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A new trough solar concentrator and its performance analysis

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Abstract

The operation principle and design method of a new trough solar concentrator is presented in this paper. Some important design parameters about the concentrator are analyzed and optimized. Their magnitude ranges are given. Some characteristic parameters about the concentrator are compared with that of the conventional parabolic trough solar concentrator. The factors having influence on the performance of the unit are discussed. It is indicated through the analysis that the new trough solar concentrator can actualize reflection focusing for the sun light using multiple curved surface compound method. It also has the advantages of improving the work performance and environment of high-temperature solar absorber and enhancing the configuration intensity of the reflection surface.

Keywords: Solar concentrator; High temperature collector; Multiple curved surface compound focusing; Trough concentrator

1. Introduction

In the field of concentrating solar collectors, the conventional parabolic trough solar concentrator is one of the most matured technologies (Richter, 1996). It has been successfully used in many large scale high-temperature solar plants (Price et al., 2002; Schwarzer et al., 2008). It can collect the solar energy up to 400 °C under the accurate control of a solar tracking system. However, this type of solar concentrator has three primary disadvantages: (1) The focus line of the concentrator is over the concentrating surface. So, the high-temperature solar receiver in the focus line can cast its shadow on the concentrating surface. (2) Some form of tracking system is required so as to enable the collector to follow the sun. This requires a high precision in optical quality and positioning of the optical system. Once the solar radiation cannot be reflected directly to the solar receiver, the reflection will be useless which is quite difficult to achieve for the large unit. (3) Because the high-temperature solar receiver is installed over the reflection surface of the concentrator, it is directly exposed to the environment and wind so heat loss to the environment is very high which is a disadvantage to the heat preservation of the receiver. In order to enhance the advantage of the conventional parabolic trough solar concentrator and overcome its disadvantage and also decrease the track precision requirement, many new systems have been researched (Murphree, 2001; Fraidenraich et al., 2008; Kiatgamolchai and Chamni, 2008).

In this paper, a new imaging compound parabolic trough solar concentrator is designed. The most important feature of the new concentrator is that the single curved focusing surface in the conventional concentrator is replaced with a multiple curved focusing surface, this enables the high-temperature solar receiver to be simultaneously heated by the upper and lower surfaces of the concentrator. This generally helps to provide a more uniform flux distribution around the receiver tube. Because the focus line of the concentrator is displaced to the underside

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Nomenclature

x	horizontal coordinate	c_p	fluid specific heat
y	vertical coordinate	δ	the included angle between the ray and the symmetrical axis of the device
p	focal parameter of a parabola	H	height
l	the half distance between two foci	β	tracking accuracy
h	the minimum length of the flat mirror	$C_{1\max}$	maximum concentration ratio
S	the half length of the contour line	C	width ratio of the inlet aperture over the outlet aperture
ϕ	the aperture width	C_1	the geometrical concentration ratio
d	the diameter of the receiver	a_1	the width of the inlet aperture of the CPC
u	the speed of the fluid	a_2	the width of the outlet aperture of the CPC
ρ	fluid density	λ	aspect ratio of the traditional CPC
μ	fluid kinetic viscosity	λ_1	aspect ratio of the concentrator proposed
m	mass flow rate	$\theta_{\max}$	the maximal concentration half angle of the CPC,
Q	quantity of heat	S_1	the distance from point C to F_1
L	the length of the receiver	w	the diameter of the receiver
η	the efficiency of the concentrator		
I	irradiance		
T	temperature		

of the unit, it is helpful to the installation and heat preservation of the receiver.

2. The operation principle of the multiple curved surface parabolic trough solar concentrator

The new solar concentrator designed in this work is shown in Fig. 1. It consists of the new compound parabolic concentrator, secondary reflection plane mirror, lower parabolic trough concentrator and high-temperature solar receiver. Its operating principle is described as follows. The light '4' at a direction parallel with the symmetry axis '5' enters the trough. The surface '1' of the new compound parabolic trough concentrator reflects the light '4' to the secondary plane mirror '2'. The light is then reflected by the secondary plane mirror '2' to concentrate at a mirror image focus line. The center line of the high-temperature solar receiver '8' just superposes with the mirror image focus line. A vacuum glass tube '7' is positioned outside the receiver '8' to reduce heat loss. The new trough solar concentrator also has a lower parabolic concentrator '3' connected with the secondary plane mirror '2' by the flange '9', which allows the lower parabolic concentrator to be removed easily to provide access to the receiver for cleaning or maintenance. The focus line of the surface '3' also superposes with the center line of the high-temperature solar receiver '8'. The light striking onto the lower trough parabolic concentrator '3' is reflected to the receive '8'. Therefore, the solar energy receiver '8' in the new trough can accept the reflected solar radiation from both upside and downside so that the receiving efficiency is enhanced.

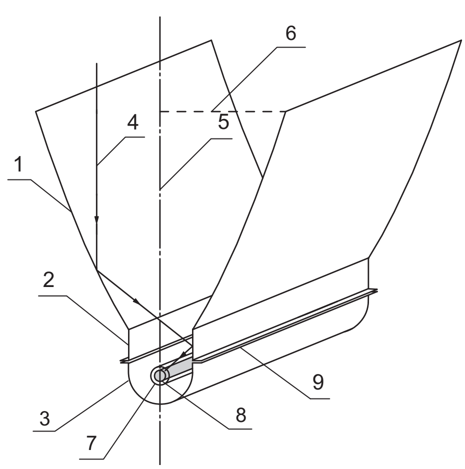

Fig. 1. Schematic diagram of the new trough solar concentrator. 1—the new compound paraboloid concentrator; 2—secondary reflection plane mirror; 3—lower trough paraboloid concentrator; 4—parallel light; 5—symmetry axis; 6—half aperture of import light; 7—transparence vacuum glass tube; 8—high-temperature solar receiver.

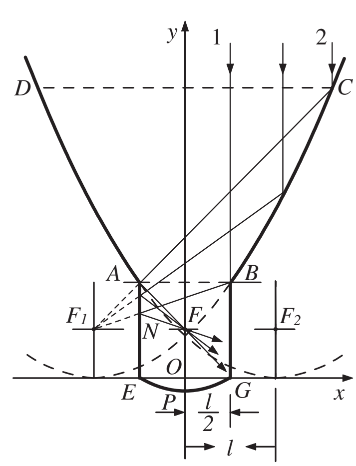

Fig. 2. The focus light principle of the concentrator.