Renewable Energy 63 (2014) 98–108

Contents lists available at ScienceDirect

Renewable Energy

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

Heat loss characteristics study of a trapezoidal cavity absorber with and without plate for a linear Fresnel reflector solar concentrator system

R. Manikumar [a,*], A. Valan Arasu [b]

[a] Department of Mechanical Engineering, Kamaraj College of Engineering and Technology, Virudhunagar 626001, Tamil Nadu, India
[b] Department of Mechanical Engineering, Thiagarajar College of Engineering, Madurai 625015, Tamil Nadu, India

ARTICLE INFO

Article history:
Received 10 April 2013
Accepted 3 September 2013
Available online

Keywords:
LFRSC
Trapezoidal cavity absorber
Numerical analysis
CFD simulation

ABSTRACT

The numerical and experimental studies are conducted to analyze the heat loss in the cavity absorbers of linear Fresnel reflecting solar concentrator (LFRSC). The cavity is trapezoidal shape in cross section, which is placed at focus of the concentrator, has multiple tubes and water is used as the working fluid. The upper surface of the cavity has two models; with copper plate, above which absorber tubes are placed together and without copper plate i.e. absorber tubes alone without copper plate underneath. In both the models, the heat loss coefficient of projected absorber surfaces is analyzed with and without black chrome coating. For the numerical simulation of the trapezoidal cavity absorber, ANSYS FLUENT 12.0 version is used to develop the two dimensional model with non-Boussinesq numerical approximation. For the experimental study, two cavity absorbers are designed for operating in conjunction with a LFRSC experimental set up for the area of 4.0 m^2. The overall heat loss coefficients are also estimated analytically by cavity correlations. The trend of variation of estimated heat loss coefficient by both methods is similar to experimental values. Also, estimated values by numerical study are very close to analytical and experimental values and the numerical model can be used for further analysis.

1. Introduction

Concentration of solar radiation is necessary for efficient photothermal as well as photovoltaic conversion of solar energy [1–3]. A variety of designs of linear solar concentrators were developed and tested for their suitability to deliver solar thermal energy in the medium temperature range [1–4]. A LFRSC (Fig. 1) basically consists of long narrow plane mirror elements arranged in a planar configuration and oriented so as to form a linear image of the sun on the absorber [5,6].

LFRSC has several advantages, (i) it is useful for medium-temperature range applications (ii) it is fabricated with narrow flat reflectors and constituent materials for its fabrication as well as replacement which are readily available in the market; (iii) the planar configuration and the air gap between the adjacent reflectors result in very small wind loading on the concentrator. The thermal efficiency of such a LFRSC system depends on the design parameters, mass flow rate, desired temperature difference, tracking accuracy [7]. Also, the recent work [8] on the design of LFRSC with trapezoidal cavity absorbers has shown that the instantaneous collection efficiency depends on concentration ratio and reflectivity of the reflectors. The amount of power delivered by the reflector to absorber (tubular) plays a key role in solar thermal energy systems.

In operation, the absorber tubes in the trapezoidal cavity heat up due to the incident concentrated solar radiation. The cavity receiver heat loss processes involve radiative, convective and conductive heat transfer, and interaction of these three modes makes it difficult to develop a purely analytical model. Pye et al. [9] carried out a study of losses in a trapezoidal cavity. They applied an analytical model for a trapezoidal cavity and found that radiation makes up 90% of the heat loss from the top surface. Using CFD analysis of the cavity, they mentioned losses due to natural convection and radiation. However, for CFD analysis, tubes were modeled as an isothermal plane surface. Reynolds et al. [10] studied the steady state computational analysis of LFR trapezoidal cavity receiver. A number of computational and experimental studies have been carried out in the area of heat transfer in cavities by natural convection combined with radiation for LFR solar system. Also, they carried out experimental and computational study of

* Corresponding author. Tel.: +91 0452 2326841.
E-mail address: mani2k72006@yahoo.co.in (R. Manikumar).

0960-1481/$ – see front matter
http://dx.doi.org/10.1016/j.renene.2013.09.005

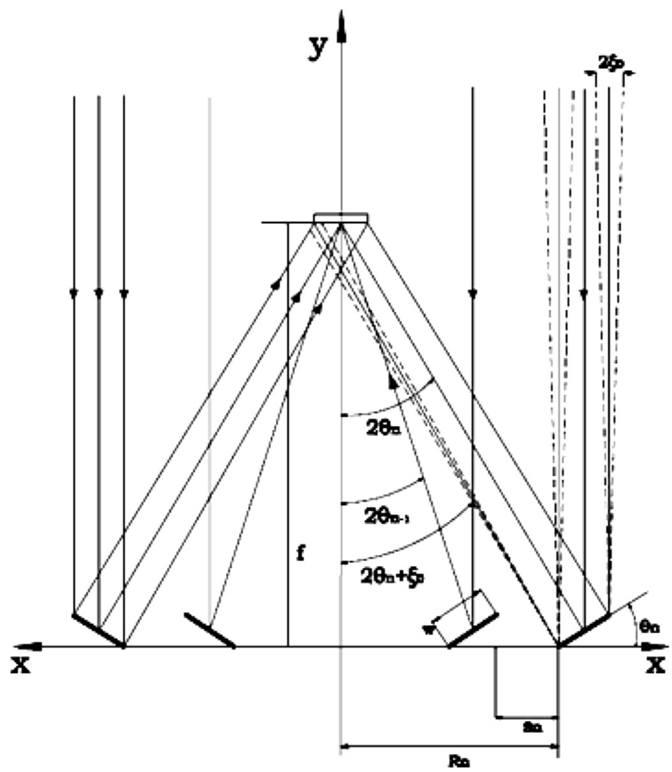

Fig. 1. Schematic representation of LFRSC system.

