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Performance characteristics of a solar driven lithium bromide-water absorption chiller integrated with absorption energy storage

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A R T I C L E I N F O

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A B S T R A C T

The use of solar–assisted absorption chiller for space cooling is limited to availability of solar radiation; hence, energy storage is very crucial in order to achieve extended hours of cooling operation. In this study, operational and performance characteristics of a solar driven lithium bromide-water absorption chiller integrated with absorption energy storage of the same working fluid are investigated. The integrated system simultaneously provides cooling and charging of the absorption energy storage during the hours of solar radiation. Simulation of the integrated system is carried out based on first law of thermodynamics. Effects of weather variables such as solar radiation and the influence of coupling absorption energy storage with an absorption chiller are investigated. The results indicate that cooling effect of the chiller varies with the variation of solar radiation, with maximum value of 20 kW for a collector area (A_c) of 96 m^2 on a typical day in July, Dhahran, Saudi Arabia. The cooling COP of the integrated system during cooling/charging and discharging is found to be 0.69 and the energy storage density of the absorption energy storage is 119.6 kWh/m^3. Furthermore, the operational characteristics of the proposed system showed that the internal operating parameters of the integrated chiller-absorption energy system such as solution temperatures and pressures are within reasonable levels. Hence, this indicates the possibility of integrating the absorption energy storage with absorption chiller.

1. Introduction

Although mechanical vapor compression air conditioning systems have been and are still widely used in many facilities including commercial, residential and industrial buildings for comfort, absorption technology is advancing and gaining wider implementation for cooling. This is because of low input energy requirement of the absorption chillers, quite operation, ecological and can be powered by solar, waste heat, geothermal and biomass energy sources [1,2]. The use of renewable energy sources such as solar to drive the absorption chiller have been in practice over the years. However, the intermittent nature of the solar energy limited the implementation of solar driven absorption chillers compared to mechanical chillers especially for small and medium cooling needs. Hence, there is need for proper solar thermal energy storage (TES) and integration approaches.

Integration of energy storage unit with intermittent energy sources such solar is inevitable for efficient and sustainable utilization. Solar thermal energy is stored in the form of sensible, latent or sorption/thermochemical heat, with sensible and latent TESs being the most widely studied and practiced [3,4]. Nevertheless, an increasing interest and development in sorption energy storage for solar thermal applications appeared recently. This could be attributed to its high-energy storage capability per unit volume (storage density) and negligible heat losses. Cooling or heating effects can be produced from sorption/thermochemical energy storage depending on the practical requirement [5]. Sorption thermal energy storage is also often referred to as refrigerant storage [6] or sorption thermal battery (STB) [7]. Many studies [8–16] appeared in the literature on seasonal energy storage using sorption technology for solar space heating applications. These storage systems are usually charged in summer using the available solar energy where the solar heat is stored in the form of chemical potential and discharged in winter for heating. The most commonly available working pair applied to commercial absorption chillers is LiBr–H_2O. The same LiBr-H_2O can be applied as working pair in absorption energy storage and be integrated with absorption chillers [13].

Though there has not been significant advancement in practice with regards to integration of sorption energy storage with absorption chillers, it has been studied theoretically since 1970th [17,18]. The chiller-sorption storage integration involves storing liquid refrigerant (a by-product of desorption process) in a storage volume between the

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Nomenclature

A	area (m^2)
AES	absorption energy storage
COP	coefficient of performance
Cp	specific heat capacity (J/kg K)
D	diameter (m)
ESD	energy storage density (kWh/m^3)
F_c	collector efficiency factor (–)
F_R	heat removal factor
h	heat transfer coefficient, enthalpy (W/m^2 K, J/kg)
I	incident solar flux (W/m^2)
k	thermal conductivity (W/m K)
M	mass (kg)
$\dot{m}$	mass flow rate (kg/s)
$\dot{m}$	mass flow rate (kg/h)
Q	energy (MJ or kWh)
$\dot{Q}$	heat transfer rate (W or kW)
r	amount of solution/refrigerant from storage tanks (%)
T	temperature (°C or K)
t	time (h)
UA	overall heat transfer coefficient, (W/K or kW/K)
U_L	overall heat loss coefficient (W/m^2 K)
V	wind speed (m/s), volume (m^3)
W	width (m)
$\dot{W}_p$	pump work (W or kW)
X	solution concentration

