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Experimental testing of the performance of a solar absorption cooling system assisted with ice-storage for an office space

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ABSTRACT

Energy storage plays a vital role in shifting cooling energy load from period of peak demand to that of low demand. This paper reports performance data of an ice-storage unit in solar absorption cooling system for cooling an office space. The cooling system consists of ammonia-water absorption chiller, evacuated tube solar collectors and ice-storage. Experiments were carried out on two consecutive days in each of the month of March and October in Dhahran, Saudi Arabia. The ice-storage unit was charged on the first day and the cool energy discharged on the other day. The results showed average coefficient of performance (COP) of the chiller during charging as 0.43 and 0.47 for the months of March and October, respectively. The results also indicate that the ice-storage can provide a backup time of about 5–6 h, which is sufficient to cool the given space during the early hours of chiller warm-up.

1. Introduction

Global climate change along with rapid population growth resulted in the increased demand of air conditioning worldwide where mechanical vapor compression systems are mostly used. These systems generally consume a huge amount of energy annually, accounting for about 55% in the residential sector [1]. In addition, the use of chlorinated fluorocarbon compounds (CFCs) in vapor compression based cooling systems pose negative environmental impact as potential contributors to the depletion of the ozone layer [2].

Sorption cooling technology as one of the cooling alternatives is becoming more commercialized in the recent decades [3]. Sorption cooling systems include absorption chillers, adsorption chillers and desiccant systems. In terms of worldwide installations, absorption chillers are the most widely adopted for air conditioning [4,5]. Five systems that include modular silica gel–water adsorption chiller, single/double effect LiBr–water absorption chiller, $CaCl_2$/AC (activated carbon)–ammonia adsorption refrigerator, and the water–ammonia absorption with internal heat recovery were studied and evaluated [6]. The systems worked under various heat source temperatures to fulfil different cooling demands. The authors concluded that the systems might offer good potentials for high efficient solar cooling in the near future. The use of renewable energy sources to drive the sorption systems is considered one of the important alternatives for cooling in order to reduce greenhouse gas emissions [7]. Due to its cleanliness and abundance in many parts of the world, solar energy has been applied to drive absorption chillers [8]. Agyenim et al. [9] reported experimental results from a study of a LiBr/H_2O solar driven absorption system with of 4.5 kW cooling capacity and 1000 L cold storage. The results showed that the absorption chiller achieved an average COP of 0.48 for an average peak solar insolation of 812 W m^{-2}. The availability of the solar energy is a critical challenge due to its variability and hence, energy storage is necessary.

A good progress on solar absorption air conditioning integrated with energy storage emerges in the recent decade [10,11,7]. Sensible and latent storages are the most widely studied storage options for solar thermal applications [12,13]. However, different configurations and implementation of energy storage strategies on absorption machines as well as robust control approaches to design highly efficient systems is very crucial [14]. Fig. 1 shows the general classifications of thermal energy storage for air conditioning and refrigeration.

Selection criteria of thermal energy storage strictly depends on the storage period required (e.g. diurnal or seasonal), economic viability, operating conditions, etc [15]. While energy storage plays

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Nomenclature

COP	coefficient of performance
Cp	specific heat capacity (kJ/kg K^{-1})
$\dot{Q}$	heat transfer rate (kW)
T	temperature (°C)
$\dot{V}$	volume flow rate ($m^3\ s^{-1}$ or L h^{-1})
ρ	density ($m^3\ kg^{-1}$)

Subscripts

abs	Absorber
c	collector
con	condenser
evap	evaporator
gen	generator
in	inlet
out	outlet
w	water
gw	glycol-water solution