heat loss characteristics on a trapezoidal cavity and used flow visualization technique to capture the flow patterns caused by density difference within the trapezoidal cavity with hot plate at the top. In computational study, flow in the cavity was assumed laminar. They concluded that, CFD prediction of heat loss was found to be 40% less compared with experimental results. Uncertainties in the experimental work were mentioned as the reason for this mismatch. Facao [11] analyzed and optimized trapezoidal cavity receiver for a linear Fresnel solar collector concentrator using ray trace and CFD simulations. To evaluate the overall heat transfer coefficient of the Fresnel collector, CFD simulations were done. Natural convection inside the cavity, thermal radiation between surfaces and conduction through the cavity walls were simulated. Two geometrical parameters were analyzed: receiver depth and insulation thickness. It was concluded that the cavity with a 45 mm depth presents the lowest global heat transfer coefficient. Regarding insulation thickness, 35 mm of rock wool presented a good compromise between insulation and shading. Recently, Singh et al. [8] studied the performance of round and rectangular pipe absorber experimentally. They concluded that the efficiency of the round pipe (multi-tube) absorber was 2–8% higher as compared to rectangular pipe absorber. Also the efficiency of the rectangular pipe absorber ranged from 24% to 63% for selective surface coated absorber as compared to 15–54% with ordinary black painted absorber at different concentration ratios. Flores et al. [12] studied the steady state thermal behavior of an LFR absorber prototype by using Energy Plus software package and concluded that the higher portion of the thermal loss occurs by radiation from the bottom window surface, that is, for a pipe temperature of 200 °C around 91% of the heat is lost from the bottom window. Jance et al. [13] demonstrated through heat loss measurements, that convective heat transfer in a trapezoidal cavity is small, and that the heat losses from the cavity are predominantly by radiation. Singh et al. [14] concluded that the overall heat loss coefficient of the absorbers increased with absorber temperature in all cases considered and also selective surface coating on the absorber found useful as compared to ordinary black paint because there was significant reduction in overall heat loss coefficient by 20–30% and no significant difference was observed between heat loss coefficient of rectangular and round pipe absorbers. Values of the heat loss coefficient for trapezoidal cavity absorber were 3.3–8.2 W/m^2 °C for different cavity absorber. Natarajan et al. [15] has presented the computational study of heat loss characteristics by using non-Boussinesq numerical procedure in CFD package with FLUENT version 6.3 and concluded that trapezoidal cavity absorber with aspect (depth to width of cavity) ratio and temperature ratio of greater than 2.5 and 0.6 can be used to minimize the internal heat loss of the absorber. Sudhansu et al. [16] studied the steady state modeling and simulation of trapezoidal cavity with eight tubes and concluded that the dominant mode of losses is radiation, the losses by natural convection found in the range of 8–15%. So, the use of evacuated cavities may be recommended to minimize convection losses. Radiation heat transfer coefficient between hot absorber plate and glass cover of the cavity can be calculated considering radiative heat transfer modeled as that between two parallel planes [17].

In the present work, the overall heat loss coefficient of the trapezoidal cavity absorber with and without plate under the absorber tubes at different temperatures is studied experimentally with and without black chrome coating at the absorber surface. Heat loss in the trapezoidal cavity absorber is also analyzed and estimated numerically by using ANSYS workbench 12.0 [18]. This numerical study is conducted for two dimensional non-Boussinesq model with steady state, combined laminar natural convection and surface radiation heat transfer in a trapezoidal cavity absorber of considered two models. Further, the heat loss is estimated analytically by using cavity correlations. Finally, the results are compared with experimental values. Since, most of the published work focused on the plane absorber surface cavity, the present study focuses on the comparison of trapezoidal cavity with plate surface and without plate surface. So, the outcome of analysis would be useful and provide significant contribution to the LFRSC system.

2. Methods and materials

2.1. Experimental set-up

The concentrator consists of 2 N reflector elements, with N (40 in the present case) reflectors present on either side from the centre of the concentrator plane in which solar radiation incident axially. In the event of perfect tracking, a LFRSC is assumed to imply, that, it is made up of a large number of flat, front reflecting reflector elements, each with a finite width ($w = 40$ mm) and a length equal to the length of the linear absorber ($L = 1$ m). The reflectors are oriented so as to form an overlapping image of the sun on the absorber tubes.

The designing of a LFRSC employing mirror elements of equal width can be carried out using conventional geometrical optics [19]. The tilt of each mirror elements is chosen such that a ray incident normally on the aperture plane and striking the midpoint of the mirror element, after reflection, reaches the focal point. If absorber tubes are arranged horizontally along the absorber plane such that the centre of the absorber plane coincides with the point *f*, the absorber tubes will be illuminated by the radiation reflected from the constituent mirror elements. It is clear from the geometry of the concentrator that the widths of the images produced on the absorber surface will increase as one move towards the rim of the concentrator from the centre of the aperture of the concentrator. This effectively means that the radiation reflected from the mirror