Elliptic Array Luminescent Solar Concentrators for Combined Power Generation and Microalgae Growth

Nima Talebzadeh[1] and Paul G. O'Brien[1,*]

[1] Department of Mechanical Engineering, Lassonde School of Engineering, York University, Toronto, ON M3J 1P3, Canada; nima.talebzade@gmail.com

* Correspondence: paul.obrien@lassonde.yorku.ca

Supplementary Material

A. Description of an ellipse for the Elliptic Array Solar Spectrum Splitter

An ellipse can be defined as a curved line that forms a closed loop around two focal points, f_1 and f_2, with the property that for any point S on the curve, the sum of the distances from f_1 to S and f_2 to S is constant. Moreover, the normal to the curve at any point S on the ellipse bisects the angle between the lines connecting f_1 to S and f_2 to S. As shown in Figure S1a, from a ray-optics perspective, this implies that all light emitted from f_1 (f_2) that is specularly reflected from the internal surface of the ellipse will be directed towards f_2 (f_1) because the angle of incidence θ_1 (θ_2) is equal to the angle of reflection θ_2 (θ_1). In this work we utilize this internal refocusing property of an ellipse to design a LSC panel with minimal optical losses.

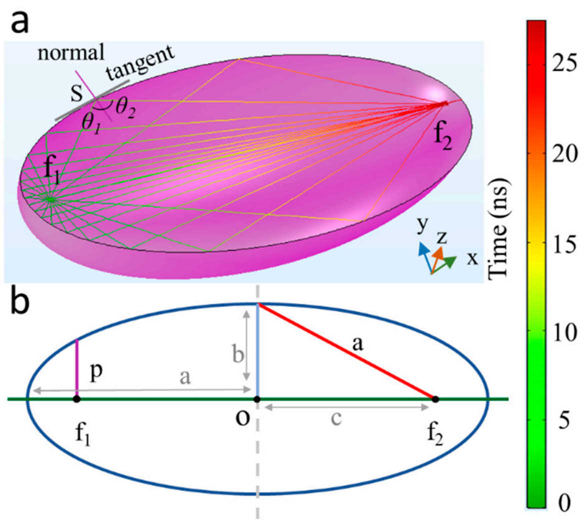

Figure S1. a) Cross-section of an ellipsoid as a closed loop curve and; b) the geometrical parameters for an ellipse. A light ray is emitted from f1 at t = 0 ns. The trajectory of this emitted ray changes color in accordance with the colored vertical bar on the right, and after 25 ns the light ray has reached f2.

The equation defining an ellipse using Cartesian coordinates is provided in Equation S1. Where the center of the ellipse is at the origin, O, and the x-axis is the major axis.

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}=1 \qquad (S1)$$

With reference to Figure A1b, the values of p and b are given in Equation S2:

$$p=\frac{b^2}{a} \quad \text{and} \quad b^2 = a^2 - c^2 \qquad (S2)$$

The shape parameters a and b are the semi-major axis and semi-minor axis, respectively. The proposed SSS is composed of an array of unit-cells wherein each unit cell has the shape of two overlapping half-ellipses that share the same focal point.

B. Thermal analysis of the EASSS

The ray tracing and heat transfer modules in COMSOL Multiphysics software are coupled to investigate the temperature distribution in a unit cell of the EASSS structure during steady state. The optical and mechanical properties are shown and explained in Table S1. The incoming solar irradiance is 1000 W/m^2.

Table S1: Mechanical and optical properties of the EASSS for thermal analysis.

Property	variable	value	unit
Heat capacity at constant pressure	Cp	1420	J/(kg*K)
Density	ρ	1190	kg/m^3
Thermal conductivity	k	0.19	W/(m*K)
Heat transfer coefficient	h	10	W/(m2*K)
Ambient temperature	T	293.15	K
Refractive index, real part	n	1.492	1
Refractive index, imaginary part	k	$3*10^{-8}$	1
Thermal variation of the real part of the refractive index	dn/dT	$100*10^{-6}$	1/K

Figure S1 shows the results of the simulations for the temperature distribution in an EASSS unit cell with h = 2 cm and c = 5 cm.

