

DETERMINING THE OPTIMUM FOCAL HEIGHT OF A PARABOLIC TROUGH CONCENTRATOR USING AN OPTICAL METHOD

M. P. S. Viraj¹, P. D. C. Kumara^{2*}, and H. H. E. Jayaweera³

² Institute of Technology University of Moratuwa, Sri Lanka

^{1,2,3} Centre for Instrument Development, Department of Physics, University of Colombo, Sri Lanka

¹ Department of Physics, University of Bologna, Italy

sameera.malwaththa@studio.unibo.it¹, ckumara@itum.mrt.ac.lk^{2*}, hiran@phys.cmb.ac.lk³

ABSTRACT: This study investigates the optimal focal height of a Parabolic Trough Concentrator (PTC) solar thermal plant, a key parameter affecting its overall performance. The dimensions of the PTC module are 4.5 m × 4.8 m with an aperture area of 20.3 m². Unlike diffuse solar systems, the effectiveness of a concentrated solar thermal plant is highly dependent on factors such as the parabola's concentration ratio and geometrical parameters. This paper presents an optical/photographic approach to determine the optimum focal height of the PTC while harnessing solar thermal energy. The findings highlight the importance of maintaining accurate geometric parameters over time due to structural deformations, environmental conditions, and aging effects. The theoretical focal height of the PTC module was calculated as 1700 mm at the design stage. A laser scanning mechanism revealed that the actual focal height of the PTC module was 1830 mm after manufacturing, when the parabolic reflective mirror was rotated to point towards the ground, and the laser pointers were fired vertically upwards to ensure they were perpendicular to the focal plane. A digital single-lens reflex (DSLR) camera was used to capture the focused solar concentrated beam on the target board. The findings verified that the optimum focal height of the PTC module is 1675 mm while harnessing solar thermal energy.

Keywords: optical methods, optimum focal height, parabolic trough concentrator, solar thermal energy, thermal distribution measurement

1. INTRODUCTION

The Parabolic Trough Concentrator (PTC) plant at the University of Colombo premises measures 4.5 m × 4.8 m × 3.0 m, and the weight is calculated as 2.5 Tons (See Fig. 1). The effective aperture area of the PTC is designed to be 20.3 m². The thermal energy harnessing capacity of PTC was calculated as 18.2 kW by considering the solar irradiance as 900 kW/m². The main objective of this research study is to experimentally determine optimum focal height of the PTC module and investigate the variation of focal height due to structural deformations, environmental conditions, and aging effects.



Fig. 1. PTC plant at the faculty of Science, University of Colombo

The precise optical geometry of the PTC systems will be maximizing its energy harnessing efficiency. Factors like aperture size, rim angle, focal height, and mirror surface quality significantly impact their performance (Meiser *et al.*, 2017). Even minor deviations in these parameters can lead to substantial losses in the optical efficiency of the PTC system (Arun *et al.*, 2024). This paper

discusses an optical method using photographic analysis to determine the optimal focal height for a PTC plant.

2. METHODOLOGY

This PTC module was designed to maintain the theoretical focal height of 1700 mm when the rim angle was 80° according to the scale of the PTC module (Brooks and Harms, 2014; Mwesigye, Bello-Ochende and Meyer, 2014; Good *et al.*, 2016; Murtuza *et al.*, 2017) and mirrors were constructed by using 3M reflective mirror films with more than 93% reflectance over 14 years (3M, 2017). A railing platform was fabricated to investigate focusing performance of the parabolic shape reflectors and get the actual focal height of the PTC module. A laboratory optical bench was modified with four numbers of nylon wheels to facilitate moving on the railing. A mild steel box iron of 2 inch \times 2 inch and 8 feet of length was placed on the optical bench with the mountings, and 8 number of red (680 nm) diode laser pointers were mounted to the box iron with three degree-of-freedom mounting with the linear moving facilities to maintain the high accuracy of evaluation of parabolic shape and the measurement of actual focal height (Fig. 2A). The parabolic reflective mirror was rotated to point towards, the ground, and the laser pointers were fired vertically upwards to ensure they are perpendicular to the focal plane. This allows us to assume that the laser beams mimic the solar beam when the mirror points toward the sun. A target board was placed on the focal line parallel to the focal plane. The ideal focus (zero deviation) line was at the middle and edges of the \varnothing 70 mm receiver tube was in both sides of the ideal line (Fig. 2B). The scanning was done along the centre axel for both sides of the parabola while varying the focal height. This method was used to measure the actual focal height of the PTC module.

