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Thermal Performance Evaluation of Macro-Packed Phase Change Materials (PCMs) Using Heat Transfer Analysis Device

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ABSTRACT

Use of PCMs is very difficult in liquid state because it has instability form. To solve to this basic problem, we should achieve a stability of state and shape. However, this simulation indicate thermal performance is less because in this experiment, the small amount of PCM was applied and it contributes to have less thermal performance. Therefore, we suggest macro-packed PCM to increase content in this study. The phase transitions for n-octadecane, n-eicosane, and n-docosane, occurred in 29.76 ˚C, 35.75 ˚C and 43.16 ˚C respectively, and also their heat latent is 256.5 J/g, 189.0 J/g, and 241.3 J/g. consequently, the results of experiment show: macro-packed PCMs have highest thermal performance rather than pure PCMs. Finally, due to thermal performance evaluation, the macro-packed PCMs that contain n-octadecane have useful application for final material in buildings.

Key words: Phase change materials (PCM), Macro-packed PCM, Thermal conductivity

Latent heat, Heat transfer analysis

1. INTRODUCTION

The thermal energy storage (TES) system plays a significant role to decrease the fusil fuel consumption in buildings to contribute to the high efficiency for use of energy [1,2]. It can reduce energy consumption directly and also has a good impact on environment. This system is a reliable solution to correct mismatching between supply energy and demand energy [3–5]. Latent heat thermal energy storage (LHTES) by use of PCM to save and realize energy is one of the most reliable and efficient ways to reduce energy consumption. PCMs has high energy storage capacity and properties near to isothermal phase change behavior. The PCM can

provide a high-energy storage density when it changes from a liquid to a solid phase [1]. The storage and application of heat is achieved through PCMs. This has the advantages of high heat storage density, and maintaining a stable temperature during the heat storage/release process [2]. The application of PCM in buildings not only saves energy, but also decreases the temperature fluctuation. The application of PCM in buildings has been one of the most popular topics in latent heat storage technology [8–11].

Mineral phase change materials have high latent technology heat and it contribute to developed application for thermal energy storage. In addition, PCMs have excellent heat characterize such as little or no super cooling, low vapor pressure, good thermal and chemical stability, and self-nucleating behavior [12–15].

Therefore, this study approach the macro packed PCM as a method to increase the content and effect of the PCM. The macro-packed PCM means packing bag that have been pack-aged in a visible form. The thermal properties of the macro-packed PCM were characterized using a TCi thermal conductivity analyzer, differential scanning calorimeter (DSC) and thermo gravimetric analysis (TGA). In addition, the thermal performance of the macro-packed PCM containing different PCMs was evaluated using a heat transfer analysis device.

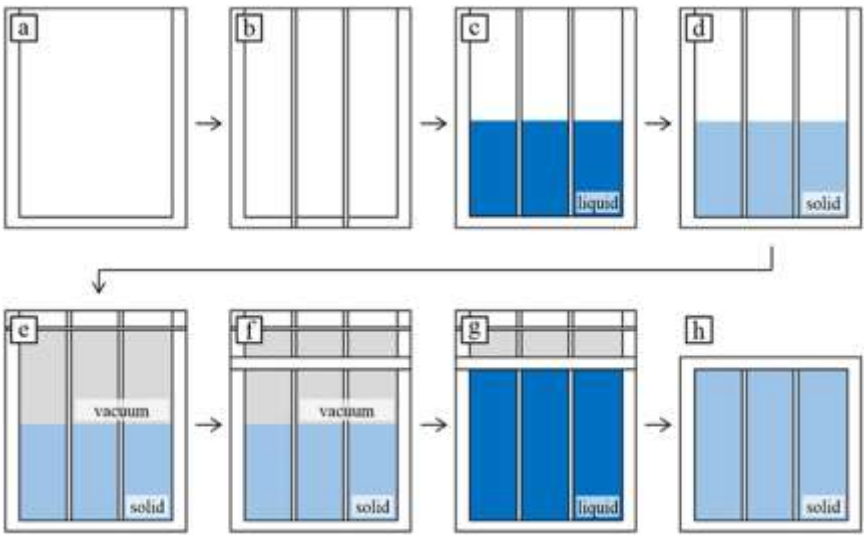

Fig. 1. Manufacturing process of the macro-packed PCM.

