A MODIFIED CPC SOLAR CONCENTRATOR INTENDED TO ACHIEVE WIDER ANGLE OF ACCEPTANCE

TIRUNEH A.T.*, DEBESSAI T.**, NKAMBULE S.*, BWEMBYA G.**
*Department of Environmental Health Science, University of Eswatini. Swaziland
**Department of Chemistry, University of Eswatini, Kwaluseni, Eswatini, Swaziland

Abstract: The performance of compound parabolic solar concentrators (CPC) is extended through the provision of additional external reflectors that increased the angle of acceptance and hence achieve concentration for longer part of the day. The modified setup increased the angle of acceptance by over 70% while achieving comparatively close concentration ratio ranging between 90-100% of the maximum attainable. For construction of geometry of the reflector profile, an approach involving coordinate transformation has been used. Satisfactory performance of the solar concentrator has been observed for applications involving grey water treatment, production of struvite and drying of fecal matter from urine diversion dry toilets and compost.

Keywords: Compound parabolic concentrators, heat energy, non-imaging mirrors, renewable energy, solar power.

1. INTRODUCTION

Solar concentrators are mirrors used for directing sunray from a greater area of collection towards an absorber surface of small area achieving greater concentration of heat energy. The energy available from the sun is available everywhere on the planet and, for much of the season in the African region including Eswatini. This provides a motivation for using the freely available form of energy. A solar concentrator may concentrate the ray to a point (called imaging mirrors) or to an area (called non-imaging mirrors) [1]. The imaging mirrors, also called parabolic mirrors, achieve greater level of concentration but with limited angle of acceptance thereby necessitating continuous tracking of the sun. The non-imaging types such as the compound parabolic concentrators offer greater angle of acceptance during which time there is no need to track the sun ray.

Compound parabolic concentrators have been in use since the nineteen sixties for wide range of uses such as water heating, distillation, drying, provision of heat, sterilization, solar cells, etc. [2,3]. The traditional design of compound parabolic concentrators took the form of a three dimension specification [4, 5] or a symmetric axis [7] that takes account of refraction. The limit to concentration ratio that can be achieved is set by thermodynamic consideration [8,9]. The second law of thermodynamics states that heat cannot spontaneously flow from a cooler surface to a hotter surface. The mathematical basis for such limit as applied to solar concentrators have been described in the literature [10]. The edge ray principle also achieves similar maximum thermodynamic limit for CPC [11]. Description of the geometric profile of CPC designs have been adequately made for reflector profiles ranging from two to three dimensions [12, 13].

For a compound parabolic concentrator with angle of acceptance $2\theta_C$ where θ_C is commonly defined as the half angle of acceptance, the concentration ratio is calculated as [1]:

$$C_R = \frac{W}{b} = \frac{1}{Sin(\theta_c)} \qquad (1)$$

Referring to Figure 1 below showing a CPC and according to Fermat's theory [16] where light travels between two points while achieving minimum time of travel, it is possible to achieve the following equality (as light travels at constant speed, c, called the speed of light);

$$CA + AB' = A'B + BB'$$

From the symmetry of the parabola it is also easy to see that in Figure 1:

$$A'B = AB'$$

The above two relationships give eventually:

$$CA = BB'$$

It is also easy to verify from Figure 1 that CA = AA′ Sin (θ_C) where θ_C is half the angle of acceptance of the concentrator. Hence finally one obtains:

$$\frac{BB'}{AA} = \frac{1}{Sin(\theta_c)} \qquad (2)$$

The concentration ratio is, therefore, seen to be the maximum limit set by thermodynamic limits. Description of the thermodynamic limits as well as formulation of the geometric profile of CPC are well explained by [14] and [15].

Fermat's theorem can also be used to construct the reflector profile shown in Figure 1. While keeping the string against the edge A′C always at right angle and fixing the end of the string always at B′ the intermediate point between points A and B can be plotted.

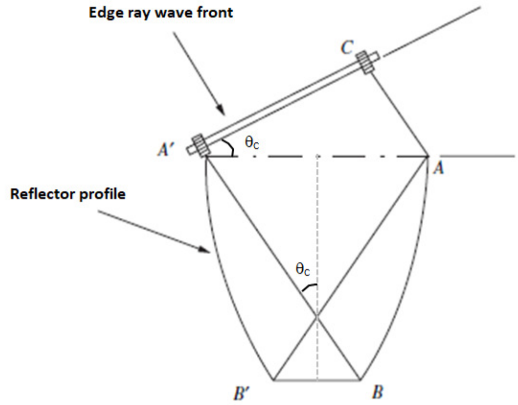

Fig. 1. Derivation of the concentration ratio of CPC from Fermat's theorem

Observation of the profile of CPC reveals that the contribution of the upper portion of the reflector progressively diminishes as it tends to approach the vertical orientation. In other words, the aperture width increases much less than the increase in vertical height of the reflector. It is, therefore, prudent to truncate the upper portion which would waste material without contributing to increased absorption [17]. In addition, truncation of the reflector surface to a useful height increases the angle of acceptance of the concentrator.

