Enhancement of Thermal Characteristics and Stability of Phase Change Materials in presenceof Nanoparticles for solar Applications in Latent Heat Storage Systems: Review

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Abstract: **Objectives**: To explore different types of Nanoparticles in based paraffin wax as Phase Change Materials (PCM) and analyzed their thermal characteristics and stability for store energy in solar thermal systems. The main focus is on solar systems using the thermal energy storage and system to get a low economic analysis as high efficiency. **Methods:** To determine the research issues and gaps in the field of thermal energy storage, a thorough and complete evaluation of the literature are conducted (TES). This paper summarizes recent research on PCM as TES and suggests next directions.. This review paper, complied different available research work related to use of various nanoparticles in presences of paraffin wax and highlighted on thermal characteristics such as thermal conductivity, viscosity, density, Latent Heat, Specific Heat, thermal efficiency of nanoparticles used by different researcher to find out best and most efficient nanoparticles for storage thermal energy. **Findings:** It was found that paraffin was as PCMs are used more predominately for latent heat storage in solar applications. By adding different nanoparticles thermal conductivity, viscosity, density, Latent Heat, Specific Heat, thermal efficiency has been improved significantly with different concentration in base paraffin wax. **Novelty/ Application:** This paper would be helpful to find the best and the most efficient nanoparticles with based paraffin wax for latent heat thermal storage systems in solar applications. An comprehensive and arduous literature review helped to recognize the research gap regrading Phase change Materials, different parameters for enhance thermal properties by adding Nanoparticles, which would store higher energy.

Keywords: Latent Heat Storage, Phase Change Materials, Paraffin wax, Nano-particles, Thermal Properties, Solar applications.

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1. Introduction

The economy has undergone significant and rapid changes, leading to a heightened need for energy. As a result, the annual output of carbon dioxide (CO_2) resulting after combustion of fossil fuels has reached approximately 35 billion metric tonnes. This phenomenon has sparked considerable interest in the scientific community and is the issue of current research. [1] The usage of fossil fuels has resulted in significant environmental damage. Renewable energy sources are sunlight, rain, waves, wind, geothermal heat, and carbon-natural. These types of energy source dissimilarities with fossil fuels. [2] Therefore, thermal storage energy has usual a lot of attention and rapid development for storage of energy. Sensible latent, reversible thermochemical reaction is main forms of storage for energy. [3] The latent heat storage reflected critically with phase change form one state to other state. PCMs, which are materials capable of storing energy at a precise temperature by going through a change phases, can be used to achieve latent storage of energy. [4, 5] The heart of heat storage by latent system is a PCM. When melted & solidified at a specific temperature, PCM container accumulation and relief substantial amounts of energy due to high heat of fusion. PCMs are basically categorized into organic and inorganic compounds. Furthermost organic compounds are not corrosive and chemically sturdy, show minor or not any chilling possess high latent heat storage energy but major drawback of lesser thermal conductivity. In-organic complexes obligate a great storage of latent heat and thermal conductivity, not-flammable. However, they are reacting with most metals and suffering from disintegration and chilling problems which can upset PCMs thermal properties. [6] The belongings of PCM affect the storage of latent heat. Storage through latent heat is compacts with a high fusion latent heat, specific heat, and thermal conductivity. [7] The combination of storage of latent with a PCM is a practical method for storage energy for solar implications systems. This implantation resulted for large amount of high energy, solidity and isothermal loading development in different solar applications**.** These store energy used into solar system such as water heater, cooker, recovery of heat, heating in air, greenhouses for solar.[8] There are many applications of PCMs, divided into storage, construction applications, preservation and transport of temperature penetrating constituents, liquid boilers etc. [9] Associated to sensitive storage of materials, PCM has great potential for storage of heat. However, many PCMs have small thermal conductivity, which results in low-slung of diffusivity and reduced actual storage capacity. Organic PCM offers superior thermos physical properties over inorganic PCMs in several respects. In recent years, the adoption of PCM for heat storage applications is increasing. As PCMs are used into renewable energy storage sources systems so it will be green clean energy roadmap towards environments developments. [10]

1.1 Nano-Enhance Phase Change Materials (NEPCMs):

The identical distribution of nano- particles in PCMs showed greater potential for LHTES. The large amount of heat release from Nano particles with Phase Change Materials is known as NEPCMs. These are promising for its rising use in different Energy sector. [11] Temperature for change of phase, thermal conductivity, latent heat, diffusivity, change in volume, outcome of chilling, price, security, constancy, solidity, vapor pressure, summation rate are identifying the right choice of particles of Nano into based

