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Synthesis of Solar Panel Cooling Devices from A Mixture of Paraffin and Coconut Shell Activated Carbon

Sintesis Perangkat Pendingin Panel Surya dari Campuran Parafin dan Karbon Aktif Tempurung Kelapa

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ABSTRACT

Coconut shell is a plantation waste that has the potential as an activated charcoal material due to its high lignocellulose content. Coconut shell activated charcoal (CSAC) is made through a carbonization process and chemical and physical activation. CSAC has been used in several applications such as adsorbents and electrode components. In this study, CSAC was used as a passive coolant mixture of Phase Change Material (PCM) from paraffin wax (PW). CSAC was made from charcoal that was carbonized at a temperature of 700ºC and activated with $ZnCl_2$. CSAC testing included specific surface area, diffraction patterns, functional groups and surface morphology. The results of the N_2 isothermic test on CSAC obtained a specific surface area of 420.22 m^2/g, a total pore volume of 0.22 cm^3/g and an average pore diameter of 2.13 nm. The results of the XRD test showed the nature of CSAC with an amorphous polycyclic aromatic carbon structure. The results of the FTIR test showed aliphatic C–H functional groups derived from the remaining hydrocarbon chains of the cellulose and lignin structures. The C–O, O–H functional groups have been formed which indicates that activated carbon has been formed. The results of the SEM test showed a hollow surface with pore sizes dominated by mesoporous structures. Furthermore, CSAC was added to PCM-PW with a ratio of 5%:95% and 10%:90%. The test results showed an increase in the thermal conductivity of PCMCSAC. The use of SPPCMCSAC in solar panels has succeeded in reducing the surface temperature of solar panels by about 10ºC and increasing efficiency by about 10%. The test results of SPPCMCSAC on solar panels demonstrate the ability of SPPCMCSAC to maintain solar panel efficiency.

Keywords: Coconut shell; activated carbon; PCM; solar panel; efficiency

ABSTRAK

Tempurung kelapa merupakan limbah hasil perkebunan yang memiliki potensi sebagai bahan karbon aktif dikarenakan kandungan lignoselulosa yang tinggi. Karbon aktif tempurung kelapa (KATK) dibuat melalui proses karbonisasi dan aktivasi secara kimia dan fisika. KATK sudah digunakan pada beberapa aplikasi seperti adsorben dan komponen elektroda. Pada penelitian ini telah dilakukan penggunaan KATK sebagai campuran pendingin pasif Phase Change Material (PCM) dari paraffin wax (PW). KATK dibuat dari arang yang dikarbonisasi pada suhu 700ºC dan di aktivasi dengan $ZnCl_2$*. Pengujian KATK meliputi luas permukaan spesifik, pola difraksi, gugus fungsi dan morpologi permukaan. Hasil pengujian* N_2 *isotermik terhadap KATK diperoleh luas permukaan spesifik 420,22* m^2*/g, total volume pori 0,22* cm^3*/g dan diameter pori rata-rata 2,13 nm. Hasil pengujian XRD menunjukkan sifat KATK dengan struktur karbon aromatik polisiklik amorf. Hasil uji FTIR menunjukkan gugus fungsional C–H alifatik yang berasal dari rantai hidrokarbon sisa struktur selulosa dan lignin. Gugus fungsional C-O, O-H telah terbentuk yang menunjukkan bahwa karbon aktif telah terbentuk. Hasil uji SEM menunjukkan permukaan yang berongga dengan ukuran pori-pori yang di dominasi struktur mesopori. Selanjutnya, KATK di tambahkan pada PCM-PW dengan rasio 5%:95% dan 10%:90%. Hasil pengujian menunjukkan peningkatan konduktivitas termal PCMKATK. Penggunaan PSPCMKATK pada panel surya telah berhasil menurunkan suhu permukaan panel surya sekitar 10ºC dan peningkatan efisiesi sekitar 10%. Hasil uji PSPCMKATK pada panel surya menunjukkan kemampuan PSPCMKATK untuk mempertahankan efisiensi panel surya.*

