A new parabolic trough solar collector

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ABSTRACT

This paper presents a new parabolic trough array designed to provide the thermal energy required to drive a organic rankine cycle (ORC) power generation system. The parabolic trough collectors have been installed in the National Solar Energy Centre at CSIRO Energy Technology in Newcastle, NSW. They consist of four rows of 18 mirrors each in a 2x2 matrix with a total aperture area of approximately 132m^2. The mirrors reflect the sun's irradiation onto a laterally aligned, 40mm copper absorber tube which has been coated with a semi-selective paint. The absorber operates in a 50mm non-evacuated glass tube to minimize convection losses. Thermal oil is circulated inside the absorber tube, and transfers the heat to a ORC FP6 unit sourced from Freepower Ltd. in the United Kingdom.

The mirror modules were developed and fabricated by the ANU Solar Thermal Group using thin low iron back silvered glass bonded to a sheet steel substrate. The support structure was developed as a collaborative effort between CSIRO Energy Technology and ANU. It features a box truss supported on semi circular hoops running on rollers for single axis tracking. The trough array is actuated by a PC-controlled stepper motor to achieve the desired target angle.

Before installation of the trough array, the optical performance was investigated with regard to the flux mapping onto the receiver tube. This paper presents results for irradiation capture and intensity over the receiver width of a single trough module.

1. INTRODUCTION

CSIRO has recently celebrated the opening of Australia's National Solar Energy Centre on site at its' facility located in Mayfield West, Newcastle NSW. As part of this facility, to develop efficient new methods of capturing and harnessing solar heat for combined heat and power generation (CHP), CSIRO has built a solar thermal parabolic trough collector field which will produce 80kW$_{th}$ at 1000W/m^2 (beam irradiation) at temperatures up to 280^{o}C. It is intended for the array to be used not just for a variety of ongoing R&D purposes, but also as demonstration of an array that can be promoted as an integral part of various solar thermal systems. Active commercialisation of near-term solar applications through industry is an important part of the Centre's objectives. Eventual applications are envisaged for both distributed generation (i.e. sited in appropriate locations in suburban communities) and remote power and energy. The array is designed to drive a small Organic Rankine Cycle unit with a power output of 6kW$_{el}$ from Freepower Ltd (an FP6 system). The trough collectors were designed by the Australian National University Solar Thermal Group, working in collaboration with CSIRO Energy Technology staff, as a low-cost and light weight system.

2. SYSTEM DESCRIPTION

The solar collectors are located at CSIRO Solar Energy Centre in Newcastle at a latitude of 32^o 56' S. The nominal design point operating conditions are:

- 1000 W/m^2 beam radiation
- Solar noon at summer solstice
- Inlet temperature of heat transfer fluid of 110±5^{o}C and outlet temperature of 240±5^{o}C.
- 25^{o}C ambient temperature
- wind < 3m/s
- heat transfer fluid Mobil M-Therm™ 605 98FV95.

The nominal output required for operation of the FP6 ORC unit is 80 kW_{th} at field exit. The system has been designed to provide an output greater than 80kW_{th} at the design point. The troughs have been mounted on concrete footings in the ground, aligned in east-west direction. See Figure 2.1 for a view of the array.

Figure 2.1 View of parabolic trough arrays at CSIRO

The FP6 ORC sourced from Freepower Ltd in the UK is shown in Figure 2.2. Details of the operating performance can be found in (Freepower 2006).

Figure 2.2. Freepower FP6 ORC unit at CSIRO

The mirror panels are an improved version of those used on the trough mirrors deployed on the demonstration concentrating Photovoltaic “Combined Heat and Power” system at ANU (Coventry 2005). The reflective surface of the mirror panels is a glass on metal laminate (GOML) which has been elastically deformed to a parabolic profile. The curvature is maintained by stamped tabs along the edge of the laminate. A patented mirror panel manufacturing process (Johnston and Lovegrove 2002), developed at ANU, is used to correct the large amount of spillage which would otherwise occur at the edge regions of the panel, as a consequence of the elastic deformation. The overall panel size is approximately 1620 mm wide by 1190 mm long. The mirrors are low iron, back silvered 1mm drawn glass, with a reflectivity of 94%. Table 2-1 gives details on the trough array. Physical characteristics of this mirror design are:

(i) Impact resistance: sufficient to withstand hail damage, handling and transport,
(ii) Abrasion resistance: sufficient to withstand sand blast in dust storms and cleaning. This is an important requirement in the Australian outback.
(iii) Rigidity: sufficient to withstand large wind loads.
(iv) Corrosion resistance: the laminate structure protects the silvered surface from exposure to moisture and subsequent corrosion.

