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# Parabolic trough collector or linear Fresnel collector? A comparison of optical features including thermal quality based on commercial solutions

R. Abbas [a,*], M.J. Montes [b], A. Rovira [b], J.M. Martínez-Val [a]

[a] Grupo de Investigaciones Termoenergéticas (GIT), Universidad Politécnica de Madrid, ETSI Industriales, C/ José Gutiérrez Abascal, 2, 28006 Madrid, Spain

[b] UNED, ETSI Industriales, C/ Juan del Rosal, 12, 28040 Madrid, Spain

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**Abstract**

Parabolic trough collectors (PTCs) are still today the most mature technology in concentrating solar power. However, linear Fresnel collectors (LFCs) have been identified by many authors as a candidate to reduce the levelized cost of electricity, although with lower efficiencies. Within Fresnel technology, two possibilities appear for the receiver: multitube receiver and secondary reflector receiver. In the present work a developed Monte Carlo Ray Trace code is used in order to compare the energy effectiveness and flux intensity map at the receiver for different days of the year and different orientations in Almería, Spain, and in Aswan, Egypt. The optical annual energy and exergy efficiencies are also obtained for PTCs and LFCs, with multitube or secondary reflector receiver, where the concentration at each tube is used to weigh the exergy efficiency. It results that the maximum efficiency is obtained by PTCs, while the lowest one corresponds to LFCs with multitube receiver. Also, it is concluded that, while for PTCs NS orientation leads to clearly higher efficiencies, this is not the case for LFCs, where both orientations achieve similar efficiencies even when the solar field has been designed for NS orientation.


*Keywords:* Concentrating solar power; Linear collectors; Monte Carlo Ray Trace; Optical losses; Flux intensity

## 1. Linear technologies in concentrating solar power

At current time there is no doubt about the need to maximize the renewable portion of the electricity mix, both due to energy demand growth and fossil fuels depletion (Reddy et al., 2013). In addition, renewable energy leads to some benefits, which are classified into three categories (Kalogirou, 2004): energy savings, generation of net working posts and decrease of both environmental pollution and limitation of climate change effects. Among all renewable power generation technologies concentrating solar power (CSP) may play a major role, as it may help to maintain grid stability thanks to thermal storage capacity (Baharoon et al., 2015).

CSP plants are generally divided into three blocks (Baharoon et al., 2015): the solar field (concentrator plus receiver), the energy storage system and the power block. The solar field is probably the main characteristic of the solar plant, which justifies that they are normally classified depending on the field technology used (Mills, 2004):

* Corresponding author. Tel.: +34 91 336 3156; fax: +34 91 336 3079.
*E-mail address:* rubenabbas@etsii.upm.es (R. Abbas).

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- Linear concentrators.
  - Parabolic trough collector (PTC).
  - Linear Fresnel collector (LFC).
- Punctual concentrators.
  - Tower solar power (TSP).
  - Stirling dish (SD).

Due to the fact that punctual concentrators potentially achieve higher concentrators factors (Romero-Alvarez and Zarza, 2007), the foregoing classification also corresponds to medium and high temperature technologies (Reddy et al., 2013). From the four existing technologies, parabolic trough collector is the most mature one, with around 95% of the total generating capacity of the operating CSP plants (Baharoon et al., 2015; Abbas and Martínez-Val, 2015). Nevertheless, this does not imply that PTCs are the cheapest technology at long term. Furthermore, it is noted by the International Energy Agency (Agency, 2014) that "other technologies offer greater prospects for cost reductions but are less mature and therefore more difficult to obtain finance for. In countries with no or little experience of the technology, financing circles fear risks specific to each country".

