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PROCEEDINGS

XII MEĐUNARODNA KONFERENCIJA O DRUŠTVENOM I TEHNOLOŠKOM RAZVOJU - STED 2023

ZBORNIK RADOVA

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CONTENT
SADRŽAJ

ORIGINALAN NAUČNI RAD – ORIGINAL SCIENTIFIC PAPER

THE POSSIBILITY OF USING POLYMER-BASED PHASE CHANGE MATERIALS FOR THERMAL ENERGY STORAGE

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ABSTRACT

Phase change materials (PCM) are attractive energy storage technologies due to their high energy storage density and the ability to reversible absorb and release thermal energy at a nearly constant temperature. Polymers and polymer-based eutectic mixtures are promising PCMs. This study aims to investigate heat properties (melting temperature (T_m), latent heat (ΔH) and thermal conductivity(λ)) of potential PCMs based on polyethylene glycol polymer (PEG2000). We prepared following two and three components materials: PEG2000: ethylene glycol (5:6): PEG2000: PPG 400 (1:5); PEG2000: PPG400: Choline chloride (2:2:15); PEG2000: ethylene glycol (5:6); PEG2000: Glyoxal (5:2). The prepared three components material belong to deep eutectic solvents. Tm of the prepared materials are lower compared to pure PEG2000 (T_m = 57 ºC) e.g. T_m of PEG2000: PPG400: Choline chloride is 43 ºC. The determined melting enthalpies are also lower for prepared materials compared to PEG2000. This decrease is lower for eutectic mixture such as PEG2000: Choline chloride: ethylene glycol. We can conclude based on the obtained result that eutectic mixtures based on polymers are promising PCMs.

Keywords: deep eutectic solvents, phase change materials, polymers, melting temperature, enthalpy.

INTRODUCTION

The growing demand for clean and sustainable energy solutions, combined with the need to reduce greenhouse gas emissions and mitigate climate change, has compelled researchers and engineers to investigate innovative energy storage technologies. Phase change materials (PCMs) offer unique advantages for thermal energy storage. At nearly constant temperatures, PCMs can store or release significant amounts of energy during the phase transition from solid to liquid or vice versa (Lamrani et al., 2021). This property makes PCMs ideal for a variety of thermal energy storage systems, including solar collectors (Karthikeyan et al., 2023), air conditioning units, heating and cooling systems, etc. (Qiao et al., 2022).

According to their chemical composition, PCMs can be classified as organic, inorganic, or eutectic. Organic materials, such as paraffin and non-paraffin substances like glycol, polyol, and fatty acid, are commonly used for thermal energy storage due to their suitable transition temperature, high storage density, and stable chemical and physical properties. These organic PCMs offer several advantages, including a wide temperature range, a high latent heat of fusion, long-term stability, compatibility with most materials, a phase transition with minimal volume change, and recyclability (Singh et al., 2021). However, there are certain drawbacks, such as low thermal conductivity, incompatibility with certain container materials (e.g., plastic containers), and flammability. Inorganic PCMs predominantly consist of salt hydrates, which are combinations of water and salts, as well as metallic compounds (Zhang et al., 2022). The inorganic PCMs have following benefits: higher storage density (almost double that of organic PCMs), greater thermal conductivity (approximately double that of organic PCMs), low cost, compatibility with plastic containers, and non-flammability. However, there are certain drawbacks: inorganic PCMs can be

corrosive, undergo a significant volume change during phase transition, and may experience issues such as separation and supercooling. Eutectic PCMs are formed by combining two or more components to create a distinct PCM with desired properties (Sun et al., 2023). This combination can involve organic-organic, organic-inorganic, or inorganic-inorganic compositions.

