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Numerical simulation of an advanced energy storage system using H_2O–LiBr as working fluid, Part 1: System design and modeling

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Abstract

The advanced energy storage technology proposed and patented by authors can be applied for cooling, heating, dehumidifying, combined cooling and heating, and so on. It is also called the variable mass energy transformation and storage (VMETS) technology in which the masses in one or two storage tanks change continuously during the energy charging and discharging processes. This paper presents an advanced energy storage system using aqueous lithium bromide (H_2O–LiBr) as working fluid. As one of VMETS systems, this system is a closed system using two storage tanks. It is used to shift electrical load and store energy for cooling, heating or combined cooling and heating. It is environmental friendly because the water is used as refrigerant in the system. Its working principle and process of energy transformation and storage are totally different from those of the traditional thermal energy storage (TES) systems. The electric energy in off-peak time is mostly transformed into the chemical potential of the working fluid and stored in the system firstly. And then the potential is transformed into cold or heat energy by absorption refrigeration or heat pump mode when the consumers need the cold or heat energy. The key to the system is to regulate the chemical potential by controlling the absorbent (LiBr) mass fraction or concentration in the working fluid with respect to time. As a result, by using a solution storage tank and a water storage tank, the energy transformation and storage can be carried out at the desirable time to shift electric load efficiently. Since the concentration of the working solution in the VMETS cycle varies continuously, the working process of the VMETS system is dynamic. As the first part of our study, the working principle and flow of the VMETS system were introduced first, and then the system dynamic models were developed. To investigate the system characteristics and performances under full-storage and partial-storage strategies, the numerical simulation will be performed in the subsequent paper. The simulation results will be very helpful for guiding the actual system and device design.

Keywords: Absorption system; Water-lithium bromide; Design; Modeling; Thermal storage; Energy storage

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Simulation numérique d'un système d'accumulation thermique de pointe employant le H_2O-LiBr en tant que fluide actif. Partie 1: Conception et modélisation du système

Mots clés : Système à absorption ; Eau-bromure de lithium ; Conception ; Modélisation ; Accumulation thermique ; Stockage d'énergie

Nomenclature

c_p	specific heat capacity (kJ kg^{-1} °C^{-1})
E	energy (kWh)
f	solution circulation ratio (kg kg^{-1})
h	specific enthalpy (kJ kg^{-1})
$\dot{m}$	mass flow rate (kg s^{-1})
m, M	mass (kg)
m_1	mass sprayed into the moistener (kg)
N	power (kW)
Q	thermal energy or heat (kWh)
$\dot{Q}$	heat power or heat transfer rate (kW)
s	specific entropy (kJ kg^{-1} K^{-1})
SD	energy storage density (kWh m^{-3})
t	time in the energy charging period (h)
T	temperature (°C or K)
W	work (kWh)
x	vapor quality of vapor–water mixture (kg kg^{-1})
Greeks	
η	efficiency (%)
ξ	LiBr mass fraction or mass concentration in working solution (kg kg^{-1})
ρ	density (kg m^{-3})
τ	time in the discharging period (h)

Subscripts	
1–13	status points in Fig. 1
ab	absorption or absorber
am	ambient
c	cooling
cw	cooling water
comp	compression or compressor
cond	condensation or condenser
e	evaporation or evaporator
ex	heat exchanger
g	generation or generator
h	heating
i	into
int	integrated
is	isentropic
o	out
pump	solution pump
re	recycle pump
stor	solution in its storage tank
w	water
ws	water in its storage tank
wv	water vapor

1. Introduction

With the fast economic expanding, the electricity demand for air-conditioning in China has been increasing at a high speed for recent decades [1]. The rapid growth of the electricity demand has contributed a significant impact to the fossil energy resources due to electricity generation and caused inevitable environmental problem. It has also caused the sharp variation of the diurnal electricity load and resulted in the decrease of the electricity supply-side efficiency. Thermal energy storage (TES) technologies can efficiently reduce the electricity demand in on-peak hours as well as the costs for initial equipment and operation of air-conditioning system [2,3]. Therefore, they have been utilized as a demand-side management (DSM) strategy to shift electricity use associated with cooling from on-peak periods to off-peak periods [4,5]. Traditionally, there are three types of TES technologies, namely sensible, latent and thermochemical technologies [6–9]. These technologies have a common characteristic that is to directly transform electricity into thermal energy and then store it. But this characteristic also restricts its application fields because it is difficult to meet both cooling and heating requirements.

Now we proposed and patented an advanced energy storage technology that is called the variable mass energy transformation and storage (VMETS) technology [10,11]. The VMETS technology can meet energy storage for cooling, heating and dehumidifying demands in heating, ventilation and air-conditioning (HVAC) engineering [12]. The VMETS technology firstly transforms the electricity into the chemical potential of the working fluid by changing the absorbent mass fraction or concentration of working fluid in its storage tank. When cooling, heating or dehumidifying is needed, the chemical potential stored in the working solution tank can then be transformed into cold or heat energy by means of absorption refrigeration or heat pump mode, or into