Stationary Reflector/Tracking Absorber (SRTA) Solar Concentrator

S.Cohen & G. Grossman
Faculty of Mechanical Engineering, Technion, I. I. T.
Haifa 32000, ISRAEL

Solar Collectors

Thermo-solar Collectors:

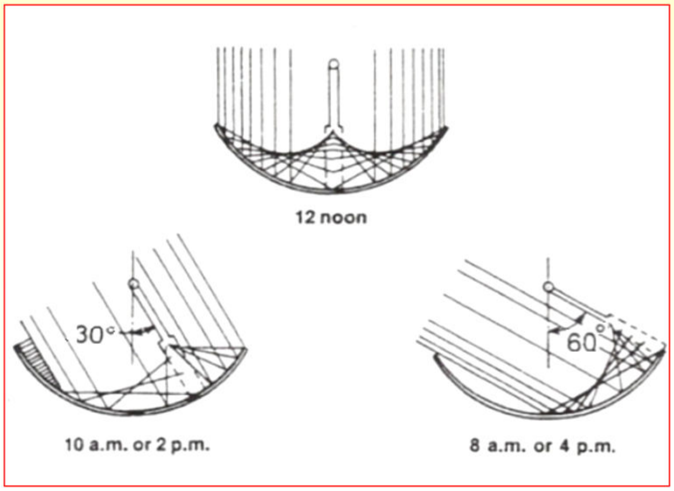
- Trough Collectors
- Tower Power
- Parabolic Dish

Why Stationary ?

- Simple Construction
- Easy to track the sun.
- Low Cost

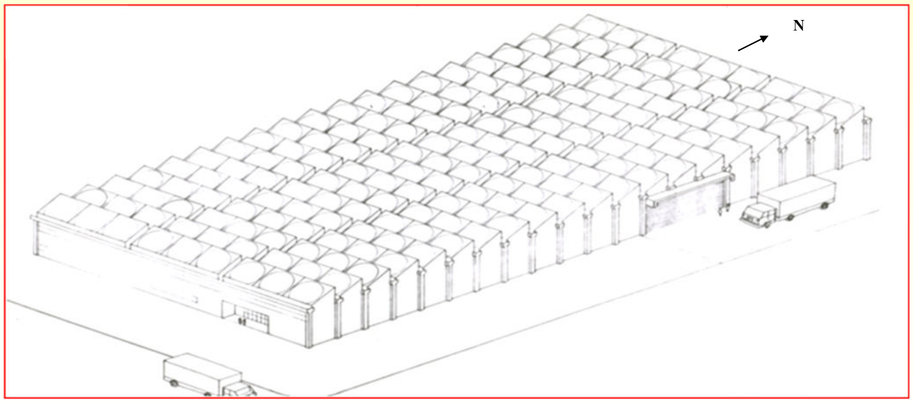
Absorber Position During the Day

The optical principle of the SRTA is illustrated in this figure, which shows the path of the solar rays reflected from the stationary reflector at five different times of the day.

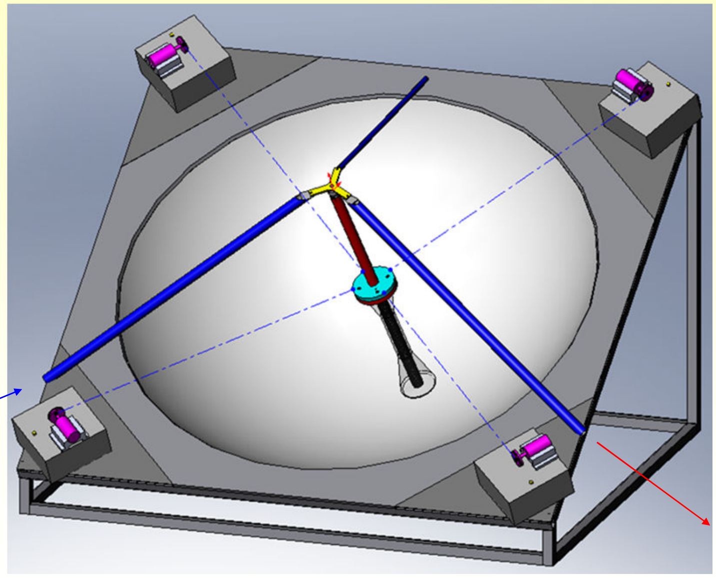


The Objective

- Part of a roof element.
- Emphasis on low cost construction.
- Use the steam as direct product.

