RESEARCH ARTICLE

Asian Research Association

INTERNATIONAL RESEARCH JOURNAL OF
MULTIDISCIPLINARY TECHNOVATION

DOI: 10.54392/irjmt2516

Material Selection and Characterization Based on Shape, Size Enhance Thermal Stability for Energy Storage Applications

Bhushan Y. Patil [a, *], Nilesh P. Salunke [b], Vijay R. Diware [c]

[a] Department of Mechanical Engineering, SSBT College of Engineering & Technology, Jalgaon, 425001, India
[b] Department of Mechanical Engineering, SVKM's, Institute of Technology, Dhule, 425405, India
[c] Department of Chemical Engineering, SSBT College of Engineering & Technology, Jalgaon, 425001, India
* Corresponding Author Email: bhushanpatilsai15@gmail.com

DOI: https://doi.org/10.54392/irjmt2516
Received: 08-07-2024; Revised: 07-01-2025; Accepted: 18-01-2025; Published: 22-01-2025

Abstract: The study explores phase change materials enhanced with complex dispersants, primarily aimed at improving the efficiency of TES systems. The energy storage and chemical stability of transition particles are anticipated to be highly dependent on their shape and size. The samples are characterized based on melting and solidification phases evaluated. Commercial phase change materials (0.1 wt.%) such as Al_2O_3, $C_{13}H_{11}NO$, $C_6H_{14}O_6$, $C_6H_6O_2$, Fe_2O_3, KSCN, $C_7H_6O_3$, and ZnO at different pH stability (2.4-7.035) having purity 99% were dispersed in H_2O and Ethylene glycol. The effect of particles in phase change materials was analyzed using TGA, FTIR, XRD, zeta potential, particle size, and FESEM for Al_2O_3 and $C_6H_6O_2$. The TGA enhances thermal stability with melting point temperature range from 184°C to 189.90°C mixture of Al_2O_3 and $C_6H_6O_2$ under weight loss conditions. The performance of zeta potential and particle size was evaluated and significantly impact their pH stability of low to medium temperature. Zeta potential is measured using methods such as concentration-based volume fraction analysis and the electrophoretic migration technique. To enhance performance the synthesis and characterization of functional materials rely significantly on determining their isoelectric point. To define functional group base hydrophobic and hydrogen bonding as their primary driving forces. For PCMs, the XRD method is utilized to analyze the atomic spacing and crystal structure in order to identify every potential plane. The spherical structure of nanophase changes particles and the required form of a rod were potential improvements for high-energy storage stability applications.

Keywords: Zeta potential, Phase change materials, FTIR, Solidification, Nanoparticles, Ethelyne glycol

1. Introduction

Energy demand harnessing sources using solar energy storage have been encouraged to increase the capacity of surface charging and discharging using phase change materials [1-2]. PCMs stability relies on heat transition load to address charging and discharging issues. PCMs significantly improve the thermal conductivity due to shape and scale size of nano developed which amend heat transfer, specific surface area and dispersion properties [3]. This review evaluates the stability and performance of PCMs in energy storage systems used in absorption refrigeration. It focused on the PCMs in energy storage and temperature variation, assessing their chemical, thermal, and mechanical properties. Key factors like thermal conductivity, phase change enthalpy, and nanoparticle enhancements are discussed to improve system efficiency. The study emphasizes the need for further research on PCM energy efficiency, cost-effectiveness, and material optimization for sustainable cooling solutions [4]. This paper provides a latent heat storage systems, focusing on advancements in phase change materials, encapsulation techniques, and applications. It evaluates various PCMs, such as paraffin waxes and hydrated salts, discussing their benefits and limitations. Encapsulation methods are explored for their role in improving thermal performance and stability [5].

This study examines latent heat energy storage systems and their applications, emphasizing methods to enhance heat transfer and improve storage performance. Key topics include the impact of geometrical configurations, design parameters and advanced enhancement techniques such as nanomaterial additives, cascaded or encapsulated PCMs, and extended surfaces like fins [6]. In the selection of suitable PCMs, those undergo solid to liquid phase transformation are highly promising due to the significant heat stored during the melting process. These materials are available of melting temperature and latent heats of fusion, making them adaptable for various applications. PCMs are classified in main category such as organic, inorganic, and eutectic, each covering different thermal ranges and properties. PCMs can enhance the performance of solar absorption refrigeration systems, particularly in aqua-ammonia and lithium bromide-water systems. The review aims to provide a selection guide, highlighting best practices for effectively leveraging PCM's thermal advantages [7]. The study analyzed latent energy storage in PCMs doped with carbon nanoparticles, showing a 13% enhancement in latent heat for wax/SWCNT composites with 1% loading. This improvement, attributed to SWCNT's large surface area and high molecular density, aligning well with experimental results. The findings highlight the potential of nanoparticle additives to optimize PCM energy storage performance [8]. This study involves paraffin wax nanocomposites with multi-walled carbon nanotubes showed reduced melting points and latent heat capacity with increased MWNT content. However, thermal conductivity improved significantly, achieving 35% enhancement in the solid state and 40% in the liquid state at 2% MWNT mass fraction, highlighting their potential for efficient heat storage applications [9].

This study developed nanocomposite-enhanced phase change materials by adding multi-walled carbon nanotubes and alumina nanoparticles to paraffin wax. Experiments revealed that nano-material concentrations (1.0, 2.0, 3.0 wt.%) influenced phase change temperature, thermal resistance, and energy storage efficiency. Adding nano-materials slightly increased the phase change temperature, reduced thermal resistance, and improved heat transfer efficiency. MWCNTs outperformed Al_2O_3 nanoparticles in enhancing thermal performance, reducing phase change time, and widening the temperature range of energy storage. These findings are applicable to solar thermal storage and waste heat recovery systems [10]. This study explored phase change materials embedded with alumina nanoparticles in paraffin using a non-ionic surfactant. The emulsions comprise 5 wt.% and 10 wt.% nanoparticles, showed that mass density matched predictions from mixture theory. Thermal conductivity and viscosity increased non-linearly with nanoparticle concentration, depending on temperature, compared to pure paraffin, highlighting the impact of nanoparticles on PCM properties [11].

This study examines the effects of heating surface, Al_2O_3 concentration, and paraffin wax dispersed with Al_2O_3 nanoparticles on the melting performance of the latent heat storage system. The study monitors important characteristics like stream function, isotherms, and the liquid-solid interface at various melting stages through numerical simulations [12]. This study explores paraffin/expanded graphite (EG) composites as PCMs for energy storage. Composites with up to 10% EG were created, with the 10% EG version being form-stable and preventing leakage. Increasing EG improved thermal conductivity and reduced melting time. DSC analysis showed similar melting temperatures and consistent latent heat capacities. The 10% EG composite due to its stability, high conductivity, and effective thermal properties [13]. This study investigates the developed a pilot plant at the to test energy storage systems using sensible and latent heat materials [14]. The investigation methods of physical characterisation when it comes to inorganic PCMs, X-Ray Diffraction (XRD) is very helpful in determining the crystal structure and phases of material [15]. The zeta potential of several solid support materials, such as SiO_2, Al_2O_3, and beta zeolites with varying silica to alumina ratios, is investigated in this work. It reveals that the zeta potential is highly influenced by temperature, pH, and acidity, with certain materials exhibiting maxima based on their microstructure and acidity. Prior to determining the zeta potential, the materials were analysed using methods like XRD, SEM, EDX, TEM, nitrogen, Al-NMR, and FTIR with pyridine as shown Figure 1 [16-17].

