Energy Conversion and Management 75 (2013) 191–201

Contents lists available at SciVerse ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Estimation of the temperature, heat gain and heat loss by solar parabolic trough collector under Algerian climate using different thermal oils

Malika Ouagued [a,*], Abdallah Khellaf [b], Larbi Loukarfi [c]

[a] Laboratory for Theoretical Physics and Material Physics LPTPM, Department of Process Engineering, Faculty of Technology, University Hassiba Benbouali of Chlef, PO Box151, Chlef 02000, Algeria

[b] Centre de Développement des Energies Renouvelables, CDER, PO Box 62, Avenue de l'Observatoire de Bouzaréah, Algeria

[c] Department of Mechanical Engineering, Faculty of Technology, University Hassiba Benbouali of Chlef, PO Box151, Chlef 02000, Algeria

ARTICLE INFO

Article history:
Received 24 December 2012
Accepted 13 June 2013

Keywords:
Direct normal solar irradiance
Tilted aperture
Tracking aperture
Solar parabolic trough collector
Heat balance
Thermal oil performance
Algerian climatic conditions

ABSTRACT

Algeria is blessed with a very important renewable, and more particularly solar, energy potential. This potential opens for Algeria reel opportunities to cope with the increasing energy demand and the growing environmental problems link to the use of fossil fuel. In order to develop and to promote concrete actions in the areas of renewable energy and energy efficiency, Algeria has introduced a national daring program for the period 2011–2030. In this program, solar energy, and more particularly solar thermal energy plays an important role. In this paper, the potential of direct solar irradiance in Algeria and the performance of solar parabolic trough collector (PTC) are estimated under the climate conditions of the country. These two factors are treated as they play an important role in the design of solar thermal plant. In order to determine the most promising solar sites in Algeria, monthly mean daily direct solar radiation have been estimated and compared for different locations corresponding to different climatic region. Different tilted and tracking collectors are considered so as to determine the most efficient system for the PTC. In order to evaluate the performance of a tracking solar parabolic trough collector, a heat transfer model is developed. The receiver, heat collector element (HCE), is divided into several segments and heat balance is applied in each segment over a section of the solar receiver. Different oils are considered to determine the thermal performances of the heat transfer fluid (HTF). Then, the HTF temperature and heat gain evolutions are compared under the topographical and climatic conditions.

1. Introduction

In recent years, the risk of global warming associated with the emission of green house gases during the combustion of fossil fuels is driving research in the efficient use of energy and renewable energy sources [1]. The solar energy incident on the Earth surface is about 10.000 times the world energy demand. The use of the southern Mediterranean countries areas for solar energy harvesting would by far suffice to supply the energy needs of those countries and of all the northern European industrialized countries. In a study carried by Greenpeace [2], it has been found that the use of concentrating solar power (CSP) can prevent the emission of 154 million tons of CO_2 by 2020. Just one 50 MW_{el} parabolic trough power plant can cut the annual heavy oil consumption by 30 million litters and thus eliminate 90.000 tons of CO_2 emissions [2].

The issues of energy, climate change and sustainable development occupy a large place in the Algerian development programs. In 2011, Algeria has launched the renewable energies (REs) and energy efficiency program. With a total budget of 120 billion US $ [3,4], this program is based on a strategy focused on developing and expanding the use of the inexhaustible resources, such as solar energy, in order to diversify Algeria energy sources and to prepare it for tomorrow. Electricity of solar origin should represent more than 37% of the national electricity production by 2030 [3,4]. The geographic location of Algeria represents the best climatic conditions such as the abundant sunshine throughout the year, low humidity and precipitation, and plenty of unused flat land close to road networks and transmission grids. The sunshine duration exceeds 2500 h/year over most of the territory and it could be as high as 3900 h/year in the high plains and in the Sahara. Algeria has several advantages for the extensive use of the solar energy as enormous potential for power generation compared to global energy demands [4].

In order to deliver high temperatures with good efficiency, a high performance solar collector is required. Systems with light structures and low cost technology for process heat application up to 773 K could be obtained with solar parabolic trough collector (solar PTC) [5,6]. Solar PTC is a proven technology that has reached industrial maturity and that is viable for commercial scale solar

* Corresponding author.
E-mail address: ouagued_malika@yahoo.fr (M. Ouagued).

0196-8904/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enconman.2013.06.011

