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Investigating organic phase change behavior with thermal photography

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Abstract

The United Kingdom has a target of reducing fossil fuel emissions to 80% of 1990s emissions levels by 2050 and the National Grid is highly likely to see a vast portion of displaced currently fossil fuelled heating provision. There is therefore a significant need for research into alternatives to grid re-enforcement and additional power stations. Thermal energy storage systems present one such alternative via the decoupling of energy production and consumption in both industrial and domestic heating demand. Reversible phase change in materials such as paraffin waxes, inorganic salts and metal alloys represent such a technology. For these, the ability to empirically assess a given phase change is invaluable for determining materials of interest, system characteristics and optimisation of systems design in addition to quantitatively validate any given numerical system models.

In this work the development and evolution of the solid to liquid phase transition in two organic phase change materials: beeswax and paraffin wax is investigated. These are characterised via visible and thermal photography of an ongoing melt/solidification in a 5cm dimensioned cube constructed of several differing wall materials. Isothermal heat is supplied via the bottom surface by a laboratory hot plate.

During the melting and re-solidification process, the thermal conduction through non-infra-red transparent wall materials has been unable to indicate the solid-liquid interface or melt/solidification times. Direct infra-red transmission through the infra-red transparent materials and visible light analysis through the transparent walls has been able to provide a solid-liquid interface track and melting time to completion but is unable to confer any useful information during the solidification process due to premature solidification on the wall exposed to imaging.

Selection and peer-review under responsibility of the 3rd Annual Conference in Energy Storage and Its Applications, 3rd CDT-ESA-AC.

Keywords: Phase Change Materials (PCM); Thermal Energy Storage (TES);Thermal Imaging

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1. Introduction

Any approach to decarbonisation of the UK's energy must incorporate an approach to decouple energy production from its utilization in order to increase the possible penetration of renewable assets needed to hit the 80% reduction from 1990s levels of pollution target dictated in the UK Climate Change Act [1]. It is highly likely that in order to achieve the decarbonisation of heating, the energy production for heating will be displaced onto the National Grid which is likely to induce demand on the grid to double at minimum [2].

Thermal Energy Storage (TES) presents a distinctive option for decoupling energy supply and demand within domestic and industrial heat production. A subset of TES materials with particular promise for this purpose are phase change materials (PCMs). These PCMs are superior to conventional sensible storage as they store the heat via a change in phase (latent heat storage) rather than a change in temperature. This utilization of the latent heat storage vector confers benefits not only via a dramatically larger amount of energy storage per unit mass (~10 times concrete) [3] but also a larger exergy due to their isothermal heat exchange.

In spite of the inimitable advantages of PCMs there are still challenges in their utilization including phase separation, thermal expansion, sub-cooling and poor thermal conductivity, as well as in the modelling of their physical behavior [4,5]. Given their potential for utilization in the built environment, determining methods of analysis and validation of numerical models is of paramount importance.

This paper investigates the usage of thermal and visual photography for melt and solidification analysis of beeswax and paraffin wax.

2. Methodology

This study conducted melting and solidification cycles utilizing a FLIR SC-Series (SC640) thermal camera, a PLAYSTATION Eye ™ webcam and a flat plate MS-H280-Pro laboratory heater. Figure 1 shows a schematic representation of the custom-made, cuboid vessel designed for this purpose. Three of the vessel's walls were insulated with 15mm of polystyrene, while the remaining wall was made of IR transparent PMMA. Isothermal heating at 80℃ was supplied during melt phases and the heater was turned off for subsequent re-solidification.

During melting and solidification cycles the thermal camera was operated in timed shot mode, taking 1 image per minute. The PLAYSTATION Eye ™ webcam was similarly configured being connected to a Raspberry Pi 2 Model B taking 1 image per minute.