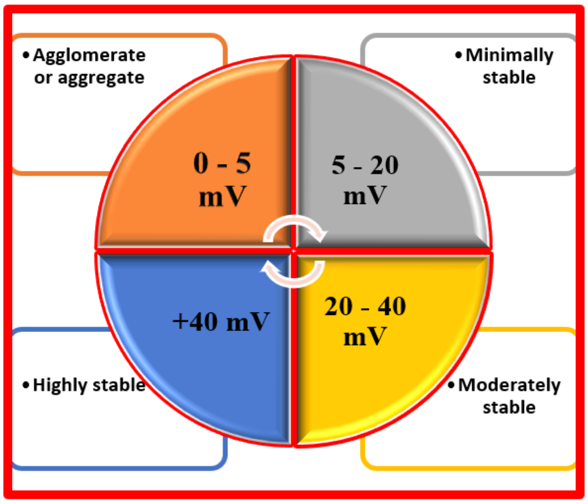

Figure 1. Zeta stability (mV) [17]

This study examines the preparation of Pt/silica catalysts by adsorbing from basic impregnation solutions. It shows that pH influences both the amount of adsorbed Pt and particle size. High Pt dispersion was achieved at lower loadings with specific drying and reduction conditions. Increasing calcination temperature reduced Pt dispersion, with temperatures above 525°C resulting in large particles. The findings suggest that by adjusting preparation methods and calcination temperatures, Pt nanoparticles of varying sizes can be produced [18]. This review investigates how catalyst metal particle size is affected by synthesis factors, emphasizing their importance for achieving well-dispersed and catalytically active particles. Key factors include pH, support properties and stabilization techniques, which are crucial for controlling particle size and preventing agglomeration. Methods like deposition, precipitation and strong electrostatic adsorption are particularly effective, with post-synthesis treatments such as washing, calcination, and reduction further influencing particle characteristics. Thermodynamic and kinetic models offer insights into nanoparticle formation, highlighting the need for precise optimization of preparation conditions to enhance catalyst performance [19].

This study uses chemical characterisation techniques to examine the zeta potential of common reservoir minerals, such as quartz, kaolinite, and calcite, at pH values between 2 and 9 and electrolyte concentrations between 0.0001 and 0.1 M. An electrophoretic cell set up for variable temperature and pressure is used. For quartz, kaolinite, and calcite, the zeta potential decreases at pressures below 45 psi with temperature at rates of -2.3 mV/°C, -0.96 mV/°C, and -2.1 mV/°C [20]. This article concentrates on the stability of nanofluids, which are nanoparticle suspensions in a base fluid that provide improved wettability, rheological, and thermal characteristics for a range of functions, including medication administration, heat transfer, lubrication, and improved oil recovery [21]. This study focused on the stability of plasma-functionalized multi-walled carbon nanotube based nanofluids, showing no agglomeration over 8 months and after heating at high temperatures (85°C and 170°C). In contrast, suspensions with Therminol VP-1 heat transfer fluid agglomerated. These stable nanofluids are perfect for use in solar thermal collectors because of the MWCNTs' exceptional solar energy absorption [22]. This article covers the creation, stabilization, and thermal characteristics of nanofluids, which have better thermo-physical characteristics than traditional fluids. It covers techniques to improve nano-fluid stability, such as surfactant addition and ultrasonic mixing, and highlights the advantages of hybrid nano-fluids. The use of nano-fluids in thermal systems improves heat transfer, reduces entropy generation, and enhances energy efficiency, making them effective alternatives to traditional working fluids [23].

This work investigates effects of surfactants on stability of nano-fluids by measuring the hydrodynamic diameter and zeta potential of (0.1 wt.%) alumina nanoparticles in deionized water. Tests were conducted on two surfactants at different pH levels and concentrations. Surfactants are essential for improving the stability of nano-fluids by avoiding the agglomeration of nanoparticles by electrostatic repulsion. Smaller particles tend to have higher surface energies, which can influence their zeta potential. Both parameters combined are essential for controlling colloidal stability and larger surface area-to-volume ratio, affecting properties like dissolution rate, reaction rate, and stability [24]. This review emphasizes the importance of dynamic light scattering (DLS) and zeta potential (ZP) for characterizing nanoparticle size and surface charge in nanomedicine. It addresses challenges like understanding principles, sample preparation, and data interpretation, offering practical guidelines and insights into their relevance for drug delivery applications [25]. This study reviews the use of nano-fluids, which are colloidal suspensions of nanoparticles (1-100 nm) in conventional fluids, to enhance heat transfer in industrial applications. Nano-fluids offer higher thermal conductivity compared to traditional fluids, helping overcome the challenge of high heat load in industrial development. The long duration stability of nano-fluids is crucial for their effective use, and preparing stable nano-fluids remains a key technical challenge [26]. This paper looks at several techniques for determining the thermal conductivity of nanofluids, including the transient hot-wire (THW), steady-state parallel-plate, and cylindrical cell approaches [27].

This study phase change materials which operate between 80°C and 100°C and are appropriate for non-concentrating solar thermal applications, are the subject of this study's investigation into the use of PCMs in solar cooling systems. Both commercial and neat chemical PCMs are evaluated for their thermo-physical performance and long-term stability, while neat materials, such as Aluminum Ammonium Sulfate Dodecahydrate, show high melting enthalpies (255 J/g), they exhibit issues like super-cooling, allotropic phase transitions, incongruent melting, and recrystallization absence, limiting their reliability [28]. In this study, a thermal energy storage (TES) system for solar cooling applications employing phase change materials (PCMs) was evaluated. Two PCMs were selected such as D-mannitol (167°C melting point) and hydroquinone (172.2°C melting point). While DSC analysis revealed sub-cooling for both PCMs, only D-mannitol showed sub-cooling at the pilot plant scale. D-mannitol stored more energy than hydroquinone under the same conditions, and its polymorphism did not affect its performance. The study also calculated effective heat transfer coefficients for PCM-HTF interaction [29]. The thermal energy storage (TES) systems for solar absorption refrigeration are reviewed here, with an emphasis on phase change materials (PCMs) with high heat of fusion. It discusses PCM selection, integration, enhancements, and challenges, offering insights and recommendations to improve efficiency, cost-effectiveness, and continuous operation during low solar radiation periods [30]. This study found that whereas metal-based NPs like Ag, Au, and Cu are innocuous in bulk form, they become more harmful at smaller sizes. NPs can interact with cellular proteins and enzymes, disrupt antioxidant defenses, generate reactive oxygen species, and cause inflammation, mitochondrial damage, and cell death. While NPs have diverse applications, their safety remains a concern, necessitating further research to balance their benefits and risks [31].

The present study evaluates the stability of PCMs for the application of energy storage systems based on physical, kinetic, chemical, thermal properties and considering drawbacks. Various PCMs used to find the surface charge with pH values in zeta potential and particle size with dispersant of water and ethylene glycol their results found some agglomerate, minimally stable, and moderately stable were tested. Also, measured hydrodynamic diameter to define a functional group of elements using frequency peak. The PCMs identify properties like crystallite size, crystal structure, and strain. Shape structures like rod and spherical in nanophase change particles with good energy stability.

2. Methodology for Material Selection

From literature survey procedure to choose selected PCM for energy storage applications has constraints in terms of complexity and time consumed. Furthermore, the recent availability or creation of a large number of PCM more than 160,000 in the field of LHS makes the process more difficult, because there is little and scattered knowledge regarding the properties of PCM at high temperatures, the selection approach becomes extremely difficult as shown in Figure 2. This review is an inclusive evaluation of experimental testing data using desirable PCMs based on advanced selection methodologies using the software's improvements [5].

3. Materials

Materials were selected based on solid to liquid transition of melting temperature and heat of fusion for the application of TES systems. List of commercial PCMs as shown in Table 1 with their sample codes shown in Figure 3, were chosen in this study to minimize cost and ensure availability, while achieving the desired thermal and chemical properties suitable for TES applications. All phase change materials (PCMs) with 99% purity were procured from Loba Chemie and utilized directly in this analytical work without additional purification.

4. Characterization Methods

During the screening of suitable phase change materials (PCMs), solid-liquid transitions demonstrated significant potential. Latent energy is transformed into heat when the PCM melts. A wide range of materials is available, offering diverse melting points and latent heat of fusion, suitable for various applications.

