Design, Construction and Operation of an Innovative Linear Fresnel Collector

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Abstract

This work presents the design, construction, and preliminary qualification of an innovative linear Fresnel collector (LFC) intended for industrial process heat applications below 250°C. The prototype incorporates optical enhancements such as concentrator inclination, independent frame rotation, and receiver displacement to reduce incidence angle effects and end losses. Local material availability and on-site manufacturing were key design premises. The collector, featuring a multi-tube cavity receiver and an advanced tracking control system, was installed in a pilot plant in Southern Spain using pressurized water as the heat transfer fluid. Initial commissioning tests were completed in 2024 and operational results got during 2025 demonstrate the proper functionality to supply heat in industrial heat processes, validating the proposed innovations.

Keywords: linear Fresnel collector, solar industrial heat, optical efficiency, thermal performance

1. Introduction

In the last two decades, linear Fresnel collectors (LFCs) have evolved from experimental concepts into a mature family of concentrating solar technologies with commercial deployment in both power generation and solar process heat for industrial processes. Platzer et al. [Platzer et al., 2021] provides a comprehensive historical overview of LFC development, from early multi-mirror concepts to present commercial designs, highlighting their modularity, reduced structural requirements compared to parabolic troughs, and the flexibility to adapt to different receiver configurations and heat transfer media. Although LFCs generally exhibit lower peak optical efficiency than parabolic trough collectors, several studies show that they can achieve competitive levelized cost of heat thanks to simple mechanics, fixed receivers and compact fields, particularly in the medium-temperature range relevant for industrial process heat.

Recent techno-economic analyses confirm that LFCs are an attractive option for Solar Heat for Industrial Processes (SHIP). David-Hernández et al. [David-Hernández et al., 2025] developed a modular quasi-dynamic model of a Fresnel-based SHIP system, validated against operational measurements from the SOLPINVAP solar field, and showed that such installations can reach annual thermal efficiencies around 28% with competitive payback times when properly integrated with steam generation and storage. Famiglietti and Abbas [Famiglietti and Abbas, 2025] compared LFC fields with PV-driven high-temperature heat pumps for industrial steam generation across Europe, concluding that for a given solar field area, LFC systems generally deliver higher annual thermal yield at lower cost in high-irradiance regions, whereas hybrid configurations become attractive at more moderate solar resource. Both studies underline that linear Fresnel technology is now considered a credible candidate for decarbonizing industrial steam supply in the 150–250 °C range, while also stressing that successful deployment depends critically on robust integration concepts and reliable performance data under real operating conditions.

From an optical and design perspective, a large body of work has focused on improving incidence-angle modifiers, reducing shading and blocking, and optimizing receiver geometries. The chapter by Platzer et al. [Platzer et al., 2021] reviews different primary mirror layouts (constant or variable width and gaps), compact linear Fresnel reflector (CLFR) configurations with mirror “flipping”, and advanced receiver concepts including multi-tube cavities and single-tube systems with compound parabolic secondary reflectors, highlighting the trade-off between optical concentration, manufacturability and thermal losses. Building on this, several authors have proposed refined secondary optics for Fresnel systems. Pardellas et al. [Pardellas et al., 2023] introduced a two-foci V-trough cavity for small-scale Fresnel reflectors, achieving higher geometric and optical concentration ratios than classical

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single-focus V-troughs and compound parabolic concentrators while preserving full acceptance within a given incidence range. Such designs aim to improve flux distribution and reduce spillage, but they are usually studied at small scale and primarily through analytical or ray-tracing approaches rather than through on-sun prototype operation

On the system level, several contributions report operational experience from Fresnel plants in industrial or utility settings. Rehman et al. [Rehman et al., 2024] describe the design, commissioning and operation of a large-scale LFR field with an evacuated compound receiver in Al-Khobar (Saudi Arabia), including measured thermal power above 60 kW, outlet oil temperatures above 200 °C and detailed energy–exergy analysis under harsh desert conditions, supported by advanced machine-learning-based performance prediction. Other works document long-term operation and enhanced monitoring of concentrating solar fields for saturated steam or hot-water production, often emphasizing control strategies, data quality, and dynamic behaviour rather than geometric innovation of the concentrator itself [e.g. David-Hernández et al., 2025]. These studies demonstrate that LFCs can operate reliably in real industrial environments, but they mostly rely on conventional horizontal mirror fields with fixed receivers and do not systematically explore alternative optical layouts aimed at mitigating transversal and longitudinal incidence-angle effects or end losses.