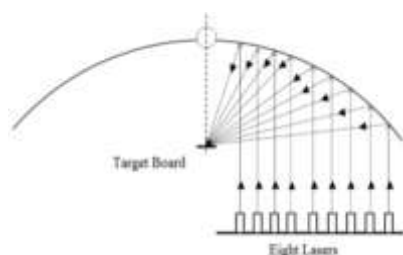


Fig. 2A. Laser scanning along the axial direction of the PTC

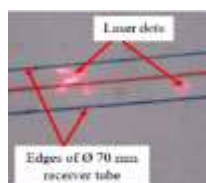


Fig. 2B. Reflected laser beams on target board



Fig. 2C. Photograph of laser scanning mechanism developed to measure the actual focal height of the PTC module

Even though the PTC module was evaluated with the above mechanism in theoretical condition, the practical values of the focal height and the rim angle can be differed while harnessing solar energy, due to the weight of the mirror corners, wind load, and loss of the strength of the structure. Therefore, measuring the deviation and making the necessary corrections to keep the PTC in optimum focus is crucial. The following optical method was developed to measure the optimum focal height at the running condition.

An optical technique was introduced with the use of a Digital Single Lens Reflex (DSLR) camera (Canon EOS REBEL T6i) with an EF-S 18-55 mm lens. The camera was used to take photographs of the focused solar beam falling on the target plane. A white colour-washed asbestos sheet served as the target board with black reference markings to assist in analysing the intensity distribution of the concentrated beam (Fig. 3). Photographs were taken at the six different heights used in the thermal distribution experiment, with the following camera settings: aperture - $f/22$, shutter speed - $1/3200$, ISO - 100. The captured images are then processed to get the intensity distribution across the focused beam to identify the best focal line.



Fig. 3. Prepared target board with white and black references

3. RESULTS AND DISCUSSION

The PTC module's primary function is to focus direct solar radiation onto the receiver tube. Therefore, it is essential to position the receiver tube on a precisely focused plane. For this, the right focal height of the parabola must be determined. According to the system's design specifications, the theoretical focal height of the parabola was predicted to be 1700 mm. Through the laser scanning mechanism revealed that actual focal height of the PTC module as 1830 mm after manufactured. This difference might be caused due to the deformations of the structure and tolerances in the manufacturing processes. However, the PTC module's primary function (module efficiency) is mainly dependent on the optimum focal height while harnessing solar thermal energy. As a solution for this, experimental setup was devised to determine the optimum focal height by analysing the intensified distribution of the images taken at different heights when the system is harnessing the solar thermal energy.

The experiment was conducted to find the ideal focal height by evaluating photographs of the focused beam at each test height. Fig. 4A depicts photographs of the concentrated beam at six distinct test heights, whereas Fig. 4B illustrates the intensity distribution across the concentrated beam for each set of images. The identical camera settings and equipment as mentioned in methodology were used for all photos, and perception error correction and scaling were performed prior to analysis.

Although the photos provide a clear visual representation of the focal height of the PTC, the full width at half maximum of the Gauss curves fitted to the intensity data was calculated to scientifically prove it. The graph below depicts the behaviour of those determined FWHM values of fitted Gaussians. According to those FWHM values (Fig. 5), the narrowest intensity distribution was obtained at 1675 mm height, which confirmed the results of the previous experiment as well.

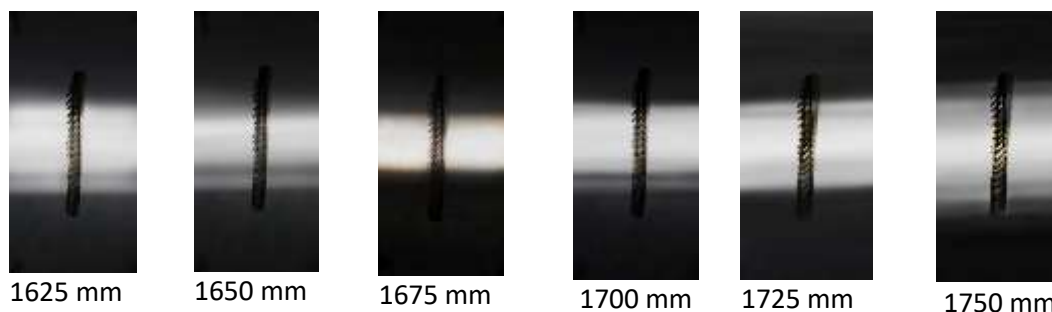


Fig. 4A. Photographs of the concentrated beam at six test heights. Please note that the perception error correction and scaling were done before analyzing the images

