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Performance assessment of a solar powered ammonia–water absorption refrigeration system with storage units

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ABSTRACT

Solar thermal energy is one of the viable options for space cooling in the quest of greener environment and energy efficiency. The major challenge in actualizing the use of solar energy to drive cooling systems such as absorption chillers is its intermittent nature, thereby not able to cover significantly the period of cooling demand in most situations. In order to achieve continuous cooling energy supply from solar driven absorption chillers, the present study considered two alternative storage units in the form of chilled water and ice, integrated to the main chiller installed in Dhahran, Saudi Arabia. The system is designed to allow different operational modes in accordance with the cooling demands. The system is tested experimentally where the storage units are used alternatively and the results are presented. A mean chiller COP for cooling the space and chilling the water was found to be 0.8 whereas it was 1.3 for only making ice. Maximum COP (0.8) was found at T_{gen} = 120 °C at an average condenser and evaporator temperatures of 34.5 °C and −2.2 °C, respectively.

1. Introduction

High demand of air conditioning and refrigeration is persistently increasing across the globe mainly due to climate change, improvement in living standard, industrialization and general population growth. Mechanical vapor compression air conditioning systems are widely used in residential, commercial and industrial buildings for comfort. These systems generally consume high amount of energy. About 40% of the total world's energy consumption annually is attributed to buildings and most of it goes to air conditioning [1]. Residential sector in Saudi Arabia is responsible for about 52% of the total national electricity consumption and a large share of it goes to space cooling where mechanical vapor compression systems are widely used [2,3].

The use of vapor absorption chillers operated by solar thermal energy or other renewable energy options is believed to reduce, to some extent, energy consumption and the negative environmental impacts caused by the conventional vapor compression air conditioning systems. This is because absorption systems required less electric power to operate compared to vapor compression systems [4]. Mazharul et al. [5] studied the prospects of using solar thermal energy for space cooling, considering 21 different locations in Saudi Arabia. They noted that in summer (between April and September); most of the selected locations have solar insolation >6 kW h/m^2/day, which is quite attractive for solar cooling applications.

Due to the discontinuous nature of solar energy, which creates a shift between energy supply and its demand, effective implementation and market penetration had not made reasonable progress. Hence, there is need for proper solar thermal energy storage (TES) system. This study is concerned with dual storages: ice and chilled water for solar absorption system, adopting novel control strategies for the system operation. Sizeable amount of research on the progress of solar absorption air conditioning appeared in the recent years [6]. Zhang et al. [7] presented review on recent developments and practical aspects of TES and highlighted the importance of different type, their maturity and cost effectiveness. Sensible and latent TES are the most widely adopted as well as studied technologies for solar thermal applications and a few of them are reported in [8–10].

Various simulation and experimental studies on solar absorption refrigeration have been reported in the literature [11–15]. Said et al. [16] developed an alternative design for 24-h-operating solar powered aqua ammonia absorption chiller. The chiller was equipped with refrigerant, heat and cold storage units and plurality of heat exchangers for continuous operation. The results indicate that the system equipped with a refrigerant storage provided

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Nomenclature

A	area
a	sensitivity
COP	coefficient of performance
Cp	specific heat capacity (J/kg K)
I	incident solar flux (W/m^2)
N	number of measurements
$\dot{Q}$	heat transfer rate (kW)
$\dot{V}$	volume flow rate (m^3/s)
ρ	density (m^3/kg)
R	number of independent measurement
S	standard deviation
T, t	temperature (°C)
U	uncertainty
η	efficiency
Q	cooling load (W)
q	heat gain (W)
W	humidity ratio
F	factor
E	evaporative heat (W)
h	latent heat (W)
m	body mass (kg)
θ	time (s)
UA	product of area-overall heat transfer coefficient (W/K)
p	pressure (kg/m s^2)