2. EXPERIMENTAL

2.1. Materials

The equipment and materials required for packing include vacuum packing equipment, a heat bonding machine, a nylon packing bag, and PCMs. The vacuum packing equipment is a device for the primary bonding after creating a vacuum inside the bag. The heat bonding machine device is used to divide the packing bag and to create the overall shape of the macro-packed

PCM. This study used three types of liquid paraffinic PCMs, with different melting points. The n-octadecane, n-eicosane, and n-docosane were used as the PCMs, which have melting points of 28◦C, 35◦C, and 44◦C, respectively; these PCMs were obtained from Celsius Korea, South Korea. The n-octadecane which has low melting point was selected in consideration of the application to the exterior wall. And then-docosane which has high melting point was selected in consideration of the application to where high energy radiation is applied such as roof system.

2.2. Preparation

Fig. 1 shows the manufacturing process of the macro-packed PCM. First, the empty nylon packing bag was prepared (Fig. 1(a)) by dividing it into three partitions using the heat bonding machine (Fig. 1(b)). The bag is divided into partitions to prevent the bag from tilting to one side. After melting the PCMs that solidified at room temperature, liquid state PCM is placed in the nylon packing bag which was divided into three partitions (Fig. 1(c)). PCM of 60 g is placed in each partition, and a total of 180 g was injected into the entire bag. The PCM is then solidified again while maintaining the nylon packing bag at room temperature (Fig. 1(d)). Primary packing is conducted after creating a vacuum inside the bag using the vacuum packing equipment (Fig. 1(e)), and the bag is then bonded to become a square using the heat bonding machine (Fig. 1(f)). Then, to spread the PCM that is gathered at the bottom, the PCM is again melted and laid in the packing bag (Fig. 1(g)). Finally, when the top layer is cut, the macro-packed PCM is completed (Fig. 1(h)). In addition, Fig. 2 shows the completed macro-packed PCM containing the n-octadecane, which has a melting point of 28◦C.

Fig. 2. Macro-packed PCM containing n-octadecane.

2.3. Characterization techniques

The thermal properties of the PCMs, such as their melting and freezing temperatures and latent heat capacities, were measured using differential scanning calorimetry (DSC: Q 1000).

The melting and freezing temperatures were measured by drawing a line at the point of maximum slope of the leading edge of the peak, and extrapolating to the base line [1]. The thermal conductivities of the PCMs were measured using a TCi thermal conductivity analyzer. The TCi developed by C-Therm Technologies Ltd. is a device used for conveniently measuring the thermal conductivity of a small sample using the Modified Transient Plane Source (MTPS) method [20]. The thermal durability of the PCMs was measured by thermo gravimetric analysis (TGA: TA Instruments, TGA Q5000) on samples of approximately 2–4 mg, at the temperature range of 20–600◦C and at a heating rate of 2◦C/min under a nitrogen flow of 20 ml/min. TGA was carried out with the composites placed in a high quality nitro-gen atmosphere (99.5% nitrogen, 0.5% oxygen content) to prevent unwanted oxidation [16]. Furthermore, to measure the influence of the macro-packed PCM on the peak temperature during the phase change, an experimental setup was constructed, as presented in Fig. 3. The heat source was 250 W of a far infrared radiation lamp, to imitate the solar energy performance. The heat source provided the heat for the upper room, and was kept at a distance of 300 mm. The heat was moved from the upper room to the inner room through the macro-packed PCM. The heating operation and non-heating times were each kept for 8 h and 16 h, respectively. Thermal sensors were placed in the upper room, the inner room, and the front and backsides of the macro-packed PCM to measure the temperature during the heating operation and non-heating times. Data acquisition was carried out using a data logger, LOGGER GL800 by Graphtec, in combination with a personal computer to store the data.