Kata Kunci: *Tempurung kelapa; karbon aktif; PCM; panel surya; efisiensi*

INTRODUCTION

Activated carbon is widely used in various fields due to its readily available raw materials, high surface area, cost-effectiveness, and environmental friendliness. Activated carbon is often produced from lignocellulosic materials, which are rich in polysaccharides and primarily composed of cellulose, hemicellulose, and lignin (Suhas et.al., 2016). Activated carbon has been widely used in various technological fields such as water purification (Nurhilal et al., 2025), battery electrodes (Nurhilal et al., 2023), and supercapacitors. In the field of energy storage, activated carbon has the potential to be used as a mixture of cooling components, one of which is phase change material (PCM).

Paraffin-based PCMs have been widely used for latent heat storage applications due to their attributes, namely little or no superheating, low vapor pressure, and good thermal and chemical stability (Chin et al., 2020), low sub-cooling, non-toxicity, etc. (Sun et al., 2020). However, paraffin-based PCMs have lower thermal conductivity, resulting in lower system efficiency. To improve the efficiency during the energy storage and release process, fins (Yang et al., 2020), foams and carbon materials (Tong et al., 2019) are used as additives to enhance the heat transfer process of PCMPs. Carbon materials, which have lower density, have the potential to enhance the energy storage and release process of PCMs. PCMs with carbon materials show higher energy storage and release efficiency, mainly due to the increased thermal conductivity.

Amin et al. tested the thermophysical parameters of graphene-enhanced wax. Thermal conductivity, thermal viscosity, and latent heat increased due to the presence of graphene nanoplatelets. The melting temperature decreased with increasing graphene concentration (Amin et al., 2017).

Kim and Drzal tested the thermal conductivity, melting temperature, and latent heat of paraffin enhanced with exfoliated graphite nanoplatelets (Kim and Drzal, 2009). The thermal conductivity increased with increasing graphite concentration. The melting temperature and latent heat of PCMs with various graphite concentrations were very close to pure paraffin because there was no reaction between paraffin and graphite. Graphite and graphene have high thermal conductivity and potential in energy storage, but their production costs are more expensive and require special processing techniques.

Activated carbon, as a largely amorphous carbon-based material with large pore structure, relatively high thermal conductivity, low density, and lower cost, is gradually being considered as a viable support material in latent heat storage materials (Prabhu et al., 2024).

Research on the use of activated carbon in coolants includes, Feng et al. adsorbed polyethylene glycol in mesoporous activated carbon and investigated the effect of confinement of the porous structure on the phase change properties of the composite (Feng et al., 2011). Chen et al. incorporated lauric acid into the porous network of activated carbon to prepare a stabilized composite PCM coolant, proving an increase in the thermal conductivity of the PCM (Chen et al., 2012). Zhao et al. prepared a paraffin/activated carbon PCM composite having a latent heat of melting of 51.7 Jg^{-1} and a melting temperature of 60.4 °C (Zhao et al., 2013).

Activated carbon has been produced and utilized in PCM mixtures derived from sources such as palm kernel shells (Chin et al., 2020), coconut shells combined with salts (Kalidasan et al., 2023), pomegranate peels (Ben Ali et al., 2025), and kapok fibers (Song et al., 2025). Research by Chin (2020) reported the production of activated carbon as a PCM composite to mitigate leakage issues, while the coconut shell-derived activated carbon produced by Kalidasan et al. served as a support material for energy storage systems. The potential application of activated carbon as a PCM support component is closely linked to its latent heat properties. Consequently, activated carbon holds significant potential as a supporting component in PCM-based cooling systems designed to lower the surface temperature of solar panels.

Theoretically, the optimal operating temperature for solar panels is 25°C (Yusuf et al., 2017). Excessive surface temperatures reduce solar panel performance; studies indicate that for every 1°C rise above the optimal temperature, efficiency drops by approximately 0.45% (Bhatia, 2014). A comprehensive study on solar panel cooling systems was reported by Tarek Ibrahim et al. (2024); however, while various cooling systems were discussed, PCM cooling systems supported by activated carbon were not addressed.

