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Research Paper

Performance model and thermal comparison of different alternatives for the Fresnel single-tube receiver

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HIGHLIGHTS

- A thermal model for a single-tube Fresnel receiver has been developed.
- A comparative analysis based on different design parameters, has been carried out.
- A comparative analysis based on different working fluids, has been carried out.
- The receiver thermal performance is characterized by energy and exergy efficiencies.

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ABSTRACT

Although most of recent commercial Solar Thermal Power Plants (STPP) installed worldwide are parabolic trough plants, it seems that Linear Fresnel Collectors (LFC) are becoming an attractive option to generate electricity from solar radiation.

Contrary to parabolic trough collectors, the design of LFC receivers has many degrees of freedom, and two basic designs can be found in the literature: single-tube and multi-tube design. This article studies the single-tube design, for which a thermal model has been developed. This model has been thought to be accurate enough to characterize the heat transfer in a non-elementary geometry and flexible enough to support changes of the characteristic parameters in the receiver design.

The thermal model proposed is based on a two-dimensional, steady-state energy balance, in the receiver cross section and along its length. One of the features of the model is the characterization of the convective and radiative heat transfer in the receiver cavity, as it is not an elementary geometry. Another feature is the possibility of studying the receiver performance with different working fluids, both single-phase or two-phase. At last, the receiver performance has been characterized by means of the energy and exergy efficiency. Both variables are important for a complete receiver thermal analysis, as will be shown in the paper.

The model has been first applied to the comparative study of the thermal performance of LFC receivers based on the value of some parameters: selective coating emissivity in the tube and inlet fluid thermal properties, for the case of using water/steam. As a second result, the model has also been used to predict the performance of different working fluids: synthetic oil, water/steam, molten salt and air, also comparing the results of the Fresnel technology with those obtained in reference parabolic trough loops.

1. Introduction and background

1.1. A review on different linear Fresnel collector plants and receiver designs

The main advantage of LFC systems is its robustness and low capital cost. Nevertheless, they seem to reach lower annual efficiencies than Parabolic Trough Collectors (PTCs), as it is shown in the technical literature [1–4]. Fresnel systems will be more effective if they are capable of reducing investment costs enough compared to parabolic trough [5].

There are already several LFC commercial plants and prototypes for power generation installed or being installed in different countries, like Puerto Errado 1 (1.4 MW_e) and Puerto Errado 2 (30 MW_e) in Spain, Kimberlina (5 MW_e) in California (USA), Augustin Fresnel 1 (250 kW_e) in France, Dhursar, (125 MW_e) in India and Rende (1 MW_e) in Italy [6–8]. In addition to the those plants, which are

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Nomenclature

Symbols

A	area (m^2)
d	diameter (m)
$\dot{E}x$	exergy transfer (W)
$\dot{e}x$	exergy transfer flux (W/m^2)
ex	specific fluid exergy (J/kg)
F_{ij}	view factor from surface i to j
h	convection heat transfer coefficient (W/m^2 K)
i	specific fluid enthalpy (J/kg)
J	linear radiosity (W/m)
k	thermal conductivity (W/m K)
L	length (m)
$\dot{m}$	fluid mass flow (kg/s)
Pr	Prandtl number
P	pressure (Pa)
p	perimeter (m)
$\dot{Q}$	heat transfer (W)
$\dot{q}$	linear heat transfer flux (W/m)
r	radius (m)
Ra_{Lc}	Rayleigh number
T	temperature (K)
u	fluid velocity (m/s)

Greek symbols

α	absorptance
δ_{ji}	Kronecker delta
ε	emittance
η	efficiency
λ	half-angle of the cone subtended by the sun's disc
ρ	reflectance
$\sigma = 5.67 \cdot 10^{-8}$	Stefan–Boltzmann constant ($W/m^2 K^4$)
τ	transmittance

Subscripts

1	heat transfer fluid
2	absorber tube inner surface
3	absorber tube outer surface
4	inner CPC surface
5	outer insulation casing surface
6	inner glass window surface
7	outer glass window surface
8	external environment
amb	ambient
cavity	Fresnel receiver cavity
coll	collector
cond	conduction
conv	convection
ex	exergy
f	fluid
i	generic surface
inc	incident
in	heat collector element inlet
inlet	collector inlet
inner	inner surface
l	lost
m	mirrors
out	heat collector element outlet
outlet	collector outlet
outer	outer surface
rec	receiver
s	sun
SolAbs	solar radiation absorbed

Acronyms

CFD	Computational Fluid Dynamics
CLFC	Compact Linear Fresnel Collector
CPC	Compound Parabolic Collector
DNI	Direct Normal Irradiation
ENEA	Ente per le Nuove Tecnologie l'Energia e l'Ambiente
HCE	Heat Collector Element
HTF	Heat Transfer Fluid
LFC	Linear Fresnel Collectors
ORC	Organic Rankine Cycle
PSA	Plataforma Solar de Almería
PTC	Parabolic Trough Collector
STPP	Solar Thermal Power Plants
TRM	Thermal Resistance Model

coupled to a Rankine cycle, there is a Fresnel plant integrated in the Liddell coal fired power station in Australia, which provides saturated steam to the conventional plant [9]. There are also some plants under construction: Alba Nova-1 of 12 MW_e (France), Kogan Creek Solar Boost of 44 MW_e (Australia), IRESEN of 1 MW_e (Morocco). In the latter LFC plants, only Rende and IRESEN plants use synthetic oil as Heat Transfer Fluid (HTF) in the solar field, coupled to an Organic Rankine Cycle (ORC); the other plants use water/steam as working fluid. The main drawback of water/steam is the storage and its controllability in transient conditions, especially in very long lines [10].

Besides the working fluid, LFC plants present differences based on the solar mirror field characteristics and also on the detailed receiver design: multiple-tube receiver or single-tube receiver. The receiver is a key element in the design of a linear Fresnel system, so this paper is devoted to the thermal characterization of the single-tube receiver. In this context, the Fresdemo prototype [11,12], which is installed in the PSA (Plataforma Solar de Almería) and uses water/steam as HTF in a single-tube receiver, is especially relevant. This prototype has been chosen as a reference, due to the many experimental data of its performance in the literature.

The receiver configuration has more degrees of freedom than in the case of parabolic troughs. Basically, two designs can be found in the literature, the multi-tube and the single-tube receiver.

The multi-tube design appears in the first prototypes and studies of LFC [13], although more studies and interest occurred as a result of the Compact Linear Fresnel Collector (CLFC) development [14,15]. It consists of a series of parallel tubes arranged horizontally in a cavity, usually with a trapezoidal cross section and therefore without secondary concentrator. A glass cover can be located at the opening of the cavity. The first mission of this cover is to protect, when necessary, the selective coating that reduces re-radiation losses; second, the glass cover is responsible for some greenhouse effect that benefits receiver performance; at last, it also minimizes convection losses. However, technical complications involved in creating vacuum in a great cavity of not elementary geometry has yield to research on selective coatings that can withstand ambient pressure [16]. These coatings are not yet in a commercial operation phase. Therefore, the tubes are usually not coated by a selective paint, although there are several studies that analyze the thermal behavior of the receiver with selective coating and, therefore, with a glass cover on the aperture. [17–20]. The Kimberlina plant has employed a multi-tube design in the receiver