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REGULAR ARTICLE

Performance Evaluation of PCM and Glycerine Compositions for Thermal Energy Storage

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This current work presents the experimental validation to improve the performance of solar thermal storage systems in solar thermal applications at intermittent, fluctuating and off-sunshine periods. This study investigates enhancing the performance of PCM, the blended composition of paraffin wax/glycerine in ratios of 75/25, 50/50 and 25/75 (weight in g), paraffin wax/iron oxide and paraffin wax/Copper oxide in different concentrations ($x = 0.05$, 0.1, 0.5) were prepared by dry grinding and melt-mixing method. During the experimental results show higher thermal accumulation at a 75/25 paraffin wax/glycerine ratio in thermal energy storage. And also, the thermal conductivity was further improved when aluminium finned strips were immersed in the blend compositions. In investigations on dielectric constant of pure paraffin wax, paraffin wax/iron oxide and paraffin wax/copper oxide are compared. The result shows that thermal conductivity improved with the increasing concentration of the iron oxide and copper oxide, that is, paraffin wax/iron oxide (5/0.5) and paraffin wax/copper oxide (5/0.5) compared to the parent compound (paraffin wax). In addition, the moisture content of the studied samples was determined, showing 0.85% (pure paraffin wax), 7.5% (paraffin wax/glycerine), 4.509% (paraffin wax/iron oxide) and 0.927% (paraffin wax/ copper oxide).

Keywords: Thermal conductivity, Dielectric constant, Moisture content.

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1. INTRODUCTION

The need for energy in the current generation is growing daily at an extremely high rate. The most plentiful and environmentally friendly energy source is solar energy. Its availability is only during the day, though, and it cannot meet consistent demand. Thermal energy storage offers a way around this drawback. In Latent heat storage, thermal energy is retained by first absorbing it during the phase change process (the latent heat of the fusion or evaporation) and then releasing it to return to the starting state. When compared to the energy of the Sensible Heat Storage, the quantity of energy stored in the LHS is significantly more. Phase change materials (PCMs) are substances that have the ability to retain this energy. Although there are many different kinds of PCM, they are often divided into three groups: eutectic, inorganic, and organic [2]. As a phase change material, Rubitherm GmbH's commercially available paraffin RT50 (which is non-poisonous, noncorrosive, and chemically stable) was utilized. The authors conducted studies using differential scanning calorimetric (DSC), viscosity measurements, and thermal conductivity, assuming the thermo-physical properties of PCM (Table 2). This study demonstrates that when compared to vertical (76%), horizontal (66%), and helical-coiled (53%), systems, the suggested latent heat thermal energy storage unit (M06) greatly reduces PCM melting time. At the end of melting time, the unit with spiral fins and helical coils (M05) has the highest energy efficiency (0.77). For climates where latent heat thermal energy storage has temporal limits, the M05, M06, and M08 units exhibit the maximum energy efficiency at times t = 1200 s and t = 3307 s [1]. In addition to a 32% increase in thermal conductivity, nano-enhanced PCMs have been shown to exhibit a 32% reduction in latent heat. A newly created 2D nanomaterial called MXene has improved electrochemical characteristics, including thermal conductivity and efficiency of up to 16% and 94%, respectively. Shape-stabilized PCMs are found to be most suitable for solar collector and PV-based heat recovery systems because they may increase the heat transfer rate several times (3 – 10 times). The best uses for cascade and molten slat PCMs are in the electricity industry (concentrated solar plants) and thermal control of buildings. Shape-stabilized PCMs and microencapsulated, nano PCMs both successfully lessen the supercooling of hydrated salt [3]. This study

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investigates the impact of different surfactants, including gum arabic (GA), polyvinylpyrrolidone (PVP), sodium dodecyl sulfonate (SDS), and sodium dodecylbenzene sulfonate (SDBS), on the melting temperature, melting latent heat, and thermal stability of paraffin wax. The weight percentage of MWCNTs ranges from 0 to 0.08 wt%. It is discovered that, when compared to paraffin wax, paraffin wax/0.06 weight percent MWCNT without surfactant exhibits the maximum thermal conductivity enhancement (48%). When paraffin wax and 0.08 weight percent MWCNT are mixed with PVP, SDBS, and SDS, their thermal conductivity is higher than when GA is added. Overall, thermogravimetric analysis (TGA) demonstrates that all samples display single-step breakdown characteristics [4].

