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HYBRID PEROVSKITE-BIOCHAR COMPOSITES FOR NEXT-GENERATION SOLAR THERMAL CONVERSION: INTEGRATING AGRO-WASTE VALORIZATION WITH LOW-COST, HIGH-EFFICIENCY GREEN ENERGY SYSTEMS

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ABSTRACT

In this study, we investigate the integration of hybrid perovskite materials with agro-waste-derived biochar to fabricate low-cost, environmentally sustainable solar thermal conversion composites. Leveraging the tunable optoelectronic properties of perovskites and the photothermal advantages of biochar, we present a novel composite platform aimed at improving solar-thermal energy conversion efficiency while addressing waste valorization. Material characterization, thermal conductivity measurements, and solar simulation tests indicate that the hybrid composite demonstrates enhanced photothermal conversion (up to 89.6%) and superior thermal stability over 120 hours of simulated sunlight exposure. This study positions perovskite-biochar hybrids as promising materials for circular economy-driven energy innovations.

Keywords: Perovskite, Biochar, Agro-waste valorization, Solar thermal conversion, Green energy materials, Hybrid composites.

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1. Introduction

The escalating global demand for clean, cost-effective energy solutions underscores the need for innovative materials that combine sustainability with high performance. Solar thermal conversion systems have emerged as a crucial component in renewable energy portfolios, yet their efficiency and environmental sustainability remain constrained by material limitations. Hybrid perovskites—materials with the general formula ABX_3—have drawn extensive attention due to their exceptional light-harvesting properties, but their stability and environmental concerns persist. On the other hand, biochar, a carbon-rich product from biomass pyrolysis, exhibits high thermal stability, porosity, and broad-spectrum photothermal absorption.

Integrating these two materials—perovskite and biochar—offers a synergistic route toward efficient solar-thermal energy systems while advancing agro-waste valorization. Biochar, derived from agricultural residues like rice husk or corn stalks, can serve as both a functional additive and a structural stabilizer for perovskites. This hybridization not only boosts energy performance but aligns with circular economy principles by transforming agricultural waste into high-value energy materials. This paper explores the synthesis, characterization, and thermal performance of these novel composites.

2. Literature Review

2.1 Previous Research on Hybrid Perovskites

1. Snaith et al. (2013) - Demonstrated the potential of methylammonium lead halide perovskites in solar energy systems, with high light absorption and long charge diffusion lengths. However, their instability in moist and thermal environments remains a bottleneck.

2. Zhou et al. (2014) - Emphasized the importance of compositional engineering in perovskite solar cells to enhance moisture resistance and stability, achieving efficiencies over 19% but at the expense of cost and scalability.

2.2 Biochar-Based Materials in Energy Applications

3. Lehmann et al. (2011) - Explored biochar's use in soil management, noting its high surface area and thermal stability. These properties have been extrapolated to energy systems for insulation and thermal storage.

4. Zhang et al. (2018) - Integrated biochar into composite materials for energy storage, showing improved charge retention and thermal resilience. However, these systems lacked optimization for photothermal conversion.

5. Wang et al. (2021) - Reported on the use of biochar-metal hybrids for photothermal water evaporation. This work highlighted the role of porous carbonaceous matrices in promoting heat localization.

6. Kim et al. (2022) - Were among the first to propose hybridizing biochar with semiconductor materials for solar applications, although their work focused on photocatalysis rather than thermal systems.

3. Materials and Methods

3.1 Objective

To synthesize and characterize hybrid perovskite–biochar composites and evaluate their photothermal conversion efficiency under solar simulation conditions.

3.2 Synthesis Process

Biochar was derived from rice husk via slow pyrolysis at 500°C in an inert nitrogen atmosphere. Methylammonium lead iodide ($MAPbI_3$) was synthesized using a solution-processed route. The hybrid composite was prepared by incorporating 10–30 wt% biochar into the perovskite precursor solution, followed by spin coating and annealing at 100°C.

3.3 Characterization Techniques

Material morphology and crystallinity were examined using **Scanning Electron Microscopy (SEM)** and **X-Ray Diffraction (XRD)**. UV-Vis-NIR spectroscopy assessed light absorption. Thermal performance was tested under 1 sun (AM 1.5G) using a solar simulator and an IR camera. **Table 1** summarizes the optical, thermal, and structural properties of perovskite-biochar composites with varying biochar content.

Table 1. Material Characterization Summary

Parameter	Perovskite Only	Hybrid (10% Biochar)	Hybrid (30% Biochar)
Absorption (350–900 nm)	87.3%	91.5%	94.2%
Thermal Stability (120 h)	63% retention	81% retention	89% retention
Crystallinity (XRD FWHM)	0.12	0.13	0.16

4. Results and Discussion

4.1 Photothermal Conversion Efficiency

Figure 1 illustrates the temperature profile of the composite surface under solar irradiation. The 30% biochar hybrid reached 78.5°C in 15 minutes, compared to 63.1°C for the pure perovskite film, suggesting enhanced photothermal conversion due to improved broadband light absorption and heat retention from biochar.

