Investigation of Latent heat storage system using Graphite micro particle enhancement

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Abstract: Low Temperature Energy Storage System (LTESS) store the thermal energy from the sun, exhaust gases and waste heat from industries and other Sources. Phase Changing materials are used as the energy storage medium for this system. The advantage of PCM is that, it has higher energy storage density, with low volume. The disadvantage of PCM for using as LTESS is that, the thermal conductivity of PCM is less and this requires more time period and surface area of contact, for loading and unloading of thermal energy. An solution to this problem can be incorporating Graphite Micro particles in the paraffin PCM to improve its thermal conductivity. The heat transfer of LTESS is determined experimentally. Incorporating micro-particle in the PCM has improved the heat transfer of the LTESS. Maxwell-Garnett Equation is used to determine the heat transfer of PCM and J-Type Temperature measuring Probe and Sensor Apparatus is used to determine the heat transfer experimentally. The encapsulation has increased the heat retaining ability and storage time by about 40% on average for the flow rates tested.

Keywords: Low temperature energy storage system; Thermal Energy Storage; Pentacosane; Micro Particles; Graphite.

1. Introduction

Among several ways to store thermal energy, Phase Change Materials (PCMs) are showing great potential with respect to higher storage density and lesser temperature gradient during storing and discharging. Ideal PCM possess high specific heat capacity, chemical stability, conductivity, non-toxicity, etc. Negligible sub cooling behaviour in thermal cycle offers stability. The incongruent melting of salt hydrates was also avoided. The non-corrosive nature holds a great deal of advantage for PCM in numerous applications as the storage takes place in the form of Latent heat (LHS). The stored amount of heat is estimated by following the equation (1).

$$Q = mC_p(T_2 - T_3) + m + mC_p(T_1 - T_3) \tag{1}$$

Non-renewable energies are facing a major crisis of depletion and environmental pollution. Hence renewable energy storage and waste heat recovery are receiving warm welcome for domestic and industrial purposes. Energy storage plays important roles in conserving available energy and improving its utilization, since many energy sources are intermittent in nature. Short term storage of only a few hours is essential in most applications. The use of Phase Change Materials as latent heat storage medium is an effective way of storing thermal energy. PCMs offer the advantages of having high energy storage density and its isothermal nature.

2. Literature Review:

The PCM with micro encapsulation prepared with different shells are compared for their thermo-physical properties [1]. The mass ratio of encapsulation for better performance was identified

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to be 1:3. The graphite was used as an extended energy storage enhancement tool in using PCM for recovering industrial waste heat [2]. The optimal ratio of designing spiral coil was investigated for better storage efficiency. Double coil tube is 25.3% shorter than that in the LTES system with single coil tube. When it comes to the case of 95wt% of composite PCM, a reduction of 13.3% in the melting time is obtained. In combination with flake graphite, erithytol and mannitol were added to form a eutectic composite with PCM [3]. The value of enthalpy decreases with increasing the content of graphite in controversy with conductivity of composite. When 3.0 wt% graphite was added, the super cooling degree could be alleviated to 62.6 °C with the ΔcrH of 185.7 J/g. Tetradecane combined with graphite in an air conditioning system was proposed and analysed using Aspen plus software [4]. The results revealed a 30% reduction in CO2 emission and compressor size. The paraffin could be stabilized using wood flour for energy storage application [5]. The stabilization was caused by the micro pores and expanded graphite reduced the interface bonding. Another attempt of improving stability by adding wood and graphite was carried out successfully [6]. Conductivity of the composite improved to 65 W/m K. Building energy wasted during the day time was used for room heating during nights with the help of Polyethylene glycol, graphite & PCM [7]. The fluctuation in demand has been met by using this composite. Solar heating system was studied for various applications in domestic purposes [8–10].

Vacuum impregnation method was used for adding expanded graphite with n-octadecane to form composites for heat energy management [11]. Char obtained from bones possess promising qualities for using as energy storage enhancement in solar applications [12]. A 100 thermal cycle tests revealed the stability of composite formed. Available heat energy of the building could be stored and reused for room heating during night time in winter seasons [13]. Expanded graphite and HDPE additives improved thermal conductivity to 0.6698 W /m K. The structural and thermal stability of expanded graphite with PCM was studied earlier [14]. 10% mass proportion of EG in PCM had improved thermal properties greatly. Recently, carbon nanotubes have been introduced into many applications including thermal energy storage [15]. The reliability and thermal durability was considerably improved with ease of compatibility to specified applications. Similarly the storage was extended by fast charging capability with the influence of expanded graphite [16].A 7 time faster charging was achieved with 30% stored energy loss was encountered while following this methodology. The solar application performance was investigated with the PCM composite containing flake graphite in the form of thin films [17–19]. A conversion efficiency raise of 13% was achieved in solar still, while the water height decreased from 2 to 0.5cm.

