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OPTICAL ANALYSIS OF VARIOUS REFLECTORS APPLIED IN SOLAR BEAM DOWN TOWER

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ABSTRACT

The concept of the reflective solar tower is based on the reflection of the solar radiations from heliostats toward reflective mirror at the top of the tower and then redirected the radiation to one of its foci on the ground. This new arrangement would allow setup the energy collection at the ground level; hence the heavy tower top setup is avoided. For the suggested beam down solar tower located at Universiti Teknologi Petronas, three reflective shapes are examined, i.e. ellipsoidal/concave, hyperboloid/convex and a flat surface. A comparative study is carried out using lightXlab simulation platform to investigate the effect of focal point distance on the radiation spread at the ground level and the effect of angle change of the second reflector on the radiation concentration as well as the beam travel. The results of the simulation showed that the flat surface reflector is having superiority and better control over the other two reflectors, in terms of beam concentration and beam travel.

Keywords: concentrating solar power, reflective solar tower, ellipsoidal and hyperboloid mirror, heliostat, beam down mirror.

INTRODUCTION

Concentrated solar power (CSP) systems use thermal energy storage (TES) [1, 2 and 3] at a cost much lower than that of the electrical storage options currently available. However, opportunities exist to improve TES implementations in terms of transport energy and heat exchanger exergy losses.

As for the conventional concentrating solar tower, solar energy from a large group of heliostats is concentrated onto a tower which picks up the heat by a receiver, and then using a steam generator and a steam turbine converts that heat to electricity. However, it is expensive in terms of constructing tower. Besides, the thermal and optical losses are considerable in order to overcome these shortcomings, it has been proposed a beam-down optical system [4], where a second set of beam-down concentrator directs the solar radiation back to a central receiver (CR) placed on the ground.

Very few teams in the world were interested in the concept, such as Weizmann Institute of Science [5] and Masdar Institute (Abu Dhabi), developed by the Tokyo Institute of Technology [6]. This is a multi-ring reflector developed under the Tokyo Tech-Cosmo-Masdar project. This reflector is made multiple hyperboloids of having the same focal points, represents a multiple reflector cup rings. The advantages put forward are numerous [7], (A lighter structure, better ventilation, reduction in wind resistance, better cooling of mirrors and Lower cost). These studies give their performance comparable to conventional power tower plants [8, 9] for a construction cost well below.

Segal and Epstein [10, 11 and 12], described the effect of using two types of secondary mirror reflectors, i.e. elliptical and hyperbolical for a comparative performance analysis. Their analysis revealed that, to reach a similar level of radiation concentration, elliptical reflectors require higher tower and larger size then the hyperboloid reflectors.

The objective of this study is to examine the suitability of various reflector shapes and height of the tower for the existing heliostat field, at UTP solar site, for a minimum radiation spread and low beam travel through air.

UTP heliostat field layout

To perform this study, solar research site at the University Technology PETRONAS was selected. The solar field is in the city of Bandar Seri Iskandar, Perak, Malaysia and is at global coordinates of 4^{o} N-latitude, 100^{o} E-longitude.

Initial investigations of the heliostat field led to a determination of 12 heliostats to be utilized in simulating the facility. The reflectivity established for the heliostat is the same as that specified for the down beam reflector, i.e. 89% specular. Heliostats of collective reflective surface area 45 m^2 were selected for modeling of the facility, distributed as shown in Figure-1, the distance between the tower and first row of heliostats is 10 meters, where is, the inter-row distance is 3.5m. The reflection area of each mirror is 3.75 m^2.

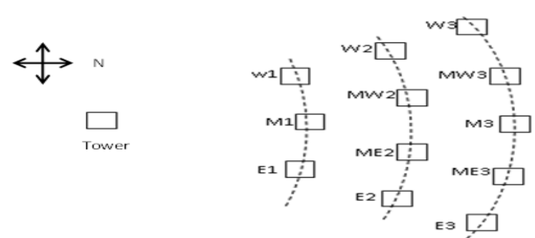


Figure-1. Schematic distribution of heliostats in the field (UTP Heliostat field) sketch not to scale.

