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# Performance analysis of a novel and cost effective CPC system

Atul S. Jadhav [a], Ajitkumar S. Gudekar [a], Ramchandra G. Patil [a], Dhanaji M. Kale [a], Sudhir V. Panse [a,*], Jyeshtharaj B. Joshi [a,b]

[a] Institute of Chemical Technology, Matunga, Mumbai 400 019, India
[b] HomiBhabha National Institute, Anushaktinagar, Mumbai 400 094, India

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ABSTRACT

Compound Parabolic Collectors (CPCs) allow large acceptance angle which concentrating the incident radiation and need only occasional tilt adjustments instead of continuous solar tracking. They have, therefore, been found useful in many low concentration applications, where ease of operation, and low cost are important criteria. In addition, researchers have recently shown that in conjunction with other concentrators, CPC can do value addition to Fresnel or heliostat technologies. Also, their usefulness in solar reactors for water disinfection or hydrogen production has been reported. One major limitation of CPC is its height which increases rapidly with an increase in the aperture, rendering the supporting structure bulky and costly. Truncation reduces height, however also reduces the concentration. An improvement in the CPC design has been suggested in this paper, which brings down its height, without much compromise on the concentration ratio. A prototype of this modified CPC design was constructed and tested for thermal efficiencies and achievable temperatures. Results show that the modified CPC design can harness the solar energy to provide low cost Industrial Process Heat.



## 1. Introduction

In commercial solar thermal installations, the Parabolic Trough Collectors (PTCs) are used frequently. However, some other designs are also considered, because of their specific advantages. For instance, a Compound Parabolic Collector (CPC) is capable of concentrating sunlight onto a flat receiver over a full day, without tracking. Unlike other solar concentrators, therefore, CPC does not require elaborate tracking arrangement; and thus provides the advantage of ease of operation. Consequently, during the past 30 years attempts have been made to understand the characteristic features of CPC, and to develop its several applications.

### *1.1. Compound Parabolic Collectors (CPCs)*

Concept of CPC was introduced by Winston [1] in 1974, which is a non-imaging type of concentrator. As seen from Fig. 1, CPC consists of sections of two parabolas 'A' and 'B', with their focal points at '$F_A$' and '$F_B$' respectively, such that the former lies on curve 'B'; and the later lies on the curve 'A'. The dotted portions of the two curves are truncated; and only the parts shown by solid lines constitute the CPC. Angle between the two lines drawn parallel to the axes of parabolas 'A' and 'B' through '$F_B$' and '$F_A$' respectively is its angle of acceptance '$2\theta$'. Rays entering CPC through $2\theta$' reach the gap between '$F_A$' and '$F_B$', after a single or multiple reflections, producing a non-imaging type of concentration. The geometrical concentration of the CPC is $(d1/d2)$ where $d1$ is aperture and $d2$ is receiver opening (Which is shown as (10) and (11) in Fig. 1). It is also clear from the figure that sections of both the parabolas, forming a CPC are above their respective focal planes.

Muschaweck et al. [2] showed that except near the equator, asymmetric CPC collectors collect more solar energy than the symmetric ones by advantageous land-use; and with marginally higher construction cost. Mills et al. [3] have pointed out recommended that the East–West alignment the absorbers of CPC collectors offer for higher annual output as compared to the North–South alignment.

In operation, CPC is deployed with its linear receiver aligned East–West, and aperture typically tilted toward south (for locations in the northern hemisphere). The tilt is such that the incident solar rays enter the collector within its acceptance angle; and it is adjusted periodically when the incident rays just spill out beyond that angle. Also, CPC is often truncated at the top in practice to restrict its height; but at the cost of drop in its concentration ratio.

### *1.2. Applications of CPC*

The concentration ratio of CPC is known to have relatively low values, as compared to parabolic dish or trough concentrators, and generate lower temperatures. Researchers have worked on many thermal applications of CPC, where ease of operation is

* Corresponding author. Tel.: +91 22 3361 2661; fax: +91 22 3361 2010.
*E-mail address:* sudhirpanse@yahoo.com (S.V. Panse).

