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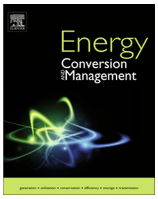

Comparative study on two low-grade heat driven absorption-compression refrigeration cycles based on energy, exergy, economic and environmental (4E) analyses

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ABSTRACT

Absorption-compression refrigeration cycle is widely studied for its energy saving potential. In this paper, a comparative study on a novel absorption-compression cycle with an evaporator-subcooler (ES) and a conventional absorption-compression refrigeration cycle with an evaporator-condenser (EC) has been done for the first time. The comparative investigation is based on energy, exergy, economic and environmental (4E) analyses. The results show EC saves 22.5% more electric energy than ES at the cost of consuming 4.6 times more low-grade heat energy than ES. EC has a higher COP, but has a lower COP_g, which takes into account both electric power and low-grade heat power. From the exergy analysis, the exergy efficiency of ES is 31.6%, 54.1% higher than EC's (20.5%), indicating ES has a much better exergy performance. The economic analysis shows that when waste heat is used, EC has a better economic performance and when solar heat is used, ES has better practical application potential. The effect of electricity price and CO_2 tax rate on economic performance is also studied. The better cycle for different electricity price and CO_2 tax rate are recommended. The results and understanding of the two cycles can be used as the basis for cycle selection and design.

1. Introduction

Energy saving and environment protection has been an important issue all over the world [1]. Absorption refrigeration cycle receives more attention and is widely studied for it can reduce non-renewable energy consumption and minimizes negative impacts to environment by utilizing low-grade heat, such as industrial waste heat, solar heat and geothermic heat [2]. It has been already used in air-conditioning, food conservation, ice production, etc.

However, absorption refrigeration cycle usually cannot achieve a very low evaporating temperature [3] and its energy efficiency drops very quickly with a decreasing evaporating temperature and generating temperature [4,5], which limiting the practical applications of absorption refrigeration cycle. Therefore, in many recent studies [6,7], absorption-compression cascade refrigeration cycle is recommended to both achieve a low evaporating temperature and reduce electric power consumption.

A most common configuration of absorption-compression cascade refrigeration cycle is presented in Literature [8], as shown in Fig. 1. The cycle consists of an absorption subcycle and a compression subcycle, which are combined by an evaporator-condenser. The evaporator-condenser is the evaporator of the absorption subcycle and is also the condenser of the compression subcycle. Such an absorption-compression cascade cycle is called EC for short in this work. In EC, the compression subcycle is condensed by the absorption subcycle and provides cooling capacity. A series of investigations [9,10] have been done on EC, demonstrating a good energy performance. Cimsit et al. [11] reported an optimization study and concluded that the system had potential to reduce electric energy consumption by 50.0%. It was also found that the exergetic efficiency was improved about 3.1%. Chen et al. [12] analyzed a heat-driven absorption–compression cascade refrigeration system at low temperature. The working substances for absorption subcycle and compression cycle were NH_3/H_2O and CO_2, respectively. At evaporating temperature of $-55\,^{\circ}C$, the cooling capacity per unit mass of flue gas was 62.70 kJ/kg and the COP of compression subcycle varied from 3.12 to 1.70 with different intermediate temperature. An absorption–compression