In summary, the literature shows that: (i) LFC technology has reached a high level of technological maturity and is being deployed for industrial process heat and steam generation; (ii) numerous optical and thermal optimization strategies have been investigated, including tailored secondary optics, improved cavity or evacuated receivers, and compact mirror fields; and (iii) several experimental facilities and demonstration plants have been reported, providing valuable operational data and model validation under real conditions. Nevertheless, there remains a clear gap regarding experimental validation of LFC concepts that combine field-level geometric innovations—such as a globally inclined concentrator plane, independent frame rotation and deliberate receiver displacement. Existing works either focus on standard horizontal configurations, advanced receivers applied to conventional fields, or detailed dynamic modelling and control of already commercial layouts, but they do not report on the complete cycle of design, construction, commissioning and preliminary operation of an LFC prototype embodying these specific optical and structural innovations for industrial process heat below 250 °C.

The present work addresses this gap by presenting the design rationale, local manufacturing approach and on-site assembly of an innovative LFC prototype featuring a south-inclined concentrator plane, two independently rotatable mirror frames and a multi-tube cavity receiver displaced with respect to the concentrator. The prototype is installed and operated at the Plataforma Solar de Almería (southern Spain), at the LAVEC test facility using pressurized water as heat transfer fluid, which enables a systematic commissioning process and the acquisition of preliminary thermal performance data under realistic direct-normal-irradiance and incidence-angle conditions. By documenting both the technological development and the initial operational experience of this configuration, this article provides experimental evidence that complements the predominantly simulation-based and conventional-layout studies available in the literature, and establishes a foundation for future ISO 9806:2017-compliant performance characterization and detailed optical–thermal model validation.

2. Materials and Methods

2.1. Prototype Design

The core of the new LFC concept is a primary optical concentrator comprised of twelve north-south aligned rows, each consisting of ten 1 m × 0.28 m facet mirrors of 1 mm-thick silvered glass. All mirrors are mounted on a plane tilted 10º south with respect to the horizontal (for its installation in the Northern hemisphere). The configuration was optimized through in-house ray tracing simulations to minimize the incidence angle of the solar rays and to shorten the optical path of the reflected rays, which consequently follow more direct trajectories toward the receiver, thereby reducing dispersion and optical losses along their path throughout the year (see Figure 1). The receiver designed is a multitube trapezoidal cavity positioned 2.3 m above the concentrator plane—consists of six parallel stainless-steel tubes (DN20), with a secondary mirrored enclosure for enhanced thermal capture and insulation.

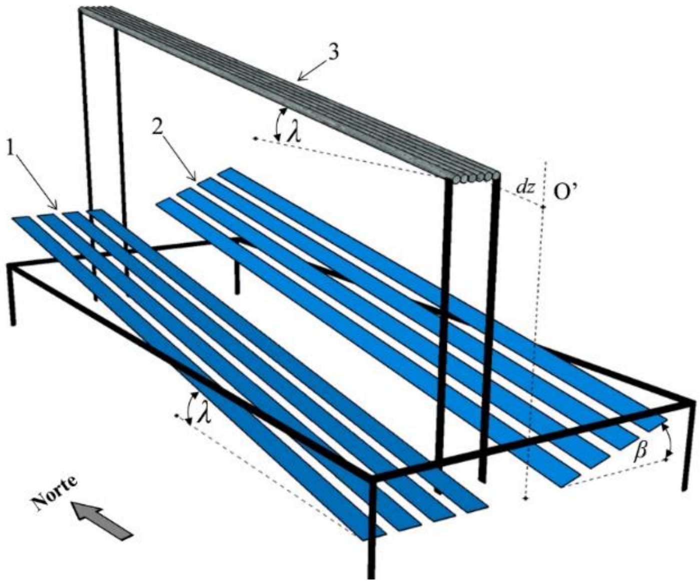

Figure 1: Sketch of the innovative LFC designed: 1,2) primary optical concentrator, inclined to the south (inclination = λ), composed of two frames that can be rotated to the East and West (rotation angle = β), and 3) multi-tube receiver, displaced to the North a distance *dz*.

Unlike conventional LFCs, each group of six mirror lines ("frame") can rotate independently about the longitudinal axis, similar to the opening and closing of a book. This allows real-time adaptation to solar trajectory, maximizing solar irradiation capture while minimizing shading and blocking.

2.2. Construction and Installation

The design of the innovative LFC was developed based on two key premises: the use of construction materials available at the local level and the feasibility of on-site manufacturing of the collector units. In terms of optical improvements, as mentioned before, the design incorporates several strategies to mitigate the negative influence of the incidence angle modifier. These include inclining the primary concentrator towards the South, allowing rotational adjustment of the two frames comprising the primary optical concentrator towards the West and East to enhance optical efficiency further, and displacing the receiver towards the North relative to the concentrator to reduce end losses. Figure 2 shows the first prototype of this LFC design, installed at a pilot plant located in Southern Spain for qualification purposes.

