

CPC-TROUGH—Compound Parabolic Collector for Cost Efficient Low Temperature Applications

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ABSTRACT: The high-performance CPC-Trough Collector has been developed for the utility scale generation of low temperature solar hot water and steam for low temperature process heat applications including solar air conditioning. With an optical concentration of 4.5:1, operating temperatures over 130°C may be reached. This novel design has included a FEM validation and is compatible with the standard reflectors and evacuated tubes in the market. The peak efficiencies of 35% with unshielded and more than 45% with evacuated tube receivers were obtained. This CPC collector requires intermittent tracking i.e. tilt adjustment is only once in a week for more than 8 hours collection in summer and 6-7 hours in winter seasons.

NOMENCLATURE

Symbol	Description	[Units]
I_b	Beam radiation on horizontal Surface	[Watt/m ²]
I_d	Diffused Radiation	[Watt/m ²]
r_b	Tilt factor for beam radiation	[None]
r_d	Tilt factor for diffused radiation	[None]
C	Geometric concentration ratio	[None]
Q_u	Useful heat gain rate	[Watt]
D	Absorber tube diameter	[m]
W	Aperture Width	[m]
F_R	Heat removal factor	[None]
U_l	Overall heat loss coefficient	[Watt/m ² ×K]
N	No. of tubes	[None]
h_f	Heat transfer coefficient	[Watt/m ² -K]
m	Mass flow rate of working fluid	[kg/sec]

C_p Specific heat capacity at constant pressure [J/kg × K]

b Absorber width [m]

L Collector Length [m]

T Temperature [°C]

T_{fi} Fluid Temperature at inlet [°C]

T_{fo} Fluid Temperature at outlet [°C]

T_a Ambient temperature [°C]

S Absorbed Flux [Watt/m²]

Greek symbols

α Absorptivity of the absorber surface [None]

τ Transmissivity of the cover [None]

ρ_e Effective reflectivity of the concentrator surface [None]

η_i Instantaneous efficiency [None]

1. INTRODUCTION

The Alternative Energy Development Board (AEDB), Pakistan currently leads the research and development (R&D) efforts on cost efficient compound parabolic collectors (CPCs) for its extremely hot regions, a simple technology for the wide use of renewable energy, accessible to the technologically less developed countries that are sunny and often have limited raw material resources and skilled labour. These CPCs are non-imaging, that function seasonally or annually with minimum or intermittent tracking requirements.

The paper presents theory, practical experience, and economy of CPC: First a simple structure design is described. Then results from designing and operating the test module in Pakistan are presented. Eventually technical issues and basic economic data for future commercial CPCs for low temperature applications in Pakistan.

2. TECHNICAL FEATURES

2.1 Functional Principle

Schematic shows the working of a CPC test module with electro-polished anodized high purity aluminium or glass mirror reflectors along with the semicircular absorber at focal

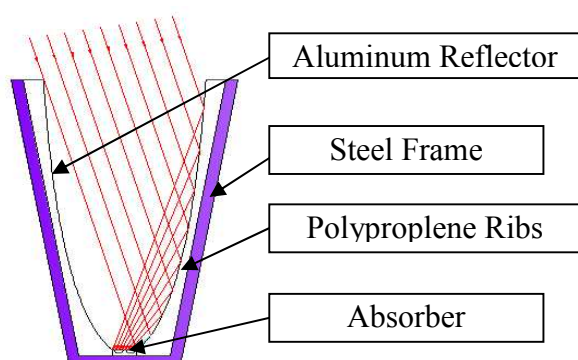


Figure 1: Functional Principle of CP Test Module

line. A heat transfer fluid is circulated in the absorber which is heated to the temperature of nearly 160°C for steam generation applications and subsequently water is circulated for hot water applications.

