Use of 1:7 rice bran wax to rice bran oil mixture as phase change material in increasing the efficiency of photovoltaic cells

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Abstract

The efficiency of photovoltaic (PV) panels decreases as their operating temperature increases. To address this, phase-change materials (PCMs) are attached to the panel to absorb heat. PCMs are used to cool PV panels since they have the desired thermodynamic properties for heat storage such as high latent heat. The study focuses on determining the conversion efficiency of PV cells with rice bran wax in rice bran oil (RBW/RBO) mixture as PCM. Rice bran wax was added to rice bran oil in 1:7 by volume ratio. Three setups were compared in this study: PV cell without PCM, with paraffin wax, and with the RBW/RBO mixture. The paraffin wax was used because it is a commonly-used PCM for PV cells. The RBW/RBO mixture was used because it is a renewable resource and considered a waste product. The voltage and current of the PV cells were measured every 15 minutes for 45 minutes to compute the conversion efficiency. The RBW/RBO mixture increased the conversion efficiency of the PV cell by 0.232%. This may be attributed to its melting point being within the PV cell's operating temperature. The RBW/RBO mixture can be used and improved to further increase the efficiency of PV cells for household use.

Keywords: *phase change materials (PCM), photovoltaic cells, rice bran, solar energy, bio-based*

Introduction. PV cells generate electricity by creating a potential difference in PV panels using light energy from the sun [1]. The sudden decrease in the efficiency of PV panels is due to the radiation losses when the operating temperature is above ambient temperature [2]. Since much of the sunlight that is shining on the PV cells becomes heat, proper thermal management improves its conversion efficiency or the amount of the solar energy that can be converted into electricity. Thus, operating temperatures above the ambient temperatures will always mean less output for PV cells [3]. Researchers are seeking to mitigate the influence of high temperature on PV conversion efficiency by rapidly removing heat from PV module surfaces to maintain as good a performance as possible, and hence better meet performance expectations [4]. Gondora et al. [5] suggested the use of phase change materials (PCM). It is an example of a passive cooling system that can function as energy storage mediums, whereby energy is stored during the melting process and is released during solidification [6]. It is the best option in maintaining ideal operating temperature of the PV cells as it absorbs a significant amount of heat without raising the temperature of the PV panel, and offers more energy storage capacity and less temperature fluctuation with respect to traditionally used materials due to their having a high latent heat capacity [6].

Paraffin wax is the most common type of PCM as it possesses a melting temperature within the thermal comfort range of PV cells, a high latent heat capacity, and exhibits small volume changes during the transition phase [7]. However, paraffin wax is unsustainable in the long term [8]. It is a non-renewable resource created as a by-product of petroleum, coal, or oil shale [8]. Schukina et al. [9] used bio-based PV cell with attached bio-based PCMs that are derived from fatty acids have higher efficiencies than those attached with salt hydrates and petroleum-based PCMs.

The food and agricultural industry produce numerous by-products that is considered by most as waste. Rice bran is a by-product of rice milling and is considered as bio waste [10]. Fatty acids from the rice bran can be extracted into rice bran oil or rice bran wax, which are organic bio-based materials. Zaccheria et al. [11] conducted a study about potential bio based PCM. The results showed that the rice bran can be used to produce an oil with a very high free fatty acids (FFA) content. Muthuvel et al. [12] checked the thermophysical properties of the rice bran oil distilled fatty acid (RBDFA); his study showed that the melting point of RBDFA ranges from 29°C to 30°C, heat of fusion value is 140.3 kJ/kgK and the value of the specific heat which is 2303 J/kgK. The high value of specific heat indicates its capacity to absorb higher amounts of heat energy, making it a viable PCM in building applications [12].

This study aimed to determine the potential of rice bran wax and rice bran oil (RBW/RBO) mixture as a bio-based PCMin determining the conversion efficiency of PV cells. It specifically aimed to:

(i) determine the thermophysical properties of the rice bran oil;

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(ii) measure the temperature, voltage, and current of the PV cells with and without attached phase-change material; and

(iii) compute the conversion efficiency of the PV/PCM systems.

Results of the conversion efficiency of the PV cells using RBW/RBO mixture from the study can be compared to the conversion efficiency of the PV cells without PCM and with paraffin wax to determine which of the following PV systems generated the highest conversion efficiency.

Methods. The study was done in three phases. The thermophysical properties of the rice bran wax and rice bran oil (RBW/RBO) mixture were analyzed using Differential Scanning Calorimetry (DSC). The second phase was the assembly of the set-up of PV cells with the PCM (PV/PCM) systems. Three PV setups were used in this study. One PV cell without PCM attached was used as a control setup. Then, the same PV cell was subjected to two kinds of PCM: paraffin wax, and the 1:7 rice bran wax in rice bran oil mixture. The last phase was the measurement of the values of the voltages and currents in order to compute and compare the conversion efficiencies of the PV/PCM set-ups.

