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Simulation study of the combination of absorption refrigeration and ejector-expansion systems

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ABSTRACT

Recently, in refrigeration industry the use of efficient dual-evaporator refrigeration systems has been paid a lot of attention. These systems sound even more interesting when they are a combination of different kinds of conventional refrigeration systems. In this paper three thermally driven chillers consisting of absorption refrigeration and ejector-expansion transcritical cascade CO_2 cycles are proposed and investigated thermodynamically. The systems are called "hybrid dual-evaporator" cycles. The absorption cycle in the systems is either the single-effect or double-effect series-flow or double-effect parallel-flow cycle for each of which a solar collector is considered to supply the required heat in their generator. The performances of hybrid dual-evaporator systems are analyzed and optimized, using the Engineering Equation Solver and applying the principles of conservation of mass and energy as well as the exergy balance to each component of each system. Results indicate that combing the double-effect parallel absorption refrigeration system with ejector-expansion system gives the highest coefficient of performance among the other configurations. However, a combination of single-effect absorption refrigeration system with ejector-expansion cycle may be preferred due to its less complexity and reasonable exergy efficiency. Results also reveal that at optimum generator temperature of 72.92 °C the coefficient of performance and exergy efficiency of hybrid dual-evaporator with single-effect absorption are 1.182 and 0.2564, respectively. In addition, it is observed that increasing the cooling capacity ratio from 1 to 6 results in increases of the coefficient of performance and exergy efficiency of configurations by up to 36.32% and 11.5% respectively.

1. Introduction

The crucial role of the refrigeration industry in global warming and ozone depletion, which threatens the world today, is undeniable. In this regard, replacing the conventional refrigerants with null ozone depletion potential (ODP) and low global warming potential (GWP) refrigerants seems to be required. Nowadays, the majority of the refrigeration systems in the industry are of vapor compression types for most of which the HFCs, with considerable GWP potential, are the working fluids. However, the carbon dioxide as a natural, non-toxic, non-inflammable and inexpensive refrigerant has been recently attracted the interest of researchers since its ODP is zero and its GWP is negligible. The absorption refrigeration systems, on the other hand, with environmental friendly working fluids such as water–LiBr and ammonia–water can be of a great help in alleviating the problem.

Recently, using CO_2, as a working fluid, in the compression refrigeration systems has been practiced theoretically and experimentally by some researchers. As the critical temperature of this refrigerant is low, its condensation needs to be done though a transcritical process. However, the COP of these systems is low compared to that of the conventional ones [1,2]. Therefore, lots of effort such as using expander [3,4], adding ejector [5–9], making the cycle as a cascade one [10–12], heat reclamation in gas cooler (condenser) [9,10], employing vortex tube [13] have been carried out by researchers to improve the performance of the systems.

Since, the gas cooler of transcritical CO_2 refrigeration cycle (TRCC) is supposed to work at comparatively higher temperature, there is a potential to use this high-grade energy for driving some bottom cycles. Neksa [14] investigated the transcritical CO_2 cycle for heating purposes. Neksa also studied on different kinds of heat pumps using CO_2 as the working fluid. He concluded that CO_2

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Nomenclature

A	area (m^2)
T	temperature (°C)
P	pump
H	enthalpy (kJ kg^{-1})
$\dot{m}$	mass flow rate (kg s^{-1})
$\dot{Q}$	heat transfer rate (kW)
$\dot{W}$	power (kW)
$\dot{E}$	exergy rate (kW)
S	entropy (kJ $kg^{-1}K^{-1}$)
D	distribution ratio
T_b	mean temperature of lower temperature source
T_h	mean temperature of higher temperature source
r_p	compressor pressure ratio

Abbreviations and subscripts

0	ambient
TRCC	transcritical CO_2 refrigeration cycle
EETC	ejector-expansion transcritical cascade
HDE(S)	hybrid dual-evaporator with single-effect absorption refrigeration
HDE(DS)	hybrid dual-evaporator with double-effect series-flow absorption refrigeration
HDE(DP)	Hybrid dual-evaporator with double-effect parallel-flow absorption refrigeration
col	collector
Gen, G	generator
ECHX	evaporator–condenser heat exchanger
P	pressure (bar)
EV	expansion valve
ABS	absorber
VG	vapor generator
T	turbine
c, COMP	compressor
CCR	cooling capacity ratio
gc	gas cooler
D	destruction
ut	utilized
i, in	input
out	output
COP	coefficient of performance (–)

