PHYS-E6570 Solar Energy Engineering (5); Mid-term exam, 21 February 2014

You may use a calculator in the exam

1. The Sun is a huge energy source driven by fusion reactions.

   a) Estimate Sun's radiative power based on its effective surface temperature and diameter.
   b) How large fraction of Sun's radiation hits the Earth?
   c) Estimate the solar constant (= incident radiation intensity per m^2 above the atmosphere).

   The effective surface temperature of the Sun is 5762 K and its diameter is 1.39×10^9 m. The mean distance between the Sun and the Earth is 1.5×10^{11} m, and the radius of the Earth 6370 km. Stefan–Boltzmann constant is $\sigma = 5.670373 \times 10^{-8}$ W m^{-2} K^{-4}.

2. The reflectance ρ of a surface is one of the key optical parameters in solar energy engineering. It determines both the absorptance α and emittance ε of a surface.

   a) Illustrate in a diagram the reflectance values (y-axis, 0–100%) as a function of the wavelength (x-axis, nm) for an ideal selective absorber in a solar thermal collector.
   b) Give 2 examples how to realize a selective absorber surface. Short answer.
   c) What is the equilibrium temperature of an ideal selective absorber in full sunshine? Stefan–Boltzmann constant is $\sigma = 5.670373 \times 10^{-8}$ W m^{-2} K^{-4}.

3. The amount of solar radiation on a surface can be increased through sun-tracking by following the movement of the sun and trying to minimize the incidence angle θ.

   Let's assume that we have a so-called 1-axis tracker with the following geometry: north–south axis (NS-axis) and east–west tracking (EW-tracking). The surface is horizontal. Determine the incidence angle of beam radiation on the surface using the solar azimuth γ_s and solar zenith angles θ_z.

4. The fin efficiency is a key parameter of a solar collector. It describes the heat transfer from absorber plate to heat transfer pipes (surface). Using the definition of the fin efficiency, design an absorber plate, incl. heat transfer pipes or channels, for a flat-plate collector. Your design should minimize the amount of materials needed or the total material cost of the absorber, while maintaining high fin efficiency. You can use Cu, Al and/or plastics. Definitions: F = fin efficiency = $X^{-1} \times \tanh(X)$, where $X = [U_L/(k\delta)]^{1/2} \times (W-D)/2$, U_L = heat loss factor, δ = thickness of absorber plate, k = thermal conductivity of absorber plate, W = width of an absorber strip, D = diameter of heat transfer pipe.

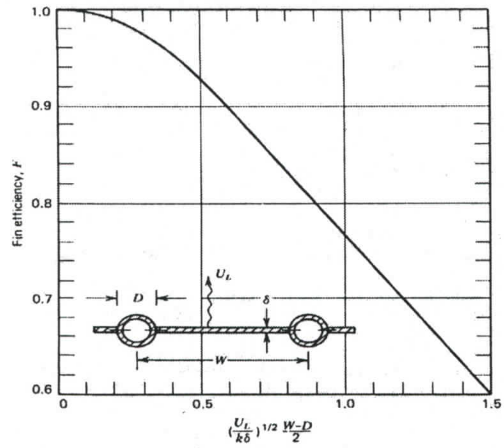

Figure 6.5.3 Fin efficiency for tube and sheet solar collectors.

Thermal conductivity (W/Km): Aluminum 211, Copper 385, Plastic 1;

Material costs ($/ton): Aluminum 2000, Copper 7000, Plastics 1000

Density (kg/m^3): Aluminum 2700, Copper 8940, Plastic 1175

5. Give a short (2–3 sentences) and precise answer to each of the following questions.
   a) Air mass
   b) Stokes law
   c) Pyranometer
   d) Ratio of diffuse radiation on a vertical surface to a horizontal surface
   e) Amount of solar radiation on a horizontal or 30° inclined surface in a year: Helsinki, Vienna, Rome or sun-belt countries (choose only one of these), give your answer in kWh/m^2
   f) U_L-value of a selective absorber flat plate collector with 1 glass cover.