INTERNATIONAL JOURNAL OF REFRIGERATION 58 (2015) 154–171

Available online at www.sciencedirect.com

ScienceDirect

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

A study of working fluids for heat driven ejector refrigeration using lumped parameter models

*Giorgio Besagni**, *Riccardo Mereu*, *Giuseppe Di Leo*, *Fabio Inzoli*

Politecnico di Milano, Department of Energy, Via Lambruschini 4, 20156, Italy

ARTICLE INFO

Article history:
Received 22 November 2014
Received in revised form
25 May 2015
Accepted 18 June 2015
Available online 26 June 2015

Keywords:
Ejector
Working fluids
COP
Entrainment ratio
Ejector refrigeration
Ejector efficiencies

ABSTRACT

This paper studies the influence of working fluids over the performance of heat driven ejector refrigeration systems performance by using a lumped parameter model. The model used has been selected after a comparison of different models with a set of experimental data available in the literature. The effect of generator, evaporator and condenser temperature over the entrainment ratio and the COP has been investigated for different working fluids in the typical operating conditions of low grade energy sources. The results show a growth in performance (the entrainment ratio and the COP) with a rise in the generator and evaporator temperature and a decrease in the condenser temperature. The working fluids have a great impact on the ejector performance and each refrigerant has its own range of operating conditions. R134a is found to be suitable for low generator temperature (70–100 °C), whereas the hydrocarbons R600 is suitable for medium generator temperatures (100–130 °C) and R601 for high generator temperatures (130–180 °C).

Une étude à l'aide des modèles à paramètres localisés de fluides actifs pour un système frigorifique à éjecteur conduit par de la chaleur

Mots clés : Ejecteur ; Fluides actifs ; COP ; Taux d'entrainement ; Système frigorifique à éjecteur ; Efficacités d'éjecteur

---

* *Corresponding author*. Politecnico di Milano, Department of Energy Via Lambruschini 4a, 21056 Milan, Italy. Tel.: +39 02 2399 3826.
E-mail addresses: giorgio.besagni@polimi.it (G. Besagni), riccardo.mereu@polimi.it (R. Mereu), giuseppe3.dileo@mail.polimi.it (G. Di Leo), fabio.inzoli@polimi.it (F. Inzoli).

http://dx.doi.org/10.1016/j.ijrefrig.2015.06.015

Nomenclature

Symbols

A	area [m^2]
CE	computational effort [–]
COP	coefficient of performance [–]
D	diameter [m]
E_R	relative error [–]
GWP	global warming potential [–]
$\dot{L}_p$	pump power [W]
k	heat capacity ratio [–]
$\dot{m}$	mass flow rate [kg s^{-1}]
ODP	ozone depletion potential [–]
p	pressure [Pa]
$\dot{Q}$	rate of heat [W]
T	temperature [°C]
u	velocity [m s^{-1}]
X	general quantity

Greek symbols

η	isentropic efficiency [–]
ϕ	throat area ratio, $\phi = A_2/A_t$ [–]
φ, ψ	loss coefficient [–]
ω	entrainment ratio [–]

Superscripts

′	isentropic condition
*	critical mode operation of ejector

Subscripts

1	nozzle exit section
2	constant area section
c	condenser
d	diffuser
e	evaporator
exp	experimental data
g	generator
m	mixing chamber
mod	calculated value from the model
n	nozzle
p	primary fluid
s	secondary fluid
t	nozzle throat section
y	mixing section

1. Introduction

The global warming and the increasing need for the thermal comfort have led to a rapidly increasing cooling energy and electricity demand. Thermal energy refrigeration would allow a significant reduction of these problems and ejector refrigeration systems seem a promising alternative because of its structural simplicity, low capital cost, reliability, little maintenance, low initial and running cost and long lifespan (Vidal and Colle, 2010). An ejector (Fig. 1) is able to provide a combined effect of compression, mixing and entrainment with no-moving parts and without limitations concerning working fluids. For these reasons, ejector refrigeration systems can be used in buildings, in distributed tri-generation systems and for the waste heat recover from industrial processes (Ben Mansour et al., 2014; Godefroy et al., 2007; Little and Garimella, 2011). Nevertheless, the ejector refrigeration has not been able to penetrate the market because of the low coefficient of performance (Sarkar, 2012): this is because the efficiency of the whole system is highly influenced by ejector performances, which significantly depends on the geometry, working fluid and operating conditions (Kasperski and Gil, 2014; Selvaraju and Mani, 2006; Varga et al., 2009a; Yapıcı et al., 2008). This paper deals with the screening of the working fluids, using a validated lumped parameter model, in the range of operating conditions of low grade energy sources (waste heat and solar energy sources). If compared with the other papers concerning working fluid for ejector refrigeration systems (Chen et al., 2014b,c; Kasperski and Gil, 2014), the present one provides a coupled evaluation of working fluids and ejector models. This paper is divided in three parts. In the first part, the role of working fluids over ejector performance is outlined with a brief literature survey. In the second part, five different ejector models are evaluated and compared over a large set of experimental data concerning different operating conditions, working fluids and geometry. In the third part, on the basis of the above mentioned analysis, the model of Chen et al. (2014a) is selected and is used for studying the influence of working fluids over ejector performance and indications for ejector models and working fluids are provided in the conclusions.

2. Working fluids for ejector refrigeration

A suitable refrigerant for refrigeration system should yield good performance in the selected operating ranges. Generally speaking, the following requirements must be taken into account (Abdulateef et al., 2009): the thermo-physical properties (latent heat of vaporization, critical temperature, the viscosity, thermal conductivity, the molecular mass, ecc), the environmental impact (zero ozone depletion potential “ODP”, low global warming potential “GWP”) and the working fluid should be chemically stable, non-toxic, non-explosive, non-corrosive, cheap and available on the market (please notice that in the follow we refer to the ASHRAE Standard 34, taking into account recent updates of the designation and safety classification of refrigerants that introduce the new flammability class 2L (ASHRAE, 2010)). Furthermore, when selecting working fluids can be classified accordingly with the saturated vapor line slope in the *T*–*s* diagram (Chen et al., 2014c): wet or dry. When considering ejector refrigeration systems, a large number of refrigerants have been used.

In early 1900s, the first working fluid employed in a jet refrigerator was water: it has a high heat of vaporization, is inexpensive and has minimal environmental impact.