MAE 119 W2018 Prof. G.R. Tynan
Quiz 4: Solar Thermal Power

Closed Book/Closed Notes. Electronic Calculators Permitted (but not needed). One significant figure will suffice for numerical answers.

This problem analyzes the performance of a large solar thermal power station similar to the Ivanpah station located in the Mojave Desert near the CA-NV border region. On a clear day, the DNI is 1000 W/m^2 and the system uses an array of steerable mirrors known as heliostats to focus this radiation on a target with a surface area of 100 m^2. There are 100,000 heliostats that focus the sunlight onto the target. Each heliostat has a surface area of 2 m^2.

a) Assume all of the heliostats reflect the solar DNI onto the target. What is flux (measured in W/m^2) of solar radiation at the target? 10 points.
b) The target has a coolant that flows through it, and this coolant removes a thermal power per unit area, P = 1 MW/m^2). The hot target surface acts as a perfect blackbody. Neglecting any convective heat losses to the atmosphere, what is the temperature of the target? [Hint: the Stefan-Boltzmann constant is approximately $6x10^{-8}$ W/m^2 K^4] 10 points.
c) If the working fluid of the plant that flows through the target reaches a temperature that is 1/3 of the value found in part (b) and flows through an ideal heat engine, how much power does the heat engine produce? 10 points.

Extra credit (i.e. these points could take your score above 100%).
Suppose *two cloud layers* pass overhead. One cloud layer is 1km thick and is composed of particles with a cross-sectional area of 10^{-10} m^2 and a density of 10 particles/cm^3. The second layer is also 1km thick and is composed of particles with a cross-sectional area of 10^{-9} m^2 and a density of 1 particle/cm^3. Assume that these clouds act to scatter the radiation so that it cannot be focused by the heliostat array. By how much is DNI reduced? 10 points.

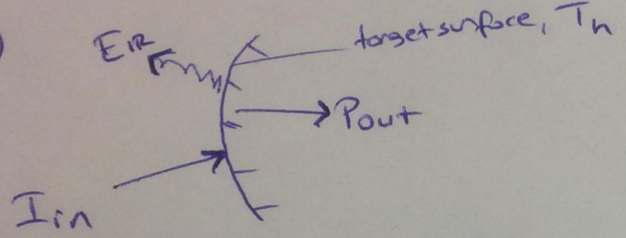
Quiz 4

a) $I_{in} = I_0 C$

$$C = \frac{100.000 \times 2}{100} = 2000$$

$$I_{in} = 2000 \times I_0 = 2 \times 10^6 \ (W/m^2)$$

b)



$$I_{in} = E_{IR} + P_{out}$$

$$I_0 C = \sigma T_h^4 + P_{out}$$

$$2 \times 10^6 = \sigma T_h^4 + 10^6$$

$$\sigma T_h^4 = 10^6$$

$$T_h = \sqrt[4]{\frac{10^6}{6 \times 10^{-8}}}$$

$T_h = 2020{,}5 \ (K)$

$T_h \sim 2020 \ (K)$

c) $T_{\text{working fluid}} \sim 673 \ (K)$

$$\eta = 1 - \frac{T_c}{T_h} = 1 - \frac{300}{673} = 0{,}55$$

$$P = 1\,MW \times 0{,}55$$

$$P = 0{,}55\,MW$$

Extra Credit

$$I(x) = I_o \exp\left(-\frac{x}{L_{scatt}}\right)$$

$$L_{scatt} = (n_p \sigma_{scatt})^{-1}$$

$$I(x) = I_o \exp(-x\, n_p\, \sigma_{scatt})$$

$$I(x) = I_o \underbrace{\exp(-10^3\, 10^{-10}\, 10^7)}_{\text{first cloud layer}} \underbrace{\exp(-10^3\, 10^{-9}\, 10^6)}_{\text{second cloud layer}}$$

(m) (m^2) $\frac{\#\text{particles}}{m^3}$

$$I(x) = I_o \exp(-1) \exp(-1)$$

$$I(x) = I_o * 0.135$$

DNI is reduced by 86.5 %