Polymers have been discovered to be a flexible PCM with typical organic PCM properties, including high latent enthalpy, a wide transition temperature range, high thermal stability, ease of chemical modification, strong biocompatibility, and non-toxic and non-corrosive natures (Sundararajan et al., 2016). Physically mixing polymers with some supporting materials, mixing two or more polymers in the proper ratio, chemical modification of polymers, and vacuum impregnation in porous materials are the most common ways to fabricate polymer-based PCMs. However, the physical thermal properties of polymers with different molar masses, such as thermal conductivity, phase transition property, heat capacity, and the corresponding thermodynamic functions, have rarely been investigated. The majority of studies on poly-based PCMs mainly focus on the design and synthesis of new PCMs and improving their performance for thermal energy storage. Different types of polymers (Polyethylene glycol or Polypropylene glycol), due to low hazardous and flammable properties, have been investigated as the PCM. The use of polymers to create effective PCM systems has been suggested because of their advantageous properties: suitable phase change temperatures and large phase change enthalpy, elevated long-term thermal/chemical stability, low toxicity and resistance to corrosion, limited volume change during solid-liquid phase change, readiness to be incorporated into porous inert substrates, and the possibility to choose the more suitable grade for the particular application (Karaman et al., 2011., Kou et al., 2019). Due to the availability of polymers with different molecular weights and, consequently, various melting temperature (Hocker et al., 2012), a polymer with the right melting point in relation to the expected operating conditions could be chosen.

The present study aims to evaluate the thermal properties of proposed PCMs based on polyethylene glycol polymer (PEG 2000), such as onset melting temperature, the melting temperature, the latent heat, and thermal conductivity. The choice of PEG is further supported by the material's high melting/crystallization enthalpy and acceptable phase change temperatures. PEG exhibits strong long-term thermal/chemical stability, corrosion resistance, and little volume change during the transition from the solid to the liquid phase. PEG2000 has high melting temperature (57 °C). In order to decrease melting temperature of PEG200 we created two- and three-component materials based on this polymer and studied their thermal characteristics.

MATERIAL AND METHODS OF WORK

The following chemicals were used for preparation of two and three component PCMs: PEG2000, PPG400, Ethylene glycol, Choline chloride (ChCl), and Glyoxal. All chemicals were purchased from Sigma Aldrich (St. Louis, MO, USA). The list of prepared and studied potential PCMs is given in Table 1.

The studied two components polymer PCMs were prepared using following procedure: accurately weighted mass of PEG2000 was stirring at magnetic stirrer and hitting at 60 °C till a monophasic solution has been formed. After melting PEG2000, the second component (PPG400, ethylene glycol, or glyoxal) was slowly added drop by drop, and the homogenization of the solution is visually monitored. Schematic view of the preparation procedure of the polymer based PCMs is given in Figure 1. The PCM 4 was synthesized by adding an organic salt (ChCl) to a homogenized mixture of two polymers (PEG 2000 and PPG400). Homogenized mixture of two polymers was the same way as two components PCMs. After obtaining monophasic homogenous mixture, stirring and heating at 60 °C was continues for 2 h.

The thermal characteristics of the samples, including the onset melting temperature (T_{om}), the melting temperature (T_m), and the latent heat (ΔH), were determined using a Differential Scanning Calorimeter (DSC 151R, SETRAM instruments). The measurement procedure involved heating the sample from 25°C to 65°C at a rate of 5°C per minute.

To accurately determine the enthalpy-temperature curve of the targeted phase change materials, a DSC baseline test was performed. This involved conducting a DSC measurement across the entire

temperature range using empty sample and reference pans, employing the same heating rate that would be used for subsequent tests. This baseline measurement provided the reference signal, against which the heat flow signals of the PCM measurements were compared and adjusted.

Table 1. Initial components, weight ration and chemical structures of the prepared two and three components materials.

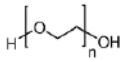
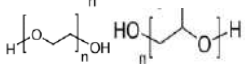
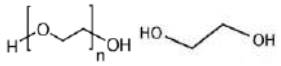
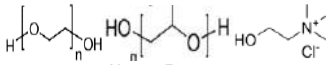
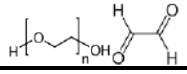
PCM samples	Initial components	Weight ration	Chemical structure
PCM 1	PEG 2000	/	
PCM 2	PEG 2000: PPG 400	(1:5)	
PCM 3	PEG 2000: Ethylene glycol	(5:6)	
PCM 4	PEG 2000: PPG400: Choline chloride	(2:2:15)	
PCM 5	PEG 2000: Glyoxal	(5:2)	

Figure 1. Schematic view of polymer PCM synthesis.

