Energy Conversion and Management 85 (2014) 425–434

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Experimental investigation on charging and discharging performance of absorption thermal energy storage system

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ARTICLE INFO

Article history:
Received 3 March 2014
Accepted 27 May 2014
Available online 21 June 2014

Keywords:
Absorption
Thermal energy storage
Experiment
$LiBr–H_2O$
Energy storage efficiency
Energy storage density

ABSTRACT

Because of high thermal storage density and little heat loss, absorption thermal energy storage (ATES) is known as a potential thermal energy storage (TES) technology. To investigate the performance of the ATES system with $LiBr–H_2O$, a prototype with 10 kW h cooling storage capacity was designed and built. The experiments demonstrated that charging and discharging processes are successful in producing 7 °C chilled water, 65 °C domestic hot water, or 43 °C heating water to meet the user's requirements. Characteristics such as temperature, concentration and power variation of the ATES system during charging and discharging processes were investigated. The performance of the ATES system for supplying cooling, heating or domestic hot water was analyzed and compared. The results indicate that the energy storage efficiencies (ESE) for cooling, domestic hot water and heating are 0.51, 0.97, 1.03, respectively, and the energy storage densities (ESD) for cooling, domestic hot water and heating reach 42, 88, 110 kW h/m^3, respectively. The performance is better than those of previous TES systems, which proves that the ATES system using $LiBr–H_2O$ may be a good option for thermal energy storage.

1. Introduction

There is an abundance of low-grade energy in the world, such as industrial waste heat or solar energy, which is usually supplied intermittently and randomly. Conversely, the cooling or heating load of buildings varies daily and seasonally. To supply cooling or heating with such low-grade and intermittent energy, mismatch on time and intensity between the supply and demand might be challenging. Thermal energy storage (TES) technology has been proven a good solution. The most studied and developed TES technologies are sensible heat storage (e.g., water and rock) and latent heat storage (e.g., ice) [1]. Sensible heat storage is easy to be implemented, but its energy storage density (ESD) is very low, approximately 2–30 kW h/m^3. Latent heat storage, using ice storage for example, has a higher ESD, but the coefficient of performance of the chiller during charging is relative low during to a lower evaporating temperature. In addition, there is a considerable cooling/heating loss for the sensible and latent heat storage in transition period.

Absorption thermal energy storage (ATES), which is based on the absorption phenomenon, was proposed due to its advantage in utilizing low-grade thermal energy and its minimal heating or cooling loss [2]. The principle of ATES is illustrated by the following formula [3] and Fig. 1:

$$AB(weak) + \Delta Q \underset{\text{Discharging}}{\overset{\text{Charging}}{\rightleftarrows}} AB(strong) + B(gas) \quad (1)$$

In the charging process as shown in Fig. 1(a), a heating source separates the refrigerant from the weak solution, which makes the solution stronger. The process can be driven by low temperature heat instead of electricity, which enables utilization of the solar energy [4,5], the waste heat from industrial processes and the heat from cogeneration/trigeneration. In the transition period as shown in Fig. 1(b), heat is stored in the form of thermochemical potential energy. The strong solution is separated from the refrigerant and no energy will be lost in this period. In the discharging process as shown in Fig. 1(c), a strong solution absorbs vapor from the evaporator, where the refrigeration effect is produced. The strong solution then becomes a weak solution and releases a significant amount of absorption heat. The process can produce heating in an absorber [6–8], cooling in an evaporator [4,5] or both of them concurrently, which could not be achieved by the other TES systems.

Because ATES is of great significance in improving energy storage performance and environmental protection due to application

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http://dx.doi.org/10.1016/j.enconman.2014.05.100
0196-8904/

Nomenclature

H	enthalpy (kJ/kg)
m	mass flow rate (kg/s)
M	mass (kg)
P	pressure (kPa)
q	heat transfer rate (kW)
Q	total heat transfer (kJ)
T	temperature (°C)
X	concentration of solution (%)
W	the power consumption (kJ)
V	volume (m^3)
η_{ele}	the primary energy efficiency
τ	time

Subscripts

a	absorber
c	condenser
e	evaporator
g	generator
i	in
loss	loss
o	out
p	pump
s	solution
v	vapor
w	water