Finding a potential bio-based PCM. For thermal storage applications of solar energy, the PCM must have a melting point of 16°C to 65°C [2]. A certificate of analysis was issued upon purchase of rice bran oil from a local oil company. According to the result of the analysis, the melting point of the rice bran oil is 15°C. To increase the melting point to be within the accepted range, rice bran oil was mixed with rice bran wax, which has a melting point of 79° C [8]. The rice bran wax was melted first using a hot plate and rice bran oil was added to it while it was being heated. It was then mixed and stirred. Several ratios were tested, and it was found that the 1:7 ratio in terms of volume was the most suitable; since, its melting temperature is in line with the operating temperature of the PV cell of between 15°C to 35° C [13].

Measuring the thermophysical properties using DSC. The melting point and latent heat of fusion were measured using DSC which was done at the University of the Philippines Miag-ao. One gram of the rice bran mixture sample was heated and the changes in its heat capacity were tracked as changes in the heat flow. This allowed the detection of changes in the physical properties of the PCM. In DSC, the 1:7 ratio of the RBW/RBO mixture was heated at a constant rate. The samples were held for 1 minute at 15 °C. It was heated at a linear rate of 10°C/min from 15 °C to 36 °C in a nitrogen atmosphere. This was to determine if the sample was starting to melt. It was held again for 2 minutes at 36 °C and was heated from 36°C to 40°C at 1°C/min before it was held for 2 minutes to determine if the samples were completely melted. It was heated again at 40°C to 500 °C with a heating rate of 10°C/min before it was cooled from 500 °C to 40 °C at 20°C/min. The latent heat of fusion of the material was determined by taking the area under the peak of the curve and the melting point was determined by taking the slope of the point tangent to the peak. Data on the thermophysical properties of RBW/RBO mixture were compared to the established thermophysical properties of paraffin wax as it is the most common type of PCM that is being attached to PV cells for cooling. The basis of the thermophysical properties of paraffin wax was acquired from the research of Kavitha and Arumugam [7].

Testing of PV set-ups. The testing of the PV cell with and without attached phase change materials was performed in Philippine Science High School-Western Visayas Campus. A box made of illustration board 21 cm high, 9 cm wide and 15 cm long was constructed to act as a dark room for the PV cell and to hold in place the xenon lamp. The container was placed under the PV module to create the PV/PCM system. K-type thermocouples were attached to the back of the PV cell and to the PCM to monitor temperature changes. The temperature, current, and voltage were measured every 15 minutes using thermocouples and multimeter. The open-circuit voltage (V_{OC}) and short circuit current (I_{SC}) were first measured by connecting the PV cell to an equivalent circuit with a single diode and series resistance mode, under illuminated light of a xenon lamp. The V_{OC} was measured when the current in the circuit was zero, while the I_{SC} was measured when the voltage is zero. Only V_{OC} and I_{SC} were measured due to the unavailability of specialized equipment for voltage sweep analysis, used in determining the actual measurement of maximum power output (P_{MAX}) in the PV cell. Instead, the actual values of the two were used in a derived equation to calculate the efficiency, together with its underlying parameters-fill factor (FF) and maximum power output (P_{MAX}). The voltage and current of the PV cells were simultaneously measured using a multimeter. The temperature of the PCM and the back surface of the PV cell were also measured simultaneously. The value of the solar irradiance was also measured every 15 minutes using the solar irradiance meter.

Figure 1. Photo of the setup with the PV cell, PCM inside the aluminum container, xenon lamp inside a dark box, multimeter for the measuring of the voltage and k-type thermocouple thermometer for measuring the temperatures.

Calculation of the Conversion Efficiency. To calculate the conversion efficiency, the fill factor (FF) of the PV cell is needed. Fill Factor (FF) was essentially a measure of the quality of the solar cell. It is solved using the equation:

$$FF = \frac{P_{MAX}}{P_T} = \frac{I_{MP} \times V_{MP}}{I\,sc \times Voc}$$

where P_{MAX} was the measured power of the PV cell, P_T was the theoretical power of the PV cell using LTSpice software simulation, I_{MP} was the current of the maximum power of the PV cell, V_{MP} was the voltage of the maximum power of the PV cell, V_{OC} was the open-circuit voltage, and I_{SC} was the short-circuit current.

The conversion efficiency of the PV/PCM systems can then be calculated using the equation:

$$\eta = \frac{FF \times Isc \times Voc}{P_{in}}$$

where V_{OC} was the open-circuit voltage, I_{SC} was the short-circuit current, FF was the fill factor, P_{in} was the power input and η was the efficiency. The gathered data was compared to the PV cell without PCM attached, and to the PV cell with paraffin wax.

