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Optimizing the Thermal Energy Storage Performance through Nanostructured Phase Change Materials for Medium Temperature Applications

Abstract: - The current generation of electricity from renewable resources is insufficient to attain the present worldwide need for energy. The main purpose is to bring more than one updated technique that could build the space in energy distribution. One of the most widely used materials is phase change materials (PCM). Recently energy storage research has been improved PCM is a natural phase transition material, which can be combined with energy storage total systems to conserve renewable energy. Due to their low thermal conductivity, the practical application of organic PCM is limited to thermal energy storage. To overcome this drawback, in this study, D-mannitol PCM and various proportions of nanoparticles (silicon carbide) were used as matrix and heat conduction enhancers of phase change materials (PCMs), respectively. The primary objective of D-mannitol when used as a Phase Change Material (PCM) is to store and release thermal energy efficiently. This compound is particularly valuable in applications requiring temperature regulation, such as enthalpy storage. The data presented suggests that D-Mannitol, a phase change material (PCM), was subjected to measurements of its melting point and enthalpy of fusion using Differential Scanning Calorimetry (DSC). At a heating rate of 10°C/min, the melting process reached its peak at 174°C, with an enthalpy of fusion of 326.8 J/g. The assessment of thermal conductivity using a laser flash test revealed a significant increase from 0.7 W/m·K to 1.9 W/m·K upon the incorporation of nanoparticles into the PCM. High-resolution transmission Electron Microscopy (HRTEM) and X-ray diffraction (XRD) were employed for structural and morphological analyses of the nanocomposite PCM. This marked enhancement in thermal conductivity indicates that D-Mannitol nano PCM is highly suitable for intermediate heat applications.

Keywords: Enthalpy Energy storage, State change material, Nanomaterial, DSC, XRD, HRTEM.

I. INTRODUCTION

Electricity demand has risen in recent years due to high energy use in the domestic and industrial sectors. Fossil fuels have supported and satisfied all human energy needs for a long time. These fossil fuels have wreaked havoc on the atmosphere, causing global warming with a focus on phase change materials (PCMs). As the name implies, the purpose of ES is to store a specific type of energy, which can be used later if necessary. The term "energy storage unit" refers to a device that can be used to store some energy. The most promising combination is LHS and PCMs. There are a variety of uses for paraffin [5].

1.1 Thermal Storage with PCMs

The solid-liquid PCMs act like traditional sensible heat storage materials below the phase transition temperature. Through the remainder of the heat storage unit board, the barrier layer protects from heat leakage to the given environment [1]. A quantum amount of research in phase change materials (PCMs) for thermal energy storage was carried out. Thermal energy storage systems are usually used to control temperature equivalence in temperature-targeted areas. PCMs will take a huge amount of energy until the temperature outside is more than the phase transition temperature [2-4]. The preparation of the nanocomposite process was studied and analyzed [5].Then a considerable shift occurs in temperature with increasing heating/cooling percent of temperature. The ratio between these heating and cooling enthalpy plots is greater than 0.5 K, even at the lowest rates. The mathematical expression of thermal energy PCM was found successfully [6]. Then its energy storage density of latent heat is also much higher than other materials. The temperature differential between storing and releasing heat was kept as low as possible [7]. The material properties of PCM were roughly examined using DSC and low-cost unconventional techniques (T-history and T-melting CHF) [8-9] In our daily lives, PCM is a promising material for energy storage.[10]

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1.2 Phase Change Transition of PCM