2.2 Collector Structure

The CPC-Trough collector model is made up of 3.6476m long collector unit. It comprises of 3 parabolic aluminum sheets or mirror panels on each side. These reflecting

TABLE 1: Specifications of CPC-Trough Test Module

CPC-Trough Test Module	Characteristic Parameters	
	Non-truncated	truncated
Absorber Type	Rectangular with circular tubes at the base	
Aperture Width	0.381 m	0.3538 m
Collector Length	3.6576 m	3.6576 m
No of Aluminum foil or Mirror Facets	6	6
CPC surface reflectivity	0.94	0.94
Number of Absorber tubes	2	2
Diameter of each tube	0.0127 m	0.0127 m
Weight of Steel Structure	5-6 kg/m ²	3-4 kg/m ²
Aperture Area	1.3935 m ²	1.2940 m ²
Height to Aperture ratio	4.2120	2.524
Acceptance Angle	15.3245°	25.5°
Dimension of each Facet	1.626 X 1.219 m	0.9144 X 1.219 m
Percentage Truncation	0%	44.36%
Transmissivity of cover	0.90	0.90

aluminium sheets or mirror panels are supported on a V-shaped mild steel structure of a hollow square cross-section pipe fixed at six points on its backside. This permits the aluminum foil/mirrors to bend within the range of its flexibility without effect on the focal point. The accuracy of the parabolas is achieved by machining six light weight parabolic ribs from 25.4mm thick polypropylene sheets using CNC high pressure water jet cutting machine. These parabolic ribs are bolted to the V-shaped steel structure. The axial horizontal hollow members provide additional strength and bracing. The accuracy of the parabolic ribs and the method of assembly reduced the time and cost of fabrication and minimized the degree of technical skill required by workshop staff, while providing sufficient structural strength.

Detailed FEM of the CPC and its interaction at high expected wind loads at different positions of the collector were analyzed. These investigations on structural behaviour (under various wind loads for range of pitching angles of the collector for various designs, ease of manufacturing and assembly, and complex computation were performed to obtain the best possible solution of the CPC structure, cost and simplicity.

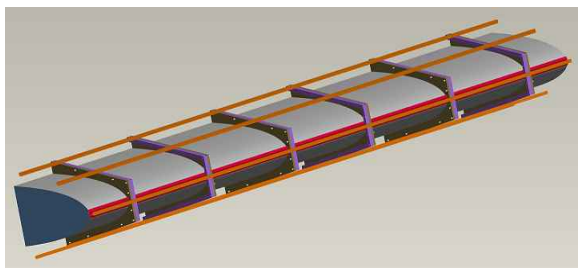


Fig. 2: Computer Model of the CPC frame Design

Based on these study and observations, light weight V-shaped structure with fewer deformations has been selected for the CPC. This simple structure has been made by welding three pieces at two joints on a jig

platform for better accuracy, reduced time and less dependency on skilled labour. The absorber is simply bolted with the rectangular slots machined at the base of the Polypropylene parabolic ribs and covered with a rectangular sheet channel fixed at the base of the polypropylene parabolic ribs. The space between the absorber and the rectangular channel is filled up with glass wool so as to minimize the heat loss from the absorber.

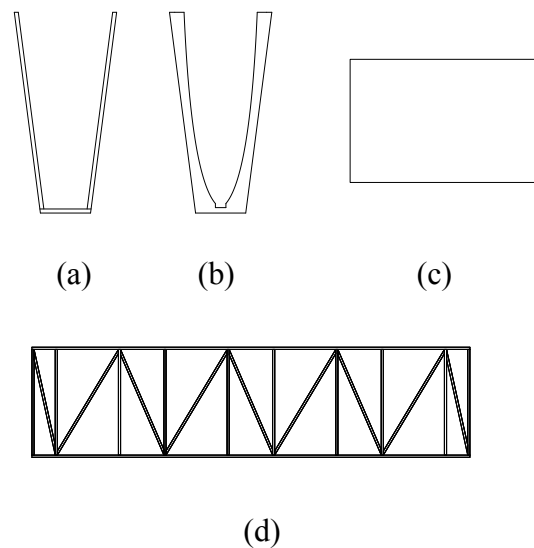


Fig. 3: CPC Trough Test Module Consisting out of (a) 6 simple steel V-frames screwed to parabolic ribs; (b) 6 polypropylene Parabolic Ribs; (c) 6 Aluminium Reflectors; (d) 2 steel bracing member bolted with parabolic ribs.