Composite CPCs are common with two different types of parabolas used as reflectors. The purpose is to increase the angle of acceptance and allow more diffuse rays [18]. There are different variations such as one involving truncation at an oblique angle of two symmetric reflectors [19]. Because the CPCs do not need tracking sun ray within their angle of acceptance, they are suitable for applications such as providing hot water and as generation of solar electric power. [20]. The absorber material used should have higher thermal conductivity [1]. Covering the CPC helps in keeping the heat and reduce the loss by convection and conduction. Reflector materials should have higher reflectance power. Using silver tint is also common to increase reflection. The temperature generated from CPC for non-evacuated tubes ranges between 80 and 100 ^{0}C. and between 100- 120 ^{0}C for evacuated cubes that remove the air inside minimizing loss by conduction and convection.

analysis and automatic protection system (APS) of UMVEN structure are subordinated to the objectives of maximizing the availability of energy and UMVEN security. By maximizing the availability of energy is obtained also the maximizing of economic efficiency of UMVEN. Sometimes there is a tendency to minimize the importance of APS of UMVEN performance, because they are more reliable than the primary equipment (RPE). In fact, as shown analytically [1, 2, 3, 4, 5], APS and its elements are at a higher level plan in which the RPE and equipment of the structure, the position that "intended" and if necessary, "occur" within the meaning of correct functioning of the RPE and all UMVEN.

2. METHODOLOGY

Modification of the CPC geometry

Figure 2 and 3 show the modified versions of the CPC used in this research. The two profiles differ both by the geometry of the absorber surface as well as profile of the reflector. The additions or modifications made to the regular CPC as used in this research are inclusion of the normally truncated lower portions of the parabola that are now retained on both the left and right side of the CPC. In the version shown in Figure 2, a V-shaped absorber is inserted between the upper and lower portion of the reflector. This is normally done by cutting through the reflector at the appropriate central location. In other words, the reflector frame is constructed monolithically as one section. The version shown in Figure 3, has flat absorber, which is a little tricky to use in the modified setup. In this case where flat absorbers are used, the focal points of the inner parabolas are coincident shown at point a in Figure 3 which is the midpoint of the absorber. Admittedly, this shifting of the focal point results in lower angle of acceptance (though with the associated higher concentration ratio). In addition, when the angle of acceptance of the inner reflectors decrease, there is a proportional increase in the angle of acceptance of the outer reflectors. The outer reflectors are pushed outwards in such a way that the left outer wing has its focal point moved from a to b leftwards while the right outer parabola is moved right way so that its focal point is moved from a to c (Figure 3).

The modified CPC has greater angle of acceptance which can be explained as follows. During the early hours of the day, the right outer wing provides reflection to the absorber starting almost from sunshine. During the normal hours defined by the angle of acceptance θ of the sun ray later in the day, the two inner reflectors provide reflection. Later in the day, the left outer wing provides reflection until almost sunset. In this way, theoretically, the entire sunshine duration can be used for absorption. While the concentration ratio varies individual among these three phases, the overall absorption of this modified design is high compared to the regular CPC design. It is also apparent from the geometry of reflection that the three phases of absorption are mutually exclusive in that they work in 'shifts' or in series rather than simultaneously in parallel as the sun travels apparently from sunshine to sunset.