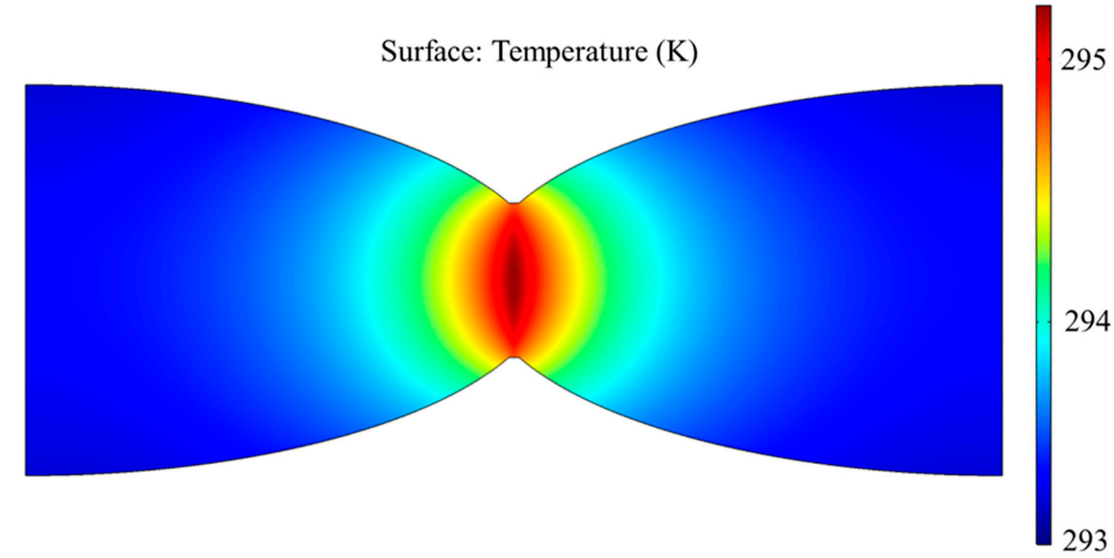

Figure S2. Temperature distribution within an EASSS unit cell for an incoming solar irradiance of 1000 W/m^2 (h = 2 cm and c = 5 cm).

Figure S2 shows the temperature profile for this case along the top surface of the EASSS as shown as the blue line in the inset (Figure S2a), and along the red horizontal line at the middle of the EASSS (Figure S2b).