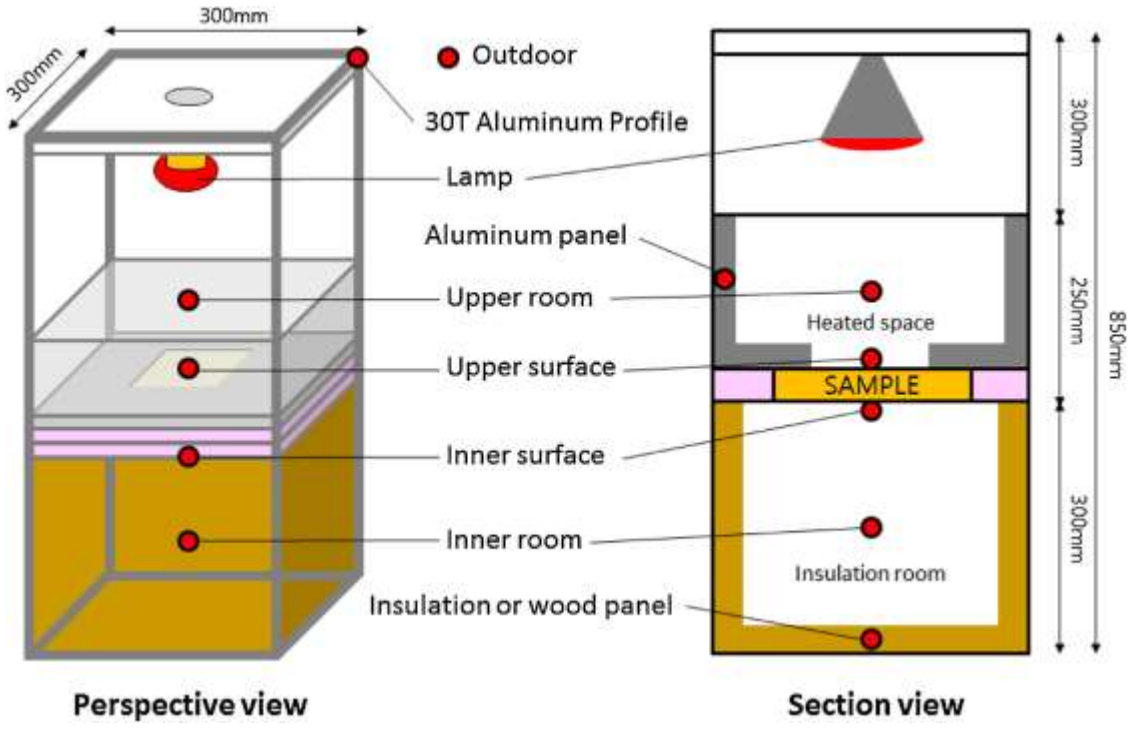

Fig. 3. Heat transfer analysis device

3. RESULTS AND DISCUSSION

3.1. Thermal properties analysis

The heating curves from the DSC measurements of the n-eicosane and n-docosane are presented in Fig. 4. DSC measurements were performed at a 5◦C/min heating rate, and a temperature range of 0–80◦C. The latent heat capacities of the PCMs were determined by numerical integration of the area under the peaks that rep-resent the solid–liquid phase transitions [2]. Table 1 shows the peak temperature and latent heats of n-octadecane, n-eicosane,and n-docosane. The phase transitions of these PCMs occurred at29.76◦C, 35.75◦C, and 43.16◦C during heating, and their latent heats were 256.5 J/g, 189.0 J/g, and 241.3 J/g. The melting point of the n-docosane is the highest, but n-octadecane has the highest latent heat. Usually, when PCMs are applied in building materials, PCMs that have the correct melting point are selected. However, itis not right, it should be considered with the latent heat.

3.2.. Thermo gravimetric analysis

TGA tests were performed to determine the percentages of impregnation of the n-octadecane, n-eicosane, and n-docosaneat temperatures ranging from 20◦C to 600◦C. Fig. 5 shows the TGA result of the n-eicosane. The n-octadecane and n-docosane have the same results. Decomposition of the n-octadecane, n-eicosane, and n-docosane started sharply at 100.0◦C and ended at around 240.0◦C. The percentages of impregnated n-octadecane, n-eicosane, and n-docosane were 98.68%, 98.63%, and 98.69%, respectively. These values are nearly 100%, and it is possible to confirm that any other mixtures are not mixed.

Table 1
Peak temperatures and latent heats of *n*-octadecane, *n*-eicosane, and *n*-docosane.

