Energy 91 (2015) 678–684

Contents lists available at ScienceDirect

Energy

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

The effect of flow, thermodynamic and geometrical characteristics on exergy loss in shell and coiled tube heat exchangers

Hamed Sadighi Dizaji, Samad Jafarmadar*, Mehran Hashemian

Faculty of Mechanical Engineering, Urmia University, Urmia, Iran

ARTICLE INFO

Article history:
Received 16 April 2015
Received in revised form
21 August 2015
Accepted 26 August 2015
Available online 19 September 2015

Keywords:
Shell and coiled tube heat exchanger
Exergy loss
Fluid properties
Thermodynamic characteristics
Geometry

ABSTRACT

This work presents experimental investigations on the effects of flow, thermodynamic and geometrical characteristics on exergy loss in shell and coiled tubes heat exchangers. Pressure drop and heat transfer characteristics in shell and coiled tube heat exchangers have been widely studied in the resent years. However, the effects of flow, thermodynamic and geometrical parameters on exergetic characteristics have not been explicitly and experimentally studied. Hence, the main scope of the present work is to clarify the effect of shell and coil side flow rates, inlet temperatures, coil pitch and coil diameter on exergy loss in shell and coiled tube heat exchangers. Both of the total exergy loss and dimensionless exergy loss are studied.

1. Introduction

Irreversibility and availability are two concepts that have found increasing use in recent years. These concepts are particularly applicable in the analysis of complex thermodynamic systems. Irreversibility and availability are very powerful tools in design and optimization studies of such systems [1]. Helically coiled tubes have wide applications in the industry because of their high heat transfer coefficients, low volume and size, narrow residence time distributions and simple manufacture method etc. Hence, knowledge about the heat transfer, pressure drop and exergetic characteristics in helically coiled tubes are very significant.

Thermal and frictional characteristics of helically coiled tubes were extensively investigated in the past years. However, exergetic characteristics have not been explicitly and experimentally studied for shell and coiled tube heat exchangers. Hence, the main scope of the present work is to clarify the effect of flow, thermodynamic and geometrical parameters on exergy loss in shell and coiled tube heat exchangers.

The flow moved through a helically coiled tube is affected by centrifugal forces. Centrifugal forces create secondary flows, and they induce significant eddies in a cross-section of the coiled tube. Indeed, as described in Wu et al. [2] study, centrifugal forces drive the fluid flow toward the outer wall and then returns by flowing back along the wall. Centrifugal forces, secondary flows and eddies can enhance the exergy loss in helically coiled tubes. Investigations on shell and coiled tube heat exchangers as well as exergetic parameters are summarized as follows.

Ko [3] offered optimal coil curvature ratio in a helical coiled tube with different combination of design parameters. The System analyzed by thermodynamic second low was based on minimal entropy generation principle for fully developed laminar flow and constant wall heat flux. Salimpour [4,5] experimentally studied the heat transfer characteristics of shell and coiled tube heat exchanger and proposed some correlations to predict the shell-side and tube-side Nusselt number. Kumar et al. [6] investigated on heat transfer and pressure drop of tube-in-tube helically coiled heat exchanger. K–ε model was used to evaluate the turbulent flow. Ghorbani et al. [7] evaluated the effects of coil pitch and tube diameters on shell-side heat transfer coefficient of a shell and coiled tube heat exchanger. Their findings showed that, the effect of tube diameter on shell-side heat transfer coefficient is negligible. Besides, their results indicated that the shell side heat transfer coefficient increases with the increase of coil pitch. Pandey and Nema [8] conducted experimental research on exergy loss in corrugated plate heat exchanger with different types of plate. Naphon [9] investigated on entropy generation and exergy loss in a concentric micro-fin tube heat exchanger. Zachár [10] analyzed the heat transfer rate

* Corresponding author.
E-mail addresses: Hamedsadighidizaji@gmail.com (H. Sadighi Dizaji), S.jafarmadar@urmia.ac.ir (S. Jafarmadar), Hashemian.Mehran@yahoo.com (M. Hashemian).

http://dx.doi.org/10.1016/j.energy.2015.08.084
0360-5442/

Nomenclature

A	coiled tube area, m^2
c	specific heat, J/kg °C
d	coiled tube diameter, m
D	shell diameter, m
D_h	shell side hydraulic diameter, m
De	Dean number, $Re(\frac{d}{2R_c})^{0.5}$
D_h	hydraulic diameter, $\frac{D^2-2\pi R_c d_o^2 p^{-1}}{D+2\pi R_c d_o p^{-1}}$
e	dimensionless exergy loss
E	exergy loss (exergy change), W
k	thermal conductivity, W/m °C
ṁ	mass flow rate, kg/s
Max	Maximum
Min	minimum
NTU	number of thermal units
p	coil pitch, m
Pr	Prandtl number, $\frac{\mu C}{k}$
q	heat transfer rate, W
Q	flow rate, LPM
R_c	coil radius, m
Re	Reynolds number, $\frac{VD}{\upsilon}$
s	specific entropy, J/kg. K
T	temperature, K
U	overall heat transfer coefficient, (W/m^2C)
V	water mean velocity, m/s
W	total uncertainty in the measurement
X	independent variable