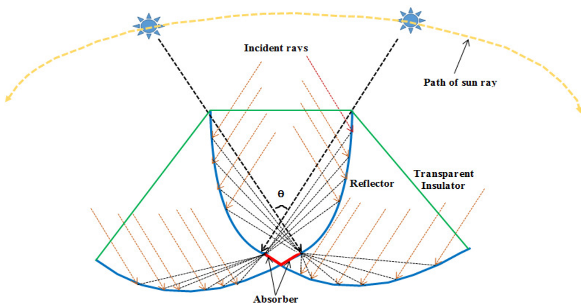

Fig.2. Modified CPC with v-shaped absorber surface

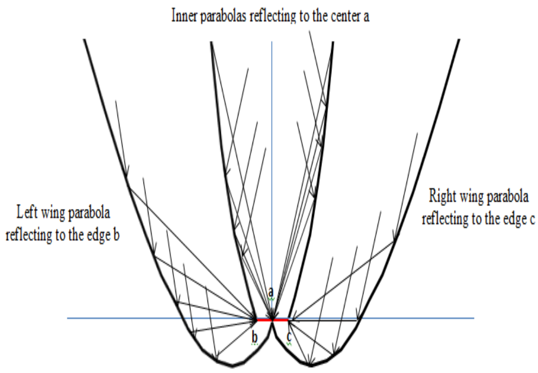

Fig.3. Modified CPC with flat absorber surface

Determination of fecal coliform counts

The fecal coliform counts in composted fecal matter, stored fecal matter from UDDT toilets, urine evaporated after struvite crystallization and distilled grey water samples were determined to assess the effectiveness of sanitization using the CPC. The 3 tube Most Probable Number (MPN) method using Brilliant Green Lactose Bile Broth (BGLBB) was used [21]. Briefly stated, three consecutive serial dilutions (10^{-1}, 10^{-2}, 10^{-3}) (1 mL) of each sample were inoculated into test tubes containing BGBB (9 mL) and a Durham tube, and were incubated at 44.5°C for 24h. Presumptive positive tubes were shown by growth and gas production. The most probable number (MPN) of coliforms was estimated from the number of tubes inoculated and the number of positive tubes using statistical tables [22].

For R-APS is a general pattern of reliability suitable containing five states, presented in Fig. 2, taking into account the two main modes of failure of protective relay, i.e. lack of response ($\overline{RC}$) operation when needed and when not needed (INT).

3. RESULTS AND DISCUSSION

Construction of the reflector geometry

The profile of the modified CPC can be constructed more easily if coordinate transformation is used to transform the coordinate from the symmetrical axis (X′, Y′) to (X, Y) shown in Figure 4. The symmetrical axis (X′, Y′) has its origin located at the focal point of the right parabolic reflector. The equation of the parabolic reflector surface using the symmetric (X′, Y′) is stated as;

$$Y' = \frac{X'^2}{4f} - f \qquad (3)$$

Where f is defined as the focal length of the parabola. Equation (3) is easy to use. Once the (X′, Y′) coordinates are determined the corresponding (X, Y) coordinates are determined using reverse transformation of Cartesian coordinates using the angle $-\theta_C$ as follows:

$$X = X' \, Cos\,(\theta_C) - Y' \, Sin\,(\theta_C) \qquad (4)$$

$$Y = X' \, Sin\,(\theta_C) + Y' \, Cos\,(\theta_C) \qquad (5)$$

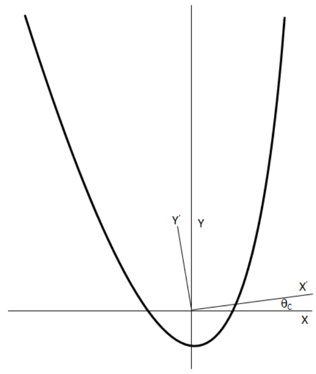

Fig.4. Geometric profile constructed using coordinate transformation from (X′, Y′) to (X,Y)

The relationship between the focal length and the absorber width is easily calculated also using coordinate transformation. Noting that the focal point of the left reflector (not shown in Figure 4) has coordinate (X, Y) = (b, 0) and using direct coordinate transformation:

$$X' = X\,Cos\,(\theta_C) + Y\,Sin\,(\theta_C) = b\,Cos\,(\theta_C) + 0 = b\,Cos\,(\theta_C)$$

$$Y' = -X\,Sin\,(\theta_C) + Y\,Cos\,(\theta_C) =$$
$$-bSin\,(\theta_C) = 0 = = -bSin\,(\theta_C)$$

Substituting these X′ and Y′ values into equation (3) yields:

$$\frac{(bcos(\theta_C))^2}{4f} - f = -bsin(\theta_C)$$

$$4f^2 - 4fb\,\sin(\theta_C) - b^2cos^2(\theta_C) = 0$$

$$f = \frac{4bsin(\theta_C) + \sqrt{16b^2sin^2(\theta_C) + 16b^2\,cos^2(\theta_C)}}{2 * 4}$$

After simplification;

$$f = \frac{b}{2}\,[(1 + sin\,(\theta_C)] \qquad (6)$$

For a given aperture width W, the corresponding height H can be calculated as follows by referring to Figure 5 showing the relevant dimensions