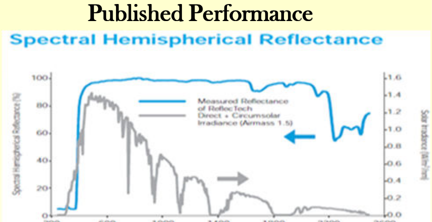


The Suggested Design

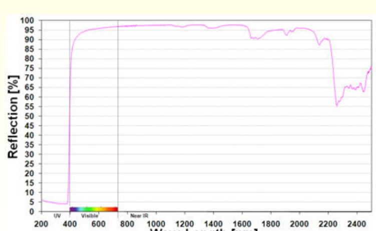


Mirror Testing

Published Performance

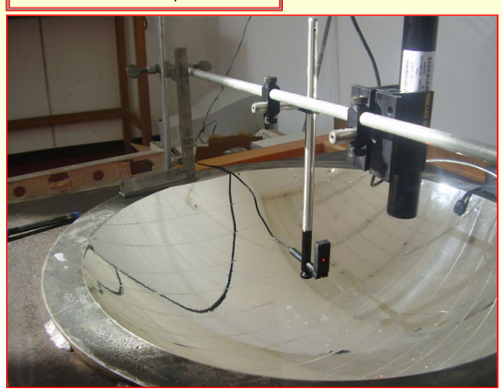


Measured Performance

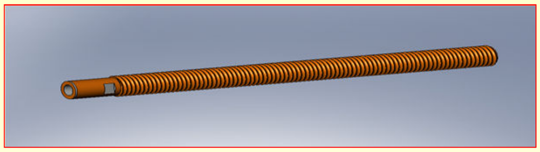


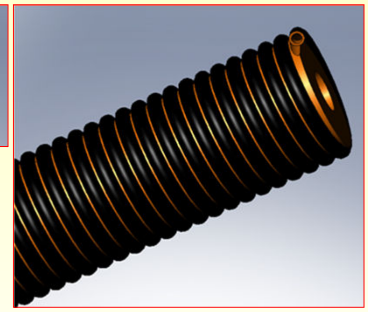
Reflectance Measurement after Application

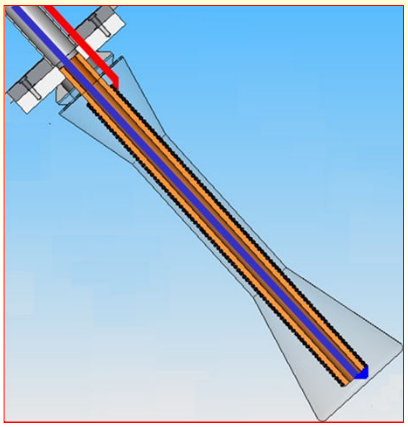
Laser Type: HeNe
Laser Power: 3,25 [mW]
Wave Length: 633 [Micrometer]
Film Reflectance: 3.03/3.25=0.932

