Experimental Analysis on Nano-based Phase Change Material for Cooling Applications in Tropical Buildings

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Abstract: **The main aim of the investigation is to develop new nano-based PCM (phase change materials) establishing thermal energy storage for catering cooling needs in tropical buildings. PCM's lag with their thermal properties like thermal conductivity, latent heat of capacity etc. To enhance its properties generally, nanoparticles are dispersed in PCMs. The present work deals with the synthesis of TiO_2 nanoparticles using sol-gel chemical method and characterizing particle size, shape and its morphology. The as-prepared TiO_2 nanoparticles were dispersed with different wt. % in Rubitherm 21 type PCM. Then, nano based PCM's were tested for its melting, freezing, latent heat characteristics and concluding for compact ability with building applications to cater cooling needs.**

Index Terms: **Phase Change Materials, Nano particles, Thermal Energy Storage, Buildings.**

I. Introduction

The increasing concerns about climate change and environmental emissions have led to conserve energy in buildings through the development of several energy-efficient technologies. From early 1970's to till this point in time, huge importance has been given to the net energy being consumed in buildings.

In the recent years, increased demand in the construction sector has paved way for the development of huge and elegant building structures worldwide. Albeit, the required purpose of these structures is being continuously met, factually, buildings would consume almost one-third to one-quarter of the total energy being produced, globally.

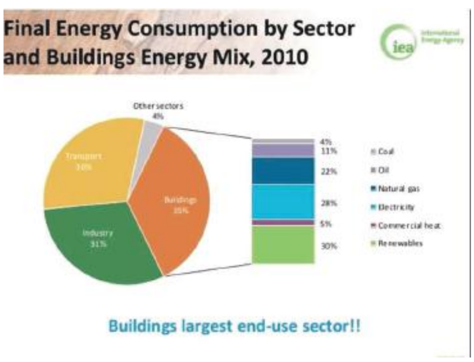

Figure 1. Energy consumption break-up by sector wise [1]

According to the statistical report of international energy agencies [1], the building sector in developed nations is accounting for about 35% of energy consumption. Further buildings consume energy from different sources; among them, it consumes approximately 30% in the form of renewable energy and 28 % in the form of electricity. Hence, there is an immense need to go for energy-efficient technologies in order to bridge the gap between the energy supply and end-use energy demand (Fig. 1).

There are wide varieties of energy storage technologies available, each type has its own advantages and limitations. Thermal energy storage is an important technique used widely for storing energy. Thermal energy storage is further classified as shown in Fig. 2. Latent Thermal Energy Storage (LTES) is widely used for storing energy to cater to cooling needs for building applications. PCM plays an important role in the performance of latent thermal energy storage system which stores energy during off-peak demand and redistributes the energy during on-peak demand.

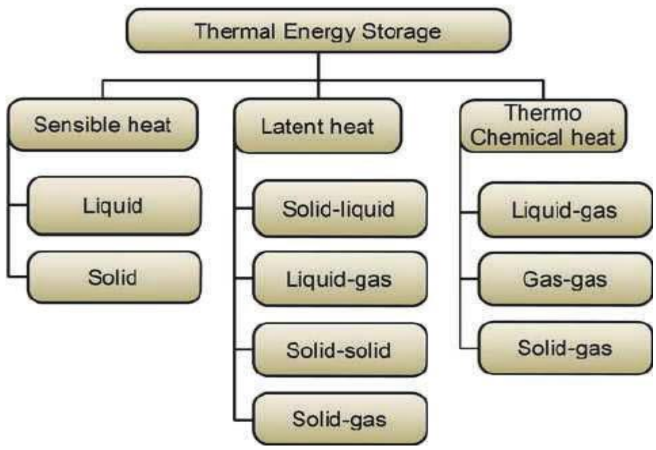

Figure 2. Classification of Thermal Energy Storage [16].

The PCMs were classified as inorganic PCMs (eg. Salt hydrates), organic PCMs (eg. paraffin's, fatty acids and fatty acid esters) and eutectic PCMs (eutectic salts and solutions) as shown in fig. 3. Among three, organic type PCMs are mostly preferred for cooling applications in buildings due to their excellent thermo-physical properties.