Additionally, the impact of utilizing a helical finned tube in the heat exchanger unit on the paraffin wax/CuO nanocomposite charging and discharging processes was examined. The outcomes of the experiment demonstrated that 1% is the ideal concentration for the paraffin wax/CuO nanocomposite, resulting in the greatest improvement in melting time (22.22%) as compared to pure paraffin. Using a helical finned tube resulted in an extra 42.85% improvement in melting time. Additionally, using the helical finned tube reduced the paraffin wax/CuO nanocomposite's solidification time by 66.66% [5].

2. MATERIALS AND METHOD

The experiment was carried out at CIT, Kokrajhar, India, at CIT. Glycerine and paraffin wax is needed for this experiment. First, 150g of paraffin wax is heated to 65 °C and the melted wax is combined in three different ratios with glycerine. Paraffin wax (75 g): Glycerine (25 g), Paraffin wax (50 g): Glycerine (50 g) and Paraffin wax (25 g): Glycerine (75 g) proportions were taken simultaneously and in parallel. And then, a thermometer is introduced and its reading is recorded after every 5 mins by taking initial temperature 62 °C. Its conductivity was also examined and compared.

Fig. 1 – Experiment Set-up for mixed of paraffin wax and glycerine in different portions

From our exploratory research study, we have found that PCM with fins increases the thermal energy storage. So, to improve the thermal storage of the selected PCM for our research study, we have selected Copper fins and Aluminium fins and compared their heat retention performance. As we found in previous experiments that 75 g: 25 g paraffin wax and glycerine showed better thermal energy retention. To increase heat retention, we added aluminum and copper fins 3 mm wide and 7 cm high to this mix. The fins were inserted vertically and a total of six fins were inserted into each selected PCM, i.e. PCM-1 (PCM + aluminum) and PCM-2 (PCM + copper fins).

Fig. 2 – Experimental set-up of paraffin wax and glycerine blend with Aluminium and Copper fins

The readings of both the PCM with different fins i.e.; Aluminium and Copper were noted in parallel after every 5 mins during the experiment and its temperature are recorded in °C. Paraffin wax are straight chain saturated hydrocarbons, obtained from petroleum. The general chemical formula of normal paraffin is C_nH_{2n+2}. They have dielectric constant which allows them to be used in making a good electrical insulator. Paraffin Wax with a melting temperature of 58 to 60 °C with different materials namely Iron (III) Oxide and Copper Oxide in different concentrations ($x = 0$, 0.05, 0.1, 0.5) were fabricated. The chemicals are measured using a digital weighing scale accurate up to four decimals places. These raw materials that is, Paraffin wax (5 g) and Iron (III) Oxide in different concentrations ($x = 0$, 0.05, 0.1, 0.5) are mixed together thoroughly in a dry grinding mode for 45 minutes by agate mortar and pestle to obtain homogenous mixture of this blending. The homogenous mixture is then compressed into the pellets by electroding with plates of thickness 1 – 2 mm and diameter 10 – 12 mm. Similarly, the same process repeats for the mixture of Paraffin Wax (5 g) with Copper Oxide in different concentrations ($x = 0$, 0.05, 0.1, 0.5) respectively.

Fig. 3 – Experimental set-up of the blending of Paraffin wax with Iron (III) Oxide and Copper Oxide in different percentages ($x = 0$, 0.05, 0.1, 0.5) and study of its characteristics.