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Nomenclature

A	heat transfer area (m^2)
A_{sol}	solar collector area (m^2)
C_{ele}	electricity price (US \$/kW h)
C_{CO_2}	penalty cost for CO_2 emission (US \$/kg)
COP	coefficient of performance
COP_g	global coefficient of performance
CRF	capital recovery factor
D	diameter (m)
EC	absorption-compression refrigeration system with an evaporator-condenser
ES	absorption-compression refrigeration system with an evaporator-subcooler
ex	specific exergy (kJ/kg)
$\dot{E}x$	exergy rate (kW)
$\dot{E}x_D$	exergy destruction rate (kW)
h	enthalpy (kJ/kg)
H	heat transfer coefficient (W/(m^2 K))
i	interest rate
I_{sol}	solar intensity (kW/m^2)
k_w	thermal conductivity (W/(m K))
$\dot{m}$	mass flow rate (kg/s)
m_{CO_2}	CO_2 emission mass (kg)
n	system life time (year)
p	pressure (Pa)
$\dot{Q}$	heat transfer rate (W)
$\dot{Q}_m$	heat load of evaporator-condenser or evaporator-subcooler (W)
r	fouling resistance ((m^2 K)/W)
t_{op}	annual operating hours (h)
T	temperature (°C)
ΔT	temperature difference (°C)
ΔT_x	pinch temperature difference (°C)
U	overall heat transfer coefficient (W/(m^2 K))
v	specific volume (m^3/kg)
w	mass fraction of LiBr
$\dot{W}$	compressor power (W)
x	quality
Z	investment cost (US \$)
$\dot{Z}$	cost rate (US \$/year)
η	efficiency
η_{or}	thermal efficiency of organic Rankine cycle
η_{sol}	efficiency of solar collector
λ	emission conversion factor
φ	maintenance factor

Subscripta

	absorbing
amb	ambient
c	condensing
com	compressor
dead	dead state for exergy
e	evaporating
e1	one end of heat exchanger
e2	the other end of heat exchanger
ele	electricity
env	environment
ex	exergy
i	inlet or inner side
inv + main	investment and maintenance
in	input
k	component
lm	logarithmic mean
m	intermediate
o	outlet or outer side
op	operational
out	output
pump	pump
s	isentropic
shx	solution heat exchanger
1–15	state point

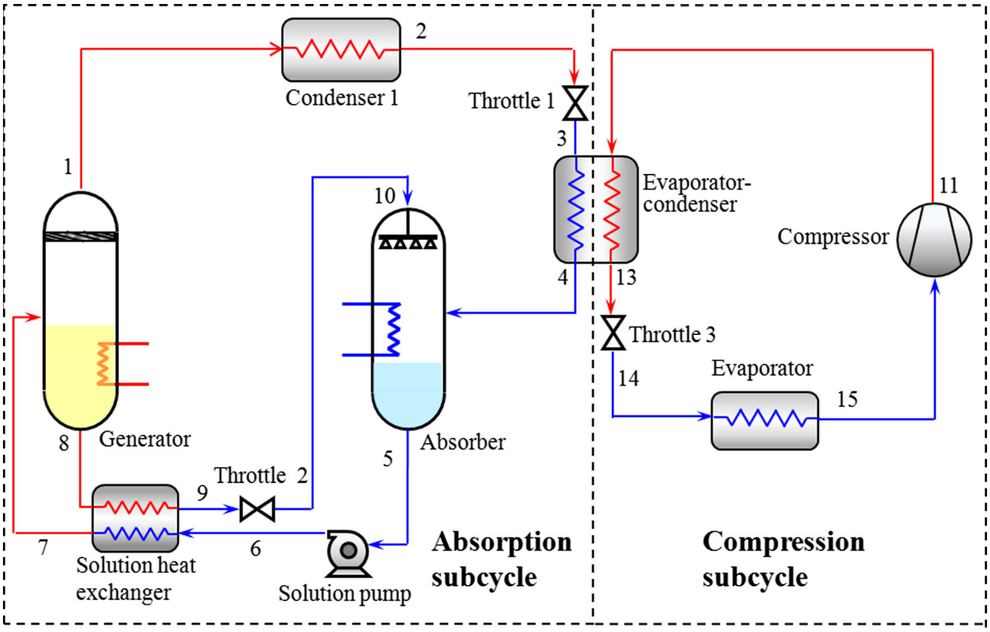

Fig. 1. Schematic diagram of absorption-compression refrigeration cycle with evaporator-condenser (EC).

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