PCMs. The required quantity of nanoparticles must be incorporated toward improve the thermal conductivity of materials of phase. Introduction of nano-particles reduces the consequence of sub-cooling and duration for change to phases. Concentration of nano- particles is directly proportionally to the density and viscosity of material of phase change. The thermo-physical assets of nano- particles embedded with PCMs change marginally after repeated thermal cycling. [12] The characteristics of nano-particles their size, number, and characteristic ratio have a substantial effect on the conductivity of changes of phase. Metal-based nanoparticles have a higher thermal conductivity compared to carbon-based ones. However, their high density leads to poor consistency in their performance. Researchers face a significant challenge in dealing with the uneven spreading and deposition of nanoparticles. Metal particles obligate better constancy, larger aspect ratio but lower density, and so they can outperform nanoparticles on thermal conductivity count. Thermal conductivity is more affected through low porosity foams than by porosity and pore size, which have minimal effects. The thermal conductivity of expanded graphite nanocomposites during phase changes can be affected by various factors, such as the mass fraction, packing density, aspect ratio, surface area, and thickness. These variables piece a serious role in determining the effectiveness of the PCM in conducting heat. Therefore, understanding the impact of each of these factors is vital used for optimizing the design and performance through expanded graphite-on composite PCMs. Ongoing research is dedicated to exploring the association amongst these parameters and the thermal conductivity for composite PCM. Due to their superior thermo-mechanical qualities and high heat conductivity, encapsulated PCMs are particularly interesting choices for both indoor and outdoor applications. Encapsulation lowers PCMs direct exposure to the environment, extending their shelf life and minimizing phase separation and leakage problems. [13] The consistency of PCMs appears to be significantly influenced by the careful selection of nanoparticles. The base PCM's thermal conductivity has increased as a result of the nano- particle volume quantity. Thermal conductivity of solar systems improves as the rate of heat transfer increases. Due to increased heat dissipation, the application of NEPCM in solar panels increased their effectiveness. [14] When measuring the effectiveness of thermal performance, heat transfer rate is a crucial component. It was detected, thermal conductivity of PCMs increases with introduction of nano-particles with higher thermal conductivity. The nanoparticles used preferably are carbon and metal based additives since they possess

Outstanding thermal conductivity. Carbon-based nanoparticles remain superior than metal based ones in respect of thermal stability, density. They find a host of applications in solar energy thermal systems. [15] Variations in size, concentration and superficial assets of dispersed CNT/CNF in the PCM alter the heat transfer behavior. PCM disseminated with metal or oxide of metal nanoparticles demonstration augmentation in conductivity of thermal and is influenced by their morphology, size and concentration. Modification in the thermal conductivity of NEPCM significantly reduces solidification, melting duration of composite. PCM properties change markedly beyond the critical concentration of nanoparticles. As a result, there is a limitation in dispersing furthermore nanoparticles in PCM beyond critical concentration. The morphology and size of nanoparticles affect nucleation, i.e., the growth of PCM crystals. Higher concentration of nanoparticles present in PCM, showed increase in dynamic viscosity although not thermal conductivity which may limit the performance of PCM. [16] The performance of PCMs showed that Al metal and Al–Si alloy are excellent candidates as fillers in PCM-based system applications. Other factors like medium volumetric change, corresponding charging or discharging cycles to influence productivity, and overcoming operational challenges are related to re-activity or corrosion of materials. [17] Moreover, the CuO- MWCNT composite dispersed in pure paraffin wax was prepared for the bettering the performance of the material ascribed to properties such as thermal conductivity, heat capacity. The presented research fallouts exposed that wholesome paraffin wax has a thermal conductivity of 6.125% less than nano-enabled PCMs. During the experiment, It was also discovered that the time required for nano-enabled PCMs to transition from solid to liquid was 66.6% less than the time required for pure paraffin wax. [18] The effectiveness of Nano-enhanced PCMs may be improved by the capacity of various additives. Silicon, nanotube/fiber, graphene nanoplatelets, foam, carbon soots, zeolite, and MXene are the additions. They also consist of silicon, metals and their oxides, graphite, graphene, and carbon. [19]

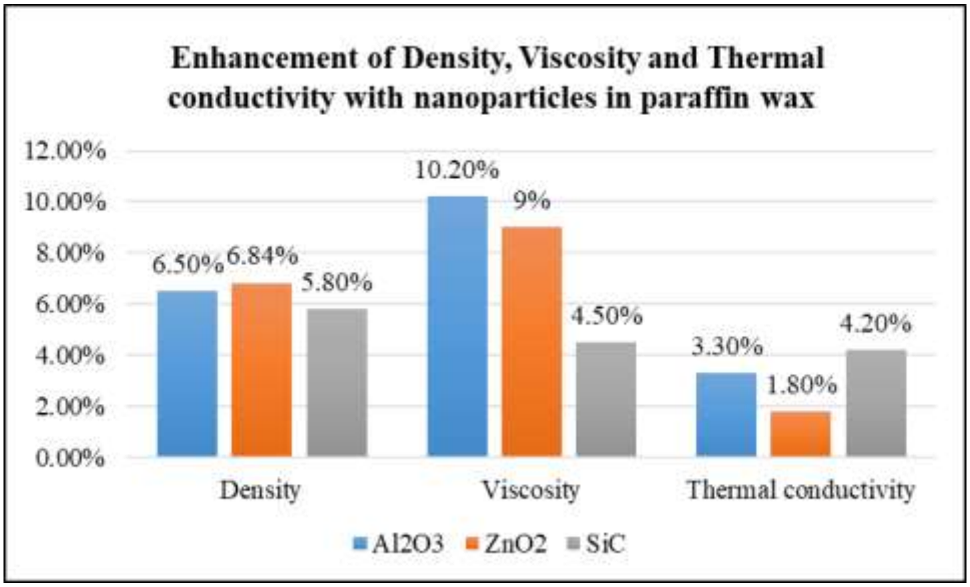
2. Thermal Properties and Stability Enhancement of PCMs with Nano-Particles:

Rise in thermal conductivity, density, and viscosity was observed for Al_2O_3, ZnO_2 and SiC on dispersing their nanoparticles in paraffin wax followed by sonication for 1 hour as shown in table 1.

