The efficiency of a specular trough arrangment collecting solar radiation

J. Goettsche[1], S. Alexopoulos[1], A. Dümmler[1], G. Breitbach[2]
[1]FH Aachen, Solar-Institut Jülich, Heinrich-Mußmann-Str. 5, D-52428 Jülich
[2]FH Aachen
Corresponding author: goettsche@sij.fh-aachen.de

Introduction

The object under consideration is a trough (static solar concentrator) based on investigations in [1]. A curved specular trough arrangement has a shape which is a combination of a circular arc and adjacent parabolic curve pieces. .
Inside a tube is placed (see Fig. 1 as a reference configuration).

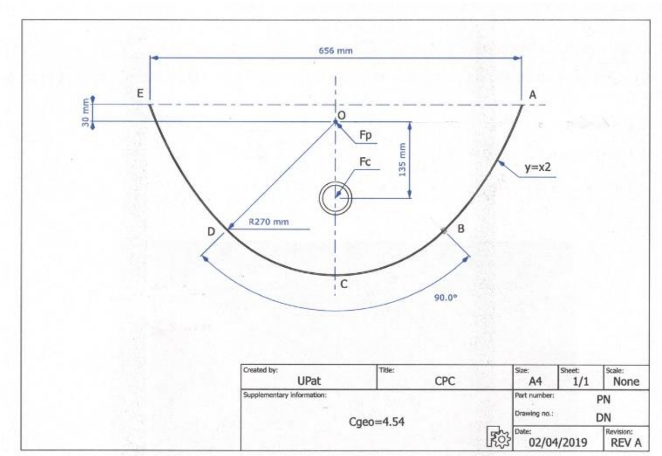


Fig. 1: Curved specular trough with tube inside; (x.y)-coordinate system with origin O.

In the following it is investigated which tube position is optimal to receive a maximum of solar radiation for different incident angles.
The analysis consists of different steps. Using MATLAB the reflection of parallel entering ray bundles are investigated. Then a ray tracing analysis is done using the COMSOL software.

Estimations for optimal tube positions at different angles of radiation incidence

Using MATLAB a programme was developed which gives the reflected rays on the surface of the trough for parallel incident ray bundles.
Only a first reflection is here considered. This preinvestigation is done to find a good position of the tube. The incident angles are chosen between 0° (radiation enters vertical from above) and 60°.
The next figures give exemplary ray configurations for the different incidence angles. Shown are the only the reflected rays leaving the mirror surface. Integrated in the figures are circles corresponding to the tube diameter. The circles are placed in such position that more then 50% of the rays cross the circular area.

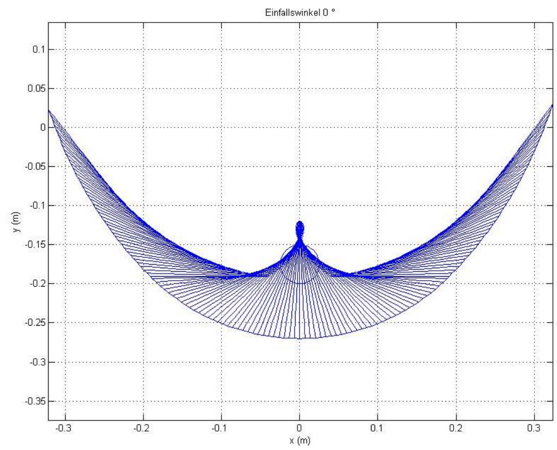


Fig. 2: Incident radiation exactly from above (0°); the center of the circle is at position (0 m | -0.175 m). 56.25% of the reflected rays cross the circular area.

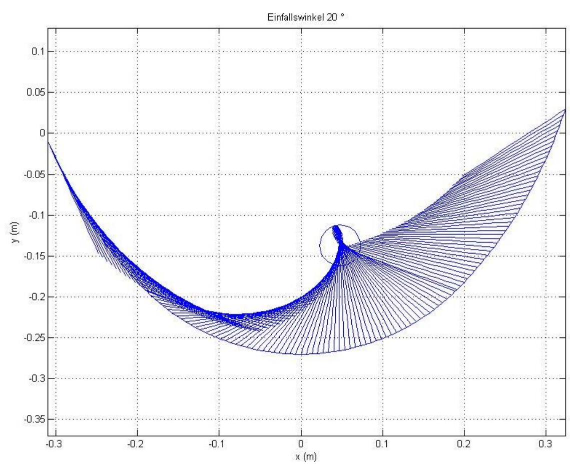


Fig. 3: Incident radiation at 20°; the center of the circle is at position (0.048 m | -0.137 m). 61.15% of the reflected rays cross the circular area.

