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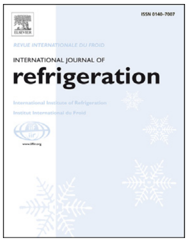

Screening of working fluids for the ejector refrigeration system

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ABSTRACT

For an ejector refrigeration system, the working fluid significantly influences the ejector behavior and system performance as well as ejector design. There are three categories of working fluids: wet fluids, dry fluids and isentropic fluids. Four wet fluids (R134a, R152a, R290 and R430A), four dry fluids (R245fa, R600, R600a and R1234ze) and one isentropic fluid (R436B) are selected in the paper. Special consideration is paid to the superheat of the ejector primary flow. This superheat is needed not only for wet fluids, but also for dry fluids and isentropic fluids at some cases, to eliminate droplets inside the ejector. A minimum superheat is found, and it is dependent on the used working fluid and the operating temperatures as well as the ejector nozzle efficiency. The comparison among these nine candidates indicates that R600 is a good candidate for the ejector refrigeration system due to a relatively high COP and its low environmental impact.

Evaluation des fluides actifs pour le système frigorifique à éjecteur

Mots clés : Ejecteur ; Réfrigération ; Fluides actifs ; Performance ; Efficacité

1. Introduction

An ejector refrigeration system is a promising alternative to produce cooling effect due to its structural simplicity, low capital cost, little maintenance and long lifespan. It is able to be driven by solar energy with an interesting feature for air-conditioning applications since solar radiation is generally in phase with cooling demands in the buildings. It can also be used to recover the waste heat from industrial processes, which helps to mitigate the problems related to CO_2 emission and to reduce the cost. Moreover, this system has an ability of using various refrigerants, particularly the environmentally-friendly refrigerants, making it even more attractive. The relatively low COP has limited the wide spread of ejector refrigeration systems. Researchers have made continuous efforts to improve the system performance and to increase its competitiveness.

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Nomenclature

Symbols

A	area (m^2)
Ar	ejector area ratio
COP	coefficient of performance
h	enthalpy ($kJ\ kg^{-1}$)
k	heat capacity ratio
$\dot{m}$	mass flow rate ($kg\ s^{-1}$)
P	pressure (kPa)
Q	heat load (kW)
T	temperature (°C)
ΔT	superheat (°C)

Greek symbols

μ	entrainment ratio
η	efficiency

Subscripts

c	condenser
cri	critical
d	diffuser
e	evaporator
g	generator
i	inlet
m	mixing
min	minimum
n	nozzle
o	outlet
p	primary flow
s	secondary flow
0–5	ejector locations in Fig. 2

The performance of an ejector refrigeration system is strongly influenced by the operating conditions, ejector geometries and properties of working fluids (Varga et al., 2013a). The dependency of ejector behavior and system performance on the operating conditions and ejector geometries has been systematically studied by applying thermodynamic ejector models (Huang et al., 1999; Chen et al., 2014a) and using CFD models (Varga et al., 2013b) as well as conducting experimental work (Al-Khalidy, 1998; Aphornratana et al., 2001; Eames et al., 2007; Yapıc, 2008). A number of refrigerants have been used in ejector refrigeration systems. The first selected working fluid was water in early 1900s (ASHRAE, 1983). Since halocarbon refrigerants emerged from 1930s, they have been extensively studied in ejector refrigeration systems, for example, R11 (Aphornratana et al., 2001), R12 (Zeren, 1982), R113 (Al-Khalidy, 1998), R114 (Sokolov and Hershgal, 1991), R123 (Yapıc, 2008), R134a (Khalil et al., 2011), R141b (Huang et al., 1999), R142b (Boumaraf and Lallemand, 2009), R152a (Varga et al., 2013b), R245fa (Eames et al., 2007). In 1987, the Montreal Protocol on substances that deplete ozone layer was ratified, and forced researchers to turn to natural refrigerants and hydrocarbons. Water (R718) attracted many revisits experimentally and numerically in last decades (Meyer et al., 2009; Pollerberg et al., 2009; Ruangtrakoon et al., 2013). Sankarlal and Mani (2006) used ammonia as the working fluid to study the effects of the generator, condenser, and evaporator temperatures on the ejector refrigeration system performance. R600 and R600a were selected by Pridasawas and Lundqvist (2004, 2007) to analyze the steady-state performance and dynamic characteristics of a solar-driven ejector refrigeration system, respectively. Chen et al. (2013) conducted an experimental study using R290 to validate a 1D ejector model for predicting ejector behavior at the critical and sub-critical conditions. These aforementioned refrigerants are pure fluids and individually investigated. Several reports on comparing the performance of different refrigerants in ejector refrigeration systems were presented by Varga et al. (2013a), Selvaraju and Mani (2004) and Roman and Hernandez (2011), but no agreement have been reached in terms of which refrigerant has the best performance. Some mixture refrigerants were also selected by Boumaraf and Lallemand (1999), Chen et al. (2011) and Buyadgie et al. (2012), and it could be concluded that mixture compositions have significant effects on the system performance. Refrigerants used in ejector refrigeration systems are briefly summarized in Table 1 with their operating conditions and relevant results.

Working fluids used in ejector refrigeration systems have been categorized into wet fluids, dry fluids and isentropic fluids, based on the slope of vapor saturation line in its T–s diagram. For wet fluids, droplets may be formed inside the ejector, which may seriously affect the gas dynamic process in the ejector and the performance of the ejector as well (Huang et al., 1999). It is suggested to superheat the primary flow to ensure that the expansion in the nozzle takes place in the superheated region (Pridasawas, 2006). The required superheat might vary largely due to the difference in thermodynamic properties for different wet fluids. However, a large superheat will not benefit the system COP, just waste energy (Khalil et al., 2011), while a too small superheat may not eliminate the droplet formation. For dry fluids and isentropic fluids, in most cases, there is no phase change during the expansion process in the nozzle and the superheat is generally not necessary. Therefore, the working fluids for ejector refrigeration systems need to be treated carefully.

Little attention has been paid to the differences in superheat for different fluids in ejector refrigeration systems. The use of superheat is rather arbitrary and not distinguished. Varga et al. (2013a) simply applied a 5 °C superheat for both wet fluids and dry fluids they selected, namely, R718, R290, R134a, RC318, R152a and R600a. The same superheat of 5 °C was also employed by Roman and Hernandez (2011) for R290, R152a, R134a, R600a, R600 and R123. Pridasawas (2006) used a superheat of 50 °C for R134a, R717, R290, methanol, and 60 °C for R718. It is not clear that if these superheats employed are sufficient and efficient.

To make distinctions of superheat between different fluids, especially wet fluids, an approach for deciding the minimum superheat before entering ejector nozzle is proposed in this paper. Applying these minimum superheats, the performance of nine refrigerants, including four wet fluids, four dry fluids and one isentropic fluid, are comparatively studied.

2. Working principles and performance evaluations

Fig. 1 schematically shows the ejector refrigeration system. It consists of a generator, a condenser, an evaporator, an ejector,