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Investigation of a graphite/paraffin phase change composite

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ABSTRACT

Latent heat thermal storage of graphite/PCM composite was investigated numerically and experimentally. Graphite, as a highly-conductive, is an excellent candidate for forming thermal energy storage composites with improved effective thermal conductivity. For numerical simulation, the graphite/paraffin composite was modeled as a two dimensional system. Three modes of graphite addition were analyzed. Graphite was added as fibers, as fins or as foam. For every case, the thermal heat storage/release cycle is evaluated versus different graphite mass fraction. For experimental verification, the effective thermal conductivity of graphite/paraffin composites was measured using an electrothermal sensor based on a Wheatstone bridge. The results indicate a noticeable improvement in the effective thermal conductivity of composites compared to the PCM. The latent heat is measured using the differential scanning calorimeter (DSC). Our results are consistent with reported literature results.

1. Introduction

The production and consumption of energy contribute to the change in thermal equilibrium at the surface of the earth by producing greenhouse gas emissions. One of the major challenges facing our society is the management of our natural resources without causing depletion without altering the environment of the planet. Therefore, reducing consumption is the most effective way not only to save energy but also to reduce pollution. Indeed, the limited reserves of fossil fuels and the increase of the use of energy are the main driving forces behind efforts to search a new and renewable energy.

During these years, scientists from all over the world are in search of an efficient and economical technology that can be used to save energy. One of these technologies, the thermal energy storage (TES) is a technique with a high potential for different thermal applications. It is well known that TES could be the most appropriate way and method to correct the gap between the demand and supply of energy and therefore it has become a very attractive technology, used in different areas, such as building heating/cooling systems and solar energy collector's power [1–10]. Three major methods for thermal storage are currently considered: sensible heat, latent heat and thermochemical heat. The latent thermal energy storage method uses phase change materials (PCM), which store heat when they go from solid to liquid, from liquid to gas or from solid to solid. Then they release energy when they have the reverse phase change. It must be mentioned that, until now the PCM studies and applications have been mainly focused on the solid–liquid phase change because of its important enthalpy variation and simultaneous weak volume variation unlike solid–gas or liquid–gas [11]. These systems are used in order to store thermal energy for a period while the supply is sufficient or cheaper, to be discharged when the supply becomes insufficient or expensive. In some applications, the thermal energy must be absorbed or released at a very fast rate. However, most phase change materials have a low thermal conductivity [12,13]. Various methods have been investigated for increasing the thermal conductivity of PCMs. These techniques include dispersing high conductivity particles within the PCM, inserting a metallic matrix, adding chunks of metal tubing into the PCM and impregnating a porous graphite matrix with PCM [14–23]. The most promising of these methods was the graphite matrix due to its high thermal conductivity and its mechanical properties.

Although some studies have been developed to investigate the heat storage through graphite/PCM composites, few detailed information on the heat storage rate and storage efficiency of these materials are known. This paper aims to investigate a numerical and experimental study of graphite/PCM latent heat thermal

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Nomenclature

C_p	heat capacity, J kg^{-1} K^{-1}
h	heat transfer coefficient, W m^{-2} K^{-1}
H	total volumetric enthalpy of the PCM, J m^{-3}
q	density of heat flow, W m^{-2}
p	static pressure Pa
L	latent heat of the PCM, J kg^{-1}
t	time, s
T	temperature, K
x,y	space coordinate, m
u	velocity, m s^{-1}

Greek symbols

ρ	density, kg m^{-3}
λ	thermal conductivity, W/m K
β	liquid fraction
τ	stress tensor

energy storage composites. The influences of the amount of graphite and its nature (fibers, fins, and foams) on the heat storage and the heat release are investigated. The heat storage/release properties were analyzed by comparing the temperature variation during storage and release phases as function of the nature of the added graphite and graphite mass fraction. Experimentally, graphite/PCM composites are elaborated using two different methods. Their thermal conductivity is measured by an electro-thermal sensor based on a Wheatstone bridge. The latent heat of composites is measured using the Differential scanning calorimetry method (DSC). The obtained results show a decrease of the latent heat versus the graphite mass fraction.