- *Primary optical concentrator*

The primary optical concentrator consists of 12 lines of facets (each facet measuring 1 m × 0.28 m, with 10 facets per line). All mirror facets were fabricated at PSA by cold-forming 1 mm-thick AGC Silver mirrors onto pre-curved aluminum sheets in accordance with the optimized cylindrical geometry. The concentrator has a North-South orientation axis and tracks the sun along the East-West direction. Notably, the facets are arranged on a plane inclined towards the South (10°) and are mounted in such a way that each set of six facet lines (a frame) can rotate around the longitudinal central axis of the concentrator surface, as mentioned before. Assembly of mirror frames, receiver supports, and actuator mountings were carried out on-site, paying close attention to geometric tolerances identified through simulation and optical alignment procedures.

Figure 2: View of the prototype of the innovative linear Fresnel collector installed in Southern Spain.

- *Solar Tracking and Control System*

The system's solar tracking is achieved with a custom electronic control architecture. Microcontrollers are used to read high-precision incremental encoders (8,000 pulses per turn) on each of the 12 mirror axes, yielding positioning accuracy better than 0.05º. Each mirror line is actuated via a DC gear motor offering dual-speed operation: rapid positioning to target angles and fine incremental movement for tracking deviation correction through pulse-width modulation (PWM) signals. The control tolerance for axis alignment is below 0.2º during steady-state operation.

Each gear motor (see Figure 3) positions its facets line independently. It has a local control to facilitate the movement of the shaft from local switches to allow start-up tasks, cleaning or maintenance operations.

Figure 3: View of one of the gear motors for the drive and control of the LFC facets lines.

The main microcontroller, assisted by a real-time clock, incorporates an astronomical algorithm for determining the solar vector at the collector's installation site and specific calculation routines to determine the position settings of the different collector axes to ensure the correct reflection and concentration of solar radiation on the receiver. Set points may be calculated autonomously by the control system or may be received from a central control computer in the control room of the solar field where the computations are carried out. For this purpose, a serial communication, RS485 standard, is established using the MODBUS RTU protocol through which the information is exchanged.

The 24Vdc gear motors deliver a torque of up to 40 Nm at a maximum speed of 9 rpm and are driven by DC servos with a brake. The gear motors are arranged in the central part of each facet line and the mechanical design allows them to rotate without any obstacle so that no limit switches or other additional safety devices are required. On the other hand, the incremental encoders are of the magnetic type without physical contact and have a reference position which avoids the use of position detectors to determine the starting position. These design concepts reduce the use of sensors and control elements and thus facilitate installation and wiring as well as reducing maintenance work on the LFC.

- *Receiver*

The cavity receiver was also assembled on site. The receiver is composed of a double loop with 3 tubes each one, so that, in the cross section of the receiver there are 6 parallel stainless steel pipes (DN 20). Once the bundle was assembled, the tubes were painted using the silicone based coating Pyromark 1200 that withstands 538 °C. The set of tubes is installed inside a trapezoidal cavity formed by a sandwich panel consisting of an outer aluminum panel, a layer of insulating material (30 mm thickness) and aluminum mirrors (0.75 mm thickness) on the inner walls of the cavity (ides and top), as well as a solar glass window (3.3 mm thickness) to protect the cavity aperture in which the tube bundle is enclosed (see Figure 4). The total length of the active area of the receiver is 10 m. The receiver is equipped with 48 thermocouples type K to measure the temperature of the metallic at different locations and 26 thermocouples type T to measure the temperature of the inner walls and the glass window. The inlet and outlet of the receiver are also equipped with redundant temperature sensors (one thermocouple type K and one thermoresistance PT-100 at each position), to measure the fluid temperature at the inlet and outlet of the receiver.

Figure 4: View of the LFC during the assembly of parts in the PSA workshop.

Integration of control hardware, electrical cabling, and safety systems completed the construction phase.

2.3. Commissioning and Initial Operation

The prototype has been installed and connected to a pilot plant utilizing pressurized water as the heat transfer fluid, the LAVEC test facility [Domínguez-López et al, 2020, Valenzuela et al, 2024]. The design pressure and temperature of the test facility are 50 barg and 280ºC, respectively, but the maximum operating temperature permitted is 250ºC. This setup was selected to qualify the optical and thermal performance of the first prototype, while also allowing comprehensive monitoring and operational follow-up in an experimental environment that would be less feasible in an industrial installation.