Subscripts

abs	absorber
c	collector
con	condenser
evap	evaporator
gen	generator
in	inlet
out	outlet
w	water
m	mean
conv	convective
s	sensitive
l	latent
ins	inside
os	outside
el	lighting
ul	lighting use
sa	lighting special allowance
ras	return air stream
sk	skin
res	respiratory
fg	vaporization of water

better coefficient of performance (COP) when operated continuously on a day and night basis. A similar theoretical study based on LiBr-H_2O was presented where the system with refrigerant storage found to be the most suitable alternative design for a 24-h cooling effect [17]. In another related study [18], an unsteady thermodynamic analysis of a solar driven dual storage absorption refrigeration cycle in an attempt to reduce energy consumption in the Kingdom of Saudi Arabia was carried out. The system consists of an aqua ammonia absorption chiller equipped with chilled water and ice storages. The results revealed a better COP (day and night) in winter than in summer, with additional (9.3% per kW) solar collector area required for winter season.

Xu et al. [19] investigated the performance of a direct solar powered absorption refrigeration system (SPAR) with refrigerant storage, where the solar collector acts as a generator. Dynamic simulation results showed that the system COP reached 0.75 with storage density of 368.5 MJ/m^3. He et al. [20] studied the performance of a 50RT absorption chillers with hot and chilled water storages powered by evacuated tube collectors by simulation. The results showed the annual average efficiency of collectors is 37.6% and about 66% reduction in primary energy consumption compared to the traditional system.

Lostec et al. [21] studied the performance of a 10 kW aqua-ammonia absorption system experimentally where water–ethylene glycol solution was used inside the cooling circuit. The results showed a COP of 0.6 when operated at the evaporator temperature of 16 °C. The authors later studied the effect of evaporator and desorber temperature on the absorption chiller's performance by simulation [22]. They found that the COP decreases by 25% with a decrease of 10 °C in evaporator temperature and the COP increases by 4% with an increase of 10 °C in desorber temperature. Agyenim et al. [23] conducted an experimental study of a H_2O/LiBr solar-absorption system with a 4.5 kW cooling capacity and 1000 l cold storage. The researchers reported that the absorption chiller achieved an average COP of 0.48 for an average peak solar insolation of 812 W/m^2.

Wang et al. [24] compared the performance of a dual source absorption chiller (AC) operated on waste heat from an internal combustion engine (ICE) and solar energy. The refrigeration performances of the mixed effect AC in both waste heat mode and solar mode were tested and discussed. Test results show that, the mixed effect AC can reach a COP of 0.91 in waste heat mode and about 0.6 in solar mode for there is only hot water heating source. In terms of primary energy consumption, waste heat mode was worse than solar mode when the part load ratio of ICE is below 0.62. Rosiek and Garrido [25] analyzed the performance of a solar-powered absorption cooling system with chilled water storage installed in the Solar Energy Research Center of Spain. The results indicate that about 20% of the total energy consumption can be save and the integration of chilled water storage tanks helps to reduce the sudden absorption chiller on/off cycles, thereby improving the efficiency of the system.

Reasonable number of research had been carried out on solar powered absorption cooling systems that use aqua-ammonia and lithium bromide–water as the working fluids, both experimental and simulation as reported in [26]. Recently, Said et al. [27] reported the design and construction of a solar powered ammonia–water absorption refrigeration system in Dhahran, Saudi Arabia under the solar thermal cooling project. Details information on the design and construction of the components as well as the operation mode of the system have been given. However, some experimental results from one operation mode concerning ice storage charging were published. The test results indicated a chiller COP of 0.69 and a cooling capacity of 10.1 kW at temperatures of 114/23/−2 (°C), representing the generator inlet, the condenser/absorber inlet and the evaporator outlet, respectively. The authors also developed thermodynamic model and analyzed the system without considering the cold storages [28].

Combining dual storages such as ice and chilled water with solar absorption system in a controlled manner and discharging the storages alternatively will help in proper utilization of the solar energy. Based in the literature review, it is noted that these studies