Greek symbols

ε	emissivity, effectiveness
η	efficiency
σ	Stefan-Boltzmann constant (W/m^2 K^4)
$(\alpha\tau)$	absorptance-transmittance product

Subscripts

a	air, absorber
amb	ambient
ap	aperture
b	bottom
c	collector, condenser
cu	copper
e	evaporator
g	generator, glass cover
i	inner, inside
icas	integrated chiller-absorption storage
o	outer, outside
p	absorber plate
r	radiation
R	refrigerant
SST	solution storage tank
t	top
u	useful
w	water

condenser and the evaporator during the hours of available or excess solar insolation [19,20]. The stored refrigerant can be utilized at any other time to meet the required cooling demand. It also involves storing of either concentrated solution or weak solution or both in addition to refrigerant storage within an absorption chiller.

Wilbur and Mitchell [17] modeled a solar absorption air conditioner with refrigerant storage. The system consists of conventional absorption chiller, refrigerant storage tank that accumulates excess liquid refrigerant from the condenser and weak solution storage tank that receives weak solution of LiBr from the absorber. Their finding revealed that the system with refrigerant storage require smaller cooling towers than conventional units. A similar system was modeled based on geographical data of Brisbane, Australia [18]. In this case, a conventional absorption chiller was incorporated with additional solution tank and a refrigerant tank. The results indicate that such storage is thermodynamically feasible and could offer considerable benefits for solar cooling applications.

Xu et al. [21,22] reported a dynamic simulation of variable mass energy transformation and storage (VMETS) system under full storage and partial storage strategies. Jia et al. [23] carried out dynamic simulation of a similar system with bubble pump instead of a mechanical pump. The authors concluded that the VMETS technology offers higher energy storage density compared to the hot water and chilled water storage techniques [21–23]. Xu et al. [24] studied the performance of a direct solar powered absorption refrigeration system (SPAR) with refrigerant storage, where the solar collector acts as a generator. In this cycle, aqueous LiBr is heated directly by solar radiation, rising its temperature to the saturation point, forming a vapor-liquid mixture. The mixture then flows into the solution tank where the water vapor is separated and goes to condenser while the strong solution is directed to the absorber. The authors carried out dynamic simulation of the system and the results showed that coefficient of performance (COP) of the system reached 0.75 with storage density of 368.5 MJ/m^3.

Said et al. [25] and Al-Ugla et al. [26] reported an alternative design for 24-h-operating solar powered aquaammonia and lithium bromide absorption chillers, respectively. The chiller is equipped with refrigerant storage, heat storage and cold storage units and plurality of heat exchangers for continuous operation. Simulation results indicate that the system equipped with a refrigerant storage provides better COP when operated continuously on a day and night basis and is the most suitable alternative design for a 24-h cooling effect. In a related study [27], the authors presented an unsteady thermodynamic analysis on a solar driven dual storage absorption refrigeration cycle in an attempt to reduce energy consumption in the Kingdom of Saudi Arabia. The system consists of aqua ammonia absorption chiller equipped with ammonia and ice storages. The results showed a better COP_{day} as well as COP_{night} in winter than in summer with more solar collector area requirement (9.3%) per kilowatt of cooling.

It is noted that the refrigerant and solution tanks in these simulations studies [17–24,28,29] are located at the high pressure side of the absorption chiller, likewise the refrigerant storage tank presented in other simulation studies [25–27,30]. In addition, the influence of the absorption or refrigerant storage on the chiller behavior as both are integrated together is not well investigated in the above studies. Moreover, some research gaps and recommendations with regards to integration of absorption energy storage with absorption chillers are highlighted recently, which includes further simulation studies on new system designs and integration approaches [31]. Therefore, based on these information, this paper presents a simulation study of an integrated solar absorption chiller-absorption energy storage system, with the storage tanks located at the low-pressure side of the chiller, hence, charging of the storage unit is accomplished after expansion. The chiller-storage configuration of the present study is aimed at offering flexible design and operation of the system. In addition, the influence of the absorption energy storage on the operational characteristics of conventional chiller cycle is investigated in the study. The system can offer short-term cooling energy storage and long-term heating energy storage, but only the former is considered in this study.

2. System description and operations

Schematic diagram of the integrated solar absorption chiller-