Table No: 1 percentage enhancement of density, viscosity and Thermal conductivity

Nanoparticles	**Density**	**Viscosity**	**Thermal conductivity**
Al_2O_3	6.5%	10.2%	3.3%
ZnO_2	6.84%	9 %	1.8%
SiC	5.8%	4.5%	4.2%

The improvement in thermal conductivity and heat capacity on adding SiC was more than on adding Al_2O_3 as shown into graph no: 1 However, the addition of ZnO_2 to Paraffin was not recommended as the thermal conductivity of ZnO_2 as showed reduction in thermal conductivity over time as against other materials, while dispersion of SiC in paraffin wax the maximum appropriate applicant for solar uses. [20]



Graph No: 1 Enhancement of density, viscosity and Thermal conductivity by % with different nanoparticles.

Further, the ternary chloride salts of anhydrous magnesium chloride, potassium chloride, sodium chloride ($MgCl_2$: KCl: NaCl in 51:22:27 molar ratio) were doped into ZnO, CuO and Al_2O_3 nanoparticles as composite nanoparticles (CPCMs). An evaporation method was employed for the preparation of CPCMs. It was characterized for the thermal properties such as melting point, phase change enthalpy, TES capacity, thermal diffusivity and upper stability limit. It was observed that the latent heat of the PCM decreased from 2.4% to 7.6% while the sensible heat of the CPCM increased from 3.9% to 13.7%. As compared to pure salt, the effect of dopants on thermal energy storage capacity (TES) was not much. The variation in the melting point of the CPCMs was marginal. However, the thermal conductivity of CPCMs was found to be significantly enhanced as against pure salt. The CPCM doped with Al_2O_3 exhibited considerable improvement, in average thermal conductivity to the extent of 61.9%. CPCMs containing metal oxide nanoparticles namely, Al_2O_3, ZnO and CuO showed a wide operating temperature range in solar applications apart from excellent thermal stability. [21] While using or not using sodium stearyl lactylate (SSL) as a surfactant, the thermal characteristics and stability of a TiO_2/paraffin dispersion were studied. Similarly, dispersions with 0.5, 0.7, 1, 2, 3, and 4% by weight of TiO_2 were prepared with and without SSL. Because of more uniform dispersal, the thermal conductivity of TiO_2/liquid paraffin dispersions was higher in samples containing surfactants.

t was also discovered that the thermal stability of TiO_2/paraffin/SSL composite was greater than that of pure paraffin and TiO_2. The addition of nanoparticles to PCM causes melting point variations, while the latent heat is reduced after several thermal cycles. The thermal conductivity coefficient of pure paraffin is 0.147W/m 0 C, and it decreases by 0.08 J/g after 80 thermal cycles. SSL's presence reduces instability and enhances the sample's thermal characteristics. After numerous thermal cycles, the thermal conductivity of the Nano-composite with SSL was greater than that of the nano-composite without SSL. [22] Paraffin–Nano-magnetite (Fe_3O_4 With mass fractions of 10% and 20%) composites (PNMC) were equipped by a scattering method for investigating thermal properties. Further it was observed that diffusivity increases 8 % and thermal conductivity increases by 48 % and 60% for 10 to 20 % weight of nanomaterials. The results showed that adding Fe_3O_4 nanoparticles is efficient and cost-effective. Mixture of 10 % nonmagnetic and paraffin carried out for 100 to 500 thermal cycles. After 500 cycles thermal stability achieved and observed not any significantly changes. [23] 1%, 4%, 7% and 10% Nano-graphite by weight was added to paraffin wax and placed in water bath at 60 ^{0}C. The mixture was homogenized by agitation and sonication at the operating temperature of 60 ^{0} C. The study examined that thermal conductivity of paraffin wax gradually increases with the addition of Nano-graphite. The thermal conductivity of the Nano-Paraffin was reported as 0.9362 W/m K for 10 % of nanoparticles. The dispersion of Nano-graphite improved the heat transmission & performance in term storage energy in heat storage systems. The thermal conductivity of the NG/paraffin composite increases is as the NG content increases, while the latent heat gradually reduces. [24] Emulsify Al_2O_3 nanoparticles (5 wt % & 10 wt %) with n-octadecane (PCM). They noticed that there is an enhancement in thermal conductivity decreases with increase in concentration of nanoparticles. With emulsion of the nanoparticles in n-octadecane led to increase in dynamic viscosity as shown in Table 2. [25]

