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A comparative study between parabolic trough collector and linear Fresnel reflector technologies

Najla El Gharbi[a,b*], Halima Derbal[b], Sofiane Bouaichaoui[a], Noureddine Said[a]

[a]*Center for Renewable Energy Development, PO Box 62, Bouzareah 16340, Algiers, Algeria*
[b]*Energetic and Fluid Mechanics Department, University of Sciences and Technology Houari Boumediene, PO Box 32 El Alia Bab Ezzouar 16111 Algiers, Algeria;*

Abstract

The production of electricity from solar radiation is a direct process. Solar energy is not very dense, it is necessary to concentrate it to produce exploitable temperatures usable for the production of electricity. The radiation may concentrate on a point or on a line, where thermal energy is transferred to the heat transfer fluid. The intensity of concentration is defined by the concentration factor, the more this one is higher, the more reached temperature will be important.
In this paper two optical technologies which showed promising results were compared, the first one is the Fresnel mirror and the second one is the parabolic trough. These two technologies are based on linear solar concentration.
The main objective of this paper is to report the performance of these technologies by means of numerical analysis. A methodological analysis to design and evaluate the technical feasibility for the use of Fresnel mirror or parabolic trough in a Concentrating Solar Power (CSP) system has been carried out. The influence of ambient conditions and the percent of different types of energy loss, etc., are analyzed. An application on a site, in the south of Algeria (Hassi Rmel), is done. In this site, a project of hybrid natural gas/solar power plant with parabolic trough technology will be inaugurated before 2011.

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Keywords: power generation, solar thermal, solar concentration, parabolic trough, Fresnel mirror, linear collector;

1. Introduction

Of all the renewable sources of available energy, solar thermal energy is the most abundant one and is available in both direct as well as indirect forms. This energy is mainly used in solar power plants to

* Corresponding author. Tel.: +213 21 90 15 03; fax: +213 21 90 15 60.
E-mail address: n.elgharbi@cder.dz.

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Nomenclature

A_a	absorber area (m^2)
A_c	total collector aperture area (m^2)
C	the concentration ratio
h	hour angle (degrees)
I_b	direct normal irradiation(W/m^2)
Q_u	heat received by collector (W)
U_c	solar collector heat transfer loss coefficient (W/m^2 °C)
U_{c0}	constant determined from empirical test (W/m^2 °C)
U_{c1}	constant determined from empirical test (W/m^2 °C)
T_a	ambient temperature (°C)
T_c	collector temperature (°C)
Greek symbols	
α_c	receiver absorptance
δ	declination angle(degrees)
γ	collector intercept factor
η	thermal collector efficiency
η_0	optical efficiency
ρ_c	mirror reflectance
τ_c	receiver transmittance

produce electricity. To extract electricity from solar radiation, the power plants use the technology of solar concentration [1]. The concentration depends on the mirror surfaces and receiver area. But if the mirrors are fixed, it will reach its maximum at a specific time of day and will decline around this time. To limit this decrease most systems have a mechanism to track the sun. The orientation is tailored to optimize the position of the reflecting surface relative to the sun. As the sun's position is characterized by two values: the height ranging from 0 to 90 °, and azimuth ranging from -180 ° to +180 °, two orientation axes of the mirrors meet the monitoring purpose. But to optimization of cost, a choice of operating flexibility may lead to adopt one parameter setting, monitoring or approximate, to the detriment of the average conversion factor.

There are four main types of Concentrating Solar Power (CSP) technology used to concentrate and collect sunlight in order to turn it into heat, see Fig 1:

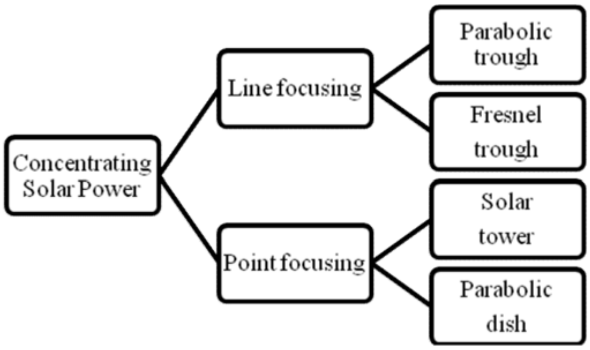

Fig. 1. Types of CSP technology

In these technologies, the solar concentrators focus sunlight into a point or a line. In this paper we are interested in the second type.