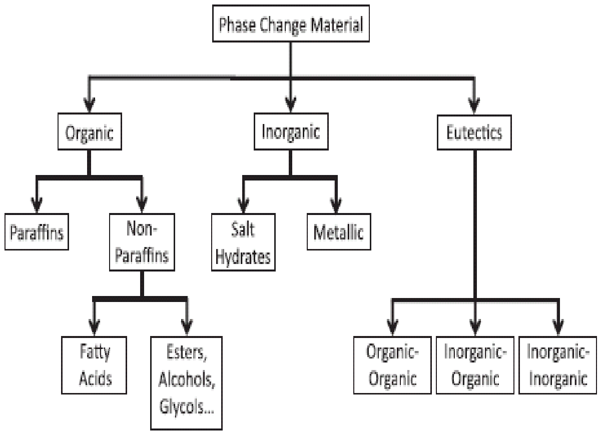

Figure 3. Classifications of Phase Change Materials [8]

Fig. 4 & 5 depict the working principle of PCM. PCMs during charging absorb cool energy thereby phase transforms from liquid to solid and during discharging they redistribute absorbed cool energy, thus maintaining human comfort temperatures for some time period.

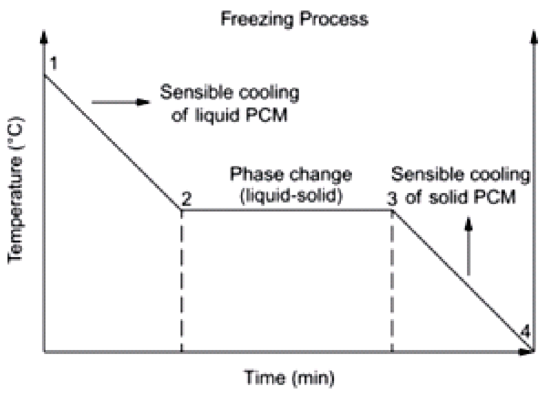

Figure 4. Schematic representation of freezing process for PCMs [15]

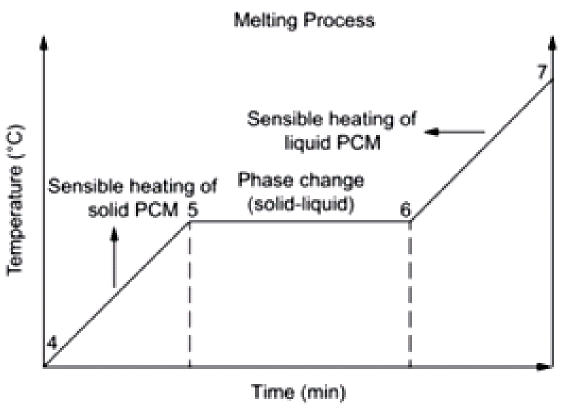

Figure 5. Schematic representation of melting process for PCMs [15]

II. Literature Survey

Pisello et al. [3] investigated for morphology, optical features, thermal characteristics, electrical properties and strain-sensing capability of cement-based composites doped with different carbon nano-inclusions, namely MWCNTs (multi walled carbon nano tubes), CNFs (carbon nano films), CB and GNPs (graphene nano platelet). The author also reported that all carbon nano-inclusions are seen to reduce solar reflectance capability, while they produce negligible variations in thermal emittance. Thermal conductivity and diffusivity were increased with Graphene nano platelet and better distribution of thermal wave. Consistently, the same graphene samples produce the largest electrical conductivity and capacitance.

Tang et al [4] prepared myristic-stearic acids (MA-SA) binary eutectics with appropriate phase change temperature. The melting temperature of the MA-SA eutectics and the mass fraction of the MA in the eutectic mixtures are 42.70°C and 54%. Then, a series of the MA-SA/CNTs with different mass fractions of the Carbon Nano Tubes (3%, 6%, 9%, 12% and 15%) were synthesized in order to investigate the thermal properties of the CPCM (composite phase change materials). The test results showed that, compared to the thermal conductivities of the MA-SA eutectics, the thermal conductivities of the CPCM's increase by 23.2%, 49.4% and 63.7% in the solid state, and 15.6%, 32.0% and 39.7% in the liquid state as the mass fractions of the CNTs are 9%, 12% and 15%.

Khodadadi and Babaei [5] performed a research study on the PCM incorporated with the copper nanoparticles, wherein the copper nanoparticles added to the PCM in molar concentrations of 0.1 and 0.2 have yielded the reduction in the overall freezing time of the PCM. This, in turn, facilitates for consuming less energy per unit mass of freezing the PCM.

