INTERNATIONAL JOURNAL OF REFRIGERATION 66 (2016) 105–120

Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/ijrefrig

Experimental investigation on flow condensation heat transfer and pressure drop of R170 in a horizontal tube

X.R. Zhuang [a,b], M.Q. Gong [a,*], X. Zou [a], G.F. Chen [a], J.F. Wu [a]

[a] Key Laboratory of Cryogenics, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing 100190, China

[b] University of Chinese Academy of Sciences, Beijing 100049, China

ARTICLE INFO

Article history:
Received 9 October 2015
Received in revised form 3 February 2016
Accepted 9 February 2016
Available online 16 February 2016

Keywords:
Condensation
Heat transfer
Pressure drop
R170
Horizontal tube

ABSTRACT

Condensation heat transfer and pressure drop of R170 were studied experimentally in a horizontal tube with inner diameter of 4 mm. The tests were conducted at saturation pressures from 1 MPa to 2.5 MPa, mass fluxes from 100 kg $(m^2 \cdot s)^{-1}$ to 250 kg $(m^2 \cdot s)^{-1}$ and average heat fluxes from 55.3 kW m^{-2} to 96.3 kW m^{-2} over the entire vapor quality range. The effects of vapor quality, mass flux and saturation pressure on condensation heat transfer and pressure drop were examined and analyzed. The experimental data were compared with various well-known correlations of condensation heat transfer coefficient and pressure drop. The comparison results showed that Koyama et al. correlation agreed with the experimental heat transfer coefficient with a mean absolute relative deviation less than 25%, and the Yan and Lin correlation can accurately predict the experimental pressure drop with a mean absolute relative deviation less than 18%.

Étude expérimentale du transfert de chaleur par condensation en écoulement et de la chute de pression du R170 dans un tube horizontal

Mots clés : Condensation ; Transfert de chaleur ; Chute de pression ; R170 ; Tube horizontal

* *Corresponding author.* Key Laboratory of Cryogenics, Technical Institute of Physics and Chemistry, Chinese Academy of Sciences, Beijing 100190, China. Tel.: +86 10 82543728; Fax: +86 10 82543728.

E-mail address: gongmq@mail.ipc.ac.cn (M.Q. Gong).

http://dx.doi.org/10.1016/j.ijrefrig.2016.02.010

Nomenclature

B	width of the copper strip [m]
c_p	specific heat capacity [J (kg·K)$^{-1}$]
d	distance [m]
D	tube diameter [m]
f	frictional factor
Fr	Froude number, $Fr = G^2/\rho^2 gD$
g	gravitational acceleration [m s^{-2}]
G	mass flux [kg (m^2·s)$^{-1}$]
Ga	Galileo number, $Ga = g\rho^2 D^3/\mu^2$
h	heat transfer coefficient [W (m^2·K)$^{-1}$]
H_{lv}	latent heat [J kg^{-1}]
J_G	dimensionless vapor velocity, $J_G = Gx/[\rho_G(\rho_L\text{-}\rho_G)gD]^{0.5}$
L	length of the copper strip [m]
M	mass flow rate [kg s^{-1}]
Nu	Nusselt number, $Nu = hD/\lambda$
p	pressure [kPa, MPa]
p_{crit}	critical pressure [kPa, MPa]
p_r	reduced pressure, $p_r = p/p_{crit}$
Pr	Prandtl number, $Pr = \mu\, c_p/\lambda$
Ph	phase change number, $Ph = c_p(T_{sat}\text{-}T_w)/H_{lv}$
q	heat flux [W m^{-2}]
Q	electrical heat power [W]
Re	Reynolds number, $Re = GD/\mu$
Su	Suratman number, $Su = \rho\sigma D/\mu^2$
T	temperature [K]
x	vapor quality
X	Lockhart–Martinelli parameter
X_{tt}	Lockhart–Martinelli parameter based on turbulent liquid-turbulent vapor flows, $X_{tt} = [(1-x)/x]^{0.9}(\mu_L/\mu_G)^{0.1}(\rho_G/\rho_L)^{0.5}$
We	Weber number, $We = G^2D/\sigma\rho$

Greek letters

ε	void fraction
η	percentage of points predicted within a deviation bandwidth of ±30%
θ_L	angle subtended from the top of tube to the liquid level
λ	thermal conductivity [W (m·K)$^{-1}$]
μ	dynamic viscosity [Pa s]
ρ	density [kg m^{-3}]
σ	surface tension [N m^{-1}]
ϕ	two-phase frictional multiplier

Subscripts

avg	average value of the entire vapor quality range
A	annular flow
B	free convection condensation
cal	calculated value
de	deceleration pressure drop
exp	experimental value
film	film conduction condensation
fric	frictional pressure drop
F	forced convection condensation
grav	gravity pressure drop
G	vapor phase
GO	vapor only
i	number of the temperature measurement point
in	inlet
L	liquid phase
LO	liquid only
out	outlet
preh	preheater
S	stratified flow
s1	the first copper strip
sat	saturation state
so	Soliman's modified
sub	subcooled state
trans	transitional
total	measured pressure drop
tp	two phase
tt	turbulent liquid – turbulent vapor
tv	turbulent liquid – laminar vapor
vt	laminar liquid – turbulent vapor
vv	laminar liquid – laminar vapor
w	wall

1. Introduction

Due to the environmental problems of traditional chlorinated refrigerants, it has become an urgent task to search for suitable substitutes. With zero ozone depleting potential, low global warming potential and high thermodynamic performance, the hydrocarbons are suitable selections. Generally, hydrocarbons have smaller liquid densities than most of the fluorocarbons. Hence, the amount of charge decreases significantly with hydrocarbons which will help further relieve the direct emission of refrigerants. Hydrocarbons have been used as refrigerant in refrigerator and air-conditioning system although they are flammable. As one kind of hydrocarbons, R170 and its mixtures can be used to replace R22 and R503 in some refrigerators and heat pump systems. Park et al. (2010) recommended R170/R1270 to replace R22 in residential air-conditioners and heat pumps from the viewpoint of energy efficiency and greenhouse warming. The results showed that the capacities of R170/R1270 were 4.2–20.4% higher than those of R22 in the composition rang of 2–10% of R170 for both refrigerators and heat pump systems. And the capacities increased as the amount of R170 increased. In addition, the compressor discharge temperatures of the R170/R1270 mixture were 8.3–18.4 °C lower than those of R22 which lead to an improvement in system reliability and lifetime. Cleland et al. (2009) presented that R170/R290 was an attractive replacement for R22 in milk silo refrigerant systems. It was reported that there was a 7–9% improvement in energy efficiency for R170/R290 compared with R22 which was attributed to the improved thermodynamic and transport properties for hydrocarbons compared with fluorocarbons. Gong et al. (2009) proposed that R170/R116 and R170/R23/R116 showed good performance as refrigerants used in the low-stage loop in the two-stage cascade