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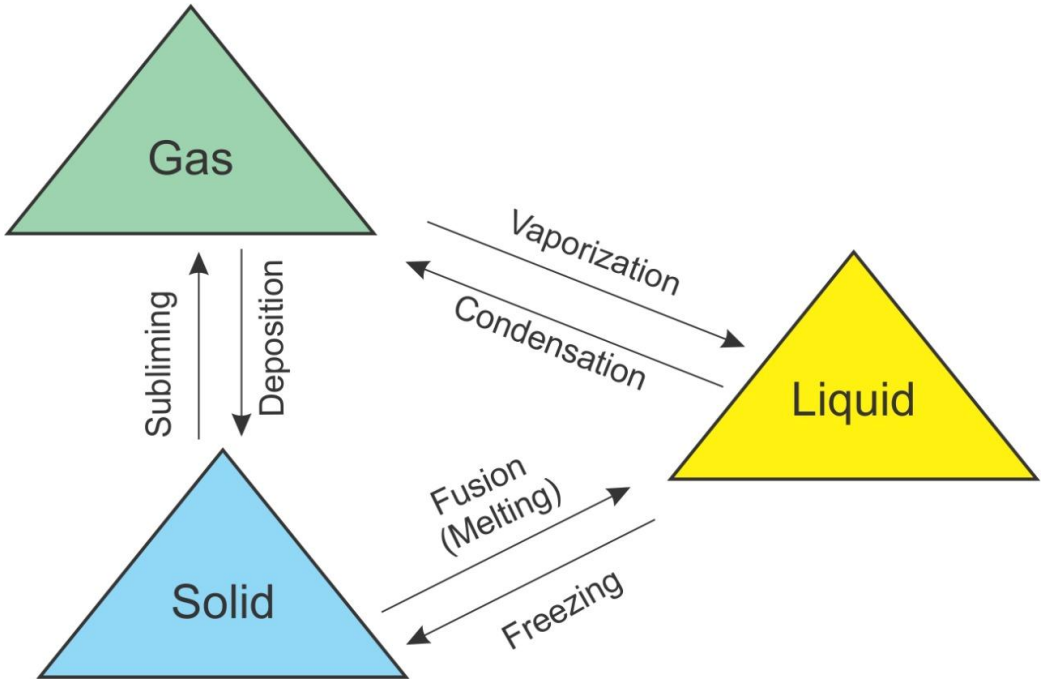

Figure 1

Fig 1. Shows phase transitions involve enthalpy changes because energy is either absorbed or released when the substance changes from one phase to another, reflecting the difference in enthalpy between the phases. The names of the phase transitions between solids, liquids, and gases.. A typical solid-liquid PCM system is depicted in Fig. 1. The PCM was created in a solid state at first.

The behavior of phase change materials (PCMs). These materials absorb and release large amounts of energy when they change between solid and liquid states, which helps in maintaining a nearly constant temperature in their surroundings.[10]

1.3. Selection of PCM and Nano Particles

Essentially, to enhance the material's performance and adaptability, higher thermal conductivity nanoparticles are combined with the states-changing substance. When done in this manner, the material has a higher capacity to absorb thermal energy, which raises the temperature of the TEG material and increases the voltage. Because Silicon Carbide (SiC) has a greater thermal conductivity than D-Mannitol, we are explicitly using SiC as the nanoparticle in conjunction with the state-changing material [11]. The objective is to create nanocomposite PCM. The PCM is D-mannitol, while the nanomaterial is silicon carbide. This PCM has the capacity to capture solar thermal energy and store it as energy. XRD, DSC, HR TEM, and other testing procedures are utilized to assess the nanocomposite.

II. Real Time Study

2.1 Material

This experimental section uses D- mannitol PCM and Silicon carbide nanomaterial.

2.2 D –Mannitol

Organic chemical-based phase change material (PCM holds thermal energy as latent heat in its crystalline form. On altering this phase, latent heat may be released or absorbed, and it only occurs at the ambient temperature within the system being controlled. Its normal melting point of D-Mannitol is 167.8 °C. The melting point and decomposition indicate that the D-Mannitol has a latent heat of 326.8 kJ /kg-1. The nominal phase change temperature of D-Mannitol is 120˚C, making it ideal for heating and cooling thermal applications. Some of the applications of D-Mannitol are chemically and thermally stable and organic material [11-12].

