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Experimental study on the transient thermal behavior of a solar cylindrical cavity receiver with MWCNT/Oil nanofluid: Implications for energy governance

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experimentally tested.

- First time constant measurement for dish–cavity with MWCNT/oil nanofluid (cooling τ=2.54 min).
- Rapid heating was founded with exponential response and uniform wall temperature (τ=1.005 min).
- Efficiencies were recorded as thermal equal to 60–65%, and exergy as 16–18% at 0.2 wt% and 10 ml/s.
- Energy governance aspects provided transparent data for policy, certification, and grid integration.

Abstract

This study experimentally investigates the transient and steady-state thermal performance of a solar dish collector with a cylindrical cavity receiver, using MWCNT/thermal oil nanofluid (0.2 wt%) at a constant flow rate of 10 ml/s. The setup, located at Tarbiat Modares University, included a two-axis tracked dish concentrator, a black chrome-coated wound copper cavity receiver, a plate heat exchanger, and a closed hydraulic loop. A key novelty is the experimental determination of the system's time constant under real outdoor conditions for both heating and cooling phases. Additionally, the study explicitly links empirical findings to energy governance frameworks. The system exhibited an exponential thermal response during heating, achieving a time constant of 1.005 min (R^2=0.976), while the cooling time constant was 2.54 min (R^2=0.971). Continuous operation tests confirmed stable outlet temperatures, uniform wall temperature distributions, and no performance

the reproducible transient behavior underscore system reliability. From an energy governance perspective, the transparent, auditable data support evidence-based policymaking, technology certification, and grid integration rules for concentrating solar power systems. While these findings are based on a single concentration and flow rate, future parametric studies will explore the full performance envelope. However, these governance implications are conditional on future scale-up validation and should be viewed as potential pathways rather than final policy prescriptions.Overall, the configuration demonstrates favorable dynamic and steady-state characteristics, with thermal and exergy efficiencies determined to within±5.0% and±6.5% relative uncertainty, respectively, suitable for high-grade solar thermal applications.

Keywords

Solar dish collector; Cylindrical cavity receiver; MWCNT/oil nanofluid; Time constant; Energy and exergy efficiencies

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Introduction

The growing demand for clean, dispatchable medium–to–high temperature heat has spurred research into concentrating solar power (CSP), where dish collectors offer high optical efficiency and modular scalability [1]. However, the transient thermal

repeatable data are required for regulatory standards, certification, and grid integration [3].

Some studies were done related to solar dish concentrators with cavity receivers [4], [5]. Hassan et al. [6] experimentally examined the thermal, exergetic, and optical behavior of two cavity–type copper tube receivers—cylindrical and conical—designed for a solar parabolic dish concentrator. The novelties include a comparative assessment of both geometries under identical operating conditions (water as working fluid, flow rate of 0.83 L/min, temperature range of 35–190 °C) and a complementary simulation using COMSOL Multiphysics to map temperature distribution. Key results reveal that the conical cavity receiver outperforms its cylindrical counterpart, achieving average thermal and exergy efficiencies of 62% and 11%, respectively, with an optical efficiency of 82% and a lower overall heat loss coefficient (125 W/m^2 versus 137 W/m^2 for the cylindrical design). Loni et al. [7] experimentally and numerically investigated a parabolic dish concentrator equipped with two distinct cavity receiver geometries—cubical and cylindrical—using thermal oil as the heat transfer fluid. The study's novelty lies in the combined experimental–numerical approach to evaluate the performance of both optimized cavity shapes under real outdoor conditions, focusing on thermal efficiency and heat gain during steady–state operation. The results demonstrated that the cubical cavity receiver outperformed its cylindrical counterpart, achieving an average thermal efficiency of 65.14% compared to 56.44%, thereby establishing the cubical design as the more effective configuration for enhanced heat capture.

Rajan and Reddy [8] conducted an integrated optical–thermal investigation of a novel cavity receiver coupled with a 40 m^2 parabolic dish concentrator. Their methodology

distribution. The main results show an optical efficiency of 84.15% at an aiming height of 4.5 m and a peak thermal efficiency of 73.11% under no–wind, 90° tilt conditions, with side–on wind yielding the poorest performance. Azzouzi et al. [9] experimentally and analytically investigated the thermal performance and heat losses of a downward–facing cylindrical cavity receiver (20 cm deep, 10 cm inner diameter, 19 helical copper turns) for a solar dish concentrator. The novelty lies in basing cavity dimensions on the critical L/D ratio, neglecting wind speed, testing at a fixed inclination angle (36°) corresponding to the site latitude, and employing a Nusselt–number–based analytical model to predict total heat loss and thermal efficiency. The experimental and analytical thermal efficiencies agreed within a maximum deviation of 12%, confirming that receiver inclination angle and L/D ratio strongly influence performance.

