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Experiments during flow boiling of a R22 drop-in: R422D adiabatic pressure gradients

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ABSTRACT

R22, the HCFC most widely used in refrigeration and air-conditioning systems in the last years, is phasing-out. R422D, a zero ozone-depleting mixture of R125, R134a and R600a (65.1%/31.5%/3.4% by weight, respectively), has been recently proposed as a drop-in substitute. For energy consumption calculations and temperature control, it is of primary importance to estimate operating conditions after substitution. To determine pressure drop in the evaporator and piping line to the compressor, in this paper the experimental adiabatic pressure gradients during flow boiling of R422D are reported for a circular smooth horizontal tube (3.00 mm inner radius) in a range of operating conditions of interest for dry-expansion evaporators.

The data are used to establish the best predictive method for calculations and its accuracy: the Moreno-Quibèn and Thome method provided the best predictions for the whole database and also for the segregated data in the annular flow regime.

Finally, the experimental data have been compared with the adiabatic pressure gradients of both R22 and its much used alternative R407C available in the literature.

1. Introduction

R22 is still widely used as working fluid in the majority of systems for air-conditioning and refrigeration. The political decisions [1,2] that scheduled its phase-out, due to its high ozone depletion potential (ODP), have been forced through major changes. During last years, new trends in the use of refrigerants established depending on the application field, as highlighted in [3–5].

The substitution of R22 is an operation that interests a lot of plants which are expected still working after its phase-out. The drop-in candidates for R22 have been checked for environmental and safety requirements, compatibility with lubricant oil, filters, sealing; moreover they have thermodynamic properties, like vapor pressure curve, vapor density, heat of vaporization and volumetric refrigerating capacity comparable to R22. Among the candidates, to establish the best substitute in a specified system it is necessary to estimate energy consumptions after the substitution. Consequently, the new balancing point of components has to be determined, requiring pressure drop and heat transfer calculations inside heat exchangers.

R407C, largely used to retrofit R22, have got a special attention from the industry with the expectation of similar energy efficiency without major changes in the system. R407C is a ternary blend of HFC compounds (23% of R32, 25% of R125 and 52% of R134a by weight). It has no chlorine content and a modest GWP (1650). It is non-flammable and non-toxic. Its main thermophysical properties are close to those of R22, but it has the disadvantage of not being suitable with mineral or alkylbenzene oils. However, in comparison with R22, experimental tests carried out with R407C have pointed out a reduction in the energetic performances with a larger environmental impact [6].

Many companies have expended much effort to develop and to identify the refrigerants able to increase the energy efficiency of a refrigerating system, depending on its application. In air-conditioning systems by direct expansion, the refrigerant R422D (commercially known as ISCEON MO29) has been recently proposed as a drop-in refrigerant to R22. R422D, originally designed to replace R22 in existing direct expansion water chiller systems, actually is also used in residential and commercial air-conditioning and low and medium temperature refrigeration systems. In spite of R407C, R422D is compatible with traditional and new lubricants, including mineral oils, alkylbenzene and polyol ester: no change of lubricant type during retrofit of R22 is required. Only minor equipment modifications such as for sealing, filter drier or expansion device adjustments could be required in some applications. R422D is a non-ozone-depleting, non-flammable, non-toxic, ternary mixtures of R125, R134a and R600a (65.1%/31.5%/3.4% by weight, respectively). The small percentage of isobutane promotes adequate oil return in properly piped systems with oil separators.

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Nomenclature

Latin letters

A	annular flow
C	parameter in Lockhart and Martinelli's equation
COP	coefficient of performance
D	dryout
G	refrigerant mass flux (kg/m^2 s)
GWP	global warming potential
I	intermittent flow
i	specific enthalpy (kJ/kg)
i_{lv}	latent heat of vaporization (kJ/kg)
L	length (m)
M	mist flow
$\dot{m}$	mass flow rate (kg/s)
n	number of points
ODP	ozone-depleting potential
p	pressure (bar)
$\dot{Q}$	power (W)
r	radius (m)
R	electrical resistance (Ω)
sd	standard deviation (%)
t	temperature (K)
V	voltage (V)
$\dot{V}$	volume flow (m^3/s)
w	velocity (m/s)
x	vapor quality
X	Martinelli parameter
z	abscissa along the tube (m).

