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Research Paper

Comparative evaluation of flow boiling heat transfer characteristics of R-1234ze(E) and R-134a in plate heat exchangers with different Chevron angles

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HIGHLIGHTS

- The flow boiling heat transfer characteristics of R-1234ze(E) and R-134a in plate heat exchangers are measured and analyzed.
- The heat transfer coefficients of R-1234ze(E) and R-134a are quite similar at the same mass flux.
- R-1234ze(E) shows higher pressure drop than R-134a owing to the lower vapor density.
- The correlations for the heat transfer and pressure drop of R-1234ze(E) are developed considering different Chevron angles.

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ABSTRACT

In this study, the flow boiling heat transfer characteristics of R-1234ze(E) and R-134a in plate heat exchangers with different Chevron angles are measured and analyzed as a function of the mass flux, saturation temperature, vapor quality, and heat flux. The effect of the mass flux on the heat transfer and pressure drop of R-1234ze(E) is substantial. The heat transfer coefficient of R-1234ze(E) for a Chevron angle of 60° is approximately 3.7 times higher than that for a Chevron angle of 30° at high vapor qualities owing to the intensified turbulent flow. Moreover, for a Chevron angle of 60°, the average heat transfer coefficient of R-1234ze(E) is on average 4.7% higher than that of R-134a due to its higher equivalent Reynolds number. However, the average pressure drop of R-1234ze(E) is higher than that of R-134a owing to the lower vapor density of R-1234ze(E). Finally, the correlations for the heat transfer and pressure drop of R-1234ze(E) are developed in the plate heat exchangers with different Chevron angles.

1. Introduction

The EU Regulation No. 517/2014 [1] announced that automobile manufacturers will be financially penalized if their new models of automobiles use a refrigerant with a global warming potential (GWP) greater than 150. HFC (Hydroflurocarbon) refrigerants such as R-134a, R-404a, and R-410A, which are widely used in various thermal systems, have high GWPs of 1430, 3922, and 2088, respectively. Therefore, it is essential to find alternative refrigerants to the conventional ones to cope with the GWP regulation [2,3]. HFOs (Hydrofluroolefins) and natural refrigerants have received significant attention as alternative refrigerants. However, the use of natural refrigerants such as water, ammonia, and carbon-dioxide is very limited because of their narrow operating condition, toxicity, and low reliability [4]. HFOs are environmentally friendly, with GWPs lower than 10, and their system efficiencies are almost similar to those of the conventional refrigerants. Among HFOs, R-1234yf and R-1234ze(E) are the leading candidates for substituting R-134a [5,6].

Previous studies on low GWP refrigerants mainly focused on refrigerant properties, drop-in tests in existing systems, and heat transfer characteristics [7–12]. Especially, Del Col et al. [9] investigated the condensation heat transfer characteristics of R-1234ze(E) in a single micro-channel. Grauso et al. [10] studied the flow boiling heat transfer characteristics of R-1234ze(E) and R-134a in a horizontal circular tube. They reported that earlier dry-out occurs for R-1234ze(E) compared with that for R-134a. Nagata et al. [11] measured the vaporization/condensation heat transfer characteristics of R-1234ze(E), R-1234ze(z), and R-1233zd(E) in a horizontal tube. They concluded that R-1234ze(E) showed slightly lower heat transfer coefficient than R-134a. However, the heat transfer characteristics of R-1234ze(E) have been only investigated in circular tubes and micro-channels.

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Nomenclature

A	area (mm^2)
Bo	Boiling number (–)
b	pitch (mm)
C_p	specific heat capacity at constant pressure ($J\ kg^{-1}\ K^{-1}$)
d	depth of corrugation (mm)
D_h	hydraulic diameter (mm)
f	function (–)
f_{tp}	friction factor (–)
G	mass flux ($kg\ s^{-1}\ m^{-2}$)
g	gravity acceleration ($m\ s^{-2}$)
h	enthalpy ($J\ kg^{-1}$)
h_r	refrigerant-side heat transfer coefficient ($W\ m^{-1}\ K^{-2}$)
h_w	water-side heat transfer coefficient ($W\ m^{-1}\ K^{-2}$)
k	thermal conductivity ($W\ m^{-1}\ K^{-1}$)
L	length (mm)
$\dot{m}$	mass flow rate ($kg\ h^{-1}$)
Nu	Nusselt number (–)
P	pressure (kPa)
p	wavelength pitch (mm)
Pr	Prandtl number (–)
t	thickness (mm)
Q	capacity (W)
Re	Reynolds number (–)
T	temperature (°C)
U	overall heat transfer coefficient ($W\ m^{-1}\ K^{-2}$)
W	width (mm)
x	vapor quality (–)
y	variable (–)