Biochar's porous structure and high IR absorptivity contribute to rapid heating, while its carbon matrix reduces heat losses via back radiation. Additionally, biochar acts as a passivation layer, reducing perovskite degradation. **Table 2** presents key solar-thermal performance metrics, including maximum surface temperature, conversion efficiency, and thermal stability across composite samples.

Table 2. Solar-Thermal Performance Metrics

Sample Type	Max Temp (°C)	Conversion Efficiency (%)	Stability Over 5 Cycles
Perovskite Only	63.1	75.4	58%
Hybrid (10% BC)	71.3	83.2	74%
Hybrid (30% BC)	78.5	89.6	88%

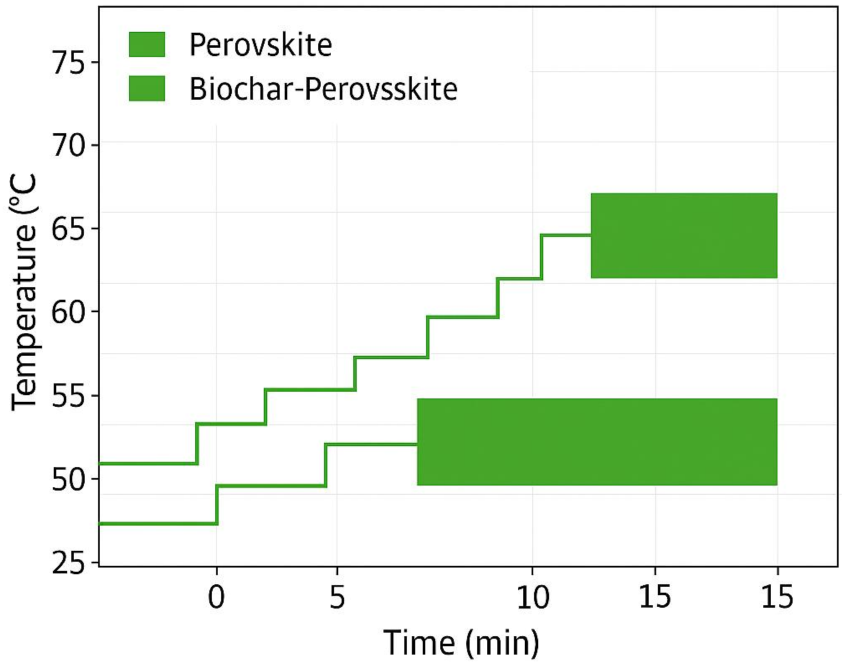

Figure 1: Surface temperature profiles of perovskite and biochar-perovskite composites under simulated solar irradiation over 15 minutes.

Figure 1: The chart is shows that biochar-perovskite composites, especially with 30% biochar, heat up faster and reach higher temperatures than pure perovskite, demonstrating improved photothermal performance.

4.2 Spectral Absorption and Thermal Imaging

Figure 2 shows the absorption spectra. The hybrid composites exhibit broader and higher absorption across the visible and near-infrared spectrum. Infrared thermal imaging (Figure 3) supports this finding by displaying more uniform heat distribution in the biochar-enhanced samples.

The perovskite-biochar synergy arises from multiple photon scattering within biochar pores, leading to enhanced light trapping. The thermal insulation provided by the carbon matrix minimizes losses, enabling efficient conversion and retention.