Table No: 2. Sentimental/cold temperatures and heat for latent of Al_2O_3-in-octadecane suspensions

Nano- particle Fraction of mass	Density (kg/m^3)	Viscosity (N s/m^2)	Thermal Conductivity (W/m·K)	Heat for Latent storage (kJ/kg)
5 wt %	810	Increase by 20 %	Increase by 2 %	225.6
10 wt %	830	Increase by 28 %	Increase by 6 %	212.3

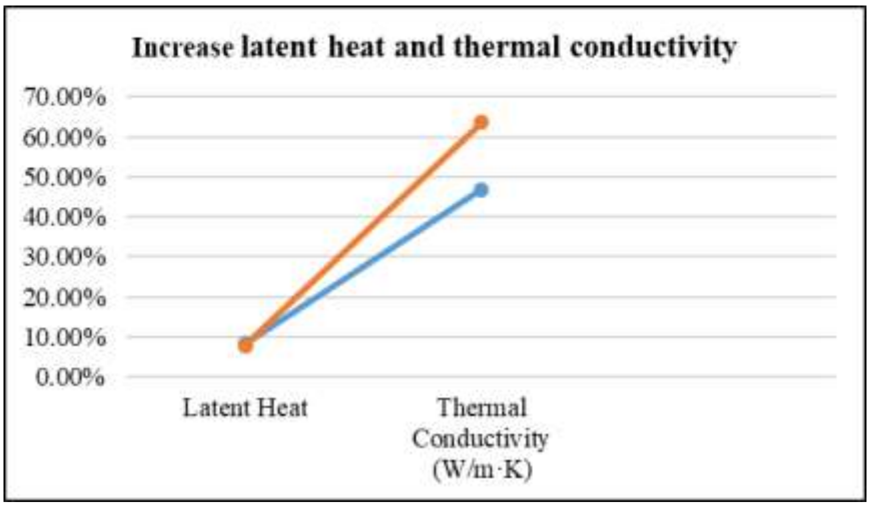
Nano-composites containing of paraffin wax, with a melting point ranging between 58^{0}C to 60^{0}C, polyaniline (PANI) and cupric (II) oxide (CuO) were prepared by using probe sonication. Triton X-

100 surfactants were added into Nano –composite was sonicated for 30 minutes. The enhancement of latent heat and thermal conductivity shown as Table No: 3 [26]

Table No: 3 Latent Heat/Thermal conductivity enhancements

Nano-particle	Enriched Latent Heat (J/g) Value	Latent Heat (% enhancement)	Thermal Conductivity (W/m·K)
Polyaniline (PANI)	166.2 ± 3.32 J/g	8.20 %	46.8%
Cupric (II) oxide (CuO)	165.62 ± 3.31 J/g	7.81%	63.6%

By adding Nano-composite PANI and CuO in sonication systems latent heat and thermal conductivity increases as showed in Graph no: 2



Graph No: 2 Increase latent heat and thermal conductivity

In a subsequent investigation, calcium chloride hexahydrate (CaCl26H2O) salt hydrate was held for 20 minutes at 50 °C while cesium tungsten bronze (CsxWO3) nanoparticles were created as additions that were near-infrared (NIR) light absorbents. The research discovered that CsxWO3 nanoparticle-containing salt hydrate PCM composites had outstanding NIR light shielding properties, high latent heat, low supercoiling degree, and strong thermal stability. Also, the development of solar energy storage technologies in the field of energy conservation is greatly anticipated by the disclosed salt hydrate/nano CsxWO3 PCM design. [27] Three diverse absorptions of Ti_3C_2 (0.1 to 0.3 %) existed encumbered (Ti_3C_2: Ti powder, aluminum powder, titanium carbide powder, sodium fluoride, hydrochloric acid and sodium hydroxide) into the PW70 heated into beaker at 100^0C. The improved specific heat and thermal conductivity found with 0.3 % shown in Table No: 3.This enhancements is advantageous in applications regarding thermal energy storage and heat transport. [28]

Table No:4 Specific Heat and Thermal Conductivity Enhancement

Nanoparticle	Specific Heat (J/g K))	Thermal Conductivity (W/m·K)
Ti_3C_2(0.3 wt % concentration)	43% rise	16 % rise