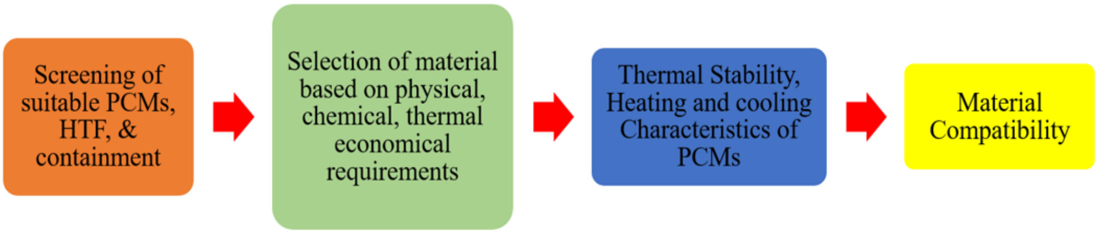

Figure 2. Selection process of PCMs

Table 1. Selected phase change materials Properties

Sample Code	**A**	**B**	**D**	**H**	**I**	**P**	**S**	**Z**
Molecular Formula	Al_2O_3	$C_{13}H_{11}NO$	$C_6H_{14}O_6$	$C_6H_6O_2$	Fe_2O_3	KSCN	$C_7H_6O_3$	ZnO
Purity	99%	98%	99%	99%	95%	99%	99%	99%
Molecular weight	101.96	197.23	182.17	159.69	159.69	97.18	138.12	81.38
Melting point [°C]	2000°C	161 - 163°C	167-170 °C	170-174 °C	1565 °C	173°C	158 - 161 °C	1975°C
Solubility in water [% weight]	Insoluble in water	Insoluble in water	Soluble in water	Soluble in water	Insoluble in water	Insoluble in water	Partially soluble in water	Insoluble in water
Colour	White crystalline	White crystalline	White powder	White powder	Reddish powder	Colorless crystals	White powder	White powder
pH value	6.5 - 7.5	-	5 - 6.5	3.7	-	5.3-8.7	2.4	-
Density [g/cm^3]	4	1.315	-	1.332	5.24	1.89	-	5.6
Particle size (70-230 mesh)	Min 70%	-	-	-	-	-	-	-
Boiling point [°C]	-	117 °C	-	285 °C	-	-	211°C	-

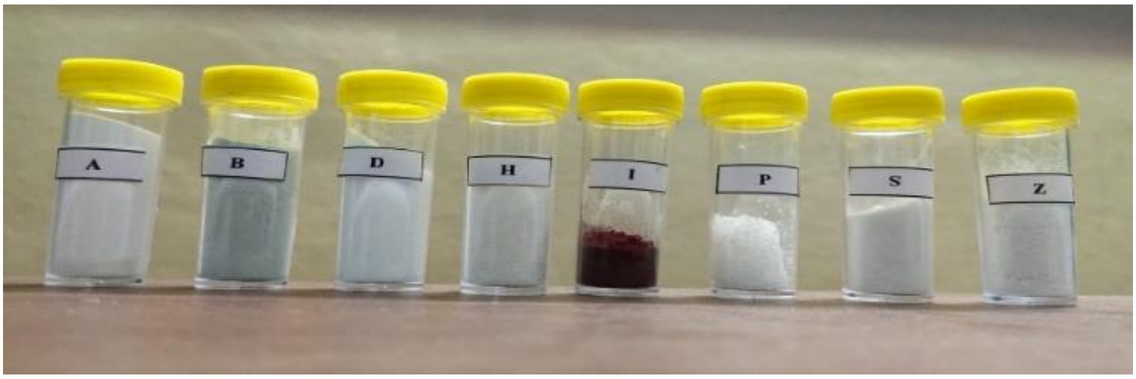

Figure 3. Material samples appearance with code

Classification of PCMs is organic, inorganic, eutectic PCMs, and nano-fluids with various thermal material temperature ranges [2]. The study more emphasis on their size and shape dependent chemical and thermal stability, phase change materials are used in energy storage applications for low to medium temperature ranges. PCMs properties fusion/solidification enthalpy, chemical and thermal stability, concentration ratio, weight ratio, mass density, the temperature of phase transition energy storage, and volumetric change coefficient during phase transition to achieve the shape and size of the pristine material with pH stability. The above study evaluates the stability of PCMs for the application of energy storage systems based on physical, chemical, and thermal properties and considers drawbacks. Various PCMs used to find the surface charge with pH values in the zeta potential and particle size with dispersant of water and ethylene glycol results found some agglomerate, minimally stable, and moderately stable were tested. The PCMs identify properties like crystallite size, crystal structure, and strain. PCMs observed the zeta potential, particle size, FTIR, XRD, and FESEM to shape structures like rod and spherical in nanophase change particles with good energy stability. The solidification (Ts) and melting (Tm) temperatures of the PCM (hexadecane) were determined to be 172.5 and 159.5°C, respectively, based on the Sample H heat flow curves that were acquired from differential scanning calorimetry (DSC) experiments. During solidification and melting, the phase change enthalpy [kJ/kg] values were determined to be 178.7(s) and 235.2(m) kJ kg^{-1}. These values were agreement with the values published elsewhere (258 kJ kg^{-1}) [29].

5. Results and Discussion

5.1. Zeta potential and particle size

Using Nano Zetasizer Malvern device was used to measure the nanoparticles' mean particle size and polydispersity index (PDI). The dispersions were diluted 10 times with distilled water for the principal measurement. At a temperature of 25 ± 1°C, the aqueous phase's refractive index was set at 1.33. As seen in Figure 4, the samples were made by suspending solid PCMs in distilled water and ethylene glycol. As seen in Figures 5 and 6, comparative testing was performed on all samples based on zeta potential, pH stability, particle volume percentage, size, and shape. Every substance that was used was in its purest form. Based on their solid-liquid phase transition behavior and thermal conductivity, the PCMs were investigated. The zeta potential (mV), size, and polydispersity index (PDI) of the PCMs are summarized in Table 2.

Figure 7, compares the Z-Average with pH stability and PdI for samples that are scattered in H2O. The physical, chemical, and thermal stability of the PCMs chosen for low to medium temperature applications were examined before they were employed in a thermal energy storage system. Particle speed and zeta potential were measured at various voltages in order to focus on the isoelectric point and the charged contact between particle surfaces. It is important to remember that the pH of the solution has an impact on the nanoparticles' surface charge. Using water and ethylene glycol as dispersants, different PCMs were evaluated to ascertain the surface charge based on pH values in the zeta potential and particle size. Different stack value of zeta potential, Z-Average, PdI and pH stability for Al_2O_3 and $C_6H_6O_2$ dispersed in H_2O and EG.

With 99% purity and a pH of 7.035, sample A's results revealed minimal stability with a zeta potential of -15 mV and a Z-Average (d.nm) of 461.7. The Z-Average (d.nm) was 412 and the zeta potential was -18.9 mV for sample H, which had a pH of 3.7 and 99% purity, suggesting reasonable stability. Figure 8, illustrates these results. The pH at which the surface charge drops to zero is known as the isoelectric point.

5.2 Thermo-gravimetric analysis (TGA)

Using Thermo-gravimetric analysis Instruments, USA were conducted the TGA test reveals that the material undergoes a significant weight loss of 70.091% between 157.95°C and 192.60°C, which is attributed to thermal decomposition or volatilization. The thermal stability of the remaining portion of the material is maintained up to 700°C.