Greek symbols

η_{ex}	exergy efficiency (%)
η_n	ejector nozzle efficiency (%)
η_d	ejector diffuser efficiency (%)
η_{IND300}	collector efficiency (%)
ε	effectiveness (%)
ψ	flow exergy (kJ kg^{-1})
δ	efficiency defect (–)
GH	high-pressure generator
GL	low-pressure generator
COND	condenser
HX	heat exchanger
e, EVAP	evaporator
SEP	separator
EJ	ejector
ω	entrainment ratio (–)

would continue to be a reasonable alternative to the synthetic working fluids. Bhattacharyya et al. [15] studied and optimized a CO_2–C_3H_8 cascade system and concluded that this system has some advantages over carbon dioxide–ammonia cascade system. Yari and Mahmoudi [10] proposed a new ejector-expansion transcritical CO_2 cascade cycle in which the high-grade thermal energy of gas cooler is utilized to run a supercritical CO_2 power cycle. They reported enhancements of 35.6% and 31.6% in COP and second-law efficiency for the proposed system compared to those of the conventional ejector-expansion TRCC cycle, respectively. Arora et al. [16] combined a transcritical CO_2 compression refrigeration cycle with a single-effect water–lithium bromide absorption refrigeration cycle through utilizing the high-grade thermal energy in the gas cooler. They reported that the COP and second-law efficiency of the combined system are 14.2% and 3.67% higher than those of the transcritical CO_2 refrigeration cycle, respectively.

In the present work three new arrangements are proposed to produce cooling effects more effectively. In the proposed cycles the ejector-expansion transcritical cascade (EETC) CO_2 cycle is combined with either the single-effect or the series double-effect or the parallel double-effect absorption cycles, through utilizing the waste heat from the gas cooler. The proposed cycles may have two advantages: (a) having a comparatively higher performance due to waste heat utilization and (b) producing cooling effects at two different temperatures. Thus, the aim of proposing such combined systems is an attempt to investigate comparatively on the performance of systems, but also the proposed systems can be accounted as dual-evaporator refrigeration cycles which provide wide range of cooling. A parametric study was performed considering the effects of various design parameters on the cycles' performance. Special attention has been paid to the influences of some important parameters such as; gas cooler pressure, gas cooler outlet, and generator temperature on the COP (coefficient of performance), second-law efficiency and exergy destruction distribution. Finally, the presented cycles were optimized thermodynamically using the EES (Engineering Equation Solver) software [17].

2. System description

The simplest well-known absorption refrigeration system is called single-effect absorption system in which the solution is heated in the generator and the cooling effect is achieved in the evaporator. Double-effect absorption refrigeration systems, on the other hand, are complex than single-effect absorption refrigeration system. Depending on the solution flow, there are two different configurations for double-effect absorption systems; the series-flow and parallel-flow systems, both with two generators. In the former the solution flow is directly pumped from the absorber to the high-pressure generator and then to the low-pressure generator while in the latter the solution flow is distributed between the high pressure and low pressure generators [18].

An ejector-expansion transcritical cascade CO_2 cycle, which is proposed by the authors in previously published work, is presented in Fig. 1. The proposed system was analyzed in detail in Ref. [10] and it was shown that the potential thermal energy in the gas cooler could be efficiently utilized to drive a supercritical CO_2 power cycle. In the present work, the basic idea of combining the ejector-expansion and absorption refrigeration systems is to use the waste heat from ejector-expansion cycle to power a thermally driven chiller. In addition, the proposed combined systems can be accounted as dual-evaporator systems.

Fig. 2 shows schematic diagrams of proposed combined refrigeration cycles: (a) hybrid dual-evaporator with single-effect (HDE(S)), (b) hybrid dual-evaporator with double-effect series-