Greeks

δ	uncertainty
Δ	difference
ε_i	error (%)
$\bar{\varepsilon}$	mean error (%)
$\lvert\bar{\varepsilon}\rvert$	mean absolute error (%)
ϕ	two-phase multiplier
λ	predicted percentage within ± 30% deviation
μ	dynamic viscosity (μPas)
ρ	density (kg/m^3)

Subscripts

A	annular flow
ATS	adiabatic test section
cr	critical
DTS	diabatic test section
exp	experimental
i	inner
I	intermittent flow
in	inlet
in_evap	evaporator inlet
l	liquid
lo	corresponding to the liquid phase flowing alone
M	mist flow
o	outer
PH	preheater
$pred$	predicted
S	slug flow
SW	stratified-wavy flow
sat	saturation for R22, bubble-point for R407C and R422D
tt	turbulent–turbulent flow
v	vapor
vo	corresponding to the vapor phase flowing alone

In comparison to R22, R422D has a higher GWP (2230), it is more expensive and reacts with aluminium.

Recently Dispenza et al. [7] have compared experimentally the performances of R22 and R422D as working fluids in vapor compression refrigerating plants. The results are reported at the same conditions at the evaporator in terms of refrigerating load and secondary fluid temperature. The COP of R422D is lower than R22 by about 25% at higher evaporating temperatures. By a cross comparison of the works in [6,7], we could retain that, for evaporating temperatures of air-conditioning systems, performances of R422D and R407C are comparable.

The results of a bibliographic research showed that there are many experimental studies on flow boiling of refrigerant HFC mixtures [8], while no data on R422D two-phase pressure drops are available. As a consequence, there are no special prediction methods for R422D and it is not sure if the available correlations apply well to this fluid. Besides, it is not available a flow pattern map to predict the two-phase flow transitions developed specifically for R422D.

In this article, the attention is focused on the pressure drop estimation inside evaporators. Preliminarily the properties of R422D that influence two-phase pressure drops will be discussed and compared to those of R22 and R407C. Then the experimental adiabatic pressure gradients of R422D during flow boiling in a smooth, horizontal, circular stainless steel tube with an inner radius of 3.00 mm are reported: 15 tests were carried out obtaining 163 experimental points in operating conditions commonly encountered in dry-expansion evaporators. The refrigerant mass flux varied within the range from 198 to 350 kg/m^2 s, the evaporating pressures within the range from 4.0 to 7.8 bar (bubble-point temperature within the range from −9.2 to 11.8 °C) and the vapor quality within the range from 0.13 to 0.99.

The results of a statistical comparison to predictive methods are reported in order to establish the best one for R422D pressure drop calculations.

Finally, the obtained R422D experimental data are compared with adiabatic pressure gradients available in literature for R22 and R407C in similar operating conditions (tube geometry and inner diameter, evaporating temperature, refrigerant mass flux).

2. Thermodynamic analysis

Table 1 compares the characteristics of R422D that influence two-phase pressure drops with those of R22 and R407C. All values have been obtained by means of REFPROP 7.0 [9].

Table 1
Properties of refrigerants at 0 °C.

Refrigerant	R22	R407C	R422D
Flammability/toxicity	NO/no	NO/no	NO/no
ODP	0.055	0	0
GWP	1700	1650	2230
Molar mass (kg/kmol)	86.5	86.2	109.9
t_{cr} (°C)	96.1	86.0	79.5
p_{cr} (bar)	49.9	46.3	39.0
p_{sat} (bar)	5.0	5.7	5.4
p_{sat}/p_{cr}	0.10	0.12	0.14
ρ_l (kg/m^3)	1281.5	1236.2	1250.3
ρ_v (kg/m^3)	21.2	22.8	30.9
ρ_v/ρ_l	0.017	0.018	0.025
μ_l (μPa s)	216.0	212.1	221.1
μ_v (μPa s)	11.4	12.1	11.8
μ_l/μ_v	19.0	17.6	18.7
i_{lv} (kJ/kg)	205.0	217.3	150.6