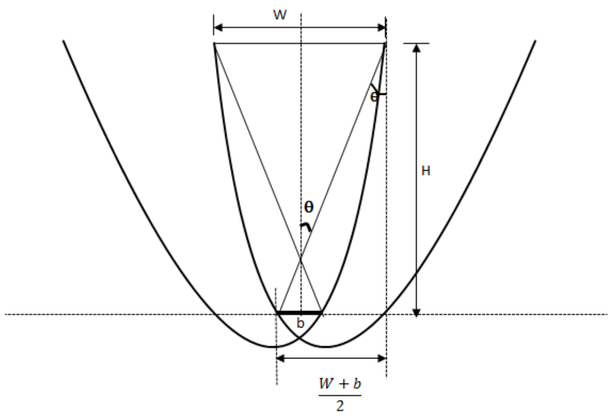

Fig.5. Dimensions of the modified CPC for computing truncation height H

$$Tan\,(\theta_C) = \frac{\frac{W+b}{2}}{H} = \frac{W+b}{2H}$$

$$H = \frac{W+b}{2Tan(\theta_C)} = \frac{W(1+b/W)}{2Tan(\theta_C)} = \frac{W(\,1+\sin(\theta_C)\,)}{2Tan(\theta_C)} \qquad (7)$$

In the above formulation of Equation (7), the absorber width b is eliminated using the concentration ratio formula, i.e., b/W = sin (θ_C).

The half angle of acceptance used for constructing the modified CPC was 11.5^0. The total angle of acceptance is therefore, 23^0. This has been reported to be the optimum angle of acceptance. Increasing the angle of acceptance will decrease the concentration ratio as is apparent from equation (1) because the concentration ratio is inversely proportional to the sine of the half angle of acceptance. Decreasing the angle of acceptance will result in a very limited range of time during which the CPC operates.

For the suitable half angle of acceptance θ_C of 11.5^0 so chosen, the recommended useful height of truncation H of 1.0 m is used for constructing the modified CPC. The calculated horizontal ranges of the reflector are 1.12 m on both sides measured from the symmetrical central axis. Therefore, the total horizontal length of the reflector is 2.24 m. The total height of the reflector including the 0.12 m absorber height is 1.12 meters. The horizontal dimensions for construction are adjusted by moving the origin of axis from the left focal point to the center of symmetry shown in Figure 5. Once this is done specification of the left coordinate and right wings will be mirror images of each other.

Table 1 shows the specification of coordinates for the right wing of the parabola reflector (X,Y) which is calculated from (X′, Y′) using the coordinate transformation equations (4) and (5) and subsequently translating the x-coordinate from the left focal point to the vertical axis of symmetry (in other words adding b/2, half of the absorber width, to the x values). Figure 6 shows the final reflector profile for both wings.

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Table 1. Dimensions of modified right wing CPC measured from the from the center of the absorber aken as the origin of axes

X	Y	X	Y	X	Y	X	Y
(m)	(m)	(m)	(m)	(m)	(m)	(m)	(m)
-1.126	1.030	-0.535	0.130	-0.076	-0.118	0.249	0.289
-1.045	0.882	-0.470	0.063	-0.028	-0.102	0.281	0.386
-0.966	0.744	-0.407	0.006	0.018	-0.077	0.310	0.493
-0.889	0.616	-0.347	-0.040	0.062	-0.042	0.337	0.610
-0.814	0.498	-0.289	-0.076	0.103	0.004	0.362	0.737
-0.741	0.391	-0.232	-0.101	0.143	0.060	0.385	0.875
-0.670	0.293	-0.178	-0.117	0.180	0.126	0.406	1.023
-0.601	0.206	-0.126	-0.122	0.216	0.202		

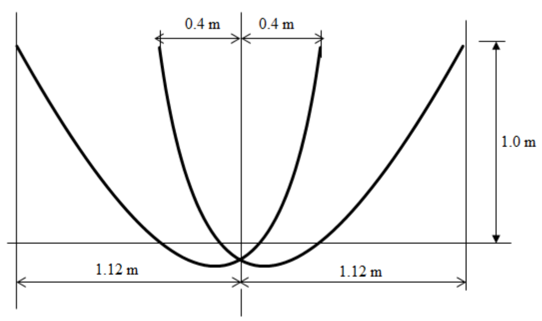

Fig.6. Final reflector profile of the modified CPC

Total length of the reflector

The total length of the reflector is computed for determining the material requirement of the reflector surface and metal frames on which the reflector rests. The length is obtained by integration of the parabolic reflector profile specified by Equation (3) and substituting the expression in equation (6) for the focal length, i.e.,

$$Y' = \frac{X'^2}{4f} - f \qquad (3)$$

$$f = \frac{b}{2}\,[(1 + \sin(\theta_C)]\qquad (6)$$

$$s = \int\left(1+\left(\frac{dY'}{dX'}\right)^2\right)^{1/2} dx = \int\left(1+\left(\frac{X'}{2f}\right)^2\right)^{1/2} dx \qquad (8)$$