Table 2-1. Trough details

Mirror aperture	mm	1548 (chord width) x 1186 (length)
Number of mirrors	-	72
Total reflector area	m	132
Specific weight (per aperture area)	kg/m^2	11.5
Reflectivity	-	0.94
Concentration factor Actual Geometric	- - -	 32:1 30:1
Thermal power output	kW_{th}	80 (nominal)
Tracking mechanism	-	1-axis, software-controlled

The basic 1.5m chord width panels can be made to a range of shapes and focal lengths which allows trough systems to be configured in a number of ways as shown in Figure 2.3

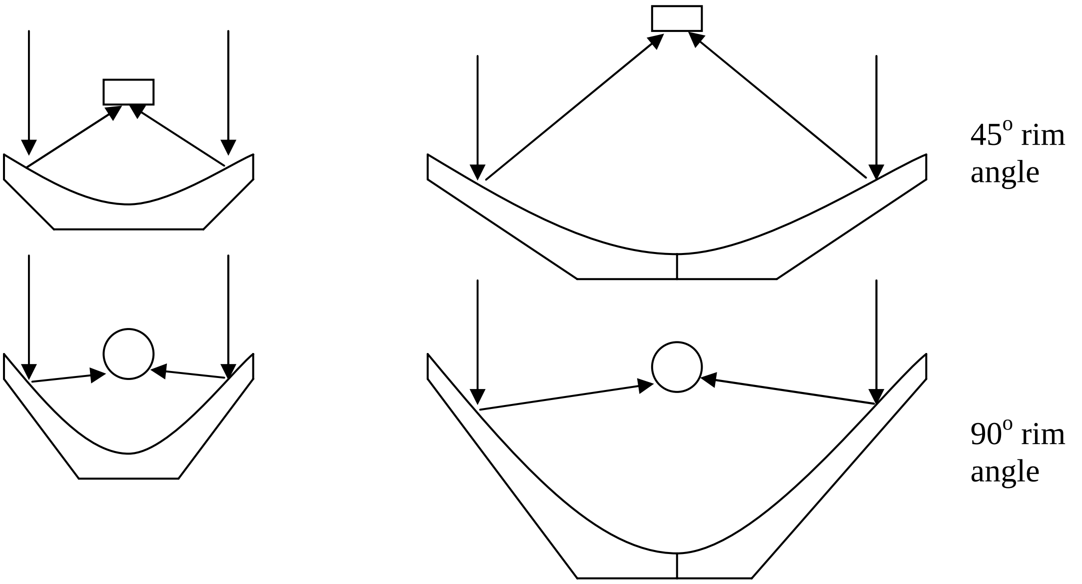

Figure 2.3 Possible trough mirror configurations based around single or double use of the ANU mirror panel type.

For the CSIRO system an approximate 45° rim angle system was chosen to allow either cavity or cylindrical type receivers to be tested. The mirror frame of the CSIRO system is a box truss supported on semi circular hoops. It has been designed for maximum torsion rigidity using Finite Element Analysis (FEA). The hoops of the frame run on metal roller wheels mounted on elevated supports. For the CSIRO system, the mirrors can be turned 80 deg north and 10 deg south at maximum limits. See Figure 2.4 for details. This angular tracking range can be varied by moving the location of the roller wheels according to the site and application.

Figure 2.4 View of box frame, hoops and roller wheels

A central receiver tube is mounted on supports at the end of each mirror element. The absorber tube consists of a laterally aligned, 40mm copper tube which has been coated with a semi-selective paint.

The absorber operates in a 50mm non-evacuated glass tube to minimize convection losses. The absorber tube is supported and centered using high-temperature resistant Viton[tm] seals inside the glass tube. Figure 2.5 shows both absorber and glass tube at the end of the array.

Figure 2.5 View of absorber tube inside glass tube

Each trough row is actuated by a microcontroller based controller which measures the angle of the trough using an incremental inclinometer and drives a stepper motor to achieve the desired target angle. The controllers receive the position of the sun from a PC program via serial communications. The stepper motor drive is reduced by a gearbox to drive the trough through a roller chain around the diameter of the trough.

3. OPTICAL PERFORMANCE RESULTS

Before installation of the trough modules the optical performance was investigated using flux mapping using the following methodology. A Kodak / Redlake ES1.0 10 bit black and white video camera is mounted on a rail near the vertex of a single module, which is aligned to point directly at the sun (i.e. 2 axis tracking). A series of images were taken of a 160mm wide target mounted at the focal plane, fabricated from aluminum sheet coated with matt white high temperature paint. Images were captured and stored on a PC using a PIXCI frame grabber card and Xcap-Lite software. Subsequent post-processing is carried out in software written in IDL 6.1, based on programs originally written by G. Johnston. The software perspective corrects and joins the individual images (each with a processed area at the focal plane of 200 x 150mm).