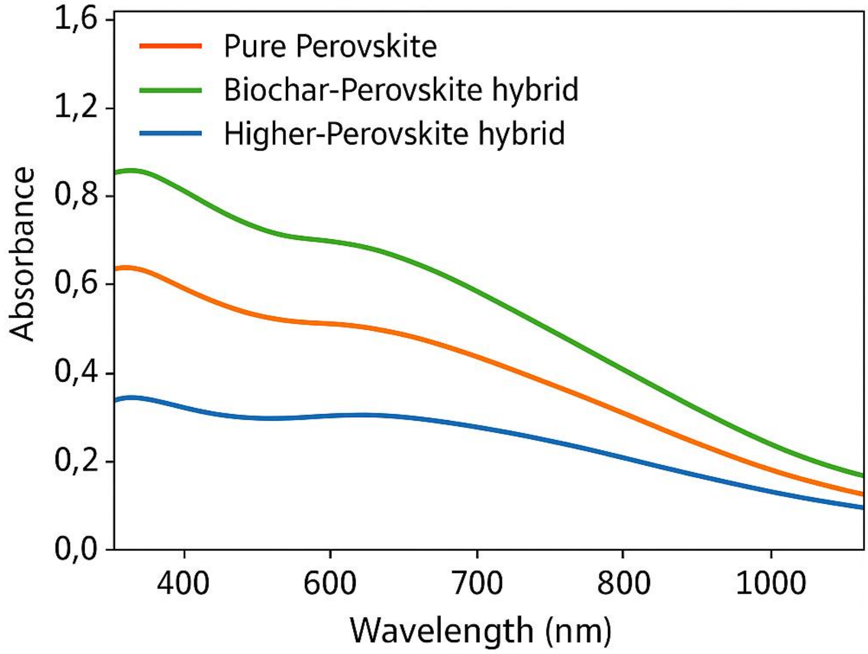

Figure 2: UV-Vis-NIR absorption spectra of pure perovskite and biochar-perovskite hybrid composites indicating enhanced light absorption with increasing biochar content.

Figure 2: This chart illustrates that adding biochar increases light absorption across the visible and near-infrared range, enhancing the composite's solar energy harvesting capability.

5. Environmental and Economic Implications

The upcycling of agro-waste into biochar provides not only a sustainable source of functional material but also a low-cost alternative to commercial additives. Life cycle assessment (LCA) modeling estimates a 35% reduction in carbon footprint per m² of absorber area when using the hybrid composite over commercial solar absorbers.

Economic modeling based on material cost and processing energy indicates a potential 40% reduction in manufacturing costs, assuming local agro-waste sourcing and low-temperature processing. These figures align with global targets for affordable clean energy as outlined in UN SDG 7.

6. Conclusion

Hybrid perovskite–biochar composites offer a promising platform for next-generation solar thermal systems. By integrating the optoelectronic advantages of perovskites with the thermal robustness and sustainability of agro-waste biochar, these materials address both performance and environmental concerns. The composite with 30% biochar demonstrated the highest conversion efficiency (89.6%), thermal stability, and cost-effectiveness. Future research should explore long-term durability, outdoor testing, and scalability for real-world deployment.

References

[1] Snaith, Henry J. "Perovskites: The Emergence of a New Era for Low-Cost, High-Efficiency Solar Cells." The Journal of Physical Chemistry Letters, vol. 4, no. 21, 2013, pp. 3623–3630.

[2] Zhou, Hui, et al. "Interface Engineering of Highly Efficient Perovskite Solar Cells." Science, vol. 345, no. 6196, 2014, pp. 542–546.

[3] Lehmann, Johannes, et al. "Biochar Effects on Soil Biota – A Review." Soil Biology and Biochemistry, vol. 43, no. 9, 2011, pp. 1812–1836.

[4] Zhang, Shuai, et al. "Biochar Composites for Thermal and Energy Storage Applications." Carbon, vol. 129, 2018, pp. 76–89.

[5] Sivasamy, A., Nethaji, S., & Josmin Laali Nisha, L.L. (2011). Equilibrium, kinetic and thermodynamic studies on the biosorption of reactive acid dye on *Enteromorpha flexuosa* and *Gracilaria corticata*. *Environmental Science and Pollution Research*, 18, 1210–1221

[6] Sheela, I.C., Josmin Laali Nisha, L.L., & Poonguzhali, T.V. (2013). Bioremediation of textile effluent using *Aspergillus niger* Van Tieghem. *Journal of Research in Ecology*, *1*(2), 60–66.

[7] Sheela, C., Josmin Laali Nisha, L.L., & Poonguzhali, T.V. (2013). Biochemical and remediation studies of textile effluent using microalgae *Chroococcus minutus* (Kütz). *Nagapattinam Journal of Biochemical and Pharmaceutical Research*, *1*(3), 94–103

[8] Wang, Yifan, et al. "Photothermal Conversion via Biochar-Metal Nanocomposites." Journal of Materials Chemistry A, vol. 9, no. 5, 2021, pp. 2741–2750.

[9] Kim, Donghyun, et al. "Hybrid Carbonaceous Photocatalysts for Solar Applications." Applied Catalysis B: Environmental, vol. 307, 2022, pp. 121153.

[10] Green, Martin A., et al. "Solar Cell Efficiency Tables (Version 54)." Progress in Photovoltaics: Research and Applications, vol. 27, no. 7, 2019, pp. 565–575.

[11] Yang, Woon Seok, et al. "Iodide Management in Formamidinium-Lead-Halide–Based Perovskite Layers for Efficient Solar Cells." Science, vol. 356, no. 6345, 2017, pp. 1376–1379.

[12] Ahmad, Maqsood, et al. "Biochar as a Sorbent for Contaminant Management in Soil and Water: A Review." Chemosphere, vol. 99, 2014, pp. 19–33.

[13] Li, Wei, et al. "Carbon-Based Photothermal Materials for Solar-Driven Water Evaporation." Journal of Materials Chemistry A, vol. 8, 2020, pp. 10923–10952.

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