Ti3C_2 foam supported composite PCMs can be created using freeze drying and vacuum impregnation techniques. These composite PCMs have a great storage of energy density, improved thermal conductivity, enhanced form steadiness, a great photo thermal adaptation amount, and low stuffing contented. PCMs so produced prevent a large drop in phase transition enthalpy as against pure PEG, thereby overcoming the limitations of the composite PCMs. Further such PCM composite developed using above mentioned methods has 96.5 % photo thermal conversion efficiency. When 7.68 percent by weight of the filler is incorporated into the said composite PCM, the thermal conductivity improves significantly, and the enthalpy of phase change can reach 131.1 J/g. The thermally conductive 3D MXene foam plays a significant character in enlightening the composite PCM thermal conductivity, which is critical in determining the photo-thermal translation effectiveness of the PCM compound substantial. As a result, the PCM composite substantial holds a lot of promise and potential in energy storage through solar. [29] In solar systems, thermally stable stearic acid, palmitic acid, myristic acid, and lauric acid were used as materials through several thermal cycles. In order to employ the fatty acids as pcm industrial grade (purity between 90% and 97%), an accelerated heat cycle was applied to them. Based on the experimental results, the change in latent heats of fusion for the PCMs was between 1.0% and -27.7%, and the variation in gentle temperatures, with exception of stearic acid 60 and 1200 melt/freeze cycles, was in the range of 0.25-7.87 C. However, there was no consistent pattern associated with the quantity of thermal sequences for the decrease in latent heat of mixture for any PCM. The impurity of palmitinic acid by weight) in stearic acid is may be responsible for the decline in melting temperature and abrupt changes in latent heat of fusion. The examined fatty acids as materials for storage energy used in applications of storage have exposed practically virtuous thermal reliability. [30] A new type of Nano encapsulated phase change material (NEPCM) heat storage material was produced by diffusing CeO_2 nanoparticles into paraffin in 3 mass fractions of 0.5% to 0.2 %. It has been observed that the storage of heat properties for paraffin was significantly enhanced by the diffusion CeO2 nano-particles. In addition, NEPCM with 1.0% CeO_2 nanoparticles needs remained originate to be the correct grouping. [31] Through their research, it was discovered that using hollow cylindrical pin fins on an absorbent plate is the most effective way to elevate it due to the small conductivity of thermal. By utilizing this approach, the efficiency and vitality productivity of a single passive solar still can be improved by 11.96% and 37.50%, respectively. This finding offers valuable insights for emerging more efficient and sustainable energy storage through solar schemes. The best nano-particles to combine with paraffin wax have been discovered to be copper oxide nanoparticles. [32] To examine affect the thermal properties, aluminum and copper nanoparticles are mixed in various concentrations (0, 0.1, 0,3, 0.6, 1, 2.5, and 5%) in pure paraffin wax.

according to experimental findings, PCM can have its melting point raised and its solidification lowered the dispersion of Al and Cu nanoparticles. This dispersion might also be constrained by the NEPCM rising dynamic viscosity. Furthermore, related to the resulting greater quantity division, Al and Cu nanocomposites 2% and 1% mass concentration respectively, demonstrate superior improvements in the paraffin's for heat storage properties. [33]

2.1 Thermal Energy storage using solar Box Still:

Developed Solar heating devices for storage of heat as presented in fig 2.1, they examined, and a SWCNT (Carbon nanotubes) /paraffin wax nano-composite were equipped in a solar air heater, tested under various weather conditions. 3 wt % of SWCNT was used as optimal concentration keeping in view the thermos-physical characteristics of carbon nanotubes dispersed in paraffin on trying various mass fractions.

