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A BEAM-DOWN LINEAR FRESNEL REFLECTOR INTEGRATED WITH AN ORCANIC RANKINE CYCLE

Summary

Beam-down concentrating solar systems are innovative concentrating technologies. These systems consist of two successive reflections aiming to concentrate the solar irradiation on the ground, where the receiver of these systems is always located. In the present study, a beam-down linear Fresnel reflector integrated with an Organic Rankine cycle is presented. The secondary reflector has a parabolic-segmental geometry aiming to optimize the balance between higher optical performance, which is achieved when having a parabolic shape, and lower construction cost, which is presented when selecting flat secondary mirrors. The receiver of the system comprises two compound parabolic concentrators for heat production. The collector is then coupled with a thermal energy storage unit and integrated with the thermodynamic power block for electricity production. The maximum optical efficiency of the system was equal to 34.8%, whereas the maximum thermal efficiency to 33.7%. For the steady-state analysis, the peak electricity power output was equal to 1.21 kW_{el}.

Keywords: Beam-down linear Fresnel reflector, Optical and thermal analysis, Organic Rankine cycle

Field of application for the findings: Beam-down solar concentrating systems

Addressed audience: Academia and solar thermal industries

1. Introduction

The energy problem is one of the most important problems humanity must face in the near future. The rapid development of technology, combined with the continuous increase in world population, has led to an increase in the demand for energy production. Concentrated Solar Power (CSP) technologies are utilized for useful heat production for medium and high-temperature applications. However, these systems seem to struggle in terms of competitiveness with other renewable-driven technologies, such as photovoltaics, mainly due to their low levelized cost of heat. In this direction, a new CSP technology has been investigated over the last few years, known as the beam-down (BD) CSP technology. The main difference between BD and conventional CSP systems is that the BD designs consist of an extra reflector, and the receiver is located on the ground. This design provides some critical advantages over the conventional CSP. First of all, the receiver remains stable and does not move or rotate. Additionally, the safety levels and the reliability of these systems are greater. This applies because the receiver is located on the ground, and allows the exploitation of chemical reactors or fluidized beds. Also, the pumping demand is significantly reduced, as well as the length of the piping configuration. Moreover, the total height of the system is reduced, which leads to less construction material and wind loads (Bellos, 2023). In the literature, there is some research conducted referring to the Beam-down Linear Fresnel Reflector (BDLFR) systems. Taramona et al. (2022) designed a flat secondary reflector for a BDLFR for construction cost reduction. Sammoutos et al. (2024) proposed a parabolic secondary reflector for enhancing the overall optical performance. In this study, a BDLFR system integrated with a Thermal Energy Storage (TES) unit and an Organic Rankine Cycle (ORC) is investigated. The scope of this work is to examine the potential of electricity production by exploiting BDLFR configurations. Detailed optical and thermal analyses for the BDLFR system are conducted, and the efficiency curves are extracted. Furthermore, a daily analysis to calculate the electricity production is also conducted. In this abstract, the analysis refers to the steady-state conditions. However, in the final manuscript, a complete dynamic analysis will also be presented.

2. Materials and Methods

2.1 Beam-down linear Fresnel reflector concentrator

The concentrator of this system is a BLDFR coupled with two Compound Parabolic Concentrators (CPCs) for heat production at medium and high temperature levels. The secondary reflector is a parabolic-segmental one aiming to combine higher optical performance and lower construction cost. The complete analysis of this collector is presented in another already completed piece of work, which is currently under review in a scientific journal. The novelty of this work lies in the integration of the collector with a TES system and an ORC power block. The collector consists of three major sections, the primary mirror field, the secondary reflector, and the receiver. The primary mirror field consists of twenty-eight flat mirrors, which are placed equidistant, and the field is North-South oriented with an East-West tracking mechanism. **Fig. 1** illustrates the BDLFR collector and its basic dimensions. The secondary reflector consists of twenty-eight flat segments placed based on the optimal parabolic contour as presented and analysed in our previous work (Sammoutos et al., 2024). This reflector is divided into two sections with a gap in between them. This gap allows a fragment of the solar irradiation to directly reach the receiver, and also avoids some extra losses due to the shading effect from the secondary mirror.

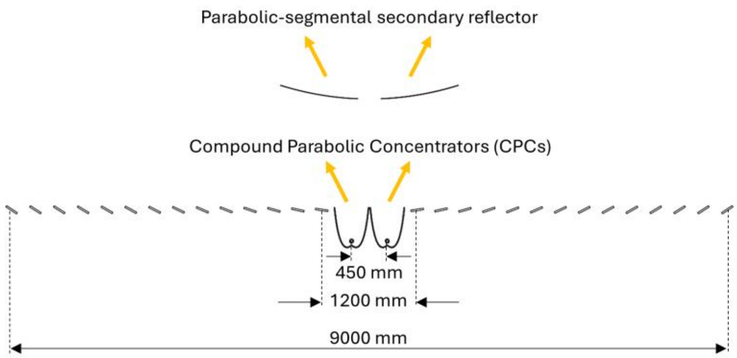


Fig. 1: The BLDFR collector

The optical efficiency (η_{opt}) is calculated using **Eq. (1)**, where the nominator is the absorbed heat (Q_{abs}) as calculated using the developed model, and the denominator is the available solar energy given by the product of the net aperture area of the primary mirror field (A_{prim}) and direct normal irradiation (DNI).