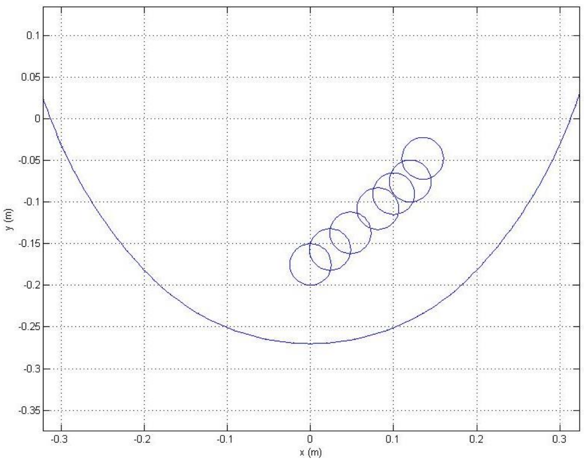


Fig. 4: Collection of the circles for the different incidence angles. The centers are found roughly along a straight line.

Table 1: Centers of circles and ratios of hits/rays (intercept factor)

Incidence angle	xcirc (m)	ycirc (m)	Intercept factor
0°	0	-0.175	0.5625
10°	0.0235	-0.157	0.5556
20°	0.048	-0.137	0.6115
30°	0.081	-0.108	0.537
40°	0.1	-0.09	0.53
50°	0.12	-0.075	0.5588
60°	0.135	-0.0475	0.5577

Ray tracing analysis using COMSOL

The previously considered geometrical configuration are analysed using a ray tracing tool which is included in the COMSOL – Software package. Plane geometry models are built for the different incidence situations. The models consist of four different lines. The first line is a closed circular one representing the tube. Than the trough is modeled via a circular arc and two parabolic pieces. The straight line represents the radiation source with rays perpendicular to the line direction. A source magnitude corresponding to 1000 W/m² is applied. Finally, an enclosure in form of a circular arc was created to catch the escaping radiation. For each incidence cases, the results are presented in four diagrams/figures. Figs. 5 to 8 show these as examples for incidence angle 0°.

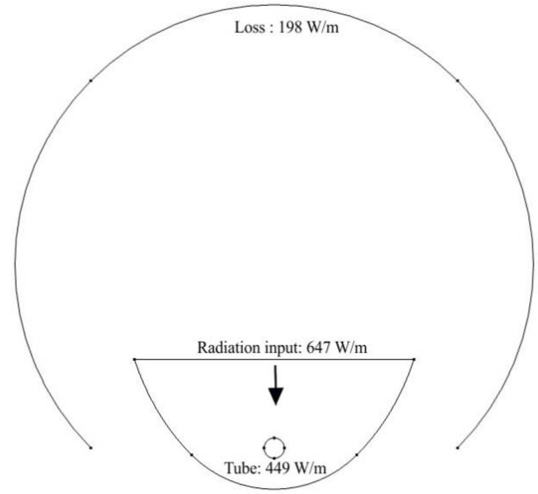


Fig. 5: Geometry; Tube position: xcirc = 0.0 m ycirc = -0.175 m; total trough radiation input (per meter of trough – length) 647 W/m. The tube receives 449 W/m. The loss through the enclosure is 198 W/m. The radiation flux of the source line corresponds to 1000 W/m².

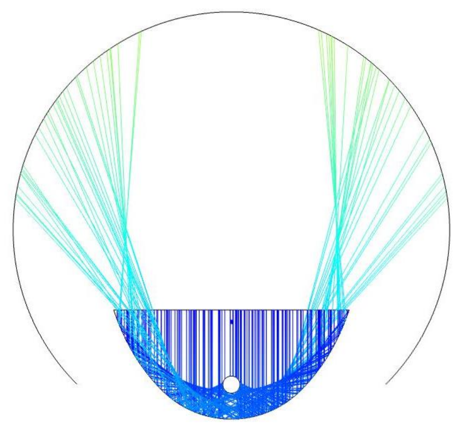


Fig. 6: Ray pattern for incidence angle 0°

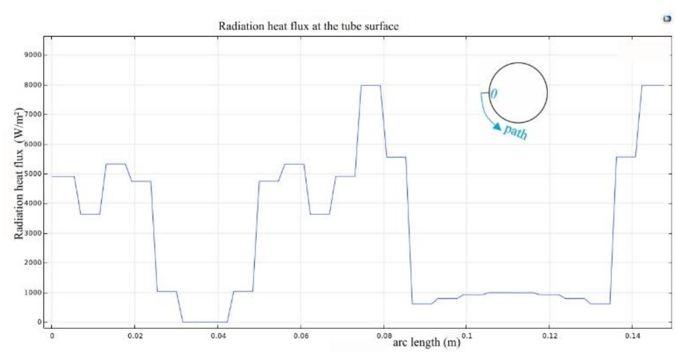


Fig. 7: Radiation heat flux distribution along the tube surface for 0° incidence angle. The 0-position of the path is shown in the figure. Integration along the path gives the value of 449 W/m.

