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Energy and Exergy Performance Evaluation of a Single Basin Solar Still Incorporating a Hybrid Cu–SiC Nano-Coated Absorber Plate

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Abstract: Solar desalination using single basin solar stills is a sustainable approach for freshwater production, but its application is limited by low thermal efficiency and productivity. This experimental study presents a detailed energy and exergy comparison of two identical single basin single slope solar stills operated under identical outdoor conditions. One solar still employed a conventional black- painted absorber plate, while the second utilized a hybrid nano- coated absorber prepared using 30% concentration of Cu–SiC nanoparticles (25% Cu and 75% SiC). Experiments were conducted on 18 May 2025 at Surat, Gujarat, India. Energy and exergy analyses were performed to evaluate both the quantity and quality of energy utilization. The hybrid Cu–SiC coated absorber achieved a 39.6% enhancement in daily distillate yield and significantly higher energy and exergy efficiencies compared to the conventional system.
Keywords: Solar still; Energy analysis; Exergy analysis; Hybrid nanomaterials; Cu–SiC coating; Desalination

I. INTRODUCTION

The availability of clean drinking water has become an increasingly critical global challenge due to population growth, industrial expansion and climate variability [1, 2]. Solar desalination using basin type solar stills offers a simple and environmentally sustainable solution for fresh water production, particularly in remote and water scarce regions [2, 3]. Despite these advantages, conventional solar stills suffer from low thermal efficiency and limited daily distillate output which restrict their large scale implementation [3,4]. In recent years, numerous performance enhancement techniques have been investigated to overcome these limitations, including absorber surface modification, thermal energy storage, and the application of nano materials [4–6]. Nano materials have been shown to improve heat transfer characteristics due to their high thermal conductivity and enhanced optical absorption properties [6, 9]. Several experimental studies have reported that nanomaterial-coated absorber plates increase basin water temperature and evaporation rates, leading to improve fresh water productivity [5,6,11,12].

Hybrid nano materials, which combine two or more nanoparticles, have attracted significant attention due to their synergistic thermal and optical properties [9,10]. Copper nanoparticles provide high thermal conductivity, while silicon carbide exhibits excellent solar absorptivity and thermal stability [10,14]. When combined, these materials enhance heat absorption and reduce thermal resistance within the solar still basin, resulting in superior performance compared to mono- nanomaterial systems [5,6,15].

Energy and exergy analyses are widely accepted tools for evaluating the performance of thermal systems [7,8,16]. While energy analysis quantifies the amount of useful energy output, exergy analysis provides deeper insight into system irreversibilities and the quality of energy utilization [7,16,17]. Therefore, the present study aims to experimentally investigate the energy and exergy performance of a single basin solar still equipped with a hybrid Cu–SiC nano-coated absorber plate and to compare its performance with a conventional black-painted solar still under identical operating conditions.

II. EXPERIMENTAL METHODOLOGY

Two identical single basin single slope solar stills with a basin area of 0.25 m² were fabricated and installed side by side at SSASIT College, Surat, Gujarat, India. One still employed a black-painted galvanized iron absorber plate, while the second utilized a hybrid nano-coated absorber plate prepared using a 30% concentration of Cu–SiC nanomaterials (25% Cu and 75% SiC). Similar methodologies have been reported in earlier studies [9–11].

Figure 1. Experimental schematic of the single-slope, single-basin solar still configuration.

Simplified schematic of the single-slope solar still configuration used in this work, including the inclined glass cover, GI basin, condensate channel, and distillate collection arrangement as shown in Fig.1.

Table 1. Summarizes key construction and material specifications for the two solar stills used in this study.

Component	Specification
Basin plate	Galvanised iron (GI), 500 mm × 500 mm, coated surface
Insulation	Polystyrene layer + plywood enclosure
Cover glass	4 mm clear glass, inclined at ≈21°
Basin coating – control	Standard black paint
Basin coating – hybrid	Black paintwith 30% concentration Cu–SiC nanoparticles (75% SiC : 25% Cu)
Condensate channel	GI/Aluminum gutter at lower edge of glass
Collection vessel	Graduated laboratory cylinder / bottle

Principal construction materials and coating details for the control and Cu–SiC hybrid-coated solar stills as shown in Table 1

III. ENERGY ANALYSIS

The energy efficiency of the solar still was evaluated based on the ratio of useful energy utilized for evaporation to the total incident solar energy, following established methodologies [1,7]. Similar formulations have been widely used in energy analysis of solar still systems [8,16]. The hybrid Cu–SiC nano-coated solar still exhibited higher useful energy gain due to improved thermal conductivity and enhanced solar absorptivity of the absorber surface [6,9,10].