The sample was situated inside a sample holder in a good contact with two polished and cleaned electrodes and the dielectric measurements of the samples were performed at room temperature in a frequency range 100 Hz to 1 MHz with impedance analyzer (phase-sensitive meter PSM 1735, N4L). The *I-V* characteristics of the studied samples of all percentages were measured at room temperature by using a programmable electrometer (Keithley, model 6517B).

3. RESULT AND DISCUSSION

3.1 Paraffin Wax and Glycerine in Different Blending Composition and Paraffin Wax and Glycerine Blended Composition with Aluminium and Copper Fins

During the experimental work the ambient temperature was 25 °C. And it was observed that the temperature outside the aluminum can was different for all the three mixtures. From the plot, it is clear that in T1 graph i.e.

When more amount of glycerine is added to PCM, the mixture absorbs and emits the heat very fast. Whereas, in T3 graph i.e.; when less amount of glycerine is added to PCM, the mixture absorbs and releases the heat very slowly in comparison to T1 graph. This indicates that 75:25 ratio of paraffin-wax: glycerine mixture holds or stores the heat for longer duration. Thus, from this observation we can comment that 75:25 mixtures' thermal performance of energy storage is better compared to the other two mixtures.

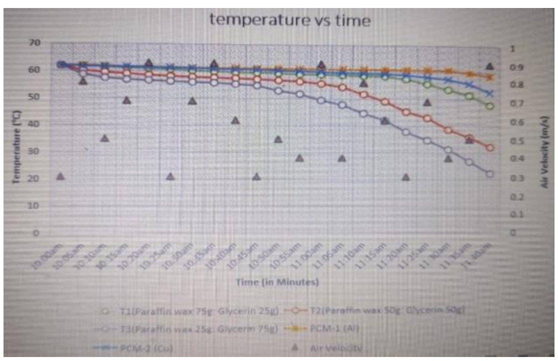

Fig. 4 – Temperature vs time Graph for Paraffin Wax and glycerine in different blending composition and Paraffin wax and glycerine blended composition with Aluminium and Copper fins

PCM shows a weak thermal performance due to its low thermal conductivity. So, to enhance its thermal performance, fins are used to increase the heat transfer area between PCM and cooling surface. In Fig. 4, graph PCM-1 and PCM-2 shows the comparison for the cases of finned tube with six fins of 3 mm width and 7 cm height. In PCM-1, we have added Aluminium fins and in PCM-2 we have added Copper fins to the 75 g:25 g blending of Paraffin wax and Glycerine PCM. In the above comparison, we observed that PCM-1 i.e.; (Aluminium fins + PCM) holds the heat till 11:25am and releases the heat (Aluminium fins + PCM) holds the heat till 11:25 am and releases the heat from 11:30 am thus indicating better heat storage compared to without finned case. Similarly, in PCM-2 i.e.; (copper fins + PCM) we have observed that almost it holds the heat till 11:10 am and releases heat or solidifies slowly from 11:15 am onwards compared to without finned PCM. From both the plot we observed that the heat transfer rate and the time reduces consequently for complete phase change when the fins are added. One can observe that the solidification temperature at 11:25 am for the graph T1 (without fins) is 55.7 °C, PCM-1 is 60.8 °C and PCM-2 is 59.6 °C respectively. This shows that the T1 graph (without fins) solidifies more quickly followed by PCM-2. The PCM-1 holds more heat compared to T1 and PCM-2 and gets solidify very slowly thus enhancing its thermal conductivity.

3.2 Determination of Moisture Content of the Samples

Studied samples were weighed in a silica crucible. The crucible is placed without lid in an electric hot-air-oven, maintained at 105 ± 10 °C for 1 hour. The crucible is then taken out, cooled in a desiccator and weighed for loss in weight.