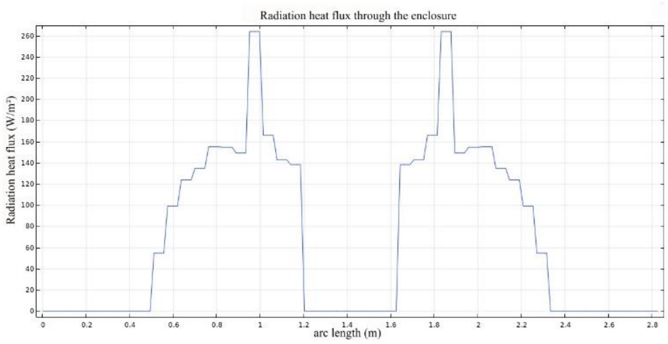


Fig. 8: Radiation heat flux distribution along the enclosure for 0° incidence angle. The 0-position of the path is the left end point of the arc. Integration along the path gives the value of 198 W/m.

Summary of Results

Under "Simulation" the results of the COMSOL analysis is shown in Table 2.
Depending on the incidence angle the total input (base value is 1000 W/m²) per 1m trough length is shown. The two following columns give their parts onto the tube and into the environment. The efficiency is calculated as quotient "tube"/"Input".

Table 1: Results of the simulations (intercept factor)

Simulation				
Incidence angle	Input	tube	Loss	Intercept factor
	(W/m)	(W/m)	(W/m)	
0°	647	449	198	0,694
10°	638	453	185	0,710
20°	610	475	135	0,779
30°	560	348	212	0,621
40°	496	277	219	0,558
50°	415	233	182	0,561
60°	323	184	139	0,570

Ray tracing analysis using COMSOL for pure vertical motion of the receiving tube

To avoid complex motions of the tube a pure vertical displacement was proposed for comparison.
The following formula of an effective vertical position was found for the position of the tube inside the trough:

$$y = 0.0035 * \theta - 0.1870 \qquad (1)$$

y is here obtained in meter, θ is in degree °.

In Fig. 9 the tube positions are shown for the two arrangements. The inclined tube movements correspond to the analysed cases above. The vertical circles are created via equation (1). The circle (tube) at the bottom is for 0° incidence the top most circle for 50° incidence.

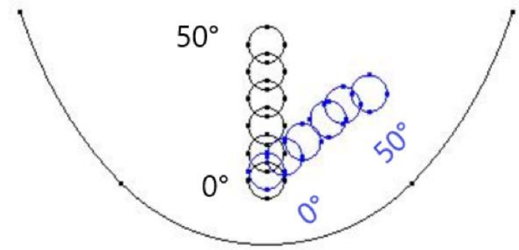


Fig. 9: Tube arrangements (0°-50° incidence)

The following figure shows efficiencies computed as quotient "tube input"/"total input".

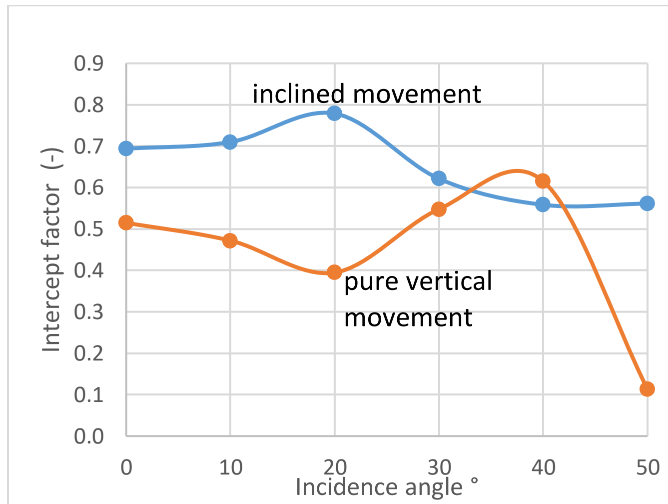


Fig. 10: Comparison of the intercept factors for the two displacement methods

A comparison of situations is made for the incidence angle 40°, where for the vertical arrangement a somewhat larger efficiency is found.

