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Development and performance analysis of a multi-temperature combined compression/ejection refrigeration cycle using environment friendly refrigerants

F. Lontsi [a,*], *O. Hamandjoda* [b], *O.T. Sosso Mayi* [a], *A. Kemajou* [a]

[a] *Laboratoire d'Energétique, EDSFA/UFD SI, University of Douala, 3353 Douala, Cameroon*
[b] *Department of Mechanical and Industrial Engineering, ENSP, University of Yaoundé1, 8390 Yaoundé, Cameroon*

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ABSTRACT

A combined compression/ejection refrigeration cycle intended for the simultaneous production of cold for refrigeration and freezing, and operating based on environment friendly refrigerants is proposed and analyzed in this study. This makes it possible to valorize the low-temperature heat sources in the ejector cycle, thereby reducing the share of mechanical energy otherwise required to operate the conventional two-stage vapor compression system.

A selection of eight candidates' fluids was performed. The developed simulation model helped to establish the strong dependence between system performances and the ratio of the cooling capacities of refrigeration and freezing. In addition to the effect of the temperature level of cold production, the influence of the ambient temperature on system performance was also analyzed when using refrigerants R290, R152a and R134a.

Développement et analyse de performance d'un cycle frigorifique combiné compression/éjection à températures multiples fonctionnant aux frigorigènes écologiques

Mots clés : Système frigorifique à cycle combiné ; Températures multiples ; Chaleur disponible à bas niveau ; Frigorigène écologique ; Coefficient de performance

1. Introduction

Conventional vapor compression refrigeration systems are the most widely used for cold production both in refrigerating systems and in the air conditioning due to the fact that they have a high coefficient of performance (COP). However these devices use some complex mechanical compressors that consume essentially high-quality mechanical power provided by means such as an electric motor, mechanical power extraction from an engine, and the like. Ejector refrigeration systems have low COP and are therefore less used in the cold

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[*] *Corresponding author.* Laboratoire d'Energétique, EDSFA/UFD SI, University of Douala, 3353 Douala, Cameroon. Tel.: +237 77 60 42 87; Fax: +237 233401998.

E-mail address: lontsi@yahoo.fr (F. Lontsi).

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Nomenclature

A	flow area [m^2]
c_p	specific heat at constant pressure [J·kg^{-1}·°C^{-1}]
d	diameter [m]
h	enthalpy [J·kg^{-1}]
M	Mach number
$\dot{m}$	mass flow rate [kg·s^{-1}]
p	pressure [Pa]
$\dot{Q}$	thermal power [W]
s	specific entropy [J·kg^{-1}·°C^{-1}]
R	gas specific constant [J·kg^{-1}·°C^{-1}]
T	temperature [°C]
v	specific volume [m^3·kg^{-1}]
x	quality
V	velocity [m·s^{-1}]
$\dot{W}$	power [W]

Greeks symbols

ΔT	superheat, subcooling [°C]
γ	specific heat ratio
η	isentropic efficiency
η_{ex}	exergy efficiency [%]
ξ	driving pressure ratio
τ	pressure lift ratio or ejector compression ratio
ϕ	ejector area ratio
ψ	cooling capacity ratio
ω	entrainment ratio

Subscripts

1,2,3. . .	state or points of cycle
a	Nozzle outlet section
b	normal chock section plane
c	condenser
co	compressor
cr	critical
d	diffuser
e	evaporator
ex	exergy
g	generator
is	isentropic
j	(=1 for primary or =2 for secondary)
m	mixing section plane
p	pump
ref	reference environment

production industry (Sokolov and Hershgal, 1990). On the other hand, they have no moving parts and they have the advantage of being easy to build and easy to maintain and their cycle has been recognized as promising cycle for the utilization of solar energy (Dang et al., 2012) as well as for the valorization of different kinds of thermal energy sources.

When cold production with two different temperatures in the same installation requires a double expansion of refrigerant, making a cycle necessitates in most cases using two-stage compression; without which the compression rate would be too high and inadmissible. In this case, the process is always accompanied by high mechanical or electrical energy consumption. This energy, when acquired from a thermal power plant or a combustion engine, is not only very costly, but also generates toxic gases (NO_x, SO_x), greenhouse gases and other unused waste heat in its production (Garris et al., 1998).

Previous works on ejector refrigeration systems showed that generators of these installations can efficiently use the waste heat, even when available thermal sources are low-grade (Sokolov and Hershgal, 1990) be they unused condensates, glue gases (Chen et al., 2013) or collected solar thermal energy (Dang et al., 2012).

Integrating the ejector or its coupling to a conventional vapor compressor refrigeration system makes it possible to realize, depending on the coupling scheme, hybrid systems which considering the performance improvement that it generates, are of great interest both from the theoretical point of view and potential applications in the multi-temperature refrigeration field (refrigeration and freezing).

Tomasek and Radermacher (1995) proposed a combined refrigeration system for home refrigerator-freezer incorporating an ejector in the diagram of a standard vapor compression refrigeration system comprising a compressor and two evaporators. The presence of ejector allowed the reduction of the compression ratio and therefore the reduction of the compressor work. The authors noted an improvement of the system performance of 12%, compared to that of a standard compression refrigeration system.

Elakdhar et al. (2007) studied a hybrid compression-ejection dual evaporator refrigeration cycle for domestic refrigeration. The work was to incorporate an ejector and a separator between the two evaporators of a domestic refrigerator in order to improve system performance by raising the pressure upstream of the mechanical compressor. This study showed that the insertion of the ejector improves performance of the new system compared to that of the standard vapor compression cycle and, in addition, R141b showed the best performance among the fluids tested.

Kairouani et al. (2009) have proposed the use of ejectors in a multi-evaporator vapor compression refrigeration system in order to improve performance. In this hybrid refrigeration system operating on three levels of pressure and temperature, two ejectors are connected in series between the evaporators and the compressor, so as to allow a double precompression of the fluid at the inlet of the single compressor of the system. Analysis of hybrid cycle performance developed and tested on several fluids showed a better performance of this compression/ejection multi-temperature system compared to the conventional system.

Sarkar (2010) also proposed and studied two transcritical CO_2 refrigeration cycles each comprising a mechanical compressor and two ejectors. These hybrid multi-evaporators compression–ejection refrigeration systems were modeled and performance simulation showed that the COP is improved compared to the conventional vapor compression cycle and can, therefore under optimal conditions, reach values of 0.241 and 0.381, respectively.

Thanks to the energy it recovers within the system, the ejector inserted into multi-temperature vapor compression refrigeration systems improves the performance of the latter and