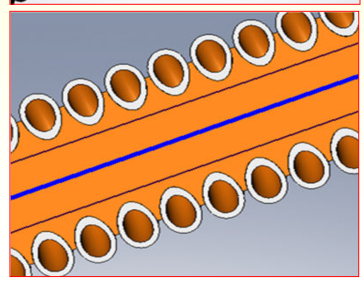


The Absorber

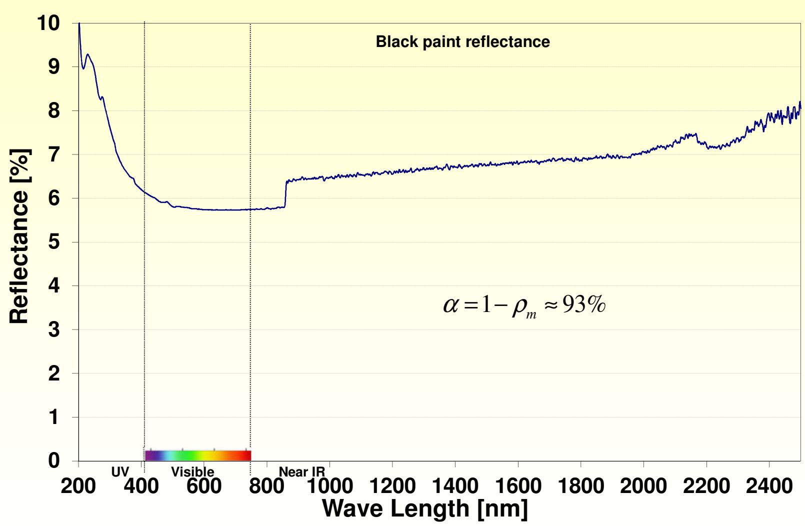








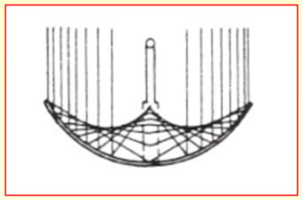
The Absorber Coating

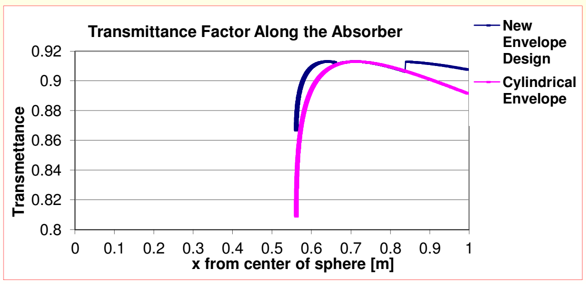


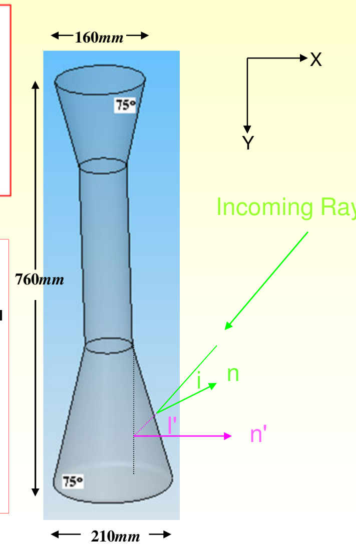
Establishing The Envelope Shape

For cylindrical envelope
The angle of incidence i:

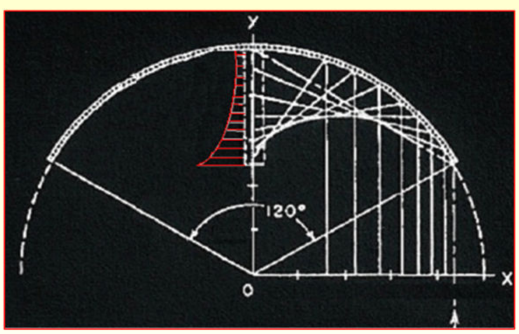
$$i = \frac{\pi}{2} - 2\sin^{-1}\left(\frac{x}{R_0}\right)$$







Flux Distribution Along the Absorber



The Geometrical Equation

$$\frac{y}{R_0} = 0.5\cdot\left(1-\frac{x^2}{R^2}\right)^{-0.5}\left\{1+\left(\frac{D_a}{2R}\right)\left(\frac{R_0}{x}-\frac{2x}{R_0}\right)\right\}$$

Energy Balance

$$I_b\rho_m(2\pi x dx) = E(\pi D_a dy)$$

$$E_{(y)} = \frac{I_b\rho_m 2x}{D_a}\cdot\frac{dx}{dy}$$

Approximate Solution

$$E_{(y)} = \frac{\rho_m I_b}{2D_a}\frac{1}{y^3}$$

The Sun Image

Absorber Sizing

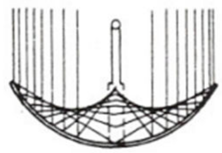
$$L_c = \frac{R}{2}$$

$$D_{i,min} = 1 \times L_c \times \frac{\Pi}{360}$$

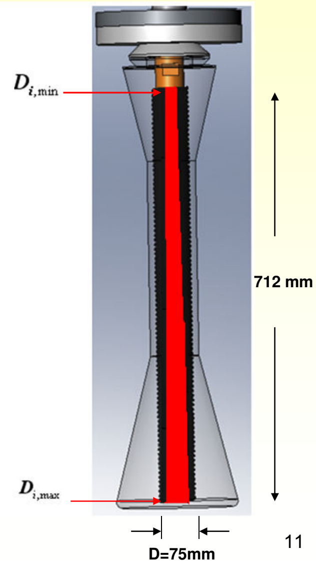
$$D_{i,max} = 2 \times L_c \times \frac{\Pi}{360}$$

$$D_{i,min} = \frac{R}{2} \times \frac{\Pi}{360} = \frac{1.616}{2} \times \frac{\Pi}{360} = 0.007\,m$$