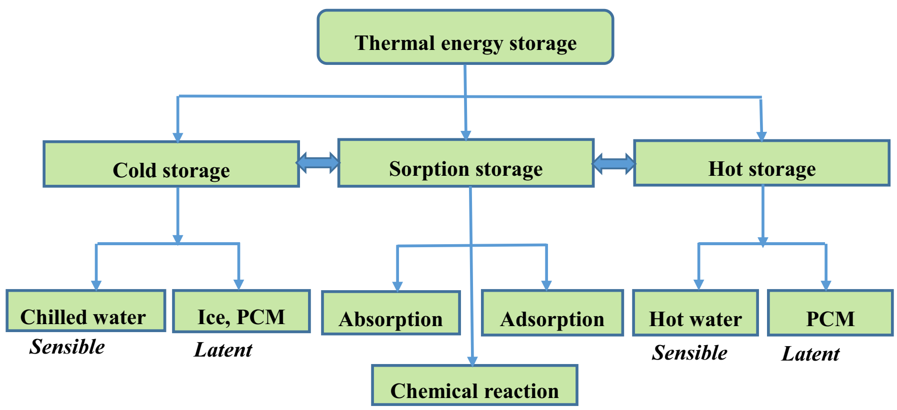

Fig. 1. Classification of common thermal energy storage options for air conditioning and refrigeration.

a vital role in reducing peak electricity demand and time-shifting the electrical load of energy systems from on-peak day times to off-peak night-times [16,17], it is equally used to shift excess thermal energy from the availability hours to non-available periods. The objective of this work is to further study operational and performance characteristics of a solar assisted air conditioning system installed in Dhahran, Saudi Arabia [18,19] considering different operational strategies. The system is composed with four basic operational modes (modes 2, 3, 4 and 5) under different combination schemes. Experimental test based on mode 2 was carried out and presented in [19]. The system was also tested experimentally based on combined operation strategy, modes 4 and 5 under different control strategies [18]. In the present study, combined operation strategy, modes 2 and 3 is considered. Detail of the operational modes is given in the subsequent section.

2. Literature review

Sanaye and Hekmatian [20] investigated the benefit of integrating a conventional compression chiller with ice thermal energy storage, employing energy, exergy, economic and environmental (4E) concept. They used multi-objective optimization technique and Genetic Algorithm for design optimization considering two full and partial load-operating modes. The results indicate reduction in electricity consumption of the integrated chiller-storage system for full and partial operating modes, respectively by 11.83% and 10.23% compared with that for traditional system. In addition, the cost of electricity consumption was reduced by 32.65% and 13.45% for the respective modes due to shifting the electricity consumption from on-peak to off-peak hours. Arcuri et al. [21] analyzed the techno-economic aspects of ice thermal energy storage (ITES) as a viable option for shifting building cooling load to off-peak time, considering five different cities in Brazil. They concluded that climate plays an important role in determining the electricity tariffs, which in turn, determine the economic feasibility of ITES. Rahdar et al. [22] compared thermodynamic performance and cost of conventional vapor compression chiller, the chiller with phase change material (PCM) and chiller with ice-storage. The results showed that the total power consumption of the chiller with ice storage and PCM systems are respectively, 4.59% and 7.58% lower than the conventional chiller. A similar analysis indicates reduction in electricity consumption and CO_2 emission of ITES system were lower 9% and 9.8%, respectively, in comparison with a conventional system [23]. In a related study [24], the power consumption by an ITES was about 11% lower than a conventional system.

Literature survey shows that many studies regarding ice-storage for buildings cooling-load shifting applications are reported and a general review of cold storage materials for air conditioning is also presented [25]. However, majority of the ice-storage units are charged by conventional vapor compression systems powered by electricity [20–23,26–30].

Drosou et al. [31] tested a double effect LiBr/H_2O absorption cooling system for application in the building sector in Greese. Concentrated solar thermal collector was employed to power the system. Energy assessment of solar cooling was also carried out for Nordic countries [32]. The study concluded that the configuration where the solar collectors, the storage tank and the absorption chiller are connected in parallel gave better performance than systems, where the chiller receives thermal energy only from the hot storage tank.

Ammonia-water absorption chillers produce sub-zero temperatures and hence, generally employed for refrigeration. However, there are limited studies on the use of ice-storage from solar powered ammonia absorption chillers for space cooling. Compared with other storage options for solar cooling, the use of ice-storage