A technology that may help to reduce the Levelized Cost of Energy (LCOE) in CSP is the linear Fresnel collector; this may be achieved via capital cost reductions, as mirrors are easier to manufacture, the structure is lighter, wind effects are less important, etc. (Ford, 2008; Zhu et al., 2014). This is why there are some published works that compare both linear technologies, where all of them agree in the fact that the efficiency of LFCs is lower than that of PTCs although values vary significantly. Morin et al. (2012) establishes that the cost of LFCs per unit aperture (which is not the same as cost per mirror square meter) should be from 28% to 79% the cost of PTCs in order to achieve the same LCOE. After Cau and Cocco (2014), the efficiency of LFCs is around 37% lower than that of PTCs, although they generate 21% more energy per land square meter thanks to the higher filling factor. The annual mean efficiency difference increases up to 75% after (Gharbi et al., 2011), although it is said that the peak efficiency difference is only around 5%. Finally, (Sait et al., 2015) compares analytically the energy impinging onto the reflecting surface, where shading and blocking effects are not considered, and it results that it is from 2% to 10% lower for LFCs than for PTCs.

Some of this works have obtained the Incidence Angle Modifier (IAM) for LFCs and PTCs (Huang et al., 2012; Cau and Cocco, 2014; Morin et al., 2012), either analytically or via MCRT codes, but none of them establishes the sources of optic losses. Some of the inefficiencies, such as end losses and interactions between neighboring mirrors, have been studied analytically (Abbas and Martínez-Val, 2015; Hongn et al., 2015; Huang et al., 2014; Sait et al., 2015; Nixon and Davies, 2012; Nixon et al., 2013; Sharma et al., 2015; Zhu, 2013). There are also many works that have obtained the radiation flux intensity for both technologies (Cheng et al., 2014, 2015; Martínez-Val et al., 2015; Abbas et al., 2012, 2013; Moghimi et al., 2015a,b; Qiu et al., 2015; Montes et al., 2014; Okafor et al., 2014; Wang et al., 2015), where most of them use commercial software such as SolTrace to obtain the flux intensity at a given instant in order to analyze the thermal behavior of the receiver.

However, no work has been found where the optical features of LFCs and PTCs are deeply compared, where the inefficiencies are characterized and the flux intensity is considered annually in order to obtain a more reliable efficiency estimation. This is carried out in the present paper. Although commercial softwares such as SolTrace could have been used for this purpose, the development of a new software, especially conceived for linear collectors, can lead to shorter computing times and to a more flexible definition in order to obtain annual performance. Therefore, a new validated code has been used in the present work.

Although there are some new designs in the market that seek for lower costs in CSP (Riffelmann et al., 2011, 2014; Schweitzer et al., 2014), commercial PTC plants have maintained the optical design of LS3 technology since the late 1980s; thus, this is the design chosen in the simulations presented in the present work. The case of LFCs is different, as the mirrors might have variable shift (Nixon and Davies, 2012; Abbas and Martínez-Val, 2015; Choudhury and Sehgal, 1986; Negi et al., 1990; Mathur et al., 1991, 1990; Singh et al., 1999, 2010; Velázquez et al., 2010) and/or variable width (Goswami et al., 1990; Sootha and Negi, 1994; Negi et al., 1990; Mathur et al., 1991; Mathur et al., 1990). Some authors also suggest to intercalate mirrors aiming at two different receivers in order to increase the filling factor (Mills and Morrison, 2000; Chaves and Collares-Pereira, 2010), although it seems that this might lead to a lower annual efficiency (Montes et al., 2014). For the sake of simplicity, the geometry of the prototype Fresdemo (Bernhard et al., 2008a,b) is used in this paper in order to compare the performance of LFCs with PTCs. It must be said at this point that Fresdemo design might not be an optimum design; it can be especially inefficient with EW oriented fields. However, its simulation and comparison with PTC simulations will lead to general trends that are also true for optimized fields.

Finally, there are different LFC receiver technologies: cavity receivers with an array of parallel tubes (Pye et al., 2003; Abbas et al., 2012, 2013; Abbas and Martínez-Val, 2015; Singh et al., 1999; Moghimi et al., 2015a,b), which is used by Areva-Solar among others (Zhu et al., 2014), single tube receiver with secondary reflector based on a compound parabolic concentrator (Qiu et al., 2015; Häberle et al., 2002; Heimsath et al., 2014), used by Novatec Solar and Solarmundo (Zhu et al., 2014), and single tube receiver with other geometries secondary reflector (Grena and Tarquini, 2011; Canavarro et al., 2014). In the present