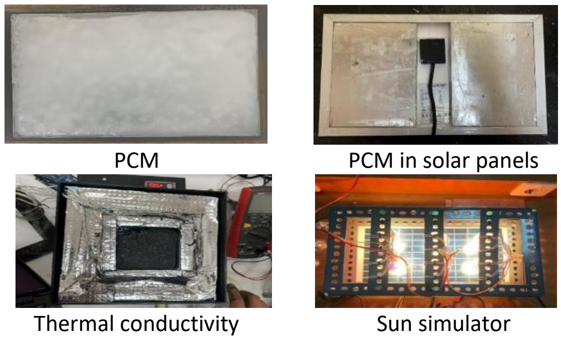

Figure 1. PCM and several testing instruments.

Solar panel cooling methods include the use of water, heat sinks, thermoelectric cooling (TEC), and fans, all of which require electrical energy to operate. To improve electrical energy efficiency, passive cooling solutions are required—such as PCMs mixed with activated carbon, including activated carbon derived from coconut shells.

Coconut shells are a common waste product in the community, often utilized merely as fuel or firewood. Southeast Asia accounts for a significant share—78%—of global coconut production, with Indonesia alone producing 34% of the world's supply (Juliana et al., 2019). Coconut shells contain 34% cellulose, 21% hemicellulose, and 27% lignin (Sujiono et al., 2022). The high carbon content of coconut shells enhances their suitability as a raw material for activated carbon production. The abundance of this carbon-rich, lignocellulosic material has motivated researchers to explore coconut shells as a promising feedstock for activated carbon production (Nurhilal et al., 2025).

In this study, coconut shell-derived activated carbon is used as an additive to paraffin wax for solar panel cooling. Cooling is necessary to maintain the solar panels' optimal operating temperature. The activated carbon was synthesized using $ZnCl_2$ as an activating agent at various concentrations to achieve high quality. The best-performing activated carbon was incorporated into the phase change material (PCM) to enhance its thermal conductivity.

METHODOLOGY

1. Materials

The materials used to manufacture PCM-CSAC include coconut shells obtained from traditional markets after coconuts have been processed into various food products. Zinc chloride ($ZnCl_2$) was obtained commercially from Sigma Aldrich (CAS Number: 7704-34-9). Paraffin wax (PW) (CAS 8002-74-2) was obtained commercially. The equipment used for the PCM testing was a commercially available 10 W solar panel.

2. Preparation of Activated Carbon and PCM

Coconut shells were cleaned, dried, and then carbonized at 700 °C for 1 hour. The carbonized coconut shells were ground into a fine carbon powder with a particle size of 200 mesh. The carbon powder was chemically activated using a 10% concentration of $ZnCl_2$ at a carbon-to-activator ratio of 1:3. The carbon-$ZnCl_2$ mixture was stirred using a magnetic stirrer for 30 minutes until thoroughly mixed, then covered with parafilm and stored in a dry cabinet at 25 °C for 24 hours. After 24 hours, the activated carbon was washed with distilled water until the pH of the filtrate was near neutral (pH ~7). The carbon was then filtered and dried in an oven at 105 °C for 1 hour. Next, the chemically activated carbon underwent physical activation in a tube furnace at 700 °C for

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1 hour under an inert nitrogen (N_2) atmosphere. The PCM-CSAC was prepared by melting paraffin at 80°C on a hot plate while stirring with a magnetic stirrer at 600 rpm for 60 minutes. Activated carbon powder was mixed into the molten paraffin at ratios of 5% and 10% of the total weight. The mixture of activated carbon and molten paraffin was then poured into an aluminum plate frame measuring 20 cm x 10 cm with a thickness of 1 cm.