Safety Procedure. Proper laboratory attire was worn, such as laboratory gown, with respect to the laboratory's rules and regulations Proper precaution during data gathering was practiced while handling the PCMs and the set-up to avoid burns. After handling the phase change materials, hands were washed to avoid accidental ingestion.

Results and Discussion. The temperatures of the PV cells and PCMs were measured and results showed that the PV cell with RBW/RBO mixture had the lowest average change in temperature of 0.050 °C/min. The conversion efficiencies of the different set-ups were calculated and the results showed that the PV cell with RBW/RBO mixture had the highest efficiency with 18.776%.

Thermophysical properties of 1:7 RBW/RBO mixture. Results of the DSC analysis show that the melting point of paraffin wax is 58.75°C, while the melting point of the RBW/RBO mixture is 30.06 °C. A PCM with melting points in the temperature range of the operating temperature of the PV cells, which is between 15 to 35° C [13], may have the advantage of not melting at most ambient temperatures and being melted solely by incident solar radiation [2]. Consequently, they may continue melting and absorbing heat for a longer period providing a longer duration of PV temperature regulation [8]. The latent heat of fusion is the amount of energy that the PCM must absorb to change from solid to liquid phase. Latent heat can play a significant role in storing greater amounts of energy [14]. Table 1 shows that one gram of PCM needs 34.945 Joules (J) to change its phase. Especially, the melting point of the material must be equal or close to the operating temperature on some applications. The latent heat should be as high as possible on a volumetric basis to minimize the size of the thermal energy storage device [15]. In this case, RBW/RBO mixture starts melting above the ambient temperature of 25° C at 30° C, in contrast with the paraffin wax which starts melting at 58° C.; hence, the RBW/RBO mixture provides better thermal regulation than the traditional paraffin wax, which is the commonly-used PCM.

Table 1. The values of the thermophysical properties of the different phase change materials.

Parameters	RBW/RBO mixture	Paraffin wax
Melting point (°C)	30.06	58.75
Latent heat (J/g)	34.95	193.9

Values of the temperature, voltage, and current of PV cells with and without phase-change materials. The PV cell with the attached RBW/RBO mixture had the highest voltage of 4.530 V followed by the PV cell with paraffin wax with 4.526 V, then lastly the PV cell without PCM with 4.500 V. As for the current, it remains constant at 0.006 A in all setups. The temperature of the PV cell with RBW/RBO rises by 1.5 °C from 34.3 °C during the first trial up to 35.8 °C during the 3rd trial. The PV cell with paraffin wax increased by 1.7 °C from 33.3 °C to 35.0 °C. The PV cell without PCM rises by 2.4 °C from 35.9 to 38.3 °C. The temperature of the PV cell in the setup without the PCM is higher than that of those with attached PCMs. The average change in temperature for the 45 -minute duration of the PV cell with RBW/RBO mixture was found to be 0.050 °C/min, the paraffin's was 0.056 °C/min and the PV cell without PCM was 0.080 °C/min. As in Figure 2, the temperature of PV cells with PCMs is lower than the PV cell without the PCM in the 45-minute duration. This implies that PCMs absorbed the heat during the period. Results show that the PV without PCM attached has a low voltage output compared to those with PCMs attached. This may be due to the elevated temperatures with which the PV cell without PCM operated in.

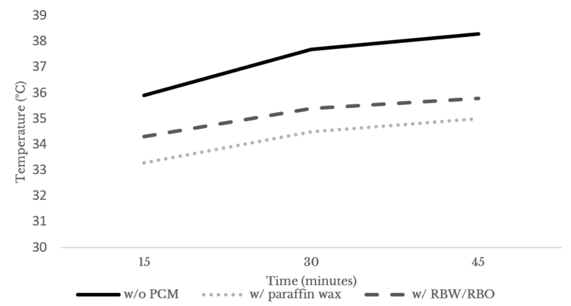

Figure 2. Graph of temperature vs time of the PV cell with and without PCM.

Computed power and efficiency of the different set-ups of PV cell. It can be seen in Figure 1 that PCM reduced the PV's temperature. As the temperature of the PV cell decreased, its voltage output increased. Therefore, attaching a PCM to a PV cell can increase the power of PV cell and conversion efficiency. The value of the efficiency of photovoltaic cells with the rice bran wax and oil (RBW/RBO) mixture was the highest among the three with 18.776% for the three trials, followed by the PV cell without paraffin wax which has a conversion efficiency of 18.750% then lastly the PV cell without PCM which has 18.544% . RBW/RBO has the highest conversion efficiency since it absorbs and discharges a large amount of energy during its phase change. Its melting temperature, which is

30.06 °C is within operating temperature of the PV cell that ranges between 15 °C and 35 °C, within which it will produce energy at maximum efficiency [13]. This contributes to the efficiency of the PV cell as the PCM absorbs the heat. This is evident in the results that the PV cell with RBW/RBO mixture has the highest efficiency value of 18.776%.

