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OPPORTUNITIES OF POLYCARBONATE-BASED SOLAR CONCENTRATORS UNDER THE CLIMATIC CONDITIONS OF THE MIRZACHO‘L REGION

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Abstract: This study investigates the performance efficiency of polycarbonate-based solar concentrators under the climatic conditions of the Mirzacho‘l region in Uzbekistan, characterized by high solar irradiance and low humidity. A parabolic concentrator made of UV-protected polycarbonate was experimentally tested and compared with a conventional aluminum-based reflector of identical geometry. Experiments were conducted during July–August 2024, with solar radiation ranging from 940 to 1020 W/m² and ambient temperatures reaching +38°C.

The findings indicate that the polycarbonate concentrator achieved an average thermal efficiency of 59 ±1.6%, only slightly lower than the aluminum model (62 ±2.0%), while being 46% lighter and 50% more cost-effective. The optical quality of the polycarbonate surface remained 97% stable over two months of exposure, confirming the effectiveness of UV-protective coatings. Statistical analysis verified a confidence interval within ±2%, ensuring the scientific reliability of the results.

The study demonstrates that polycarbonate materials can serve as an economical and durable alternative to traditional metals for solar concentrator systems, particularly in hot and arid environments like Mirzacho‘l. The outcomes are directly applicable to the development of energy-efficient solar heaters, dryers, and greenhouse systems within Uzbekistan’s renewable energy framework.

Keywords: Polycarbonate solar concentrator; solar thermal efficiency; Mirzacho‘l climate; renewable energy; UV protection; optical stability; thermal analysis; sustainable technology; energy economics; Uzbekistan.

Intoruction

The Mirzacho‘l Valley, located in the central part of Uzbekistan, is characterized by its hot, arid continental climate and abundant solar radiation throughout the year. The region receives an average of 310 sunny days annually, with daily solar insolation levels ranging from 5.4 to 5.8 kWh/m²/day, making it one of the most favorable areas for the practical utilization of renewable solar energy resources. These climatic advantages create significant potential for developing solar concentrator systems designed to harness and convert solar energy into thermal or electrical power in a sustainable manner.

In recent years, both international and local studies have extensively explored the performance efficiency of solar concentrators as a promising solution to meet increasing energy demands through environmentally friendly technologies. For example, Hadi et al. (2020) demonstrated that polycarbonate-based parabolic solar concentrators are approximately 30–40% lighter and more cost-effective than conventional aluminum-based reflective systems, while maintaining a comparable thermal efficiency. Similarly, Li and Zhou (2021) investigated the implementation of UV-protected polycarbonate coatings, showing that the optical transparency and reflectivity of such materials can enhance overall energy conversion efficiency by 6–8%, particularly under high solar irradiance conditions.

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In Uzbekistan, research on solar concentrators has mainly focused on assessing the solar radiation intensity and its influence on thermal systems in desert and semi-desert climates. Notably, A. Kholmatov (2021) and M. Rahimov (2023) studied the energy efficiency of solar thermal systems in the Mirzacho‘l and Kyzylkum regions, providing valuable insights into the potential of solar power in local contexts. However, these studies primarily addressed general thermal system performance and did not thoroughly examine the mechanical durability, thermal stability, or economic feasibility of polycarbonate-based optical concentrators under local environmental conditions.

Moreover, most existing works have relied on metallic or glass reflector systems that, while efficient, are often heavy, expensive, and prone to corrosion or deformation under extreme temperature fluctuations common in the Mirzacho‘l region, where daytime surface temperatures may exceed +45°C. The need for lightweight, cost-effective, and weather-resistant concentrator materials remains a crucial research gap that this study aims to address.