Commissioning included staged verifications: electrical connection, software validation, dry-run tracking without solar input, and subsequent daytime operations under real sky conditions. The SCADA system was configured for real-time monitoring, data logging, and local/remote command handling. Early functional tests focused on axis synchronization, solar-tracking reliability, response to setpoints, and system stability under varying wind conditions.

Figure 5: View of the SCADA system of the solar pilot plant during the operation of the LFC prototype on April 24, 2025.

Figure 5 provides a view of the SCADA system of the pilot plant, where key process variables such as the inlet and outlet temperatures of the circulating pressurized water, pressure, mass flow rate, direct solar radiation, ambient temperature, and wind speed and direction are monitored. As mentioned before, the LFC fluid inlet and outlet temperatures are measured redundantly by means of thermocouples type K Class I (2-wire) and thermoresistance PT-100 Class A. The mass flow rate through the collector is measured by means of a Coriolis flowmeter, model Rotamass from Yokogawa, with an accuracy of 0.1% in the measuring range (0-0.150 kg/s). The test facility is also equipped with a meteorological station where direct and global solar radiation, wind speed and direction, and ambient temperature are measured. The direct solar radiation, which is relevant for the evaluation of performance of the LFC prototype, is measured by means of a pyrheliometer model DR20-A1 from Hukseflux.

The first experimental phase was structured in two stages: (a) a commissioning phase to verify the correct operation of all manufactured and installed components (mirror facets, tracking system, cavity receiver, and sensors); and (b) a qualification phase to determine the optical and thermal performance of the prototype.

3. Results

The commissioning of this first LFC prototype (stage (a)) was completed in 2024. Initial tests were conducted to verify the correct operation of all instrumentation, the tracking system, and the temperature monitoring at various points of the cavity receiver (cavity walls, tube walls, and glass window). The qualification phase (stage (b)), started at the end of 2024, aimed at measuring the prototype's optical and thermal performance. The tests are carried out according to the quasi-dynamic test method as defined in the ISO 9806:2017 standard.

3.1. Geometric and Functional Verification

After completing the construction of the LFC prototype, and before the connection of the collector to the hydraulic circuit of the test facility, several tests were carried out to check the geometrical and solar-tracking system verification of the collector. Such verifications were:

- Alignment deviations of mirrors and receivers measured during installation
- Flux measurement test campaign (Fernandez-Reche et al, 2022)
- Practical achievement of design tolerances (<0.2º axis alignment)
- Initial calibration and tracking accuracy of the control system

3.2. Commissioning Campaign Overview

Upon completion the hydraulic connection of the LFC to the LAVEC test facility, a hydrostatic pressure test was carried out to verify the integrity of the system and to detect any leaks prior to putting the collector into service. The test was completed successfully. After that, the filling process with pressurized demi water, venting and inertising the entire facility with nitrogen was carried out.

The first test carried out had the objective of verifying the proper functionality of the temperature and flow rate sensors following the initiation of pressurized water circulation inside the circuit. Initially, the system was subjected to a heating process at a temperature of 100°C, facilitated by the electrical heater of the LAVEC test facility. In the course of the gradual heating process, a detailed inspection of all temperature sensors installed in the receiver of the LFC was conducted.

During these preliminary tests, the functionality of the remote control and supervision via SCADA and data logging was also verified. The final stage of the process was the accomplishment of the first solar-tracking of the LFC collector to start heating pressurized water using solar radiation.

3.3. Preliminary Operating Data

The following process conditions were defined for the LFC's test campaign were selected to align with the quasi-dynamic test method in ISO 9806:2017, which specifies steady-state and transient characterization under controlled inlet temperatures, mass flows, and irradiance levels to derive key parameters such as peak efficiency, incidence angle modifier (IAM), and heat loss coefficients. Specifically:

- Inlet water flow rates from 0.085 kg/s to 0.125 kg/s, corresponding to nominal collector loads and Reynolds numbers in the turbulent regime ($> 10^4$).
- Inlet water temperature from 25 °C to 150 °C, covering low, medium, and high operating temperatures to map the efficiency curve $\eta = f(\Delta T/G)$ and heat losses coefficients.
- Operating pressure from 5.0 to 12.0 bar, ensuring subcooled flow ($T_{in} < T_{sat}$ at all points) and avoiding two-phase regimes during transients.

In the course of field test already performed it has been found that, due the prevailing weather conditions on the Plataforma Solar de Almería during this year, the direct normal irradiance available on days with clear skies has varied between 800 W/m^2 and even more than 1000 W/m^2. The occurrence of clear skies days with DNI values between 600 W/m^2 and 800 W/m^2 has been less common. This issue with testing at lower DNI values and the need to collect as much data as possible with different incidence angles, both transverse and longitudinal, will extend the test campaign.

