

Solar Energy Conversion Devices and Plants: Exercise 3

In this exercise, you will learn how to calculate performance indicators for solar collectors.

Exercise 1

Consider a solar collector with plate-to-cover spacing of 20mm, a plate emittance of 0.90, glass emittance of 0.85, and tilted 30°. According to measurements, the mean temperature of the plate is 110°C, the ambient temperature is 10°C, and the heat transfer coefficient induced by wind is 10 W/m²K. Assuming that the sky temperature is the same as the ambient temperature, calculate the overall heat loss coefficient, U_t .

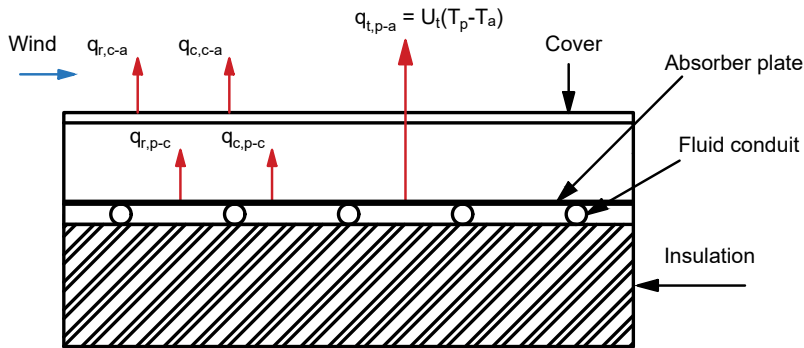


Figure 1: Scheme of the solar collector.

Hints: Use the following Nusselt correlation to compute the convection heat transfer coefficient between the plate and the cover, $h_{c,p-c}$.

$$Nu = 1 + 1.44 \left[1 - \frac{1708(\sin 1.8\beta)^{1.6}}{Ra \cos \beta} \right] \left[1 - \frac{1708}{Ra \cos \beta} \right]^+ + \left[\left(\frac{Ra \cos \beta}{5830} \right)^{1/3} - 1 \right]^+ \quad (1a)$$

$$Ra = \frac{g\beta' \Delta T L^3 Pr}{\nu^2} \quad (1b)$$

Where β is the collector tilt, β' is the volumetric coefficient of expansion (for an ideal gas $\beta' = 1/T$), L is the plate spacing, ΔT is the temperature difference between plates, and ν is the kinematic viscosity. The air properties have to be evaluated with an average temperature, $T_m = (T_p + T_c)/2$.

Note that the + exponent indicates that only positive values of the terms in the square brackets are to be used (i.e. use zero if the term is negative).

Exercise 2

An array of 12 solar collector modules are installed in parallel, at a slope of 60° and a surface azimuth of 0° . The hourly radiation on the plane of the collector I_T , the hourly radiation absorbed by the absorber plate S , and the hourly ambient temperature T_a are given in table 1. Assume the overall loss coefficient of the collector $U_L = 7.0 \text{ W/m}^2\text{K}$ and the plate efficiency factor $F' = 0.8$. The water flow rate through each $1 \times 2\text{-m}$ collector panel is 0.02 kg/s and the inlet water temperature remains constant at 40°C . Assume a controller turns off the water flow whenever the outlet temperature is less than the inlet temperature and $c_p = 4190 \text{ J/kgK}$.

- (i) Calculate the daily useful gain and efficiency of the array.
- (ii) Reevaluate the daily performance considering the effect and shading.

Hints: The average useful energy gain per unit of collector area is:

$$q_u = F_R[S - U_L(T_i - T_a)] \quad (2)$$

Where F_R is the heat removal factor and can be computed as follows:

$$f_1 = \frac{\dot{m}c_p}{A_c U_L F'} \quad (3a)$$

$$F'' = f_1 \left[1 - \exp\left(-\frac{1}{f_1}\right) \right] \quad (3b)$$

$$F_R = F' F'' \quad (3c)$$

Time	T_a ($^\circ\text{C}$)	I_T ($\text{MJ/m}^2\text{h}$)	S ($\text{MJ/m}^2\text{h}$)
7-8	-11	0.02	0.01
8-9	-8	0.43	0.35
9-10	-2	0.99	0.82
10-11	2	3.92	3.29
11-12	3	3.36	2.84
12-1	6	4.01	3.39
1-2	7	3.84	3.21
2-3	8	1.96	1.63
3-4	9	1.21	0.99
4-5	7	0.05	0.04

Table 1: Solar collector operational conditions.

Exercise 3

Estimate the reduction in useful energy gain due to heat capacity effects. The plate and tubes are cooper. The collector has the following specifications:

Plate thickness	0.5 mm
Tube thickness	0.5 mm
Internal diameter of the tube	12 mm
Tube spacing	125 mm
Glass cover thickness	3.5 mm
Back-insulation thickness	70 mm

	c , kJ/kgK	ρ , kg/m ³
Copper	0.48	8800
Glass	0.80	2500
Insulation	0.80	50

Hints: Compute the additional heat required to rise the temperature of the collector to the inlet water temperature and reduce that amount from the useful energy that was previously calculated. Assume that at 7 am the collector has the same temperature than the external environment and during the period in which the collector doesn't heat water, rather heats the collector components. The initial temperature has to be updated in every period of time. Use the following equations to perform the computations:

$$\frac{S - U_L(T_p - T_a)}{S - U_L(T_{p,\text{initial}} - T_a)} = \exp\left(-\frac{A_c U_L t}{(mc)_e}\right) \quad (4a)$$

$$(mc)_e = (mc)_p + \sum_{i=1}^n a_i (mc)_{c,i} \quad (4b)$$

Where m is the mass, c is the specific heat, $(mc)_p$ is the heat capacitance of the whole plate assembly, therefore is the sum of heat capacitance of the plate, tubes, water in the tubes, and half of the insulation (part of the insulation remains at ambient temperature), and t is time. The collector has only one cover ($n = 1$), use $a_1 = 0.27$.