Optical analysis and comparison of a single-sided absorber CPC (SSACPC) and double-sided absorber CPC (DSACPC) solar collectors

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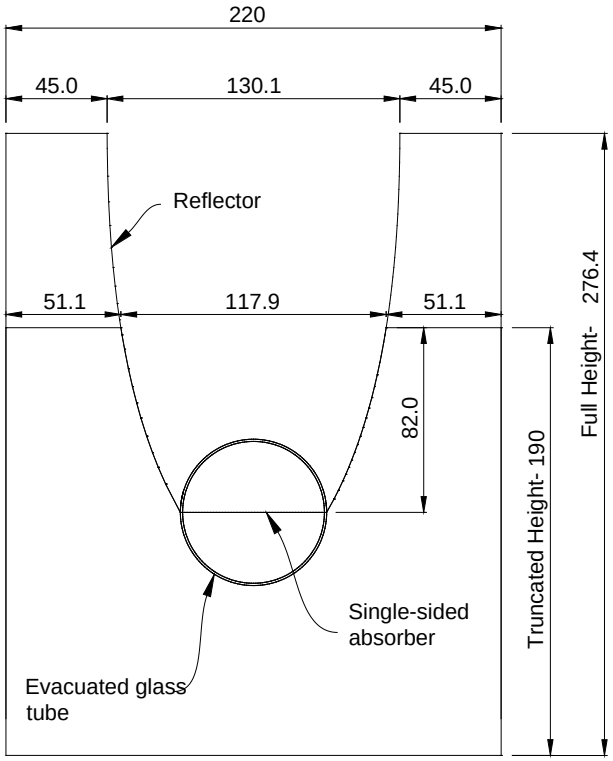
Introduction

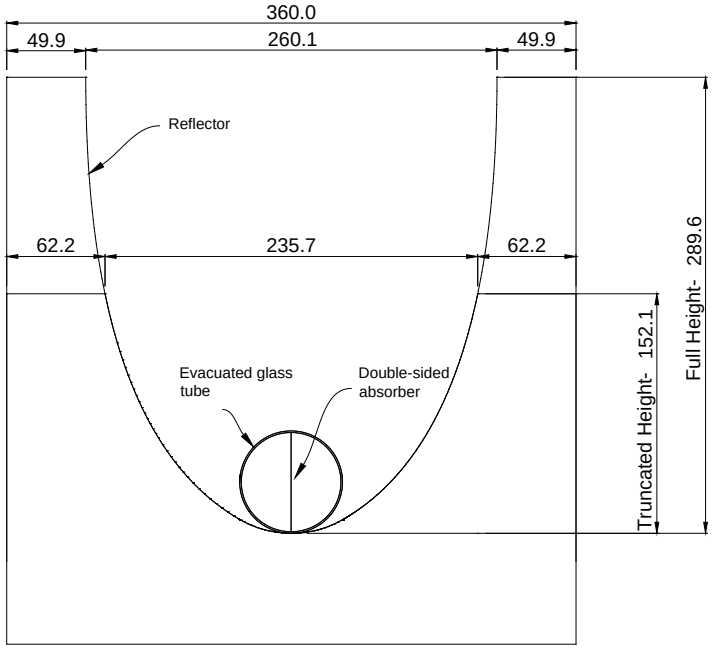
This is part of a much larger study for use in medium temperature applications such as solar powered refrigeration systems and aimed at;

- reducing system losses,
- improving thermal performances and temperature enhancement of evacuated tube heat pipe solar collectors,
- making solar powered refrigeration systems far cheaper and more compact by better integrating the collector-generator function,
- achieving bigger temperature lift, and reducing the number of collector–generator tubes for a given cooling load through the use of solar concentrators.

System design- SSACPC and DSACPC solar collectors



The fabricated full and truncated SSACPC solar collectors (dimensions in mm)



The fabricated full and truncated DSACPC solar collectors (dimensions in mm)

Why SSACPC and DSACPC?

- Their higher optical performances calculated by ray trace.
- Their theoretical calculated higher concentrations ratios.
- Their lower material and fabrication costs.
- The suitability for Northern European Maritimes climates.

