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Experimental investigation on energy and exergy performance of adsorption cold storage for space cooling application

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ABSTRACT

The adsorption cold thermal energy storage (TES) system was investigated for space cooling application by considering both energy and exergy analysis. With regeneration temperature of 70 °C, ambient temperature of 30 °C, heat transfer fluid (HTF) inlet temperature for evaporator 30 °C, the cold energy storage density (ESD) achieved was approximately 400 kJ kg^{-1} with energy efficiency of 44.6%. In addition, the exergy efficiency was 4.5%, and the loading difference was 0.165 (adsorbate/adsorbent). As the HTF mass flow rate of the evaporator was decreased, the evaporator HTF outlet temperature decreased, and the exergy efficiency increased. As the evaporator HTF inlet temperature and the regeneration temperature were increased, the cold ESD, cold thermal efficiency and cold exergy destruction all increased. As the adsorption HTF inlet temperature was decreased, the cold ESD, and recovered exergy increased. The evaporator chamber HTF inlet temperature affected more on energy and exergy performances than that of the evaporator chamber HTF mass flow rate.

Etude expérimentale de la performance énergétique et exergétique sur l'entreposage frigorifique à adsorption pour les applications de refroidissement des espaces

Mots clés : Accumulation d'énergie thermique ; Adsorption ; Exergie ; Echangeur de chaleur à ailettes ; Densité de l'énergie accumulée ; Efficacité

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Nomenclature

Abbreviations

CHP	combined heat and power
DAQ	data acquisition
ESD	energy storage density
HTC	heat transfer coefficient
HTF	heat transfer fluid
HX	heat exchanger
OD	outer diameter [mm]
P	pressure [kPa *or* bar]
Q	accumulated energy [kJ]
$\dot{Q}$	heat transfer rate [kW]
T	temperature [°C]
TES	thermal energy storage
Z01	Mitsubishi Plastics AQSOA FAM-Z01 zeolite

Greek Symbols

s	entropy [kJ kg^{-1} K^{-1}]
ρ	density [kg m^{-3}]
h	enthalpy [kJ kg^{-1}]
Δ	change *or* difference
ε	exergy efficiency
η	energy efficiency
x	loading

Subscripts

ads	adsorption
cond	condenser
des	desorption
evap	evaporator
in	inlet to a component
out	outlet of a system *or* outlet of a component

1. Introduction

Thermal energy storage (TES) technologies can reduce or eliminate the peak electric power loads in buildings, and utilize benefits of waste heat recovery and renewable energy (Li et al., 2012; Li et al., 2013a). There are three typical TES technologies: sensible, latent and sorption TES. The sensible TES technology has been developed well and has already been proven to be feasible for large-scale district heating/cooling demands. However, it usually has the requirement of a larger storage volume due to its low energy storage density. In contrast, the latent TES technology has a higher storage density with a much smaller temperature change. However, the latent materials usually have the issues of the phase separation, large degree of supercooling, low thermal conductivity, corrosion, etc., which hinder their practical application. In addition, the latent materials can only be applied at specific temperature level as their phase transition temperatures are definite. To solve these challenges of the sensible and latent TES technologies, sorption TES technologies, especially adsorption technologies, have been developed. Adsorption is the general phenomenon resulting from the interaction between a solid (adsorbent) and a gas (refrigerant), based on a reversible physical or chemical reaction process. In general, the energy storage density (ESD) of adsorption materials is higher than that of other TES materials in theory (N'Tsoukpoe et al., 2009). Different from the latent TES technology, the input and output temperature levels of the adsorption TES can be determined by practical demand and operating conditions, exhibiting some extent of flexibility. In addition, different from sensible and latent heat, adsorption heat can be stored for a long time without causing pollution and with less energy losses.

Regarding the adsorption TES, currently there are only limited researches conducted with low-grade heat source lower than 80 °C. A study by Lu et al. (2003) investigated a closed adsorption cold storage system with a water/zeolite 13X as a working pair for locomotive air conditioning applications, and the experimental cold storage capacity was 5.5 kWh with 140 kg of 13X zeolite grains (i.e. ESD was approximately 141 kJ kg^{-1}). However, the heat source was exhaust gas from the locomotive with temperature as high as 350 °C. Another study by ZAE Bayern investigated using water/zeolite 13X to heat a school building in winter and to cool a jazz club in summer (Hauer, 2002). The heat source temperature was 130~180 °C. Results showed that material-based storage densities were 124 kWh m^{-3} for heating and 100 kWh m^{-3} for cooling, respectively. The water/zeolite 13X was also studied for the closed adsorption TES by Institut für Solartechnik SPF from Switzerland with heat source temperature of 180 °C (Bales, 2007). Another working pair H_2O/silica gel was investigated for the closed adsorption storage within the framework of the EU-project MODESTORE (Bales, 2007). The silica gel used in this prototype was microporous silica gel Grace 127B. The storage capacity was 13 kWh with heat source temperature at around 90 °C. In addition, to reduce the heat source temperature, one study by Li et al. (2013b) proposed dual-mode thermochemical sorption energy storage system with thermodynamic analysis, and heat input temperature can be decreased from original 99 °C–81 °C by employing the two-stage regeneration method. As discussed, there is not much research conducted with low-grade heat source below 80 °C, and there is a lack of extensive studies for the adsorption cold storage under various operating conditions.

The performance assessment of TES units requires a sound and comprehensive knowledge on their thermal behavior. The energy efficiency of a TES system, the ratio of the energy recovered from storage to that originally provided, was conventionally used to measure the TES performance. However, the energy analysis does not take into account all the considerations necessary in the TES evaluation. For an example, it does not evaluate how close the system performance approaches to the ideal storage performance. Exergy analysis can overcome many shortcomings of energy analysis and could play a major role in the TES performance assessment. Reasonable energy and exergy analysis for the storage system performance evaluation can achieve an optimized