Wu et al [9] investigated on melting/freezing characteristics of paraffin by adding Cu nanoparticles. Thermal stability of Cu/paraffin is good after 100 thermal cycles. With the increase in mass concentration of Cu nanoparticles, there was a nonlinear increase in thermal conductivity of Cu/Paraffin composites. With 2 wt % Cu/paraffin the maximum thermal conductivity enhanced up to 14.2% in solid state and 18.1% in the liquid state. The melting and freezing times for 1 wt % Cu/paraffin can be saved as about 33.3 and 31.6 %.

Lotfi et al [10] performed thermodynamic simulation using TRNSYS 17 software by incorporating PCM 204 in the walls of concrete ceiling and hollow bricks. The results revealed that there was 4 °C increased temperature in winter and reduced temperature of 7 °C in summer. There was energy saving of 25% in heating and cooling with the implementation of 30% PCM in gypsum panels used as interior plaster in buildings.

The study conducted by Li et al. [11] revealed the importance of incorporating the expanded graphite/paraffin PCM into the cement mortar, wherein the composite material developed, showed good temperature regulation with reduced maximum indoor centre temperature difference by 2.2 K and 1.5 K during heat storage and release processes, respectively. The test board fabricated using this composite material exhibited 1.74 higher heat storage coefficient than an ordinary cement mortarboard.

III. SYNTHESIS AND CHARACTERIZATION

For a synthesis of nanoparticles, sol-gel method was used. 25 ml of titanium tetrachloride ($TiCl_4$) is kept in ice cool bath which liberates heat because of an exothermic reaction. The solution having a very low temperature is slowly made to room temperature with a stirring process done on the magnetic stirrer at 350 rpm as shown in Fig. 6. Later the bath temperature should be increased slowly to 100 ºC until solutions get converted to thick as shown in Fig. 7. The contaminants present in the solution need to be removed, which can be done by incremental heating in a furnace to 250, 350 and to 550 ºC, Later it is milled using ball milling at 550 RPM. Finally, TiO_2 nanoparticles are prepared. The nanoparticles are then characterized for its size and morphology. It was revealed from TEM studies that the size is approximately 50nm as shown in Fig. 9. The as-prepared nanoparticles are then dispersed with varying increments of 0.5, 1, 2, 5 % in Rubitherm 21 type PCM.

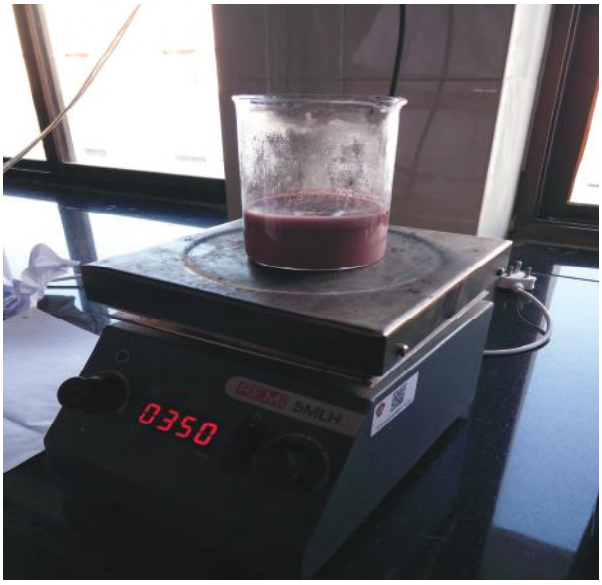

Figure 6. Solution stirred on magnetic stirrer

Figure 7. Thick solution of TiO_2

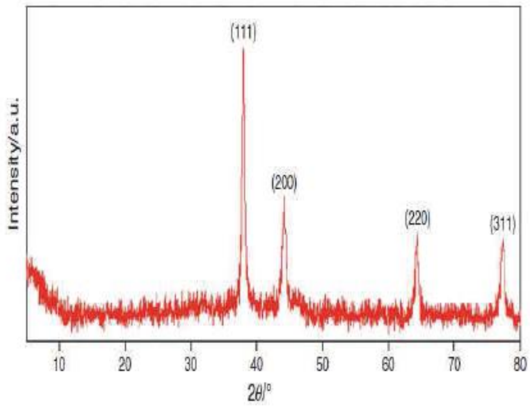

Figure 8. XRD pattern of Titania nanoparticles.

The nanoparticles were examined by X-Ray diffraction. The graph as shown in Fig. 8 reveals that nanoparticles prepared were highly crystalline. The XRD peaks for Titania nanoparticles obtained at 38.11º, 43.26º, 65.38º, and 76.39º of 2θº. Debye–Scherrer method [12] was used for average crystallite size which is 61 nm.

