Thermal and Heat Transfer Performance of Leakage-Proof Phase Change Material

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Abstract: Phase change materials (PCM) have become researcher interest in the area of thermal energy storage (TES) due to their high storage capacity, simple structure, low cost and so on. However, its application in TES is limited due to leakage issues. In this study, a leakage-proof composite PCM has been successfully prepared, in which paraffin is used as PCM and styrene-b-(ethylene-ran-butylene)-b-styrene (SEBS) as supporting material. Furthermore, different mass fraction, i.e., 10, 15 and 20wt% of SEBS, is incorporated in paraffin to investigate the performance of the composites against the leakage issue of paraffin. Results revealed that when the mass fraction of SEBS reached 20wt%, negligible leakage of paraffin has been observed. Moreover, the thermal stability of composite PCM has been determined by thermogravimetric analysis. TGA and DSC results suggested that the degradation of composites is negligible below 200ºC with an excellent storage capacity about of 167.91 J/g. Finally, the heat transfer performance has been observed experimentally.

Keywords- *Phase change material, Paraffin, SEBS, Thermal Energy Storage*

I. Introduction

The problem of environmental pollution and the debilitating assets of petrochemical fuels have sped up the advancement of clean and sustainable energy as well as thermal energy storage (TES) technologies. In recent years, phase change materials (PCMs) have gained much attention in the field of TES due to their high energy storage density and nearly isothermal operating characteristic during phase transition (solid-solid, solid-liquid and liquid-gas) [1,2]. Among numerous types of PCM (hydrate salts, paraffin, esters, fatty acids etc.), paraffin is the most promising one because of its high storage capability, non-toxicity, non-corrosiveness, low supercooling and vapor pressure [3,4]. Apart from various mentioned advantages, the utilization of paraffin is limited due to leakage issues during phase transformation. To address this problem, mainly three approaches have been endeavored- (i) direct incorporation of porous materials into paraffin (ii) micro-encapsulation of paraffin and (iii) shape stabilization technique of paraffin with polymeric matrices [5]. However, the direct incorporation of porous materials did not fully solve the leakage issue or may interact with a base material, while microencapsulation of PCM is a complex and costlier process. Review studies revealed that the shape stabilization method is grown significantly in recent years. The shape stabilizes PCM do not need encapsulation or any containment, hence saving the cost [6,7]. In this paper, we introduced a leakage-proof PCM for TES application. For this, composites based on SEBS incorporated with paraffin has been prepared. Paraffin served as PCM and SEBS as supporting matrix. We also attempted to study the thermal properties and heat storage/retrieval performance of PCM in the polymer matrix. The leakage of paraffin inside the composites has been studied through the leakage test.

II. Materials And Tailoring of Sample

The selected PCM and polymer in this work was paraffin (m.p.=55-60ºC) and styrene-b-(ethylene-ran-butylene)-b-styrene (SEBS) purchased from Sigma Aldrich. The samples have been prepared by the melt-mixing method [8]. The paraffin is first fully melted at 70ºC, then SEBS is slowly added into it with constant stirring for 2 hours to yield a homogeneous solution. After mixing, the blend has been taken into a round mold with a size of 20mm in diameter for hot pressing. In this way, three samples, named P1, P2 and P3 having 10, 15 and 20wt% of SEBS, have been synthesized in this process.

III. Characterization

Thermal Properties

The thermal stability of composites has been assessed by Thermo Gravimetric Analysis (TGA) performed under N_2 atmosphere from temperature around 30ºC to 600ºC with a heating rate of 10ºC/min. The phase change properties of paraffin and paraffin/20%SEBS composite have been characterized by DSC under N_2 atmosphere with a flow rate of 20 ml/min. The heat storage capacity of PCMs has been calculated by numerical integration of area under the peaks corresponding to solid-solid and solid-liquid phase transition.

