Energy Conversion and Management 124 (2016) 1–12

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Experimental investigation on motive nozzle throat diameter for an ejector expansion refrigeration system

Nagihan Bilir Sag, H. Kursad Ersoy *

Department of Mechanical Engineering, Faculty of Engineering, Selcuk University, Alaeddin Campus, 42250 Konya, Turkey

A R T I C L E   I N F O

Article history:
Received 5 April 2016
Received in revised form 6 June 2016
Accepted 2 July 2016
Available online 7 July 2016

Keywords:
Experimental analysis
Refrigeration
Ejector
Throat diameter
COP
Nozzle position

A B S T R A C T

In this study, ejector was used to reduce throttling losses in a vapour compression refrigeration system. Effects on system performance of throat diameter and position of motive nozzle of ejector were investigated experimentally. An ejector was designed based on the established mathematical model and manufactured. The experiments were carried out by using different primary nozzle throat diameters. The experiments were further conducted by changing condenser water inlet temperature, which is one of the external parameters. The experimental results of the ejector system and those of the classic system were compared under same external operating conditions and for the same cooling capacity. In order to obtain same external operating conditions in both systems, the inlet conditions of the brine supplied to the evaporator and inlet water conditions (flow rate and temperature) to the condenser were kept constant. Maximum performance was obtained when the primary nozzle throat diameter was 2.3 mm within the areas considered in this study. When compared, it was experimentally determined that the ejector system that uses the optimum motive nozzle throat diameter exhibits higher COP than the classic system by 5–13%. Furthermore, it was found that the variation of coefficient of performance based on position of motive nozzle in two-phase ejector expander refrigeration cycle is lower than 1%.

1. Introduction

There are numerous studies conducted on energy consumption reduction in vapour-compression refrigeration systems. One of these studies involves reduction in expansion loss during throttling. It is for this reason that recent usage of a simple and cost-effective ejector that has no moving parts has been researched for application in place of an expansion valve. This is so because the ejector provides possibility of using the energy that can be produced during pressure drop process contrary to the isenthalpic expansion valve. Beside the theoretical and experimental works on how much energy recovery is achieved when ejector is used instead of an expansion valve, Bilir et al. [1] experimentally found that the use of ejector in place of expansion valve in refrigerating systems leads to an increase of 7.34–12.87% in system performance while the exergy efficiency tends to increase at the rate of 6.6–11.24%. When an ejector is used in an auto-cascade refrigeration cycle that uses R134a/R23 refrigerant, COP and exergy efficiency of the new cycle can be improved by 8.42–18.02% compared with those of the basic cycle [2]. In a research by Deng et al. [3], it was found that a classic transcritic CO_2 refrigerating cycle would theoretically exhibit 22% increase in coefficient of performance if an ejector is used. It was determined that the COP of internal heat exchanger systems that employ R125 refrigerant and that of the intercooler ejector based refrigerating systems is higher by 21% as compared to the COP of the classic cycles [4]. A conclusion was reached that if the internal heat exchanger and intercoolers are used in the CO_2 ejector based transcritic refrigerating cycles, then their COP will be higher by 26% when compared to that of the classic transcritic CO_2 cycles [5]. Xing at al. [6] conducted a research where performance evaluation of an ejector subcooled vapour-compression refrigeration cycle was studied. From that study it was found that when R404A is used, the COP of the novel cycle increases by 9.5%, while when R290 refrigerant is used, the COP increase becomes 7.0%. In studies presented in [7], it was determined that if ejector is used instead of expansion valve, then isobutene yields maximum COP improvement of 21.6% followed by propane (17.9%) and ammonia (11.9%). In this study, the results obtained show that the heating COP of the two-ejector, two-stage internal heat exchanger based transcritical heat pump cycle that uses CO_2 as refrigerant tends to increase at the range of 10.5–30.6% with respect to the classic system [8]. In a study by Bilir and Ersoy [9], where ejector cooling system that uses R134a refrigerant was investigated, it was

* Corresponding author.
E-mail addresses: hkersoy@rocketmail.com, kersoy@selcuk.edu.tr (H.K. Ersoy).

http://dx.doi.org/10.1016/j.enconman.2016.07.003

Nomenclature

Symbols

A	cross section (m^2)
a	area (m^2)
d	diameter (mm)
e	void fraction (–)
h	specific enthalpy (kJ/kg)
L	length (mm)
M	Mach number (–)
$\dot{m}$	mass flow rate (kg/s)
P	pressure (kPa)
$\dot{Q}$	refrigeration capacity (kW)
s	specific entropy (kJ/kg K)
T	temperature (°C)
u	velocity (m/s)
U	amount of uncertainty (–)
v	specific volume (m^3/kg)
w	entrainment ratio (–)
x	vapour quality (–)
a	sound speed (m/s)
ρ	density (kg/m^3)
η	efficiency (–)