Various applications and thermal conductivity enhancements were studied further and are reported [20]. The differential scanning calorimetry was proposed for estimating the specific heat capacity of different PCM composites [21]. The values estimated were within acceptable range of <3% error when compared with other traditional methods. The principles and properties in selecting suitable PCM was provided as a guide for high temperature applications [22]. Few more researches were conducted in evaluating the performance of PCM with different additives and enhancing medium [23–26]. This work proposes a novel attempt in using flake graphite with pentacosane phase change material for quicker storing and retaining of energy for longer time period. The energy wasted in the hot water/steam from cooking could be recovered using this method and placed to use later.

3. Materials and Methods

The phase change material chosen for this experimentation is Pentacosane Paraffin wax ($C_{25}H_{52}$). It has a good heat storage capacity of 2.9 kJ/kg K and latent heat of fusion as 214kJ/kg. The drywall modification is making use of this property of paraffin wax, as the thermal cycle enables it to absorb and discharge heat energy in a day. The melting point was measured to be 59 ℃ having a density of 850kg/m^3 at an ambient condition of 32℃ temperature and atmospheric pressure. Thermal conductivity varies from 04W/m℃ & 0.15 W/m℃ in solid and liquid state respectively. It was used in cooling of electronic components in Lunar Rover in combination with retractable radiator. The micro particle copper oxide was chosen because of its high thermal conductivity, electrical conductivity, and catalytic nature for maintaining the homogeneity of materials in mixture. These properties in particular

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will be helpful in storing higher heat energy in shorter time period and space.

Micro particles are sized between 0.1 and 200 μm. Commercially micro particles are available in a wide variety of size, type, nature, etc. They have larger surface-to-volume ratio and behave quite differently according to their environment. Natural Graphite is a mineral consisting of graphitic carbon. It varies considerably in crystalline. A SEM image of the graphite used in this work is shown in figure 1. Flake like crystal structure ensures that the micro particle used is graphite. Froth floatation technique is used for increasing the concentration of mined graphite. It possesses a melting temperature of 3650°C and good thermal conductivity.

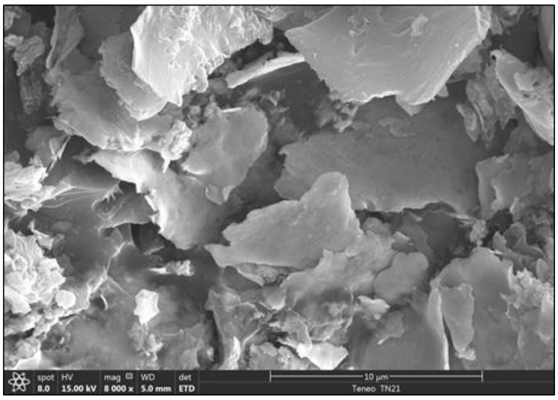

Figure 1. SEM analysis of Graphite

The schematic layout of experimental setup used for this experimentation is shown in figure 2. The PCM with micro particle is placed in the cylinder for evaluation during the operating cycle. Temperatures were noted for the PCM composite at three intermittent positions in cylinder using J type thermocouple having a measuring range of -210°C to 760°C. The setup consists of flow meter to monitor the flow rate of water, valves to control the flow, a geyser for producing hot water and a cold water collector.

WORKING METHODOLOGY:

a) Charging process

Water is the heat transfer and sensible heat fluid, flowing through the coils inside cylinder having PCM. During charging process, hot water flows into the cylinder and transfers energy to PCM. Initially the system is in complete equilibrium with the environment and up on working, the temperature of PCM increases to 65±1 °C. The PCM starts to get heated up and melts to store energy sensibly. Charging is carried for about an hour (equilibrium between PCM & hot water) and temperature is noted for every 10 minutes interval at different locations.

b) Discharging process

Discharging is done by means of batch wise process. While taking readings for discharging the cold water is given through inlet and heat stored in paraffin wax is transferred to cold water and hot water is given through outlet. Here a defined amount of hot water is released from the tank and mixed with cold water (at 32^0 C) to get the required hot water of 27 liters at an average of 45±0.5°C for direct use and the tank is again filled with cold water of quantity equal to the amount of water withdrawn. The water flow at three different flow rates (5, 10 & 15 liters per minute) were used for the analysis.