2.3. Nanoparticles

The size of silicon carbide nanoparticles is 50 nm. In order to improve the PCM's operating temperature execution and stabilize the characteristics of the stage-evolving substance (D-Mannitol), nanoparticles were utilized. The dispersion of nanoparticles into the base material resulted in a disgusting merging of the particles with PCM, which caused the particles to settle at the base of the holder.[13]

III. An Overview of Preparation of Nanocomposite PCM

Figure 2. Preparation of Nanocomposite PCM

Fig.2 depicts a high-level overview of the Nanocomposite Phase Change Material synthesis process. D-Mannitol is a pure organic phase change material with a Medium melting point. The material was kept in separate ovens at 200 ° for different periods to change it from a solid to a liquid state. After the material was liquified, a SiC nanoparticle was added to the PCM. After that, it was kept in a magnetic stirrer at warm heat for a few hours. It was sonicated for an hour after the process was completed. Under the DSC, HR TEM, and XRD, the synthesis now samples was completed. The steps in the synthesis process are listed below in Fig. 3, which shows the process flow of Nanocomposite PCM.

3.1. Preparation of Nanocomposite D Mannitol PCM

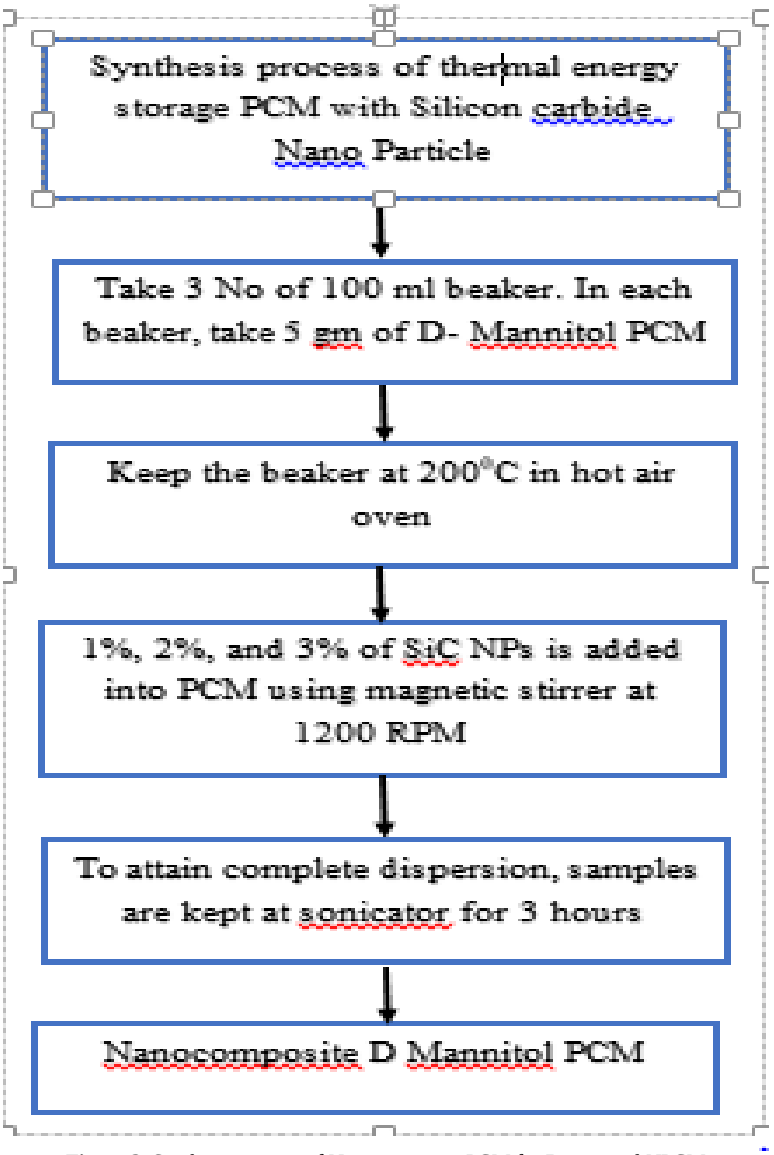

Figure 3. Synthesis process of Nanocomposite PCM for D mannitol NPCM

IV. CHARACTERIZATION

4.1 Morphological Analysis

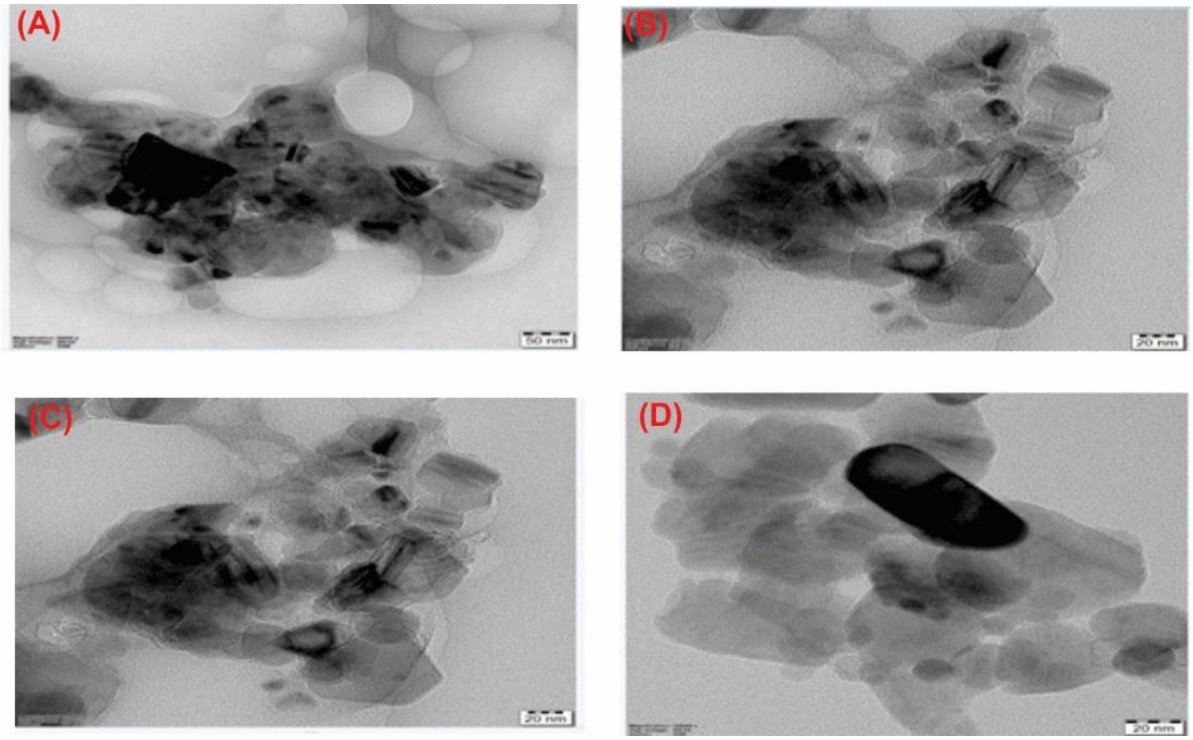

Figure 4.1 A, B, C, D -Morphological image of D-Mannitol Nanocomposite PCM

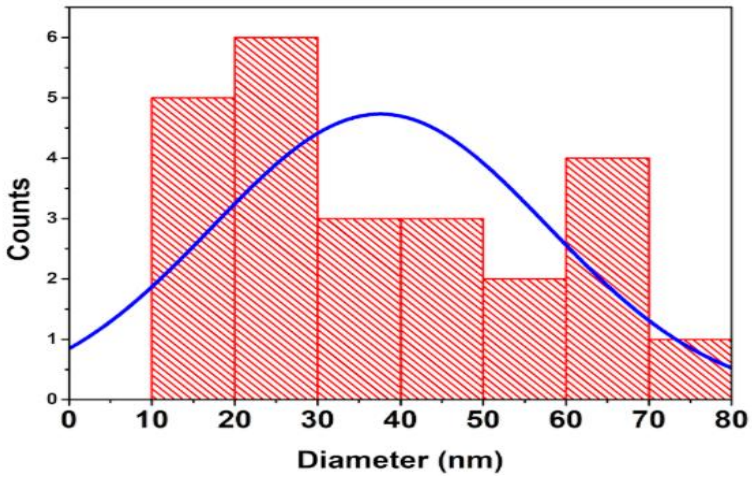

Figure 4.2 Average particle size from HRTEM image

After mixing the nanocomposite material with an ethanol solution, it was placed in a sonicator for an hour. It was passed through a microinjector following the complete dispersion to leave a solution droplet on the grid. The grid was then kept in an oven for 20 minutes at 150°C. HRTEM and XRD were used to characterize the dried sample. The surface morphology of the nanoparticle is shown in figures (4.1 A, B, C, D).

Figures 4.1 A, B, C, and D show a High-Resolution TEM image of D Mannitol Nanocomposite- particle sizes such as 20nm and 50nm. Figures A ,B and C display the crystal forms. The average particle size calculated is 37nm, as represented in Figs. 4.1 -D.

V. RESULTS AND DISCUSSION

5.1 Structural Analysis

X-ray diffraction (XRD) is a commonly employed technique for the nanoscale characterization of materials. Powder XRD examination of a sample can yield valuable information about the sample, including phase identification, sample purity, crystallite size, and, in certain cases, morphology, in addition to several microscopic and spectroscopic techniques. XRD patterns for the nanocomposite D-mannitol were examined.

On an X-ray diffractometer, XRD patterns were studied. The tests were carried out at 40 kV and 200 mA, with a scanning rate of 5°/min ranging from 2° to 90°. The XRD pattern results are mentioned in Figures (5.0), comparing 1%, 2%, and 3% of Nano SiC with D Mannitol PCM. The crest demonstrates a change of forerunner to SiC with

2theta= 35.62°, 41.5°, 59.95, 71.44 (reference code: 00-029-1129) attributed to cross-section planes (111), (200), (220), (311) individually [18]. Also, the slight widening base of the crest is demonstrative of either unreacted material or some unshaped SiC staying in the particle. The remaining crests are D Mannitol PCM-staying material [14-16].