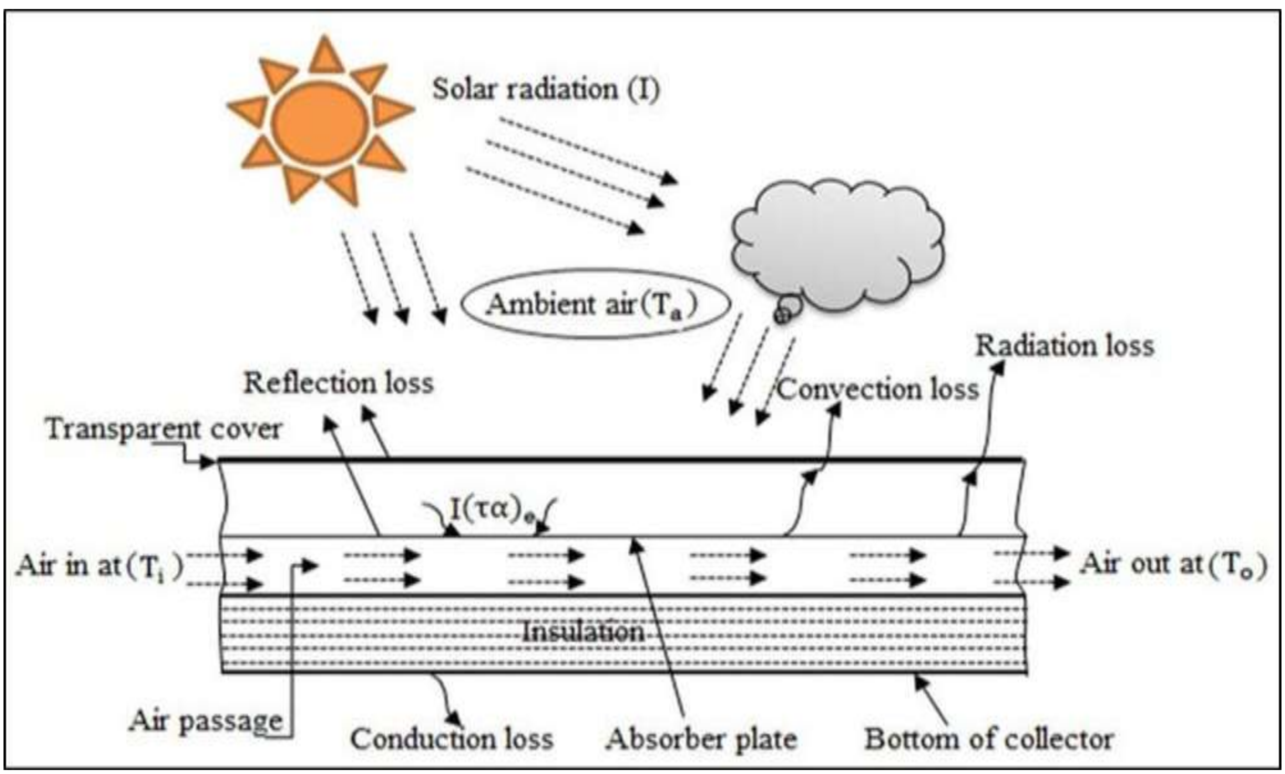


Fig 2.1 Solar air heater

SWCNT is responsible for increasing the thermal conductivity of paraffin by about 12 although lowering point of melting by 4.5 ^{0}C and freezing point by 9 ^{0} C. In comparison to using unalloyed paraffin for forced and natural convection processes, the SWCNT/paraffin nano-composite increases storage of heat in the morning and promotions the temperature of the warmer components by reducing charging and discharging time. With the help of natural & forced convection thermal energy stored is approximately 20.7 % & 21.2 % respectively which is far more than pure paraffin. The literature reviewed has indicated that the intensity of the sun is the most significant factor affecting the efficiency of solar heaters. To prolong the operational period of the solar heater, it is recommended to divert excess heat from the partying air that exits the cooled room to the heater.

During the measurement period, it was found that the effectiveness of the heater using natural convection was higher than that of the solar heater utilizing forced convection. Consequently, the solar heater's effectiveness decreased by approximately 13.75 percent over the course of the day when utilizing forced convection. These findings have important implications for optimizing the design and performance of solar heaters [34] The thermal presentation of 3 identical-capacity passive solar stills, one conservative (Still 1), one with a 1 phase change material (Still II), and one with 2 phase change materials (Still III), was investigated (Solar III). Still III's two PCMs were chosen so that their latent heat storage capacities are nearly identical, but their phase transition temperature ranges differ. The phase change temperature (PCT) ranges for PCM1 and PCM2 used in solar still III are 58.03 °C- 64.5 °C and 53.05 °C- 62 °C, respectively, as shown in Fig 2.2