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**Nomenclature**

| | |
|---|---|
| 2D | two dimensional CPC |
| 3D | three dimensional CPC |
| AHP | analytical Hierarchy Process |
| CPC | compound Parabolic Collectors |
| $d1$ | aperture of CPC |
| $d2$ | receiver opening |
| DC | dish Concentrator |
| DNI | daily Normal Insolation, W/m$^2$ |
| F | focus |
| FPC | flat plate collector |
| IPH | Industrial Process Heat |
| ORC | Organic Rankin Cycle |
| PTC | Parabolic Trough Collector |
| $R$ | receiver pipe |
| SODIS | solar disinfection |
| $M$ | weight of water + equivalent weight of pipe and tank |
| $W$ | percentage uncertainty |
| $W_I$ | percentage uncertainty in solar insolation |
| $W_{\mathrm{Mw}}$ | percentage uncertainty in weight of water |
| $W_{\Delta T}$ | percentage uncertainty in temperature difference |
| $W_A$ | percentage uncertainty in aperture area |
| $W_{\mathrm{Cos}\theta}$ | percentage uncertainty in Cos$\theta$ factor |
| $W_t$ | percentage uncertainty in time |

*Greek symbol*

| | |
|---|---|
| $\theta$ | half acceptance angle |
| $\lambda$ | specific enthalpy |

important, and moderate temperatures are sufficient. Use of CPC has also been reported for enhancing the power generation of photovoltaic power plants [4]. Because of their ability to concentrate radiation incident through large acceptance angles, CPC have been found to be effective as secondary concentrators in combination with the other concentrating devices [5]. As a result, they have a fruitful role to play in solar tower technology, which generates very high temperatures (800 °C and above). A case study [6] has shown that, after carefully weighing all options, a preference for using CPC has been proposed for concentrating solar power in solar thermal power production plants, over other competing technologies. Table 1 gives a list of latest published reports on applications of CPC. It illustrates that the CPC is expected to play a crucial role in the emerging technologies for concentrating solar power.

### 1.3. Vacuum Tube, heat pipe and CPC

Vacuum Tube Collectors (VTCs) are non-concentrating, non-tracking solar collectors, capable of producing moderate temperatures, because convective heat losses from their receivers are reduced to minimum. One major application of (VTC) is heating of water. Chow et al. compared performance and cost of VTC water heaters in the market of Hong Kong with flat plate solar water heaters there. They concluded that efficiency for VTC is comparatively higher, but so is cost. Consequently, payback period is same for both; but VTC have an edge in temperatures attained [7]. VTC are often associated with heat pipes. Work has also been reported on the fluids used in heat pipes. Esen et al. reported the experimental comparison for three refrigerants R-134a, R407C and R410A in case of water heaters employing heat pipes [8].

Balzar et al. used a VTC and a long heat pipe to heat the oven plate of a solar cooker. They could attain the temperature of 252 °C for a pot containing 5 l of oil [9]. Stumpf and others further used a double stage heat pipe thermal coupling in a solar cooker; and compared its performance with a solar cooker using a flat plate collector, and that using a single stage heat pipe. They found that the performance of the first type of solar cooker was significantly better [10].

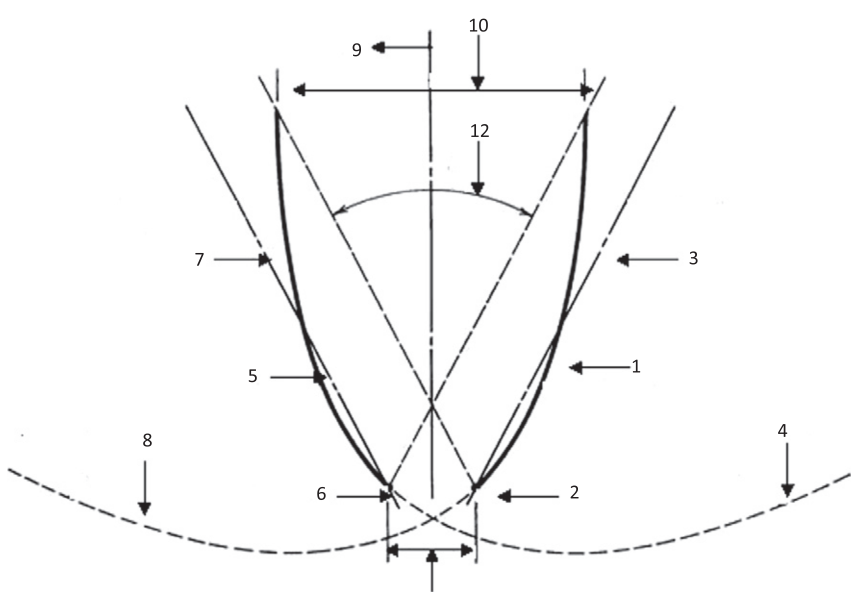


**Fig. 1.** The geometry of compound parabolic concentrator (CPC). (1) Parabola A, (2) focus of parabola A, ($F_A$) (3) axis of parabola A, (4) truncated part of parabola A, (5) parabola B, (6) Focus of parabola B (FB), (7) axis of parabola (B), (8) truncated part of parabola B, (9) axis of CPC, (10) aperture of CPC ($d1$), (11) receiver opening ($d2$), (12) acceptance angle ($2\theta$).