From the starting of the test campaign, during the weeks in which the LFC is being tested, a scheduled routine cleaning is carried out three days per week. This ensures the solar reflectance of the mirrors remains close to its nominal value of 0.96.

Figure 3 presents an example of the collector's thermal performance recorded on April 24, 2025. The main process parameters are displayed in the left graph, while the thermal output of the collector is shown in the right graph.

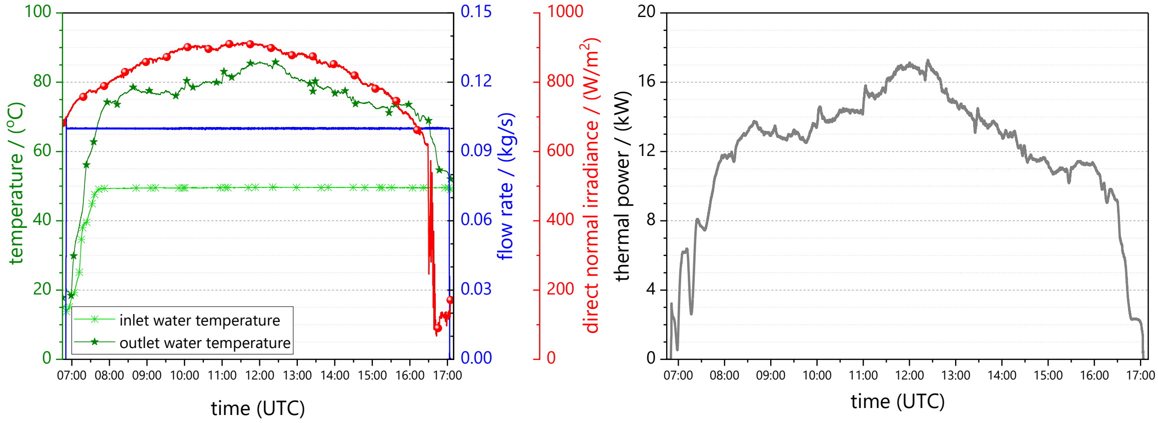

Figure 3: Main operational data recorded during the operation of the LFC prototype on April 24, 2025.

Over 50 test days have been completed to date; however, the test campaign remains ongoing. The current tests cover all previously described operating conditions, and results indicate that the collector's thermal power output has reached up to 18 kW. At temperatures above 100 ºC, the non-evacuated receiver affects thermal efficiency, with observed efficiency reductions of about 20% at the highest temperatures tested (around 150 ºC).

The experimental campaign continues according to the quasi-dynamic test method specified by ISO 9806:2017, and comprehensive analysis of collected data will be presented in a subsequent publication.

3.4. Discussion

The preliminary results confirm that the innovative optical design—southward inclination, independent frame rotation, and receiver displacement—effectively mitigates incidence angle modifiers and end losses, as evidenced by stable operation up to 18 kW thermal output across 50+ test days. The observed efficiency reduction of ~20% above 100–150°C is attributable to the non-evacuated cavity receiver's convective and radiative losses, rather than optical limitations, aligning with literature expectations for similar geometries [Pardellas et al., 2023]. These findings validate the design assumptions from ray-tracing simulations [Pulido-Iparraguirre et al., 2022] and establish that locally manufactured components achieve the targeted tracking accuracy (<0.2°) required for process heat applications below 250°C. The ongoing ISO 9806:2017 test campaign will quantify incidence angle modifier curves and peak efficiency under standardized conditions:

4. Conclusions and further work

An innovative linear Fresnel collector prototype developed in this work has demonstrated robust performance for industrial process heat applications below 250 °C, integrating key improvements such as concentrator inclination, independent frame rotation, and receiver displacement to minimize optical losses. The use of locally available materials and on-site manufacturing has proven both feasible and practical, supporting the adaptability of the design.

Preliminary operation at the Plataforma Solar de Almería confirms that the collector can reliably deliver thermal output up to 18 kW with precise solar tracking and control. The multi-tube cavity receiver, though non-evacuated, achieved consistent performance up to 150 °C, showing promise for further efficiency gains.

An ongoing ISO 9806:2017-compliant experimental campaign will extend performance characterization under a wide range of environmental conditions, particularly exploring operation at lower irradiance and various incidence angles. Future work will focus on optimizing the receiver configuration, potentially through selective coatings or partial evacuation, as well as refining the tracking control system. Economic analysis, lifecycle assessment, and prototype scale-up will be pursued to enable broader industrial adoption of this advanced LFC technology.

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