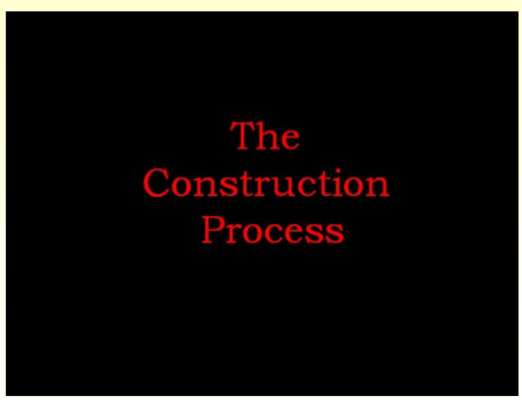
$$D_{i,max} = R \times \frac{\Pi}{360} = 1.616 \times \frac{\Pi}{360} = 0.0141\,m$$



- 5 times the theoretical size will compensate tracking error of 1 degree and surface irregularities.
- Da=5 x $D_{i,max}$



Movie



Thermal Analysis

1. $Q_{sol,a} = E\tau_{e,sol}(i)\alpha_{a,sol}\frac{1+\rho_{a,sol}\rho_{e,sold}}{1-\rho_{a,sol}\rho_{e,sold}}$

2. $Q_{sol,e} = E\left(a_{e,sol}(i) + \frac{\alpha_{e,sold}\tau_{e,sol}(i)\frac{D_{ei}}{D_{eo}}\rho_{a,sol}}{1-\rho_{a,sol}\rho_{e,sold}}\right)\frac{D_{ei}}{D_{eo}}$

3. $Q_{ir,ae} = \varepsilon_{eff}\sigma\left(T_a^4 - T_e^4\right)$

4. $Q_{e,sky} = \varepsilon_{e,ir}\sigma\left(T_e^4 - T_{sky}^4\right)\frac{D_{eo}}{D_a}$

5. $Q_{c,ae} = h_{c,ae}\left(T_a - T_e\right)$

6. $Q_{c,e} = h_{c,e}\left(T_e - T_\infty\right)\frac{D_{eo}}{D_a}$

$$Q_{sol,a} = Q_{(y)} + Q_{c,ae} + Q_{ir,ae}$$

$$Q_{sol,e} + Q_{ir,ae} + Q_{c,ae} = Q_{e,sky} + Q_{c,e}$$

$$\frac{dT_f}{dy} = Q_{(y)}\frac{\pi D_a}{C_p\dot{m}}$$

$$T_{f\,(y+\Delta y)} = T_{f\,(y)} + \left(\frac{dTf}{dy}\right)_y dy$$

$$T_a = T_f + (Q_{(y)}D_{tube,o}/2)/(h_{c,f}D_{tube,i})$$

$$\varepsilon_{eff} = \left(\frac{\rho_{e,ir}}{\varepsilon_{e,ir}} + \frac{\rho_{a,ir}}{\varepsilon_{a,ir}} + 1\right)^{-1}$$

$$T_{sky} = 0.09936\left(\frac{T_\infty}{1.8}\right)^{1.5}$$

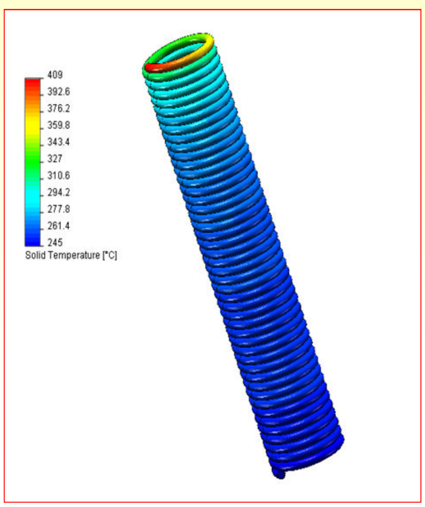
$$h_{c,ae} = 2\frac{k_{eq}}{D_a}\ln\left(\frac{D_{ei}}{D_a}\right)$$

