfully approach and is applied to find out the optimum levels of the design factors. Moreover, Taguchi method is a leading optimization technique to decreasing the simulations runs, enables us to minimize period time of simulation [21–27]. Jamshidi et al. [28] experimentally analyzed heat transfer rate of shell and tube heat exchanger and used Taguchi procedure to obtain optimum design parameters. Yun and Lee [29] applied Taguchi approach to considered the effects of design parameters on heat transfer and flow friction characteristics in a slit type fins heat exchanger. The results were depicted that the most efficient parameters are fin pitch, angle of slit pattern, slit length and slit height, respectively. They figured out overall heat transfer goes up when shell side flow rate elevates. Also, correlations of friction factors, Nusselt number for heat performance were obtained according to experimental data. Taguchi methodology has been extensively used to investigate heat exchangers [30–36].

Exergy analysis which may be considered as accounting of the use of energy and material resources provide information on how effective a process takes place towards conserving natural resources. So, it plays a deterministic role in rectifying the components of shell and helical tube heat exchangers. To the best of authors' knowledge, no studies have been considered the effect of design parameters on heat transfer and exergy loss of this type of heat exchanger, simultaneously. In this study, the effect of geometry and design parameters on heat transfer and exergy loss of helical tube heat exchanger was investigated for the first time. The influence of four parameters on comprehensive performance is detailed numerically. Finally, pursuant to results of Taguchi method, the optimum values of design parameters are anticipated.

2. Model description and numerical method

2.1. Physical model

A physical model of a shell and helical tube heat exchanger with 10 turns of coil is depicted in Fig. 1. Furthermore, geometric parameters are listed in Table 1. Tetrahedral and combination of tetrahedron and hexahedron generated for shell side and helical tube of heat exchanger, respectively

[1] Shell and helical tube heat exchanger