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Erythritol, glycerol, their blends, and olive oil, as sustainable phase change materials

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Abstract

In searching for new candidates to be used in latent heat storage, it is desirable to explore food-grade materials of renewable origin. Here, erythritol, glycerol, and olive oil have been characterized as PCMs. An assessment of the production process of erythritol (melting between 117-120 °C with an enthalpy around 300 kJ/kg) indicates its renewable aspects as a PCM. In addition, a simplified cost assessment of high-purity erythritol production, using glycerol, indicates a potential cost reductions up to 130-1820 times lower than the current laboratory-grade prices. Glycerol already is cost-effective. However, the glycerol-erythritol system, evaluated using the Temperature-history (T-history) method, did not exhibit phase change suitable for PCMs. Glycerol, and up to 30 mol% erythritol compositions had no phase change due to glass transition; the remainder froze but with large supercooling; and the system underwent thermally activated change. Hence, to realize glycerol or the glycerol-erythritol system as PCMs, further research is needed primarily to device fast-crystallization. Olive oil is a cost-effective food commodity, with potential for further cost reductions by mass-production. An olive oil sample, containing the fatty acids: linoleic, palmitic, oleic, margaric, and stearic was evaluated using the T-history method. This olive oil melted and froze between -4.5 to 10.4 °C and -8 to -11.9 °C respectively, with the respective enthalpies 105 and 97 kJ/kg. As the specific heat (cp) profiles of olive oil displayed two peaks, the composition adjustment of olive oil could yield a eutectic or confirm a polymorph. In either case, olive oil has a potential to be a PCM e.g. in chilling applications, while its properties such as thermal conductivity need to be determined. As a whole, this study exemplifies the potential of renewable organic materials, in pure and blend forms, as sustainable PCMs, making TES with PCMs sustainable.

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1. Introduction

Phase change materials (PCMs) are an attractive alternative today, for thermal energy storage (TES). The energy management and saving opportunities provided by PCMs include load shifting, peak shaving [1]-[3], industrial surplus energy harvesting [4]- [6] and mobile TES [7]- [9]. Apart from the water-ice system which is the cheapest PCM, several materials (e.g. paraffins, salt-hydrates and fatty acids [10], [11]) have been considered for TES applications. For sustainability, the PCMs themselves must also be renewable, non-toxic, environmental-friendly, and cost-effective. Some materials, e.g. paraffins and salt-hydrates are cost-effective, yet non-renewable. Some others, e.g. polyols, and fatty-acids, are renewable, bio-degradable and non-toxic, though are not as cost-effective as salt hydrates or paraffins [12]-[14].

Finding a PCM that fulfils sustainability criteria, in addition to the TES design requirements (a suitable melting temperature, large melting enthalpy and high thermal conductivity) is challenging. Polyols and fatty acids are materials emerging as PCMs since they come with attractive TES properties. They are also non-toxic, some even being food-grade (e.g. erythritol, xylitol, glycerol, and oleic, linoleic and palmitic fatty acids) [15], [16]. Olive oil, a blend of fatty acid-derivatives, has so far not been considered in the PCM-context. If suitable, olive oil would be a candidate PCM of renewable origin. Contributing to identify and develop sustainable PCM materials, this study aims to evaluate: the potential for cost-reduction of erythritol as a bulk PCM; the melting temperatures and enthalpies of glycerol and the erythritol-glycerol system; and food-grade olive oil as a PCM. Here, the Temperature-history (T-history) method is used [15], [17]. Finally, the potential of these materials as being sustainable PCMs for TES is assessed as a whole.

Nomenclature

Avg.	average
c_p	specific heat (kJ/(kg·K))
DSC	differential scanning calorimetry
Gal	gallon
ΔH	enthalpy change (kJ/kg)
Er	erythritol
Frz	freezing
HT	high-temperature
HPLC	high-pressure liquid chromatography
L	liquid
Mel	melting
NA	not available
PCM	phase change material
T	temperature (°C)
TAG	triacylglycerol/triglyceride
TES	thermal energy storage
T-history	temperature-history
RBC	repeated batch cultures
S	solid
SS	stainless steel