Subscripts and abbreviations

b	primary and secondary flow entrance state to the suction chamber
c	condenser
coni	condenser inlet
COP	coefficient of performance
cp	compressor
dif	diffuser
e	evaporator
eo	evaporator outlet
EES	engineering equation solver
EERC	ejector expander refrigeration system
ej	ejector
ex	exit
f	fluid
g	gas
is	isentropic
mix	mixture
mn	motive nozzle
mne	motive nozzle exit
mnt	motive nozzle throat
p	primary flow
r	entity measured on the experimental set
s	secondary flow
sat	saturation
sn	suction nozzle
sne	suction nozzle exit
SC	subcooling
SH	superheating
VCRC	vapour compression refrigeration cycle
w	water
3m	constant area mixing chamber
$X_1, X_2, \ldots, X_J$	uncertainties belonging to each of the variables

determined that the system performance can theoretically increase up to 22.3% when compared with the classic system. According to the findings of Ersoy and Bilir [10], as the efficiencies of the ejector elements increase, the system performance increases whereas the ejector area ratio decreases. Under the same operating conditions, the irreversibility rate of CO_2 cycle was found to be higher by 39.1% than that of the ejector-expanded system [11]. Lawrence and Elbel [12] found that the standard two-phase ejector cycle has lower availability destruction and higher Second Law efficiency than the alternate ejector cycles despite having the same theoretical COP. Unal and Yilmaz [13] reported that the system performance had a 15% higher COP than the conventional double-evaporator refrigeration system. A strong dependence between the cooling capacity of a multi-evaporator refrigeration system and its ejector was found to exist [14]. The COP of a novel dual-nozzle ejector enhanced refrigeration cycle for household refrigerator-freezers is higher by 22.9–50.8% than the classic cooling cycle [15]. Smolka et al. [16] compared a performance of fixed- and controllable-geometry ejectors equipped with convergent and convergent-divergent nozzles installed in a CO_2 refrigeration system. They found that the fixed ejector offers high efficiency for all the considered operating conditions. Wang and Yu [17] carried out an experimental analysis of a novel ejector enhanced refrigeration cycle applied in the domestic refrigerator-freezer where the system performance was studied and 5.45% energy consumption reduction obtained compared with the conventional system. In a theoretical study by Wang at al. [18] on an ejector enhanced vapour injection cycle (EVIC) for air-source heat pumps, it was found that when R22, R290 and R32 are used as refrigerants in this cycle, the improvement in COP is observed at the rate of 2.6–3.1%, 3.2–3.7% and 2.9–3.1% respectively. Zheng at al. [19] presented a dynamic model of a transcritic CO_2 ejector-expansion refrigeration cycle with two-stage evaporation and found that the throat area of ejector nozzle is an efficient method to change the gas cooler pressure and the entrainment ratio of the ejector.

The flow passing through ejector is a two-phase flow and determination of the ejector geometry is rather difficult. That is why, in the literature, studies on effects of ejector parameters such as motive nozzle throat and exit diameter, mixing chamber diameter, diffuser angle and length of mixing chamber on the performance of vapour compression refrigeration systems are carried out too. One of the studies on effects of ejector geometry on the system performance of the transcritic ejector cycles is the thesis carried out by Elbel [20]. It was experimentally found in this study that in ejector system which uses CO_2 as refrigerant, lowering the diffuser angle from 15° to 5° results into improving the COP by about 3–8% provided that all other parameters remain constant. In addition, with this study, it was found that as the length of mixing chamber becomes smaller the system performance increases and that decreasing the mixing chamber length from 82.5 mm to 7.5 mm yields a corresponding increase in the COP from 2.5% to 7.5%. In another study, optimum motive nozzle's throat diameter, mixing chamber diameter and optimum location of the motive nozzle with respect to mixing chamber that yield maximum performance for a CO_2 cooled inner heat exchanger ejector system were obtained [21]. It was however found that when a nozzle with diameter of 0.5 mm greater than the optimum diameter is used, the COP dropped by about 29% and when the optimum mixing chamber diameter decreased by 0.5 mm, COP dropped by about 5%. Under the given experimental conditions where coefficient of performance of CO_2 ejector refrigerating system was being studied, it was found that by reducing the throat diameter of the motive nozzle, the COP could increase by 60% and that there exists an optimum location of the motive nozzle with reference to the mixing chamber [22]. However, the researchers presented no results on optimum throat diameter. It was experimentally found that in a