Renewable Energy 63 (2014) 735–740

Contents lists available at ScienceDirect

Renewable Energy

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

Performance analysis of a novel dual-nozzle ejector enhanced cycle for solar assisted air-source heat pump systems

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ARTICLE INFO

Article history:
Received 11 January 2013
Accepted 15 October 2013
Available online 8 November 2013

Keywords:
Solar energy
Heat pump
Air-source
Ejector
Performance
Enhancement

ABSTRACT

In this study, a novel dual-nozzle ejector enhanced vapor-compression cycle (DEVC) for solar assisted air-source heat pump systems is proposed. In DEVC, the use of the dual-nozzle ejector for recovering the expansion losses is a very promising approach to improve the cycle performance. A mathematical model of the DEVC is developed to predict its performance under specified operating conditions. The simulation results indicate that for the range of given operating conditions, the coefficient of performance (COP) and the volumetric heating capacity of the novel cycle using refrigerant R410A are theoretically improved by 4.60–34.03% and 7.81–51.95% over conventional ejector enhanced vapor-compression cycle (CEVC), respectively. The results imply that the solar-air source heat pump systems could take advantage of the best features of the DEVC. The potential use of DEVC therefore deserves further experimental validation. It is expected that this new cycle will be beneficial to developing dual-source coupled heat pump applications.

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1. Introduction

Heat pump systems can offer energy-efficient and environmentally friendly methods for various industrial, commercial and residential heating applications. During the past years, the extensive heat pump research and development have been under way in the world [1]. The most common type of heat pump systems is based on the vapor-compression cycle, which can use the solar, ambient air and geothermal energies as heat sources, respectively [2]. Lohani and Schmidt [3] modeled and compared the energy and exergy flow for a space heating system with different heat generation plants and found the ground source heat pump heating system is better than air source heat pump or conventional heating system. Choi and Chung [4] measured the performance of a heat pump unit with variation of secondary fluid flow rate and compressor speed and the results are applied to design the Ground-coupled heat pump system. Nam et al. [5] suggested an estimation method to determine the thermal and hydraulic properties of the ground and the results can be used to design the heat exchanger of energy pile system base on geotechnical investigation. However, solar, ground and air-source have different temperature level and characteristic, and the purely single source heat pump is faced with different problems when it comes to practical application for heating applications. Thus, various dual-source coupled heat pump systems have draw considerable attention and have been an interesting subject for researchers in recent years [6–12]. Among them, solar assisted air-source heat pumps have great advantages in improving the heating performances [13]. When the solar energy is available, the heat pump systems can absorb heat from the ambient air and solar energy by two evaporators with two different evaporator temperatures simultaneously. In this case, the heat pump systems raise the thermal energy gained from two sources to a higher temperature level, and thus there are reasons for expecting higher performance for such systems than conventional air-source heat pumps. In addition, the solar-air source heat pump systems allow for efficient operation over a wider range of seasons and weather conditions, and for more hours throughout the day.

Commonly, the single air source heat pump typically operates on a conventional vapor-compression cycle (VC). To achieve high heat pump efficiency, one of various efforts needs to be devoted to improving the vapor-compression cycle performance. One way is to apply an ejector expansion device in the vapor-compression cycle. In this case, the ejector could recover the expansion losses and increase the cycle efficiency. Previous studies have focused primarily on application of the conventional ejector with one nozzle in the vapor-compression cycle for performance improvement [14–17]. Actually, the ejector can be also applied in a vapor-compression cycle based dual-source coupled heat pump system to make the heat pump operate very efficiently. For this purpose, we present a novel vapor-compression cycle with dual-

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0960-1481/$ – see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.renene.2013.10.030

Nomenclature

COP	coefficient of performance
h	specific enthalpy (kJ kg^{-1})
$\dot{m}$	mass flow rate (kg s^{-1})
$\dot{P}$	compressor input power (kW)
p	pressure (kPa)
$\dot{Q}_h$	heating capacity (kW)
$\dot{Q}_e$	refrigeration capacity (kW)
q_{hv}	volumetric heating capacity (kJ m^{-3})
r_p	pressure lift ratio
t_c	condensing temperature (°C)
t_e	evaporating temperature (°C)
v	specific volume (m^3 kg^{-1})
w	velocity (m s^{-1})
x	vapor quality

Greek letters

η	efficiency
μ	entrainment ratio
φ	mass flow rate allocation ratio

Subscripts

d	diffuser
h	high-temperature evaporator
l	low-temperature evaporator
m	mixing chamber
n	nozzle
p	primary fluids
s	secondary fluid, isentropic
1–9	state points of refrigerant
1	inlet
2	outlet

nozzle ejector for dual-source coupled heat pumps, such as a solar assisted air-source heat pump [11,18]. In this dual-nozzle ejector enhanced vapor-compression cycle (DEVC), the ejector equipped with two nozzles has the advantage of a very efficient expansion losses recovery. Moreover, the use of dual-nozzle ejector in the cycle not only may operate the heat pump with two heat sources at the same time, but also may improve the heat pump performances. In the present work, the performances of the proposed cycle DEVC are studied with simulations. The object of this study is to present an evaluation of potential performance improvements of the DEVC for its application in solar assisted air-source heat pump systems.