Limitations. The solar simulator was improvised using a xenon lamp as it emits the same irradiance value of 1000 W/m^2 as the solar simulator.

Conclusion. Rice bran oil in wax mixture was investigated as a possible PCM for PV panels. Comparing PV cell with and without PCM showed that the rice bran oil and wax (RBW/RBO) mixture as PCM was effective in reducing temperature and improving the efficiency of the PV cell. The reason was that the melting point of RBW/RBO mixture was around the operating temperature of the PV cell, which contributes to the heat removal from the panel by phase change. Results showed that the PCM with rice bran mixture had the lowest temperature of the PV cell among the three. Among PCMs that were evaluated, the RBW/RBO mixture showed a potential for the desired application of the photovoltaic cells. Based on the presented results, it can be concluded that the incorporation of RBO/RBW on the back surface of the PV cell had a positive impact on lowering the temperature of the PV cell and on increasing its power and conversion efficiency.

Recommendations. Considering the findings and the conclusions drawn from the results, it is recommended that further studies should explore other bio-based phase change materials. Rice bran oil has a low melting point of only 15°C and it would not suit as a PCM if put under the operating temperature of a PV cell. Hydrogenation of the PCM can increase its melting temperature, but the lack of time and complexity of the process made mixing of two PCMs a better option. The setup was an improvised solar simulator to have a controlled condition. It would have been better if a real solar simulator was used. Testing the PV/PCM systems in practical conditions, e.g. under the sun, is also recommended.

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References

[1] Gafford A, Minor R, Allen A, Cronin A, Brooks E, Pavao-Zuckerman M. 2016. The Photovoltaic Heat Island Effect: Larger solar power plants increase local temperatures. Scientific Reports volume6, Article number: 35070 (2016).

[2] Biwole PH, Eclache P, Kuznik F. 2013. Phase-change materials to improve solar panel's performance. Energy and Buildings. 62: 59-67.

[3] Dincer I, Rosen MA. 2007. Exergy: Energy, Environment and Sustainable Development. Elsevier Science Publishers.

[4] Thaib R, Rizal S, Rizal M, Manila TM, Rizal TA. 2018. Beeswax as phase change material to improve solar panel performance. Mater. Sci. Eng. C. 30: 012024.

[5] Gondora W, Doudin K, Nowakoski DJ, Xiao B, Ding Y, Bridgwater T, Yuan Q. 2016. Encapsulation of phase change materials using rice-husk-char. Applied Energy. 182, 274-281. https://doi.org/10.1016/j.apenergy.2016.08.102

[6] Paria S, Sarhan, A, Goodarzi, MS, Baradaran S, Yarmand H, Alavi, MA, Kazi, SN, Metselaar HSC. 2015. Indoor solar thermal energy saving time with phase change material in a horizontal shell and finned-tube heat exchanger. Sci. World J. 2015: 1-7.

[7] Kavitha K, Arumugam S. 2013. Performance of paraffin as a PCM solar thermal energy storage. International Journal of Renewable Energy Resources 3 (2013) 1- 5.

[8] Hassan, A. (2010) Phase Change Materials for Thermal Regulation of Building Integrated Photovoltaics. Doctoral Thesis. Dublin Institute of Technology. doi:10.21427/D7461W.

[9] Shchukina EM, Graham A, Zheng Z, Shchukin DA. 2018. Nanoencapsulation of phase change materials for advanced thermal energy storage systems. RSC. 47(11): 4156–4175.

[10] Sharif MK, Butt MS, Anjum FM, Khan SH. 2014. Rice bran: a novel functional ingredient. Critical Reviews in Food Science and Nutrition. 54(6): 807-816. DOI:10.1080/10408398.2011.608586.

[11] Zaccheria F, Mariani M, Ravasio N. 2015. The use of rice bran oil within a biorefinery concept. Chem. Biol. Technol. Agric. (2): 1.

[12] Muthuvel S, Saravanasankar S, Sudhakarapandian R, Muthukannan M. 2014. Passive cooling by phase change material usage in construction. BUILD SERV ENG RES T. 3 (64): 411-421.

[13] Tan Jian Wei N, Jian Nan W, Guiping C. Experimental study of efficiency of solar panel by phase change material cooling. IOP Conf. Series: Materials Science and Engineering 217 (2017) 012011 doi:10.1088/1757-899X/217/1/012011

[14] Tan L, Datea A, Fernandesa G, Signhb B, Ganguly S. 2019. Efficiency gains of photovoltaic system using latent heat thermal energy storage. Energy Procedia. 110(2017): 83-88.