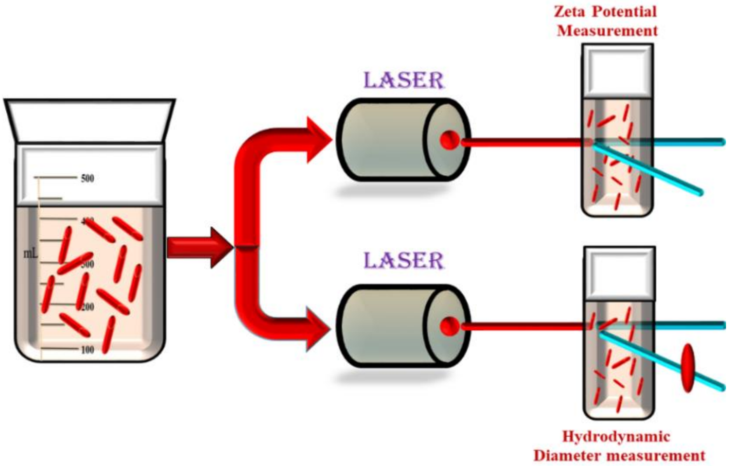

Figure 4. Preparation of zeta potential and particle Size (mV)

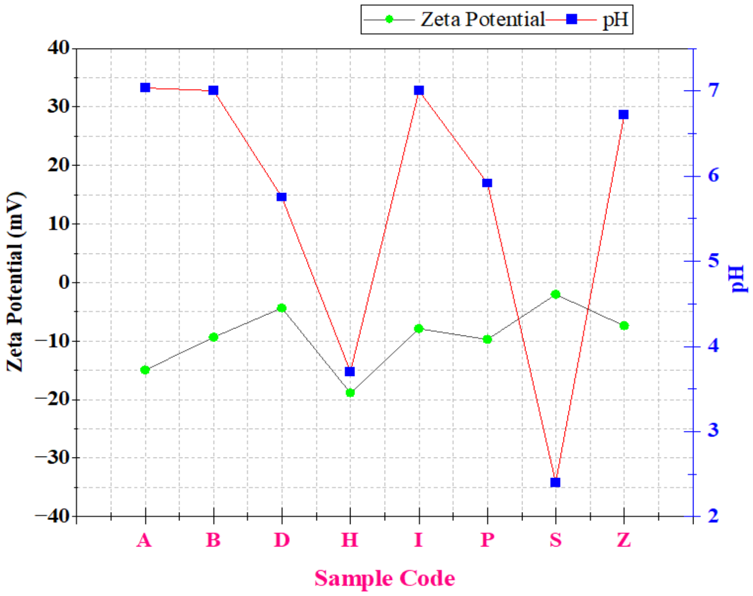

Figure 5. Comparison of samples zeta potential (ZP) with pH values when dispersed in H_2O

Table 2. Tested PCMs used zeta potential (mV) with pH stability dispersed in H_2O and EG [6]

Dispersant	Materials sample code	Compound	ZP (mV)	Z-Average (d.nm)	PdI	pH Value	Surface charge
H_2O	A	Al_2O_3	-15	461.7	0.741	7.035	Minimally stable
	B	$C_{13}H_{11}NO$	-9.36	327.2	0.573	7	Minimally stable
	D	$C_6H_{14}O_6$	-4.41	335.3	0.614	5.75	Agglomerate or aggregate
	H	$C_6H_6O_2$	-18.9	412	0.675	3.7	Moderately stable
	I	Fe_2O_3	-7.9	743.3	0.656	7	Minimally stable
	P	KSCN	-9.74	278.2	0.576	5.915	Minimally stable
	S	$C_7H_6O_3$	-2.07	333.2	0.598	2.4	Agglomerate or aggregate
	Z	ZnO	-7.43	609.5	0.808	6.72	Minimally stable
EG	A	Al_2O_3	-2.62	141.7	0.33	7.035	Agglomerate or aggregate
	H	$C_6H_6O_2$	-20.8	116.4	0.251	3.7	Moderately stable

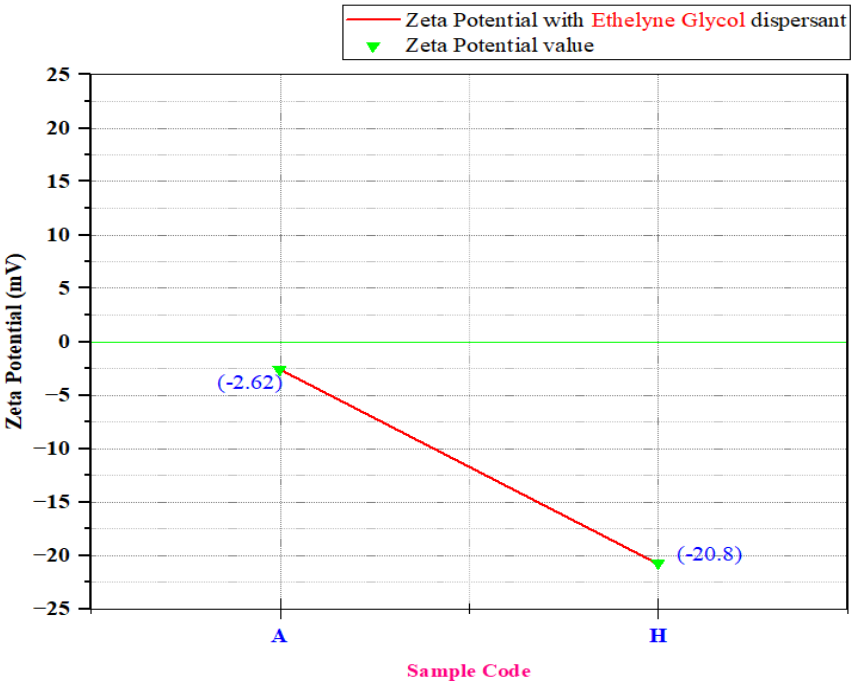

Figure 6. Zeta potential (ZP) of Al_2O_3 and $C_6H_6O_2$ dispersed in ethylene glycol (EG)

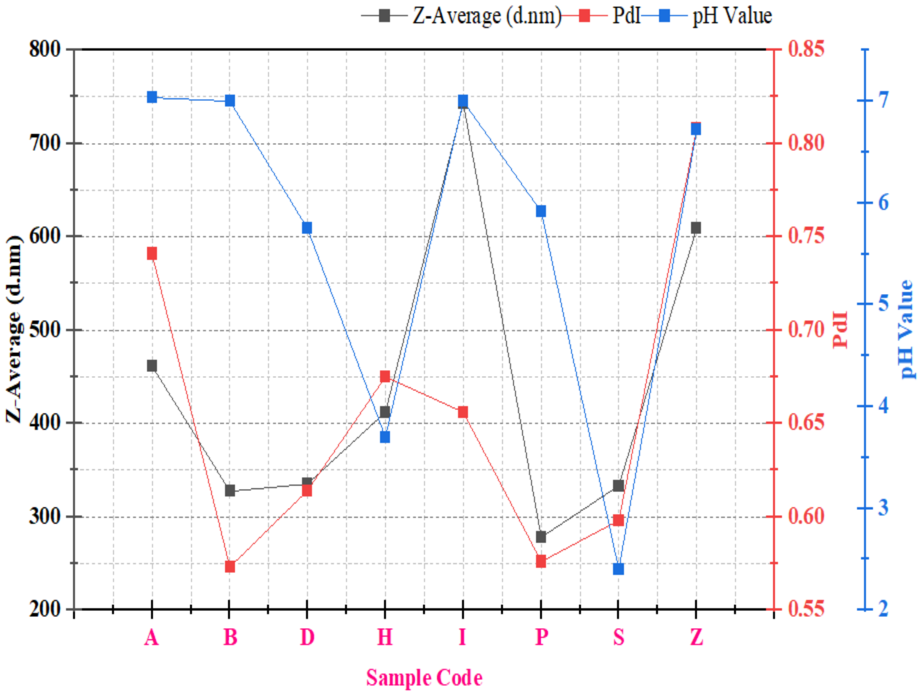

Figure 7. Comparison of Z-Average with PdI and pH stability for samples dispersed in H_2O