Among the solar power with line focusing, the largest thermal power plant in the world with parabolic concentrator it is located at Kramer Junction in California, where nine (9) SEGS (Solar Electric Generating Systems) of 30 MW, are connected to the electricity grid of California. Another solar power plant of the same type with a power of 64 MW, was built in 2007 near Boulder City in the state of Nevada, its goal is to meet the needs of about 40,000 families. In Hassi Rmel region, in southern Algeria, a power plant hybrid gas / solar is being built in collaboration with Spanish (Abengoa). This power plant will combine parabolic mirrors (25MW of solar power, an area of 180000 m2) in conjunction with a gas turbine plant (130 MW).

For plants with Fresnel mirrors, a study was conducted in 2002 by several German research institutes on the benefits of such type of plant [2]: the Project was implementing a system of Fresnel mirrors in Hurguada, a site in Egypt. The study concludes that the thermal performance of the Fresnel collectors are 30% less compared to conventional systems, but a less production cost per kWh is obtained: 0.075 $/ kWh compared to 0.0845 $/ kWh for conventional collectors [3]. The multinational company Areva has developed the technology of a central concentration with linear Fresnel reflectors. Its first plant in Bakersfield, California, was operational in October 2008, and generated up to 5 megawatts of electricity at full output [4]. The German company Novatec Biosol, built the first commercial Fresnel plant in the World in Almeria in Spain. This plant "NOVA-1" has a capacity of 1.4 MW. The plant produced electrical powers to the local network since March 2009 [4]. In August 2010, CNIM Group launched its Fresnel's pilot solar concentrator module technology in site located at Lagoubran Seyne sur Mer and it is the only example of concentrated solar technology that is operating in French territory.

These two technologies; parabolic trough collector and linear Fresnel reflector, are particularly promising, and concentrated solar power could revolutionize the use of sunlight for power generation in coming decades.

2. Linear concentration

The linear concentration is the technology where the concentration can be done on a line, it is the case of parabolic or Fresnel trough, see Fig 2 and Fig 3. There is not a precise point of focusing, but a line. For linear concentrator, only one coordinate needs to follow the sun with an optimized collector adjustment.

The development of this technique of focusing on a line came after that in a point. It seems to have from now on to take the step on the first. In fact, an analysis of the systems, led that, why focus in a point the concentration of heat, when it is necessary to redistribute it by the lines of the circuits of transfer of heat.

With the collectors aligned in the North-South direction, a simple orientation, perpendicular in the East-West direction bring back whatever the hour of the day the image concentrated of the sun on the receiving tube laid out on the focal of the concentrator. The solar concentration obtained varies, according to the season and the hour, between 60 and 400.This type of concentration represents the main part of the thermodynamic installations of the world.

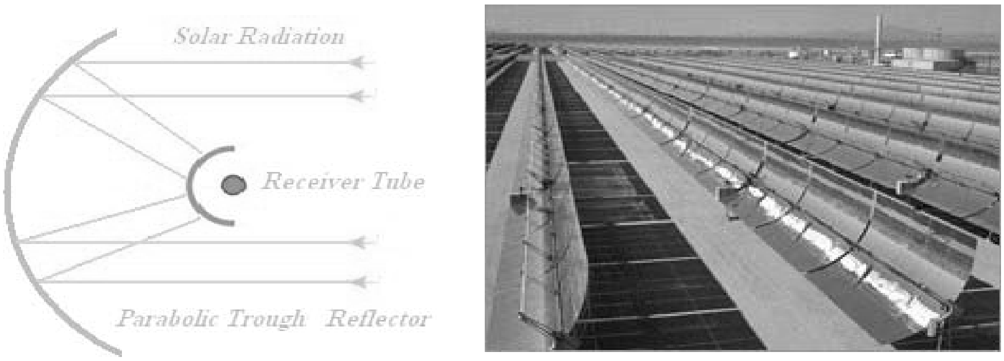

Fig. 2. Line focusing, parabolic trough collector: The solar parabolic trough mirror Hassi Rmel (Algeria)