Phase change materials	Peak temperature	Latent heat
n-Octadecane	29.76 °C	256.5 J/g
n-Eicosane	35.75 °C	189.0 J/g
n-Docosane	43.16 °C	241.3 J/g

3.3. Thermal conductivity analysis

Fig. 6 shows the thermal conductivity analysis of the n-octadecane, n-eicosane, and n-docosane. The analysis indicated the thermal conductivities of the n-octadecane, n-eicosane, and n-docosane to be 0.260 W/mK, 0.248 W/mK, and 0.240 W/mK, respectively. Also, thermal conductivities of the macro-packed PCM was measured, which were 0.847 W/mK, 0.776 W/mK, and0.648 W/mK, respectively. This indicates an increase of thermal conductivity of

about 300%. The thermal conductivity analysis shows that after these PCMs were packed, the thermal conductivity was higher than pure PCMs. Generally, the increase of the thermal conductivity in buildings seems to be a disadvantage. However, it is an advantage in terms of PCM, because the low thermal conductivity of the PCM can be improved.

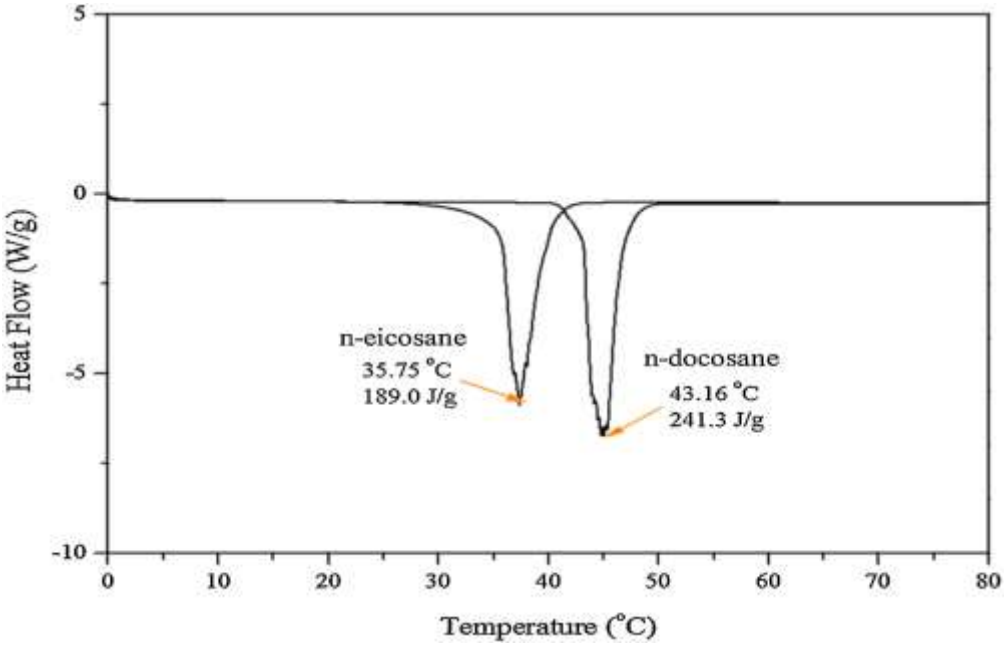

Fig. 4. DSC graphs of n-eicosane and n-docosane.

