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Boiling of ammonia/lubricant mixture on a horizontal enhanced tube in a flooded evaporator with inlet vapor quality

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ABSTRACT

In a flooded evaporator of an ammonia vapor-compression refrigeration system, boiling commonly takes place with ammonia mixed with compressor lubricant and subjected to a vapor quality at the inlet of the evaporator. In the present study, flooded boiling tests of ammonia on an enhanced tube under simultaneous influence of a miscible lubricant and inlet quality were conducted. The results suggest that the boiling heat transfer coefficient increases with both saturation temperature and heat flux. The coefficient slightly increases or does not significantly vary with the inlet quality. The coefficient in general is decreased by adding lubricant to the refrigerant, but the coefficient does not necessarily decrease as the lubricant concentration increases. The lubricant effect is generally more significant than the inlet quality effect. A correlation was developed based on the present data for flooded boiling of lubricant/ammonia mixture on an enhanced horizontal tube under the influence of inlet quality.

Ebullition d'un mélange d'ammoniac/lubrifiant à l'extérieur d'un tube à surface améliorée dans un évaporateur noyé

Mots clés : Système frigorifique ; Évaporateur noyé ; Expérimentation ; Ébullition libre ; Ammoniac ; Lubrifiant ; Tube horizontal ; Surface améliorée ; Coefficient de transfert de chaleur

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Nomenclature

A	heat transfer area (m^2)
D	tube diameter (m)
h	heat transfer coefficient ($W/m^2\,°C$)
i	specific enthalpy (J/kg)
Δi	change of specific enthalpy between tube's inlet and exit (J/kg)
i_{fg}	latent heat of vaporization (J/kg)
k	thermal conductivity (W/m °C)
m	mass (kg)
$\dot{m}$	mass flow rate (kg/s)
Nu	Nusselt number, $Nu = hD/k_f$ (dimensionless)
Pr	Prandtl number of liquid ammonia (dimensionless)
p_r	reduced pressure, p/p_{crit} (dimensionless)
q	heat transfer rate (W)
q''	heat flux (W/m^2)
r	radius (m)
T	temperature (°C)
T_s	saturation temperature (°C)
ΔT_{lm}	log mean temperature difference (°C)
U	overall heat transfer coefficient (W/m^2)
$\dot{V}$	volumetric flow rate inside tube (m^3/s)
w	mass concentration of lubricant (dimensionless)
x	quality (dimensionless)
x_{in}	quality at the inlet of the evaporator (dimensionless)

Greek

ρ	density

Subscripts

f	liquid refrigerant
g	vapor refrigerant
i	inside tube
in	inlet of test section
lb	lubricant
o	outside tube
p	pre-heater
s	saturation
t	tube
ts	test section
v	vapor

1. Introduction

This study investigates the boiling heat transfer performance of ammonia on the outside surface of a horizontal enhance tube under the influence of both compressor lubricant and inlet vapor quality, simulating a tube in a horizontal tube flooded evaporator of an ammonia vapor-compression refrigeration system. Lubricant is applied to lubricate, cool, and seal the compressor in a refrigeration system. However, lubricant tends to be carried by the refrigerant and to accumulate in the evaporator where the temperature is the lowest in the cycle. The accumulated lubricant causes change in the boiling heat transfer performance of ammonia in the evaporator.

Published works on shell-side boiling of refrigerants mixed with lubricants were summarized by Zheng et al. (2001) who also conducted experiment of flooded boiling using ammonia mixed with miscible lubricant on a plain tube. Miscible lubricant was used in order to avoid the formation of oil film or sludge in the evaporator and thus potentially yielding improved heat transfer performance compared with the conventional immiscible oil. The results of Zheng et al. (2001) showed that the effect of miscible lubricant strongly depends on saturation temperature, and weakly depends on heat flux. Under a particular saturation temperature and heat flux, the heat transfer coefficient generally first decreased with lubricant concentration up to 5%, and then followed by an insignificant increase with a further increase in concentration to 10%. The largest degradation of ammonia boiling heat transfer performance due to the miscible lubricant was 33%, which occurred at a low temperature of −23.3 °C.

In vapor-compression refrigeration system with a flooded evaporator, refrigerant may enter the evaporator with vapor content; in other words, the fluid entering the evaporator may be a two-phase flow with a certain level of quality. The inlet vapor quality may affect the boiling heat transfer performance of tubes in the evaporator. In fact, in a tube bundle contained in a flooded evaporator, tubes in different rows are subjected to different levels of quality due to vapor generated by tubes in lower rows. This effect is more pronounced with enhanced tubes (Ayub et al., 2006). Vapor quality plays a key role in tube bundle effect, i.e., higher heat transfer coefficients in higher rows in the bundle. In order to better understand such effect in an ammonia flooded evaporator, it is necessary to study the performance of a single enhanced tube under the influence of variable levels of vapor quality.

A recent review paper by Casciaro and Thome (2001) summarized published works on thermal performance of flooded evaporators, and revealed limited published information on simultaneous effects of lubricant and inlet vapor quality on flooded boiling. Cotchin and Boyd (1992) used R113/oil mixture and found a weak effect of local vapor quality on the local heat transfer coefficient, which increased local coefficient by up to 25% compared with single plain tube. Payvar and Tatara (1999, 2000a,b) measured boiling heat transfer coefficients for R-134a with POE oil and R123 with mineral oil under an inlet quality of 15% on an enhanced tubing. The literature review revealed no published data available for boiling of ammonia/lubricant mixture on enhanced tubes with an inlet quality. It is thus the objective of the present study to investigate the flooded boiling heat transfer performance of ammonia/lubricant mixture at different levels of lubricant concentration on a horizontal enhanced tube subjected to a two-phase flow with different levels of inlet quality at the inlet of a flooded evaporator. Miscible lubricant instead of the conventional immiscible oil was used for the same reason discussed above. In compliance with the condition in real devices, the experiment covered the range of heat flux approximately from 10 to