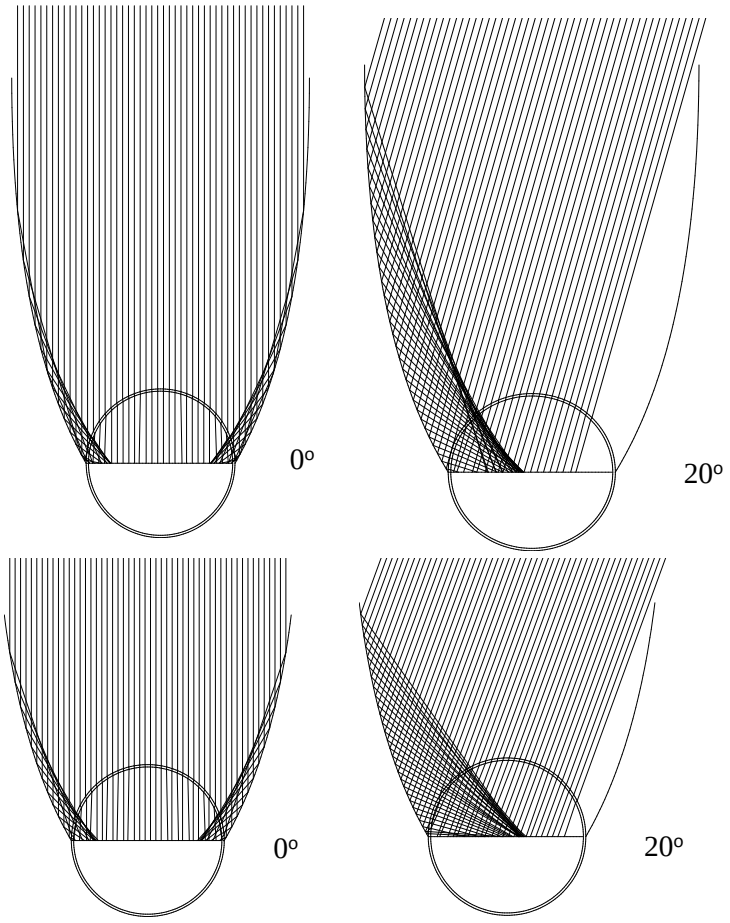
Additional advantages offered by the DSACPC collector

- They require the same amount of absorber material thus lower material cost.
- A more efficient use of the absorber material (illumination on both sides).
- They do not have back heat losses.

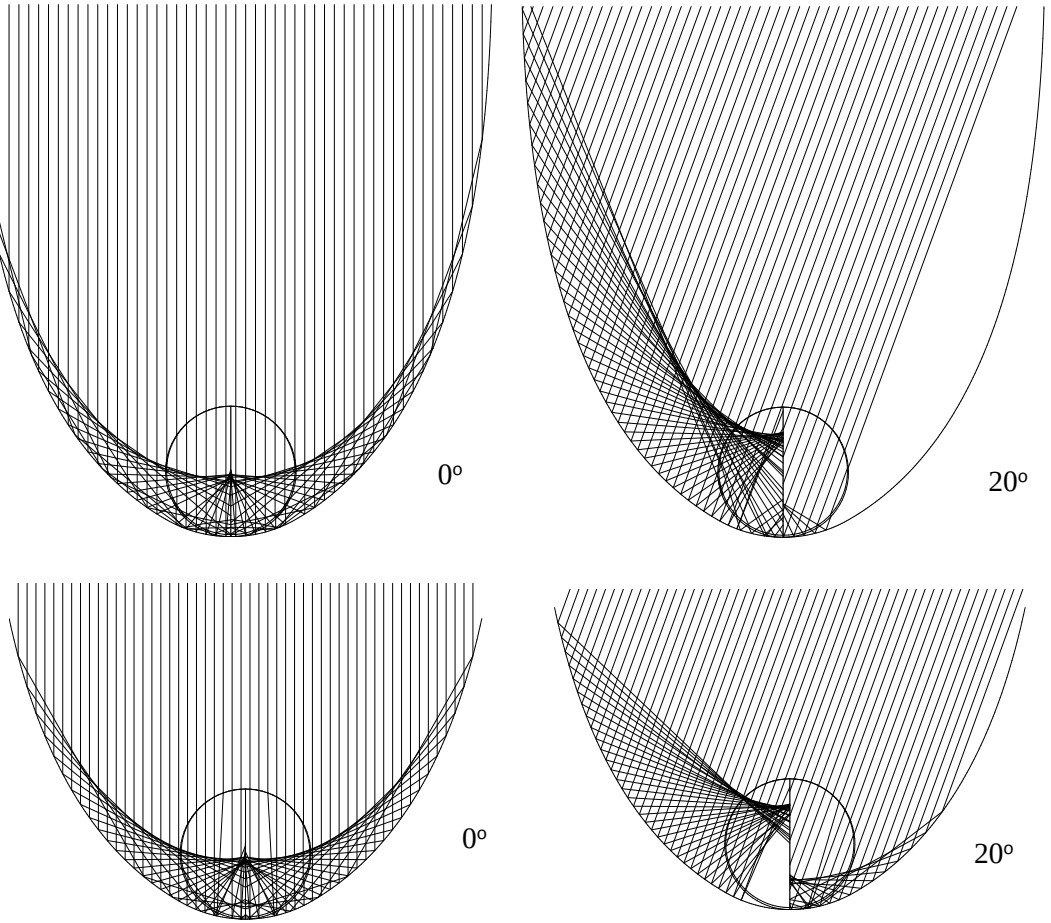
Effect of truncation on concentration ratio & reflective material