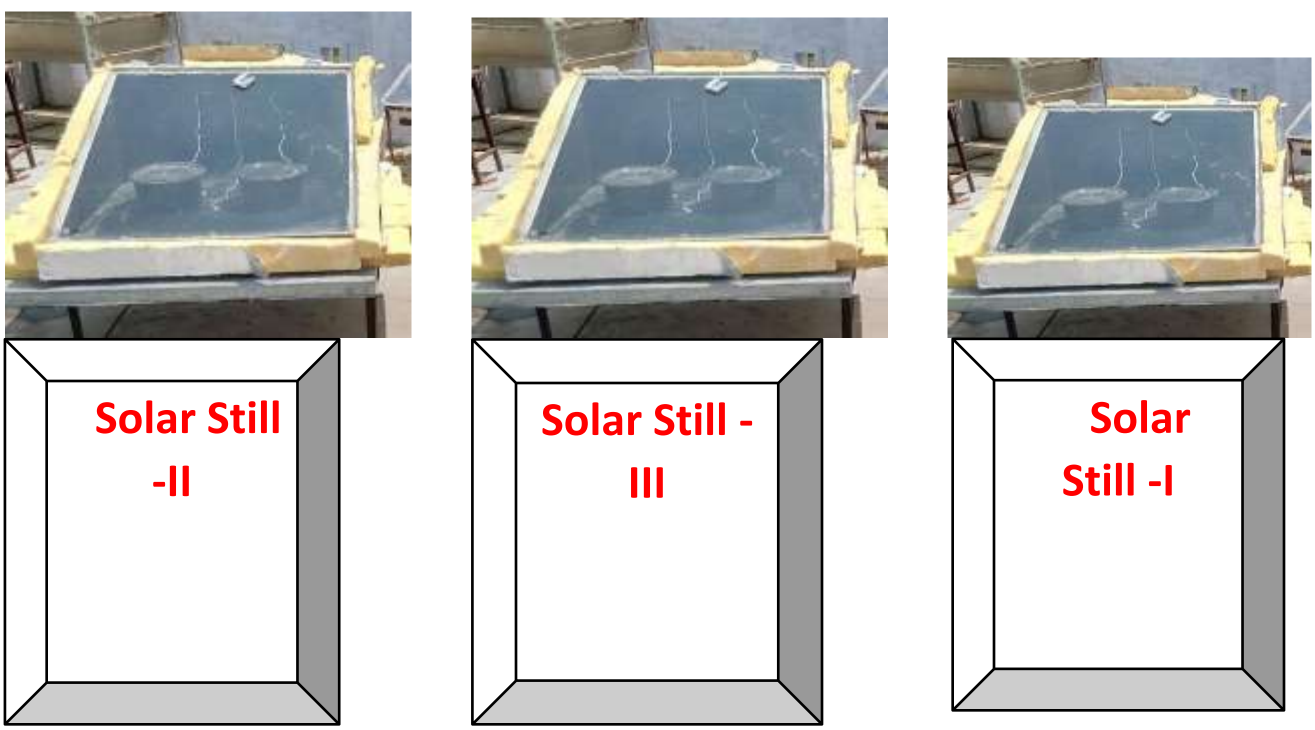


Fig 2.2 solar system with respective I, still II and still III

The thermal performance of Still I, II, and III was evaluated in terms of hourly yield per day and exergy efficiency. Still I produced 3.680 L/m2/day of water, while Still II and III produced 4.020 and 4.400 L/m2/day of water, respectively. Nonetheless, Exergy Efficiency I, II, and III were 3.92%, 3.23%, and 3.52%, respectively. [35] Using a physical hybrid technique, two different types of composite PCMs were created. These materials include sodium acetate trihydrate and expanded graphite (SAT/EG) as well as sodium acetate trihydrate and graphene oxide (SAT/GO/EG). For latent heat of fusion, SAT/EG has melting points of 57.9 0 C and 218.1 J/g, respectively. When two PCMs are exposed to sunlight, the thermophysical properties of the composite PCMs change, and the rate of phase change is approximately

the same. The solar radiation measuring system, as shown in Fig. 2.3, is made up of three parts: a total solar radiation sensor, a data logger, and a computer.