Therefore, the present research focuses on evaluating the technical, thermal, and economic performance of polycarbonate-based solar concentrators under the climatic conditions of Mirzacho‘l. The study seeks to identify how polycarbonate materials—enhanced with UV-protective coatings—can be effectively utilized to improve the durability, efficiency, and affordability of solar concentrator systems in hot and arid regions. Through systematic experimental analysis, the research also aims to determine the long-term operational stability and optical performance of polycarbonate concentrators compared to traditional aluminum-based systems.

METHODS

2.1. Experimental Object

In this study, a parabolic-type solar concentrator with a diameter of 80 cm and a depth of 18 cm was designed and fabricated using polycarbonate as the base material. The reflective surface of the concentrator was coated with a 95% reflective aluminum layer, covered by a thin transparent UV-protective coating to prevent surface degradation due to prolonged solar exposure. For comparison, a control system was constructed using a glass-surfaced aluminum reflector of identical geometric parameters — including curvature radius, aperture size, and focal length — to ensure experimental consistency. Both concentrators were mounted on adjustable stands allowing the tilt angle to be optimized according to the solar declination angle of the Mirzacho‘l region (approximately 37° latitude). The overall aim of this setup was to evaluate and compare the thermal efficiency, optical durability, and economic viability of polycarbonate-based concentrators relative to traditional metallic systems.

2.2. Experimental Conditions

Experiments were conducted in Mirzacho‘l District (Jizzakh region, Uzbekistan) during July–August 2024, when solar irradiance reaches its annual maximum. Measurements were performed between 10:00 a.m. and 3:00 p.m., corresponding to the period of peak solar radiation. Meteorological parameters during the experiment were as follows: Global solar radiation 940–1020 W/m², Ambient air temperature +38°C (±1.2°C), Wind velocity 4.6 m/s (±0.3 m/s), Relative humidity 35% (±2%), Atmospheric pressure 740 mm Hg. These conditions represent typical summer weather in the Mirzacho‘l steppe zone and were monitored continuously using a TES-1333R solar meter and a Kestrel 5500 weather station to ensure measurement reliability.

2.3. Measurement Methodology

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A blackened steel plate with a diameter of 8 cm and a thickness of 2 mm was placed at the focal point of each concentrator to act as a heat absorber. The surface temperature of this plate was measured every 5 minutes using a K-type thermocouple (accuracy ±0.1°C) connected to a UNI-T UT325 digital thermometer. Each experiment was repeated three times, and the mean value of temperature readings was calculated to minimize random errors. The rate of temperature increase, maximum thermal power, and overall system efficiency were determined for both concentrator types. Thermal efficiency (η) was calculated using the following formula:

- $\eta = (m * c * \Delta T) / (E * t) \times 100\%$

where: m — mass of the absorber plate (kg); c — specific heat capacity (J/kg·K); ΔT — temperature difference during exposure (K); E — solar radiation intensity (W/m²); t — exposure time (s).

Measurement uncertainty was analyzed by standard error propagation, and the confidence interval was estimated at a 95% confidence level using Student's t-distribution

RESULTS

3.1. Experimental Findings (O'lchov natijalari)

System Type	Max. Temperature (°C)	Mean Efficiency (%)	±Error (%)	Unit (USD)	Cost
Aluminum Reflector	145 ± 1.5	62 ± 2.0	2.0	180	
Polycarbonate Reflector	138 ± 1.8	59 ± 1.6	1.6	90	

The results show that the maximum temperature achieved by the polycarbonate concentrator was slightly lower (by approximately 4.8%) than that of the aluminum one, due to its lower thermal conductivity (0.22 W/m·K vs. 205 W/m·K). However, the overall system efficiency remained relatively high — around 59%, with only a 3% difference compared to the aluminum reflector. Importantly, the polycarbonate system weighs 46% less and costs half as much, offering a favorable trade-off between performance and practicality, particularly for portable or low-cost solar thermal applications such as water heating and small greenhouse systems.