Optical simulation approach

A number of simulation software are available to simulate the optical phenomena, i.e. Soltrace, lightXlab, etc. In this study, the lightXlab optical simulation platform is used to compare the performances of solar beam down tower using three types of reflectors. Different optical formations for beam down systems have been studied. The optical comparison of hyperboloid, ellipsoidal and flat shaped mirrors, is conducted.

The establishment the stages was to identify the position and orientation of all reflecting mirrors which need to be described as input parameters in the ray tracing simulation as follows:

- The heliostat is a primary mirror installed on a two axis sun tracking mechanism, to maintain maximum level of solar concentration at a target point.
- LightXlab software requires the distances between primary and secondary mirror, angles of reflection of both the mirrors and focal point of curved in towers.

The main parameters affecting the performance of the plant are shown in Figure-2. The simulation analysis is mainly prepared for the two cases. The first case is for the effect of the focal point distance on the radiation spread (w), and the second case is for the effect of reflector's tilt angle on the concentration of radiation at ground.

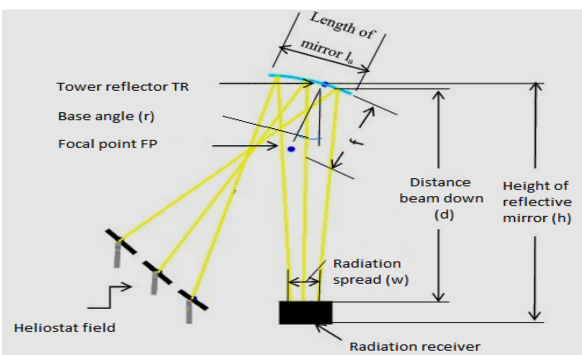


Figure-2. Schematic diagram showing parameters of interest for beam down solar tower.

Simulating the reflection using tower reflector

Different optical formations for beam down systems have been simulated. Optical comparison of hyperboloid, ellipsoid and flat shaped beam down mirrors was conducted. The analysis has been categorized into two distinct cases:

Case-1: Effect of focal point distance on the radiation spread (w) at the ground level:

To simulate the beam down tower, the height of reflector on the tower is assumed at 16 meters and three different focal lengths have been tested i.e. 4, 8 and 12meters.

In case of elliptical mirror, focal point lies between the mirror and the ground and the effect of changing the focal length is visible in Table-1. By increasing the focal length, the spread of radiation increases on the ground, which is not required, i.e. the radiation need to be focused on the ground. On the other hand, the beam travel increases due to increase in focal length, which obviously would increase the optical losses, as shown in Figure-3.

In case of hyperbolic mirror, the radiation spread is squeezing with the increase of focal length, whereas the beam travel does not have significant effect. The above two effect are shown in Table-1 and visualized in Figure-4.

Case-2: Effect of reflector angle change on radiation spread and beam travel through air:

Since the idea of beam down reflective tower is to reflect the solar beams twice in such a way that they have minimum spread and are focused at a certain point on the ground.

In case of elliptical mirror reflector, the increase of mirror angle with the vertical would defocus the radiation on the ground, whereas in case of similar angular movement of hyper bolide mirror reflector, the image motion is slow but still the radiation spread is widening. However, in case of flat (straight) mirror, an increase of mirror angle with the vertical line would move the image on the ground, a bit slow and the radiation spread in also very slow, i.e. the effect of angle change of mirror would not be effecting the concentration and location of the image on the ground seriously.