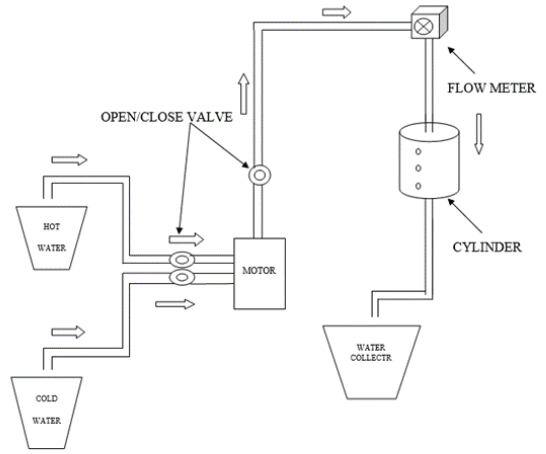

Figure 2. Experimental setup layout indicating all the components

3. Results

The reading has taken for improving Thermal Conductivity by means of micro particle encapsulation of Graphite in PCM. The difference in energy is used for heating and cooling water.

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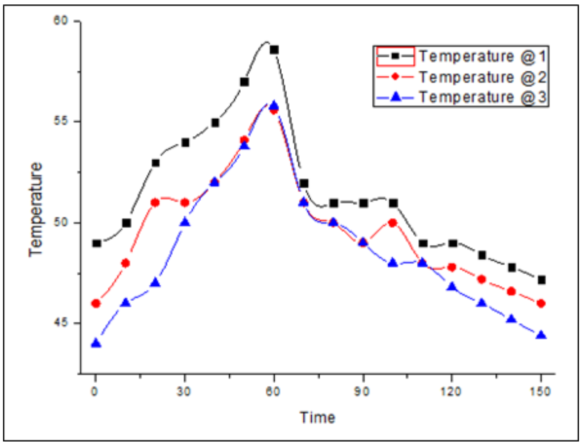

Figure 3. *PCM + Graphite at 5lpm*

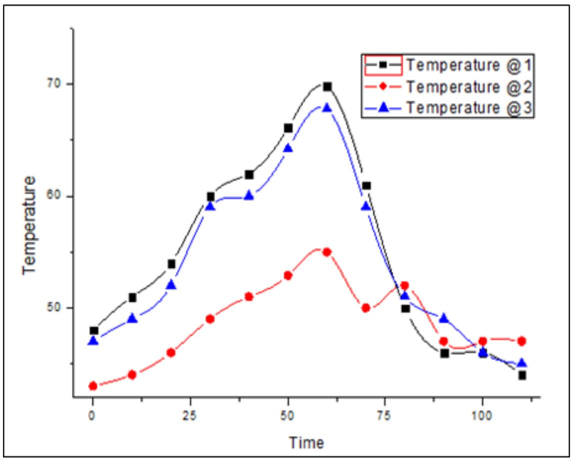

Figure 5. *PCM + Graphite at 15 lpm*

The temperatures at different positions inside cylinder is noted and the time-temperature plot is shown in figures 3 – 5, for all the flow rates. Based on the figures, higher flow rate increases the PCM temperature at position 1. Higher contact time improves the body temperature of PCM and melts it. The experiment was conducted till the equilibrium is attained or water temperature is same in the operation. The drop in temperature is steady for the flow rate of 5lpm, and drastically changes for higher flow rates.