The thermal conductivity of the PCM samples was measured using a thermal conductivity measurement platform (MP-2, Thermtest instruments) equipped with a THW-L3 sensor. The procedure involved preparing the sample by shaking it and heating it to its melting temperature. The molten PCM was then poured into a warm measuring cell placed inside a dry bath. The temperature of the dry bath was gradually reduced to 25 °C, and measurements were taken. The THW-L3 sensor used a detect current setting to determine the appropriate amount of current based on a test measurement. By analyzing the test result, an optimal current value was selected to achieve the desired temperature rise during testing. This allowed for an accurate determination of the thermal conductivity of the PCM samples using the MP-2 platform and THW-L3 sensor.

RESULTS AND DISCUSSION

DSC measurements were used to acquire data on the melting temperature, melting onset temperature, and latent heat of fusion. The measured thermal properties of the PCM samples are shown in Table 2. As shown in Figure 2, each DSC curve has one peak for the heating process. The highest peak was obtained for pure PEG2000. The obtained T_m of PEG2000 (57.4 °C) is higher than the corresponding published data (50.92 and 52.65 °C) and the calculated latent heat of PEG2000 (ΔH = 126.72 Jg^{-1}) is lower comparing with literature data (154.1 and 165.43 Jg^{-1}) (Kou et al. 2019).

Thermal storage properties of the PEG2000 were affected by the addition of the second and third components. The melting temperature, and onset melting temperature of the samples display a tendency to decrease with the addition of PPG400, Ethylene glycol, Choline chloride, and Glyoxal. The lowest melting temperature of 43.99 ºC was recorded for the sample PCM 4, while the onset melting temperature is 33.54 ºC. The measured value of the latent heat of this sample is 41.84 Jg^{-1} and this is the highest value after the latent heat of PEG2000. For PCM2, PCM3, and PCM5 samples, besides reducing the melting temperature, there was also a notable decrease in the

value of latent heat. The lowest value of latent heat was recorded for sample PCM 2 where with the addition of PPG400 latent heat value of PEG2000 drops from 126 Jg^{-1} to 15.56 Jg^{-1}.

Table 2. Thermal characteristics of the samples determined using a DSC.

PCM sample	Thermal properties		
	T_{om}, °C	T_m, °C	ΔH, J g^{-1}
PCM 1	48.83	57.40	126.72
PCM 2	41.88	47.03	15.56
PCM 3	34.32	44.15	29.68
PCM 4	33.54	43.99	41.84
PCM 5	40.53	45.35	19.40

The measured thermal conductivity of the investigated PCMs is shown in Figure 3. The highest thermal conductivity value of 0.23 $Wm^{-1}K^{-1}$ was recorded for sample PCM 1, which consists of PEG2000. On the other hand, PCM 3 and PCM 5 materials have a slightly lower thermal conductivity of approximately 0.21 $Wm^{-1}K^{-1}$ compared to PCM 1. PCM 2 displays the lowest thermal conductivity of 0.066 $Wm^{-1}K^{-1}$ among the samples.

CONCLUSIONS

The possible two and three component phase change materials based on polymer PEG2000 were synthesized and their thermal properties were investigated in this study. Preparation of the proposed material are easy and no time consuming. The thermal properties of the synthetized materials, such as the melting temperature, melting onset temperature, and latent heat of fusion were measured using DSC. The melting temperatures of the prepared materials are lower compared to pure PEG2000. The determined values of latent heat are also lower for prepared materials compared to PEG2000. The lowest decrease in latent heat value was obtained for PCM 4 (PEG2000: Choline chloride: ethylene glycol), while the biggest decrease was obtained for PCM 2 (PEG 2000: PPG 400 (1:5)). PCM 2 also displays the lowest thermal conductivity of 0.066 $Wm^{-1}K^{-1}$ among the samples. It should be emphasized that the PCMs with addition of either ethylene glycol or glyoxal only slightly decrease thermal conductivity of PEG2000. These findings pave the way for further exploration and investigation.