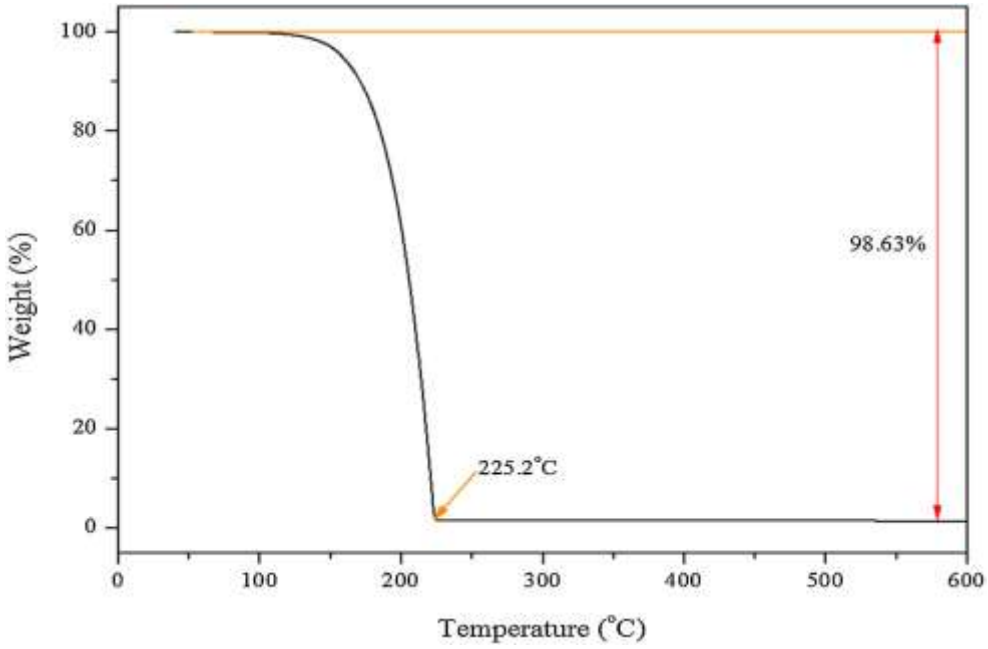

Fig. 5. TGA graph of n-eicosane.

3.4. Thermal performance evaluation

The results of the thermal performance evaluation of the macro-packed PCM containing the n-octadecane, n-eicosane, and n-docosane are presented in Figs. 7–9 respectively. The heating operation and non-heating times were 8 h and 16 h, respectively, and Fig. 7 shows the thermal characters of the macro-packed PCMs during the heating operation and non-heating of periods of 8 h.

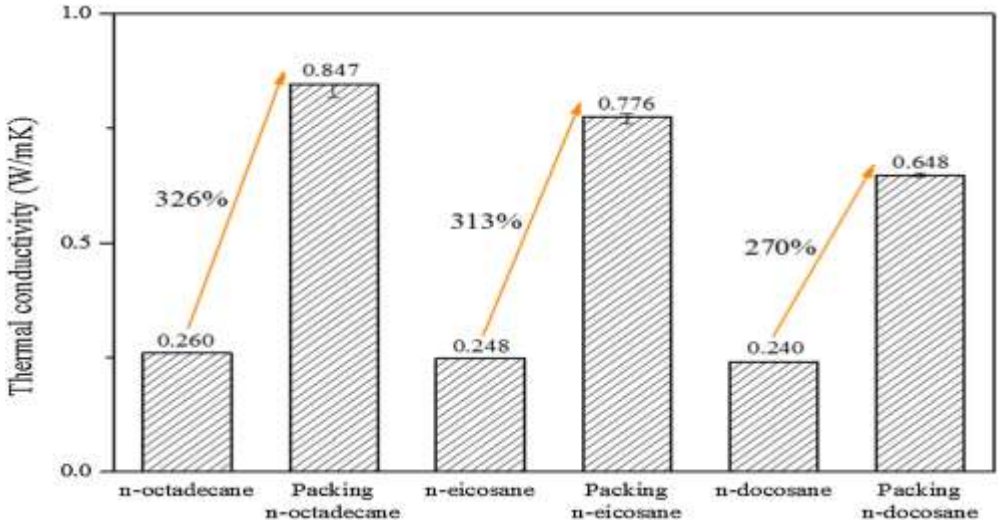

Fig. 6. Thermal conductivity of n-octadecane, n-eicosane, and n-docosane.