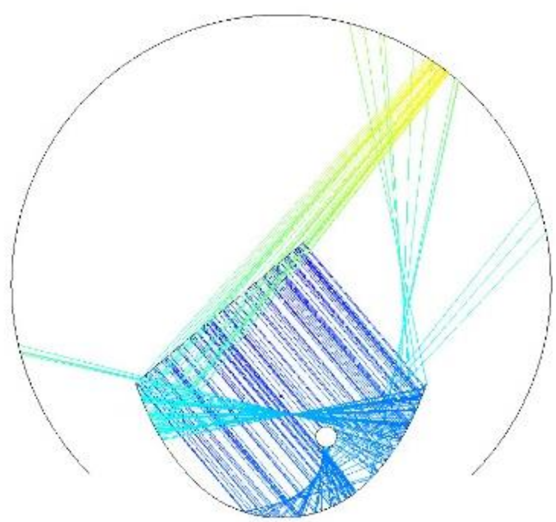


Fig. 11: Ray pattern for the inclined movement

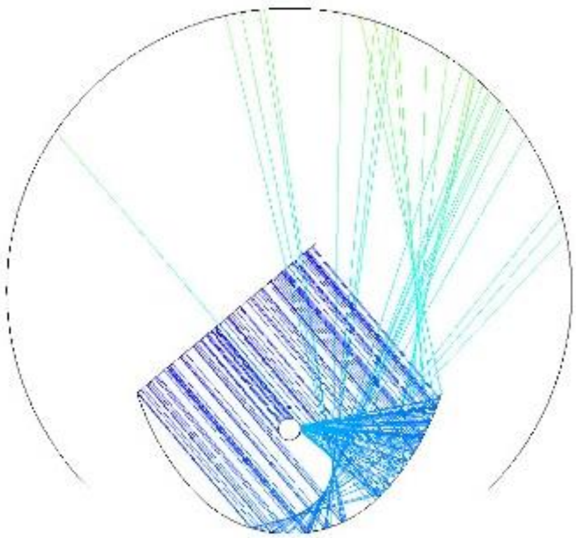


Fig. 12: Ray pattern for the pure vertical movement

It is found that due to the nature of the reflector, basically two separate focal areas are present. At these different positions complementary sets of rays can be absorbed.

Conclusion

Optimum absorber positions of a solar collector with static concentrator as proposed by [1] were found. The intercept factor was found to be between 56% and 78 % for incidence angles between 0° and 50°. An absorber motion along a straight line brings reasonable results. The geometric optics module of COMSOL is a suitable tool for systematic investigations for the application treated here.

References

[1] Tripanagnostopoulos Y., Yianoulis P., “CPC solar collectors with multi-channel absorber”. Solar Energy 58 (1-3), pp. 49-61, 1996

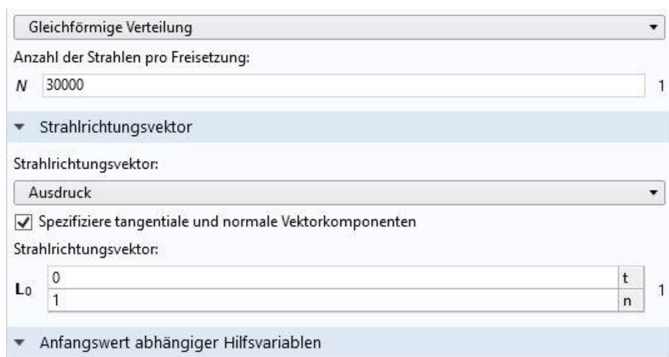
Acknowledgements

This project was co-funded by the German Federal Ministry of Education and Research and the Hellenic Secretariat for Research and Technology (SCOSCO project) in the framework of the Greek-German co-operation.

Appendix

Working with 2D applications, the following features in the program are important.
The section “Geometrische Optik” is used. The features “Einlass”, “Spiegeln”, "Wand" serve to
specify the properties of the geometric objects which are curves and lines

In “Einlass” the number of rays is specified (here 30000) and the ray direction vector



Via the "Akkumulator Typ" the radiation flux connected with a ray is specified. In case that the source is on a straight line with intensity q (W/m or W/m²) the "Quelle"-term is computed as
R = ("line length" x q) / (number of rays).
This gives finally the local heat flux absorbed by a wall.