The as-prepared nanoparticles are characterized by shape, size using transmission electron microscope. The SEM results reveal that the nanoparticles are spherical in shape and size ranging from 50 nm to 100 nm.

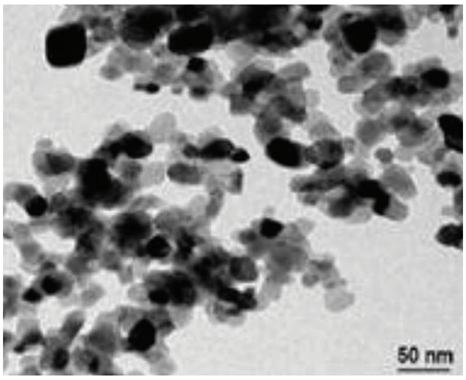

Figure 9. TiO_2 nanoparticles.

IV. PREPARATION OF NPCM

Ultrasonication process to avoid agglomeration and uniform mixing of titania nanoparticles in Rubitherm 21 type PCM.

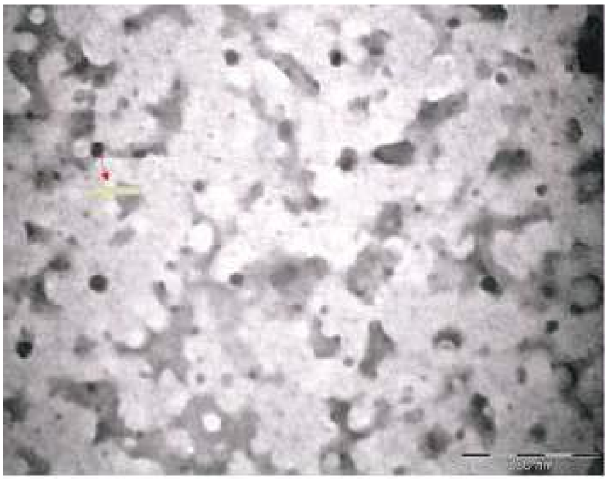

Figure 10. PCM dispersed with 0.5 % TiO_2 nanoparticles

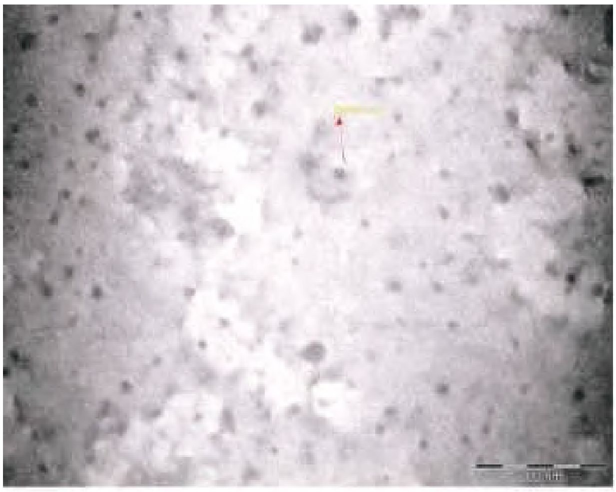

Figure 11. PCM dispersed with 1 % TiO_2 nanoparticles

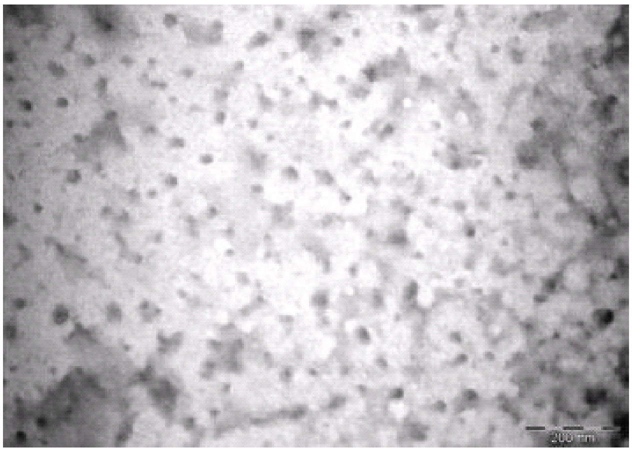

Figure 12. PCM dispersed with 2 % TiO_2 nanoparticles.

