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Comparison of magnesium hydroxide/expanded Graphite composites for thermal energy storage in cogeneration nuclear power plants

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Abstract

Thermal energy storage via reversible chemical reactions is proposed for the assisting cogeneration in nuclear power plants (NPP) for district heating or middle-temperature industrial processes. Thermal energy at 350-400°C from NPP can be stored or released by operating reversible dehydration of magnesium hydroxide ($Mg(OH)_2$) and the hydration of magnesium oxide (MgO). The packed beds can be transported to a different site for reutilization of heat. Expanded graphite (EG) was utilized as thermal conductivity enhancer for $Mg(OH)_2$ and MgO. Composites of $Mg(OH)_2$ and EG, named EM8 and EM4, were obtained by mixing $Mg(OH)_2$ to EG with different mass mixing ratio [g of $Mg(OH)_2$: g of EG], respectively 8:1 and 4:1. EM8 and EM4 were compressed in figure of tablets (diameter of 10 mm, thickness 6 mm). Heat storage/output experiments were conducted on a packed bed reactor (diameter 48 mm, height 48 mm). Dehydration in a packed bed of EM4 tablets resulted faster than in a bed of EM8 ones, but a larger amount of thermal energy could be stored in the EM8 packed bed (in 60 min, 467 MJ m_{bed}^{-3} for EM8 bed, 379 MJ m_{bed}^{-3} for EM4 bed). The effect of thermal conductivity enhancement was investigated numerically. Finally, the volumes of packed beds of EM8 and EM4 tablets required for thermal energy storage from a nuclear power plant were estimated.

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1. Introduction

Thermo-chemical energy storage is a key technology for efficient utilization of heat. It can be applied for the recovery of waste heat from industrial processes and then re-used heat on demand. Especially, it is possible to store heat in one place and, by transportation, to re-utilize it on a different site [1]. Such a technology would be applicable for a better utilization of heat from nuclear power plants (NPP): for instance, when the demand of electricity is low, steam can by-pass the turbine-generator and the enthalpy drop is used to accomplish the chemical reaction (heat storage) rather than be converted into electricity. The reacted materials in the packed bed, contained in suitable heat storage units, can then be transported to a different place to accomplish the heat output reaction, making it possible to re-utilize heat. This would be particularly convenient in case heat has to be used for cogeneration purpose (district heating or other industrial processes). As the NPP are usually placed remotely from the city center where district heating is utilized, the transportation of heat storage units from plant would make it possible to avoid the construction of long piping infrastructure for connection of the plant to the city center. Similarly, in case heat is used for industrial process [2]. Once used, the heat storage units would be re-transported back to the NPP for a new heat charging cycle. The packed beds contained into the heat storage units have to store large amount of heat per unit volume but also they should be able to release heat at a fast rate, in order to satisfy peaks of demand.

In this work, a comparison between two different composites of magnesium hydroxide ($Mg(OH)_2$) and expended graphite (EG), named EM8 and EM4, is presented. EM8 and EM4 were obtained by mixing $Mg(OH)_2$ powder EG for achieving a high thermal conductivity material for packed bed reactors. Thermal conductivity enhancement was in fact successful for accelerating the chemical reactions [3]. However, the random arrangement of the EM tablets did not allow achieving high values of volumetric heat storage capacity. Piles of EM tablets can be considered an optimal compromise of high thermal conductivity and water vapor distribution in the packed bed. It is therefore necessary to compare the EM8 and EM4 in function of the arrangement in the packed bed reactor. The EM composite was compressed in figure of tablets (ϕ=10mm, h=6 mm, which were arranged in piles into the cylindrical chemical reactor. Dehydration and hydration reaction performances were compared. Thermal conductivity of piled tablets was measured using a thermal conductivity meter. The results of experiments were also analyzed numerically for understanding the effect of thermal conductivity enhancement. Finally, supported by the results of the dehydration experiments, the volumes of EM8 and EM4 required for heat storage in NPP were estimated.

Nomenclature

EG	expanded graphite
EM	composite material (Expanded graphite mixed with Magnesium hydroxide)
EM4	composite material (Expanded graphite mixed with Magnesium hydroxide) with r_{mix} 4:1
EM8	composite material (Expanded graphite mixed with Magnesium hydroxide) with r_{mix} 8:1
M:	molecular weight [g mol^{-1}]
m:	initial charged material weight [g]
$Mg(OH)_2$	magnesium hydroxide
P:	pressure [kPa]
q_d:	heat storage capacity from dehydration, per unit volume of packed bed [MJ m_{bed}^{-3}]
q_h:	gross heat output of hydration, per unit volume of packed bed [MJ m_{bed}^{-3}]
T:	temperature [°C]
t:	reaction time [s]
x:	reacted fraction [-]
z:	height [m]
α:	heat transfer coefficient [W m^{-2}K^{-1}]
ΔH_r:	standard enthalpy change of reaction [J mol^{-1}]
Δm:	weight change of reactor [g]