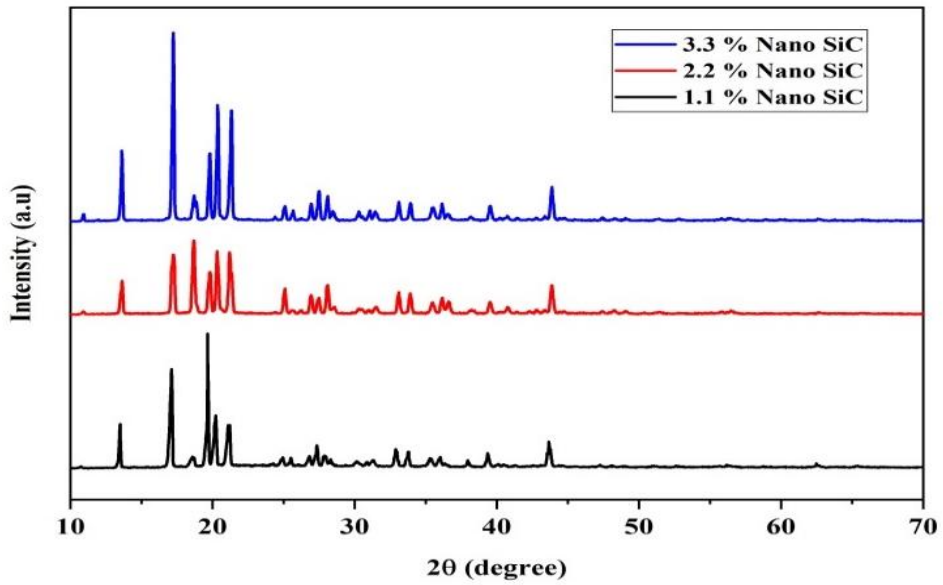

Figure 5 Structural Analysis of D-Mannitol Nanocomposite PCM

The thermal storage properties of the chosen Nano composite were determined using a DSC with a temperature range of up to 300 °C and a heating and cooling rate of 5 degrees Celsius per minute under nitrogen gas. The performance of PCM samples was assessed through a melting and freezing test following the reported method.[17]. The DSC results show an increasing the latent heat of fusion and melting points by adding a large amount of nanoparticles [18]

It is a very effective method to evaluate the properties of materials since DSC is a heat examination approach where the intensity stream is calculated as a component of temperature or time. The DSC test provides information on a wide range of materials, including composites, plastics, coverings, glues, food, polymers, coatings, pharmaceuticals, natural materials, elastic, gasoline, synthetics, and organic examples. From there, the possibilities are endless. Additionally, DSC measures the intensity stream's speed and compares it to the speeds of well-known reference materials. Different types of material formation, crystallinity, and oxidation are determined by the distinction. Using a DSC with a temperature range of 300 °C and a heating and cooling rate of 5 °C per minute under nitrogen, the thermal storage characteristics of the selected Nanocomposite

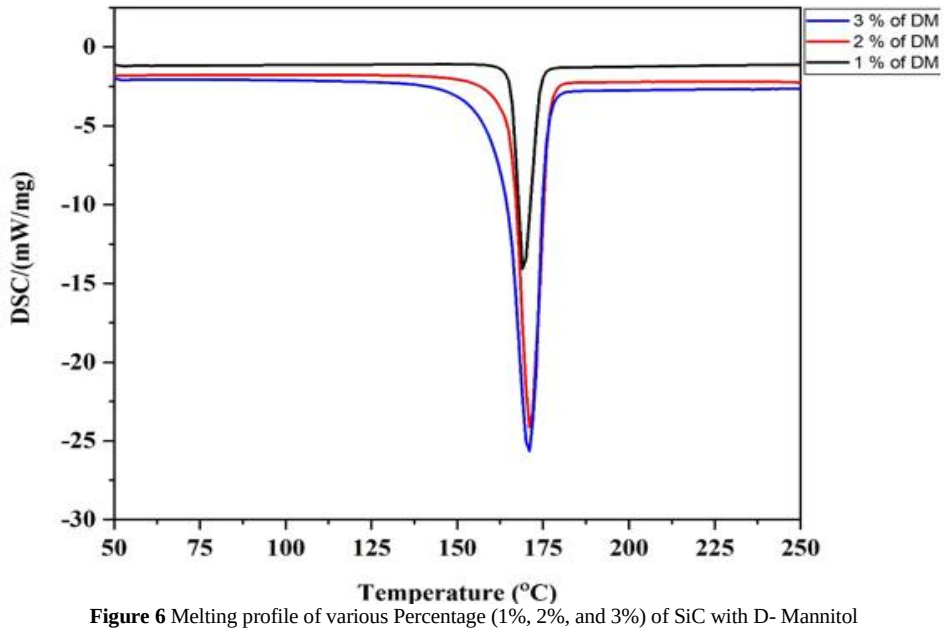

Figure 6 Melting profile of various Percentage (1%, 2%, and 3%) of SiC with D- Mannitol

Fig 6. Shows the melting temperature of Nanocomposite D mannitol PCM with various percentages of the nanoparticle. The melting temperature is increased. The maximum melting point obtained from 3% Nano composite PCM.