No measurements were made of insolation or of point flux intensities on the target. The composite image was scaled by integrating the total power (in camera bit levels) and comparing it to a calculated power in watts based on the geometry of the trough, the mirror reflectivity, and an insolation of 1000 W/m^2. The technique has the advantage of being relatively simple and low-cost. However it is limited in accuracy by the scaling technique, which assumes that in at least one of the 200 x 150mm fields 100% of the reflected flux falls on the target. The process also makes the assumption that the illumination of the target by diffuse radiation is uniform, as a constant background level is subtracted from the composite image. Circumsolar radiation reflected onto the target cannot be distinguished from direct beam radiation, which will tend to cause the quality of the optics to be underestimated.

There is insufficient information in the images of the planar target to fully reconstruct the irradiation on a cylindrical receiver; the flux capture can only be determined for a receiver with a planar aperture. However an estimate of the true capture can made by processing the image for a hypothetical planar receiver with an aperture width slightly greater than the absorber tube of the actual receiver (50mm versus 40mm in this case). A further source of error, in determining the flux incident on the actual receiver, is that the flux mapping target is significantly wider than the receiver tube, so that there is increased shading of the mirror.

Results for a typical mirror panel are shown in the figures below.

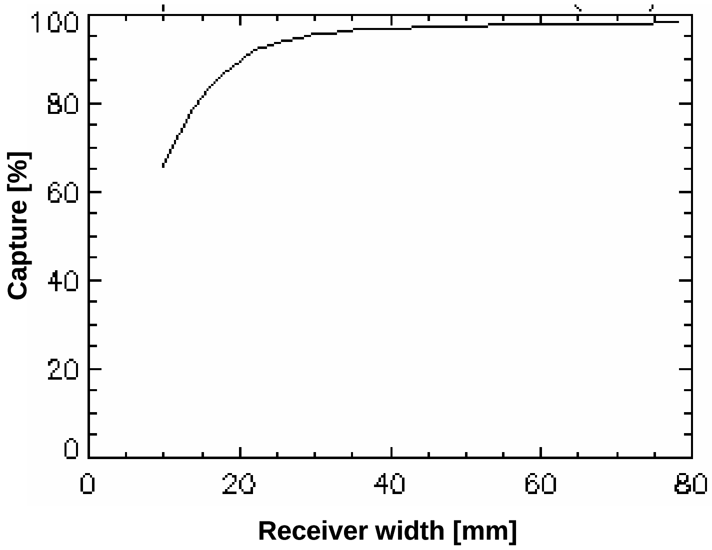

Figure 3.1 Capture vs receiver width

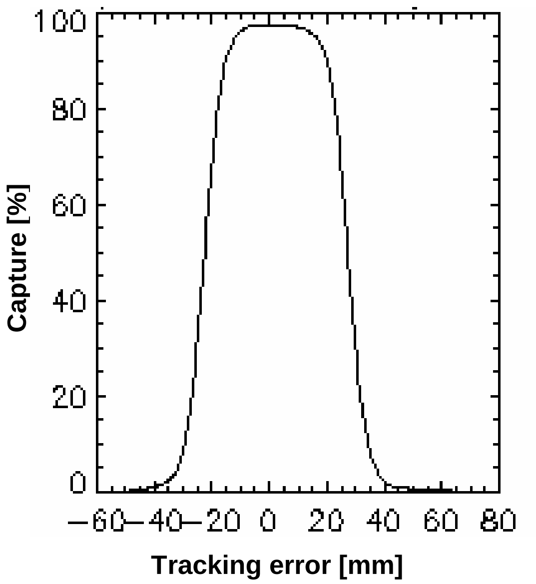

Figure 3.2 Capture vs tracking error at the target plane

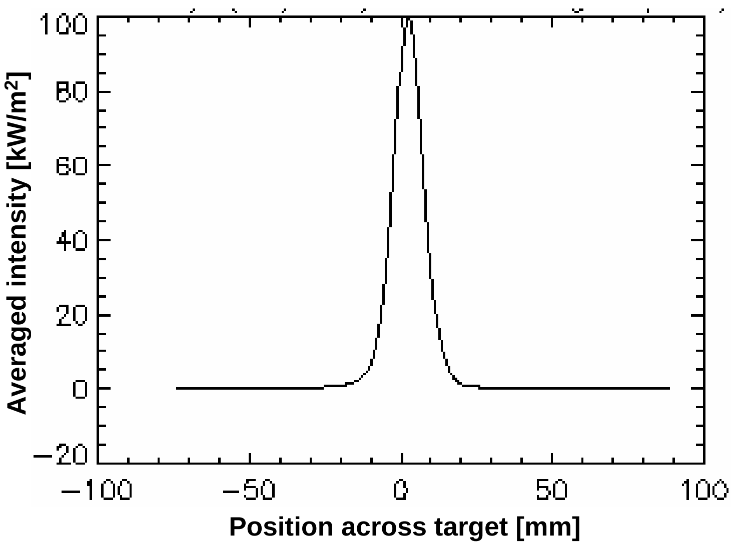

Figure 3.3 Averaged intensity vs position across target

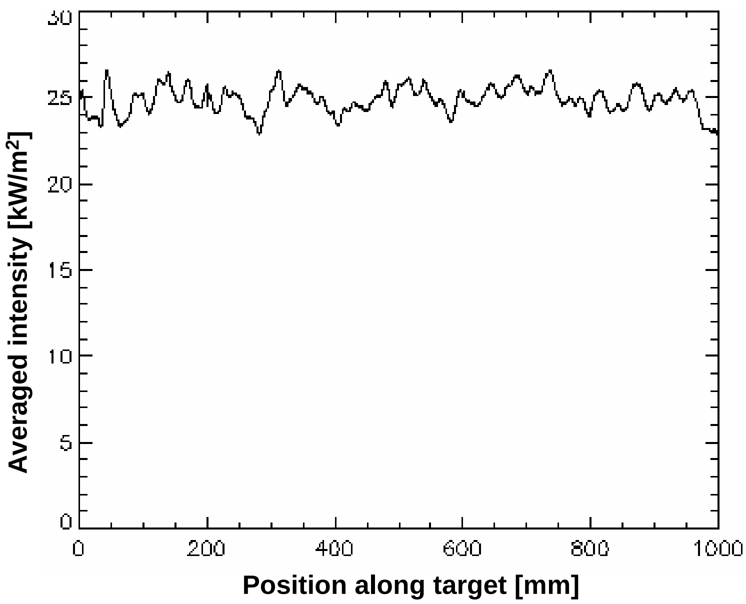

Figure 3.4 Averaged intensity vs position along target for a 50mm receiver width

Figure 3.1 gives the dependence of capture (in each case for maximum power point tracking) on the aperture width of a hypothetical planar cavity receiver located at the focal plane. The increase in capture percentage becomes small beyond a (planar) aperture of about 40mm; however it is preferable to use a larger aperture of 50mm, as this gives some tolerance for tracking errors and variation in trough quality.