Figure 13. Nano based PCMs samples

Figure 14. Thermal Energy Storage Set up

V. EXPERIMENTATION

Thermal energy storage system was used for melting and freezing temperatures of different samples as shown in Fig. 14. System equipped with heating and refrigeration circuits controlled automatically for increasing and decreasing temperatures of the water bath. The setup has a capacity to perform experiments in the range of 2 ºC to 90 ºC. Thermocouples were used for sensing temperature of the water and samples. The Stirrer is provided in the water bath for stirring by making a uniform water temperature.

The thermal conductivity of pure PCM is 0.2 W/ m k. With the TiO_2 nanoparticles dispersion in PCM, thermal conductivity enhances, it varies from 0.279 to 0.749 W/ m k.

For freezing and melting characteristics of NPCM, bottles filled with NPCM having a room temperature are immersed in a cool water bath. Solidification process takes place in three stages. Firstly, PCM gives out sensible heat to the cool fluid, thereby PCM temperature decreases gradually. In the second stage, it dissipates latent heat at isothermal conditions. The solidification starts from outer most and ends at the center with uniform conditions. In the third stage after complete solidification, further decrease in temperature takes place. The results revealed that solidification takes place at the fastest rate and latent heat capacity increases due to a dispersion of TiO_2 nanoparticles.

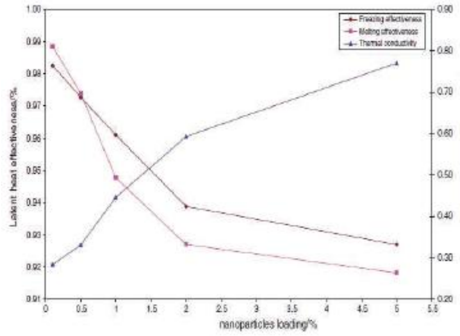

Figure 15. Effect on latent heat effectiveness and thermal conductivity with varying % nanoparticles

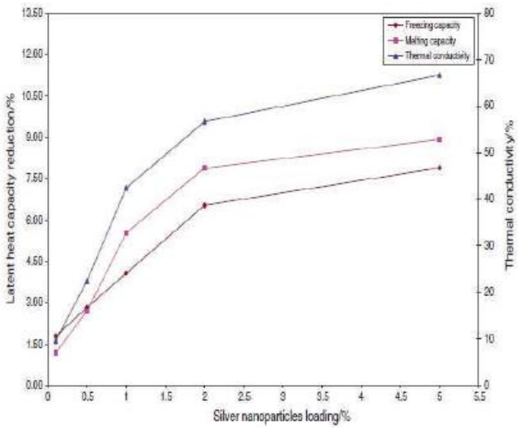

Figure 16. Effect on latent heat reduction and thermal conductivity with varying % nanoparticles

VI. RESULTS AND DISCUSSION

TABLE I

Summary of latent heat and degree of super cooling for different nano particles loading in pcm.

TiO_2 % loading	Latent heat kJ/kg		Degree of super cooling
	Freezing	Melting	
0	148	155	1.76
0.5	147	152.78	1.65
1	147.45	151.01	1.52
2	144.44	150.98	1.51
5	143.20	150.2	1.30

The Titania nanoparticles prepared were uniformly dispersed leading to enhanced thermal properties compared with pure PCM. During charging, it was noticed that there was a faster rate of cold energy transfer from HTF (heat transfer fluid) to PCM, because of the nanoparticles. Due to a faster rate of heat transfer, the time taken for charging (Off-peak demand) and discharging time (On-peak demand) were reduced. The Titania nanoparticles, when dispersed in PCM were chemically stable.

The experimental results suggest that NPCM can be beneficial and practically implemented for cooling needs in buildings, cold storage, etc.

VII. CONCLUSIONS

From the experimental work following points were concluded.

1. With the sol-gel process and controlled process parameters like volume percentage of solute, solvent and treating temperatures, TiO_2 particles prepared were in nano range.
2. The prepared TiO_2 nanoparticles are spherical in shape and average size distribution is 61 nm.
3. When the nanoparticles are dispersed in PCM the mixture is stable with no chemical reaction between PCM and nanoparticles.
4. From the experimentation, it is concluded that with the increased mass percentage of nanoparticles thermal conductivity increases enhancing the faster rate of nucleation making solidification faster.
5. Latent heat storage capacity has increased compared to pure PCM and exhibits slight differences during melting and freezing cycles.
6. It is also noticed that with the increased percentage of nanoparticles, degree of super cooling has decreased.

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