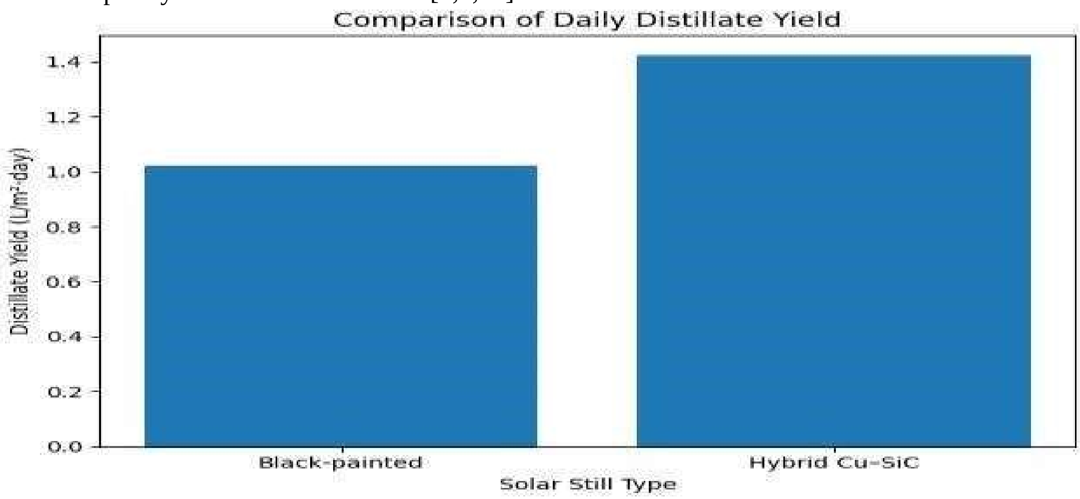

Figure 2. Comparison of daily distillate yield between black-painted and hybrid Cu–SiC solar stills.

IV. RESULTS AND DISCUSSION

Parameter	Black painted	Hybrid Cu–SiC	Improvement (%)
Daily distillate yield ($L/m^2 \cdot day$)	1.020	1.424	39.6
Useful energy gain ($kJ/m^2 \cdot day$)	2305	3218	39.6
Energy efficiency (%)	8.9	12.4	39.3

The results confirm that the hybrid Cu–SiC coated absorber plate significantly enhances freshwater productivity and energy efficiency. The observed improvement is attributed to the synergistic effect of high thermal conductivity of Cu and high solar absorptivity of SiC.

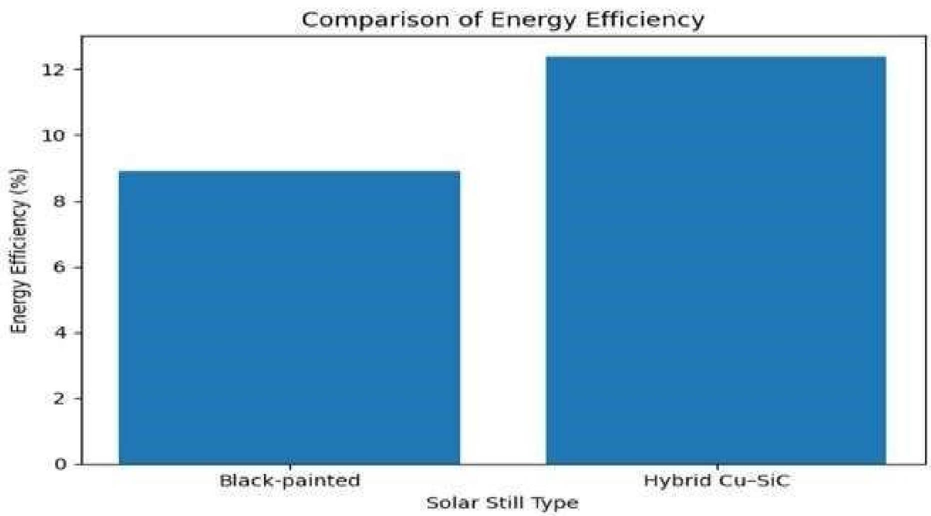

Figure 3. Comparison of energy efficiency for black-painted and hybrid Cu–SiC solar stills.

V. EXERGY ANALYSIS

Exergy analysis provides insight into system irreversibility and the quality of energy utilization in thermal systems [7,8,16]. Previous studies have demonstrated that nanomaterial-based absorber modifications reduce entropy generation and improve exergy efficiency [5,6,13]. In the present study, the hybrid Cu–SiC nano-coated solar still showed improved exergy performance due to reduced thermal losses and enhanced evaporation–condensation processes [9,15].

