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A combined effect absorption chiller for enhanced performance of combined cooling heating and power systems

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HIGHLIGHTS

- Propose a method that enhances the COP compared to conventional methods.
- A theoretical approach in fine tuning double and combined effect absorption chillers.
- Possibility to utilize two different heat sources simultaneously in cooling.
- Improved utilization of waste heat compared to conventional methods.

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ABSTRACT

Most industrial waste heat (e.g. waste heat from engines) is available as two or more heat sources or in a wider temperature range. Additionally, solar thermal energy has a higher harnessing efficiency at low temperatures while its work potential increases with temperature. However, well-established absorption cooling technologies, such as single and double effect absorption chillers, operate in relatively narrow firing temperature ranges. The use of the maximum temperature range of the sources or of multiple sources together increases the energy harnessing efficiency as well as the productivity of the absorption technology.

This paper introduces a combined effect absorption cycle that can utilize two energy sources at different temperature ranges or a single source at a wide temperature range. This new method reduces the capital investment and the operation costs of two conventional cycles that would otherwise have to be deployed in a series for an efficient energy conversion from heat to the cooling energy. The simulation results show that the proposed cycle improved the coefficient of performance (COP) of the system by 11% compared to the conventional separate production of the same capacity at the same temperature intervals.

1. Introduction

Demand for renewable energy technologies and efficient use of conventional energy sources is increasing day by day due to the irreversible impact on the biosphere of the use of fossil fuels [1,2]. The potential renewable energy availability is massive, but harnessing technology is still in its infancy. Therefore, it seems that rather than an energy crisis, we face a technical barrier. Most renewable thermal energy sources (e.g. solar) are easy to explore at low temperature ranges. The power generation from fossil fuel releases a gigantic amount of low grade waste heat into the environment as well.

Today, the major cooling production share comes from vapor compression cycles that consume electricity [3–5]. In the meantime, the cooling production technology from low grade heating is attractive and well established. Absorption chillers play a significant role in the use of low temperature heat for cooling purposes, instead of using electricity for cooling. Therefore, the use of solar thermal energy, as well as the waste heat from electricity production from fossil fuels, can be converted directly into cooling where electricity would otherwise have been used [6,7]. This helps enormously in reducing overall fossil fuel consumption and the related environmental impact.

The single effect absorption chiller operates between 80 °C and 115 °C with a maximum coefficient of performance (COP) of around 0.7 [8–10]. Similarly, the double effect cycle operates between 140 °C and 180 °C with a maximum COP of 1.2 [11,12]. The lower the operating temperature, the lower the performance is. However, most waste and renewable energy sources have higher harnessing efficiency at low temperatures [13,14]. The use of double effect absorption chillers at the upper end (180 °C) of

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Nomenclature

D	Mass diffusivity ($m^2\ s^{-1}$)
T	Temperature (°C)
$\dot{m}$	Mass flow rate ($kg\ s^{-1}$)
C_p	Specific heat capacity ($J\ kg^{-1}\ K^{-1}$)
P	Pressure (Pa)
h	Specific enthalpy ($kJ\ kg^{-1}$)
$\dot{Q}$	Heat transfer rate ($J\ s^-1$)
g	Acceleration due to gravity ($m\ s^{-2}$)
u	Tangential velocity ($m\ s^{-1}$)
v	Radial velocity ($m\ s^{-1}$)
R	Tube external radius (m)
r	Tube internal radius (m)
K	Thermal conductivity ($W\ m^{-1}\ K^{-1}$)
$\bar{q}$	Heat transfer rate ($J\ s^-1$)
A	Surface area (m^2)
l	Distance along the tube length (m)
x	Tube circumferential distance (m)
y	Tube radial distance (m)
Greek letters	
α	Thermal diffusivity ($W\ m^{-1}\ K^{-1}$)
θ	Azimuth angle
ρ	Density ($kg\ m^{-3}$)
μ	Viscosity ($kg\ m^{-1}\ s^{-1}$)
χ	*LiBr* mass fraction
θ	Azimuth angle
Subscripts	
abs	Absorber
con	Condenser
dsb	Desorber
rec	Recuperator
i	In
o	Out
cw	Cooling water
chw	Chilled water
evp	Evaporator
s	Solution
sat	Saturated
shw	Secondary hot water
sti	Solution–tube interface
svi	Solution–vapor interface
v	Vapor
w	Water
hp	High pressure
lp	Low pressure
hw	Hot water
ws	Weak solution
ss	Strong solution

the temperature range would increases the coefficient of performance (COP) as well as reduces the harnessing efficiency of heat from the energy source. The use of the single effect absorption chiller increases the energy harnessing efficiency while operating at a lower COP due to the low operating temperature (80 °C and 115 °C). This shows that there is an obvious need for technology that generates cooling from heat sources at wider temperature ranges while improving the system's energy harnessing efficiency and COP. With current technology, both cycles have to be deployed in a series for an effective utilization of these energy sources (e.g. solar between 80 °C and 180 °C). This increases investment as well as operational difficulties and cost. Therefore, the use of a single unit that operates in a wider temperature range with similar or improved performance to that of the conventional method would increase practical applicability. The operation strategies of double effect and proposed combined effect absorption chillers are very important in achieving the expected outcomes. The operating pressure of the high pressure (HP) desorber is the one of the key parameters affecting system performance. Therefore, the optimum operating pressures of both chillers at different firing and cooling temperatures are also presented in this paper.

1.1. Contribution

This paper introduces a combined effect absorption chiller that utilizes heat sources at two different temperatures or a single energy source in a wide temperature range for the first time. In addition, the optimum operating pressure maps of the double effect and proposed combined effect cycles are determined. The COP of the proposed cycle is greater than that of the conventional method that use the single and double effect cycles in a series.

1.2. Outline of the paper

This paper presents computer simulations of the conventional double effect and the proposed combined effect LiBr–H_2O absorption chillers. Section 2 presents an overview of the literature, with a brief introduction to the proposed method and its importance. Section 3 describes the methodology used in mathematical modeling of both absorption chillers, including three dimensional concentration and temperature distributions. The results are presented and discussed in Section 4. The article concludes with a brief summary.

2. Related work and proposed improvements

Numerous methodologies are adopted in the literature, of which the following is a selective taxonomy.

2.1. Previous work

Most previous studies focused on improving the performance of the conventional single effect and double effect LiBr–H_2O absorption chillers or their extensions. Few have introduced novel cycles that exhibit their performance in the operating temperature regions where the conventional cycles are not available. Mathematical modeling of absorption chillers requires clear understanding of the system's physics which has been given less attention due to its complexity in solving three dimensional heat and mass diffusion problems. Banasiak and Koziol [15] introduced a mathematical model of a LiBr–H_2O absorption chiller including two-dimensional distributions of temperature and concentration fields for heat and mass exchangers. A similar approach was taken by Sun et al. [14], with experimental verification for the simulations performed. Wang and Zheng introduce the half effect cycle [16], operating between 40 °C and 60 °C. Subsequently, they introduce the one and half effect absorption chiller that operates between 110 °C and 130 °C; that is the temperature region where none of the conventional chillers perform well and in some cases cannot operate at all. Grossman and Zaltash [17] propose a multi effect absorption chiller with a series of extensions to the conventional double effect cycle and show the gain in COP. Hellmann and