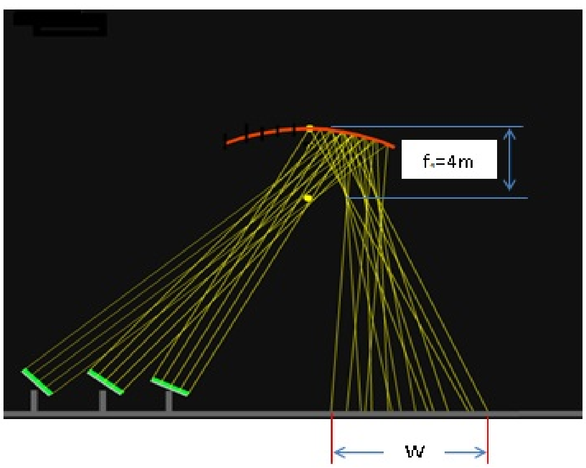
Figure-5 shows simulation results for three types of a hyperbolic, elliptical and flat beam down mirrors. Simulations showed that the change of reflective mirror angle for three configurations lead to optimize the radiation spread. Changing the mirror reflector angle from the horizontal position to angle 15^0 and 25^0 for elliptic and hyperbolical mirror would lead to reduce of radiation spread percentage up to 52% and 36% respectively. While comparing the two reflective mirrors with that of the flat mirror, it is clear that the radiation spread on the ground is minimum i.e. 2.6 meter as compared to 5.5meters and 6 meters for ellipsoidal and parabolic mirror respectively [13].

Table-1. Characteristics of the beam down ellipsoidal and hyperboloid mirrors for various focal lengths.

Solar tower system	Ellipsoidal mirror			Hyperboloid mirror		
	f_1= 4m	f_2=8 m	f_3=12m	f_1=4 m	f_2=8 m	f_3=12m
Radiation spread (w)	9	10	11.5	16	10.5	9.5
Distance beam down (d)	17.5	18.5	21	17.5	17	18.5
Arc Length (l_a)	5	5.5	5.5	4	4.5	5
Height of reflective mirror(h)	16	16	16	16	16	16

Table-2. Comparison of characteristic parameters for three beam down mirror shapes for optimum conditions. (f=12m).

Solar tower system	Ellipsoidal mirror	Hyperboloid mirror	Flat mirror
Radiation spread (w)	5.5 m	6 m	2.6 m
Beam travel in air (d)	16.5 m	17 m	18 m
Length of mirror (l_a)	4.5 m	4.5 m	5 m
Height of reflective mirror(h)	17 m	17 m	18 m
Optimum mirror angle(r)	15°	25°	14.5°



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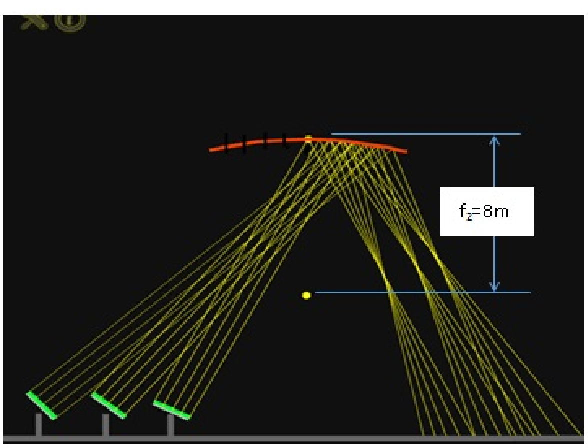

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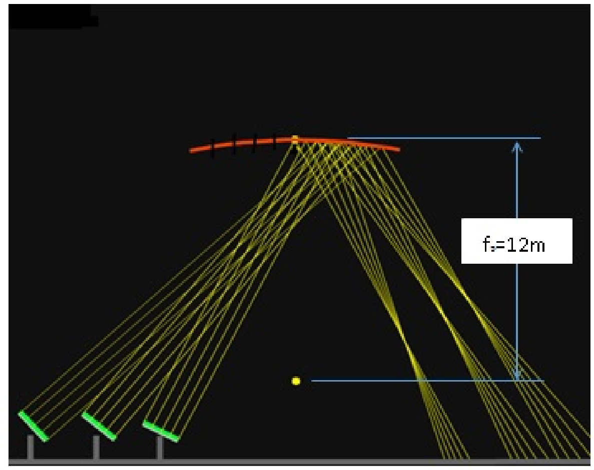
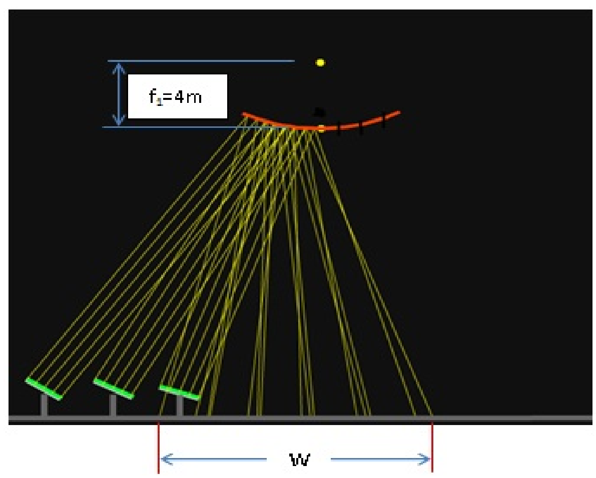