3.2. Graphical and Statistical Analysis

The time–temperature relationship was plotted for both concentrators. The temperature of the absorber plate in the polycarbonate system rose steadily from 25°C to 125°C within 30 minutes, whereas the aluminum system reached approximately 132°C in the same duration. This 7°C difference can be attributed to the lower heat transfer coefficient of the polycarbonate material. Nevertheless, the rate of temperature rise during the first 10 minutes was almost identical for both systems (average slope: 3.6°C/min vs. 3.8°C/min), indicating comparable initial optical efficiency. Furthermore, thermal loss coefficients were calculated using transient cooling data, revealing that the polycarbonate concentrator exhibited 15% lower heat loss to the ambient environment, thanks to its lower emissivity and insulation properties. The uncertainty analysis

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yielded a relative error below 2%, confirming the statistical reliability of the obtained data. A t-test comparison of both systems ($p < 0.05$) verified that the difference in performance, though small, was statistically significant. Overall, the polycarbonate-based concentrator demonstrated stable and reproducible performance, combining high optical efficiency with low material cost and structural resilience, making it well-suited for Mirzacho'l's hot, arid, and high-irradiance conditions.

DISCUSSION

The experimental results obtained in this study are largely consistent with the findings of Li and Zhou (2021), who conducted comprehensive testing of UV-protected polycarbonate solar concentrators in China and reported a thermal efficiency range of 58–60%. The efficiency achieved in our Mirzacho'l experiments—59 ±1.6%—closely matches those results, confirming the reliability and adaptability of polycarbonate-based concentrators under the intense solar radiation characteristic of arid climates.

The Mirzacho'l region, situated in the central part of Uzbekistan, receives solar irradiance levels up to 1000 W/m² during summer, coupled with low humidity and minimal cloud cover. These conditions provide an ideal natural laboratory for testing optical materials exposed to prolonged sunlight. Under such conditions, the optical transparency of polycarbonate (90–92%) remained stable throughout the two-month experiment, with only a 3% degradation, resulting in an average maintained quality of 97% of initial optical efficiency. This indicates that the applied UV-protective coating effectively mitigated photodegradation and discoloration of the reflective surface.

Although polycarbonate inherently has a lower thermal resistance compared to aluminum, its UV-resistant coating and laminated structure substantially enhance its long-term stability. Visual inspection during and after testing revealed no yellowing, surface cracking, or deformation of the polycarbonate layer, demonstrating excellent mechanical resilience even at ambient temperatures exceeding +38°C.

A key advantage of this research lies in addressing the limitations observed in previous studies. Earlier investigations (e.g., Kholmatov, 2021; Rahimov, 2023) lacked detailed economic analysis, thermal stability testing, and statistical validation. In contrast, this study employed multiple experimental repetitions, uncertainty analysis, and comparative cost evaluation, ensuring both scientific rigor and practical significance.

The results thus provide strong evidence that polycarbonate solar concentrators—when properly coated and geometrically optimized—can perform effectively in hot, dry, and high-radiation environments like Mirzacho'l. Moreover, due to their light weight (46% less than aluminum models) and lower production costs (50% cheaper), they represent a viable alternative for decentralized solar applications, including rural heating systems, solar dryers, and small-scale agricultural facilities.

CONCLUSION

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1. Under the climatic conditions of Mirzacho‘l, the average thermal efficiency of the polycarbonate-based solar concentrator was determined to be 59 ±1.6%, which is comparable to aluminum-based systems.
2. Polycarbonate concentrators are lightweight, cost-effective, and require minimal technical maintenance, making them particularly advantageous for remote or low-income rural areas.
3. The application of UV-protective coatings ensured long-term optical and structural stability, preserving over 97% of reflective quality after continuous exposure.
4. The findings confirm that such systems are highly suitable for energy-efficient applications including water heating, greenhouse climate control, and agricultural drying systems under Mirzacho‘l’s climatic conditions.
5. Statistical analysis indicated a confidence interval of ±2%, ensuring the scientific reliability of the obtained results in compliance with modern research standards.

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