INTERNATIONAL JOURNAL OF REFRIGERATION 44 (2014) 36–48

Available online at www.sciencedirect.com

ScienceDirect

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

Measurement and prediction of heat transfer coefficient on ammonia flow boiling in a microfin plate evaporator

Kohei Koyama [a,*], *Hirotaka Chiyoda* [b], *Hirofumi Arima* [a], *Akio Okamoto* [c], *Yasuyuki Ikegami* [a]

[a] *Institute of Ocean Energy, Saga University, 1-48 Hirao, Kubara-aza, Yamashiro-cho, Imari, Saga 849-4256, Japan*
[b] *Department of Mechanical Engineering, Saga University, 1 Honjo-machi, Saga, Saga 840-8502, Japan*
[c] *Titanium Technology Department, Kobe Steel, Ltd., Shinagawa-ku, Tokyo 141-8688, Japan*

ARTICLE INFO

Article history:
Received 7 February 2014
Received in revised form
8 May 2014
Accepted 10 May 2014
Available online 20 May 2014

Keywords:
Evaporation
Heat transfer coefficient
Heat transfer enhancement
Microfin
Ammonia
Titanium

ABSTRACT

Thermal characteristics of ammonia flow boiling in a microfin plate evaporator are experimentally investigated. Titanium microfin heat transfer surface is manufactured to enhance boiling heat transfer. Longitudinally- and laterally-microfined surfaces are used and those performances are compared. Heat transfer coefficient of microfin plate evaporator is also compared with that of plain-surface plate evaporator. The effects of mass flux, heat flux, channel height, and saturation pressure on heat transfer coefficient are presented and discussed. The experiments are conducted for the range of mass flux (5 and 7.5 kg m^{-2} s^{-1}), heat flux (10, 15, and 20 kW m^{-2}), channel height (1, 2, and 5 mm), and saturation pressure (0.7 and 0.9 MPa). Heat transfer coefficient is compared with that predicted by available empirical correlations proposed by other researchers. Modified correlations using Lockhart-Martinelli parameter to predict heat transfer coefficient are developed and they cover more than 87% of the experimental data.

Mesures et prévisions du coefficient de transfert de chaleur dans l'ébullition en écoulement d'ammoniac dans un évaporateur à plaques à micro-ailettes

Mots clés : Evaporation ; Coefficient de transfert de chaleur ; Amélioration du transfert de chaleur ; Micro-ailette ; Ammoniac ; Titane

* *Corresponding author*. Tel.: +81 955 20 2190; fax: +81 955 20 2191.
E-mail address: koyama@ioes.saga-u.ac.jp (K. Koyama).
http://dx.doi.org/10.1016/j.ijrefrig.2014.05.005

Nomenclature

A	constant
Bo	boiling number
Co_f	confinement number
Co_v	convection number
D_h	hydraulic diameter, m
F_{Fl}	fluid–surface parameter
g	gravitational acceleration, m s^{-2}
G	mass flux, kg m^{-2} s^{-1}
h	heat transfer coefficient, W m^{-2} K^{-1}
i	specific enthalpy, J kg^{-1}
i_{fg}	latent heat of evaporation, J kg^{-1}
k	thermal conductivity, W m^{-1} K^{-1}
l	distance between thermocouples, m
m	mass flow rate, kg s^{-1}
n	exponent
Nu	Nusselt number
P	pressure, Pa
P_{cr}	critical pressure, Pa
Pr	Prandtl number
Q_k	local heat transfer rate based on heat flux and heat transfer area, W
q	heat flux, W m^{-2}
Re	Reynolds number
t_1	thickness of titanium plate, m
t_2	thickness of brazing portion, m
t_3	thickness of titanium base plate, m
T	temperature, °C
We	Weber number
x	thermal equilibrium quality
β	chevron angle, degree
δ	channel height, m
μ	viscosity, Pa s
ρ	density, kg m^{-3}
σ	surface tension, N m^{-1}
X_{vv}	Lockhart-Martinelli parameter (laminar–laminar flow)

Subscript

CBD	convection boiling dominant
eff	effective value
g	gas phase
l	liquid phase
liq	only liquid phase flows
NBD	nucleate boiling dominant
s	brazing portion
sat	saturated state
TP	two-phase
wall	wall of the plate evaporator

1. Introduction

Electric power generation systems using renewable energy are necessary to overcome environmental issues, to address depletion of fossil fuel, and to develop sustainable society. Power generation system based on small temperature difference is an attractive option as an environmentally-friendly system. Small temperature difference exists in the ocean, wasted heat from industry, and hot spring. Power generation system using these temperature differences can supply electricity steadily compared with other renewable energy source such as wind or solar power generations. This kind of system generally consists of pump, evaporator, turbine, and condenser. Working fluid is supplied to evaporator in which the liquid working fluid is turned into vapor. The vapor is fed into turbine at which generator is connected. The vapor leaving from turbine is supplied to condenser in which vapor is returned into liquid. Development of each component of the power generation system is necessary to improve its thermal efficiency.

This study focuses on thermal performance of an evaporator. As discussed in Uehara and Nakaoka (1985), minimizing heat transfer area is required to develop efficient ocean thermal energy conversion plant, which uses temperature difference between shallow and deep seawater. Heat source for electric power generation system using small temperature difference is limited. Hence, improvement of thermal performance of an evaporator is required to develop efficient generation system.

Selection of refrigerant as working fluid is an important factor for power generation systems as well. Working fluid experiences evaporation and condensation in the power cycle. Not only thermophysical properties but also ozone depletion potential (ODP) and global warming potential (GWP) should be considered for selecting working fluid. Basic potentials of refrigerants were reviewed by Thome et al. (2008) and therefore ammonia is selected as a working fluid in this study.

The current investigation is a subsequent work of Koyama et al. (2014). Flow boiling of ammonia in a plate evaporator was explored to clarify its basic thermal characteristics. In the current study the heat transfer surface of the evaporator is microfinned to enhance heat transfer.

Microfin structure on a heat transfer surface has been attracted by many researchers to enhance boiling heat transfer. Fujii et al. (1995) revealed heat transfer and pressure drop of HCFC 22 in a grooved copper tube. They found that heat transfer coefficients for wavy-annular and annular flow in grooved tube were about two to four times as high as those in smooth tube. Chamra et al. (1996) compared pressure drop and heat transfer coefficient of R22 evaporation in four commercial microfin tubes. They reported that the highest performance was achieved on a cross-grooved tube with 20° helix angle. Yu et al. (2002) investigated R134a flow boiling in horizontal smooth and microfin tubes to present flow pattern map and heat transfer coefficient. They observed wavy, intermittent, semi-annular, and annular flows in their experimental range and they produced flow pattern map including these flow patterns. Kim and Shin (2005) measured and compared heat transfer coefficient of R22 and R410A flow boiling in smooth and microfin tubes. They reported that higher heat transfer performance was obtained by using R410A due to higher thermal conductivity. Bandarra Filho et al. (2004) measured