$$\eta_{opt} = \frac{Q_{abs}}{A_{prim} \cdot DNI} \qquad \text{(eq. 1)}$$

The thermal efficiency (η_{th}) is given by **Eq. (2)**, where the nominator is the useful heat produced by the collector calculated as the product of the mass flow rate (m), the heat capacity under constant pressure (C_p), and the temperature difference between the outlet (T_{out}) and inlet (T_{in}) heat flow rates of the working fluid, and the denominator is again the available solar energy. The working fluid is a thermal oil, the Therminol VP-1.

$$\eta_{th} = \frac{m \cdot C_p \cdot (T_{out} - T_{in})}{A_{prim} \cdot DNI} \qquad \text{(eq. 2)}$$

2.2 Integrated system with a storage unit and an Organic Rankine cycle

The BDLFR collector is coupled with a TES unit and then integrated with an ORC. The recuperative ORC is fed with heat produced by the collectors and produces electricity. The use of various working fluids for the ORC is examined, including R600, R601, R1233zd(E), and R1233zd(Z). The tank's energy balance, taking into account the stored thermal energy inside the tank (Q_{st}), the useful heat of the collectors (Q_u), the heat provided to the ORC (Q_{ORC}), and the thermal losses to the ambient (Q_{loss}), is given in **Eq. (3)**.

$$Q_{st} = Q_u - Q_{ORC} - Q_{loss} \qquad \text{(eq. 3)}$$

The ORC electricity production load ($P_{el,ORC}$) is defined by the expander electricity production load ($P_{el,exp}$) minus the pump electricity consumption load ($P_{el,pump}$), and it is given in the following equation, **Eq. (4)**.

$$P_{el,ORC} = P_{el,exp} - P_{el,pump} \quad \text{(eq. 4)}$$

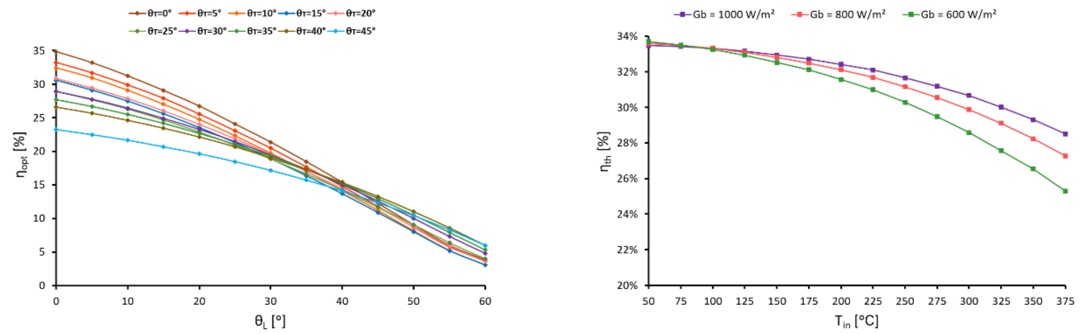
The electrical efficiency of the ORC ($\eta_{el,ORC}$) is calculated using **Eq. (5)** as the ratio of the ORC power output to the heat input to the ORC.

$$\eta_{el,ORC} = \frac{P_{el,ORC}}{Q_{ORC}} \quad \text{(eq. 5)}$$

3. Results

3.1 Optical and thermal analysis of the collector

Fig. 2 shows the optical efficiency variation for various incident angles in the transversal (θ_T) and longitudinal (θ_L) directions, and the variation of the thermal efficiency against the inlet temperature (T_{in}). The maximum optical efficiency is equal to 34.8%, and the maximum thermal efficiency to 33.7%.

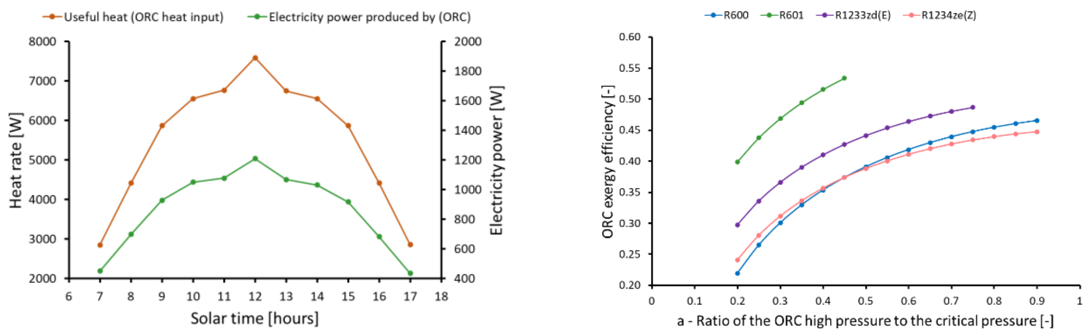


(a) **(b)**

Fig. 2: Optical (a) and thermal (b) efficiency of the BDLFR collector.

3.2 Daily analysis and power production

The daily power production by the integrated system is illustrated in **Fig. 3a** for a typical summer day, the 21st of July. Also, **Fig. 3b** depicts the exergy efficiency of the ORC against the a-ratio for a T_{out} of 166.5°C. The peak power output equals 1.21 kW_{el}, and the average electrical efficiency of the ORC to 15.7%.



(a) **(b)**

Fig. 3: Electricity power produced and heat rate (a) for the 21st of July, and exergy efficiency of the ORC (b).

4. References

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