Comparison parameters for the design systems	Designed reflector profiles	
	SSACPC	DSACPC
Original height (mm)	168.8	289.6
Original concentration ratio	2.0	2.0
First truncated height (mm)	92.8	168.9
First truncated concentration ratio	1.9	1.9
Reduced reflective material at 1.9 concentration ratio (%)	55.1	58.3
Reflective material saving at 1.9 concentration ratio (%)	44.9	41.7
Second truncated height (mm)	82.0	152.1
Second truncated concentration ratio	1.85	1.85
Reduced reflective material at 1.85 concentration ratio (%)	48.7	52.5
Reflective material saving at 1.85 concentration ratio (%)	51.3	47.5

Ray trace analysis-SSACPC and DSACPC collectors

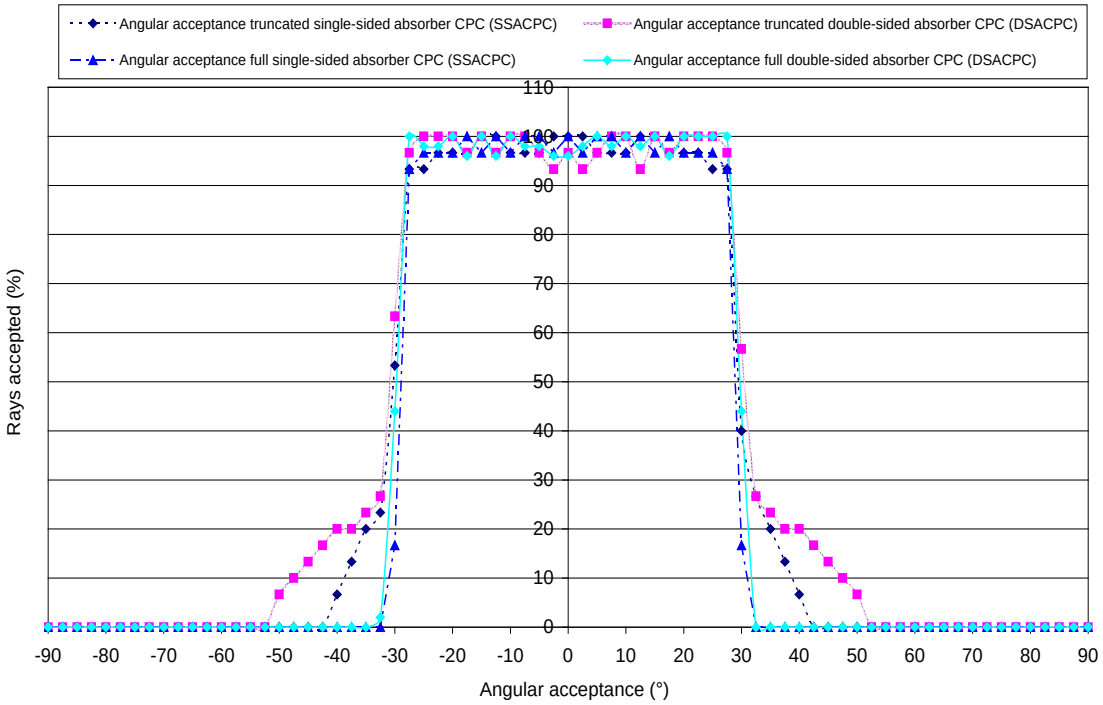


Ray trace diagram-full and truncated SSACPC solar collectors at 0° and 20° incident angles



