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Ammonia evaporation in a mixed configuration chevron plate heat exchanger with and without miscible oil

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ABSTRACT

An experimental study was conducted to determine the effects of miscible lubricant oil on evaporation of ammonia in a vertical chevron plate heat exchanger. The heat exchanger was configured in a U-type counter flow arrangement with mixed (30°/60°) chevron plate configuration. Experiments were carried out for four saturation temperatures ranging from −25 °C to −2 °C for a fixed ammonia mass flux rate of 6.5 kg m^{-2} s^{-1} and over a range of heat flux levels resulting in a vapor quality at the heat exchanger exit ranging between 0.5 and 0.9. For a given saturation temperature, experiments were performed for 0%, 3%, 6% and 9% oil concentrations, by volume in ammonia. The oil concentration, exit vapor quality, heat flux and saturation temperature were found to have significant effects on the heat transfer coefficient and pressure drop of ammonia. Based on the experimental data, correlations to estimate two phase Nusselt number and friction factor, generalized for the whole range of oil concentration have been presented.

Evaporation d'ammoniac dans un échangeur à plaques à chevrons avec et sans huile miscible

Mots clés : Echangeur de chaleur à plaques ; Ammoniac ; Evaporation ; Huile miscible ; Transfert de chaleur ; Chute de pression

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Nomenclature

Bo	Boiling number
D_h	Hydraulic diameter (m)
f	Fanning friction factor
G_r	Refrigerant mass flux (kg m^{-2} s^{-1})
h	Heat transfer coefficient (W m^{-2} K^{-1})
i	Enthalpy (kJ kg^{-1})
k	Thermal conductivity (W m^{-1} K^{-1})
L	Length, (m)
Nu	Nusselt number
P	Pressure (kPa) or Plate pitch (m)
P*	Reduced pressure (P/P_{cr})
Pcr	Critical pressure (kPa)
PHE	Plate heat exchanger
Pr	Prandtl Number
q″	Heat flux (kW m^{-2})
Re	Reynolds number
t	Plate thickness (m)
T	Temperature (°C)
U	Overall heat transfer coefficient (W m^{-2} K^{-1})
w	Miscible oil concentration (percent by volume)
x	Exit vapor quality

Greek symbols

Δ	Change or difference
μ	Dynamic viscosity (kg m^{-1} s^{-1})
ρ	Density (kg m^{-3})

Subscripts

acc	Acceleration
core	Core
elev	Elevation
eq	Equivalent
f	Liquid
fg	Liquid vapor mixture
g	Vapor
meas	Measured
port	Port
r	Refrigerant
sat	Saturation
sp	Single phase
tp	Two phase
wall	Wall

1. Introduction

1.1. *Background*

In refrigeration applications, lubricant oil is used to lubricate, cool and seal the compressors. Sometimes, the lubricant oil entrainment in the discharge refrigerant vapor may not be avoided. Similarly, the amount of oil vapor in refrigerant depends on temperature of discharge side of the refrigerant compressor. Several techniques are employed to minimize oil transfer in the refrigerant loop. In ammonia refrigeration systems, usually conventional or complex oil separators are employed to separate oil droplets. In spite of all these precautions, oil still migrates to evaporator where it accumulates. The oil accumulation could cause change in boiling heat transfer performance of ammonia in the evaporator. Since lubrication is necessary in the ammonia compressors, studies have been conducted to use such lubricants that are miscible with refrigerants so that formation of oil film is avoided in the evaporator.

1.2. *Effects of oil/lubricant*

Immiscible mineral oils are usually used for lubrication in ammonia systems. Liquid oil film forms on the tube wall in a tubular direct expansion system, Koster (1986). The heat transfer performance of the evaporator is reduced due to the formation of the oil film. A 30% reduction in tube side heat transfer coefficient was reported by Shah (1975) due to such oil film. Chaddock and Buzzard (1986) also reported that the heat transfer coefficient was reduced by 50–90% due to the presence of immiscible mineral oil layer on the heat transfer surface. Experiments of refrigerant and oil mixtures boiling in a planar confined space between a heated plate and an opposing adiabatic plate were reported by Marvillet and De Carvahlo (1994). It was shown that while the presence of oil was observed to have only a relatively minor effect on low heat flux nucleate boiling, it caused a serious degradation of boiling performance in high heat flux range. This deterioration was reported to be more severe with a higher oil concentration and a smaller gap size. However, for a given gap size, the critical heat flux was reported to increase with oil concentration accompanied by greater surface superheats. The effects of refrigerant/oil solubility of mixture of refrigerants and oils on system performance were analyzed by Hewitt and McMullan (1997). They focused on refrigerants that can possibly replace chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs), and synthetic oils. Refrigerant solubility with compressor lubricant oils was reported to affect composition of fluid mixtures and to reduce the system performance.

Effects of synthetic oil on the operation of a plate heat exchanger type condenser and evaporator with R-410A were studied by Lottin et al. (2003). Lubricant quantity in refrigerant ranged from 10^{-5} to 5%. Existing two-phase flow correlations with corrections to account for mass transfer thermal resistance of zeo-tropic mixtures, such as R410A were incorporated for both condensation and evaporation studies. They reported that different existing correlations produced scattered results; however same results were reported at 0.01% oil mass fraction in condenser using correlations considered in the study. Results of different correlations used in evaporator analysis showed heat transfer coefficient decreasing with lubricant mass fraction. The lubricant effect on temperature within the condenser was reported insignificant. Pressure loss in condenser was reported negligible; however, it increased several times in evaporator as oil quantity reached 5%, reducing suction pressure and hence the compressor efficiency, as well as favoring release of more refrigerant and enhancing heat transfer in evaporator. Therefore, a balance between these two phenomena is important.