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Condensation heat transfer and two-phase frictional pressure drop in a single minichannel with R1234ze(E) and other refrigerants

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ABSTRACT

R1234ze(E), trans-1, 3, 3, 3-tetrafluoropropene, is a fluorinated propene isomer which may be a substitute of R134a for refrigeration applications. R1234ze(E) has a much lower $GWP_{100\text{-}years}$ than that of R134a. In this paper, the local heat transfer coefficient during condensation of R1234ze(E) is investigated in a single minichannel, horizontally arranged, with hydraulic diameter equal to 0.96 mm. Since the saturation temperature drop directly affects the heat transfer rate, the pressure drop during adiabatic two phase flow of R1234ze(E) is also measured. Predictive models are assessed both for condensation heat transfer and pressure drop. A comparative analysis is carried out among several fluids (R1234ze(E), R32, R134a and R1234yf) starting from experimental data collected at the same conditions and using the Performance Evaluation Criteria (PEC) named Penalty Factor (PF) and Total Temperature Penalization (TTP) to rank the tested refrigerants in forced convective condensation.

Transfert de chaleur de condensation et chute de pression diphasique de frottement dans un minicanal unique avec le R1234ze(E) et d'autres frigorigènes

Mots clés : Minicanaux ; Condensation ; Chute de pression ; R1234ze(E) ; Critère d'évaluation de la performance ; Facteur pénalisant

1. Introduction

In 1997, the Kyoto Protocol established limitations and reduction obligation with respect to a basket of six greenhouse gases, including many common hydrofluorocarbon refrigerants (HFCs) such as R134a and R32. Furthermore, the European Union has faced the climate change issue by drawing the Regulation No 842/2006 and the mobile air conditioning (MAC) Directive 2006/40/EC, which prohibits the use of fluorinated gases (F-gases) with a global warming potential

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Nomenclature

$a_0, \ldots, a_M$	coefficients of the water temperature fitting equation
A	parameter in Annex D [/]
C	Hagen-Poiseuille constant [/]
CF	coverage factor to obtain the expanded uncertainty [/]
c_p	specific heat [J kg^{-1} K^{-1}]
d	inner diameter [m]
D_h	hydraulic diameter [m]
dp/dz	pressure gradient [Pa m^{-1}]
E	entrainment ratio [/]
e_P	percentage deviation = 100 $(\tau_{CALC} - \tau_{EXP})/\tau_{EXP}$ [%]
e_R	average deviation = $(1/N_P)\ \Sigma e_P$ [%]
f	friction factor [/]
F	parameter in Annex D [/]
g	gravitational acceleration [m s^{-2}]
G	mass velocity [kg m^{-2} s^{-1}]
h	specific enthalpy [J kg^{-1}]
H	parameter in Annex D [/]
h_{LV}	latent heat = $h_V - h_L$ [J kg^{-1}]
HTC	heat transfer coefficient [W m^{-2} K^{-1}]
j_G	superficial gas velocity = xG/ρ_V [m s^{-1}]
J_G	dimensionless gas velocity [/]
J_G^T	transition dimensionless gas velocity [/]
L_{MS}	length of the measuring sector [m]
$\dot{m}$	mass flow rate [kg s^{-1}]
N_P	number of data points [/]
nTC	number of water thermocouples considered for data reduction [/]
p	pressure [Pa]
p_R	reduced pressure = p/p_{CR} [/]
PF	penalty factor for condensation [K^2]
Pr	Prandtl number = $\mu c_p/\lambda$ [/]
q'	local heat flux [W m^{-2}]
R^2	R square coefficient of determination [/]
R^2_{adj}	adjusted R square coefficient of determination [/]
Ra	arithmetic mean deviation of the assessed profile according to EN ISO 4287:1998/A1 [μm]
Re	Reynolds number = GD_h/μ [/]
Re_{LO}	liquid-only Reynolds number = GD_h/μ_L [/]
RR	relative roughness = $2Ra/D_h$ [/]
t	temperature [°C]
T	temperature [K]
T_S	saturation temperature [K]
T_W	tube internal wall temperature [K]
TTP	total temperature penalization [K]
u_A	type A uncertainty
u_B	type B uncertainty
u_C	combined experimental uncertainty
W	parameter in Annex D [/]
x	thermodynamic vapour quality [/]
X	coefficient in Eq. (D.2) [/]
X_{tt}	parameter in Annex C [/]
y	fitting function for water temperature as a function of z
z	axial position [m]
Z	parameter in Annex D [/]

Greek symbols

α	heat transfer coefficient [W m^{-2} K^{-1}]
Δp	pressure drop [Pa]
Δt	temperature difference [°C]
ΔT	temperature difference [K]
ΔT_{sw}	$T_S - T_W$ [K]
ΔT_{dr}	driving temperature difference [K]
ΔT_{sr}	saturation temperature decrease [K]
ε	absolute roughness of the channel [m]
θ	directly measured quantity
λ	thermal conductivity [W m^{-1} K^{-1}]
μ	dynamic viscosity [kg m^{-1} s^{-1}]
ξ	quantity expressed as function of uncorrelated inputs
ρ	density [kg m^{-3}]
σ	surface tension [N m^{-1}]
σ_N	standard deviation (prediction method) = $[\Sigma(e_p - e_R)^2/(N_P - 1)]^{1/2}$ [%]
τ	generic quantity
Φ	two-phase multiplier [/]
χ^2	merit figure [/]

Subscripts

A	ΔT independent flow regime
CALC	calculated
CR	critical
D	ΔT dependent flow regime
EXP	experimental
f	frictional
GC	gas core
i	corresponding to *i-th* water thermocouple
in	inlet
L	saturated liquid
LO	liquid phase with total mass flow rate
MS	measuring sector
out	outlet
PS	pre-section
ref	refrigerant
sat	saturation
STRAT	fully stratified flow regime
V	saturated vapour
wall	wall
water	water

(GWP) higher than 150 in new vehicles from 1 January 2011 and for all vehicles from 1 January 2017. The European Commission adopted a roadmap (endorsed by the European Parliament in its Resolution of 15 March 2012) for moving to a competitive low carbon economy in 2050; the roadmap establishes that non-CO_2 emissions (including fluorinated greenhouse gases but excluding non-CO_2 emissions from agriculture) should be reduced by 72–73% by 2030 compared to 1990 levels. The original F-gas Regulation (No 842/2006) is being replaced by a new Regulation (No 517/2014) adopted in