Ray trace diagram for the full and truncated DSACPC solar collectors at 0° and 20° incident angles

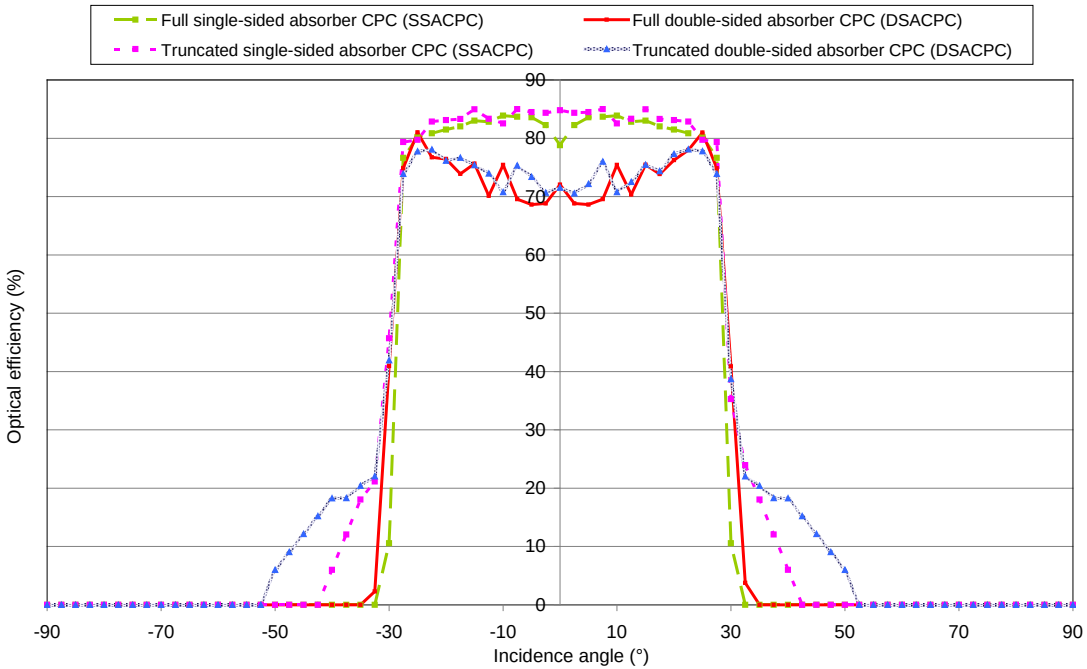
Angular acceptance for the full and truncated SSACPC & DSACPC collectors



Comparison of angular acceptance of incident rays at different incident angles

- The full DSACPC collected 100% of all incident rays reaching the absorber at seven different incident angles (5º, 10 º, 15 º, 20 º 22.5, 25 and 27.5˚).
- The full SSACPC collected 100% of all incident rays reaching the absorber at five different incidence angles (0 º, 5°, 7.5°, 12.5 º and 17.5º)
- The truncated DSACPC collected 100% of the incoming rays reaching the absorber at six different incidence angles (7.5º,10º, 15º 20º, 22.5º& 25º).
- The truncated SSACPC collected 100% of the incoming rays reaching the absorber only at four different incidence angles (0º,2.5º, 12.5º& 15º).