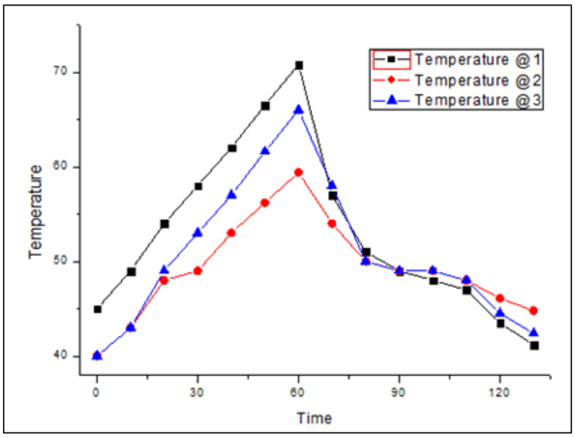

Figure 4. *PCM + Graphite at 10 lpm*

4. Discussion

The heat energy stored and released during the operation cycle is shown in figures 6 – 8 for the three different flow rates. From the figures, it is clearly visible that the heat energy retaining ability of PCM increases with graphite encapsulation. The changes in viscosity of PCM with inclusion of graphite has influenced the heat storing ability. The time period of attaining equilibrium is longer by the addition of graphite. The amount of heat energy during discharging process is higher compared to the plane PCM liberation. This is achieved by the thermal conductivity enhancement and porous nature of crystal. Highest amount of heat transfer of 118 kW is obtained for the flow rate of 15 lpm. For all flows, the heat is retained for 60 minutes of time period in operating with plane pentacosane. Presence of graphite in the structure of wax, retards the heat evolution from PCM during discharging. Hence, it is evidential that heat energy can be stored for a prolonged period by embedding micro metal oxides. Based on the results, the retaining time was extended by 30 minutes to 90 minutes for all flow rates of heat transfer fluid.

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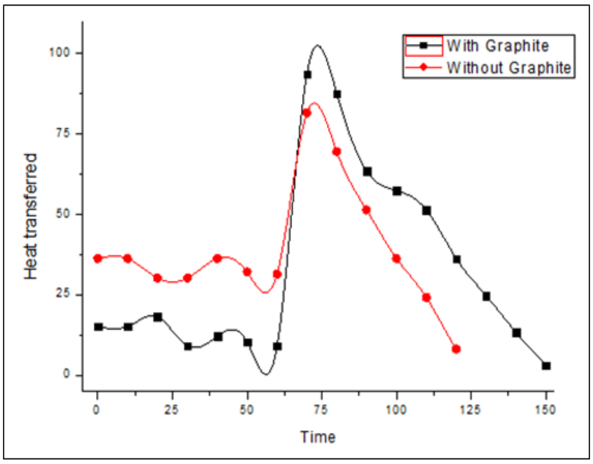

Figure 6. *Flow rate of 5 l/min*

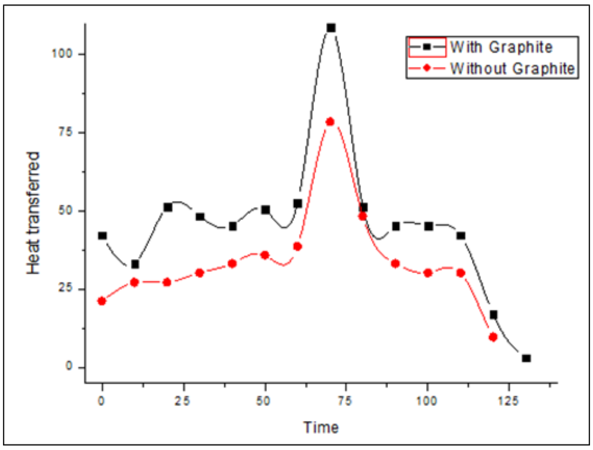

Figure 7. *Flow rate of 10 l/min*

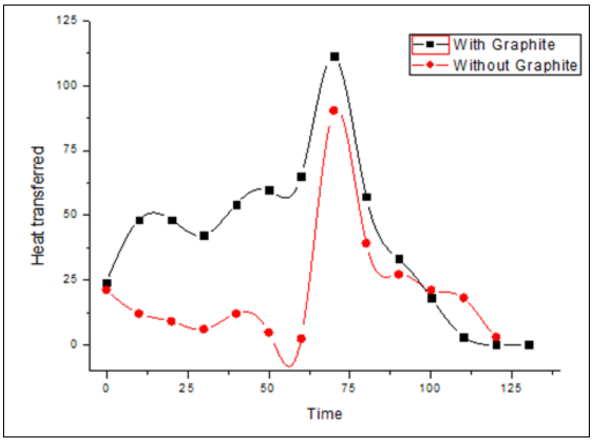

Figure 8. *Flow rate of 15 l/min*

5. Conclusions

The experimentation is conducted in the designed layout for evaluating the heat energy storing ability of pentacosane paraffin wax. The experiments were conducted for three different flow rates of heat transfer fluid. The thermal conductivity and stability of PCM is increased by the addition of graphite. Naturally available heat energy is stored as latent heat has proven to be effective in reducing the cost and waste of energy. An inbuilt thermal storage could result in efficient way of designing solar water heaters with less complexion in design. The experimental results revealed that heat retaining ability and storage time increases about 40% (on average) by encapsulating graphite micro particle into the PCM.