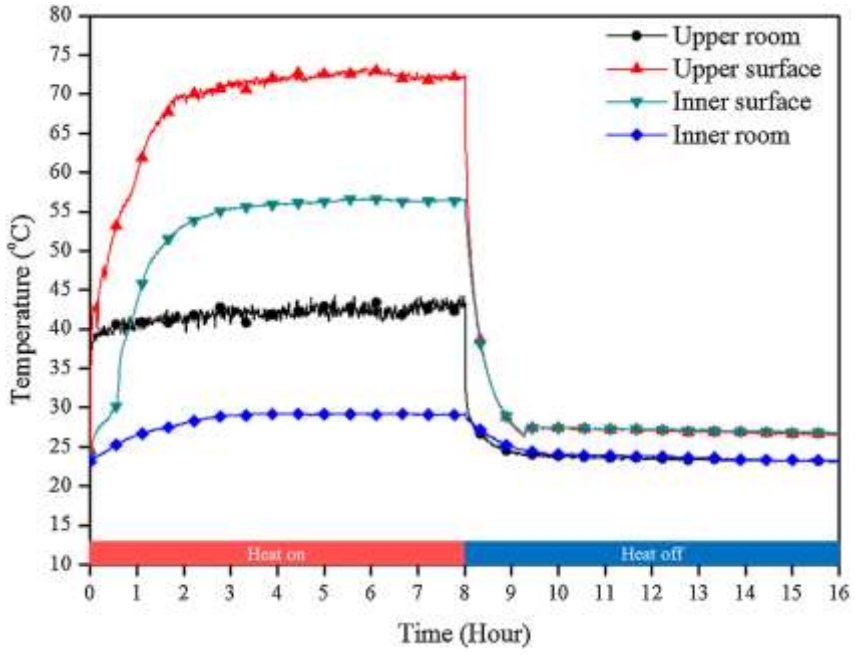

Fig. 7. Thermal behavior of the macro-packed PCM containing n-octadecane.

As shown in Fig. 8, the inner surface temperature does not change for about 1 h at 35◦C during the heating operation time. This indicates heat saving while the n-eicosane is changing phase. Also, the inner surface temperature of the macro-packed PCMs containing the n-eicosane does not change for about 4 h at 35◦C during the non-heating time. The macro-packed PCMs containing the n-octadecane (Fig. 7) and n-docosane (Fig. 9) also indicate a change of inner surface temperature at each melting point.

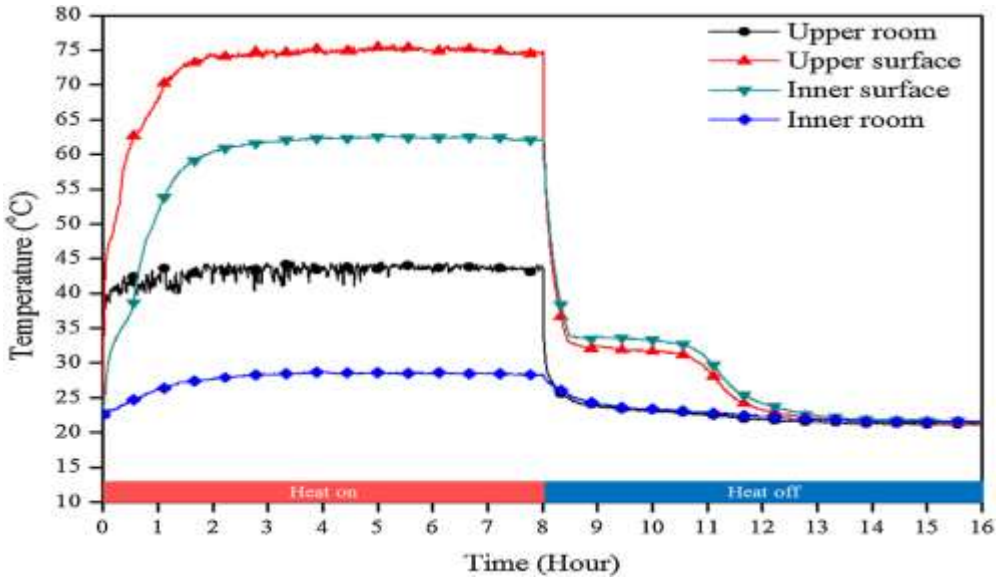

Fig. 8. Thermal behavior of the macro-packed PCM containing n-eicosane.

