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Original research article

Flux concentration on tubular receiver of compound parabolic collector by surface areal irradiance method of ray tracing

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ABSTRACT

Ray tracing for solar collectors finds wide application for designing the components. In this research, a solar flux concentration on the tubular receiver of compound parabolic collector (CPC) is determined by a novel approach of surface areal irradiance (SAI). The objective of this method is to determine the solar reflected irradiance at the receiver by incorporating effective areas of reflector and receiver. These areas are determined by 2D graphical ray tracing technique. Multiple ray tracing iterations are performed on various geometric possibilities of receiver–collector combinations by varying receiver diameter and height. The collector dimensions are fixed as per authors previously designed CPC to reduce the number of possibilities of receiver – collector combinations. The results of these iterations are presented in terms of utilization ratio (*U*), projection ratio (*P*) etc. based on which concentrated solar flux and heat equations are determined. It is observed that there is saturation point for all receiver diameters at which a receiver – collector combination gives highest utilization ratio and the corresponding height gives the best location for that receiver. SAI method gives a strong methodology for designing solar collectors on the basis of utilization ratios and heat equations.

1. Introduction

Solar collectors enhance solar radiation on the receiver portion to increase the thermal performance [1–5]. Compound parabolic collectors are non-imaging type of solar collectors which needs less tracking and offers great flexibility in design [6–8]. Acceptance angle of CPC accommodates angular variation of incoming solar rays thus reduces tracking effort and tracking frequencies. In CPC, as the acceptance angle increases, the receiver height from the base decreases rapidly [9]. Higher acceptance angle decreases aperture area of collector which simultaneously decreases a geometric concentration ratio (GCR) too. GCR is defined as a ratio of aperture area to the receiver area [10]. It is fixed for a particular geometry of receiver – collector assembly. But it is limited to only aperture width and size of receiver and does not give idea about the vertical location of the receiver. There may be possibilities of having same GCR for different collectors and receiver positions as shown in Fig. 1. The geometric possibilities of receiver sample can be from *R1* to *Rn* whereas possibilities of collector

Abbreviations: CPC, compound parabolic collector; GCR, geometric concentration ratio; LCR, local concentration ratio; LD, limiting diameter; SAI, surface areal irradiance.

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Nomenclature

A_{CA}	Available area for collector (mm^2)
A_{CU}	Utilized area for collector (mm^2)
A_{RA}	Available area for receiver (mm^2)
A_{RU}	Utilized area for receiver (mm^2)
C	Collector sample
D	Receiver tube diameter (mm)
D_m	Maximum receiver tube diameter (mm)
f	Sample focus height for collector
H	Sample receiver height
I_b	Incoming solar irradiance (W/m^2)
P	Projection ratio
Q_D	Direct heat energy at the receiver (W)
Q_R	Reflected heat energy at the receiver (W)
Q_T	Total heat energy at the receiver (W)
R	Receiver sample
S	Concentrated solar flux (W/m^2)
U	Utilization ratio
U_C	Collector utilization ratio
U_R	Receiver utilization ratio
W	Aperture width (mm)
α	Absorptivity
2θ	Acceptance angle (°)
ρ	Reflectivity

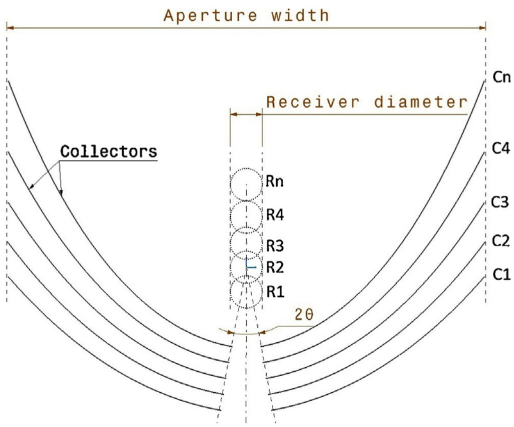

Fig. 1. Different possibilities of receiver – collector combinations of CPC for same GCR.

sample can be from *C1* to *Cn*. Furthermore receiver sample *R* has geometric possibilities of diameter *D* and receiver height *H* and collector sample has possibilities of various half acceptance angle θ and focus height *f*. These large numbers of geometric possibilities of receiver–collector combination is shown in Table 1.

For CPC with tubular receiver, GCR is a given by

$$GCR = (W - D)/\pi D \tag{1}$$

Here *W* is the aperture width and *D* is tubular receiver diameter. Higher GCR leads to high solar flux concentration on the receiver. Solar irradiance is accepted from the aperture area of the collector and reflected towards the receiver. This reflected solar irradiance is amplified by an amount ideally equal to GCR when it reaches to the receiver. When a concentration ratio is expressed in terms of solar flux then it is called as optical concentration ratio or local concentration ratio (LCR). It is defined as a ratio of reflected solar flux at the receiver to the total solar flux accepted by the collector [11,12]. The amount of incoming solar flux is derived by considering aperture area of the collector. Even for solar rays with certain incident angle the aperture area is taken into account for deriving incoming solar radiation [13–17]. It will result the same amount of solar flux incident on different sized reflectors within the same aperture area. This problem can be eliminated by considering the reflector area which receives direct solar irradiance [18]. The total amount of solar irradiance captured by a collector surface will reflect