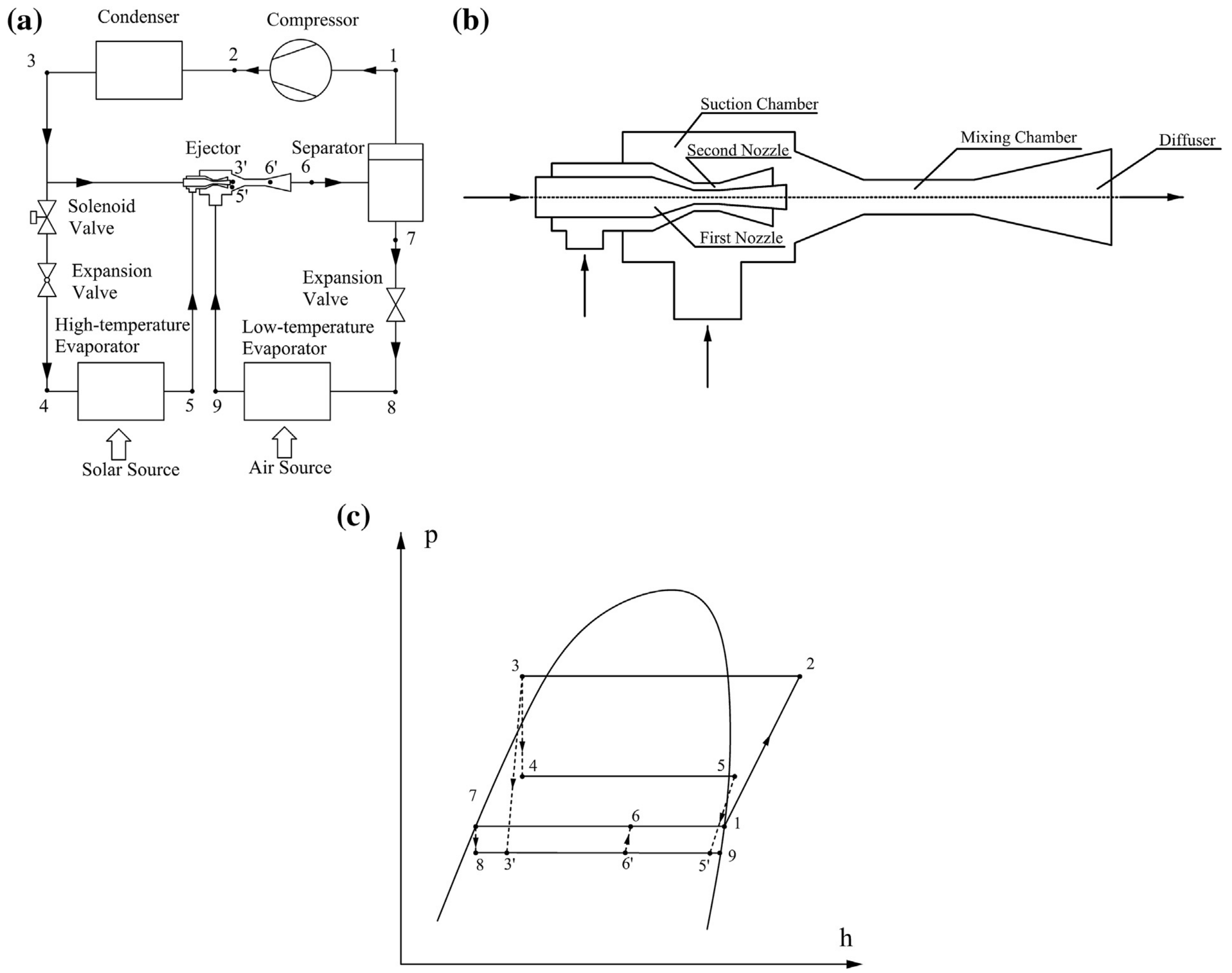

Fig. 1. (a) Scheme of the dual-nozzle ejector enhanced vapor-compression cycle. (b) Constructional drawing of the dual-nozzle ejector. (c) The pressure–enthalpy diagram for the cycle.

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