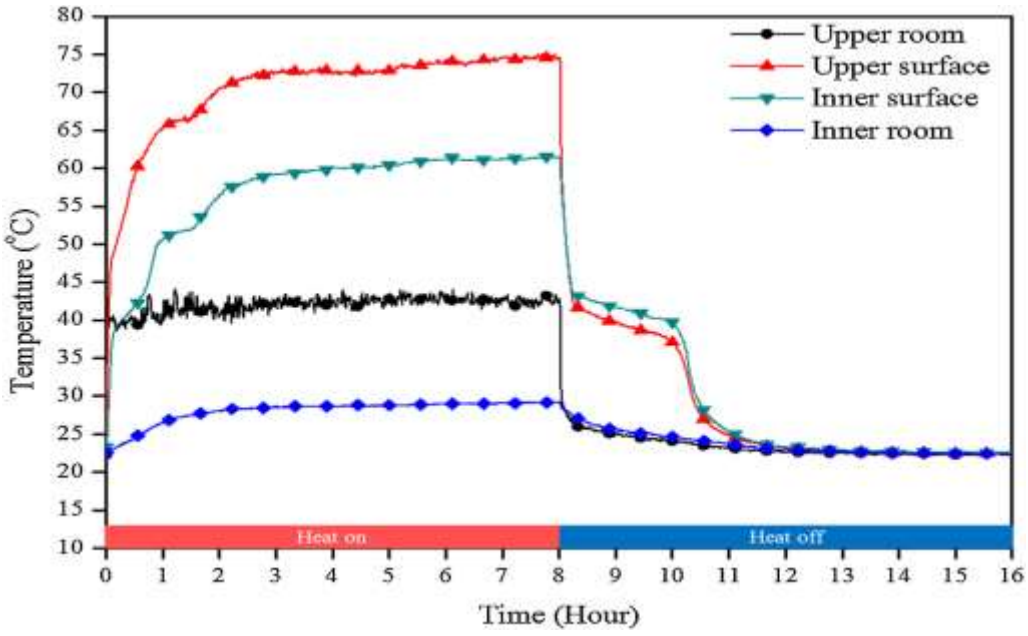

Fig. 9. Thermal behavior of the macro-packed PCM containing n-docosane.

As shown in Fig. 7, however, the inner surface temperature and upper surface temperature were maintained at 28◦C for non-heating for 8 h. This shows the continuation of the phase change of the macro-packed PCM. The result of the thermal performance of the macro-packed PCM containing the n-octadecane for non-heating for 16 h is presented in Fig. 10. After non-heating for 12 h, the inner surface temperature and the upper surface temperature decreased, and these did not change for about 10 h at 28◦C during the non-heating time. This reaction occurs because the latent heat of n-octadecane is higher than the other PCMs. Also, the time of the phase change increased because the temperature of the laboratory is similar to the melting point of the n-octadecane after the end of heating operation. In other words, applying the PCM that has a phase change temperature similar to the temperature of the application areas of buildings is most effective. The application of the n-octadecane not only prolongs the time of the phase change, it also has a considerable influence on the peak temperature. In the thermal performance comparison of macro-packed PCM containing the n-octadecane and n-eicosane, the upper room temperature is constant, but the inner surface temperature and upper surface temperature of the macro-packed PCMs containing the n-octadecane were lower. This is also because the latent heat of n-octadecane is higher than the other PCMs. Fig. 11 shows the inner room temperatures of the macro-packed PCM containing the three PCMs. The inner room temperatures decreased during 8 h of non-heating, after which these temperatures were 23.3◦C, 22.3◦C, and 21.6◦C, respectively. The inner room temperature of the macro-packed PCM containing the n-octadecane was less reduced and the reduction was slow. As this is due to the effect of the aforementioned results, the thermal performance of the macro-packed PCM containing the n-octadecane is considered to be the best.