(c)

Figure-3. Effect of curvature of concave lens on beam down radiation spread.



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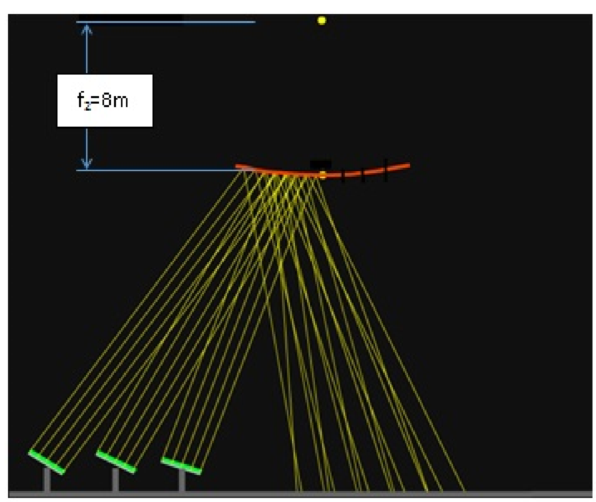

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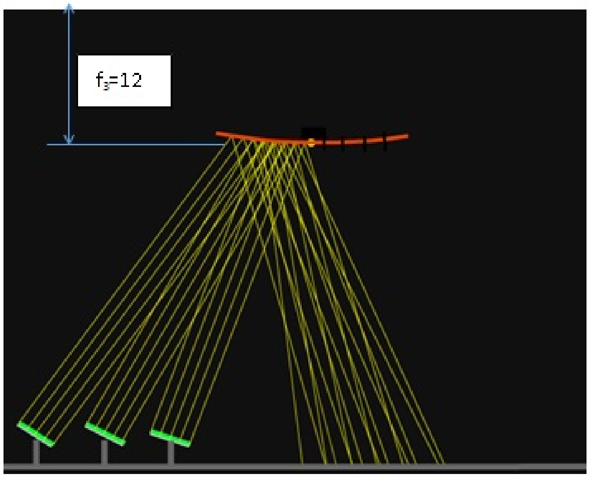

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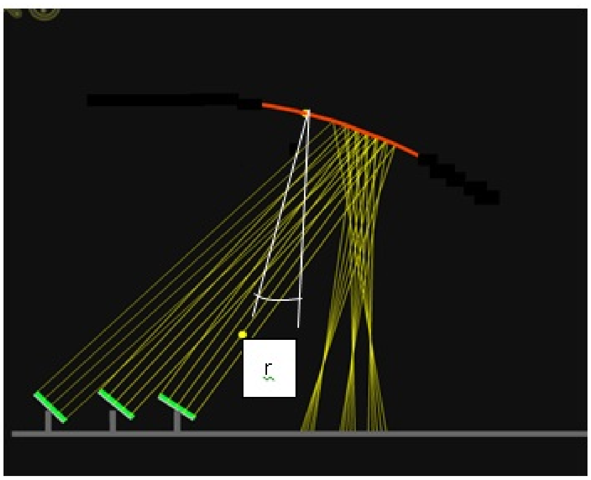
Figure-4. Effect of curvature of concvex lens on beam down radiation spread.