Evaluation of the integral in equation (8) gives:

$$s = f\left[\frac{X'}{2f}\sqrt{1+\left(\frac{X'}{2f}\right)^2} + \ln\left(\frac{X'}{2f} + \sqrt{1+\left(\frac{X'}{2f}\right)^2}\right)\right] \qquad (9)$$

For a specified absorber width b of 20 cm the corresponding focal length is computed from equation (6), i.e.,

$$f = \frac{b}{2}\,[(1 + \sin(\theta_C)] = \frac{0.2}{2}[(1 + \sin(11.5^0)] = 0.120m$$

It is to be noted that the corresponding aperture width W for the specified absorber width b of 20 cm is calculated from the concentration ratio using Equation (1), 1.e.,

$$C_R = \frac{W}{b} = \frac{1}{Sin(\theta_c)} \qquad (1)$$

$$W = b\,.\frac{1}{Sin(\theta_c)} = 0.2 * \frac{1}{(\sin(11.5^0)} = 1.00\,m$$

However, the actual aperture width W shown in Figure 6 is 0.8m because of truncation by specifying the useful height of the reflector as being 1.0 m Using transformation of coordinates the limits of integration to be used in equation (9) are evaluated as follows:

$$(X_{left},\ X_{right}) \rightarrow (X'_{left},\ X'_{right})$$

$$(-1.12,\ +0.4) \rightarrow (-0.8,\ +0.7)$$

Once the f value as well as the limit of integration (-0.8, +0.7) are specified, Equation (9) gives:

S = 2.917 meters

The total length of the reflector is twice the S value since the right and left reflectors are symmetrical:

Total length of reflector profile = 2S = 2.917* 2 = 5.834 meters

Determination of solar concentration data for the three pahases of absorption

Figure 7 shows the aperture widths for the three phases of absorption. Because of symmetry, both the left and right outer reflectors have similar aperture width, i.e., W_E. The central reflectors have aperture width W. from the constructed profile of the reflector discussed above, the aperture widths corresponding to the three phases were evaluated as shown in Table 2. Table 2 shows the calculation of the concentration data for the three phases of absorption.

As can be seen from Table 2, truncation of the reflector height from the theoretical value of 2.95 m to the usable height of 1.00 m did not appreciably reduce the concentration ratio. The concentration ratio reduced from 5 to just 4 while saving considerably on material cost

On the positive side, truncation of the height increased the angle of acceptance of the internal reflectors from 23^0 to more than double the value, i.e., 53.2^0. This increase in angle of acceptance is quite significant from the point of view of the overall efficiency of energy absorption of the reflectors.

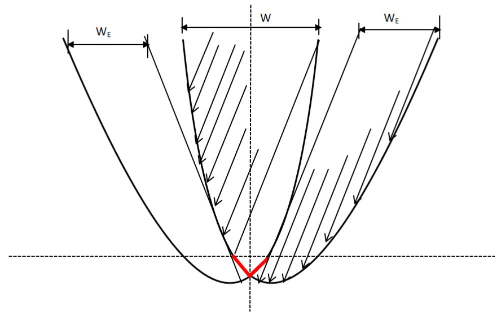

Fig.7. The aperture widths for the three phases of absorption

Table 2. Solar concentration ratio data for the three phases of absorption

Phase	I (right wing)	II (central reflectors)	III (left wing)
Absorber width (b)	0.20 m	0.20 m	0.20 m
Theoretical width W_T	1.8-0.5 = 1.3 m	$W_T = b/Sin(\theta_C)$ $= 0.2/(Sin(11.5^0) = 1.00$ m	1.8-0.5 = 1.3 m
Theoretical height (H_T)	2.95 m	$H = \frac{W(1+\sin(\theta_C))}{2Tan(\theta_C)} = 2.95\,m$	2.95 m
Theoretical angle of acceptance	$Tan^{-1}(2.95/(1.8-0.1) = 60^0$ $\theta = 90-11.5-60 = 18.5^0$	$2*11.5^0 = 23^0$	$Tan^{-1}(2.95/(1.8-0.1) = 60^0$ $\theta = 90-11.5-60 = 18.5^0$
Truncated height (H)	1.00 m	1.00 m	1.00 m
Truncated aperture width	$W_E = 1.12-0.4 = 0.72$ m	W = 0.8 m	$W_E = 1.12-0.4 = 0.72$ m
Actual angle of acceptance	$Tan^{-1}(1.00/(1.12-0.1) = 44.4^0$ $\theta = 90-26.6-44.4 = 19^0$	$Tan^{-1}\left(\frac{W+b}{2H}\right) = Tan^{-1}\left(\frac{0.8+0.2}{2*1.00}\right) = 26.6^0$ $\theta = 2*26.6 = 53.2^0$	$Tan^{-1}(1.00/(1.12-0.1) = 44.4^0$ $\theta = 90-26.6-44.4 = 19^0$
Concentration ratio (C_R)	$W_E/b = 0.72/0.2 = 3.6$	W/b = 0.8/0.2= 4	$W_E/b = 0.72/0.2 = 3.6$
Theoretical limit to Concentration ratio	$1/(Sin(11.5^0) = 5.0$	$1/(Sin(11.5^0) = 5.0$	$1/(Sin(11.5^0) = 5.0$