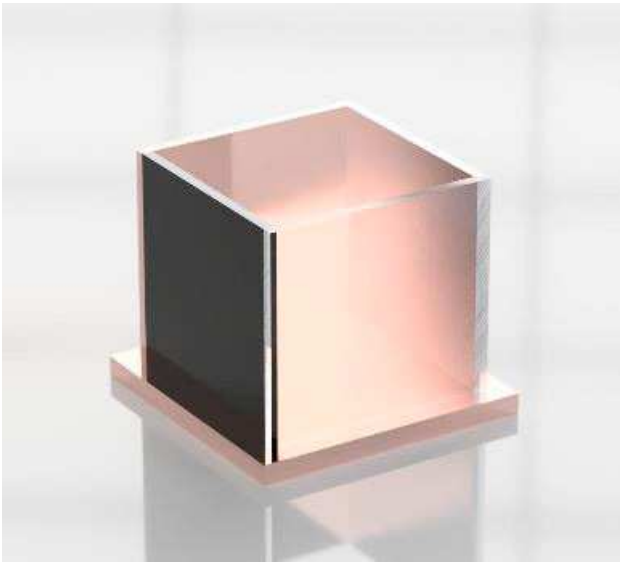


Fig. 1. 5 x 5 x 5 cm internal dimensioned custom-made storage vessel composed of a copper base and single walls made of polycarbonate, IR transparent PMMA (Bay Plastics LTD), copper and aluminium.

3. Results

3.1. Visible Light

Figures 2 (a-c) present images through the transparent wall vessel of the paraffin wax melt at 30, 60 and 103 minutes respectively. As can be seen in Figure 2 (a), the melting process has begun with a darker region observable at the base of the vessel that indicates the height of the now liquid wax. The melting process progresses upwards with time, as can be seen with the progress of the darker region up the vessel in Figures (a) and (b). From the imagery through the transparent faces it is concluded that the total melting time for both beeswax and paraffin wax are 157 and 103 minutes respectively.

(a) (b) (c)

Fig. 2. Thermal imagery of paraffin wax melting at (a) 30 minutes; (b) 60 minutes; (c) 103 minutes duration observed from polycarbonate wall.

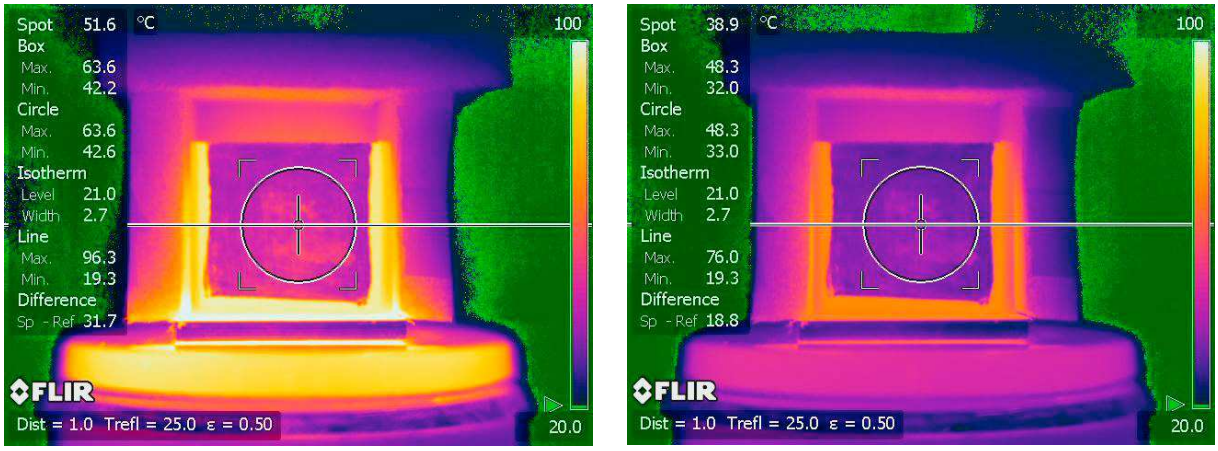
It is important to note that the metal walls of this experimentation vessel have conducted significant amounts of heat, thus melting phase change material adjacent more rapidly than the polycarbonate or IR transparent PMMA. This fact is important to account for in the event of validation studies of numerical models and is a limitation to investigating the 4 different materials utilizing one vessel. Other flow phenomena such as convection currents and their directions have not been captured using visual photography.

In addition, visual imaging is unable to determine the solidification time due to premature solidification taking place on wall being exposed for imaging; solidification of the whole mass is complete significantly later than when the observed wall shows a solid mass top to bottom. This is also likely an issue with melting as the same exposed face is likely where the last solid mass remains prior to melting completion and relates to observation of later stages of the melting appearing to increase in rate.