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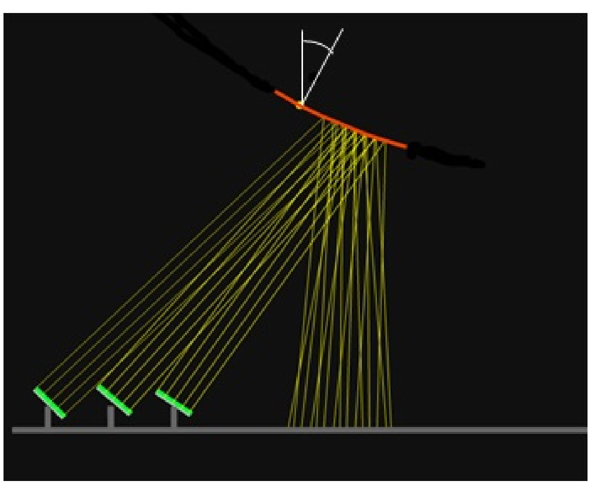

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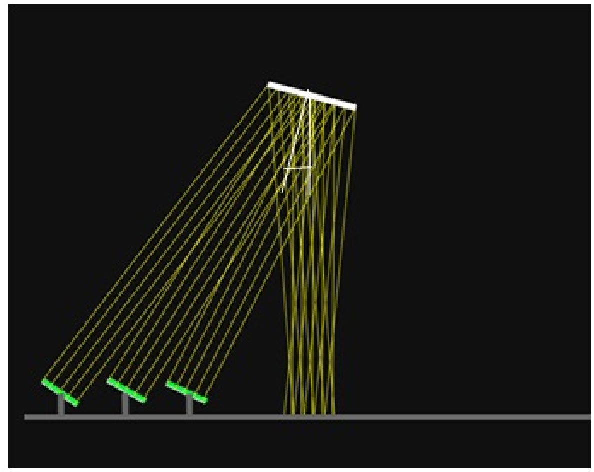

(c)

Figure-5. Effect of the secondary mirror reflector angle on the concentration area for (a) elliptical, (b) hyperbolic and (c) flat down beam mirror.

Proposed design

On the basis of above discussion, schematic design of the beam down solar tower facility at UTP solar research site is proposed and shown in Figure-6. The main characteristic of the design is to get the radiation on the ground with a minimum spread and also with a minimum optical loss.

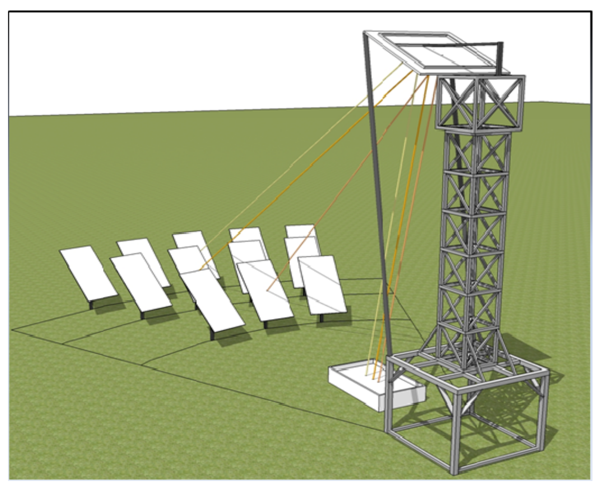

Figure-6. Conceptual design of solar site layout at UTP, for beam down tower.

CONCLUSIONS

On the basis of above discussion, the following are the main conclusions of the research.

- Flat mirror has 50% less radiation spread, as compared to elliptical and hyperboloid mirror.
- Effect of change of angle on the image size and location is different for different types of mirrors. Flat mirror again has less effect on the shape and location of the image on the ground.

- Availability, replace ability and cost are good for a flat mirror.

Thus, the flat plate mirror is the best option to be used as a second reflector, to focus the radiation on the ground. Due to its easy handling and replace ability, it offers better control over the image.

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