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Numerical and experimental investigation on nozzle parameters for R410A ejector air conditioning system

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ABSTRACT

The experimental and numerical study on R410A air conditioning system with two-phase ejector were presented in this paper. An adjustable liquid–gas ejector based on a two-phase flow simulation model was designed and manufactured for experiment in the R410A air conditioning system. Both throat diameter (D_{nt}) and position (D_{nm}) of nozzle were studied under the given conditions. The experimental results showed that D_{nt} of 1 mm and D_{nm} of 4 mm yielded the best ejector efficiency and system EER. Nozzles with different D_{nt} and the adjustable ejector were also studied under different conditions. The experimental results showed that the ejector with adjustable nozzle can meet the requirements of different operation conditions. It was very useful for the future application of ejector in the air conditioning system.

Etude numérique et expérimentale des paramètres des tuyères pour un système de conditionnement d'air à éjecteur au R410A

Mots clés : Ejecteur diphasique ; Paramètres des tuyères ; Ejecteurs ajustables ; Ratio d'entraînement ; R410A

1. Introduction

Throttling loss in the expansion device is one of the thermodynamic losses in the conventional vapor compression refrigeration cycle. The loss can be greatly reduced by the isentropic throttling process instead of the isenthalpic process. In order to recover the potential kinetic energy in the expansion process, various possible methods of the expansion process have been proposed. Recently, the application of

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Nomenclature

A	cross sectional area (m^2)
C	sonic velocity ($m\ s^{-1}$)
COP	coefficient of performance
D	diameter (mm)
EER	energy efficiency ratio
h	specific enthalpy ($J\ kg^{-1}$)
m	mass flow rate ($kg\ s^{-1}$)
n	rotation speed (rpm)
P	power (W)
n	nozzle
p	pressure (Pa)
Q	capacity (W)
T	temperature (°C)
u	velocity ($m\ s^{-1}$)
v	specific volume ($m^3\ kg^{-1}$)
φ	entrainment ratio
ρ	density ($kg\ m^{-3}$)
x	vapor quality
θ	pressure recovery coefficient

Subscripts

cond	condenser
comp	compressor
diff	diffuser section
cr	critical
evap	evaporator
i	indoor
d	dry bulb temperature
l	liquid
m	mixture section
nt	nozzle throat
ne	nozzle exit
ni	nozzle inlet
o	outdoor
w	wet bulb temperature
s	suction nozzle
se	suction exit
si	suction in
v	vapor

liquid–gas ejector has been considered as one of the most efficient methods to reduce the throttling loss in compression refrigeration cycle.

Compared with the conventional compression refrigeration cycle, there are several differences in the ejector refrigeration cycle, as is shown in Fig. 1 (a): In ejector refrigeration cycle, a two-phase ejector is used to recover the kinetic energy loss during the expansion process. The motive flow from the high pressure side of the system is expanded in the motive nozzle, meanwhile the static pressure converts into kinetic energy during the expansion process, and some of the liquid turn into gas due to the pressure drop. Since the pressure at the nozzle outlet is lower than evaporation pressure, gas from the evaporator is sucked into the suction nozzle of the ejector, then motive flow and suction flow are mixed in the mixture section. The velocity of high speed two-phase flow slows down with the increasement of the static pressure in the diffuser section, after that the mixture is separated in a separator, the gas is sucked into the compressor and the liquid is sucked into the evaporator. The ejector cycle schematic and P-h diagram are shown in Fig. 1(a) and (b). Because of the pressure recovery in the ejector, the suction pressure is higher than that of the conventional system, so the compression ratio of the compressor can be reduced. Therefore the compressor energy consumption can be decreased. It eventually improves the system performance in terms of COP and cooling capacity.

There are a lot of difficulties in the two-phase ejector research due to the complex flow, however, more and more researchers focus on this field due to the potential of energy recovery in the refrigerating system. Ohta et al. (1993) researched the two-phase nozzle with different sizes, and they used thin filament in the nozzle to increase the phase change. Experiments showed that the pressure coefficient can increase by 10% through improving the nozzle efficiency. Eames (2002) studied the pressure recovery of the ejector, and found that a constant rate of momentum change within the diffuser passage of a supersonic jet-pump can get better results. By studying the nozzle diameter and the diffuser angle, Stefan Elbel and Hrnjak (2008) found that a properly designed ejector can increase the system COP over 14.5%. Kim et al. (2011) replaced the expansion valve with two-phase ejector in the CO2 system, and the system COP increased 15%. Nakagawa et al. (2011) studied the length of mixture section, and discussed the impact of inner heat exchanger. Experiments showed that the system COP improved 26%. Zha et al (2007) studied the ejector parameters in R744 system, and pointed out that the local sonic velocity at the nozzle throat. Angelino and Invernizzi (2008) pointed out that the main energy loss was in the mixture process of the drive flow and the second flow, and optimized the ejector cycle for thermodynamics process. Although the problem of two-phase ejector flow for ejector expansion refrigeration cycle systems has been known for many years, no model has been found which deals with it specifically.

With the development of computational fluid dynamics, a large number of CFD models have been published which deal with multi-dimensional, multiphase flow problems. Some of the ejector calculation solvers are based on the Naveri–Stokes equation in 2D and 3D model (Rusly et al., 2005; Zhu et al., 2009; Yazdani et al., 2012). By this way the ejector performance can be predicted, but these multi-purpose CFD codes and softwares still could not deal specifically with two-phase ejector flow conceivably due to the model limitations. Therefore the prediction accuracy is limited.

Because of the model limitations, experiment was the best method to predict the ejector performance. Nakagawa et al. (2009) presented experimental decompression phenomena which could be used in designing nozzles. For an assessment of Isentropic Homogeneous Equilibrium, supersonic two-phase flow of CO_2 in the diverging sections of rectangular converging-diverging nozzles was investigated. The divergence angles with significant variation of decompression were 0.076°, 0.153°, 0.306° and 0.612°, which could be applied to circular nozzles by introducing minor mathematical corrections. The effects of size of the motive nozzle outlet on the