Optical efficiencies-full & truncated SSACPC & DSACPC collectors



Comparison of optical efficiencies at different incident angles

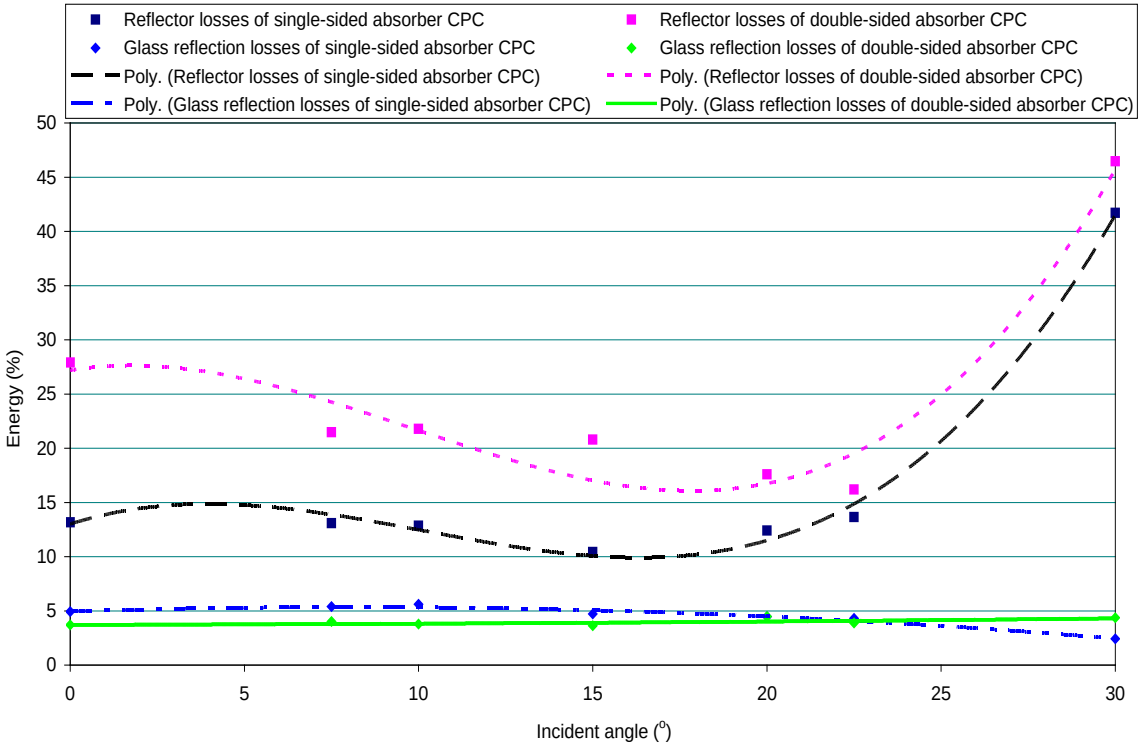
- The overall optical efficiency for the full SSACPC collector was 76.14% compared to 71.17% recorded by the full DSACPC solar collector. Thus 4.97% higher optical efficiencies in favour of the full SSACPC collector.

- The overall optical efficiency recorded by the truncated SSACPC collector was 79.47% compared to 71.47% for the truncated DSACPC collector, representing 8% higher optical efficiency in favour of the truncated SSACPC collector.

- The full and truncated DSACPC collector show similar optical efficiencies over 0° to 30° incident angles.

- The truncated SSACPC recorded 3.33% higher optical efficiencies compared to the full SSACPC collector.

