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Experimental study on the heat transfer and flow characteristics of nanorefrigerants inside a corrugated tube

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ABSTRACT

The heat transfer and flow characteristics of MWCNT-R141b nanorefrigerant with different mass fractions have been studied through experiments. Experimental results were compared with existing correlations. A two-step method was used to prepare the nanorefrigerants. Span-80 was used as surfactant with an average particle diameter of 20 nm. Transmittance method was used to evaluate the stability of nanorefrigerants. Results showed that the stability of MWCNT-R141b nanorefrigerant, which is the added dispersant, was good during the experiments. The 0.3 wt% MWCNT-R141b nanorefrigerants had optimal heat transfer enhancement effects compared with pure refrigerants. The maximum Nusselt number increased by 40%. The specific pressure drop of nanorefrigerant increased as the Reynolds number (*Re*) increased, and the specific pressure drop of the pure refrigerant was minimum, which is similar to R141b.

Etude expérimentale sur le transfert de chaleur et les caractéristiques d'écoulement de nanofrigorigènes à l'intérieur d'un tube ondulé

Mots clés : Transfert de chaleur ; Caractéristiques de l'écoulement ; Nanofrigorigène ; Production d'entropie ; Tube ondulé

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Nomenclature

C	Specific heat (J kg^{-1} K^{-1})
d	Diameter (mm)
D	Equivalent diameter (m)
E	Two phase strengthening factor
Fr	Froude number
G	Mass flux (kg s^{-1})
H	Gas liquid saturated evaporation enthalpy (kJ kg^{-1})
h	Heat transfer coefficient (W m^{-2} K^{-1})
k	Thermal conductivity (W m^{-1} K^{-1})
l	Length of test section (mm)
N	Boiling suppression factor
Nu	Nusselt number
M	Mass flow rate (kg m^{-2} s^{-1})
P_f	Heat taken away by fluid (W)
P_{rl}	Prandtl number of liquid
Q	Heating capacity (W)
q_v	Volume flow rate (m^3 h^{-1})
q_w	Heat flux (W m^{-2})
Re	Reynolds number
$S_{gen,\ t}$	Entropy generation caused by heat
$S_{gen,\ f}$	Entropy production caused by friction
T	Temperature (K)
t_w	Outside temperature of insulation (°C)
t_s	Environment temperature (°C)
u	Velocity (m s^{-1})
X_{tt}	Martineli number
x	Vapor quality
Greek symbols	
α	Ratio of thermal conductivity between nanoparticles and R141b
γ	Percent error
μ	Dynamic viscosity (Pa s)
ν	Kinematic viscosity (m^2 s^{-1})
ρ	Density (kg m^{-3})
δ	Insulation thickness (mm)
σ	surface tension (N m^{-1})
φ	Volume fraction
Subscripts	
ave	Average
in	Inlet of test section
f	Base liquid
g	Gas phase
l	Liquid phase
nf	Nanorefrigerant
out	Outlet of test section
p	Nanoparticle
pool	Pool boiling
test	test section
wi	inner surface

1. Introduction

In 1995, Choi (1995) of the U.S. Argonne National Laboratory proposed the concept of nanofluids, which caused a new research direction for the field of strengthening heat transfer. He prepared nanofluids by adding nanoparticles to a liquid and found that nanoparticles can significantly increase the thermal conductivity of fluid. Kim et al. (2011) studied the characteristics of carbon nanofluids at room temperature, and the results showed that nanofluids with 300 wt% PVP and oxidized MWCNTs exhibited good thermal conductivity; the thermal conductivity of oxidized carbon nanofluids was the highest among nanofluids; and the use of additives in nanofluid preparation increases viscosity.

The concept of nanorefrigerants has been proposed based on nanofluids. The thermal physical properties of nanorefrigerants have a large influence on the heat transfer characteristics; hence, many scholars investigated the thermal physical properties firstly. To date, most scholars studied the thermal conductivity and viscosity of nanorefrigerants through experiment and simulation method (Alawi and Sidik, 2014a,b; Mahbubul et al., 2013b,c). Otherwise, studies on heat transfer of nanorefrigerants (Bi et al., 2011; Kedzierski, 2011; Kedzierski and Gong, 2009; Mahbubul et al., 2013a; Naphon et al., 2009) have shown that adding nanoparticles to refrigerants can improve the heat transfer coefficient of the base fluid. Kedzierski et al. studied the effect of CuO-R134a (Kedzierski and Gong, 2009) and Al_2O_3-R134a (Kedzierski, 2011) on pool boiling heat transfer. The results of CuO-R134a pool boiling heat transfer showed that the nanoparticles increase the heat transfer by 50–275% compared with the heat transfer of pure R134a/polyester (99.5/0.5); the results of Al_2O_3-R134a pool boiling heat transfer showed that for the 0.5% nanolubricant mass fraction, the nanoparticles increase the heat transfer by as high as 400% for the lowest heat flux compared with the heat transfer of pure R134a/polyester (99.5/0.5). Bi et al. (2011) studied the performance of a domestic refrigerator using a TiO_2-R600a nanorefrigerant. They found that the performance of a refrigerator with 0.5 g L^{-1} TiO_2-R600a nanorefrigerant was better than that of a pure R600a system with 9.6% less energy used. Chen and Xie (2009) studied the thermal conductivity of silicon oil on the basis of multiwalled carbon nanofluid. The results showed that the collective effects, which involve the straightness ratio, aspect ratio, and aggregation of TCNTs, have an important function in the thermal conductivity of CNT nanofluids.

Shoghl and Bahrami (2013) studied the effect of surfactant on the heat transfer characteristic of ZnO and CuO water-based nanofluids, results showed that the boiling performance of nanofluids with surfactant revealed better performance. Hu et al. (2013) investigated the boiling heat transfer characteristics of Cu-R113/VG 68 refrigerant/nanolubricant with surfactants SDS, CTAB and Span-80, experimental value indicated that the heat transfer coefficient of nanorefrigerants with surfactants increased with the increase of surfactant concentration and then decrease, and increase with the