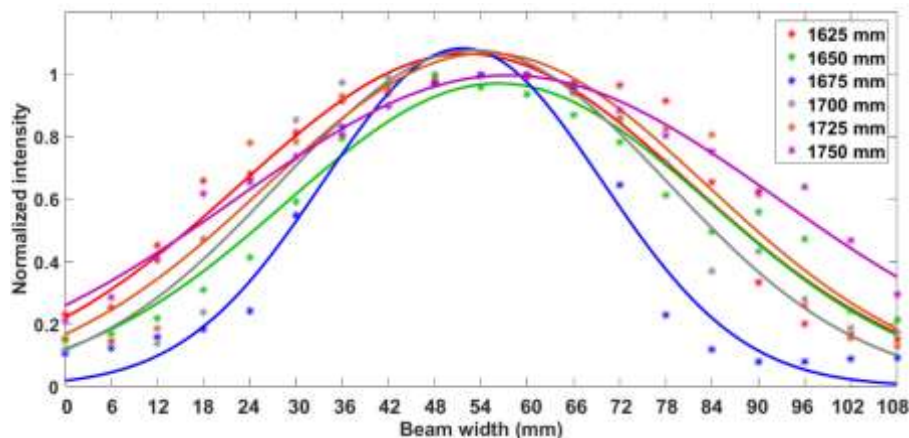


Fig. 4B. Intensity distributions of analyzed images of focused line

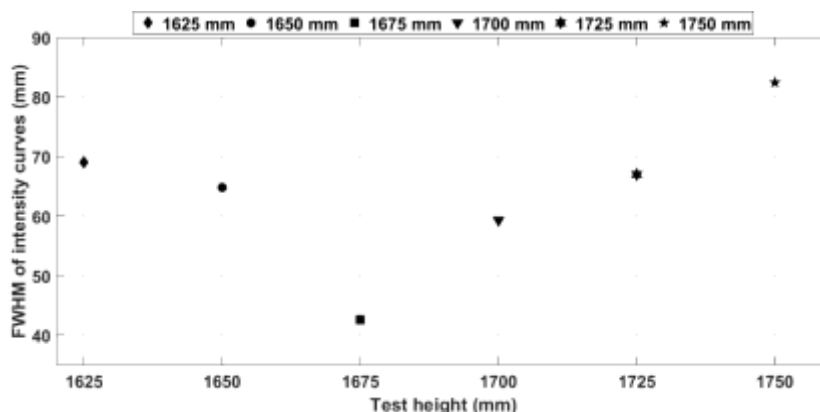


Fig. 5. Full width at half maximum values of intensity distribution curves of each test height

4. CONCLUSION

The optimal focal height of the PTC was obtained by analysing images of the concentrated beam. So, the optimum focal height for the PTC was found to be 1675 mm while harnessing the solar thermal energy. At this height, the system also reached its highest temperature. The PTC consists of two reflector mirrors, and it was also found that there is no difference in the focal height of each segment. Moreover, this investigation also discovered that the maximum beam width with more than 50% intensity at the focal height is 50 mm.

5. REFERENCES

3M (2017). Technology reduces costs, enables new designs for concentrating solar power systems, Retrieved from <http://news.3m.com/press-release/company/3m-launches-3m-solar-mirror-film-1100>.

Brooks, M.J. and Harms, T.M. (2014). Design, construction and testing of a parabolic trough solar collector for a developing-country application. Retrieved from <http://scholar.sun.ac.za/handle/10019.1/37173?show=full>.

Good, P., Ambrosetti, G., Pedretti, A. and Steinfeld, A. (2016). A 1.2 MW (th) solar parabolic trough system based on air as heat transfer fluid at 500 °C: Engineering design, modelling, construction, and testing. *Solar Energy*, 398-411.

Meiser, S., Schneider, S., Lüpfert, E., Schiricke, B. and Pitz-Paal, R. (2017). Evaluation and assessment of gravity load on mirror shape and focusing quality of parabolic trough solar mirrors using finite-element analysis. *Applied Energy*, 185, 1210-1216.

Murtuza, S.A., Byregowda, H.V., Ali, M.M. and Imran, M. (2017). Experimental and simulation studies of parabolic trough collector design for obtaining solar energy. *Resource-Efficient Technologies*, 414-421.

Mwesigye, A., Bello-Ochende, T. and Meyer, J.P. (2014). Minimum entropy generation due to heat transfer and fluid friction in a parabolic trough receiver with non-uniform heat flux at different rim angles and concentration ratios. *Energy*, 1-12.

Pratap, A., Rathod, S., Gowri, R., Adhikari, A. and Dubey, V.P. (2024). Factors affecting the efficiency of solar harnessing systems: a brief review. *2024 International Conference on Automation and Computation (AUTOCOM)*.