3. PERFORMANCE ANALYSIS OF CPC

3.1 Total Flux Absorbed by the Absorber

The working fluid enters the tubes at a mass flow rate m and inlet fluid temperature T_{fi} and exits at a temperature of T_{fo} . The mass flow rate of the fluid can be adjusted with a by pass pipeline with a valve for easy control of the flow rate of fluid.

The expression for the total effective flux entering the aperture plane is;

$$S = \left[I_b r_b + \frac{I_d}{C} \right] \tau \rho_e \alpha \dots\dots\dots (i)$$

3.2 Useful Heat Gain Rate

$$Q_u = F_R W L \left[S - \frac{U_l}{C} (T_{fi} - T_a) \right] \dots\dots\dots (ii)$$

Where,

$$F_R = \frac{m C_p}{b U_l L} \left[1 - \exp \left\{ - \frac{F' b U_l L}{m C_p} \right\} \right] \dots\dots\dots (iii)$$

and

$$\frac{1}{F'} = U_l \left[\frac{1}{U_i} + \frac{b}{N \pi D_i h_f} \right] \dots\dots\dots (iv)$$

3.3 Exit Fluid Temperature and Collector Efficiency

$$T_{fo} = \frac{Q_u}{m C_p} + T_{fi} \dots\dots\dots (v)$$

and

$$\eta_i = \frac{Q_u}{(I_b r_b + I_d r_d) W L} \dots\dots\dots (vi)$$



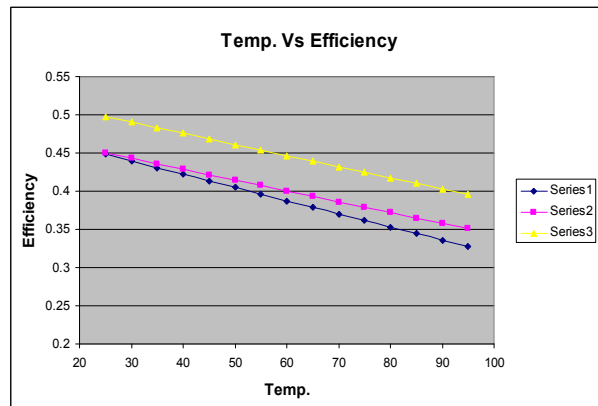
Fig. 4: CPC under construction with parabolic ribs, frames and bracing members.

3.4 Performance over a Day

Using input data for solar radiation, ambient temperature and wind speed, the performance of the collector test module is studied for several whole days in summer and winter seasons. Data was obtained with water as the working fluid in the closed loop configuration under a variety of weather

conditions; this module required only four tilt adjustments in a year, at intervals of four months, in order to ensure a minimum of 7 hours of collection per day.

Fig. 5: Efficiency as a function of absorber Temperature



Plot shows the variation of efficiency with increase in inlet temperature. It will be noted that the general pattern of efficiency variation over a day is the same for all days of the year. On any day, the value of efficiency decreases; this is due to the fact that efficiency is strongly influenced by the heat loss at elevated temperatures.

The temperature attained by the CPC is more than 120°C in summer season and below 100°C in winter, thus best suited for the low temperature applications like Solar air conditioning, hot water for tanning, Solar heaters etc.

It is to be noted that there is not a general thumb rule to truncate the CPC, but for our convenience the maximum width of a standard aluminium reflector sheet is utilized which fits in the curve and covers 65% of the height of CPC, consequently an added advantage of area.

3.5 Cost Reduction

Following cost reduction potential have been exploited:

a) Cost reduction by simplification of the design:

Less different profiles, parts, better transportation; assembly concept; cost reduction by weight reduction of the structure; frame work structure, Finite Element method for structural design calculations, wind analysis for proper wind load case.

b) Cost reduction by the optical performance of the collector:
Rigid support structure, frame work, manufacturing and assembly accuracy.

c) No complex tracking assembly requirement.

d) From the previous work done on CPC, it has shown that if the height of CPC is reduced by fifty percent, there is not a significant effect on the performance of CPC. But at the same time there is a significant reduction in the cost.

e) Very good results and economic when used in place of flat plate collectors in tanning industry, car wash, and textile.

5. ACKNOWLEDGMENTS

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