Nomenclature

A_c collector aperture (m^2)
A_a receiver tube cross-section area (m^2)
A_f fluid flow cross-section area (m^2)
A_v glass envelope tube cross-section area (m^2)
C_a absorber specific heat (J/kg K)
C_{air} air specific heat at T_{amb} (J/kg K).
C_f HTF specific heat in segment "i" (J/kg K)
C_v glass envelope specific heat (J/kg K)
D_{ae} outside diameter of absorber pipe (m)
D_{ai} inside diameter of absorber pipe (m)
D_{ve} outside diameter of glass envelope (m)
D_{vi} inside diameter of glass envelope (m)
f friction factor for the inner surface of the absorber pipe
F_f HTF flow rate (m^3/s)
h_a convection heat transfer coefficient of annulus gas at T_{moy1} (W/m^2 K)
h_f convection heat transfer coefficient of the HTF (W/m^2 K)
h_v convection heat transfer coefficient of ambient air (W/m^2 K)
I_{ba} direct normal irradiance per unit of collector area (W/m^2)
k_{air} thermal conductivity of the ambient air at temperature T_{moy2} (W/m K)
k_f thermal conductivity of the HTF at temperature T_f^i (W/m K)
k_{std} thermal conductivity (W/m K)
L receiver length (m)
m_a^i absorber mass in segment "i" (kg)
m_f^i HTF mass at inlet of receiver segment "i" (kg)
m_v^i glass envelope mass in segment "i" (kg)
Nu_{air} Nuselt number at T_{moy2}
Nu_f Nuselt number at T_f^i
Pr'_{air} air Prandtl number at T_{amb}
Pr''_{air} air Prandtl number at T_v^i
Pr_f Prandtl number at T_f^i
Q_{aconv}^i convection heat transfer rate for receiver segment "i" between the surface of the absorber to the surface of the envelope (W)
Q_{arad}^i radiation heat transfer rate for receiver segment "i" between the surface of the absorber to the surface of the glass envelope (W)
Q_{asol} direct incident solar irradiance absorption rate into the receiver segment "i" (W)
Q_{fconv}^i convection heat transfer rate between the heat transfer fluid and wall of the absorber pipe in the segment 'i' (W)
Q_{vconv}^i convection heat transfer rate between the surface of the envelope to the atmosphere for receiver segment "i" (W)
Q_{vrad}^i radiation heat transfer rate between the outer surface of the envelope to the sky receiver segment "i" (W)
Q_{vsol} direct incident solar irradiance absorption rate into the envelope of receiver segment "i" (W)
Q_{sol} direct incident solar irradiance per unit length of receiver (W/m)
Q_z heat rate coming to the segment 'i' (W)
$Q_{z+\Delta z}$ heat rate leaving from the segment 'i' (W)
Re_f Reynolds number at T_f^i
t time (s)
T_a^i absorber pipe temperature in segment 'i' (K)
T_{amb} ambient temperature (K)
T_f^i HTF temperature inlet of receiver segment "i" (K)
T_f^{i-1} HTF temperature in the segment "$i-1$" (K)
T_{moy1} average temperature, $(T_{moy1} = (T_a + T_v)/2)$ (K)
T_{moy2} average temperature, $\left(T_{moy2} = \left(T_v^i + T_{amb}\right)/2\right)$ (K)
T_{sky} estimated effective sky temperature (K)
T_v^i glass envelope temperature in segment "i" (K)
w collector width (m)

Greek letters
α_a absorptance of the absorber selective coating
α_v glass envelope absorptance
ρ_a density of the absorber selective coating (kg/m^3)
ρ_{air} air density at T_{amb} (kg/m^3)
ρ_f HTF density at average temperature of receiver segment "i" (kg/m^3)
ρ_v density of glass envelope (kg/m^3)
η_a effective optical efficiency of the absorber
η_{col} collector efficiency
η_v effective optical efficiency of the glass envelope
τ_v glass envelope transmittance
Δz receiver segment length (m)
λ mean-free-path between collisions of a molecule (cm)
δ molecular diameter of annulus gas (cm)
γ ratio of specific heats for the annulus gas
σ Stefan–Boltzmann constant (5.6697 W/m^2 K^4)

power generation in the sunbelt countries of the world [7–9]. The commercialization of this technology took a major step forward in the mid 1980s and early 1990s with the development of the SEGS plants in California by Luz International Ltd. More than 1.2 billion US $ in private capital was raised in debt and equity financing for the nine SEGS plants. Whereas a conventional power plant depends on fuel that is purchased as a continuous string of payments during the lifetime of the plant, a solar power plant needs to finance its "fuel costs" through capital investment at the beginning of the project. In a typical parabolic trough SEGS-type plant, the solar field represents 50% of the total investment costs. However, once a solar plant is built the "solar fuel" is free, resulting in less uncertainty in the cost of power over the life of the project. Besides reducing the dependence on the hydrocarbon limited resources, solar PTC offers the opportunity to increase the country energy mix and to contribute to the local development through job creation during construction. A parabolic trough power plant also lessens dependence on fossil fuels, which provides a hedge against fossil fuel price fluctuations [2,9].

PTC heat transfer analyzes have received increasing attention since 1980. Clark [10] has presented an identification of the principal design factors that influence the technical performance of a parabolic trough concentrator. These factors include reflectivity of the mirror system, the mirror-receiver tube intercept factor, the incident angle modifier and the absorptivity–transmissivity product of the receiver tube and cover tube. The temperature profile in the absorber tube of a direct steam generating PTC has been estimated by Heidemann et al. [11]. To this end, a computer program has been developed to calculate the two-dimensional transient temperature field using a modular nodal point library. Using different type of receiver selective coating and different receiver configuration, Dudley et al. [12] have tested LS-2 PTC to determine the collector efficiency and the thermal losses. LS-2 is the second-generation PTC installed in SEGS solar plant. Thomas and Thomas [13] have presented a design data for the computation of thermal losses in the receiver of a PTC for specific absorber tube diameters, various ambient temperatures, wind velocity and absorber temperatures. A numerical model has been used by