international journal of refrigeration 34 (2011) 1676–1683

available at www.sciencedirect.com

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

Experimental evaluation of an ejector as liquid re-circulator in an overfeed NH_3 system with a plate evaporator

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ARTICLE INFO

Article history:
Received 13 August 2010
Received in revised form
22 December 2010
Accepted 23 December 2010
Available online 4 January 2011

Keywords:
Ejector
Evaporator
System
Overfeed
Ammonia

ABSTRACT

This paper deals with the experimental performance evaluation of an ejector, linked to a manual expansion valve, working as a liquid re-circulator component in an overfeed NH_3 plate evaporator. The evaporator was tested in a single stage system belonging to a cascade refrigeration system prototype. The evaporator is an ALFANOVA HP76 plate heat exchanger with 50 plates. A Phillips ejector with a 1/2″ diameter throat and 1.4 mm diameter nozzle was used. The recirculation rate was experimentally determined for different operating conditions. Experimental data are reported for volumetric flow rate at the manual expansion valve inlet from 0.8 to 1.6 l min^{-1}, evaporating pressure from 0.14 to 0.22 MPa and condensing pressure from 0.85 to 1 MPa. The experimental result showed recirculation rates between 2 and 4. The evaporating capacity varied from 9.48 kW to 18.37 kW. In addition, another two nozzles were tested and the results are also presented and discussed.

Evaluation expérimentale d'un éjecteur utilisé pour recirculer l'ammoniac liquide dans un système avec un évaporateur à plaques suralimenté

Motsclés : Éjecteur ; Évaporateur ; Système ; Suralimentation ; Ammoniac

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 flow of liquid through the evaporator. In this case, the amount of liquid used to feed the evaporator is limited by the amount of refrigerant that can be vaporized in it, so that the refrigerant leaves the evaporator superheated and only vapour is suctioned off by the compressor. The second concept is the flooded evaporator, whereby the

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0140-7007/$ – see front matter

doi:10.1016/j.ijrefrig.2010.12.023

Nomenclature

A	area, m^2
d	diameter, mm
h	specific enthalpy, $kJ\,kg^{-1}$
m	mass flow rate, $kg\,s^{-1}$
P	pressure, MPa
Q	heat transfer rate, kW
R	recirculation rate
PR	pressure ratio
T	temperature, °C
V	volumetric flow rate, $l\,min^{-1}$
v	velocity, $m\,s^{-1}$
X	vapour quality, %

Greek symbols

ρ	density, $kg\,m^{-3}$

Subscripts

c	condenser, condensation
CO_2	carbon dioxide
dis	discharge
e	evaporator, evaporation
ejec	ejector
m	mean, average
main	main ejector inlet
mev	manual expansion valve
in	inlet
NH_3	ammonia
out	outlet
rec	re-circulated, recirculation
sat	saturated, saturation

evaporator is completely filled with liquid refrigerant so that the entire evaporator inner surface is wet thus improving the heat transfer coefficient (Dossat, 1980). The flooded evaporator is coupled to a liquid receiver from which the liquid is re-circulated taking advantage of gravity action, and the vapour is suctioned off by the compressor. The liquid level in the receiver is controlled by using a float device.

In liquid overfeed systems much more liquid is fed into the evaporator than actually vaporizes. Some liquid boils in the evaporator and the remainder floods out of the outlet. As a result, the refrigerant leaving the evaporator is always saturated with a vapour quality less than one. The mass flow rate flowing through the evaporator (low pressure side) is higher than the compressor and condenser (high pressure side) rates. The ratio of the total mass flowing through the evaporator compared to the refrigerant vapour mass flow generated in the evaporator is defined as the recirculation rate. There is an ideal circulation rate for each evaporator which will result in the minimum temperature difference and the best evaporator efficiency (Lorentzen, 1968). Several parameters have to be considered to obtain the optimum recirculation rate, such as the heat load, pipe diameter, circuit length, top and bottom feed evaporators and number of parallel circuits in order to achieve the best performance. Usually, the evaporator manufactures specify the ideal recirculation rates for their equipment. For ammonia, ASHRAE (2002) recommends recirculation rate using larger diameter tubes as 6–7 for top deed evaporators and using smaller tubes as 2–4 for bottom feed evaporators.

A liquid overfeed system includes a liquid/vapour separator to separate the liquid and supply vapour to the compressor and saturated liquid to the evaporator. The compressor is fed using the vapour from the top of the tank. The vapour coming out of the separator is close to saturation conditions, which mean lower compressor inlet gas temperatures and consequently, lower discharge gas temperatures, which are a critical factor for ammonia systems working at low temperature applications. To feed the evaporator with saturated liquid re-circulated from the separator, a common practice is to use a pump as a liquid re-circulator component, described by Stoecker (1988), Bivens et al. (1997) and Giuliani et al. (1999). However, the use of pumps increases the initial investment of the facility and the operation and maintenance costs, especially in low capacity refrigeration systems.

On the other hand, Gac (1974), in his publication "Automatisme des systemes frigorifiques", comments that an alternative to the use of pumps in liquid overfeed systems is the use of ejectors. The principal advantage of this option is its simplicity, without mobiles parts, and strong construction. In addition, ejectors are more economical compared to pumps. Nevertheless, Gac (1974) stated that the effectiveness of ejector performance is strongly linked to the quality of its construction, pointing out that in practice the use of ejectors had been consigned to auxiliary refrigeration systems in which the refrigeration capacity remained constant or with few changes. One liquid overfeed system using R-22, in which an ejector was used to feed a plate freezer of eight freezing stations was studied by Radchenko (1985). His results included data of the liquid collected in the liquid/vapour separator. However, recirculation rate data were not shown.

In recent years, ejectors and their applications in jet refrigeration cycles have been widely studied. As examples of this latter, the researches of Sarkar (2008), Elbel and Hrnjak (2008) and Nakagawa et al. (2009), and the reviews performed by Chunnanond and Aphornratana (2004) and Abdulateef et al. (2009), can be cited. The authors have not found any other references about the use of ejectors in liquid overfeed systems. The main purpose of this work was to experimentally evaluate the performance of an ejector working as a liquid re-circulator component in an overfeed plate evaporator with NH_3. The experimental tests were performed using an experimental prototype cascade refrigeration system with CO_2 and NH_3. In this paper, the experimental setup and procedure are described, the reduction data process detailed, and the results shown and discussed.

2. Experimental facility

The experimental facility consists of a cascade refrigeration system prototype made of two single stage systems connected by a heat exchanger. CO_2 is used as the refrigerant in the low