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The connection between the heat storage capability of PCM as a material property and their performance in real scale applications

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ABSTRACT

Using phase change materials (PCM) for Thermal Energy Storage, the most important material property is their heat storage capability, usually given as h(T). Ideally, h(T) changes suddenly at a single temperature. However, many PCM change phase in a temperature range and show hysteresis. In addition, experience shows that even measurements with the same device on the same material can give different results when the heating rate, the amount of sample mass or the equipment device are varied. The question thus arises how to deal with different h(T) results when trying to predict the performance of a real scale application. This paper identifies the main origins of these effects and gives strategies for dealing with them.

1. Introduction

The accurate knowledge of material properties to predict the performance of an application is a common problem in R&D. Using Phase Change Materials (PCM) for Thermal Energy Storage (TES), the most important material property is the heat storage capability, usually given as the enthalpy h as a function of temperature T (Fig. 1).

In an idealized case, the enthalpy changes suddenly at a phase change temperature. The heat stored is then called latent heat, while heat stored with a temperature change is called sensible heat. The latter is described by the heat capacity c (thus, the term heat storage capability is used here to refer to heat storage in general). However, many PCM change phase in a temperature range and this must be taken into account when applying such PCM in a real application.

In addition, heating and cooling processes often show different thermal behaviour, called hysteresis (Fig. 2). This includes subcooling, which means that for the material to change to the lower temperature phase (in a solid-liquid phase change the solid phase), a certain temperature lower than the phase change temperature has to be reached to start the phase change. At this temperature, the nucleation temperature T_{nuc}, a small nucleus of the lower temperature phase forms.

Subcooling is very common when using the phase change between solid and liquid. In addition to these effects, experience shows that even measurements with the same device on the same material can give different results for h(T) [1]. The question thus arises how to deal with different h(T) results when trying to predict the performance of an application. The topic of this paper is to review and investigate these effects and to give strategies for dealing with them.

2. Basics

The performance of real scale applications is commonly derived from the behaviour of the materials they are composed of, which are described by their material properties. A material (or substance) is what things are made of. As such, a material is composed of many atoms in a defined consistency, in a homogeneous or heterogeneous way. Objects consist of a single or several materials, in a certain amount, size, shape, etc. A material property is a property that is characteristic for the material, and therefore depends on the material by its composition, but not on amount, size, and shape. Examples are the density of a material, its thermal conductivity, melting point, etc. Material properties in general depend on boundary conditions like temperature, pressure, etc.

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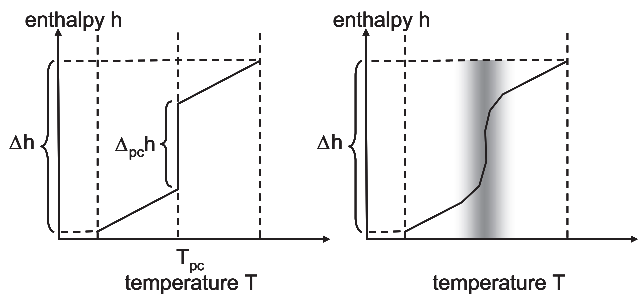

Fig. 1. Enthalpy h as a function of temperature T for the case of a phase change temperature and a phase change temperature range.

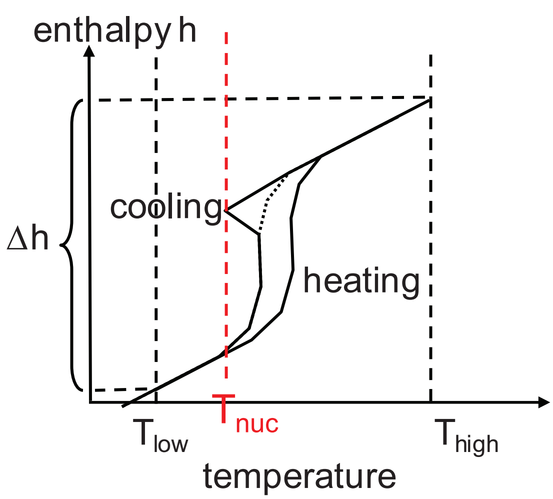

Fig. 2. Enthalpy h as a function of temperature T for the case of a phase change temperature range, here with hysteresis including subcooling.