Table 1 – Observation table for moisture content

Material	**Weight of Sample (*w*)**	**Loss of weight of sample (*l*)**	**Moisture conten (*l*/*w* × 100)**
Pure paraffin wax	5.96 gm	0.0507 gm	0.85 %
Paraffin wax and glycerine blend	5.332 gm	0.405 gm	7.5 %
Paraffin wax and Iron (III) oxide blend	4.524 gm	0.204 gm	4.509 %
Paraffin wax and copper oxide blend	4.96 gm	0.046 gm	0.927 %

3.3 Dielectric Characterization of Paraffin Wax, Paraffin Wax with Iron (III) Oxide and Paraffin Wax with Copper Oxide Indifferent Concentrations

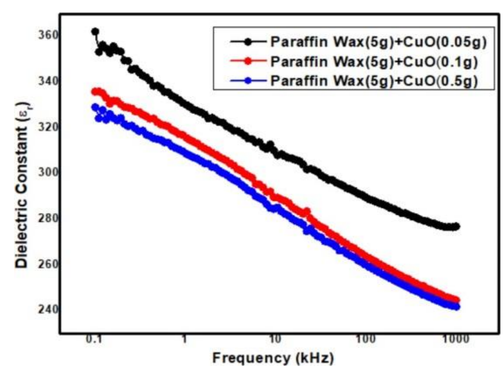

Fig. 5 – Variation of Dielectric Constant with Frequency of Paraffin Wax (5 g) with Different Concentration of Copper oxide (0.05 g, 0.1 g & 0.5 g) at room temperature

The study of dielectric parameters of different materials is very significant due to their wide range of potential applications in several fields like energy storage devices. All the readings were taken at the room temperature (25 °C) with frequency ranging from 100 Hz to 1 MHz using a LCR meter or Impedance analyzer (phase-sensitive meter PSM 1735, N4L) for the pure paraffin wax, blending of paraffin wax with iron (III) oxide and paraffin wax with copper oxide at different concentrations ($x = 0$, 0. 05, 0.1, 0.5) as shown in Fig. 5 and Fig. 6.

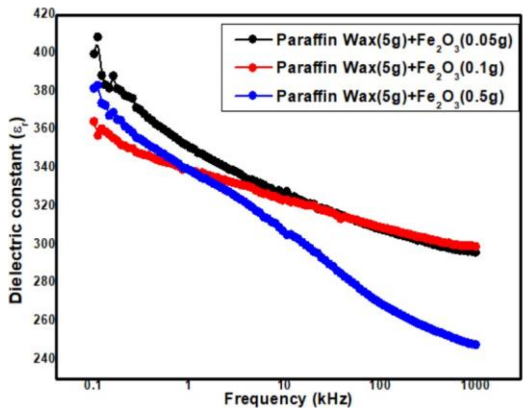

Fig. 6 – Variation of Dielectric Constant with Frequency of Paraffin Wax (5 g) with Different Concentration of Iron (III) oxide (0.05 g, 0.1 g & 0.5 g) at room temperature

From Fig. 5 and Fig. 6 we observed that the value of dielectric constant is high in the low-frequency region, and with the rise in frequency the value of dielectric constant decreases showing the general tendency of the dielectric materials. The cause behind this nature is that at low-frequency range, the existence of all the four types of polarization (electronic, ionic, orientation and space charge) is found and they provide total polarization, hence dielectric constant retains large in this region. When we increase the frequency the space charge polarization decreases because of fast moving ions towards the boundary, thus having small dielectric constant values.

4. CONCLUSION

From this experiment, we have concluded that increasing the paraffin wax content in the glycerine blend (75 g : 25 g) contributed to better thermal energy storage compared to the 50 g : 50 g and 25 g : 75 g paraffin and glycerine blend. To increase the heat transfer area between the PCM and cooling surface, copper fins and aluminium fins were inserted vertically into a mixture of paraffin wax and glycerine (75 g : 25 g). We have found that aluminium fins with PCM retain more heat compared to copper fins with PCM. Thus, an improvement in thermal energy storage is indicated in case of aluminium fins with PCM. When different concentration of iron (III) oxide ($x = 0.05$, 0.1, 0.5) were added to the parent paraffin and copper oxide ($x = 0.05$, 0.1, 0.5) were added to the parent paraffin, we observed that electrical resistivity increases with increase in the concentration and in low concentration it shows regular percolation characteristics. Also, its dielectric constant value is high at low frequency region showing general tendency of dielectric material thus, making them attractive for device application. Comparing the blending of iron (III) oxide+ parent paraffin with copper oxide+ parent paraffin we observed that iron (III) oxide + parent paraffin shows better dielectric constant value. In general, there was a good improvement in the performance of thermal energy storage in case of parent paraffin and glycerine blend (75 g : 25 g) with aluminium fins. In addition, it exhibits good thermal insulation when parent paraffin is blended with iron (III) oxide ($x = 0.5$ g) displaying broad application prospects in the field of thermal energy storage.