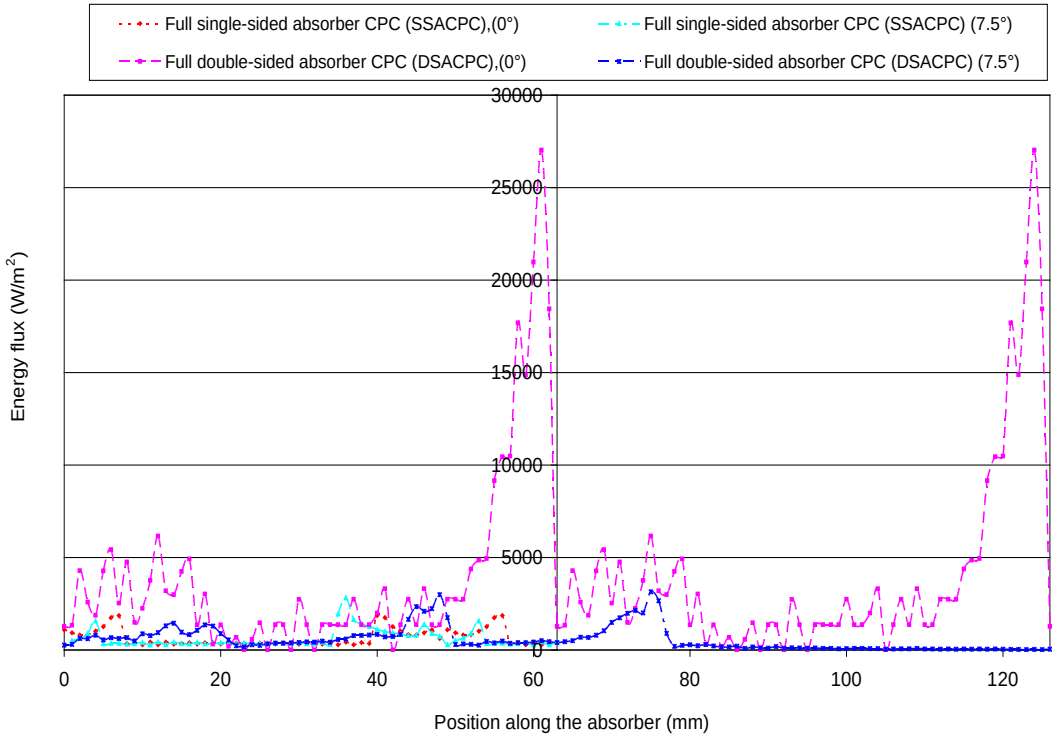
Reflector & reflection losses of the evacuated glass tube for the full SSACPC and DSACPC collectors



Reflector and reflection losses through the evacuated glass tube-full SSACPC and DSACPC at different incident angles

- Up to 16.76% and 24.60% of reflector energy losses recorded by the full DSACPC & SSACPC collectors respectively at 0° to 30° incidence.
- The extra reflector length of the full DSACPC collector with multiple reflection was responsible for the additional 7.84% reflector losses incurred by the full DSACPC collector.
- Up to 4.55% and 3.98% overall reflection losses on the glass surfaces of the full SSACPC and DSACPC collectors respectively.
- The additional 0.75% reflection losses incurred by the full SSACPC collector most have resulted from greater direct incident radiation falling on the glass surface of the SSACPC collector.

Flux distribution on the absorber of full SSACPC % DSACPC



Energy flux distribution on the absorber-full SSACPC and DSACPC collectors incident at 0° and 7.5°