Greek letters

α	dimensionless corrugation parameter (–)
β	Chevron angle (degree)
μ	viscosity (Pa s)
υ	specific volume ($m^3\ kg^{-1}$)
ρ	density ($kg\ m^{-3}$)
σ	surface tension ($N\ m^{-1}$)
ϕ	enlargement factor (–)
ω	uncertainty (–)

Subscripts

avg	average
eq	equivalent
fg	vapor-liquid
in	inlet
l	liquid
lo	liquid only
m	mean
n	data number
out	outlet
r	refrigerant
sat	saturation
tp	two-phase
v	vapor
w	water

A plate heat exchanger has a large heat transfer area compared to other types of heat exchangers with the same volume. Table 1 summarizes recent research trends on the heat transfer characteristics in plate heat exchangers [13–22]. The heat transfer characteristics of the conventional refrigerants such as R-410A and R-134a in plate heat exchangers have been analyzed extensively. Jokar et al. [16], Longo [17], Longo and Gasparella [18], Djordjevic and Kabelac [19], Hsieh and Lin [20], and Han et al. [21] developed correlations of the vaporization/condensation heat transfer characteristics of R-134a and R-410A in brazed plate heat exchangers. Furthermore, Eldeeb et al. [23], Amalfi et al. [24,25] and Ayub [26] reviewed the correlations of the vaporization/condensation heat transfer coefficient and pressure drop of the conventional refrigerants in plate heat exchangers with various geometries.

As described above, various competitive alternative refrigerants have been proposed by property comparisons, drop-in tests, and heat transfer tests. However, it is still difficult to clarify the differences between the flow boiling heat transfer characteristics of alternative and conventional refrigerants in plate heat exchangers owing to the lack of research on low GWP refrigerants. Furthermore, the existing studies on the flow boiling heat transfer characteristics of the low GWP refrigerants focused on conventional fin-tube heat exchangers rather than on plate heat exchangers. Overall, although R-1234ze(E) is expected to replace R-134a in the applications for various facilities and automobiles, experimental studies on the flow boiling heat transfer characteristics of R-1234ze(E) in a plate heat exchanger are very limited. Especially, the effects of Chevron angle on the flow boiling heat transfer characteristics of R-1234ze(E) in a plate heat exchanger have barely

Table 1
Research trends on the heat transfer characteristics in plate heat exchangers [13–22].

Author(s)	Topics	Fluid	β (degree)	G ($kg\ m^{-2}\ s^{-1}$)	T_{sat} (°C)
Solotych et al. [13]	Evaporation heat transfer and pressure drop	HFE 7100	60, 65	25–100	–
Lee et al. [14]	Evaporation heat transfer in plate heat exchanger at low mass flux condition	R-134a	60	0.00128–0.0017	17.7–25.8
Huang et al. [15]	Evaporation heat transfer and pressure drop	R-134a R-507A	28, 28/60, 60	10.7–31.4	5.9–13
Jokar et al. [16]	Evaporation and condensation heat transfer and pressure drop	R-134a	60	13.1–49.6	30–120 (condensation), −6–29 (evaporation)
Longo [17]	Condensation heat transfer and pressure drop	R-134a	65	11.6–41.3	24.6–40.2
Longo and Gasparella [18]	Evaporation heat transfer and pressure drop	R-134a	65	11.8–36.7	9.7–20.3
Djordjevic and Kabelac [19]	Evaporation heat transfer	R-134a R-717	63, 27	55–60 (R-134a) 10–25 (R-717)	−8–10
Hsieh and Lin [20]	Evaporation heat transfer and pressure drop	R-410A	60	50–125	7.5–30.5
Han et al. [21]	Evaporation heat transfer and pressure drop	R-22R-410A	45, 55, 70	11–34	5–15
Longo et al. [22]	Models for evaporation heat transfer	HFCs, HCs, HFOs	–	–	–