De Souza et al. [10] investigated the reduction of forced convection losses in a cylindrical cavity receiver of a Dish/Stirling system through aerodynamic modifications to the aperture opening. Using CFD simulations under varying receiver inclinations (0°–90°) and proposing four distinct aperture geometries—including a novel torus–like configuration—the study introduced an approach focused on the cavity entrance region rather than internal receiver alterations or advanced working fluids. The optimized toroidal shape reduced internal air recirculation by up to 95.6% and lowered forced convection heat losses by approximately 96% compared to the original design, demonstrating that aperture geometry optimization is a highly effective, low–complexity strategy for enhancing receiver thermal performance. It should be mentioned that researches related to time constant in solar dish collectors was limited to be reported in this paper.

reported a 13.12% improvement in thermal efficiency (63.9% vs. 56.44% for pure oil) using MWCNT/thermal oil nanofluid in a wounded cylindrical cavity receiver. Loni et al. [13] compared Al_2O_3/oil and SiO_2/oil nanofluids, finding Al_2O_3/oil gave the highest thermal efficiency and lowest heat loss. Ahmed et al. [14] showed that MWCNT nanofluid improved heat transfer by 19.1% over SWCNT, and adding a second cylinder raised performance by 71.7%. Loni et al. [15] performed a three–step experimental study across cubical, cylindrical, and hemispherical cavities with various nanofluids; the hemispherical cavity yielded the highest mean thermal efficiency enhancement (12.90%) when nanofluids were used.

Some studies were done related to energy governance [16]. Zheng et al. [17] investigated how renewable energy policies influence environmental governance performance across 30 Chinese provinces from 2010 to 2021, focusing on policy clarity, stakeholder participation, and implementation tools. By incorporating governance investment and conducting heterogeneity analysis, the study introduces a novel framework linking policy design to measurable governance outcomes, particularly under varying regional and demographic conditions. The key findings reveal that well–defined targets, active subject engagement, and effective instruments significantly enhance governance performance—an effect amplified by dedicated environmental spending and more pronounced in eastern China, densely populated provinces, and periods of intensive policy rollouts. Sen et al. (2025) [18] investigated how environmental taxes shape renewable energy consumption across OECD nations, highlighting the mediating influence of environmental governance and environment–related technological innovation. Using econometric methods, the study introduced a novel mediation framework revealing that taxation alone exerts only a limited effect, whereas its efficacy substantially rises when reinforced by

quality and innovation, underscoring the necessity of integrated policies to accelerate clean energy transitions.

Eitan et al. [19] examined how non–governmental organizations (NGOs) act as regulatory intermediaries in Israel's solar energy sector, addressing tensions between centralised planning frameworks and local realities. Using a qualitative case–study approach, the work introduces a novel perspective by revealing that NGOs mediate institutional complexity across three arenas—between regulators, between regulators and developers, and between regulators and communities—thereby extending regulatory intermediation theory beyond formal authority to credibility and procedural fluency. The main findings show that NGOs translate administrative procedures, resolve institutional frictions, and amplify community voices, effectively bridging fragmented governance domains and coordinating renewable energy implementation through embedded engagement across state, market, and society. Garg et al. [20] investigate the drivers of sustainable economic development across ASEAN economies, focusing on the interplay between renewable energy deployment, educational quality, and institutional governance. Employing empirical analysis, the study introduces a novel interaction framework that reveals how sound governance and education mitigate the negative effects of natural resource depletion while amplifying the positive role of renewable energy and foreign direct investment in achieving sustainable development goals. The key results demonstrate that robust governance not only directly fosters sustainable growth but also transforms natural resource management into a development asset, with renewable energy acting as a critical lever—highlighting that effective energy governance, combined with education, serves as a powerful catalyst for long–term economic sustainability.

converting annual data (2000–2022) into quarterly series and applying Kernel–based Quantile Regression (KRQR), the study introduced a novel asymmetric, quantile–specific analytical framework capable of capturing nonlinearities and distributional shifts across varying levels of sustainability performance. The key findings revealed that all four drivers exert stronger and more consistent positive effects at higher sustainability quantiles, confirming that robust governance, when integrated with technological innovation, digital tools, and skilled workforce development, is essential for advancing ecological resilience and green growth in advanced economies.

