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Optimal and critical values of geometrical parameters of shell and helically coiled tube heat exchangers

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ABSTRACT

In the present study, calculations of the heat transfer and entropy generation have been performed for the steady state forced convection heat transfer in shell and helically coiled tube heat exchangers. The effect of geometrical parameters of the heat exchanger including: tube diameter (d_t), coil diameter (d_c), diameter of the inlet of shell (d_v), shell diameter (d_{sh}), height of the coil (H_c), height of the shell (H_{sh}), pitch (p) and the distance between the inlet and outlet of the shell (f) on the heat transfer rate and entropy generation has been investigated simultaneously. The critical and optimal values of these parameters have been obtained which minimize and maximize the COD (heat transfer rate per entropy generation), respectively.

1. Introduction

Heat exchangers are one of the key components in many industrial application like: HVAC, petroleum process, refrigeration, food preparation and etc. shell and helically coiled tube heat exchangers which usually consist of helical coiled tube and a cylindrical shell, are one of the most widely used heat exchangers in that mentioned applications. There are numerous studies about the heat transfer process in these types of heat exchangers. Many researchers [1–10] proposed equations for calculation of the heat transfer rates of inner and outer side of the coil or the heat exchanger efficiency as functions of geometrical as well as operational parameters of the heat exchanger. Also there are some studies which investigate the second law of thermodynamics and entropy generation in these types of heat exchangers. Ko [11] studied steady, laminar, fully developed forced convection heat transfer in a shell and helically coiled tube heat exchangers. He suggested an equation which determine the optimal curvature ratio based on the minimum entropy generation principle. Sasmito et al. [12] numerically investigated the effect of various cross sections geometries (i.e. circular, ellipse and square) on the heat transfer rate and entropy generation in a shell and helically coiled tube heat exchanger. Ahadi et al. [13] analyzed combined effects of length and heat flux of the coil as well as the effects of temperature dependence of thermo physical properties on the entropy generation rates and optimal operation in shell and helically coiled tube heat exchangers. Then, by using the minimal entropy generation principle, the inlet Reynolds number is optimized. Also they found that the entropy generation rates are highly dependent on the combined effects of length and heat flux of the coil. Huminic et al. [14] studied the laminar flow regime heat transfer and entropy generation inside a helically coiled tube-in-tube heat exchanger by using two different types of nano-fluids. Results show that, the use of nano-fluids in a helically coiled tube-in-tube heat exchanger improves the heat transfer performances and leads to reduction of the entropy generation. Abdous et al. [15] studied the entropy generation in the helically coiled tube under flow boiling. They found the optimum tube and coil diameters. The effect of different flow conditions such as mass velocity, inlet vapor quality, saturation temperature, and heat flux on contributions of pressure drop and heat transfer in entropy generation was discussed. The entropy generation analysis shows that there is a favorable region to use the helically coiled tube with respect to the

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Nomenclature

Q	heat transfer rate (W)
c	specific heat capacity (J/kg°C)
COD	Coefficient of design (K)
d	diameter (m)
f	distance between inlet and outlet of the shell (m)
H	height (m)
m°_{c}	mass flow rate (kg/s)
p	pitch (m)
S°_{gen}	Entropy generation rate (W/K)
T	temperature (K)

Subscripts

c	coil
in	inlet
out	outlet
sh	shell
v	shell inlet

straight one. Arabkoohsar et al. [16] found the optimal geometry and operational conditions of tube-in-tube helically coiled heat exchangers for both laminar and turbulent flows based on the second law of thermodynamics. First, they derived a dimensionless function for entropy generation number as a function of four dimensionless variables, i.e. Prandtl number, Dean number, the ratio of helical pipe diameter to the tube diameter and the duty parameter of heat exchanger. Then entropy generation number was minimized to develop analytical expressions for the optimal values of that mentioned parameters.

In this study, the effect of all geometrical parameters of the cylindrical shell and helically coiled tube heat exchangers on the heat transfer and entropy generation rate will be obtained. Then the optimum values of these parameters which maximize the heat transfer rate and minimize the entropy generation rate will be found. According to literature review, this investigation was not performed for these special types of shell and helically coiled tube heat exchangers. Also there are some new geometrical parameters in this study which their effect and optimum values have not been obtained already.

2. Heat exchanger specification and applied equations

The heat exchanger with its geometrical parameters has been shown in Fig. .1. The range of change of these parameters has been shown in Table 1. The reason for selecting these ranges is that, the most producer companies design these types of heat exchangers, in that mentioned range. For example, SENTRY produce models (TLR and FLR) of shell and helically coiled tube heat exchanger for cooling applications. The dimensions of these heat exchangers are as follows: $d_t = 6.35$ and 9.5 mm, $d_c = 108$ and 133 mm, $d_{sh} = 124$ and 143 mm, $d_v = 12.7$ and 19.05 mm, $f = 283$ and 337 mm, $p = 10$ and 14.92 mm, $H_c = 169$ and 205 mm and $H_{sh} = 283$ and 337 mm, respectively [17]. As it can be seen from Table 2, most dimensionless geometrical parameters of these two models are in the range of the present work. In the previous work [1], the heat transfer phenomena in these heat exchangers was studied by using a numerical code with the following specification:

a) The standard K-ε model for simulation of the turbulence.
b) The SIMPLE algorithm as the pressure and velocity coupling scheme.
c) First order Upwind as discretization scheme for momentum, K-ε and energy equations.
d) Water as the working fluid with its temperature dependent properties.

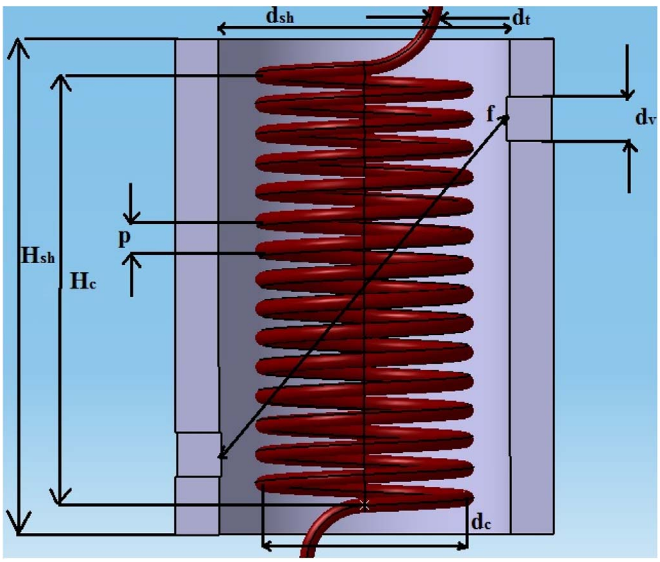

Fig. 1. Geometry of the heat exchanger.