INTERNATIONAL JOURNAL OF REFRIGERATION 43 (2014) 36–49

Available online at www.sciencedirect.com

ScienceDirect

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

Numerical evaluation of ejector-assisted mechanical compression systems for refrigeration applications

Ridha Ben Mansour*, Mohamed Ouzzane, Zine Aidoun

CanmetENERGY-Natural Resources Canada, Varennes, QC, Canada

ARTICLE INFO

Article history:
Received 25 November 2013
Received in revised form
9 April 2014
Accepted 10 April 2014
Available online 24 April 2014

Keywords:
Ejector
Refrigeration cycles
Modelling
Performance
Cascade
Low temperature

ABSTRACT

A study of the conjugate effects of ejector performance characteristics, the activation pressure–temperature conditions at the generator and the interaction with the compressor on refrigeration systems was performed. Besides the conventional compression cycle which was used as a reference, three more configurations were selected for this study: a hybrid ejector–compressor booster and two cascade compressor–ejector cycles. The modelling methodology developed to handle such systems was based on the principles of thermodynamics and fluid dynamics and included two separate sub-cycles in constant interaction: a loop driven mechanically by a compressor, coupled with a thermally activated ejector loop. This cycle model was combined with a validated ejector model and manufacturer's compressor performance maps. A performance analysis and a parametric optimization were performed to select promising cycles. For given working conditions, substantial improvement in COP of the selected cycles over the conventional mechanical compression cycle was found.

Evaluation numérique de systèmes à compression mécanique à éjecteurs pour applications frigorifiques

Mots clés : Ejecteur ; Cycles frigorifiques ; Modélisation ; Performance ; Cascade ; Basse température

1. Introduction

Mechanical compression refrigerators and heat pumps are widespread and compressor power consumption represents a heavy load on electrical grids, particularly when the demand for cooling or heating is high. As is often the case in chemical and food processing plants, large amounts of low-grade heat are released in the environment while refrigeration may simultaneously be required. Non-mechanical, thermally activated ejector-based machines may therefore represent excellent means of heat recovery for cooling or heating needs. In other cases hybrid compression-ejection machines may be designed for internal heat recovery, thus improving overall

* Corresponding author.
E-mail addresses: ridha.benmansour@nrcan.gc.ca, ridha.b.mansour@usherbrooke.ca (R. Ben Mansour).
http://dx.doi.org/10.1016/j.ijrefrig.2014.04.010

Nomenclature

A	Area, m^2
AR	Area ratio
COP	Coefficient Of Performance
D	Diameter, m
GWP	Global Warming Potential
h	Specific enthalpy, kJ kg^{-1}
$\dot{m}$	Mass flow rate, kg s^{-1}
ODP	Ozone Depletion Potential
P	Pressure, kPa
Q	Rate of heat transfer, kW
s	Specific entropy, kJ $(kg\ K)^{-1}$
T	Temperature, °C
V	Velocity, m s^{-1}
W	Power, kW
x	Quality

Greek letters

ϕ	Friction loss coefficient
η	Efficiency
ρ	Density, kg m^{-3}
τ	Compression ratio
ν	Specific volume, m^3 kg^{-1}
ω	Entrainment ratio

Subscripts

0	Stagnation state
1,2,3, …	Thermodynamic states of refrigerant
c	Condenser
comp	Compressor
d	Diffuser
e	Evaporator
ej	Ejector
ex	Heat exchanger
g	Generator
i	Inlet
int	Intermediate
is	Isentropic
m	Mixture
n	Nozzle
p	Primary
pump	Pump
o	Exit
s	Secondary
t	Throat

performance. Supersonic ejectors for compressible fluids are not new in engineering (aerospace and steam-based industrial air-conditioning applications) (ASHRAE, 1969; Munday and Bagster, 1977; Chen et al., 1994; Sun and Eames, 1995; Wang and Chen, 1996). In refrigeration and cooling ejectors have also been around for many years but, despite this fact, their potential has not been fully exploited because of their relatively low efficiency. However their simplicity and reduced cost makes them very attractive for many applications, considering the new environmental context. In buildings, ejectors may be used for heating and cooling in combination with renewable energy or distributed generation systems in tri-generation applications. In industry they represent an attractive solution for waste heat upgrading and new opportunities for their integration in innovative cycles based on the most appropriate combinations of ejectors with vapour compression or absorption systems. Recent studies have shown that the operation and performance of ejector-based cycles largely depended on appropriate and careful overall design (Dahmani et al., 2010a,b, 2011). Modelling-experiments integration represent therefore a valuable selection approach for the purpose of identifying the best technological options accounting for ejector and compressor characteristics, refrigerants properties and external conditions.

1.1. *Ejector operating principles*

Supersonic ejectors are simple mechanical components (Fig. 1), which perform mixing and/or recompression of two fluid streams at different energy levels. Their principle of operation is the same, regardless of the application. It is briefly described here but a more detailed account can be found in many journal publications (Ouzzane and Aidoun, 2003). The primary stream having the highest total energy is motive (depicted A, on Fig. 1), the secondary stream with the lowest total energy (depicted B) is induced. Operation of such systems is quite simple: the motive stream (high pressure and temperature) flows through a convergent divergent nozzle to reach supersonic velocity. By an entrainment-induced effect, the secondary stream is drawn into the flow and accelerated. Mixing and recompression of the two streams then occurs in a mixing chamber, where complex interactions take place between the mixing layer and shocks. There is a mechanical energy transfer from the highest to the lowest energy level, with the mixing pressure lying between the motive and the induction pressures. The focus of the present work is on the use of single phase gas ejectors powered by an external low quality heat source (waste, solar, ground heat) for performance enhancement of conventional mechanical compression cycles. Only elements related to this class of applications will be discussed in the next sections.

1.2. *Previous research outline on ejectors*

Extensive experimental and theoretical work on ejectors and their operation has been continuing for some decades but, despite the apparent simplicity of the ejector geometry and working mechanisms, its modelling remains a problem not yet completely resolved because of its highly complex flow field structure. Thus there is still no comprehensive theory capable of completely describing how ejector performance and operation are affected by the geometry and external constraints. The available literature, some going back to the very early years, contributes however to a better understanding of ejector design and operation. Many theoretical and experimental studies have been performed in order to explain not only the fundamental mechanisms in terms of fluid dynamics and heat transfer, but also in terms of ejector