Despite the potential of dish–cavity collectors, previous work has largely focused on steady–state performance, leaving the transient time constant of nanofluid–based systems under real outdoor conditions unexamined. This study introduces three novelties: (i) experimental determination of both heating and cooling time constants for a cylindrical cavity receiver using MWCNT/thermal oil nanofluid (0.2 wt%, 10 ml/s) under variable irradiance and ambient conditions; (ii) concurrent evaluation of thermal and exergy efficiencies during continuous operation; and (iii) generation of reproducible, auditable data to support energy governance objectives (technical standards, certification, evidence–based policies). Thus, this work bridges transient thermal characterization and governance–ready data, offering a replicable framework for certifying the dynamic reliability of nanofluid–enhanced solar thermal systems. It is important to emphasize that the governance implications discussed in this study are based on a prototype-scale (1.9 m diameter) dish collector with a single nanofluid concentration and flow rate. While the measured time constants and efficiency metrics establish credible baseline performance benchmarks, translating these directly into regulatory instruments—such as feed-in tariffs, certification criteria, or

that could be considered if the observed performance is confirmed at commercial scales—rather than definitive policy prescriptions.

Section snippets

Experimental setup

Experiments were conducted at Tarbiat Modares University, Tehran (35.68°N, 51.42°E). The primary solar collector was a parabolic dish concentrator (aperture diameter 1.9 m, focal length 1 m, f/D≈0.526, reflectivity 0.84) with a dual–axis sun–

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Heating

The dynamic response of the solar dish–cylindrical cavity receiver using 0.2 wt% MWCNT/thermal oil nanofluid at 10 ml/s was quantified via time constant determination (Fig. 4a). The dimensionless temperature rise followed an exponential approach to steady state, yielding a heating time constant $\tau = 1.005$ min ($R^2 = 0.9761$). This confirms a first-order lumped-capacitance behaviour, simplifying predictive controller design [[34], [35]].

Comparison with literature: The heating time constant obtained …

Financial governance is advanced by continuous test outcomes that mitigate investment risks [53]. The system maintained outlet temperature ±2°C under wind gusts up to 3.8 m/s, inlet near 40°C, thermal efficiency 60–65%, and exergy efficiency 16–18% below thermal—with no degradation. The nanofluid preparation (stirring at 400 rpm and 150°C, ultrasonication) proved scalable and stable (no sedimentation over nine months).

Strategic governance benefits from the rapid heating time constant (~1 min), making the dish–cavity-nanofluid configuration suitable for variable irradiance or frequent cycling (e.g., hybrid solar-gas plants, industrial heat). The 2.54 min cooling constant allows rapid discharge without oversized buffers.

Conclusions

This experimental study examined the transient and steady–state behaviour of a solar dish collector with a wounded cylindrical cavity receiver, heat exchanger, and hydraulic circuit using 0.2 wt% MWCNT/thermal oil nanofluid at a constant 10 ml/s flow rate. Calibrated sensors measured solar irradiance, fluid temperatures, flow rate, wind speed, and ambient temperature, enabling preliminary thermal and exergy assessments under real outdoor conditions. All reported values are subject to the …

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CRediT authorship contribution statement

Reyhaneh Loni: Writing – original draft, Software, Methodology, Investigation, Formal analysis, Data curation. **Ezzatollah Askari Asli-Ardeh:** Supervision, Project administration. **Barat Ghobadian:** Supervision, Project administration. …

Declaration of competing interest

References (54)

R. Loni *et al.*
Developing solar vacuum cylindrical cavity receiver for reducing CO2 Pollutant: a new approach to energy governance
Sustainable Energy Technol Assess (2024)

K. Shahverdi *et al.*
Solar-driven water pump with organic Rankine cycle for pressurized irrigation systems: a case study
Therm Sci Eng Prog (2021)

A. Hassan *et al.*
An experimental investigation on thermal and optical analysis of cylindrical and conical cavity copper tube receivers design for solar dish concentrator
Renew Energy (2021)

R. Loni *et al.*
Experimental and numerical study on dish concentrator with cubical and cylindrical cavity receivers using thermal oil
Energy (2018)

A. Rajan *et al.*
Integrated optical and thermal model to investigate the performance of a solar parabolic dish collector coupled with a cavity receiver
Renew Energy (2023)

Renew Energy (2017)

N. Aslfattahi *et al.*

Efficiency enhancement of a solar dish collector operating with a novel soybean oil-based-MXene nanofluid and different cavity receivers

J Clean Prod (2021)

R. Loni *et al.*

Experimental study of carbon nano tube/oil nanofluid in dish concentrator using a cylindrical cavity receiver: outdoor tests

Energ Conver Manage (2018)

K.S. Wasankar *et al.*

Numerical and experimental analysis on convective heat losses from a fully open cylindrical cascaded cavity receiver

Energy (2024)

H. Ahmed *et al.*

Mixed convection and entropy generation analysis of carbon nanotube-water nanofluid in a square cavity with cylinders and flow deflectors

Results Eng (2025)

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