3.2. Infra-red Light

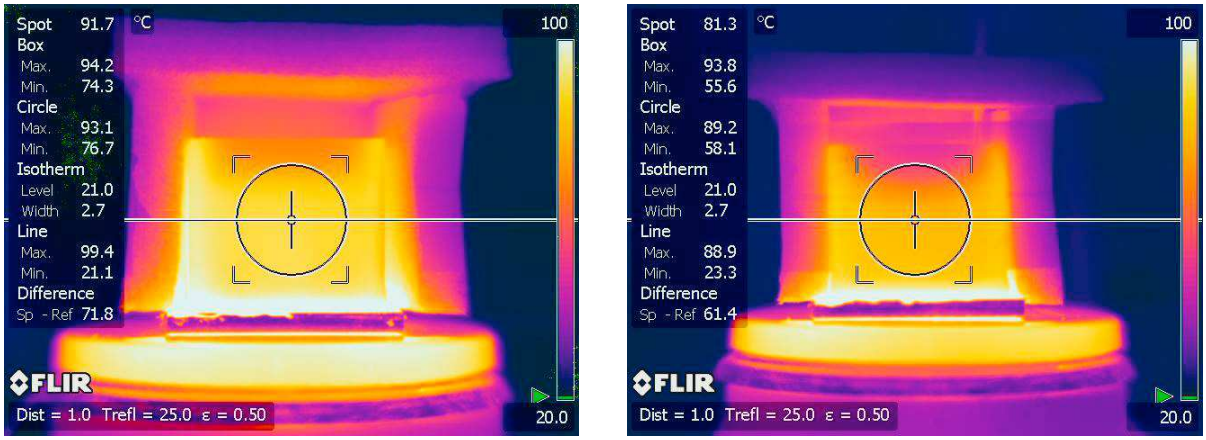
Results for thermal imaging were generated for both IR opaque and IR transparent materials and are shown in Figure 3 and 4 respectively. As can be seen in Figure 3, observation of the melt and solidification imagery for beeswax and paraffin wax clearly demonstrates that the aluminium and copper walls confer no useful information about the melt or solidification process due their being opaque in both visible and infra-red spectrums. The infra-red light radiated from the copper and aluminium wall surfaces do not show a melt or solidification front progression. This conclusively demonstrates that the re-radiated infra-red radiation from the metal wall surfaces (derived from heat conducted from the PCM) is not significant for analysis of melt or solidification progress in this study.

In contrast, as can be seen in Figure 4, the IR transparent PMMA and polycarbonate wall demonstrated an indication of the solid-liquid interface allowing for the calculation of relative melt fraction and time to melt completion. Like the visual light imagery, further details such as convection currents have not been resolved. Clearly, the same limitations that apply to the visual light photography analysis such as surface blemishes and metallic wall conduction effects will also apply to thermal photographic analysis.



(a) (b)

Fig. 3. Thermal imagery of beeswax solidifying at (a) 1 minute; (b) 20 minutes duration observed from copper wall.



(a) (b)

Fig. 4. Thermal imagery of beeswax melting at 169 minutes duration observed via the (a) IR Perspex wall (b) polycarbonate.

4. Conclusion

Thermal and visual photography has been demonstrated to be a useful analysis method for the **melting** of beeswax and paraffin wax through infra-red and visible light transparent materials, which are able to both track the solid-liquid interface and determine time to melt completion using a simple webcam. Further detail into the developing convection currents has not been realized, this is likely due to the resolution of the cameras utilized and the materials characteristics of the walls and phase change materials.

In this specific design, this study has also demonstrated that re-radiated infra-red radiation from IR opaque metal wall surfaces from heat conducted from the PCM is not significant for analysis of melt or solidification progress. In addition, the experimentation has also shown that visual and thermal photography is not a useful method for the analysis of **solidification** due to heat losses to the environment via the wall under imaging causing premature solidification on the imaged surface which prevents any useful imagery being taken. It is likely that this is also having an effect on melting progress as it is likely that the last solid phase change material will adhere to this colder wall. This particular limitation may be countered by utilizing removable insulation to only be removed during imaging.

Other limitations to this experiment have also been found and demonstrated in the visual imagery; the metal walls are conducting heat into the sides of the phase change mass. Subsequent validation studies for numerical modelling will need to account for this, or the containment vessel design adjusted. This is important in any CFD validation studies and could necessitate a redesign of the vessel.

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