$$h_{c,e} = 0.54\frac{k_f}{D_{eo}}\left(Gr\,\mathrm{Pr}\right)^{1/4}$$

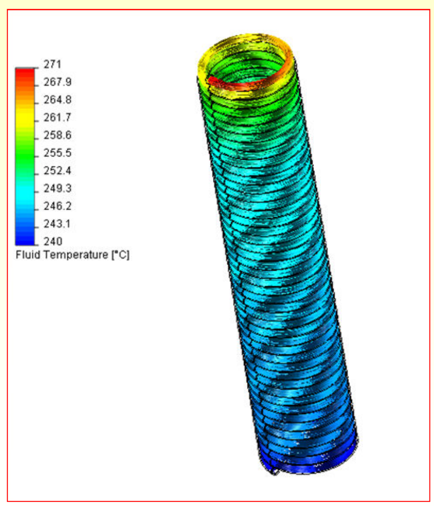
$$h_{c,e} = C\frac{k_f}{D_{eo}}\mathrm{Re}^n$$

CFD Results

Pipe Temperature



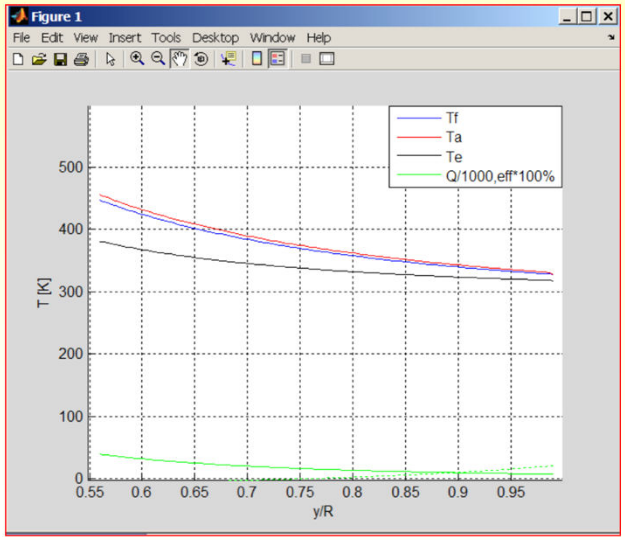
Fluid Temperature



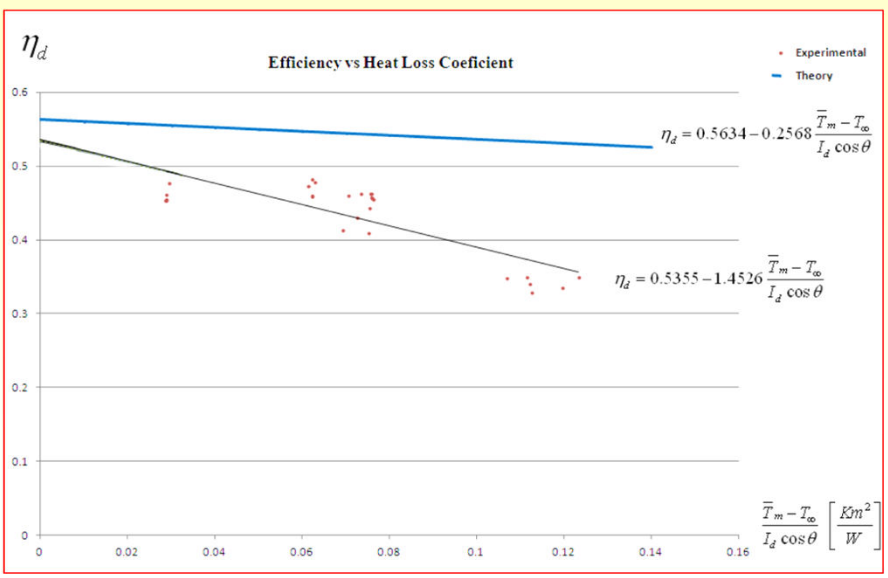
Numerical Code

Code input :
Includes all the design and operational parameters.

Code output :
T_a *- Absorber temperature*
T_f *- Fluid temperature*
T_e *- Envelope temperature*
$Q_{(y)}$ *-Net heat delivery to the fluid*
η *- Efficiency solar to thermal*



Water Results – Mirror Reflectance 90%



Summary

- An experimental system based on a stationary reflector and tracking absorber was designed and tested.
- The stationary reflector was manufactured by a combination of spinning and machining. More suitable technology for mass production has been considered.
- The design involved a detailed analysis of the optical and thermal behavior.
- A tracking system wad employed using an algorithm that predicts the sun movement.
- The system was tested over a number of days and the experimental performance was compared to the theoretical prediction.

Thank you !