References

1. Giro-Paloma, J.; Alkan, C.; Chimenos, J.; Fernández, A. Comparison of Microencapsulated Phase Change Materials Prepared at Laboratory Containing the Same Core and Different Shell Material. *Appl. Sci.* **2017**, *7*, 723, doi:10.3390/app7070723.
2. Zheng, X.; Xie, N.; Chen, C.; Gao, X.; Huang, Z.; Zhang, Z. Numerical investigation on paraffin/expanded graphite composite phase change material based latent thermal energy storage system with double spiral coil tube. *Appl. Therm. Eng.* **2018**, *137*, 164–172, doi:10.1016/j.applthermaleng.2018.03.048.
3. Zeng, J. L.; Chen, Y. H.; Shu, L.; Yu, L. P.; Zhu, L.; Song, L. Bin; Cao, Z.; Sun, L. X. Preparation and thermal properties of exfoliated graphite/erythritol/mannitol eutectic composite as form-stable phase change material for thermal energy storage. *Sol. Energy Mater. Sol. Cells* **2018**, *178*, 84–90, doi:10.1016/j.solmat.2018.01.012.
4. Aljehani, A.; Razack, S. A. K.; Nitsche, L.; Al-Hallaj, S. Design and optimization of a hybrid air conditioning system with thermal energy storage using phase change composite. *Energy Convers. Manag.* **2018**, *169*, 404–418, doi:10.1016/j.enconman.2018.05.040.
5. Guo, X.; Zhang, S.; Cao, J. An energy-efficient composite by using expanded graphite stabilized paraffin as phase change material. *Compos. Part A Appl. Sci. Manuf.* **2018**, *107*, 83–93, doi:10.1016/j.compositesa.2017.12.032.
6. Huang, Z.; Luo, Z.; Gao, X.; Fang, X.; Fang, Y.; Zhang, Z. Preparation and thermal property analysis of Wood's alloy/expanded graphite composite as highly conductive form-stable phase change material for electronic thermal management. *Appl. Therm. Eng.* **2017**, *122*, 322–329, doi:10.1016/j.applthermaleng.2017.04.154.
7. Zhang, D.; Chen, M.; Liu, Q.; Wan, J.; Hu, J. Preparation and thermal properties of molecular-bridged expanded graphite/polyethylene glycol composite phase change materials for building energy conservation. *Materials (Basel).* **2018**, *11*, doi:10.3390/ma11050818.
8. Chinnarasu, K.; Ranjithkumar, M.; Lakshmanan, P.; Hariharan, K. B. Analysis of Varying Geometri Structures of Fins using Radiators. **2018**, *11*, 115–

