available at www.sciencedirect.com

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

Study on medium-temperature chemical heat storage using mixed hydroxides

Yukitaka Kato, Rui Takahashi, Toshiya Sekiguchi, Junichi Ryu*

Research Laboratory for Nuclear Reactors, Tokyo Institute of Technology, 2-12-1-N1-22, Ookayama, Meguro-ku, Tokyo 152-8550, Japan

ARTICLE INFO

Article history:
Received 6 November 2008
Received in revised form
23 January 2009
Accepted 27 January 2009
Published online 7 February 2009

Keywords:
Thermal storage
Chemical material
Hydroxide
Magnesium
Nickel
Experiment
Heat transfer
Reactor

ABSTRACT

It was demonstrated that chemical heat storage materials mixed with metal hydroxides were capable of storing heat at medium temperatures of approximately 200–300 °C. The performances of the developed materials were demonstrated in a thermo-balance and-packed bed reactor. The mixed hydroxides can increase the operation heat storage temperature by changing the composition of mixed metal oxides in the material. $Mg_{\alpha}Ni_{1-\alpha}(OH)_2$, which is a mixed hydroxide of magnesium hydroxide, $Mg(OH)_2$, and nickel hydroxide, $Ni(OH)_2$, is a candidate heat storage material. The mixed hydroxide was dehydrated, that is, it was capable of storing heats at 200–300 °C, at which pure $Mg(OH)_2$ could not be dehydrated and could not store heat. The heat output performance of the material was examined in a packed bed reactor. It was shown that the mixed hydroxide material was potentially useful for chemically storing medium-temperature heat such as waste heats emitted from internal combustion engines, solar energy system and high-temperature processes.

Etude sur l'accumulation thermique chimique à température modérée à l'aide de plusieurs hydroxydes

Mots clés : Accumulation thermique ; Produit chimique ; Hydroxyde ; Magnésium ; Nickel ; Expérimentation ; Transfert de chaleur ; Réacteur

1. Introduction

Significant amounts of medium-temperature (200–300 °C) waste heat are emitted from high-temperature processes. However, storage methods for medium-temperature heat remain limited. The use of medium-temperature waste heat could be sufficiently effective to reduce carbon dioxide emission and energy cost (Ministry of Economy, Trade and Industry of Japan, 2006). In the present paper, a hybrid system that combines a medium-temperature heat storage system

* *Corresponding author*. Tel./fax: +81 3 5734 2967.
E-mail address: yukitaka@nr.titech.ac.jp (Y. Kato).

0140-7007/$ – see front matter
doi:10.1016/j.ijrefrig.2009.01.032

Nomenclature

P_0	standard pressure (Pa)
P_{H_2O}	water vapor pressure of reaction (Pa)
R	gas constant ($J\,mol^{-1}\,K^{-1}$)
T	temperature (K)
t_h	hydration time (min)
x	reacted fraction (–)

Greek symbols

α	molar fraction of magnesium ion to total metal ion in mixed hydroxide.
ΔG	Gibb's free energy change of a reaction ($J\,mol^{-1}$)
ΔS	entropy change of a reaction ($J\,mol^{-1}\,K^{-1}$)
Δx_h	amount of reacted fraction at hydration (–)

Subscripts

b	packed reactor bed

and a high-temperature process is proposed for enhancement of the primary energy utilization efficiency. In order to realize the proposed hybrid system, an efficient heat storage function is needed for recovery of medium-temperature waste heat.

A chemical heat pump uses chemical reactions for heat storage and transformation operations. The chemical heat pump is useful for heat storage because of its relatively high heat storage density and long-term heat storage ability. By selecting appropriate chemical reactions, the heat pump may be applicable for heat storage sources at medium temperature (200–300 °C) in the hybrid system. Possible medium-temperature processes include not only internal combustion engines (ICE) but also cogeneration engines, solar heat systems, fuel cells, and high-temperature industrial processes. A hybrid system that combines such a medium-temperature chemical heat pump and a heat management system may be able to realize efficient load leveling of the processes by the utilization of waste heat.

However, chemical heat pumps for medium-temperature heat are few. The ability of a chemical heat pump is regulated by the chemical reaction used in the heat pump. Therefore, reaction candidates for the chemical heat pump were first surveyed, and a number of chemical mixed hydroxide materials were developed based on this survey. The applicability of these materials for the chemical heat pump is discussed in the present study.

2. Proposal of a hybrid system with a chemical heat pump and a high-temperature process

Waste heat recovery from high-temperature processes have been well established for heat at over 400 °C by steam and gas turbines and at less than 100 °C by sensible and latent heat storage technologies. On the other hand, medium-temperature heat at 200–300 °C has not been efficiently utilized. Efficient utilization of medium-temperature heat would allow improved energy efficiency of high-temperature processes. Motor vehicles are important high-temperature systems because global vehicle production continues to increase. Carbon dioxide emission due to vehicle usage has a significant impact on global warming. The enthalpy conversion efficiency from fuel to driving work in vehicles is approximately 20% and the remaining 80% of fuel enthalpy is emitted as exhaust heat (Suzuki, 2005).

Although significant efforts have been made to improve engine efficiency for axial output, the efficiency has already approached the mechanical limitation. On the other hand, there is room for improvement of the energy efficiency of vehicles by utilizing excess heat emitted as exhaust gas from the muffler and heat exchanged air from the radiator. Heat storage of waste heat is possible by using sensible and latent heat storage. However, from the standpoint of heat quality (exergy) recovery, these storage methods are insufficient for the storage of medium-temperature heat because of upper limitation of heat storage temperature and temporal diffusivity of stored heat.

Medium-temperature heat recovery is important for not only vehicles, but also for solar energy systems, fuel cells, and high-temperature processes. For practical heat processes, the influence of instable thermal operations on the reduction of total energy efficiency is not negligible. A solar energy system, for example, has frequent thermal operation changes between start, solar energy conversion and stop. The instability of the solar process is obvious problem to stable and efficient solar energy utilization. For a practical cogeneration engine, mismatch between heat output from the engine and heat demand generates significant waste heat that is dumped into the atmosphere. Then, a waste heat storage function for medium-temperature heat becomes important for efficient operation of high-temperature processes.

An electric hybrid system (EHS), which combines an internal combustion engine (ICE) with an electrical battery and a power controller as shown in Fig. 1, has good energy saving performance. Upon braking, the EHS kinetically converts surplus work into electricity, which is stored in the electrical battery. The stored electricity is used to start the vehicle or to

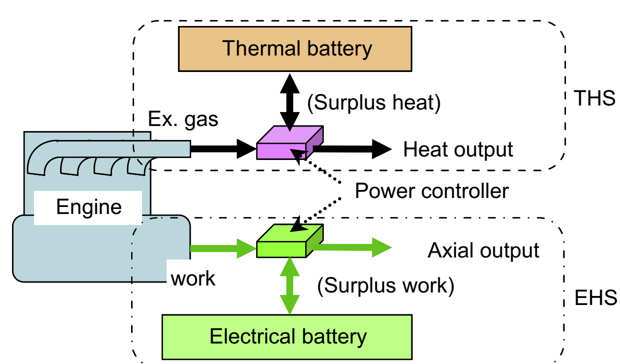

Fig. 1 – Thermal hybrid system (THS) combined with a medium-temperature chemical heat pump and a high-temperature exhaust gas from ICE, in comparison with the electric hybrid system (EHS) currently employed in some hybrid vehicles.