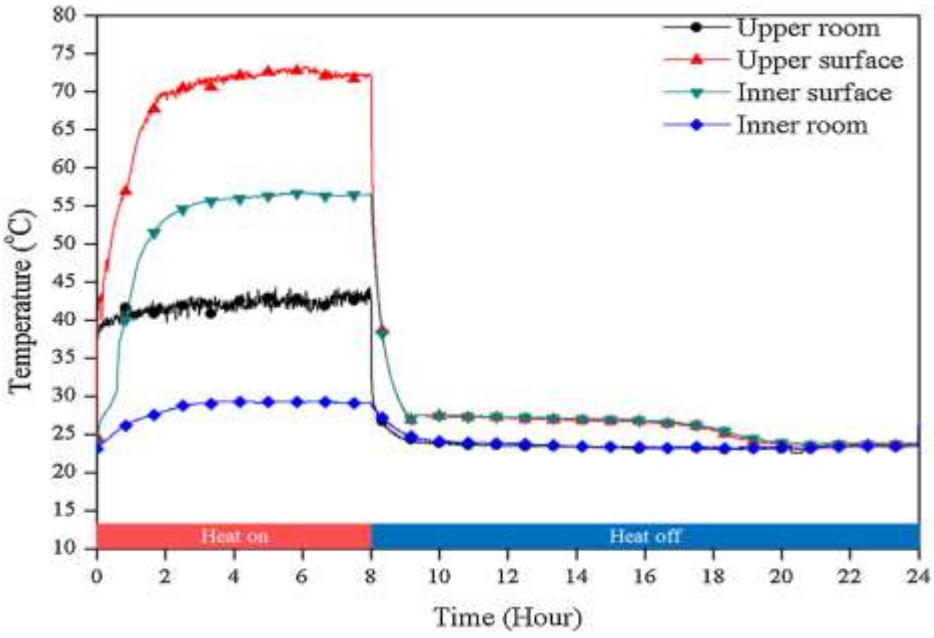

Fig. 10. Thermal behavior of the macro-packed PCM containing n-octadecane for 24 h.

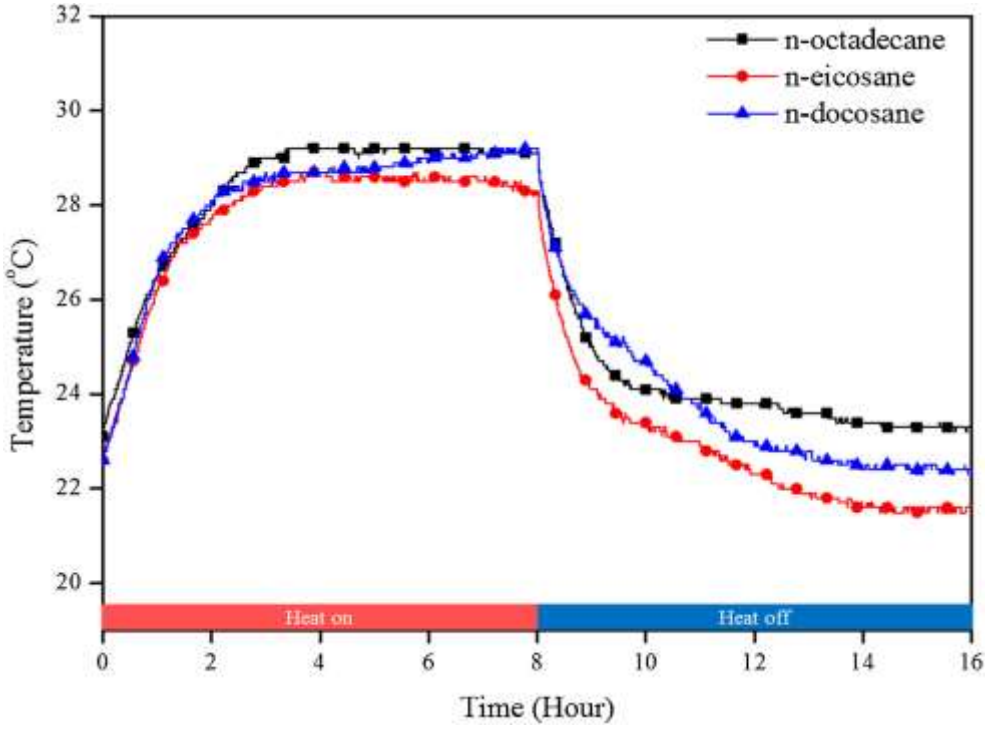

Fig. 11. Inner surface temperatures of the macro-packed PCM containing the three PCMs.

4. CONCLUSION

In this article, macro-packed PCMs that contain n-octadecane, n-eicosane, and n-docosaneused as a method to increase content and efficiency. The thermal properties of macro-packed PCMs were evaluated by TCi thermal conductivity test, DSC and TGA. Also their thermal performances were reevaluated by thermal analysis. Phase transitions were occurred at 29.76˚C,35.75˚C, and 43.16˚C during heating, and also their latent heats were 256.5 J/g, 189.0 J/g, and 241.3 J/g. N-docosane has the highest melting point, while n-octadecane has the highest latent heat. Additionally, TGA results illustrate that the percentage of impregnate PCMs are nearly 100%, and it is possible to confirm that any other mixtures are not mixed.

Thermal performance shows that when PCMs were packed have the higher thermal conductivity in compare with pure PCMs. The results of thermal performance test showed a good time-leg between the heating operation and non-heating times, and the peak temperature was reduced. Among the three PCMs, the thermal performance of the macro-packed PCM containing the n-octadecane is considered to be the best, making it useful in real applications as a finishing material in buildings.

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