REFERENCES

1. A.S. Shareef, F.N. Al-Mousawi, H.S. Sachit, *IOP Conf. Ser.: Mater. Sci. Eng.* **671** 012018 (2020).
2. J. Wołoszyn, K. Szopa, G. Czerwiński, *Appl. Therm. Eng.* **196**, 117332 (2021).
3. H.M. Ali, T. Rehman, M.Arıcı, Z. Said, B. Durakovi´, H.I. Mohammed, R. Kumarj, M.K. Rathod, O. Buyukdagli, M.Teggarl, *Prog. Energy Combustion Sci.* **100**, 101109 (2024).
4. K.Y. Leong, S. Hosbi, K.Z. Ku Ahmad, N. Jali, H.C. Ong, M.F. Md Din, *J. Energy Storage* **52**, Part C, 105027 (2022).
5. A. Sharma, A.E. Kabeel, B.M. Moharram, H.F. Abosheiasha, *Appl. Nanosci.* **11**, 2033 (2021).
6. A.K. Bhardwaj, R. Chauhan, R. Kumar, M. Sethi, A. Rana, *Case Studies in Thermal Eng.* **10**, 302 (2017).
7. A.J.H. Almality, H.F. Hussein, K.I. Ajeel, *IOP Conf. Ser.: Mater. Sci. Eng.* **987**, 012023 (2020).
8. H. Atalay, *Energy* **172**, 1037 (2019).
9. M. Abuşka, S. Şevik, A. Kayapunar, *Appl. Therm. Eng.* **148**, 684 (2019).
10. S. Yadav, V.P. Chandramohan, *Sustain. Energy Technol. Assessment.* **37**, 100609 (2020).

Оцінка ефективності композицій PCM і гліцерину для зберігання теплової енергії

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Ця поточна робота представляє експериментальне підтвердження для покращення продуктивності систем накопичення сонячної тепла в сонячних теплових системах у періодичні, коливальні періоди та періоди відсутності сонячного світла. У цьому дослідженні досліджується підвищення продуктивності PCM, змішаної композиції парафінового воску/гліцерину у співвідношенні 75/25, 50/50 та 25/75 (вага в г), парафінового воску/оксиду заліза та парафінового воску/оксиду міді в різних концентрації (x = 0,05, 0,1, 0,5) становили готують методом сухого подрібнення та змішування в розплаві. Під час експериментальних результатів показано більш високе накопичення тепла при співвідношенні парафін/гліцерин 75/25 у накопичувачі теплової енергії. Крім того, теплопровідність була додатково покращена, коли алюмінієві ребристі смуги були занурені в суміші композицій. У дослідженнях діелектричної проникності чистого парафіну порівнюють парафіновий віск/оксид заліза та парафіновий віск/оксид міді. Результат показує, що теплопровідність покращилася зі збільшенням концентрації оксиду заліза та оксиду міді, тобто парафінового воску/оксиду заліза (5/0,5) та парафінового воску/оксиду міді (5/0,5) порівняно з вихідною сполукою (парафіном). віск). Крім того, було визначено вміст вологи в досліджуваних зразках, який показав 0,85% (чистий парафін), 7,5% (парафін/гліцерин), 4,509% (парафін/оксид заліза) та 0,927% (парафін/оксид міді).

Ключові слова: Теплопровідність, Діелектрична проникність, Вміст вологи.