Leakage rate Determination

The leakage rate of paraffin in composites samples have been investigated by leakage test. In this test, the samples were packed with filter paper and placed in the oven at 80ºC for 1 hour. After every 1 hour, the sample was taken out and weighted through an analytical balance, and every time, the filter paper was replaced by a new one. Repeating this process about 13 times. The initial weight of the sample is denoted as W_o and after thermal treatment, the final weight represents as W_n. Here 'n' represents cycle numbers. The leakage rate of paraffin has been calculated by the following relation [9]

$$L = \frac{W_o - W_n}{W_0} \times 100\%$$

Heat transfer characterization

A thermal storage/release test has been carried out by using a self-made constant temperature water bath technique to examine the heat transfer performance of paraffin and paraffin/20%SEBS composite [10,11]. Prior to the examination, the 20g

specimen is filled in a 25 ml beaker and placed into a water bath at room temperature for 2 hours to unify their temperature. Then the thermocouples have been inserted in the center of the samples without touching the wall of the beaker. The heating process has been carried out by placing the beaker into the homothermal water bath at 90 ºC, and the cooling process has been done at room temperature. During heating and cooling, the temperature changes in samples are recorded by the data acquisition system.

IV. RESULT AND DISCUSSION

Thermal Stability

The TGA curve of paraffin and composites samples (P1-P3) is displayed in Fig. 1. As seen from Fig. 1, the weight loss curve of paraffin suffers in one step degradation. The degradation begins at around 220ºC and finishes at around 350ºC. The TGA curve of paraffin/SEBS composites showed two-step degradation, which is typical for immiscible blends having different degradation temperatures. The first step ranged from around 250ºC to 370ºC, linked to the degradation of paraffin and the percentage of mass loss during this step indicated the quantity of paraffin mixed in the composites. The second step starts above 370ºC is corresponds to the degradation of SEBS polymer. The results revealed that the composites (P1-P3) maintain good thermal stability up to 250ºC.

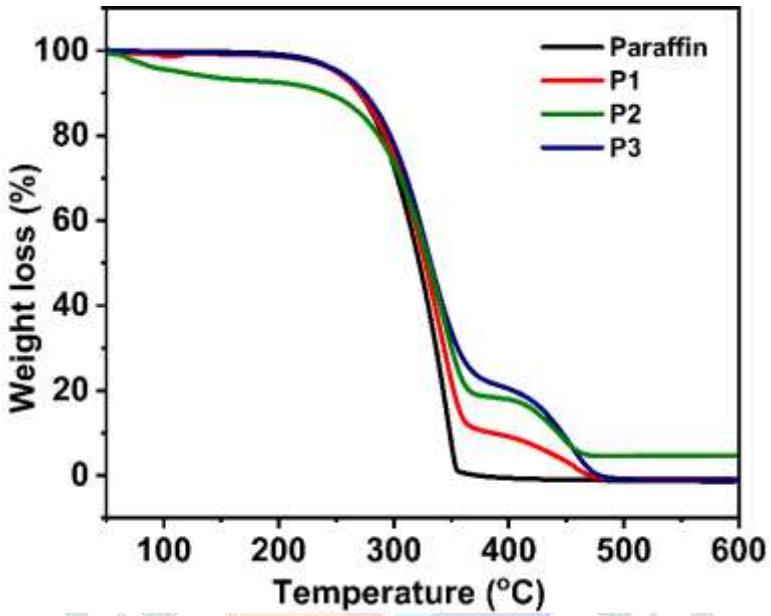

Fig. 1: TGA graph of samples

Leakage test

Results obtained from the leakage test (shown in Fig. 2) revealed that the composites P1 and P2 perform worse performance and leakage of paraffin increases with increasing the cycle number, while the sample P3 in which SEBS content was 20wt% shows negligible leakage of paraffin. The leakage rate for this sample stabilizes at about 0.38%. This low leakage may be ascribed due to the reason that paraffin in a liquid phase is successfully entered in the ethylene- butylene (EB) blocks of SEBS polymer matrix, and the styrene blocks cover the EB block from both the end, hence forming a crosslinked network, which gives certain strength to the material and restricts the chain movement of paraffin inside it, therefore minimizes the leakage issue [12].