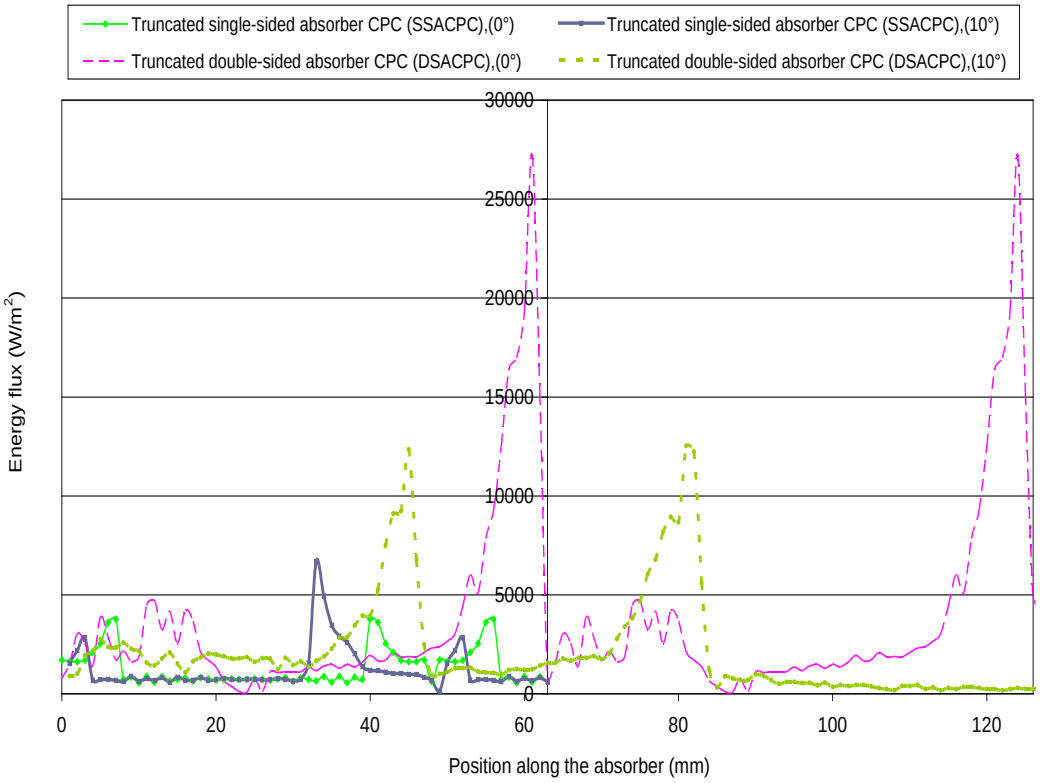
•it is evident that varying the incidence angle on the collector aperture resulted to areas with different energy concentration (low and high).

•It was also determined that, at 0º incident angle for example, up to 93.1% more peak in energy concentration was recorded on the left and right side of the absorber of the full DSACPC collector compared to the full SSACPC collector.

• up to 24.3% and 48.6% overall higher peak in energy concentration was realised on the left and right sides of the full DSACPC collector respectively compared to the full SSACPC collector.

•This represents a 72.8% higher peak in energy concentration realised by the full DSACPC collector compared to the full SSACPC collector.

Flux distribution on the absorber of truncated SSACPC & DSACPC collectors



Energy flux distribution on the absorber-truncated SSACPC and DSACPC collectors incident at 0° and 7.5°

- It was determined that at 0º and 10º incident angles, up to 86.74% and 46% more peak in energy concentration was recorded on the left and right side of the absorber of the truncated DSACPC collector compared to the truncated SSACPC collector respectively.

- Up to 45.98% and 57.05% overall higher peak in energy concentration was collected on the left and right sides of the truncated DSACPC solar collectors respectively compared to the truncated SSACPC solar collector.

- This represents up to 75.07% overall higher peak in energy concentration realised by the truncated DSACPC solar collector compared to the truncated SSACPC solar collector.

Conclusion

•With the incident solar radiation perpendicular to the aperture of the collectors, rays are concentrated on the left and right absorber edge and on the lower absorber section of the SSACPC and DSACPC collectors respectively with mirror symmetry between the right and the left sides of the absorbers.

•An overall 4.97% and 8% further reduction in optical efficiency (increase in optical losses) was realised by the full and truncated DSACPC compared to the full and truncated SSACPC collectors respectively.

•Higher optical efficiencies realised by the truncated SSACPC and DSACPC collectors compared to their full profiles resulted from reduced average number of reflections of the rays before reaching the absorber due to reduced reflector heights, increase acceptance of beam and diffuse radiation and decreased heat losses per aperture area.

•The extra reflector length and the multiple reflection of the incident solar radiation incurred by DSACPC collector were responsible for the additional 7.84% of reflector losses why additional reflection losses on the glass incurred by the full SSACPC resulted from more direct incident radiation hitting the glass tube.

▪ Up to 75.07% higher peak in energy concentration was realised by the truncated DSACPC solar collector compared to the truncated SSACPC solar collector resulted from the effective use of the absorber and increase collection of incoming radiations.

- Thanks for your attention

- Comments and Questions