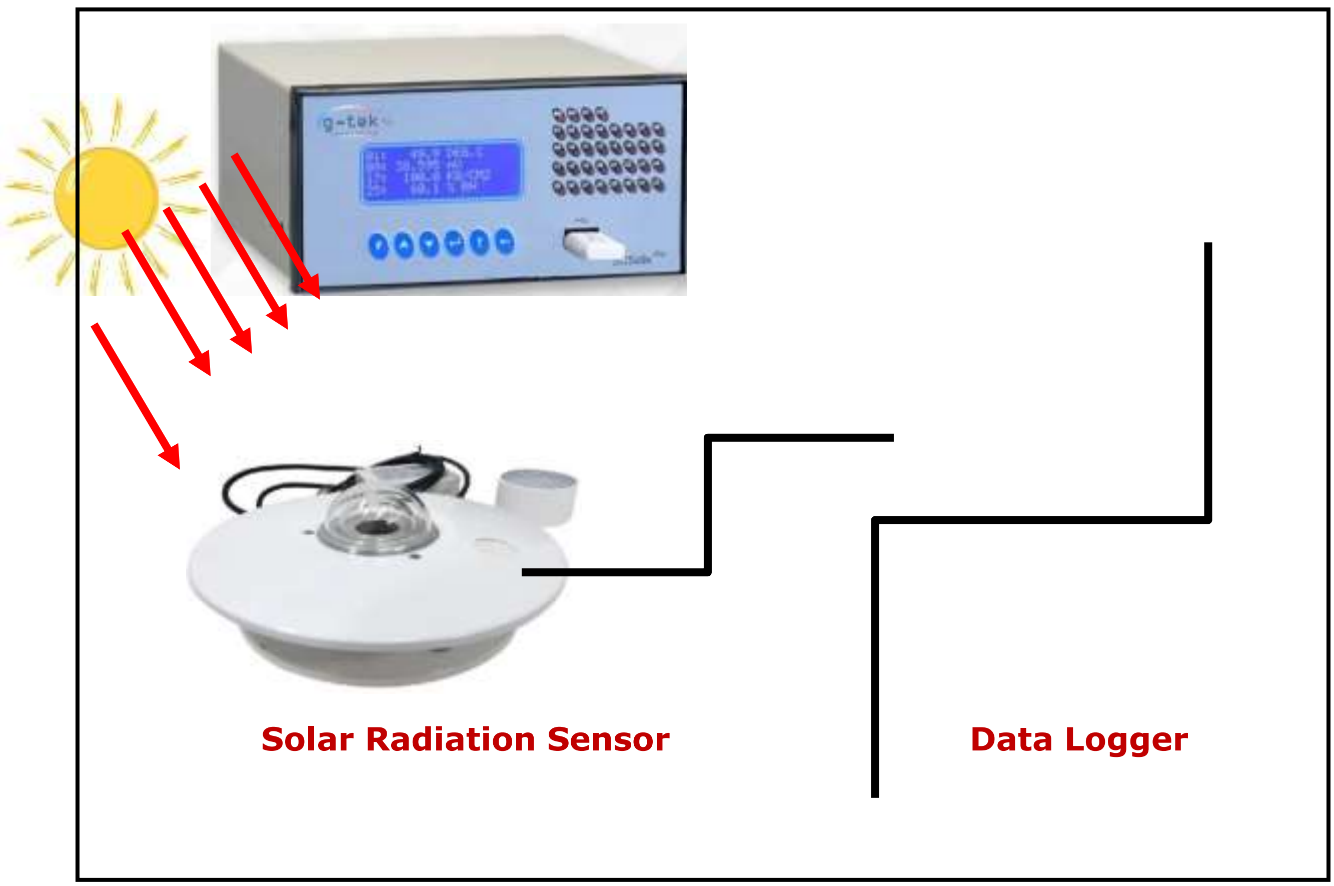


Fig 2.3 the experimental setup of solar radiation measurement system

Maximum densities of 0.8 g/cm3 for SAT/EG and 1.0 g/cm3 for SAT/GO/EG, respectively, traces of GO (less than 0.1 wt%) can improve compressed PCM form stability. When a novel form of collector was employed with a solar water heating system, SAT/GO/EG (1.0 g/cm3, 1628 g) was used as the material that simultaneously absorbed solar energy and served as a thermal storage medium. The efficiency of the systems solar to heat conversion was calculated to be 54.5%. These results demonstrate that SAT/GO/EG has outstanding solar energy absorption capabilities and has great promise for the creation of novel solar water heating systems. [36]

2.2 Thermal Energy Storage Applications as Phase Change Materials

To utilize heat obtained from industrial waste as needed, storage of latent heat is employed. The expanded natural graphite matrix is utilized in various configurations to enhance thermal conductivity. By incorporating this matrix, the systems can efficiently store and release thermal energy, allowing for on-demand utilization of the heat from industrial waste. Ongoing research continues to explore the optimal configurations and properties of the expanded natural graphite matrix for the most effective show storage of latent heat. A comprehensive study thermal efficiency of stowage through the chilling and warming phases was carried out. The findings revealed that the stowage can save 6 kW h, or 15% of the energy used in the process, and thus the delivered heat power is greater than 100 KW. Thus, it is demonstrated that heat losses occur through the external casing or variations in thermal contact resistance, affecting heat recovery. [37] Free cooling, solar refrigeration and air conditioning, heating and cooling, solar cooker, solar water heater, solar air heater, solar thermal power plants, and solar thermal energy are all applications for phase change materials. [38] The strategies and media adopted for the seasonal storage of collected solar heat for suburban applications are discussed in this research paper.

Primarily three types of storages are discussed: chemical, latent, and sensible. Chemical and latent principles continue to pose challenges, and further study is required in this regard. Right choice of materials, strong thermal stability (cyclability) and cost effectiveness are essential of PCMs. Nonetheless, these technologies have a host of appealing features, the most important of which is the ability to eliminate long-term self-disposal. [39] Phase change materials (PCM) have been studied for their potential to store thermal energy for a variety of uses, with concentrated solar thermal power (CSP) generation systems receiving the most attention. Systems using concentrated solar energy are intended to increase thermal energy, storage thermal performance, dependability, and system cost efficiency. Thermal storage in the form of sensible heat, latent heat, or a mix of the two is considered in the CSP sector. [40] Solar domestic hot water systems using PCMs showed better performance in terms of higher efficiency, prolonged operative duration etc. [41]

3. Conclusion

The carbon and metal based nanoparticles are found to have outstanding thermal conductivity. Nevertheless, carbon-based particles are greater than metal based in respect of thermal stability and density. CPCMs containing metal oxide nanoparticles namely, Al_2O_3, ZnO and CuO showed an extensive functioning temperature variety in solar applications apart from excellent thermal stability. Tio_3 with the PCM composite material has found very promising and has excessive probable for stowage of energy with 96.5 % efficiency. Copper oxide nanoparticles have been found to be the best nanoparticles to combine with paraffin wax for solar thermal energy storage. CuO- MWCNT nanoparticles with paraffin wax has improved 6.125 % thermal conductivity then only based paraffin wax. Adequate concentration of silicon, nanotube/fiber, graphene Nano platelets, foam, carbon soots, zeolite, and MXene, silicon, metals and their oxides, graphite, graphene, and carbon has shown better performance in terms of stability for energy storage. While metal-based additives have a higher thermal conductivity compared to carbon-based additives, their poor stability due to high density limits their performance. On the other hand, metallic foams offer good stability, low density, and a large aspect ratio, making them a more effective alternative to nanoparticles for improving thermal conductivity. By utilizing metallic foams, it is possible to achieve better thermal conductivity enhancement than with nanoparticles. This discovery has important implications for the development of advanced materials and thermal management systems. Carbon-based nanoparticles as well as carbon fiber, carbon nanotubes, and graphene show higher performance than metal-based nanoparticles because of lower density and higher dispersion. Nano-particles selectively used and they performance a significant role in the enhancement of thermal behavior and stability when used in thermal energy storage applications. Increased heat transfer rate improved effective thermal conductivity in solar stills. In comparison to base fluids without dispersed nanoparticles, PCMs exhibit excellent thermal conductivities. The heat energy immersed and unconstrained by PCMs, over a selected temperature range vary, and therefore PCMs are excellent candidates in numerous commerce uses covering thermal, solar, electrical, battery-operated current managing, textiles, heat pipes and food wrapping.

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