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# A linear Fresnel reflector as a solar system for heating water: Theoretical and experimental study

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ABSTRACT

This work is concerned with assessing the thermal performances of a solar water heating system which is dependent on a linear Fresnel receiver (LFR) as a solar energy converter. The main objective of this paper is validation the experimental work carried out in the winter of 2015 on the concentrator in the climatic conditions of Algerian city “Blida” by a numerical simulation, where the tap water used as a heat carrier fluid. This simulation was used to solution of the energy balance equations of the absorber tubes and the water, where the solution is based on the finite difference method with an implicit scheme. After the solution of nonlinear equations, the program performed by using the MATLAB language gives the thermal efficiencies, the absorber temperatures, the water temperatures at the absorber tubes outlet, and thermal losses coefficients. The thermal efficiency of the reflector is exceeded 29%. The results obtained proved the existence of substantial convergence between the experimental and the numerical results, where in all cases the water temperature exceeded 347 K.


## 1. Introduction

Fresnel collectors have two types: the linear Fresnel reflector (LFR) and the Fresnel lens collector (FLC) [1]. The linear Fresnel mirror concentrator technology is still young and has taken place in the field of concentrating solar systems, this technology was conceived by the French physicist Augustin-Jean FRESNEL (1788–1827), he was used this technique in the optical system of the marine indication headlights [2]. The work of Alessandro Battaglia is the origin of the concentration technique by linear Fresnel reflector [3,4]. The Italian mathematician Giovanni Francia (1911–1980), designed the first prototype of linear Fresnel concentrator with the downward facing aperture covered with glass honeycomb tubes at Marseille built in 1962, he got on the performance equal to 60% and steam water temperature equivalent to 450 °C [5]. In the general case and according to the literature searches, the performance of this type of concentrator is varied between 30% and 40% [6,7].

In this day of many international institutions are investing and working to develop this technology, for instance at Almeria in Spain, the German company NOVATEC BIOSOL built the first commercial linear Fresnel reflector plant in the world. This electric station has a capacity of 1.4 MW, and since March 2009, their power supplies the local electricity power lines [8]. In France and since August 2010, CNIM group invested the only module of its Linear Fresnel solar concentrator at

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**Nomenclature**

| | |
|---|---|
| $\Delta X$ | length element, m |
| $A_{A,\ ext}$ | surface external of absorber, $m^2$ |
| $A_{A,\ int}$ | surface intern of absorber, $m^2$ |
| $A_c$ | total collector aperture area, $m^2$ |
| $C_A$ | specific heat of the absorber, J/kg K |
| $C_F$ | specific heat of the fluid, J/kg K |
| $D_{A,\ ext}$ | diameter external of absorber, m |
| $D_{A,\ int}$ | diameter external of absorber, m |
| DNI | direct-normal irradiance, $W/m^2$ |
| $f$ | focal length, m |
| $h_F$ | heat transfer coefficient by convection, $W/m^2$ K |
| $h_w$ | wind heat transfer coefficient, $W/m^2$ K |
| j | number of day |
| $K_F$ | thermal conductivity of the fluid, $W/m^2$ K |
| L | absorber tube length, m |
| $L_m$ | mirror length, m |
| Nu | nusselt number |
| *Pr* | prandtl number |
| $q_{absorbed}$ | thermal power received by the absorber tubes, W |
| $q_{ext}$ | global heat exchange between the absorber and the environment, W |
| $q_{ext,\ conv}$ | convection exchange between the absorber and the environment, W |
| $q_{ext,\ ray}$ | radiation exchange between the absorber and the environment, W |
| $q_{gain}$ | heat flux exchanged by convection between the cylindrical absorbent tubes and fluid, W |
| $q_{out}$ | quantity of a heat to the output of an element of the absorber tubes, W |
| $Q_V$ | volume flow of the water with the intern to absorber, $m^3/s$ |
| *Re* | Reynolds number |
| $S_e$ | reflectors effective surface, $m^2$ |
| $T_A$ | absorber temperature, K |
| $T_{amb}$ | ambient temperature, K |
| $T_F$ | fluid temperature, K |
| $T_{fi}$ | water inside temperature, °C |
| $T_{fo}$ | water outside temperature, °C |
| $U_L$ | heat transfer loss coefficient of solar collector, $W/m^2$ K |
| $V_w$ | wind speed, m/s |
| W | width of the mirror, m |
| $\phi$ | latitude, deg |
| $\omega$ | hour angle, deg |

*Greek symbols*

| | |
|---|---|
| $\alpha$ | absorption coefficient of the absorber tube |
| $\alpha_F$ | fluid thermal diffusivity, $m^2/s$ |
| $\gamma$ | interception factor |
| $\delta$ | declination angle, deg |
| $\varepsilon_{Ab}$ | absorber emissivity |
| $\eta$ | thermal efficiency |
| $\eta_{opt}$ | optical efficiency |
| $\theta_n$ | slope angle of an nth mirror element, deg |
| $\theta_t$ | angle in the transversal plane, deg |
| $\mu$ | dynamic viscosity, kg/m s |
| $\nu$ | kinematic viscosity, $m^2/s$ |
| $\rho_A$ | absorber density, $kg/m^3$ |
| $\rho_F$ | fluid density, $kg/m^3$ |
| $\rho_m$ | reflectance factor of the mirror |
| $\sigma$ | Stefan-Boltzmann constant, $W/m^2$ $K^4$ |

the site of Lagoubran to generate electricity from a steam turbine [8]. In Australia, the company Areva has developed the technology of a linear Fresnel concentrator for electricity generation, Australia has two central, the first is Kimberlina in Bakersfield, California with a rated power of 24 MW, the second central will be built in Kogan Creek near Dalby at Australia, where their capacity equal to 44 MW [8].

There are many studies, addressed to use of the technology of linear Fresnel reflector, including the study conducted by Choudhury et al. [9], they made a design and analysis of a linear Fresnel Reflector (LFR), where they got the concentration ratio of 18% with two-thirds of the periphery of a tubular receiver of 0.025 m in diameter, their concentration can produce temperatures above 350 °C. Singh et al. [10], who studied the performance of the linear Fresnel solar concentration device with a single absorber tube of an aluminum which contains Hytherm-500 oil as heat carrier fluid. Mills et al. [11], they evaluated concept of a compact linear Fresnel (CLFR), assuming that the size of the solar field will be great, because it must be designed for the production of electricity across MW. In the field of water heating in the range between 60 and 95 °C, Singh et al. [10], studied the thermal performance of the linear Fresnel concentrator which contains a trapezoidal cavity with two types of absorber tubes (rectangular and circular). The reflector performance of their collectors is varied between 16% and 64%, depending on the shape of the absorber tubes and the quality of the selective surface [12]. Moghimi et al. used the Computational Fluid Dynamics (CFD) to estimate the optical efficiency of linear Fresnel reflector, their study is considered a new or innovative computational approach for an accurate assessment of the contributions of heat loss in a multi-tube trapezoidal cavity receiver [13]. In another study, Moghimi et al. conducted a mathematical optimization on the trapezoidal cavity absorber for the Linear Fresnel Reflector In order to get the optimal designs of the cavity, the objectives of their study are finding the most appropriate architecture to reduce heat losses and side wind load [14].

The water-heaters are an essential instrument in our daily lives; it use of large-scale domestically and industrially. There are many scientific research conducted on solar water-heaters, which it has been used several types of solar collector [15–19]. This paper aims to characterize the thermal performances of a solar system for heating water which is based on a linear Fresnel solar converter in the city of Blida, Algeria. The thermal study was made by numerical simulation; this simulation is