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Experimental investigation of a two-phase ejector cycle suitable for use with low-pressure refrigerants R134a and R1234yf

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ABSTRACT

This paper presents the results of an experimental investigation in which the performance of the low-pressure fluids R134a and R1234yf was compared between a two-phase ejector cycle and expansion valve cycles. An alternate two-phase ejector cycle, in which the pressure lift provided by the ejector was utilized in order to provide multiple evaporation temperatures, was constructed and tested. The experimental results show that ejectors designed for low-pressure fluids were able to achieve similar but lower work recovery efficiencies compared to CO_2 ejectors. When compared to a two evaporation temperature expansion valve cycle, the ejector cycle showed maximum COP improvements of 12% with R1234yf and 8% with R134a. When compared to a single evaporation temperature expansion valve cycle, the ejector cycle showed maximum COP improvements of 6% with R1234yf and 5% with R134a. The effect of evaporator design on ejector cycle COP improvement was also demonstrated experimentally.

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Etude expérimentale d'un cycle d'éjection diphasique adapté pour une utilisation des frigorigènes à basse pression R134a et R1234yf

Mots clés : Ejecteur ; Récupération du travail de détente ; Comparaison de cycle ; Coefficient de performance ; Conception de l'évaporateur

1. Introduction

An ejector is an ideally isentropic expansion device capable of recovering the work that is otherwise lost by the isenthalpic throttling associated with the expansion process in conventional vapor-compression refrigeration cycles. In an ejector, a high-pressure motive stream is expanded through a converging–diverging nozzle (motive nozzle) to a low pressure and high velocity. At the same time, a low-pressure suction stream enters the ejector through a separate, generally converging only, nozzle (suction nozzle) and is entrained by the motive fluid through momentum transfer between the

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Nomenclature

Abbreviations and variables

COP	coefficient of performance [–]
COS	condenser outlet split
h	specific enthalpy [kJ kg^{-1}]
$\dot{H}$	total enthalpy rate [kW]
LMTD	logarithmic mean temperature difference
$\dot{m}$	mass flow rate [g s^{-1}]
P	pressure [kPa]
V	velocity [m s^{-1}]
$\dot{W}$	compressor power [kW]
x	quality [–]

Greek symbols

Δ	change in a quantity
η	efficiency [–]
π_s	suction pressure ratio [–]
ρ	density [kg m^{-3}]
Φ_m	mass entrainment ratio [–]

Subscripts

Butrymowicz	referring to a publication by Butrymowicz et al. (2005)
cp	compressor
diff	diffuser of ejector
Ejector	COS ejector cycle
Elbel	referring to a publication by Elbel and Hrnjak (2008)
Expansion Valve	expansion valve cycle
evap	evaporator
high	high-temperature
in	inlet of component
isen	isentropic process
lift	pressure lift of ejector
liquid	liquid separation
max	theoretical maximum
mn	motive nozzle
Nakagawa	referring to a publication by Nakagawa and Takeuchi (1998)
out	outlet of component
rec	work recovery
sep	liquid–vapor separator
sn	suction nozzle
throttling	throttling loss
vapor	vapor separation

two streams. After mixing has occurred between the two streams, they enter a diffuser, where they are further decelerated and compressed to a pressure higher than the initial pressure of the suction stream. Thus, the effect of the ejector is to provide a pumping effect to the suction stream by means of expansion of the motive stream. The first use of a two-phase ejector as a work recovery device in a refrigeration cycle was proposed by Gay (1931), as shown in Fig. 1. Based on a review of the open literature, this cycle has been the most commonly studied refrigeration cycle employing a two-phase ejector and will be referred to in this paper as the standard two-phase ejector cycle.

Much of the recent work on two-phase ejectors has been focused on transcritical CO_2 cycles. CO_2 has larger throttling loss, which contributes to lower cycle efficiency, than most other refrigerants, especially at elevated ambient temperatures. Thus, transcritical CO_2 cycles offer larger potential for improvement than other cycles. Elbel and Hrnjak (2008) performed an experimental investigation of a transcritical CO_2 ejector cycle and observed simultaneous COP and capacity improvements of 8 and 7%, respectively. Nakagawa et al. (2011) and Lee et al. (2011) observed COP improvements of 26 and 15%, respectively, in their studies of transcritical CO_2 ejector cycles. More recently, Lucas and Koehler (2012) and Banasiak et al. (2012) observed COP improvements of up to 17 and 8%, respectively, on CO_2 ejector cycles. COP improvement of these cycles has also been seen to range as high as 147%, as reported by Liu et al. (2012). Ejector efficiency, system operating conditions, and quality of the baseline cycle can all have a significant influence on the COP improvement of an ejector cycle, which may help explain the differences in COP improvement reported by the different transcritical CO_2 ejector cycle studies.

Low-pressure working fluids have received less attention in the open literature, as they are more difficult to successfully implement with the standard two-phase ejector cycle than CO_2 due to their lower work recovery potential; however, ejector cycles with these refrigerants can still offer some

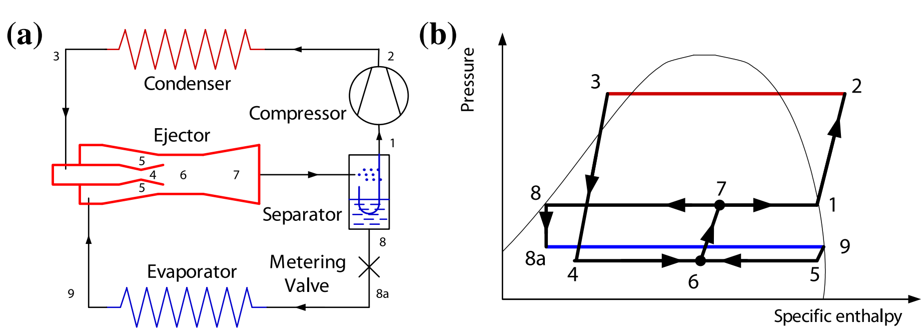

Fig. 1 – (a) Layout diagram and (b) pressure-specific enthalpy diagram of the standard two-phase ejector cycle proposed by Gay (1931).

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