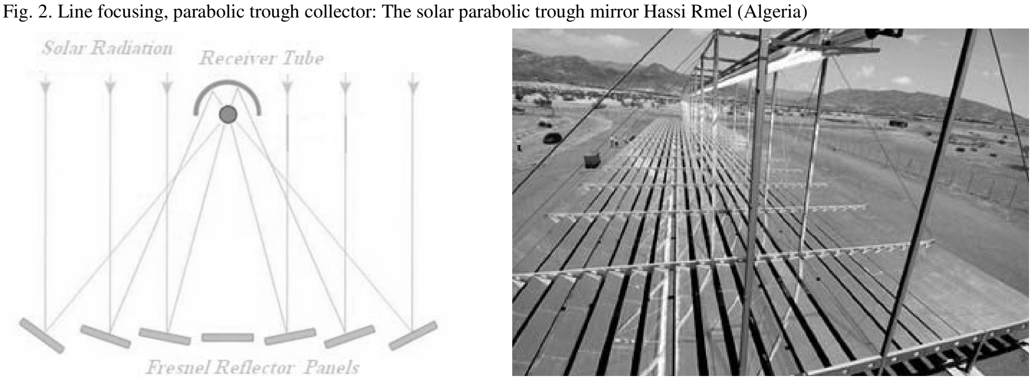

Fig. 3. Line focusing, linear Fresnel reflector: The solar mirror Fresnel Almeria in Andalusia (Spain)

An important cost factor in the technology of parabolic trough collector is required to making glass in parabolic form. To reduce this cost, several research groups are working on prototypes of Fresnel linear focusing collectors. The idea is to approximate the parabolic shape of the collector by a succession of plane mirrors [2]. The choice can be made by sacrificing a part of focusing in parabolic trough by adopting the system of the Fresnel mirrors. The parabola is reconstituted roughly using flat mirrors (according to projects the number varies from 15 to 50) whose slope will be regulated according to the position of the sun. A second stage of fixed reflexion, redirects the radiation towards the receiving tube. This focusing is simpler than the preceding one with parabola, easier to go up, less expensive in investment, but the efficiency is little reduced. Table 1 gives a comparison between the two technologies.

Table 1. Linear CSP technologies and its application [2, 5 and 6]

	Capacity Unit(MW)	Concentration	Peak solar efficiency (%)	Annual solar efficiency (%)	Capacity solar factor (%)	Temperature output(°C)	Land use per MWh/y (m^2)
Parabolic Trough	10-200	70-80	21	17-18	25-70	300-550	6-8
Linear Fresnel	10-200	25-100	20	9-11	25-70	250-500	4-6

3. Thermal linear collector efficiency

The efficiency η of a Parabolic trough collector and linear Fresnel reflector depend on the operating temperature of the collector, the direct normal irradiation I_b and the incidence angle θ_i of the solar radiation. The efficiency is defined as the ratio of the thermal power, absorbed by the heat transfer fluid, to the direct normal irradiation on the aperture area [7-9]:

$$\eta = \frac{Q_u}{I_b A_c} \quad (1)$$

$$Q_u = \eta_0 I_b A_c - U_c (T_c - T_a) A_a \quad (2)$$

$$\eta_0 = \rho_c (\alpha_c \tau_c) \gamma \cos\theta_i \quad (3)$$

where A_c is the collecting area of the concentrators, U_c is the solar collector heat transfer loss coefficient that depends on the temperature and can be written like a linear function of difference in temperatures between absorber (T_c) and ambient conditions (T_a) [10]:

$$U_c = U_{c0} + U_{c1} (T_c - T_a) \quad (4)$$

where U_{c0} , U_{c1} are constants determined from empirical test and A_a is the total area of absorber given by the following expression :

$$A_a = A_c / C \quad (5)$$

where C is the concentration ratio, ρ_c is the mirror reflectance, α_c and τ_c are respectively the absorptance and transmittance of the receiver (absorber and glass cover) γ is the intercept efficiency taken equal to 1 in our case (we assume all reflected rays are intercepted).

The angle of incidence $\cos\theta_i$ varies depending on the type of mirrors collector and the direction of collector East-West or North-South [11]. In our case we take the East-West direction, in terms of the declination angle δ and the hour angle h:

$$(\cos\theta_i)_{PT} = \sqrt{1 - \cos^2(\delta)\sin^2(h)} \quad (6)$$

The incidence angle of the Fresnel mirror is evaluated as a function of that of the parabolic trough by:

$$(\cos\theta_i)_{LF} = F(\cos\theta_i)_{PT} \quad (7)$$

where F is a factor empirically evaluated and it is taken equal to 0.7 in our case [3]. Figure 4 gives the variation of the angle of incidence during the year for both parabolic trough and linear Fresnel mirrors.