Material properties are generally determined by a measurement on a sample in an idealized situation. To be able to use material properties to predict the performance of an application some general conditions have to be met.

2.1. Representative sample – choosing a suitable sample

The material has to be well defined to be able to say that characterization and application refer to the same material (representative sample). The selection and preparation of a suitable sample are thus crucial. Special care has to be taken when a material is heterogeneous, such that a sample is large enough to have the consistency of the material to be characterized.

2.2. Repeatable result – getting the same result reliably again

For a measured property to be a material property, that means to be characteristic for the behaviour of a material and thereby to allow a prediction of the performance of an application, it is necessary that the material behaves the same under the same conditions, meaning the measured property has a repeatable result. Repeatability then refers to the closeness of the agreement between the results of successive measurements of the same measurand (particular quantity subject to measurement) carried out under the same conditions of measurement [2].

For example, the heat capacity of liquid water at 20 °C and ambient pressure is always the same; it is a material property. The same holds for the phase change enthalpy between solid and liquid at ambient pressure. The heat of combustion of a material is the same for the same material under the same conditions, and is thus also a material property (but for repeated measurements new samples have to be used). The history of the material therefore plays a crucial role. The crystallinity in a glass transition depends on the cooling rate, and not only on the boundary conditions like temperature and pressure. It can thus only be seen as a material property if the history of the material, here the cooling rate, is included in the definition of the material. Regarding PCM, the most crucial case is its cycling stability, referring to the PCMs heat storage capability during repeated phase change cycles.

2.3. Reproducible result – transferring the material property to the application

The conditions of the sample when determining the material property are in general different from the conditions in the application. To be able to transfer the result of the material property to the application the result must be reproducible, that means the same, or at least similar enough. Reproducibility of results of measurements refers to the closeness of the agreement between the results of measurements of the same measurand carried out under changed conditions of measurement [2].

Therefore, unless well known, it is better to scan a range of conditions and not a single value. Specifically, the amount of the material is always different between material characterization and application, and the boundary conditions are different at least in most cases.

When using PCM, the most important one is the temperature, as PCM are selected for thermal energy storage specifically because of their high heat storage capability in a narrow temperature range. Therefore, h(T) has to be determined in a temperature range covering the phase change with sufficient resolution in the temperature (resolution = density of data points in a parameter range) as well as with sufficient accuracy in the temperature (accuracy = closeness of the agreement between the result of a measurement and a true value of the measurand, quantified by the uncertainty [2]) (Fig. 3).

Nevertheless, additional effects could be due to different pressures, surfaces, etc. Further on, it is common measurement practice to investigate several samples, and measure each sample several times to check reproducibility and repeatability of the results.

3. Observed effects in material property determination

The connection between the heat storage capability of PCM as a material property and their performance in real scale applications is now reviewed and investigated.

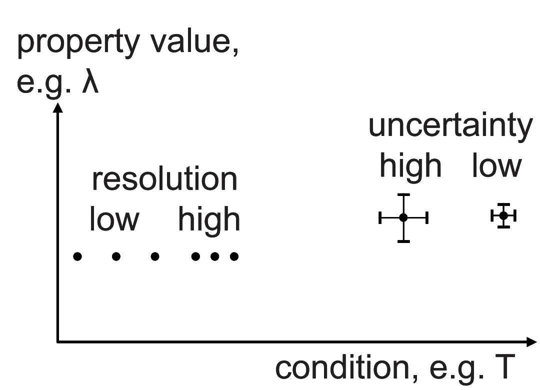

Fig. 3. Meaning of resolution and accuracy (quantified by the uncertainty).