The provision of external reflectors in the modified CPC setup augmented the angle of acceptance by a total of 38^0. Compared to the actual angle of acceptance, this constitutes a further 71% increase in the angle of acceptance. The overall total angle of acceptance amounts to 91^0. Truncation of the height did not result in appreciable gain in the angle of acceptance as far as the external reflectors are concerned. Table 2 shows that the angle of acceptance of the external reflectors just increased by one degree from 18 to 19^0. However, the material gain is even greater for the external reflectors because of truncation since the theoretical width of the external reflectors reduced from 1.3 m to 0.72 m.

The concentration ratio for the external reflectors is 3.6 compared to a ratio of 4.0 for the internal reflectors. This represents a 90% ratio between the external and internal reflectors. The concentration ratio, therefore, does not appreciably differ throughout the duration of absorption among the three phases. The modified CPC, therefore, provided added advantages in terms of extending the angle of acceptance of solar radiation with a reasonable close concentration ratio, thus enabling the use of the solar concentrator with comparable efficiency through a long duration of sunshine during the day. For household applications that require stationary solar installation, such modification comes in handy as sun ray tracking is not required the modified CPC continue operating for long hours during the day.

Construction of the modified CPC

A galvanized sheet metal of 1 mm thickness was used to build the reflector. In order to increase the reflection a silver tit was applied to the surface of the galvanized sheet both to the internal as well as the external reflectors. The absorber material used a mild steel of 3 mm thickness which was bent to the v shape as required. The top width is 20 cm and the sides are each 14 cm length. The absorber was painted black both inside and outside. Figure 8 shows the construction of parabolic reflector at dimension setting stage.

Fig.8. The modified CPC being constructed

The supporting frames for the reflector surface were built from 5 cm flat bars and 12 mm reinforcement bars. The frame would maintain rigidity and support during transport and use. The reflector was mounted on rectangular seater frame that allows room for adjustment which is required seasonally. Figure 9 shows the frame seater and reflector under construction.

Fig.9. The modified CPC reflector with the frame seater

In order to preserve the heat that is trapped, the top surface roof of the reflector was covered with 4 mm Perspex glass. The side walls of the reflector were covered with polyethylene sheets in order to preserve the heat generated during use. These are shown in Figure 10 and Figure 11.

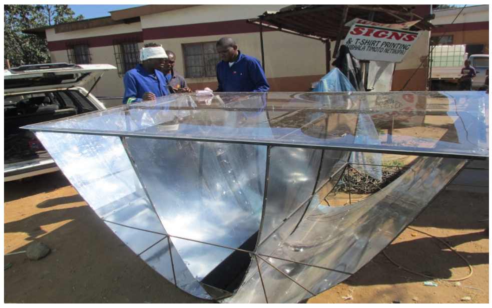

Fig.10. Perspex glass of 4 mm thickness used for the top cover

Fig.11. Sides of the reflector covered with polyethylene sheets

Once the setup was completed, it was installed in the project area where it can receive sun ray without any obstruction throughout the day. Figure 12 shows the modified CPC in its place of use.

