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The study of entropy generation during flow boiling in a micro-fin tube

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ABSTRACT

Increasing in the heat transfer rate in flow boiling is a common and key issue for engineers. Generally, the heat transfer coefficient augmentation methods are divided into two main categories (active and passive methods). In passive methods the increase in heat transfer rate causes the increase in pressure drop. In order to evaluate the contribution of heat transfer and pressure drop mechanisms, the entropy generation analysis is used. In this paper, the entropy generation in micro-fin tube is investigated under flow boiling condition. The effect of different geometrical parameters and flow conditions is discussed on pressure drop contribution and heat transfer one in entropy generation, irreversibility distribution ratio (*IDR*) and Bejan number (*Be*). The frictional pressure drop and heat transfer coefficient in the micro-fin tube and the helically coiled one are compared as two enhancements passive heat transfer methods with the smooth straight tube in the literatures. Therefore, by introducing entropy generation number (N_s), the favorable geometry between the micro-fin tube and the helically coiled one with respect to the smooth straight tube is recognizable at equivalent boundary conditions.

L'étude de la production d'entropie pendant l'ébullition en écoulement dans un tube à micro-ailettes

Mots clés : Coefficient de transfert de chaleur en ébullition ; Chute de pression ; Tube à micro-ailettes ; Nombre de production d'entropie (N_s) ; Nombre de Bejan (*Be*) ; Ratio de distribution d'irréversibilité (*IDR*)

1. Introduction

Augmentation of the heat transfer rate has obtained significant importance in recent years due to increase in the energy and material costs. Various methods have been investigated over a period of years to augment the two-phase heat transfer coefficient as applied to refrigeration and air-conditioning systems (Bergles et al., 1981). One of the most common methods in increasing the heat transfer coefficient is the use of micro-fin tubes. The increase in heat transfer coefficient relative to the pressure drop is one of the reasons for growing popularity of the micro-fin tube. Generally, while increasing in pressure drop is 20–50 percent, enhancement in evaporation andcondensation heat transfer coefficient is 50–100 percent for various kinds of refrigerants, including R-l13 (Khanpara, 1986),

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Nomenclature

A_c	cross sectional flow area [m^2]
A_w	cross sectional tube wall area per fin [m^2]
Be	Bejan number [–]
B_T	bottom thickness [m]
B_w	bottom width [m]
dz	element discretization [m]
D_h	hydraulic diameter [m]
D_c	coil diameter [m]
D_o	tube outer diameter [m]
e_f	fin height [m]
G	mass velocity [$kg \cdot m^{-2} \cdot s^{-1}$]
h	specific enthalpy [$J \cdot kg^{-1}$]
IDR	irreversibility distribution ratio [–]
L	length [m]
$\dot{m}$	mass flow rate [$kg \cdot s^{-1}$]
N	number of fins [–]
N_s	entropy generation number [–]
p	pressure [Pa]
P	perimeter [m]
q	heat flux [$W \cdot m^{-2}$]
$\dot{Q}$	heat rate [W]
s	specific entropy [$J \cdot K^{-1}$]
$\dot{s}'_{gen}$	entropy generation per unit length [$W \cdot m^{-1} \cdot K^{-1}$]
T	temperature [°C]
U	convective heat transfer coefficient [$W \cdot m^{-2} \cdot K^{-1}$]
U_{sl}	liquid superfacial velocity [$m \cdot s^{-1}$]
U_{sv}	gas superfacial velocity [$m \cdot s^{-1}$]
x	vapor quality

Greek symbols

ε	void fraction [–]
α	fin angle [deg.]
ρ	density [$kg \cdot m^{-3}$]
β	fin spiral angle [deg.]
υ	specific volume [$m^3 \cdot kg^{-1}$]

Subscripts

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

R-22 (Chiang, 1993) and HFC-134a (Eckels and Pate, 1991; Wongsa-ngam et al., 2004).

The investigation of pressure drop and heat transfer mechanism in micro-fin tube performed by some researchers in flow boiling and condensation. Nidegger et al. (1997) and Zurcher et al. (1998) investigated flow boiling heat transfer coefficient and pressure drop of R-134a/Oil and R-407C/Oil, respectively in micro-fin tube. They studied the effect of oil concentration on heat transfer coefficient and pressure drop. Filho et al. (2004) studied convective boiling pressure drop of refrigerant R-134a in micro-fin tube and smooth one for three different tube outer diameters. The variation of mass velocity and vapor quality was considered in this study. The review of heat transfer coefficient and pressure drop correlations in condensation of refrigerant in enhanced tube of various types was investigated by Cavallini et al. (2000) and Dalkilic and Wongwises (2009).

It is possible to assess the weight of heat transfer and pressure drop mechanisms with entropy generation analysis to find the optimized and suitable geometry of heat exchanges or channels in single phase and two phase flow. Some authors have been focused on the single phase flow entropy generation to find the optimum geometrical parameters and flow conditions for enhancing heat transfer rate. Bejan and Pfister (1980) studied entropy generation to evaluate the heat transfer augmentation techniques. They indicated that techniques which increase heat transfer coefficient do not necessarily reduce the destruction of exergy. Webb (1981) developed performance evaluation criteria (PEC) equations, which was applicable for single phase flow in tubes. The effects of shell-side enhancement and fouling included in these equations and were applicable to roughness and internally finned tubes. Prasad and Shen (1993) used exergy analysis in a tubular heat exchanger with wire-coil insert to evaluate the effectiveness of a passive heat transfer augmentation. Based on entropy production theorem, Zimparov and Vulchanov (1994) presented performance evaluation criteria (PEC) equations to evaluate the heat transfer enhancement techniques. The inappropriate enhanced surfaces founded with these criteria aid the engineers to design the better heat transfer equipment. Zimparov (2001a, 2002) experimentally investigated heat transfer and friction characteristics of two single-start and three-start spirally corrugated tubes combined with five twisted tape. He found that the thermodynamic optimum determined by minimizing the entropy generation number. In order to include the effect of fluid temperature variation along the length of a tubular heat exchanger, Zimparov (2001b) developed (PEC) equations for enhanced heat transfer surfaces. The entropy generation minimization (EGM) method in optimizing a single-phase, fully developed flow with uniform and constant heat flux studied by Ratts and Raut (2004). The optimal Reynolds number for laminar and turbulent flow obtained by assuming fixed heat transfer and mass flow rate with a constant heat flux. The entropy generation analysis using a circular duct with three different shaped longitudinal fins for laminar flow performed by Dağtekin et al. (2005). They found that the number and dimensionless length of fins have significant effect on both entropy generation and pumping power. Sahiti et al. (2008) performed the minimization of entropy generation for double-pipe pin fin heat exchanger. The optimization model was developed based on the entropy generation minimization for different heat exchanger flow lengths and pin length. Naphon (2011) performed the experimental and theoretical investigations on the entropy generation and exergy loss of a horizontal concentric micro-fin tube heat exchanger. The effect of mass velocity on the entropy generation, entropy generation number, and exergy loss are studied. The heat transfer characteristics of mini shell-and-tube heat exchanger equipped with multi-scale distributor was analyzed based on the first and second laws of thermodynamic by Tarlet et al. (2014). They found that under