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119.
9. T. Avudaiappan, V. Vijayan, S. Sundara Pandiyan, M. S. and S. D. Potential Flow Simulation through Lagrangian Interpolation Meshless Method Coding. *J. Appl. Fluid Mech.* 2018, *11*, 129–134.
10. R. Srinivasan, V. V. and K. S. Computational Fluid Dynamic Analysis of Missile with Grid Fins. *J. Appl. Fluid Mech.* 2017, *10*, 33–39.
11. Xia, Y.; Cui, W.; Zhang, H.; Zou, Y.; Xiang, C.; Chu, H.; Qiu, S.; Xu, F.; Sun, L. Preparation and thermal performance of n-octadecane/expanded graphite composite phase-change materials for thermal management. *J. Therm. Anal. Calorim.* **2018**, *131*, 81–88, doi:10.1007/s10973-017-6556-1.
12. Wen, R.; Jia, P.; Huang, Z.; Fang, M.; Liu, Y.; Wu, X.; Min, X.; Gao, W. Thermal energy storage properties and thermal reliability of PEG/bone char composite as a form-stable phase change material. *J. Therm. Anal. Calorim.* **2018**, *132*, 1753–1761, doi:10.1007/s10973-017-6934-8.
13. Tang, Y.; Lin, Y.; Jia, Y.; Fang, G. Improved thermal properties of stearyl alcohol/high density polyethylene/expanded graphite composite phase change materials for building thermal energy storage. *Energy Build.* 2017, *153*, 41–49, doi:10.1016/j.enbuild.2017.08.005.
14. Li, Y.; Yan, H.; Wang, Q.; Wang, H.; Huang, Y. Structure and thermal properties of decanoic acid/expanded graphite composite phase change materials. *J. Therm. Anal. Calorim.* **2017**, *128*, 1313–1326, doi:10.1007/s10973-016-6068-4.
15. Karaipekli, A.; Biçer, A.; Sarı, A.; Tyagi, V. V. Thermal characteristics of expanded perlite/paraffin composite phase change material with enhanced thermal conductivity using carbon nanotubes. *Energy Convers. Manag.* 2017, *134*, 373–381, doi:10.1016/j.enconman.2016.12.053.
16. Ghasemi Bahraseman, H.; Languri, E. M.; East, J. Fast charging of thermal energy storage systems enabled by phase change materials mixed with expanded graphite. *Int. J. Heat Mass Transf.* 2017, *109*, 1052–1058, doi:10.1016/j.ijheatmasstransfer.2017.02.078.
17. Sharshir, S. W.; Peng, G.; Wu, L.; Essa, F. A.; Kabeel, A. E.; Yang, N. The effects of flake graphite nanoparticles, phase change material, and film cooling on the solar still performance. *Appl. Energy* 2017, *191*, 358–366, doi:10.1016/j.apenergy.2017.01.067.
18. Cheng, F.; Wen, R.; Huang, Z.; Fang, M.; Liu, Y.; Wu, X.; Min, X. Preparation and analysis of lightweight wall material with expanded graphite (EG)/paraffin composites for solar energy storage. *Appl. Therm. Eng.* 2017, *120*, 107–114, doi:10.1016/j.applthermaleng.2017.03.129.
19. Yang, H.; Wang, Y.; Liu, Z.; Liang, D.; Liu, F.; Zhang, W.; Di, X.; Wang, C.; Ho, S. H.; Chen, W. H. Enhanced thermal conductivity of waste sawdust-based composite phase change materials with expanded graphite for thermal energy storage. *Bioresour. Bioprocess.* 2017, *4*, doi:10.1186/s40643-017-0182-4.
20. Lin, Y.; Jia, Y.; Alva, G.; Fang, G. Review on thermal conductivity enhancement, thermal properties and applications of phase change materials in thermal energy storage. *Renew. Sustain. Energy Rev.* 2018, *82*, 2730–2742, doi:10.1016/j.rser.2017.10.002.
21. Ferrer, G.; Barreneche, C.; Solé, A.; Martorell, I.; Cabeza, L. F. New proposed methodology for specific heat capacity determination of materials for thermal energy storage (TES) by DSC. *J. Energy Storage* 2017, *11*, 1–6, doi:10.1016/j.est.2017.02.002.
22. Wei, G.; Wang, G.; Xu, C.; Ju, X.; Xing, L.; Du, X.; Yang, Y. Selection principles and thermophysical properties of high temperature phase change materials for thermal energy storage: A review. *Renew. Sustain. Energy Rev.* **2018**, *81*, 1771–1786, doi:10.1016/j.rser.2017.05.271.
23. Xu, T.; Li, Y.; Chen, J.; Liu, J. Preparation and thermal energy storage properties of LiNO3-KCl-NaNO3/expanded graphite composite phase change material. *Sol. Energy Mater. Sol. Cells* 2017, *169*, 215–221, doi:10.1016/j.solmat.2017.05.035.
24. Ye, R.; Lin, W.; Yuan, K.; Fang, X.; Zhang, Z. Experimental and numerical investigations on the thermal performance of building plane containing CaCl2·6H2O/expanded graphite composite phase change material. *Appl. Energy* 2017, *193*, 325–335, doi:10.1016/j.apenergy.2017.02.049.
25. Li, C.; Xie, B.; Chen, J.; Chen, Z.; Sun, X.; Gibb, S. W. H2O2-microwave treated graphite stabilized stearic acid as a composite phase change material for thermal energy storage. *RSC Adv.* 2017, *7*, 52486–52495, doi:10.1039/c7ra11016b.
26. Liu, S.; Han, L.; Xie, S.; Jia, Y.; Sun, J.; Jing, Y.; Zhang, Q. A novel medium-temperature form-stable phase change material based on dicarboxylic acid eutectic mixture/expanded graphite composites. *Sol. Energy* **2017**, *143*, 22–30, doi:10.1016/j.solener.2016.12.027.

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