Fig.12.The modified CPC installed at the project site

Performance evaluation of the modified CPC

The constructed modified CPC was tested for its performance over a number of activities involving sterilization of fecal matter derived from urine diversion dry toilets. Production evaporated residue after struvite precipitation of urine, grey water distillation, sterilization of composted fecal matter. Trials with liquids such as grey water distillation showed that temperature between 80 and 100^0C were attained during most hours of the solar radiation. Trials with both stored as well as composted fecal matter showed that the solid materials could attain a temperature of 70^0C which is adequate for disinfection of these waste products. Test for microbiological quality using fecal coliforms and plate count indicated that the fecal coliforms were non-detectable in both the stored fecal matter from the UDDT toilets as well as composted fecal matter (Table 3).
Experiments were made to concentrate urine products by evaporation after the ammonia and phosphate from the urine were partly precipitated as struvite using dolomite as a source of magnesium. First magnesium oxide was added to the urine and struvite was allowed to precipitate. This experiment was done on a separate container. Once the struvite precipitated, the remaining liquid was filtered with a cloth and applied to the modified CPC concentrator. The excess ammonia and water evaporate and the remaining residue is mixed with the struvite as a source of nutrient to be used for agricultural application. The process also achieves additional sterilization apart the one provided by the urine (Table 3). The process effectively combined struvite precipitation with solar concentration.

Table 3. Comparison of results of coliform test on different waste products before and after solar concentration with the modified CPC

Sample	Material status	Number of positives			MPN index / g
		10^{-1} Dilution	10^{-2} Dilution	10^{-3} Dilution	
Composted fecal matter	Before drying	3	2	0	93
	After drying	0	0	0	<3
Stored fecal matter from UDDT toilet	Before drying	3	3	0	240
	After drying	0	0	0	<3
urine after struvite precipitation	Before drying	0	0	0	<3
	After drying	0	0	0	<3
Grey water	Before distillation (10^{-3}, 10^{-4}, 10^{-5} dilutions)	3	3	2	$1.1*10^7$/100 mL
	After distillation	0	0	0	<3

Seasonal adjustment of the CPC is needed as Swaziland is located at the lower latitudes of the southern hemisphere with considerable difference in the winter and summer solstice as is shown in Figure 13. Orientation of the CPC concentrator needs to be adjusted seasonally during the different seasons. Particularly during the winter season the angle of inclination is large as can be seen from Figure 13 which requires adjustment of the concentrator so that its tilt angle faces the sun as required. The winter season is a season where the intensity of the sun radiation is low because of the greater winter solstice which further reduces the efficiency of absorption.

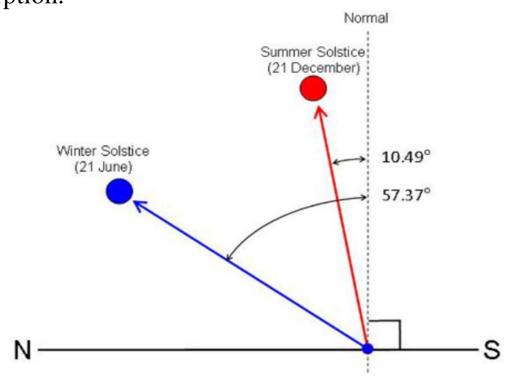

Fig.13. The variation in angle of inclination of the sun during winter and summer in Swaziland

CONCLUSION

A modification of the regular CPC design in which external reflectors that are extensions of the truncated parabolic reflectors are provided to the left and right of the regular CPC is presented and discussed. It was shown that the resulting modification increased the angle of acceptance by over 70% while the concentration ratio is within 90-100% of the value normally attained with truncated CPC. The modified setup as such allows the use of the concentrator for greater part of the day with comparable efficiency without requiring sun ray tracking. Truncation of the modified CPC to reduce the height did not appreciably reduce the concentration ratio of both the internal and external reflectors. On the other hand, through truncation of the height, the angle of acceptance of the internal reflectors doubled while for the external reflectors the angle of acceptance increased only marginally.
Two possible profiles of the absorber surface have been presented one involving a v shaped absorber and the other a flat absorber. The resulting reflector profiles differ according to the shape of the absorber used. The v-shaped absorber has greater angle of acceptance for the internal reflectors while the flat absorber has greater angle of acceptance for the external reflectors since the focal points of the internal reflectors are moved towards

the center of the absorber thus coinciding in location. Overall, the v shaped absorber offers comparatively better absorption characteristics and is simpler to construct.

For the purpose of construction the modified CPC, the formula for Cartesian rotation of coordinates has been used. The x′-y′ coordinates along the axes of symmetry are easily computed and the coordinates needed for construction in the regular x-y coordinate are obtained using the rotation of axes formula. The total length of material required is obtained by integration of the parabolic profile using the coordinates of the symmetric axes.