5.3 X-ray diffraction (XRD)

Using Bruker D2 phaser instrument shown in Figure 11, the XRD graph of sample A shows broad peaks with higher intensity in the range of 30°–50° (2θ), indicating the presence of crystalline phases.Sharp peaks at specific angles suggest a high degree of crystallinity, likely corresponding to the stable α-A (corundum phase), while broader peaks may imply a nanocrystalline or transitional γ-A phase. The noisy, low-intensity signal at lower angles (5°–30°) could indicate amorphous content or poorly crystalline regions. The adverse effect of humidity to maintain room temperature for powder samples in an X-ray diffraction (XRD) pattern indicated shown in Figure 12. A novel phase was found using X-ray XRD, which compared its reference patterns to those of pure conformers. The sample H shows the presence of crystal structure and atomic spacing in sample H are face-centred cubic (FCC) which matches well with reported previously [29]

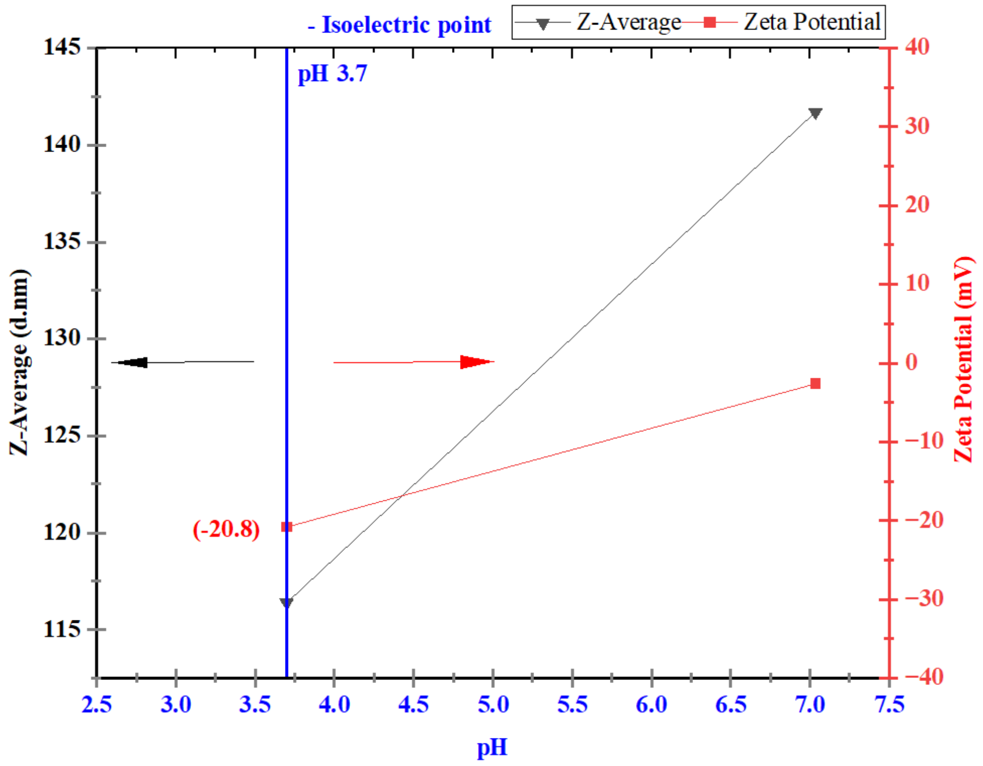

Figure 8. Compare Z-Average with pH stability dispersant with EG

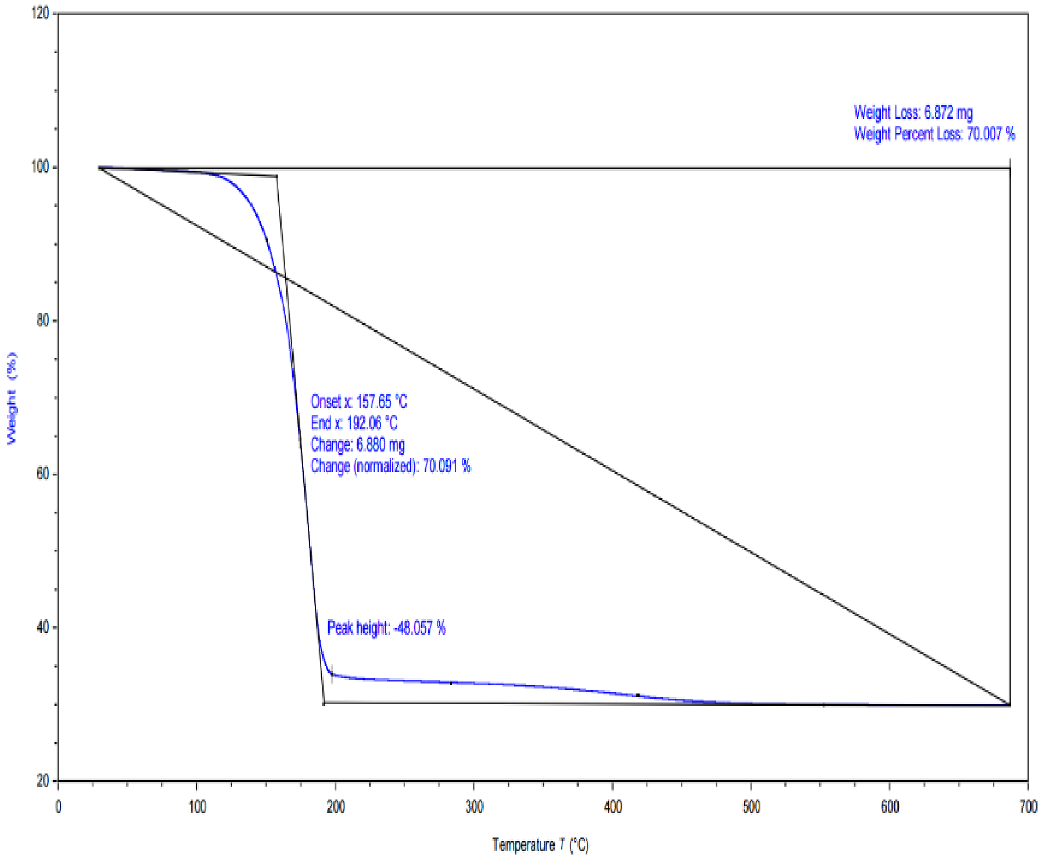

Figure 9. Weight loss and Percentage loss on A and H sample

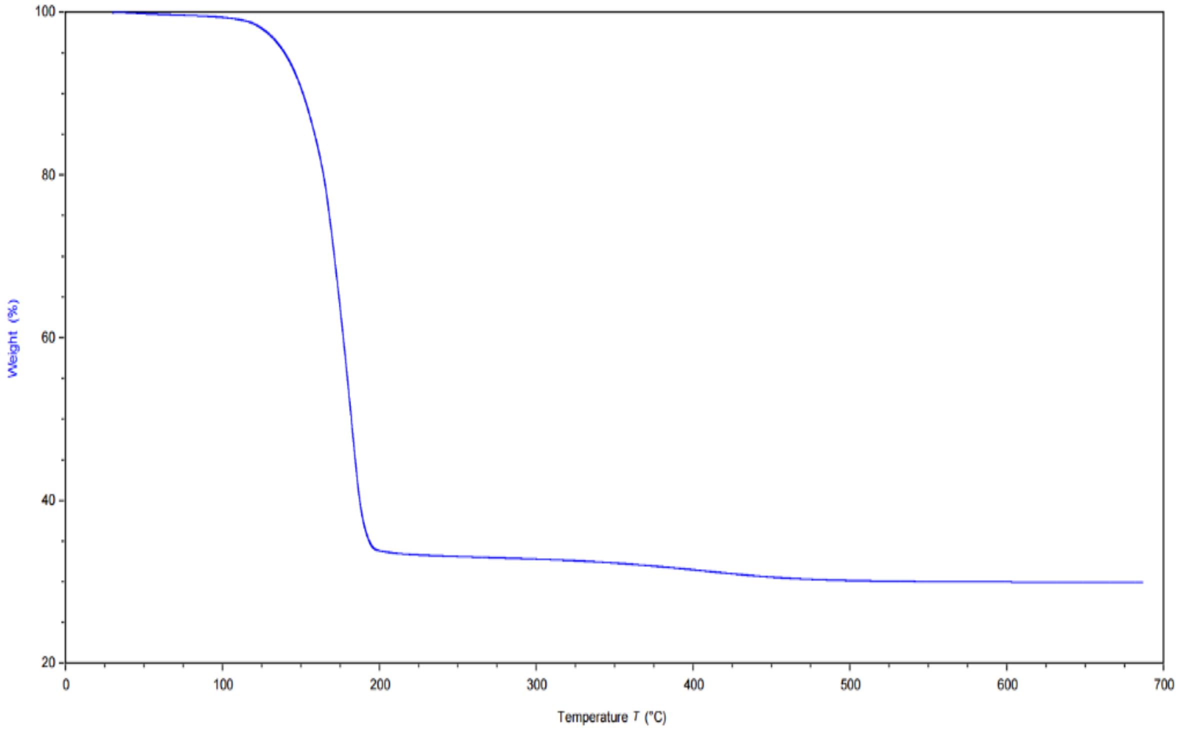

Figure 10. Without derivative showing weight loss on A and H sample

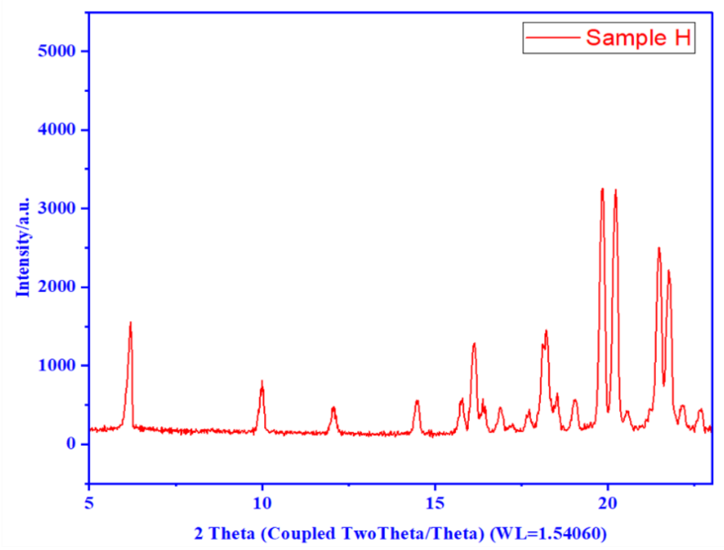

Figure 11. X-ray diffraction for sample H

5.4 FTIR Spectroscopy

The tested elemental analysis of sample A and H were analysed by Fourier transform infrared spectroscopy. The 4000–400 cm^{-1} range was used to record the FTIR spectra. The FTIR technique was used to investigate any potential driving forces between samples A and H. Sample H, peak at 1551.20 to 1651.20 cm^{-1} the strong absorption band, at 1651 cm^{-1}, for the pure, corresponding to the stretching of the (C=O) carbonyl unsaturation functional