INTERNATIONAL JOURNAL OF REFRIGERATION 40 (2014) 309–316

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Experimental evaluation of an ejector as liquid re-circulator in a falling-film water chiller

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ARTICLE INFO

Article history:
Received 15 August 2013
Received in revised form
5 October 2013
Accepted 2 November 2013
Available online 10 November 2013

Keywords:
Falling film
Liquid–liquid ejector
Re-circulation ratio
Entrainment ratio

ABSTRACT

To experimentally evaluate the performance of an ejector working as a liquid re-circulator in a horizontal-tube falling-film evaporator with R134a, experimental tests are performed using a horizontal-tube falling-film water chiller prototype. Experimental observations on intertube liquid flow pattern of tube bundle validate the feasibility of the liquid re-circulation system using a liquid–liquid ejector. The analysis results show that the influence of the motive flow rate on the entrainment ratio of the ejector is small, and the average entrainment ratio of the ejector is about 2.03. With the increase of the valve opening of the regulating valve, the evaporating capacity of the falling-film water chiller rises 4.8%, from 940.2 kW with the re-circulation ratio of one, to 985.5 kW with the re-circulation ratio of 1.135. The COP of the falling-film water chiller reaches a maximum and then drops down with the increase of the re-circulation ratio, and the optimal re-circulation ratio is 1.135.

Evaluation expérimentale d’un éjecteur comme recirculateur liquid dans un refroidisseur d’eau à film tombant

Mots clés : Film tombant ; éjecteur liquide/liquide ; Taux de re-circulation ; Taux d’entraînement

1. Introduction

Refrigeration evaporators can be classified according to the liquid feed method employed, as direct-expansion evaporators, flooded evaporators and overfeed evaporators. Direct expansion evaporators are usually fed by using an expansion valve that regulates the liquid flow, the refrigerant which leaves the evaporator is superheated, and only vapor flows to the compressor. Flooded evaporators are completely filled with liquid refrigerant, so that the entire inner surface of evaporator is wet thus improving the heat transfer coefficient. For overfeed evaporators, some liquid boils in the evaporator and the remainder floods out of the outlet, and the refrigerant leaving the evaporator is always saturated. The mass flow rate flowing through the evaporator is higher than through the compressor or condenser.

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0140-7007/$ – see front matter © 2013 Elsevier Ltd and IIR. All rights reserved.
http://dx.doi.org/10.1016/j.ijrefrig.2013.11.001

Nomenclature

COP	coefficient of performance
CP	compressor
EJ	ejector
EMV	electromagnetic valve
EV	expansion valve
FFE	falling-film heat exchanger
FFWC	falling-film water chiller
FM	flow meter
GS	gas–liquid separator
h	specific enthalpy, kJ kg^{-1}
m	refrigerant mass flow rate, kg s^{-1}
OS	oil separator
R	re-circulation ratio
RRS	refrigerant re-circulation system
RV	regulative valve
SHE	shell-and-tube heat exchanger
u	entrainment ratio of the ejector
V	volumetric flow rate, m^3 s^{-1}
Greek symbols	
ρ	density, kg m^{-3}
subscripts	
1	point 1
2	point 2
3	point 3
4	point 4
5	point 5
7	point 7
cir	re-circulation
cond	condenser
mot	motive port of the ejector
suc	suction port of the ejector

Horizontal-tube falling-film evaporators belong to typical overfeed evaporators. In air conditioning and refrigeration applications, compared with flooded evaporators, falling-film evaporators have the advantages of higher cycle efficiency, lower costs and a smaller environmental impact due to its reduced charge of refrigerant. The advantages of falling-film evaporators drive researchers to do experimental and numerical studies on overfeed liquid flow rate, the liquid distribution, the flow pattern, liquid subcooling, tube surface phenomena, tube spacing and heat flux, etc.

Structured surfaces promote nucleate boiling in the film at modest temperature differences, enhance convection within the film and provide an increase in heat transfer area. The parameters that influence the enhancement are mainly the shape, geometry and surface area of the cavities. Chien and Webb (1998a, b) investigated enhanced surfaces with R-11 and R-123. They observed that, at low heat flux, the tubes with smaller total open areas had higher heat transfer coefficients; and that at higher heat fluxes, tubes with larger total open areas yielded higher heat transfer performance. Moeykens et al. (1995) found that enhanced boiling surfaces obtained higher performance than finned tubes but lower performance than enhanced condensing surfaces used for evaporation. They illustrated an increase of heat transfer coefficient with heat flux up to a maximum, then, with the increase of heat flux, the heat transfer coefficient decreased. Roques and Thome (2007a, b) studied three different enhanced surfaces of the Gewa-B, Turbo-Bii and High-Flux. Similar trends for each surface were found, as well as a strong dependence of heat transfer on the heat flux. The performance of High-Flux tube achieved up to three times better than that of the other tubes. Habert and Thome (2010) investigated three enhanced surfaces of the Gewa-B4, Turbo-EDE2 and the condensing Gewa-C. The tests were performed using R-134a and R-236fa. Christians and Thome (2012) presented falling-film evaporation experiments using a single tube, a vertical row of ten horizontal tubes and a small tube bundle with three rows of 10 tubes each, and the Wolverine Turbo-B5 and the Wieland Gewa-B5 were tested using R-134a and R-236fa.

Horizontal-tube falling-film evaporation on tube bundle is more complex than on a single tube or several tubes. In tube bundle, partial dryout of the bottom tubes is a key problem in practical applications. The bottom tubes may suffer from dryout, because the liquid flow rates decrease due to evaporation while flowing downwards. How to select operation conditions is concernful for falling-film bundles. Lorenz and Yung (1982) identified the critical Reynolds number of 300, below which the falling film evaporation coefficients on tube arrays were less than those on a single tube. Moreover, when the Reynolds number was small, the bottom tubes of the array would suffer more from partial dryout than those on higher layers. Since the dry areas transferred the heat only by natural convection, a sudden drop of heat transfer coefficients was observed both on smooth tube arrays by Fujita and Tsutsui (1998) and Ribatski and Thome (2007), and enhanced ones by Roques and Thome (2007b).

The device used for liquid distribution can greatly affect the evaporator performance. Chien and Tsai (2011) tested the heat transfer performance on horizontal copper tubes with refrigerant R-245fa. The refrigerant in the falling-film heat exchanger was pure liquid, and the liquid film distributor consisted of a 6.35 mm outer diameter copper tube, having 15 holes of 1 mm diameter each, at 5 mm pitch above the heated section of the test tube. Li et al. (2011) investigated the mean heat transfer coefficients of water falling film using different enhanced tubes. The liquid distributor was a horizontal perforated integral-fin tube with 0.8 mm holes at the top and a fin density of 26 fins per inch. Hou et al. (2012) tested a liquid film falling around a horizontal tube to determine the distribution characteristics of the film thickness. The working fluid included fresh water and seawater, and the liquid distributor was 200 mm length, with the flow entering at the top through a hole and leaving at the bottom through a semicircle with 2 mm diameter holes spaced 3 mm apart. Lee et al. (2012) designed a new drip tray which was placed above the tube bundles to distribute dilute solution on the tubes; the tray had 4 rows of 75 holes for the insertion of 1.5 mm OD capillary tubes, which distributed the dilute solution on the first row of the tube bundle.

Up to now, the falling-film technology has been studied by many investigators; however, the focus is primarily on falling-film evaporators, only a few researchers have carried out investigations on the system performance of refrigerant units using falling-film evaporators. Yang and Wang (2011)