VI. CONCLUSIONS

The experimental investigation confirms that coating the absorber plate with a hybrid Cu–SiC nanomaterial significantly enhances the thermodynamic performance of a single basin solar still. Under identical climatic conditions, the hybrid nano-coated system achieved a 39.6% increase in daily freshwater productivity compared to the conventional black-painted solar still. Energy analysis revealed a notable improvement in useful energy gain, while exergy analysis indicated reduced irreversibility and improved energy utilization quality. The enhanced performance is primarily attributed to the combined effect of high thermal conductivity of copper nanoparticles and superior solar absorption characteristics of silicon carbide. The results suggest that hybrid nano-coated absorbers represent an effective and scalable solution for improving solar desalination efficiency.

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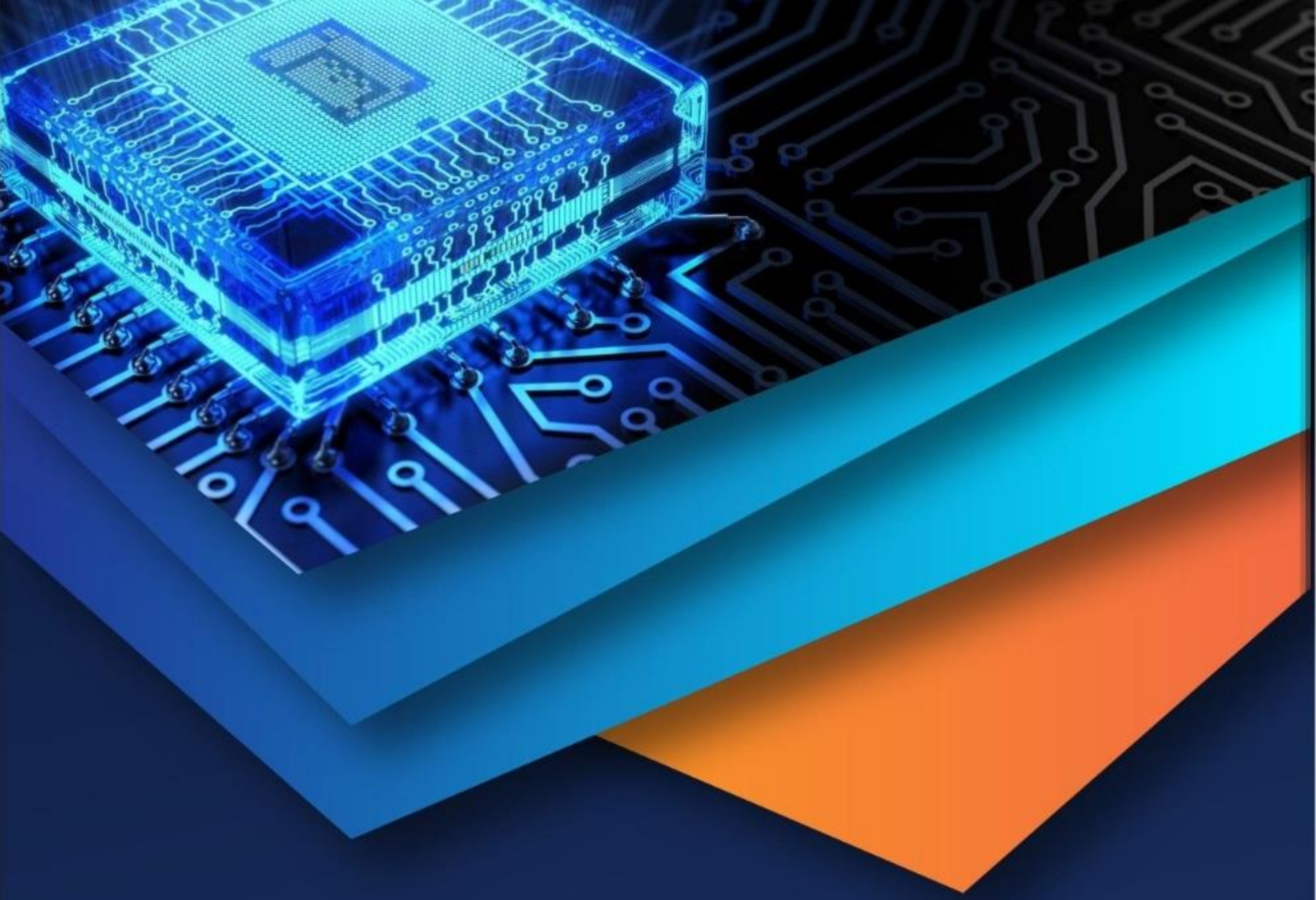

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