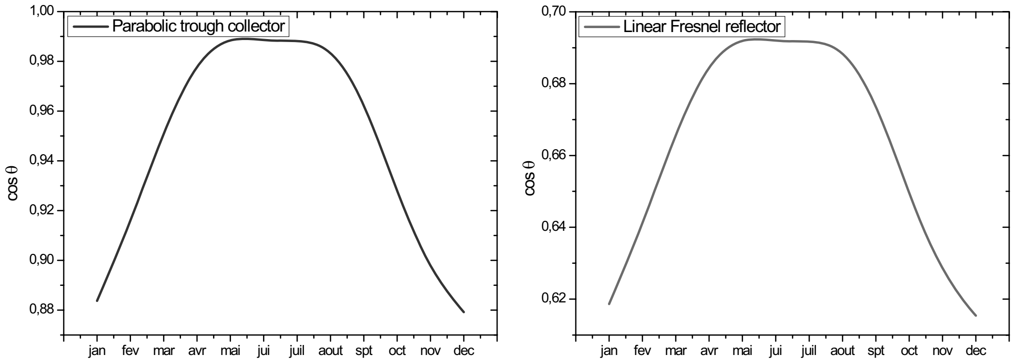

Fig. 4. Variation of incidence angle during a typical year

For comparison purpose between the two linear technologies, parabolic trough collector and linear Fresnel reflector, we have taken as an example the data of Hassi Rmel region which is located 420 km south of Algiers (Algeria). Algeria is a country located in North Africa. It is the largest country on the Mediterranean Sea area. Over 70% of its area are South of 20° latitude, it seems an obvious source of solar power, figure 5 gives the annual direct normal intensity for this region. We calculate the annual efficiency of the concentrator with the data of parabolic troughs and Fresnel power plants and evaluate the differences. Table 2 gives the characteristics of the tested two cases.

The result of annual collector efficiency calculation gives, η_{PT}=55.8% and η_{LF}=45.75% for parabolic trough and linear Fresnel plant respectively. Linear Fresnel efficiency value is not too far compared to that of parabolic trough; this is due particularly to the incidence angle and the cosine factor.

Table 2. Linear CSP technologies and its application [6, 7 and 10]

	Parabolic trough collector	**Linear Fresnel reflector**
ρ_c	0.92	0.92
$(\alpha_c\,\tau_c)$	0.81	0.81
γ	1	1
$A_c\,[m^2]$	183000	237900
$U_{c0}\,[\frac{W}{m^2\,°C}]$	0.631[6]	$U_c\,[\frac{W}{m^2\,°C}]$ 1.5 [7]
$U_{c1}\,[\frac{W}{m^2\,°C}]$	0.018[6]	

T_c [°C]	400	300
T_a [°C]	25	25
C	82	30

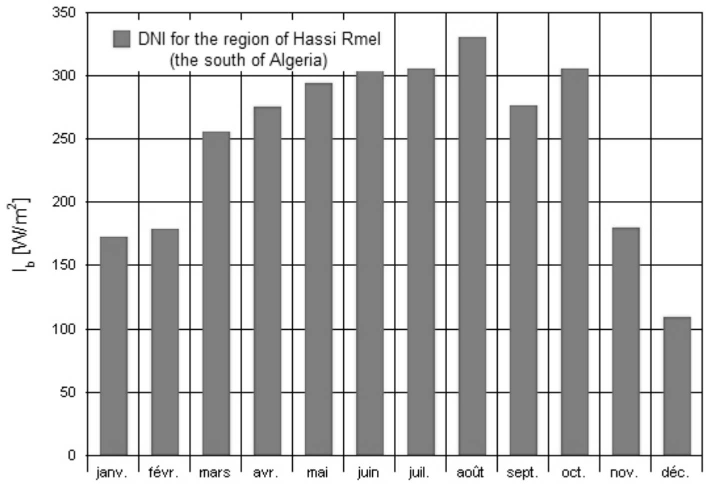

Fig. 5. Annual direct normal intensity for the region of Hassi Rmel

4. Conclusion

Linear Fresnel reflectors are optical analogous to parabolic troughs. They are concentrating reflectors with linear focus, where the parabolic reflective surface is obtained by an array of linear mirror strips which independently move and collectively focus on absorber lines suspended from elevated towers. The objective of this study is to reproduce the performance of parabolic troughs though with lower costs, this can be achieved with linear Fresnel reflectors (Häberle A et *al*. 2002). However with linear-Fresnel reflectors, optical quality and thermal efficiency is lower because of a higher influence of the incidence angle and the cosine factor. Because of that, this technology is not still much applied into ISCCS or in regenerative Rankine cycles.

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