Table c.1 DSC Result of Nanno composite PCM sample at the various percentages of nanoparticle

PCM	SiC	Onset Temp. °C	Offset Temp.° c	Melting Temp.in ° c	Latent Heat J/g
5grams	1%	165	172	167.1	451
5 grams	2%	166	176	170	956.8
5 Grams	3%	164.8	175.7	173	1114

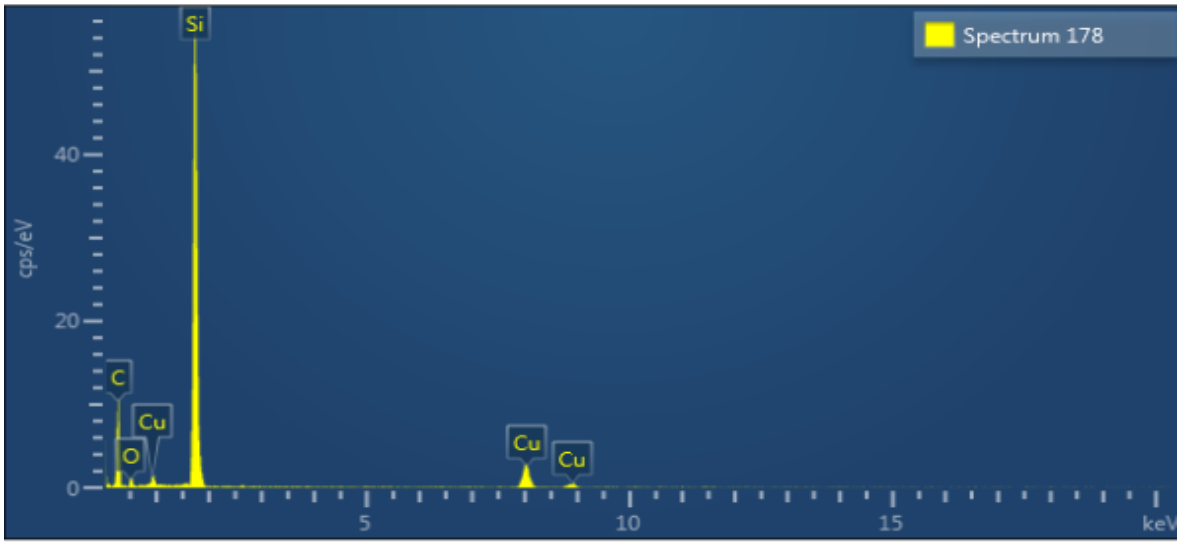

Figure 7 Elemental Composition of Nanocomposite PCM

Table 2. Elemental composition of Nanocomposite PCM

Element	Line Type	k Factor	Absorption Correction	Wt%	Wt% Sigma	Atomic %
C	K Series	2.769	1.00	22.48	0.69	41.30
O	K Series	2.020	1.00	2.06	0.25	2.83
Si	K Series	1.000	1.00	67.70	0.69	53.17
Cu	K Series	1.247	1.00	7.76	0.31	2.70
Total				100.00		100.00

Fig.7 and Table 2 show the elemental compositions of Nanocomposite PCM found. From the Table, silicon is 67.70 %, carbon is 22.48 %, oxygen is 2.06% and copper is 7.76 %.

VI. Thermal Conductivity Measurement Process

Figure 8

The goal of the research is to define D-mannitol with different percentages of Sic by utilizing thermophysical properties such as thermal diffusivity and conductivity. These characteristics were measured using the Laser Flash Apparatus. A value of 1.9 W/mk was obtained for the thermal conductivity of Nano SiC combined with pure D Mannitol in the investigation.

VII. Conclusion

D-mannitol PCM is combined with nano-silicon carbide to form the three ratios. The D-Mannitol nanocomposite's morphology, average sample size, particle shape, crystallization temperature, latent heat, thermal conductivity, and thermal stability were evaluated using tests like TGA, XRD, DSC, and HRTEM. This study has contributed to the following things. The thermal conductivity of the 3% nano SiC with D Mannitol composite is

higher than that of the 1% and 2% composites. In comparison to 1% and 2% composites, it also improves thermal conductivity and latent heat.

Declaration:

Regarding the subject matter of this paper, the writers have no relevant conflicts of interest to disclose.