3. Analysis Techniques

The CSAC was characterized using Brunauer–Emmett–Teller (BET) surface area analysis (Quantachrome Nova 4200e, Anton Paar, Graz, Austria), scanning electron microscopy (SEM-EDS, S-4800, Hitachi Limited, Tokyo, Japan), and X-ray diffraction (XRD, Rigaku-TTRIII). The process of measuring the solar panel surface temperature involved using a halogen lamp solar simulator as the light source, with an irradiance of 341.36 W/m² and a measurement duration of 3 hours. The PCM system on the solar panel, the thermal conductivity measuring instrument, and the solar simulator are shown in Figure 1.

RESULTS AND DISCUSSION

Table 1. S_{BET}, volume, and diameter (d) values of CSAC at various $ZnCl_2$ concentrations

Sampel	S_{BET} (m^2/g)	V (cm^3/g)	d (nm)
CSACZnCl5	394.18	0.21	2.11
CSACZnCl10	420.22	0.22	2.13
CSACZnCl15	417.52	0.22	2.12

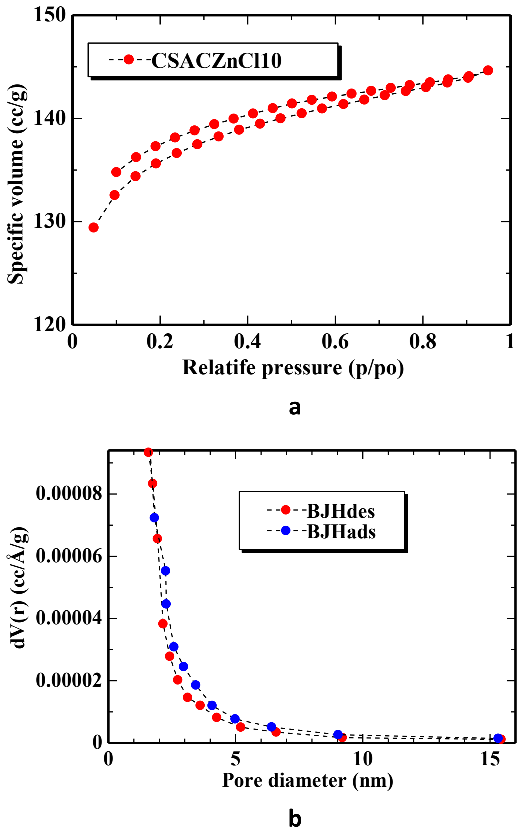

Figure 2. a) N_2 adsorption isotherm of CSAC, b) BJH pore distribution.