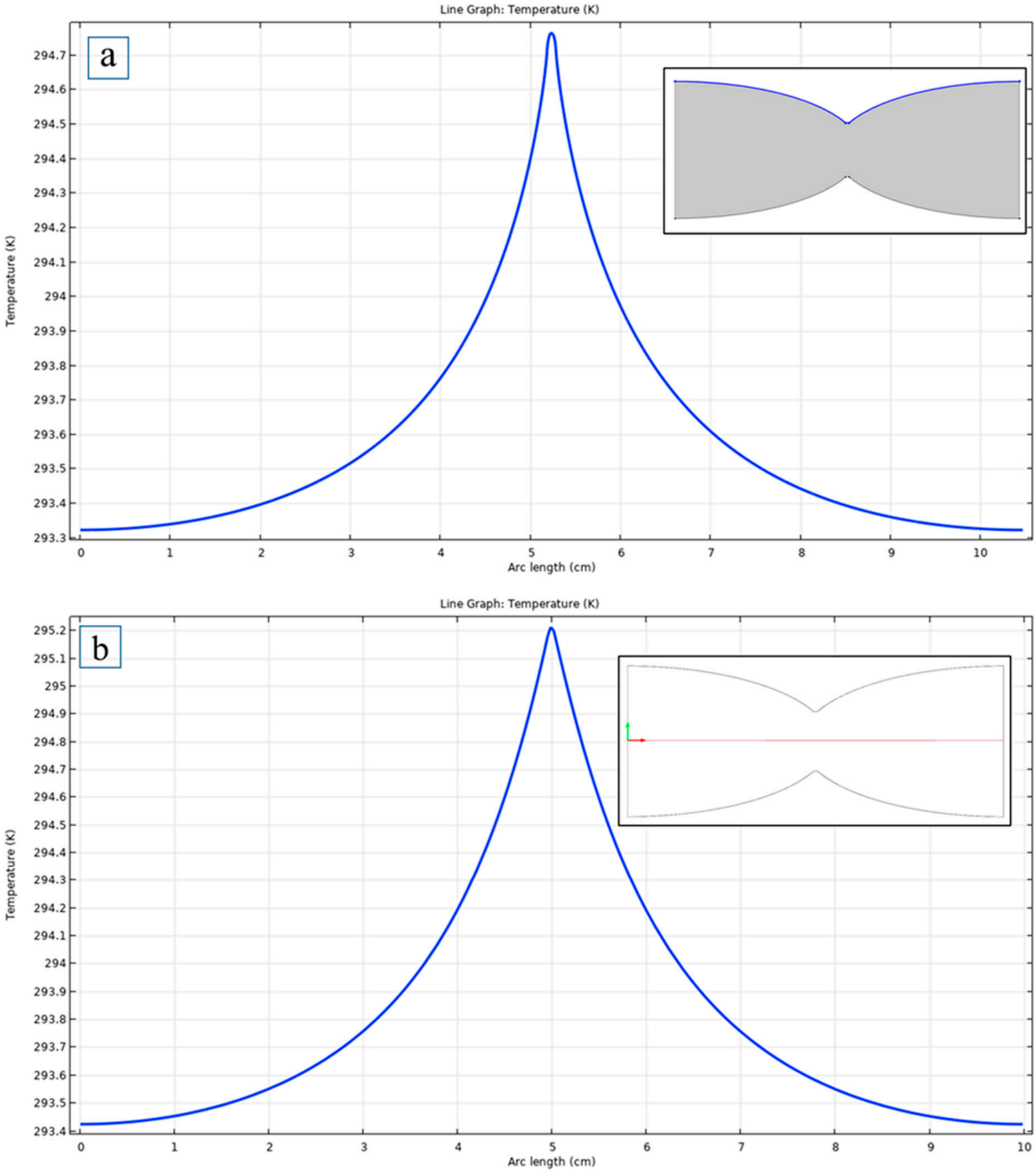

Figure S3. Temperature profile for the case study (h = 2 cm and c = 5 cm) of the EASSS along the a) Top surface of the EASSS shown in the inset with blue line, and b) Horizontal middle line shown in the inset with red line.

C. Comparison of the weights of the EASSS and conventional LSC

To compare the weights of the EASSS and standard LSC we selected LSCs and EASSS with equal heights. We considered two cases: 1) c = 5 cm and b = 1cm, and 2) c = 5 cm and b = 2 cm. Noting the thickness of the normal LSC is $h = 2 \cdot b$, and taking the density of PMMA as ρ = 1190 Kg/m^3, the results are shown below:

1) c = 5 cm and b = 1 cm => $weight\ of\ normal\ LSC\ (23.8\ Kg) - weight\ of\ EASSS\ including\ the\ Petzval\ lens\ array\ (21Kg) = 2.8\ Kg\ for\ 1m^2\ of\ surface\ area\ for\ each\ structure$

   This result implies that for an area of 1m^2 the EASSS is 2.8 Kg lighter than LSC.

2) c = 5 cm and b = 2 cm => $weight\ of\ normal\ LSC\ (47.6\ Kg) - weight\ of\ EASSS\ including\ the\ Petzval\ lens\ array\ (41.34\ Kg) = 6.26\ Kg\ for\ 1m^2\ of\ surface\ area\ for\ each\ structure$

   This result implies that for an area of 1m^2 the EASSS is 6.26 Kg lighter than LSC.

   It should be mentioned that the weight of the Petzval lens array can be vary between 2 Kg to 15.6 Kg based on its distance from the unit cells of the EASSS. If the lenses are close to the unit cells (~10 cm), the Petzval lenses would be thick and therefore they will be heavy (15.6 Kg for these sample cases when c = 5cm). If the Petzval lens array is further from the EASSS (~80cm), the weight of the lens arrays would be 2 Kg for the same sample case. In the calculations above it is assumed that the weight of the Petzval lens array is 2 Kg.