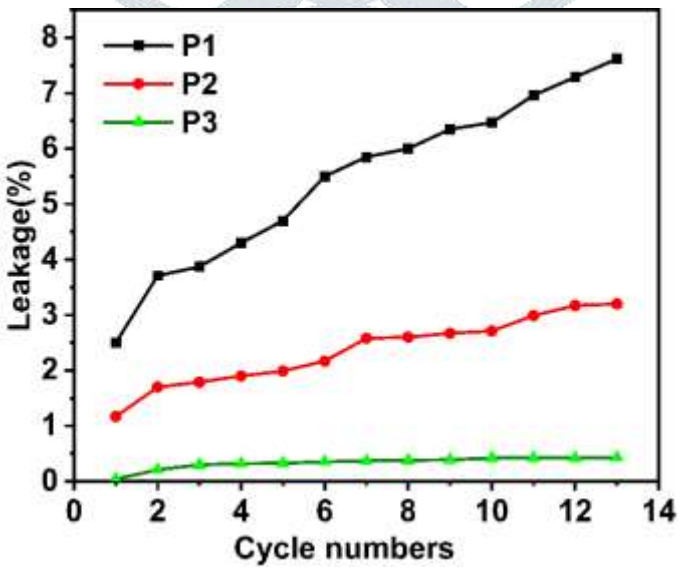

Fig. 2: Leakage rate graph of samples (P1-P3)

Latent Heat Capacity

From the DSC thermograms results (Fig. 3), the latent heat of paraffin is 225.50 J/g and that of composite P3 is 167.91 J/g. Theoretically, the enthalpy of composite PCM linearly depends on the mass fraction of paraffin and is determined by the following relation [13]

$$\Delta H_{p.Theoretical} = \varphi \, \Delta H_{paraffin}$$

Where φ is the mass fraction of the paraffin, ΔH_p is the latent heat of composite material and $\Delta H_{Paraffin}$ is the latent heat of paraffin. It can be observed that the SEBS doesn't contribute to latent heat in their paraffin/20%SEBS composites. It is worth mentioning here in the present work that the observed values of ΔH_p are in close agreement with the theoretical value. However, the investigated and theoretical values might be slightly different because of the paraffin leakage during the hot compression. Moreover, as seen from Fig. 3, SEBS hardly disturbs the phase transition of paraffin and doesn't affect the application of paraffin as PCM.

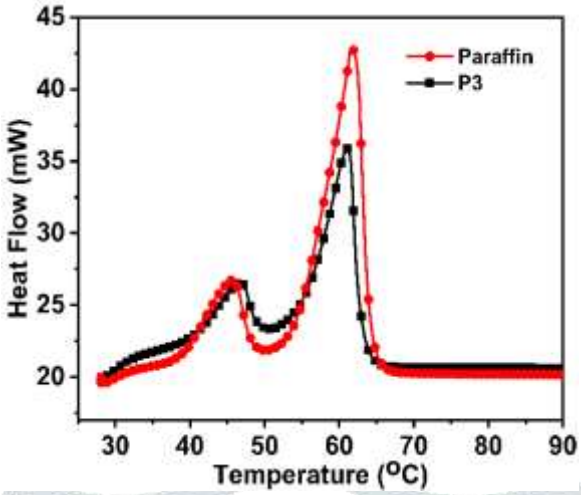

Fig. 3: DSC thermograms of paraffin and paraffin/20%SEBS (P3)

Heat transfer Performance

The temperature changes of paraffin and paraffin/20%SEBS composite during the charging and discharging process are displayed in Fig. 4a, b. During the charging process, there is no phase change in paraffin and P3 within the temperature range of 35-55°C and the temperature of these two samples rises gradually. When the temperature approaches the melting point of paraffin, heat is absorbed as latent heat; thus, the temperature increases very slowly. In this stage, the solid paraffin is transformed to a liquid phase, and a moving solid, liquid interface could be observed. Due to the buoyancy force of the melted paraffin, the natural convection in the liquid region starts to participate in heat transfer during the melting process of paraffin. On the contrary, paraffin/20%SEBS composite is able to preserve the solid morphology at the macro level even after the paraffin has melted, demonstrating the excellent shape stability of composite material.