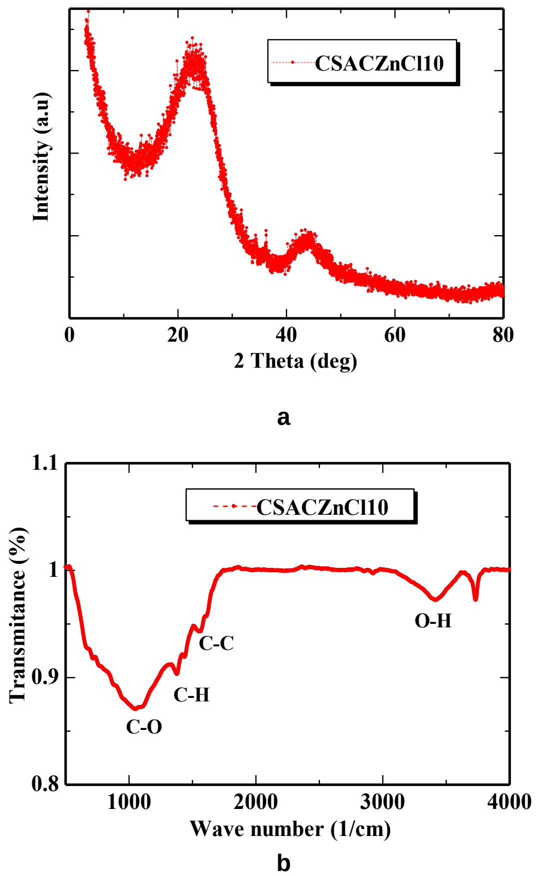

Figure 3. a) The XRD pattern of CSACZnCl10, b) FTIR spectrum of CSACZnCl10

Figure 2 depicts the N_2 adsorption isotherm and size distribution of CSAC. CSAC has a specific surface area of 420.22 m^2/g, a total pore volume of 0.22 cm^3/g, and an average pore diameter of 2.13 nm. Figure 2(a) illustrates the mesoporous structure of CSAC, as classified by International Union of Pure and Applied Chemistry (IUPAC), which plays a key role in facilitating molecular diffusion into the pores. The existence of the mesoporous structure is further confirmed by the pore size distribution in Figure 2(b), which shows a pore diameter of 2-50 nm (Thommes et al., 2015). The surface area of the CSAC produced is superior to that reported in studies by Gilar (Gilar et al., 2013) and Jamilatun (Jamilatun et al., 2015), which recorded specific surface area values of 447.53 m²/g and 389.67 m²/g, respectively. Large pores can increase thermal conductivity. A $ZnCl_2$ concentration of 10% resulted in an optimal improvement in three activated carbon characteristics—namely surface area, total pore volume, and average pore diameter—as shown in Table 1.

Figure 2a presents the diffraction pattern of CSAC, which illustrates its crystallinity and structural properties. Two characteristic diffraction peaks of amorphous carbon appear at 2θ = 23.5° and 2θ = 44.6°, which correspond to the reflections from the (002) and (100) crystal planes of the ordered carbon structure, respectively. The (002) reflection at 2θ = 23.5° originates from the interlayer reflection of regularly arranged amorphous polycyclic aromatic carbon (Taer et al., 2020). This indicates that CSAC has a higher degree of structural order and atomic density. The addition of $ZnCl_2$ as an activator causes an increase in the (002) peak, which induces disruption in the carbon structure and facilitates the formation of an amorphous carbon phase.

Figure 3b shows the FTIR spectrum of the CSAC sample. The bands at 2923–2924 cm^{-1} and 2855–2856 cm^{-1} indicate the presence of aliphatic C–H groups derived from the residual hydrocarbon chains of the cellulose and lignin structures. Very low intensity indicates the decomposition of aliphatic groups due to the activation process and the nature of $ZnCl_2$ as a dehydrating agent (Baihong et al., 2023).

Figure 4 shows a well-developed porous structure, indicating a large number of surface sites available for adsorption at the initial stage.

The white dots visible in the SEM image indicate the presence of residual zinc salts, as the carbon was activated using $ZnCl_2$. The cavities visible in the image are formed due to the evaporation of the activating agent during the carbonization process, leaving behind cavities previously occupied by $ZnCl_2$ (Kundu et al., 2020). The SEM image in Figure 4 shows a surface with increased porosity, featuring pores predominantly in the mesoporous size range. $ZnCl_2$ plays a role in inhibiting the formation of tar and volatiles during carbonization, allowing more pores to form and their distribution to become more random. This is consistent with the porosity structure shown in Figure 2b.

The mesoporous structure of CSAC is formed according to the needs of CSAC as a PCM-PW mixture. The porosity of CSAC serves to deviate PW in either the solid or liquid phase. The limitation of air in PCM-SCAC will affect the resulting thermal conductivity (κ). The results of thermal conductivity measurements for each PW material, CSAC and the mixture (PW/CSAC) are listed in Table 2. A mixture of paraffin wax and CSAC is abbreviated as PCM/SCAC.

Table 2. Thermal conductivity of paraffin wax (PW), CSAC, and PCM/CSAC

Sample	κ ($Wm^{-1}K^{-1}$)
PW	0.21
CSAC	0.51
PCM/CSAC (95:5) %wt	0.37
PCM/CSAC (90:10) %wt	0.38

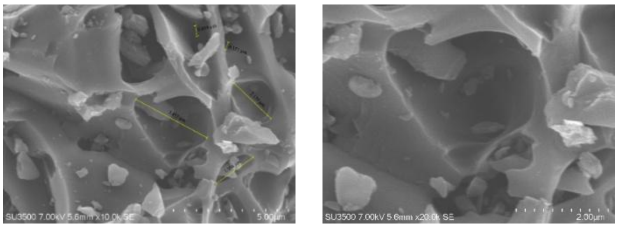

Figure 4. SEM images of CSAC-ZnCl10.