group. The carbon oxygen single bond stretch indicates peak at 1471.24 to 1515.37 cm^{-1}. They are sharper and less intense, where two new absorption bands appeared at 1600 and 1667 cm^{-1}, which corresponded to the asymmetric and symmetric stretching of C=O, respectively. In fingerprint range peak at 641.80 to 1351.57 cm^{-1} indicating stretching (O-H) the formation of nano PCMs. This is more noticeable in the solid state, when the aggregates' group undergoes the majority of the thermal transition. As a result, the PCM loaded with the carbonyl group has relatively higher thermal conductivity. As depicted in Figure 13, sample A showed a peak at finger print region range 636.11 to 948.99 cm^{-1} which indicates (O-Al-O) functional group revealed that there are 636.11 and 700.62 cm^{-1}. Figure 13 is shown in FTIR spectra for $C_6H_6O_2$ (a) and sample A (b) in stack manner.

5.5 Field Emission Scanning Electron Microscopy Analysis

The surface morphology of material the FESEM images of samples A and H for PCMs are shown in Figure 14. The presence of homogeneous particles within the commercial samples was validated by the FESEM images. There was no notable change in the surface morphology of the PCMs for sample H in rod shape. Sample A in spherical shape as noticed in the FESEM images. The shape and particle size to increase the thermal energy storage capacity. Sample H shows a one-dimensional (1D) structure that has amazing cylinder shapes with high length-to-diameter ratios that construct linear heat transmission routes. Samples A and H are extremely pure forms to immersed with water to indicate high surface charge stability.

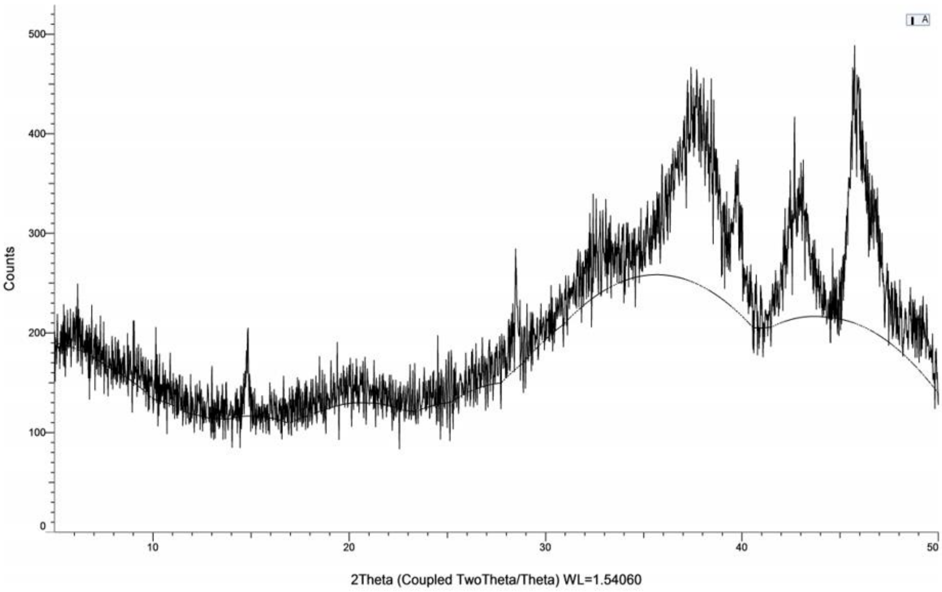

Figure 12. X-ray diffraction for sample A

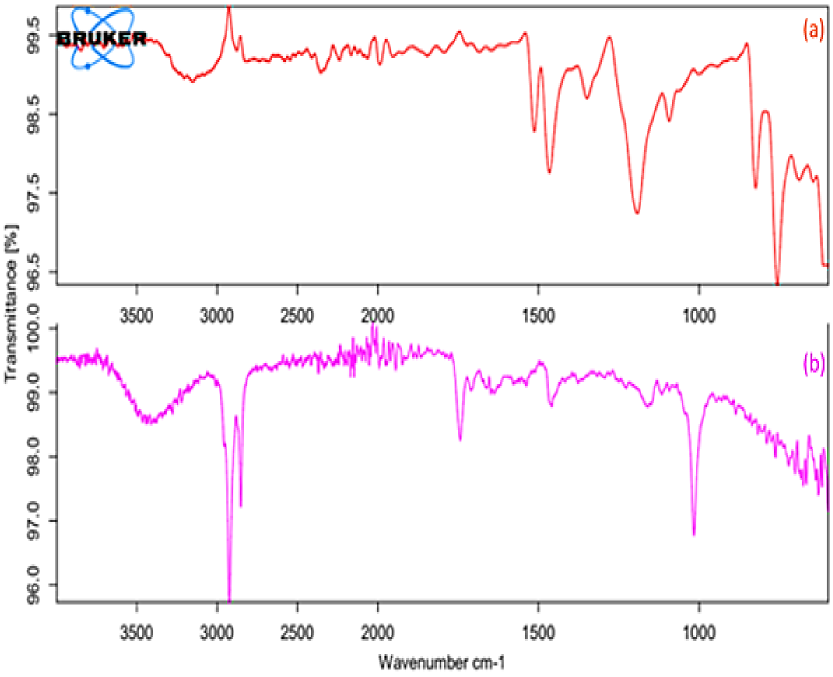

Figure 13. FTIR spectra for sample H (a) and sample A (b)