Consequently, the natural convection strongly endorses the phase change and improves the heat transfer, which causes the time of pure paraffin to reach the completion of melting to be less than that of P3. After melting, the temperature again rises quickly due to the loss of latent heat-absorbing capacity of paraffin. The time taken by the paraffin and P3 to reach the temperature from 40 °C to 90°C was 972 and 4930 seconds. The discharging process took about 4371 and 4082 seconds to cool their temperature to the same low point. The larger time of paraffin than its composite (P3) is due to its larger latent heat. According to the above results, it can be concluded that the heating and cooling processes are mainly affected by three factors, namely thermal conduction, natural convection and latent heat absorption capacity.

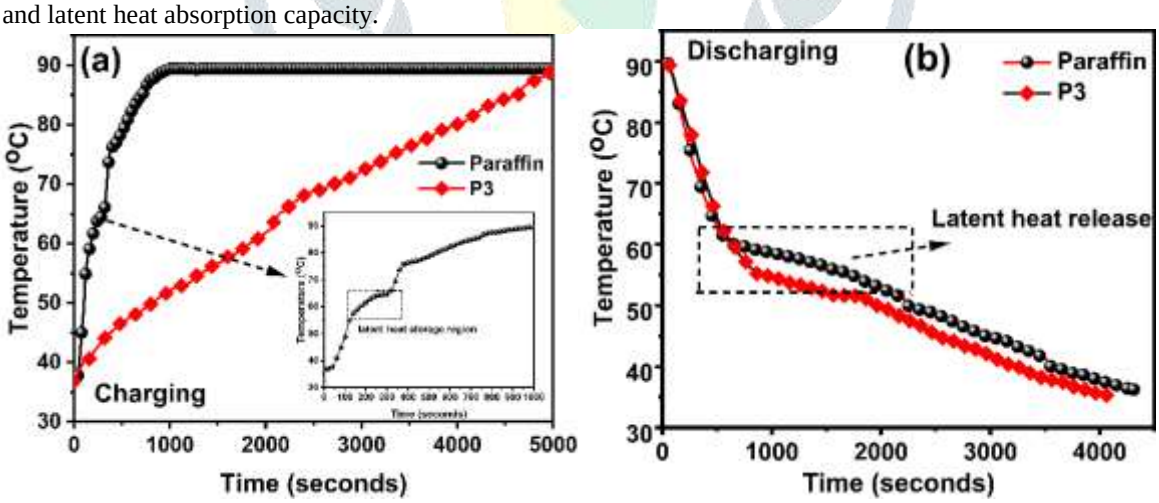

Fig. 4: (a) Charging and (b) Discharging of paraffin and paraffin/20% SEBS (P3)

V. Conclusion.

In this paper, a kind of leakage-proof SEBS/Paraffin based phase change material has been prepared by the melt mixing method. Furthermore, a TGA test has been carried out to investigate the effect of SEBS polymer on paraffin stability. Results showed that thermal stability increases with an increase in mass fraction of SEBS. DSC results confirmed that the SEBS does not affect the phase change behavior of paraffin. Moreover, the paraffin leakage has been determined through a leakage test in which composites are subjected to repeated heating and cooling cycles at 75°C. Among three samples (P1-P3), composite P3 with 20wt% of SEBS shows excellent leakage proof ability with good thermal stability. In addition, the heat transfer performance of composite has been studied and it can be concluded that the heating and cooling processes are mainly affected by three factors, namely thermal conduction, natural convection and latent heat absorption capacity. Therefore, this composite has the potential to expand its application for thermal energy storage.

VI. ACKNOWLEDGMENT

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