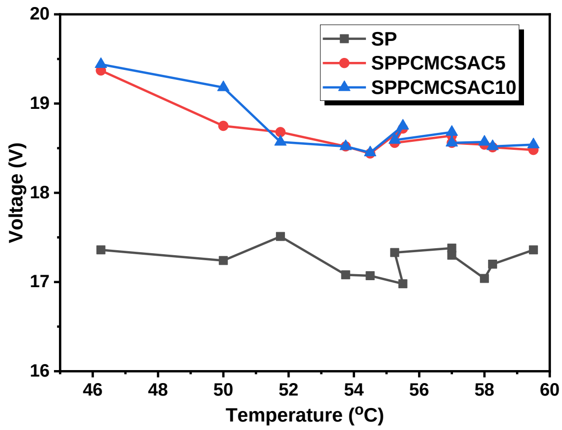

Figure 5. Solar panel voltage versus surface temperature

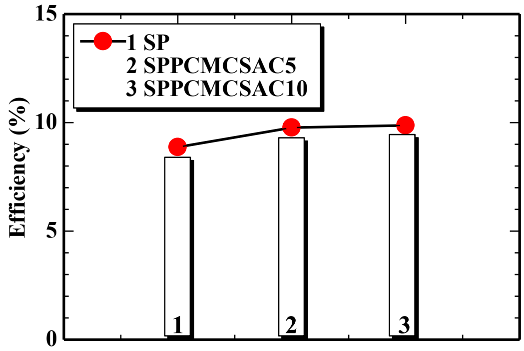

Figure 6. Average efficiency of solar panels

The data plotted in Figure 5 represents the voltage measured across a surface temperature range of 46–60°C for each solar panel. This temperature range allows for a comparison of solar panel voltage before and after the application of cooling. The average voltage of the solar panel without cooling was lower than that of the solar panel with cooling. Voltage decreased with rising temperature, exhibiting fluctuations. The average voltages were approximately 17.19 V, 18.65 V, and 18.71 V for the standard solar panel (SP) and the SPPCMCSAC variants with 5% and 10% concentrations, respectively.

The conductivity value of paraffin is in accordance with the conductivity value of commercial paraffin, which is around 0.2-0.22 W/mK (Usman et al., 2020). While the value of activated carbon is 0.51 W/mK. The thermal conductivity value of activated carbon based on the literature is 0.17 to 1.0 W/mK (Kuwagaki et al., 2003). The thermal conductivity of PCM/CSAC shows almost the same value for 5% and 10% CSAC mixtures. The results of voltage measurements against the surface temperature of the solar panel (SP) are shown in Figure 5.

The results of the calculation of the average efficiency of solar panels are shown in Figure 6**.** Figure 6 shows the increase in solar panel efficiency. The efficiency increases from uncooled (SP) solar panels to SPPCMCSAC5 and SPPCMCSAC10 by 10.15% and 11.27%, respectively. An efficiency increase of around 10% in solar panels by adding a cooling system is quite significant and effective, especially in hot climate conditions. Passive PCM cooling can reduce the temperature by 10 to 30 °C with an efficiency gain of 3–15% (Pusponegoro et al., 2025).

CONCLUSION

CSAC has been made and used for passive cooling mixture of paraffin wax PCM. The resulting CSAC has good characteristics as a PCM mixture, namely a moderate specific surface area with a pore distribution with a mesoporous structure. Activated charcoal also shows good amorphous properties with a graphite-like carbon structure. The mixture of activated charcoal in PCM has succeeded in increasing the thermal conductivity of PCM. PCMCSAC has succeeded in reducing the surface temperature of SP by about 10^{o}C compared to SPCMCSAC. SPCMCSAC has also succeeded in increasing the voltage and efficiency produced by solar panels. An increase in efficiency of about 10% compared to uncooled solar panels is quite effective and rational, especially for summer conditions.

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