DESIGN AND DEVELOPMENT OF A 5 M COMPOSITE PARABOLIC SOLAR DISH FOR HIGH-TEMPERATURE APPLICATIONS

Summary

This work reports the development of a locally manufacturable 5 m diameter (19.6 m^2 aperture) parabolic dish concentrator, targeting a nominal geometric concentration ratio of ~2500 intended as the cornerstone of a high-temperature solar pilot plant for research on solar fuels, solar metallurgy, and high-temperature process heat. The dish geometry and supporting structure were designed to meet parabolic shape requirements while maintaining mechanical robustness under expected operational loads. A lightweight, low-cost sandwich concept was adopted using fiberglass-reinforced epoxy skins and a polystyrene foam core, enabling fabrication from materials readily available in Saudi Arabia. The concentrator was manufactured as nine segments to simplify tooling, handling, and assembly. Surface calibration was then performed to achieve the target paraboloid prior to applying highly reflective flexible mirrors. Mirror installation was carried out to eliminate air gaps and ensure full conformity to the calibrated surface. Finally, the concentrator was installed on a concrete foundation and integrated with a two-axis tracking system. The system is commissioned and ready for on-sun testing and receiver integration for high-temperature experiments.

Keywords: Parabolic dish, concentrating solar, high-temperature solar, composite sandwich structure, surface calibration, optical characterization, two-axis tracking, solar fuels pilot plant

Field of application for the findings: High-temperature concentrating solar systems for pilot-scale research, including thermochemical solar fuel production, solar metallurgy, and high-temperature process heat.

Addressed audience: Researchers and engineers in concentrating solar thermal systems, solar concentrator design/manufacturing, optical/structural calibration, and high-temperature solar pilot-plant development.

1. Introduction

Concentrated solar technologies provide a pathway to supply high-temperature renewable heat for power generation, industrial process heat, and solar thermochemical conversion routes that store solar energy in chemical form (Romero and Steinfeld, 2012). In these applications, the receiver/reactor is a critical component because it must efficiently absorb highly concentrated radiation while maintaining thermal and mechanical integrity under transient operating conditions (Koepf et al., 2017).

Thermochemical fuel production methods, such as solar-driven methane reforming (steam reforming and dry reforming) and two-step redox cycles for H_2O/CO_2 splitting, along with other high-temperature solar-chemistry processes, typically require reactor temperatures above ~800 °C and high incident solar fluxes, pushing requirements on concentrator optical accuracy, thermal stability, and receiver/reactor design (Koepf et al., 2017; Wei et al., 2025). High-flux solar facilities illustrate the relevant operating envelope, achieving on-sun peak fluxes on the order of thousands of suns and temperatures approaching ~1800 °C (and higher with secondary optics), which are representative of the conditions targeted in advanced solar-chemistry and high-temperature materials testing (National Laboratory of the Rockies, 2026).

Point-focus parabolic dish concentrators are particularly attractive for such applications because they can provide very high concentration at a compact focal region and are inherently modular. Dish-based systems have also demonstrated record system-level performance in dish–Stirling configurations, underlining the potential of dish concentrators when optical alignment and tracking are well controlled (U.S. Department of Energy, 2016). However, translating this capability into a robust research-grade platform requires a reflector structure that preserves the parabolic figure under operational loads, a practical manufacturing route, and a repeatable surface calibration method, especially when aiming for cost-effective fabrication using locally accessible materials.

Recent reviews highlight that parabolic dish concentrators span a wide range of diameters and design choices (reflector materials, segmentation strategies, structural concepts, and alignment approaches), and that performance is strongly coupled to geometry control and manufacturing tolerances (Abbas et al., 2022). In this context, there remains value in detailed, reproducible demonstrations of large-diameter, research-oriented dishes that combine low-cost lightweight structures with documented calibration and commissioning workflows.

This paper presents the design, fabrication, and surface calibration of a 5 m diameter (19.6 m^2 aperture) parabolic dish concentrator with a 45° rim angle and focal length of ~3 m, targeting a nominal geometric concentration ratio of ~2500 developed as the cornerstone of a high-temperature solar pilot-plant platform. The work covers (i) definition of the dish geometry and structural concept to withstand expected operational loads, (ii) fabrication of a segmented lightweight composite sandwich structure, (iii) calibration of the reflector surface to the target paraboloid, (iv) conformal application of flexible high-reflectivity mirrors, and (v) installation on a fixed foundation with integration of a two-axis tracking system, enabling near-term on-sun experiments for high-temperature solar applications.