Figure 3.2 shows the dependence of capture on tracking accuracy (relative to maximum power point tracking) for a 50mm planar receiver aperture. The flat top of the peak implies a good tolerance to tracking error. The capture for a 10mm tracking error (corresponding to a 12 mrad tracking error) is 96.2% of the reflected radiation, compared to 97.5% for perfect tracking. Using a value of 96% capture, the net intercepted radiation is 87.5% of the insolation on the trough aperture, once allowance is made for mirror reflectivity and shading by the receiver.

Figure 3.3 shows the variation in intensity across the full width of the target, averaged along the length of the target. The peak concentration is seen to be close to 100 suns.

Figure 3.4 shows the intensity variation along the target, for a planar receiver aperture of 50mm, with maximum power point tracking. Only 1000mm of the flux was mapped, rather than the full length of the focal line (~ 1200mm), due to mechanical restrictions on the camera position.

Previous work on flux mapping and surface characterization of troughs with similar design, but somewhat different geometry, was reported in Coventry et al (2002), Burgess and Johnston (2003), and Coventry (2005).

4. CONCLUSIONS

A new parabolic trough collector to provide the thermal energy required to drive an organic Rankine cycle (ORC) power generation system has been presented. The parabolic trough collectors have been installed at in the National Solar Energy Centre at CSIRO's Energy Technology in Newcastle, NSW. They were designed and manufactured by the Australian National University (ANU) as a low-cost and light weight unit and consist of sheet metal with laminated thin glass mirrors. The troughs installed will deliver $80kW_{th}$ at $1000W/m^2$ beam irradiation at temperatures up to 280^oC. Optical performance measurements prior to installation on a trough module with normal incidence irradiation showed a capture of approximately 96% of the reflected radiation, or 88% of the total direct beam insolation.

The array is intended to be used for a variety of ongoing R&D purposes, demonstration and active commercialization of near-term solar applications. Eventual applications are envisaged for both distributed generation (i.e. sited in appropriate locations in suburban communities) and remote power and energy.

5. REFERENCES

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6. ACKNOWLEDGEMENTS

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