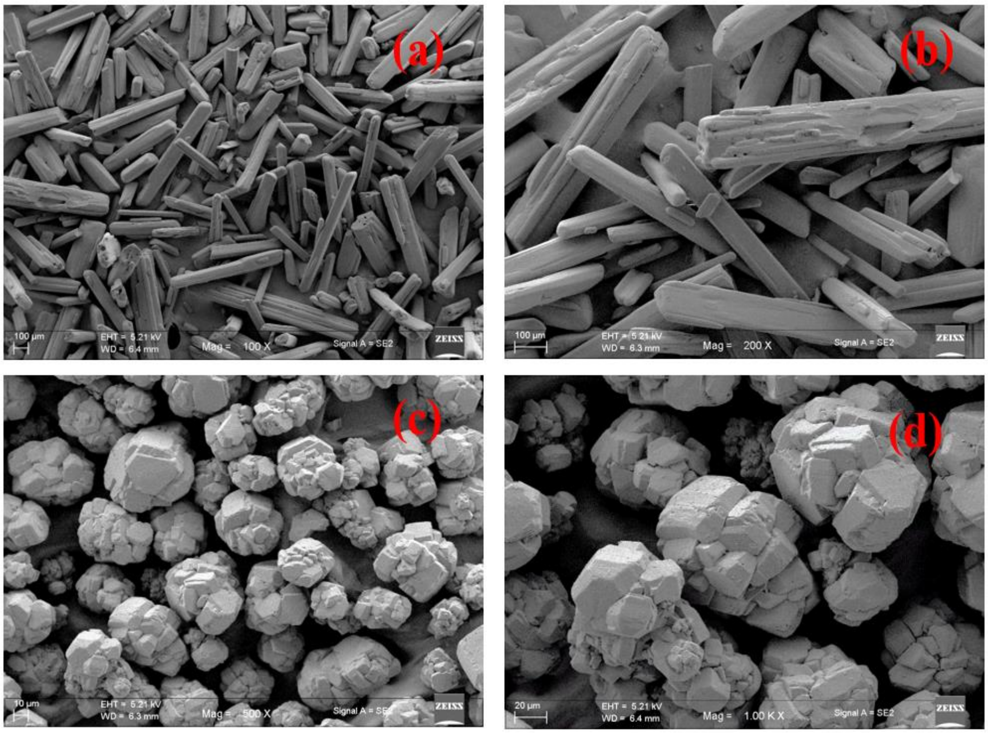

Figure 14. FESEM rod shape images for sample H (a and b), and spherical shape images for sample A (c and d)

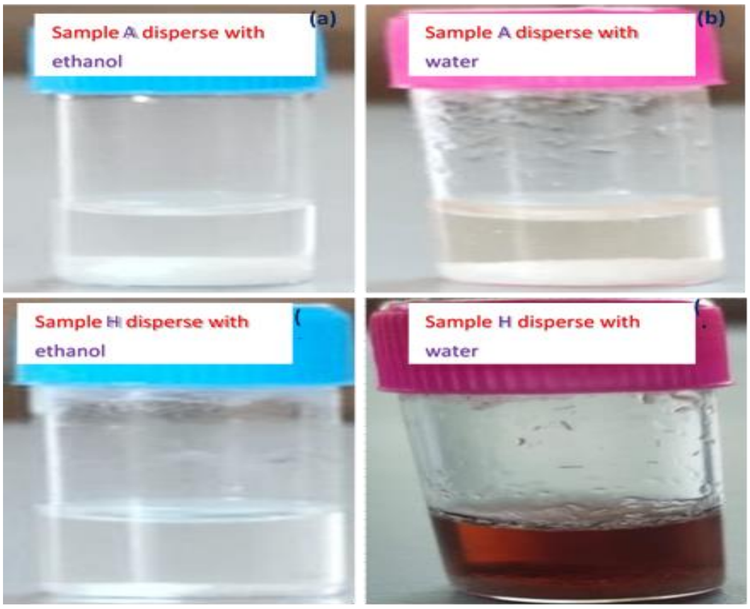

Figure 15. Concentration of storage stability for sample A **(a)** dispersed with ethanol **(b)** dispersed with water and sample H **(c)** dispersed with ethanol and **(d)** dispersed with water

5.6 Stability Evaluation

Figure 15, shows the concentration of sample storage mass and both fluid quantities are 50 gm and 100 ml in the findings of samples A and H dispersed with distilled water and ethanol. The ethanol and distilled water used to disperse sample A shown in Figure 14a and Figure 14b were unable to dissolve, and sample size and color remained unchanged. The sample H shown in Figure 15c and Figure 15d was dispersed in ethanol was completely dissolved, and when it was dispersed in distilled water sample H size remained stable, but the color changed to brown after 24 hr. The particle shape and size of sample A and H dispersed with water of PCMs was stable after a long duration.

6. Conclusion

This study explored the thermal stability and surface charge properties of phase change materials for thermal energy storage applications, focusing on Al_2O_3

and $C_6H_6O_2$, which demonstrated promising stability and energy storage potential. Characterization techniques, including zeta potential and particle size analysis, revealed that these materials possess moderate to minimal stability, making them suitable for further analysis. TGA results showed a significant weight loss of 70.091% between 157.95°C and 192.60°C due to thermal decomposition, while maintaining stability up to 700°C. Structural analysis confirmed the face-centred cubic (FCC) crystal structure of $C_6H_6O_2$, with functional groups such as (C=O) and (O-Al-O) identified through strong absorption peaks. Dispersions in water and ethylene glycol showed moderate stability, with Zeta Potential values of -18.9 mV and -20.8 mV, and Z-Average sizes of 0.675 nm and 0.251 nm, respectively, along with high purity (99%) and stability at a pH of 3.7. These findings highlight the potential of rod- and spherical-shaped PCMs in enhancing energy storage stability in low to medium temperature applications and underscore the importance of properties like Zeta Potential, pH, Polydispersity Index, and conductivity for optimizing PCMs in solar thermal energy systems.

References

[1] S.P. Sukhatme, S.P. Sukhatme, (1996) Solar energy: principles of thermal collection and storage. Tata McGraw-Hill, New Delhi,

[2] A.S. Fleischer, (2015) Thermal energy storage using phase change materials: fundamentals and applications. Springer International Publishing.

[3] B. Zalba, J.M. Marín, L.F. Cabeza, H. Mehling, Review on thermal energy storage with phase change: materials, heat transfer analysis and applications. Applied thermal engineering, 23(3), (2003) 251-283. https://doi.org/10.1016/S1359-4311(02)00192-8

[4] M.M. Kenisarin, High-temperature phase change materials for thermal energy storage. Renewable and sustainable energy reviews, 14(3), (2010) 955-970. https://doi.org/10.1016/j.rser.2009.11.011

[5] M.M. Farid, A.M. Khudhair, S.A.K. Razack, S. Al-Hallaj, A Review on Phase Change Energy Storage: Materials and Applications. Energy Conversion and Management, 45(9-10), (2021) 4-23. https://doi.org/10.1016/j.enconman.2003.09.015

[6] R. Elarem, T. Alqahtani, S. Mellouli, F. Askri, A. Edacherian, T. Vineet, I.A. Badruddin, J. Abdelmajid, A comprehensive review of heat transfer intensification methods for latent heat storage units. Energy Storage, 3(1), (2021) e127. https://doi.org/10.1002/est2.127

[7] B. Patil, N. Salunke, V. Diware, A.R.S. Raheman. K.B. Ansari, Stability assessment of emerging phase change materials for solar thermal storage in absorption refrigeration: A review. International Journal of Green Energy, 22, (2025) 1-28. https://doi.org/10.1080/15435075.2024.2413678