2. Dish requirements and design

The concentrator was conceived as a pilot-plant cornerstone for high-temperature solar research where receiver/reactor temperatures above ~800 °C are commonly required (Section 1). Consequently, the dish was designed to (i) deliver high concentration to a compact focal region , (ii) maintain the parabolic figure under gravity and wind loading through adequate stiffness, and (iii) remain lightweight and affordable using widely available materials. Lightweight yet stiff reflector structures are widely recognized as key requirements for parabolic dishes to limit deflection and preserve optical performance under wind and self-weight effects.

The following are the optical and geometrical design targets:

Tab. 1: Optical and geometrical design targets of the dish

Parameter	Value
Area	19.6 m^2
Rim angle	45°
Concentration ratio	~2500 suns
Focal length	~3 m

Because a parabolic dish is a point-focus optical system, accurate solar tracking is essential to maintain the reflected beam on the receiver; dual-axis tracking is therefore typically required to achieve high efficiency. Accordingly, the design included provisions for integration with a two-axis tracking mechanism and a receiver support located at the focal region. In addition, the receiver/support geometry was considered to minimize optical losses such as shading, which is generally small when the receiver is much smaller than the dish aperture.

3. Manufacturing, calibration, and assembly

To achieve a lightweight and mechanically robust reflector suitable for outdoor operation, the dish structure was realized as a composite sandwich using fiberglass-reinforced epoxy resin skins and a polystyrene foam core. The sandwich configuration was selected to provide high stiffness-to-weight ratio while keeping the dish affordable and manufacturable from locally available materials.

For manufacturability, handling, and field assembly, the 5 m reflector was divided into nine segments. Segmented ("petal") architectures are widely used in dish concentrators to simplify fabrication and assembly while maintaining an overall paraboloid. The segmentation also provides a practical pathway for iterative surface correction during calibration and for managing tolerances at segment interfaces. Each segment was produced, cured, edge-finished, and prepared with mechanical interfaces for integration into the full dish assembly.

After assembly, the parabolic surface was calibrated prior to mirror installation using a laser reflection test. A target was placed at the nominal focal distance (~3 m) and a laser beam was directed to the segment surface where a temporary small mirror patch was applied; the reflected spot location (x,y) relative to the target center was recorded. Each segment was divided into eight rows (matching the later mirror-row layout), and measurements were taken at three lateral locations per row (Right, Mid, Left) to reveal local deviations and systematic aim-point shifts.

The calibration criterion was defined by the intended receiver: reflections should fall within a 10 cm diameter circle at the focal plane (radius 5 cm). Based on the calibration dataset available at the time of abstract preparation, ~96% of recorded reflections fall within the 5 cm radius acceptance circle, with $r_{90} \approx 4.5\ cm$ (radius of the circle where 90% of the points fall) and a worst-case deviation of $r_{max} \approx 6.7\ cm$ at the target plane (see Fig. 1).

Following calibration, highly reflective flexible mirror sheets were installed on the dish surface in eight rows per segment to match the calibration grid and to promote conformity to the calibrated paraboloid. Installation procedures emphasized eliminating air gaps between the mirror and substrate (to avoid local waviness and local slope deviations) and minimizing discontinuities at strip edges and segment interfaces through careful seam alignment and bonding.

The assembled dish was installed on a concrete foundation and integrated with a two-axis tracking system to maintain point-focus alignment with the sun during operation. The assembly includes provisions for mounting the receiver at the focal region while limiting shading and blockage. The concentrator is fully installed and ready for receiver integration and on-sun commissioning for high-temperature solar experiments as shown in Fig. 2.

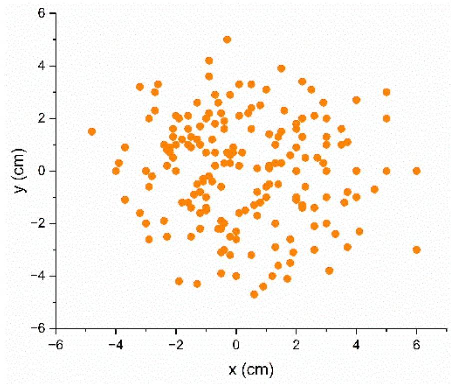

Fig. 1 Reflected-spot positions on target (cm)

Fig. 2 The dish after installation on site

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