2. Experimental

2.1. Graphite/paraffin composite elaboration

For this study, two different methods have been used for the elaboration of graphite/PCM composites: The first method involves the dispersion of graphite in the PCM. This is achieved above the melting temperature by mechanical dispersion within the molten PCM. In this case, the stirring rate is of great importance to obtain a homogeneous dispersion and avoid a local concentration of the graphite. Above the melting temperature, the obtained composite can be poured into a stainless steel mould to obtain a desired external shape.

The second method is based on the cold uni-axial compression, in which paraffin powders and graphite particles are mixed together, and then the obtained mixture (paraffin + graphite) is poured into a stainless steel mould followed by an uni-axial compression (80 bar) at ambient temperature. A series of graphite/paraffin composite PCMs with different mass fractions of graphite and paraffin were prepared. The used graphite is an industrial graphite "graphite waste". It was obtained from damaged Tubular graphite Heat Exchangers. It is a form of carbon with crystalline structure; it has good thermal and mass transfer characteristics that have led to its use for thermal conductivity enhancement. The average size of graphite particles is about 85 μm. Moreover, graphite has strong resistance to corrosion and chemical attacks, which makes it compatible with most PCM. The recycling of graphite has a lot of benefits, it can preserve natural resources of graphite for future generations i.e. recycling graphite reduces the need for raw materials; it also uses less energy, and it have economic benefits. The thermal properties of the used graphite are: thermal conductivity $\lambda = 23$ W/m K, density $\rho = 1936$ kg/m^3 and specific heat Cp = 650 J/kg K. Fig. 1 presents examples of elaborated composites.

2.2. Thermal conductivity measurement

The thermal conductivity of the elaborated composites is measured using the experimental setup illustrated in Fig. 2 and constituted by an electrothermal sensor sandwiched between two composites graphite/paraffin. The sensor is connected with a current generator and an Agilent acquisition card. The recorded signal from the output of the Agilent card is transferred to a computer using the RS 232 serial interface. The sensor is based on a Wheatstone bridge. As long as the sample temperature is uniform, the bridge is inherently balanced. A constant current is passed through the bridge to heat the resistances, thus resulting in unbalancing the bridge due to the hot-wire's temperature and therefore resistance change. The bridge input V_{in} and output V_{out} voltages are measured using a computerized data acquisition system (Agilent card). The bridge voltage output and time are measured and stored simultaneously. Post-processing of the acquired data is then performed in order to calculate the resistance change, temperature change and then thermal conductivity of the test sample.

The thermal conductivity is deduced from the expression as follow:

$$\lambda = \frac{q \cdot \mathrm{Ln}(t_{i+1}/t_i)}{4\pi \cdot d(\Delta T_{\max})} \cdot x \tag{1}$$

where q is the heated flux and x is the slope of the experimental signal.

The intensification of the thermal conductivity is given by:

$$I = \frac{\lambda_{\text{composite}} - \lambda_{\text{paraffin}}}{\lambda_{\text{paraffin}}} \tag{2}$$

The composites graphite/paraffin with different mass fraction (5%, 10%, 15%, and 20%) were elaborated using the two different methods cited above. For each sample different measures are effectuated and a mean value of thermal conductivity is calculated.

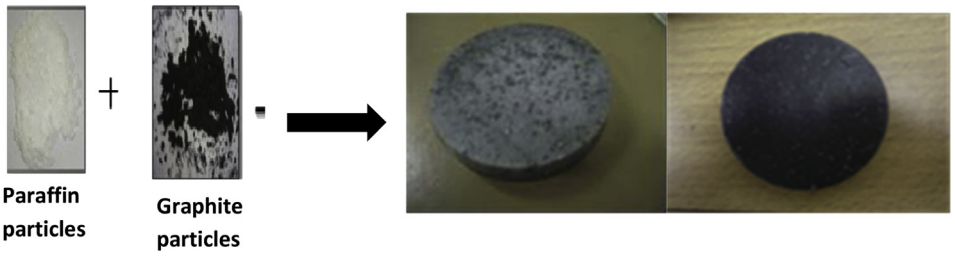

Fig. 1. Example of graphite/PCM composite samples elaborated by uni-axial compression and dispersion methods.