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Study of thermal effectiveness and its relation with NTU in shell and helically coiled tube heat exchangers

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ABSTRACT

In the present study, the effect of operational and geometrical parameters on the thermal effectiveness of shell and helically coiled tube heat exchangers was investigated. Analysis was performed for the steady state. The working fluid of both sides is water, that its viscosity and thermal conductivity were assumed to be dependent on temperature. Based on the results, two correlations have been developed to predict the thermal effectiveness, for wide ranges of mass flow rates ratio, dimensionless geometrical parameters and product of Reynolds numbers. Furthermore, it was found for same values of NTU and C_r, the effectiveness is averagely 12.6% less than the effectiveness of parallel flow heat exchangers and this difference is approximately constant.

1. Introduction

Shell and coiled tube heat exchangers, are one of the most important heat exchangers which are used in various applications. The common applications of these types of heat exchangers are: pump-seal coolers, tank-vent condensers and steam jet vacuum condensers. The study of thermal performances of these types of heat exchangers was performed in two fields:

1.1. Field 1

Many researchers [1–12] have proposed correlations for prediction of Nusselt numbers of coil side as well as shell side.

1.2. Field 2

There are few studies that investigated the effectiveness and its relation with the number of transfer units (i.e. NTU). For example:

Ghorbani et al. [9] studied the mixed convection heat transfer in a helically coiled tube heat exchanger for wide ranges of geometrical parameters, Reynolds and Rayleigh numbers. Results indicate that, the mass flow rate ratio (i.e. R_m which is equal to $\dot{m}_c/\dot{m}_{sh}$) is effective on the axial temperature profiles and the effectiveness of the heat exchanger. Also the ε-NTU relations of that experiment were compared with the standard counter flow relations for different Cr values of 0.2, 0.5 and 0.8. It was found that, the data are reasonably correlated by counter-flow relations. They proposed a correlation to predict the effectiveness of the shell and coiled tube heat exchanger as follows:

$$\varepsilon = 0.4744 R_m^{-0.4627} \tag{1}$$

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Nomenclature

A	area (m^2)
c	specific heat capacity (J/kg °C)
C	heat capacity (J/kg)
d	diameter (m)
f	distance between inlet and outlet of the shell (m)
H	height (m)
h	heat transfer coefficient (W/m^2 K)
k	thermal conductivity (W/m K)
l	coil's length (m)
m°	flow rate (kg/s)
NTU	number of transfer units
p	pitch (m)
Q	heat transfer rate (W)
q	heat flux (W/m^2)
Re	Reynolds number
T	temperature (K or °C)
u	average velocity (m/s)
U	overall heat transfer coefficient (W/m^2 K)

Greek symbols

ε	effectiveness
μ	viscosity (Pa s)
ρ	density (kg/m^3)

Subscripts

b	bulk
c	coil
cr	critical
i	inner
o	outer
r	relative
sh	shell
t	tube
v	shell's inlet
w	wall

which is applicable for: $0.15 < Rm < 5$.

Taherian et al. [13] studied natural convection heat transfer in shell and coiled tube heat exchangers. An aqueous solution of propylene glycol was pumped from a tank into the coils through an electric heater and a distributor manifold and recirculated after passing through rotameters. They studied the effect of tube diameter, coil diameter, coil surface and shell diameter on the effectiveness. They found that, the effectiveness decreases with increasing mass flow rate ratio. Also they found that, the ε– NTU relation of the natural convection heat exchangers is similar to a pure counter flow heat exchanger.

Purandare et al. [14] experimentally studied thermal performance of conical coil heat exchangers. They fabricated and analyzed fifteen conical coils of different cone angles (0° (helical), 45°, 90°, 135°, 180° (spiral)), with three different tube sizes (ID×OD, 8×10, 10×12 and 12×15). For all cases the coil diameter was 200 mm and tube length was 3 m. The experimentation was carried out with hot and cold water of flow rate 10–100 lph ($500 < Re < 5000$) and 30–90 lph, respectively. It was found that, the effectiveness of coiled tube heat exchanger is a function of Re inside the tube and it reduces with increases in Re. They proposed a correlation to predict the effectiveness as follows:

$$\varepsilon = 0.\ 5177 R_m^{-0.4114} \tag{2}$$

Naphon [15] investigated the thermal performance and pressure drop of a helical coil heat exchanger with and without helical crimped fins. The heat exchanger was a shell and 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 were between 15 and 25 °C, and between 35 and 45 °C, respectively. Results indicate that, inlet hot and cold water mass flow rates and inlet hot water temperature have significant effect on the heat exchanger effectiveness.

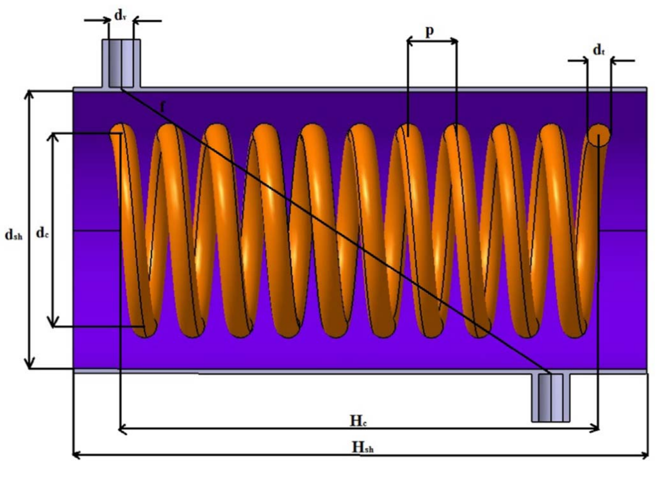

Fig. 1. Typical heat exchanger and its geometrical parameters.