Experimental trials of the modified CPC were performed for the purpose of sterilization of solid waste product that are derived from stored UDDT fecal matter and composted fecal matter. In addition the solar concentrator was studied for its efficiency in distilling water from grey water as well as producing residue from urine through evaporation after struvite precipitation. The solid products were sterilized whereby a temperature of 70^0C was attained. Test for coliforms indicated that they were absent in the dried samples. The liquid samples both from grey water and urine were able to attain temperatures between 80 and 100^0C which is high enough for both distillation and obtaining evaporative residue. The combination of struvite precipitation followed by solar drying of the filtered urine liquid sample allowed obtaining a mixed nutrient that retains both the ammonia through struvite precipitation as well as other nutrients retained after the excess ammonia and water were evaporated with the sola concentrator.

The modified CPC concentrator has the potential for providing a convenient use such as for heating, sanitization of waste products and other useful applications that require stationary use of the solar concentrator without requiring tracking of the sun.

REFERENCES

[1]. Mansi, G. S., Dr.P.K.Shah, P.K., India, M.P., M.P. (2013). Design and development of compound parabolic concentrating solar collector with flat plate absorber. International Journal of Innovative Research in Science, Engineering and Technology, Vol. 2, Issue 8.

[2]. Sanchez, M., Martinez, I.G., Rincon, E.A. and M.A. Duran (2014). Design and thermal-optic analysis of an ultra-solar concentrator. Energy Procedia;:57, 311 – 320

[3]. Winston, R. (1974). Principles of solar concentrator of a novel design. Solar Energy, Vol. 16, pp. 89-95, 1974.

[4]. Baranov, V. K. (1965[a]). Opt. Mekh. Prom. 6, 1–5. A paper in Russian that introduces certain properties of CPCs.

[5]. Baranov, V. K. (1967). Device for Restricting in One Plane the Angular Aperture of a Pencil of Rays from a Light Source” (in Russian). Russian certificate of authorship 200530, specification published October 31, 1967.

[6]. Baranov, V. K., and Melnikov, G. K. (1966). Study of the illumination characteristics of hollow focons. Sov. J. Opt. Technol. 33, 408–411.

[7]. Ploke, M. (1967). Lichtführungseinrichtungen mit starker Konzentrationswirkung. Optik 25, 31–43.

[8]. Hinterberger, H., and Winston, R. (1966[a]). Efficient light coupler for threshold C ˇerenkov counters. Rev. Sci. Instrum. 37, 1094–1095.

[9]. Hinterberger, H., and Winston, R. (1966[b]). Gas counter with optimized light-collecting efficiency. Proc. Int. Conf. Instrum. High Energy Phys. 205–206.

[10]. Winston, R. (1970). Light collection within the framework of geometrical optics. J. Opt. Soc. Am. 60, 245–247.

[11]. Smestad, G., Ries H., Winston, R. and Yablonovitch, E. (1990) The Thermodynamic Limit of Light Concentrators. Solar Energy Materials 21, 99-111.

[12]. Winston, R., and Hinterberger, H. (1975). Principles of cylindrical concentrators for solar energy. Sol. Energy 17, 255–258.

[13]. Harper, D. A., Hildebrand, R. H., Pernlic, R., and Platt, S. R. (1976). Heat trap: An optimized far infrared field optics system. Appl. Opt. 15, 53–60.

[14]. Rabl A. (1976[a]). Comparison of solar concentrators. Solar Energy. Vol. 18, pp. 93.

[15]. Rabl A (1976[b]). Optical and thermal properties of compound parabolic concentrator. Solar Energy; 18:497–511, 1976.

[16]. Winston, R., C., Juan C. and P. Benítez. (2005). Non-imaging optics. Elseveier Academic Press, 497 pages

[17]. A. Rabl. A. (1985) Active Solar Collectors and Their Applications. 503 p. Oxford University Press, New York. 1985.

[18]. Mallick, T.K. (2003). Optics and heat transfer for asymmetric compound parabolic photovoltaic concentrators for building integrated photovoltaics. Ph.D. Thesis. Faculty of Engineering, University of Exeter.

[19]. Rönnelid, M., & Karlsson, B. (2003). Optimised truncation of a wide acceptance angle CPC. Proceedings of ISES Solar World Congress 2003 in Gothenburg, Sweden.

[20]. Nilson, J. (2005). Optical Design and Characterization of Solar Concentrators for Photovoltaics. Division of Energy and Building Design. Department of Architecture and Built Environment Lund University. Faculty of Engineering LTH, Report EBD-T--05/6.

[21]. APHA. (1989) Standard Methods for the Examination of Water and Wastewater. 17th Edition, American Public Health Association, Washington D.C., 1,268 pp.

[22]. United States Department of Agriculture (USDA) (2014). Most Probable Number Procedure and Tables. Food Safety and Inspection Service, Office of Public Health Science, Georgia, USA.