Greece symbols

ν	kinematic viscosity, m^2/s
γ	dimensionless pitch, $\frac{p}{2\pi R_c}$

Subscripts

c	cold fluid
e	environment condition
h	hot fluid
i	inner
o	outer
in	inlet
out	outlet

in the outer side of the coiled tube in several cases with different combination of geometrical and flow parameters. Hashemi [11] used CuO-oil based nanofluid flow inside the helically coiled tube with constant wall heat flux. Experimental investigations showed that, using of coiled tube instead of straight tube causes heat transfer enhancement as well as more pressure drop. Besides, analogy of two heat transfer enhancement method showed that the employment of helically coiled tube instead of straight tube preferred to the adding additives to the base fluid. Mohammed and Narrein [12] numerically investigated the effects of using different geometrical parameters with the combination of nanofluid on heat transfer and fluid flow characteristics in a helically coiled tube heat exchanger. It was found that the heat transfer rate can be increased by reducing the helix radius, increasing the inner tube diameter and decreasing the annulus diameter. Jamshidi [13] experimentally concluded that the increasing coil diameter, coil pitch and fluid flow rate leads to higher heat transfer rate in shell and coiled tube heat exchangers. Pan et al. [14] performed a comprehensive study of thermal and hydraulic performances of shell and tube exchangers, and presented the detailed thermal and hydraulic calculations on the shell and tube heat exchangers with implementing conventional intensification techniques. According to the Kumar et al. [15] study the use of nanofluid in coiled tubes creates stronger secondary flow through the tube. The second flows properly mix nano-particles and also avoid particles concentrations which lead to higher heat transfer rate and also more pressure drop.

According to the literature review no experimental investigation has been performed to study the effect of flow, thermodynamic and geometrical parameters on exergy loss in shell and helically coiled heat exchangers. In the present work, the effect of shell and coil side flow rates, hot and cold water inlet temperatures, coil diameter and coil pitch on exergy loss experimentally evaluated for the shell and coiled tube heat exchanger.

2. Experiments

2.1. Experimental apparatus and tubes geometry

A general view of the experimental set-up is shown in Fig. 1. An electrical heater (inside the hot water tank), rheostat and a thermostat maintain the hot water inlet temperature at around a constant value. The heated water is pumped from the hot water tank, and then it passes the control valve, goes into a Rota-meter, enters the helically coiled tube and finally it returns into the hot water tank. A cooling unit maintains the cold water inlet temperature at around a constant value. The cooling unit consists of an evaporator (inside the cold water tank), compressor, condenser, refrigerant, expansion valve, thermostat and a fan (the fan is used when lower temperatures are needed).

The cooled water is pumped from the cold water tank and then it passes the control valve, goes into a rotameter, enters the shell side of heat exchanger, and finally it returns into the cold water tank. The hot and cold water inlet and outlet temperatures were recorded at fully steady state condition using EXTECH data logger (SDL200) with K type thermocouples (accuracy ±0.5 °C and resolution 0.1 °C). Besides, all Rota-meters were calibrated for hot and cold water by using a stopwatch and measuring cylinders.

As seen in Fig. 1(c) the test section (which presents a new simple method to make a shell and coiled tube heat exchanger for research applications) consists of a shell tube, a coiled tube, two insulated grooved end plates and four screwed steel rods. The shell of heat exchanger was placed between the end-plates and screwed steel rods were used to hold and adjust the position of the end-plates. The coiled tube was constructed by copper material with 9 mm inner diameter and 12 mm outer diameter and the outer tube (shell) was made from PVC. Helical tubes in this study have 12 turns. A schematic illustration of the coiled tube is shown in Fig. 2.

2.2. Experiments procedure

Different conditions considered in this study are presented in Table 1. In first step, geometrical and thermodynamic parameters (inlet temperatures) were kept constant and the effects of shell and coil side flow rates were investigated. For this purpose, each shell side flow rate (3, 4, 5, 6 and 7 LPM) was experimented with five different coil side flow rates (3, 3.5, 4, 4.5 and 5 LPM). It is noted that, used water pumps can't supply more than around 6 LPM to coil side of test section because of the high pressure drop through the coiled tube compared to straight tube. All selected amounts for other parameters such as temperatures are proportional with the