Recycled Tetra Pak-based PCMs for enhanced photothermal conversion and thermal energy storage

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Due to the rapid rise in global energy demand, recent studies focus more on renewable energy resources to deal with fossil fuel depletion and associated environmental concerns. Solar energy is the most widely studied renewable source of energy due to its abundant availability. However, its intermittent characteristics necessitate a thermal energy storage system to ensure a continuous energy supply. Phase change materials (PCMs) store a large amount of thermal energy as latent heat and are frequently used in thermal energy storage systems. Paraffin wax (PW) is often preferred over inorganic PCMs due to its non-corrosiveness, nontoxicity, chemical and thermal stability, and high enthalpy. However, leakage, low photo absorbance, and thermal conductivity are the major limitation of PCMs in photothermal conversion and storage applications. Therefore, PCM composites are prepared by mixing with conductive fillers, impregnated in conductive scaffolds (Maleki et al., 2019; Umair et al., 2019), and blending with polymers (Chriaa et al., 2021; Sobolčiak et al., 2021). Polymeric PCM composites offer high mechanical strength, leakage prevention, high strength-to-weight ratio, abundance, and availability. Therefore, in this study, polymeric PCM composites are prepared by blending PW with polyethylene in the tetra Pk (TP) waste. The recycled tetra Pak contains polyethylene and aluminum which are unable to separate during the recycling stage. The aluminum in the composite improves thermal conductivity. The thermal conductivity is further enhanced by adding expanded graphite (EG). Two different PWs of different phase transition properties (i.e., RT44 and RT64) are used to prepare the composite for various applications.

The composites (TP_PW_EG) are prepared by melt mixing the components in the Brabender® Plastograph® chamber at 160 °C for 15 minutes at 35 rpm speed. The mixture was then hot pressed under a hydraulic mounting machine at 3-ton force at 160 °C. A composition of 40% TP, 50% PW and 10% EG by weight was used in this study. Thermophysical properties, leakage, and photothermal conversion performance of the composites were studied. Thermal conductivity was obtained from a multipurpose apparatus for pure TP, PWs and PCM composites. The phase transition temperature and latent heat capacity are measured from DSC analysis and a homemade device based on the transient guarded hot plate technique (Figure 1). The PCM leakage was evaluated from the composite mass loss during its placement in an oven at 80 °C for 14 days. The photothermal conversion and storage performance of the composites were a simulated solar intensity of 1000 W/m2. The temperature and heat flux evolution of the composite during the study was used to estimate the photothermal conversion efficiency of the composite.

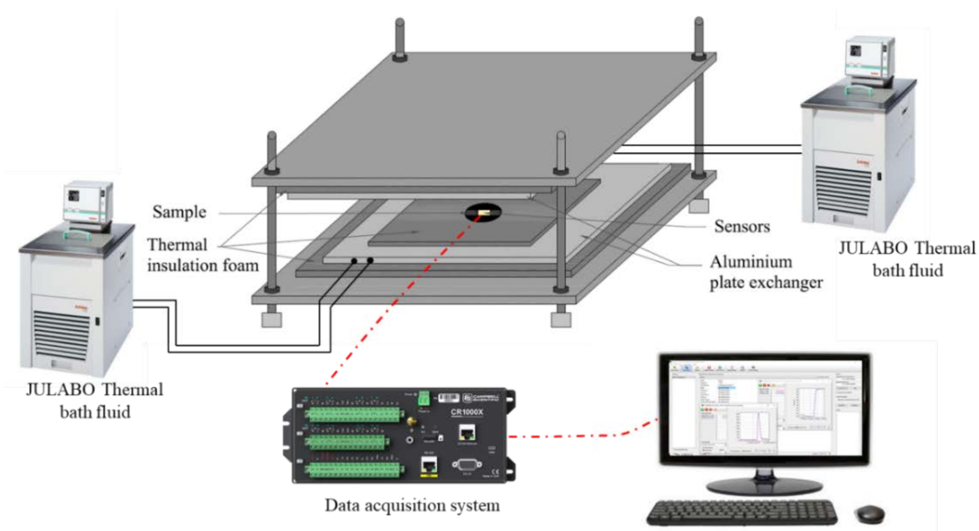
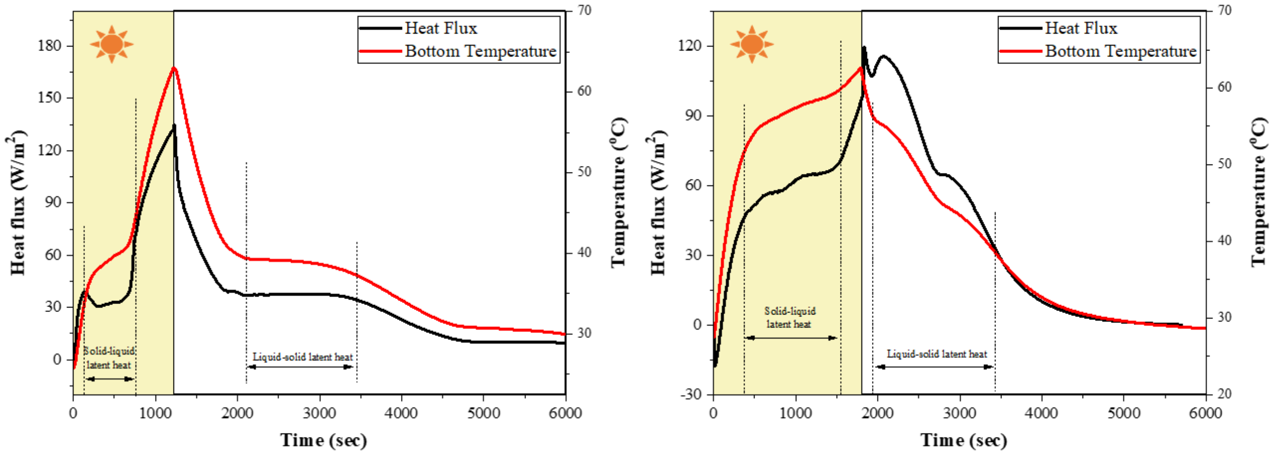


Figure 1: Transient guarded hot plate technique

The aluminum in the TP and the EG in the composite improved the thermal conductivity of the PCM composite by 360% of that of pure PW. The leakage of liquid PCM from the composite was only 7% after 14 days at 80 ℃. The peak phase transition temperatures of the PCM composites were 46.4 and 67.2℃, and latent heat enthalpies were 102 and 114 J/g for the two composites, respectively. The temperature of the composite under the simulated light was increased to 65℃ after 20 and 30 minutes for TP_RT44_EG and TP_RT64_EG composites, respectively. The temperature plateau in the evolution curves in Figure 2 indicates the phase change of the PCMs and corresponding thermal storage. After the lights are turned off, the stored energy is released at a constant temperature as shown in Figure 2. The photothermal conversion efficiencies of composites with RT44 and RT64 were 80 and 55%, respectively. The time taken for the phase change of the TR_RT64_EG composite was more compared to the TP_RT44_EG composite due to the convective heat loss from the sample surface being higher at a higher temperature.

The PCM composites in this study utilize recycled tetra Pak to improve the thermophysical properties and thereby encourage the recycling of tetra Pak waste into a useful product. Studies on practical applications of this composite for water heating and electricity generation by thermoelectric generators are ongoing.



(a) (b)

Figure 2: The heat flux and temperature evolution of TP_PW_EG composites during photothermal conversion study; (a) TP_RT44_EG, and (b) TP_RT64_EG.

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