REFERENCES

[1] Kiziroglou, M.E., Wright, S.W., Toh, T.T., Mitcheson, P.D., Becker, T. and Yeatman, E.M., 2013. Design and fabrication of heat storage thermoelectric harvesting devices. IEEE Transactions on Industrial Electronics, 61(1), pp.302-309.

[2] Pielichowska K, Pielichowski K. Phase change materials forthermal energy storage. Prog Mater Sci. 2014;65:67–123.

[3] Sarier N, Onder E. Organic phase change materials and their textile applications: an overview. Thermochim Acta. 2012;540:7–60.

[4] Chang SJ, Wi S, Jeong S, Kim S. Analysis on phase transition range of the pure and mixed-phase change materials (PCM) using a thermostatic chamber test and differentiation. J Therm Anal Calorim. 2017. https://doi.org/10.1007/s10973-017-6603-y.

[5] Li, X., Zhou, Y., Nian, H., Zhang, X., Dong, O., Ren, X., Zeng, J., Hai, C. and Shen, Y., 2017. Advanced nanocomposite phase change material based on calcium chloride hexahydrate with aluminum oxide nanoparticles for thermal energy storage. Energy & Fuels, 31(6), pp.6560-6567.

[6] Fortunato, B., Camporeale, S.M., Torresi, M. and Albano, M., 2012. Simple mathematical model of thermal storage with PCM. AASRI Procedia, 2, pp.241-248.

[7] Kumar, R.S. and Krishna, D.J., 2013. Differential scanning calorimetry (DSC) analysis of latent heat storage materials for low temperature (40–80 C) solar heating applications. Int. J. Eng. Res. Technol, 2(8), pp.429-455.

[8] Martínez, A., Carmona, M., Cortés, C. and Arauzo, I., 2020. Characterization of thermophysical properties of phase change materials using unconventional experimental technologies. Energies, 13(18), p.4687.

[9] Pujula, M., Sánchez-Rodríguez, D., Lopez-Olmedo, J.P., Farjas, J. and Roura, P., 2016. Measuring thermal conductivity of powders with differential scanning calorimetry. Journal of Thermal Analysis and Calorimetry, 125(2), pp.571-577.

[10] Mishra, A., Shukla, A., and Sharma, A., 2015. Latent heat storage through phase change materials. Resonance, 20(6), pp.532-541.

[11] Manickam, R., Kalidoss, P., Suresh, S., and Venkatachalapathy, S., 2019. Erythritol-based Nano-PCM for Solar Thermal Energy Storage. International Research Journal of Engineering and Technology (IRJET), 6, pp.1631-1636.

[12] Kumaresan G, Velraj R, Iniyan S. Thermal analysis of D-mannitol for use as phase change material for latent heat storage. Journal of Applied Sciences. 2011 Dec; 11:3044-8.

[13] Mondal, S., 2008. Phase change materials for smart textiles–An overview. Applied thermal engineering, 28(11-12), pp.1536-1550.

[14] Salinas, A., Altecor, A., Lizcano, M. and Lozano, K., 2016. Production of b-silicon carbide nanofibers using the force spinning method. J. Ceram. Sci. Tech, 7(03), pp.229-234.

[15] Salinas, A., Lizcano, M. and Lozano, K., 2015. Synthesis of β-SiC fine fibers by the force spinning method with microwave irradiation. Journal of Ceramics, 2015.

[16] Gil, A., Barreneche, C., Moreno, P., Solé, C., Fernández, A.I. and Cabeza, L.F., 2013. Thermal behavior of d-mannitol when used as PCM: Comparison of results obtained by DSC and in a thermal energy storage unit at pilot plant scale. Applied Energy, 111, pp.1107-1113.

[17] S. Mondal, " Phase change materials for smart textiles–an overview," Applied, thermal Engineering, vol. 28, no. 11-12, pp. 1536–1550, 2008.

[18] Kenisarin, M. and Mahkamov, K., 2007. Solar energy storage using phase change materials. Renewable and sustainable energy reviews, 11(9), pp.1913-1965.