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Investigation of entropy generation in a helically coiled tube in flow boiling condition under a constant heat flux

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ABSTRACT

There are many methods to augment the heat transfer rate in flow boiling in industrial applications. The helically coiled tubes are one of the best geometries to enhance the heat transfer rate. The entropy generation analysis is an appropriate tool to evaluate the contribution of heat transfer and pressure drop mechanisms. In the present paper, the entropy generation in the helically coiled tube under flow boiling is studied. The optimum tube and coil diameters under specified conditions are found. 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 is discussed. The Bejan number (*Be*) and irreversibility distribution ratio (*IDR*) at different saturation temperatures versus mass velocity are plotted. The comparison between entropy generation and contributions of pressure drop and heat transfer for the helically coiled tube and the straight one is presented. The entropy generation number (N_s) for different flow conditions is plotted. The entropy generation analysis shows that there is a favorable region to use the helically coiled tube with respect to the straight one.

Etude de la production d'entropie dans un tube enroulé en hélice en condition d'ébullition en écoulement sous un flux de chaleur constant

Mots clés : Ebullition ; Production d'entropie ; Tube enroulé en hélice ; Chute de pression ; Taux de transfert de chaleur ; Nombre de Bejan

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Nomenclature

A	cross section (m^2)
Be	Bejan number (–)
dz	element discretization (m)
D_r	diameter ratio (–)
d_i	tube diameter (m)
D_c	coil diameter (m)
G	mass velocity ($\mathrm{kg\,m^{-2}\,s^{-1}}$)
H	pitch of the helically coiled tube (m)
h	specific enthalpy ($\mathrm{J\,kg^{-1}}$)
IDR	irreversibility distribution ratio (–)
L	length (m)
$\dot{m}$	mass flow rate ($\mathrm{kg\,s^{-1}}$)
N_s	entropy generation number (–)
p	pressure (Pa)
P	perimeter (m)
q	heat flux ($\mathrm{W\,m^{-2}}$)
$\dot{Q}$	heat rate (W)
s	specific entropy ($\mathrm{J\,K^{-1}}$)
$\dot{S}'_{gen}$	entropy generation per unit length ($\mathrm{W\,m^{-1}\,K^{-1}}$)
T	temperature (°C)
U	convective heat transfer coefficient ($\mathrm{W\,m^{-2}\,K^{-1}}$)
x	vapor quality

Greek symbols

ρ	density ($\mathrm{kg\,m^{-3}}$)
υ	specific volume ($\mathrm{m^3\,kg^{-1}}$)

Subscripts

ht	heat transfer
in	inlet
l	liquid
pd	pressure drop
sat	saturation
tp	two-phase
v	vapor
w	wall

1. Introduction

The enhancement of heat transfer rate in flow boiling is a crucial issue for engineers. These methods are classified into active and passive ones. The active methods require the external power to augment the heat transfer rate. Passive methods are mainly based on the change in the geometry of heat exchanges.

The use of the helically coiled tubes is one of the best passive methods to enhance heat transfer rate. The issue of flow boiling heat transfer has been studied by some researchers in these tubes, such as Owhadi et al. (1968), Zhao et al. (2003), Yu et al. (2003), Wongwises and Polsongkram (2006), Cui et al. (2006) and Chingulpitak and Wongwises (2010).

The simulation of flow boiling in the helically coiled tubes has been studied by several authors. The numerical model of heat transfer and fluid dynamic behavior of a helical double pipe evaporator has been developed by Colorado-Garrido et al. (2009). Also, Colorado et al. (2011a, 2011b) developed the computational model to describe the thermo-fluid-dynamic behavior of a helically coiled steam generator device.

The increase in pressure drop along with the heat transfer rate is one of the disadvantages of using the helically coiled tubes. The entropy generation is a good criterion to assess the contribution of these mechanisms. Since the use of these tubes are very common in industrial applications, their entropy generation analysis is very important.

The single phase flow entropy generation has been studied by many researchers. Bejan (1979) proposed an important optimization technique in forced convective applications. He applied the second law analysis to the four fundamental flow configurations and studied the irreversibility due to heat transfer and viscous effects. Poulikakos and Bejan (1982) used the entropy generation minimization in forced convection in designing the extended surfaces. They formulated the total entropy generation due to heat transfer and fluid friction. London and Shah (1983) presented an operationally convenient methodology to relate the economic costs to the thermodynamic irreversibility. Şahin (1998) studied the entropy generation in a laminar viscous flow through ducts with constant wall heat flux. He presented optimum duct geometry which minimizes frictional losses. Ratts and Raut (2004) investigated the entropy generation minimization (EGM) method to optimize a single-phase, fully developed flow with uniform and constant heat flux. They obtained an optimal Reynolds number for laminar and turbulent flow by assuming fixed heat transfer and mass flow rate with a constant heat flux. Dağtekin et al. (2005) performed the entropy generation analysis using a circular duct with three different shaped longitudinal fins for laminar flow. The results demonstrated that the number and dimensionless length of fins have significant effect on both entropy generation and pumping power.

Entropy generation in the helically coiled tubes for single phase flow has been studied by some authors. Ko and Ting (2005) investigated the optimal Reynolds number for steady, laminar, fully developed, forced convection in a helically coiled tube under constant wall heat flux. The optimal helical coil design is obtained using the minimal entropy generation principle based on the second law of thermodynamics. Ko (2006a) numerically studied the steady laminar forced convection and entropy generation in a helical coil with constant wall heat flux. The optimal curvature ratio based on the minimal entropy generation principle for helically coiled tubes is presented by Ko (2006b). Shokouhmand and Salimpour (2007a) investigated the effect of various flow and coil parameters on optimum Reynolds number for fully developed laminar flow and heat transfer in a helically coiled tube with uniform wall temperature based on minimal entropy generation principle. Shokouhmand and Salimpour (2007b) analytically studied the influence of various coil and flow parameters on the total entropy generation for laminar viscous flow subjected to constant wall temperature. The results explained that the increase in coil pitch leads to the decrease in entropy generation. Wu et al. (2008) investigated forced convective heat transfer and non-dimensional entropy generation number for turbulent flow in a helically coiled tube with uniform wall temperature. They discussed the effects of Reynolds number, curvature ratio, and coil pitch on the average