Abbreviations

ATES	absorption thermal energy storage
C/E	condenser/evaporator
ESD	energy storage density (kW h/m^3)
ESE	energy storage efficiency
G/A	generator/absorber
TES	thermal energy storage

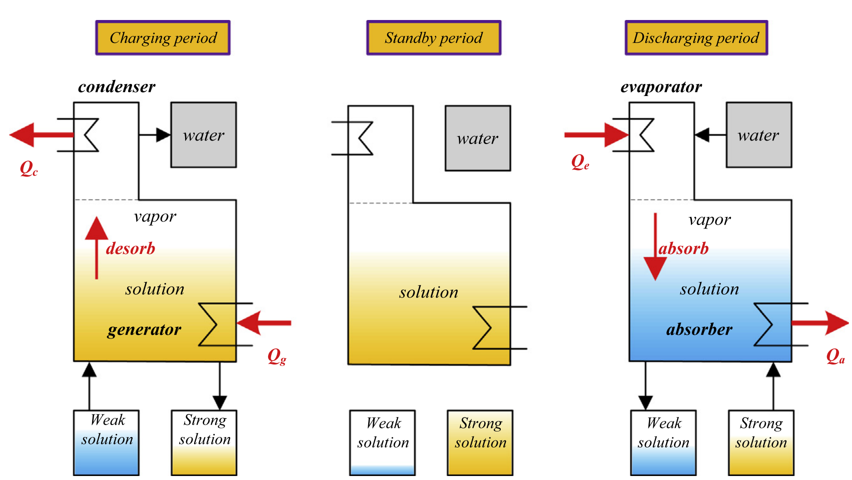
of the environment friendly refrigerant, such as water, it has received increased attention. Grassie and Sheridan proposed a solar driven absorption refrigeration system with refrigerant storage [9]. They added a solution tank and a refrigerant tank into the traditional absorption chiller, as shown in Fig. 2(a). Based on that, Kaushik et al. proposed a ATES system with three storage tanks (Fig. 2(b)) and compared it with the Grassie's two-tank system (Fig. 2(a)) [6]. The results showed that the system with two storage tanks has a higher ESD than the one with three tanks.

In order to reduce the cost and the volume of the system, the four heat exchangers configuration can be transferred into two heat exchangers configuration. That is, the generator and condenser in the charging process function as the absorber and evaporator, respectively, in the discharging process, as shown in Fig. 3. Compared with the four-heat-exchanger ATES system, the simplified two-heat-exchanger ATES system only operates in intermittent mode of charging and discharging. However, the ATES system is developed with aim to achieve intermittent energy storage and peak load shifting, so, in the most of the situations, the thermal energy storage system needs to work in intermittent mode. Moreover, the two-heat-exchanger ATES system is simpler and easier for research. And the principles found in it also can be used to evaluate the four-heat-exchanger ATES system, so a lot of studies have been conducted on the two-heat-exchanger ATES.

TCA (Thermo-Chemical Accumulator) carried out by SERC in Sweden is likely one of the most successful projects in the field of ATES [10–14]. It can store crystals of lithium chloride (LiCl) to improve the storage density. Experimental results showed that ESD can reach 54 kW h/m^3 for a cooling supply temperature of 12 °C and 85 kW h/m^3 for a heating supply temperature of 30 °C [13]. The technology also was commercialized [15]. However, the LiCl–H_2O's high price [16] has limited its application.

Hence, another prototype using a cheaper working pair containing sodium hydroxide (NaOH) was built in EMPA, Switzerland [17]. The experimentally achieved storage density was only 5 kW h/m^3 for heat storage, although the theoretical heat storage density of the NaOH solution is approximately 250 kW h/m^3 for supplying domestic hot water at approximately 65 °C [13]. In addition, its strong corrosion limits its application. As shown in Table 1 [18], when the mass fraction of NaOH–H_2O is 70% and temperature is 90–143 °C, the corrosion data for stainless steel 304 is 0.68 mm/year.

After comparing several working pairs [16], the LOCIE laboratory selected LiBr–H_2O as a storage media and developed a



(a) Charging period (b) Transition period (c) Discharging period

Fig. 1. Principle of absorption thermal energy storage (ATES) technology.