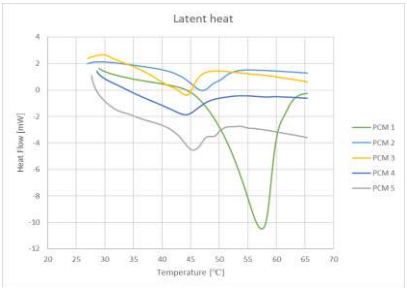


Figure 2a. DSC curves of PCM samples.

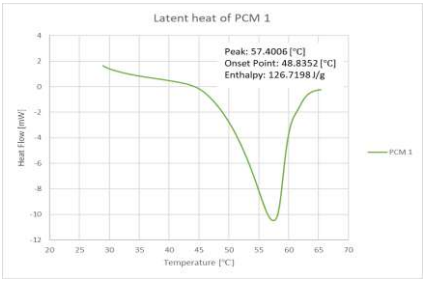


Figure 2b. DSC curve of PCM 1.

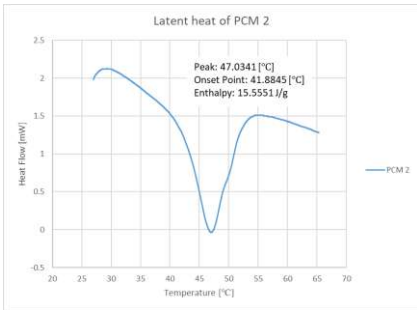


Figure 2c. DSC curve of PCM 2.

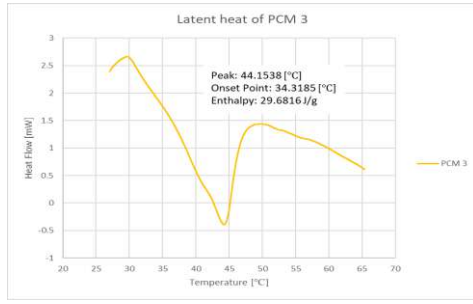


Figure 2d. DSC curve of PCM 3.

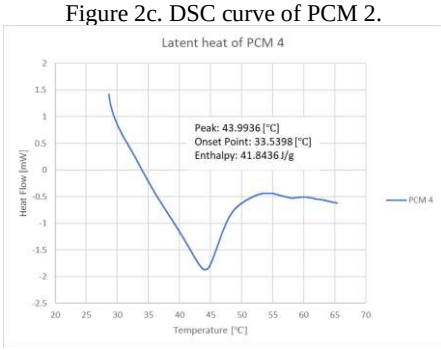


Figure 2e. DSC curve of PCM 4.

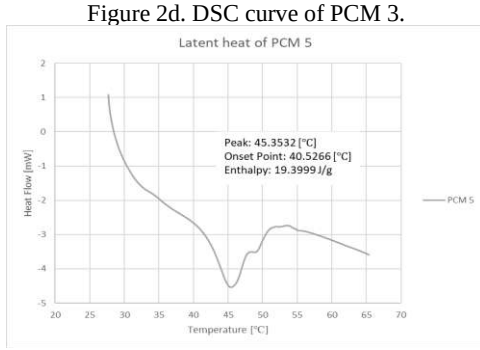


Figure 2f. DSC curve of PCM 5.

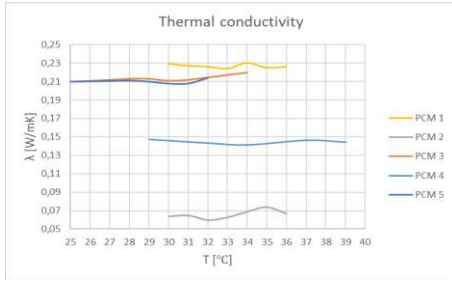


Figure 3. Thermal conductivity of PCMs.

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