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Characterization of granular phase change materials for thermal energy storage applications in fluidized beds

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HIGHLIGHTS

- Granular PCMs are tested in 3D and 2D fluidized beds.
- Density, particle size and angle of repose were measured for different granular PCMs.
- DSC measurements confirm that there is no loss of material after fluidization.

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ABSTRACT

This work investigates commercially available granular phase change materials (PCMs) with different transition temperatures for the use of thermal-energy storage systems in fluidized beds. The hydrodynamic characteristics of granular PCMs were tested in cylindrical-3D and planar-2D fluidized beds. The density, particle size distribution and angle of repose were measured for various PCM materials. Further attrition studies were conducted with changes in particle surface from abrasion, which were characterized using a Scanning Electron Microscope (SEM). The results indicate that some materials with smaller particle size and thinner supporting structure can lose the paraffin during the fluidization process, when paraffin is in a liquid state. As a consequence, the particles agglomerate, and the bed defluidizes. For all of the tested materials, only GR50 (with a transition temperature of 50 °C) properly fluidizes when the paraffin is in the liquid state and has shown to endure >75 h of continuous operation and 15 melting-solidification cycles in a fluidized bed. Additional differential scanning calorimetry (DSC) measurements of the cycled particles did not show a decrease in energy storage capacity of the granular PCM, which corroborates that there is no loss of material after >75 h of fluidization.

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1. Introduction

To satisfy the global energy demand, thermal energy storage (TES) is a promising technique to complement the variability in renewable energy supplies and increase the market demand [1]. In this context, phase change materials (PCMs), which use latent heat storage, are an attractive alternative to sensible heat materials in either shell-and-tube storage systems [2] or dual-media (solid particles-fluid) energy storage tanks because they provide high storage density [3]. In this case, the PCM is encased in capsules of different geometries and sizes. The advantage of the encapsulation is its applicability for both liquid and air as heat transfer fluids because they are easily handled and maintain their macroscopic solid state during the solid-liquid transition. Encapsulated PCMs in small particles (micro-encapsulation) have high heat transfer area between the particles and the heat transfer fluid.

In the literature, there are studies of packed beds of macro-encapsulated spheres of PCM with diameters of a few centimeters and water as the heat transfer fluid [4,5]. In addition to these bound PCMs, granular phase-changing composites with small particle diameters (1–3 mm) have been tested in latent heat thermal-storage packed beds [6,7] using air as the heat transfer fluid and in combination with a compressed-air energy storage system [8].

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Nomenclature

AOR	angle of repose [°]
d_p	mean particle size [mm]
DSC	Differential Scanning Calorimetry
EDS	Energy Dispersive Spectroscopy
PCM	Phase Change Material
PSD	Particle Size Distribution
SEM	Scanning Electron Microscope
T	temperature [°C]
T_{pcm}	transition temperature of the granular PCM [°C]
T_{peak}	peak temperature [°C]
U	superficial gas velocity [m/s]
$\dot{V}$	volumetric flow rate [l/min]
z	axial coordinate in the bed [cm]

Greek symbols

ΔH	enthalpy change [J/kg]
ρ	density [kg/m^3]
σ	standard deviation

Subscripts

fus	fusion
in	inlet conditions
mf	at minimum fluidization conditions
sol	solidification

Pitié et al. [9] also studied the potential use of granular PCMs in a high-temperature (500–750 °C) circulating fluidized bed. They concluded that the PCM would help to reduce the temperature in the tubes and circulation rate of the particles, although granular materials for such high temperatures remain to be developed and manufactured.

Previously, we have published different works on granular phase change materials for low-temperature storage applications in bubbling fluidized beds [7,10–12], as an alternative to the traditional packed beds. The authors have observed that a fluidized bed of granular PCM has higher charging efficiencies during the charging process than a fluidized bed of sand or a packed bed of the identical granular material. The heat transfer coefficient between the particles and a heated surface, which is immersed in the bed, is also notably augmented in a fluidized bed with granular PCM because of the latent heat of the particles, when the bed works at approximately the transition temperature of the PCM. In all previous works, the authors used the same commercial product available from Rubitherm: "*GR bound PCM*", which consists of an inorganic matrix in which the PCM is adsorbed and rigidly bounded irrespective of whether the PCM is solid or liquid form. Different paraffins can be used as PCM in the granular material, depending on the transition temperature desired. In our case, we used the material GR50 with a transition temperature of approximately 50 °C. This material was properly fluidized at temperatures below and above this transition temperature and did not present agglomeration problems. Although it suffered some attrition after 75 h of continuous operation with 15 charging-discharging cycles, no evidence of loss of PCM was observed.

In the present work, we tested the same commercial product, "*GR bound PCM*" from Rubitherm, but commercialized with different phase change temperatures: GR42 and GR80, with transition temperatures of approximately 42 °C and 80 °C, respectively. The first experimental observations showed that GR42 and GR80 did not properly fluidized at temperatures above the transition temperature: the particles agglomerated, and the bed was defluidized.

To understand the agglomeration behavior of various granular phase-changing composites, where two of three materials have

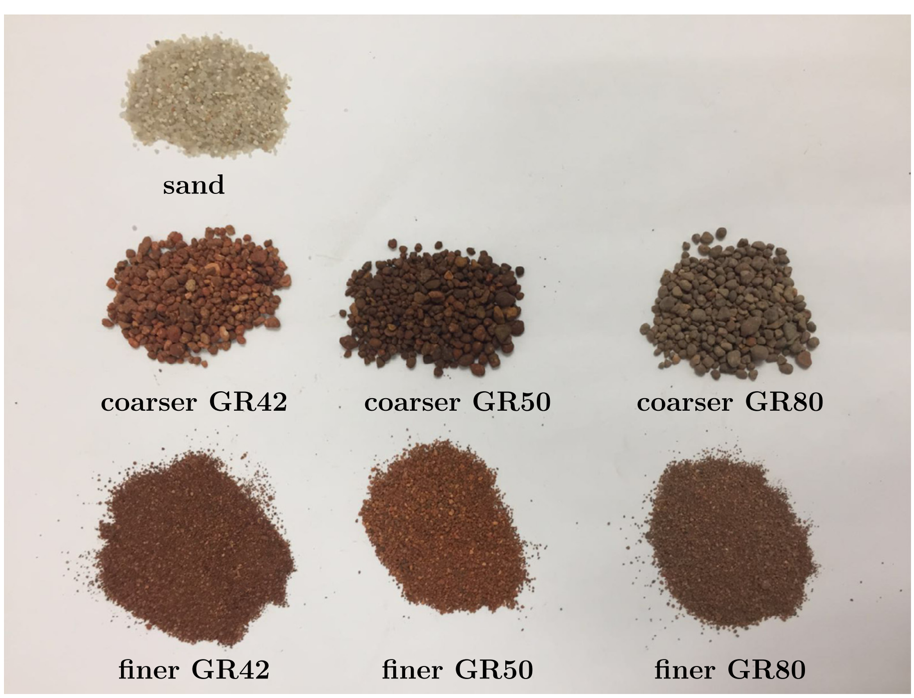

Fig. 1. Images of different granular PCMs that are used for sensible heat storage, and silica sand is also shown as a reference.

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