[8] S. Shaikh, K. Lafdi, K. Hallinan, Carbon nanoadditives to enhance latent energy storage of phase change materials. Journal of applied physics, 103(9), (2008) 094302. https://doi.org/10.1063/1.2903538

[9] J. Wang, H. Xie, Z. Xin, Thermal properties of paraffin based composites containing multi-walled carbon nanotubes. Thermochimica Acta, 488(1-2), (2009) 39-42. https://doi.org/10.1016/j.tca.2009.01.022

[10] T.P. Teng, B.G. Lin, Y.Y. Yeh, Characterization of heat storage by nanocomposite-enhanced phase change materials. Advanced Materials Research, 287, (2011)1448-1455. https://doi.org/10.4028/www.scientific.net/AMR.287-290.1448

[11] C.J. Ho, J.Y. Gao, Preparation and thermophysical properties of nanoparticle-in-paraffin emulsion as phase change material. International Communications in Heat and Mass Transfer, 36(5), (2009) 467-470. https://doi.org/10.1016/j.icheatmasstransfer.2009.01.015

[12] A.V. Arasu, A.S. Mujumdar, Numerical study on melting of paraffin wax with Al2O3 in a square enclosure. International Communications in Heat and Mass Transfer, 39(1), (2012) 8-16. https://doi.org/10.1016/j.icheatmasstransfer.2011.09.013

[13] A. Sarı, A. Karaipekli, Thermal conductivity and latent heat thermal energy storage characteristics of paraffin/expanded graphite composite as phase change material. Applied thermal engineering, 27(8-9), (2007) 1271-1277. https://doi.org/10.1016/j.applthermaleng.2006.11.004

[14] A. Gil, E. Oró, L. Miró, G. Peiró, Á. Ruiz, J.M. Salmerón, L.F. Cabeza, Experimental analysis of hydroquinone used as phase change material (PCM) to be applied in solar cooling refrigeration. International journal of refrigeration, 39, (2014) 95-103. https://doi.org/10.1016/j.ijrefrig.2013.05.013

[15] A.T. Muzhanje, M.A. Hassan, A.A. El-Moneim, H. Hassan, Preparation and physical and thermal characterizations of enhanced phase change materials with nanoparticles for energy storage applications. Journal of Molecular Liquids, 390, (2023) 122958. https://doi.org/10.1016/j.molliq.2023.122958

[16] X. Liu, P. Mäki-Arvela, A. Aho, Z. Vajglova, V.M. Gun'ko, I. Heinmaa, N. Kumar, K. Eränen, T. Salmi, D.Y. Murzin, Zeta potential of beta zeolites: Influence of structure, acidity, pH, temperature and concentration. Molecules, 23(4), (2018) 946. https://doi.org/10.3390/molecules23040946

[17] B.Y. Patil, N.P. Salunke, V.R. Diware, V.K. Suryavanshi, P.S. Patil, Concentration of nano fluid/base fluid suspension enhance surface charge with pH stability for low to mediumtemperature phase change materials. ShodhKosh: Journal of Visual and Performing Arts, 5(4), (2024) 525–542. https://doi.org/10.29121/shodhkosh.v5.i4.2024.2258

[18] J.T. Miller, M. Schreier, A.J. Kropf, J.R. Regalbuto, A fundamental study of platinum tetraammine impregnation of silica: 2. The effect of method of preparation, loading, and calcination temperature on (reduced) particle size. Journal of Catalysis, 225(1), (2004) 203-212. https://doi.org/10.1016/j.jcat.2004.04.007

[19] P. Mäki-Arvela, D.Y. Murzin, Effect of catalyst synthesis parameters on the metal particle size. Applied Catalysis A: General, 451, (2013) 251-281. https://doi.org/10.1016/j.apcata.2012.10.012

[20] K. Rodríguez, M. Araujo, Temperature and pressure effects on zeta potential values of reservoir minerals. Journal of colloid and interface science, 300(2), (2006) 788-794. https://doi.org/10.1016/j.jcis.2006.04.030

[21] S. Chakraborty, P.K. Panigrahi, Stability of nanofluid: A review. Applied Thermal Engineering, 174, (2020) 115259. https://doi.org/10.1016/j.applthermaleng.2020.115259

[22] N. Hordy, D. Rabilloud, J.L. Meunier, S. Coulombe, High temperature and long-term stability of carbon nanotube nanofluids for direct absorption solar thermal collectors. Solar Energy, 105, (2014) 82-90. https://doi.org/10.1016/j.solener.2014.03.013

[23] D. Yılmaz Aydın, M. Gürü, Nanofluids: preparation, stability, properties, and thermal performance in terms of thermo-hydraulic, thermodynamics and thermo-economic analysis. Journal of Thermal Analysis and Calorimetry, (2021)1-34. https://doi.org/10.1007/s10973-021-11092-8

[24] K. Cacua, F. Ordoñez, C. Zapata, B. Herrera, E. Pabón, R. Buitrago-Sierra, Surfactant concentration and pH effects on the zeta potential values of alumina nanofluids to inspect stability. Colloids and Surfaces A: Physicochemical and Engineering Aspects. 583, (2019) 123960. https://doi.org/10.1016/j.colsurfa.2019.123960

[25] S. Bhattacharjee, DLS and zeta potential–what they are and what they are not?. Journal of controlled release, 235, (2016) 337-351. https://doi.org/10.1016/j.jconrel.2016.06.017

[26] S.K. Sharma, S.M. Gupta, Preparation and evaluation of stable nanofluids for heat transfer application: a review. Experimental Thermal and Fluid Science, 79, (2016) 202-212. https://doi.org/10.1016/j.expthermflusci.2016.06.029

[27] H.W. Chiam, W.H. Azmi, N.A. Usri, Rizalman Mamat, N.M. Adam, Thermal conductivity and viscosity of Al2O3 nanofluids for different based ratio of water and ethylene glycol mixture. Experimental Thermal and Fluid Science, 81, (2017) 420-429. https://doi.org/10.1016/j.expthermflusci.2016.09.013

[28] V. Brancato, A. Frazzica, A. Sapienza, A. Freni, Identification and characterization of promising phase change materials for solar cooling applications. Solar Energy Materials and Solar Cells. 160, (2017) 225-232. https://doi.org/10.1016/j.solmat.2016.10.026

[29] A. Gil, E. Oró, G. Peiró, S. Álvarez, L.F. Cabeza, Material selection and testing for thermal energy storage in solar cooling. Renewable Energy, 57, (2013) 366-371. https://doi.org/10.1016/j.renene.2013.02.008

[30] M.M.A. Khan, R. Saidur, F.A. Al-Sulaiman, A review for phase change materials (PCMs) in solar absorption refrigeration systems. Renewable and sustainable energy reviews. 76, (2017) 105-137. https://doi.org/10.1016/j.rser.2017.03.070

[31] A.M. Schrand, M.F. Rahman, S.M. Hussain, J.J. Schlager, D.A. Smith, A.F. Syed, Metal-based nanoparticles and their toxicity assessment. Wiley interdisciplinary reviews: Nanomedicine and Nanobiotechnology, 2(5), (2010) 544-568. https://doi.org/10.1002/wnan.103

Acknowledgement

We are grateful to SSBT COET Bambhori, Jalgaon, for providing the necessary facilities. Finally, heartfelt thanks to our colleagues and families for their encouragement and assistance.

Authors Contribution Statement

Bhushan Y Patil: Conceptualization, Methodology, Data curation, Formal analysis, Writing – original draft, Writing –review & editing. Nilesh P Salunke: Formal analysis, Validation, Supervision. Vijay R. Diware: Visualization, Investigation.

Funding

The authors declare that no funds, grants or any other support were received during the preparation of this manuscript.

Data Availability

The data supporting the findings of this study can be obtained from the corresponding author upon reasonable request.

Competing Interests

The authors declare that there are no conflicts of interest regarding the publication of this manuscript.

Has this article screened for similarity?

Yes

About the License