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Operation performance enhancement of single-double-effect absorption chiller

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HIGHLIGHTS

- This study presents a new system configuration of a single-double-effect absorption chiller.
- A newly developed performance maximisation method of this system is suggested.
- The absorber outlet solution flow-rate and the solution distribution ratio are controlled.
- The COP can be maximised by manipulating internal parameters (1.55 at full load, and up to 2.42 at 60% partial load).
- A significant reduction of the primary energy consumption can be achived.

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ABSTRACT

Absorption chillers constitute a valuable option for utilising solar energy. Specifically, when installed in tropical regions, this technology ideally matches the needs for refrigeration and air-conditioning because of the abundance of solar energy throughout the year. A single-double-effect absorption chiller combines the single and double-effect configurations to compensate for the unpredictable instantaneous availability of solar radiation and cooling load fluctuations. The operative performance of this system is strongly affected by internal parameters such as the absorber outlet solution flow rate and the solution distribution ratio, which connect the operability of the single and double-effect configurations. Therefore, these important parameters are currently used to maximise system performance while assuring its stability. This study discusses how the COP of a single-double-effect absorption chiller, for solar cooling applications in tropical areas, can be maximised (1.55 at full load, and up to 2.42 at 60% partial load) by manipulating those internal parameters. The simulation results were compared with the experimental data (field test data) and, by adopting the appropriate control method, showed an improvement of the system performance between 12 and 60% when compared to a corresponding double-effect configuration.

1. Introduction

The high daily temperatures in Asian tropical climates [1] necessitate an air-conditioning system, which creates a thermal comfort zone for the daily indoor activities. During the hot season, the air-conditioning system is required even more. Consequently, the energy consumption of the building sector could increase and this would burden the energy load of a country. For example, in Singapore, the electricity demand of the building sector only for cooling is around 31% of the total electricity consumption [2]. Furthermore, approximately 40% of the total energy in the building sector is consumed by air-conditioning systems [3].

Due to the high electricity consumption of the building sector's cooling systems, solar energy is one of the future alternative energy sources because non-renewable energy, such as fossil fuels that are still in use, is limited. Moreover, solar energy can be obtained from nature without direct cost. The utilisation of solar energy indirectly reduces carbon dioxide emissions from power plants [4], and Asian tropical areas have a significant potential for using solar energy [5,6]. Therefore, air-conditioning systems that can be driven by solar energy are

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Nomenclature

C_p	specific heat, kJ/kg K
h	specific enthalpy, kJ/kg
P	pressure, kPa
Q	heat transfer rate, kW
T	temperature, °C
UA	overall heat transfer coefficient, kW/K
X	solution concentration, -
$\dot{m}$	mass flow rate, kg/s
ΔT	delta temperature, °C
γ	solution distribution ratio, -

Subscript

A	absorber
atm	atmosphere
C	condenser
CL	crystallisation line
cw	cooling water
chw	chilled water
CON	conventional
DE	double-effect
E	evaporator
HTG	high-temperature generator
HHX	high-temperature heat exchanger
hw	hot water
in	inlet
LHX	low-temperature heat exchanger
LMTD	log mean temperature difference
LTG	low-temperature generator
M	maximum
out	outlet
r	liquid refrigerant
s	solution
SC	special condenser
ss	strong solution
STG	special-temperature generator
v	vapour refrigerant
ws	weak solution

excellent options for reducing the solar heat gains in the building sector [7]. As a thermally driven technology, absorption chillers can be efficiently driven by solar energy in a wide range of heat input temperatures [8]. Utilising solar energy for an absorption chiller system in Asian tropical areas comes along with the significant advantage of large availability of radiant heat, which constitutes a power source able to make up for the high ambient temperature throughout the year.

Absorption chillers that use solar energy as heat input, together with the related technology of the absorption heat pumps (heat transformers) driven by industrial waste heat [9,10], have been described as one of the promising cooling systems that could meet all the requirements needed to solve the energy and environmental issues [11]. The excellence of this system is its high performance, low-temperature heat input, low operational costs, and environmentally friendly working fluid. Therefore, in several countries, many types of solar cooling systems, with single or double-effect absorption chiller systems, have been investigated in order to understand their characteristics and performance [12–24].

A single-double-effect absorption chiller combines the single and double-effect systems to take advantage of the merits of both these individual configurations. Arnas et al. have previously investigated the performance and characteristics of the single-double-effect in order to fully utilise the solar energy in the tropical area in Indonesia [25], presenting the performance of this system configuration for one-day operation.

The control strategy plays an essential role in the absorption chiller system to maintain a stable cooling capacity and keep the system operating safely. Moreover, an appropriate control strategy applied to the absorption chiller could drastically enhance the seasonal system performance. The control system in absorption chiller systems can be classified into internal and external [26,27]. The internal control usually refers to the control of the internal parameters (solution and refrigerant) of the system, such as mass flow rate, level, concentration, temperature, and pressure. The external control is used to provide the required cooling load for a building by setting the hot, chilled, and cooling water temperatures and by adjusting or fixing their flow rates. Changing the external parameters gives a direct effect on the internal parameters of the absorption chiller.

Many studies focus on the control of the external parameters of the single-effect absorption chiller. Xiaohong Liao and Reinhard Radermacher proposed a new control methodology for the $LiBr–H_2O$ air-cooled absorption chiller while avoiding the crystallisation issue. The ambient temperature is used as a feedback to set the chilled water and exhaust temperatures [28]. For the water-cooled absorption chiller, other researchers showed that the adaptation of the cooling water temperature to the generator temperature could be an option for the external control strategies of the single-effect absorption systems [26,29–33]. The cooling water flow rate and cooling tower fan have to be suitably adjusted to achieve the required cooling water inlet temperature. Another study with a different focus on the external parameters is that of Shirazi et al. who suggested a proper external control for a solar-assisted absorption air-conditioning system by adjusting the inlet temperature and flow rate of the hot water. The hot water inlet temperature varied according to the required cooling load [33].

A new control strategy for absorption chiller systems using Artificial Neural Networks (ANN) has been developed by [27,34,35]. Verda et al. used ANN in the absorption chiller system to minimise its primary energy consumption. The input variables of ANN are the solar radiation, ambient temperature, and the cooling request [34]. Furthermore, Labus et al. combined ANN and Genetic Algorithms (GA) optimisation to minimise the primary energy consumption of the absorption chiller by adjusting the hot and cooling water inlet temperature while maintaining constant the chilled water outlet temperature [27]. Additionally, Labus et al. manipulated the hot water inlet temperature, cooling water inlet temperature, and cooling water flow rate by using Inverse ANN to produce the proper cooling capacity [35].

Due to the strong interdependence between heat, mass, and momentum transfer [36,37], controlling the internal parameters of the absorption chiller results into a direct influence on the system operation [38]. Jose Fernandez-Seara and Manuel Vazquez developed a new internal control strategy for a NH_3-H_2O absorption refrigeration system to set and maintain the optimum generator temperature by adjusting the generator heat flux [39]. Furthermore, Xu et al. suggested that manipulation of the generator's solution temperature is a better control in off-design conditions for the single-effect absorption chiller [40]. Seo et al. proposed an internal control strategy for the solution level in the high-temperature generator, of the double-effect absorption chiller system, for linear controllability and solution economy [41]. This control strategy shows that the solution level can be maintained by adjusting the solution mass flow rate [41,42].

In this study, the configuration of the single-double-effect absorption chiller uses two energy sources, solar and gas, at the same time in manner dependent on the specific conditions. Owing to the complex interconnections between the components under continuous strong