Regular exam

Thermal Energy Conversion (SEE020)

2023-01-10, 08:30 - 12:30

Examiner	David Pallarès (tel.nr. 031 772 1435)
Allowed resources:	calculator, course book, formula sheet
Mark scale	Mark 5: at least 24 p Mark 4: at least 18 p Mark 3: at least 12 p Not passed: less than 12p
Exam review	week 3 (after agreement via e-mail: david.pallares@chalmers.se)

1. Describe under which circumstances biomass combustion is: a) renewable, and b) sustainable. **(2p)**

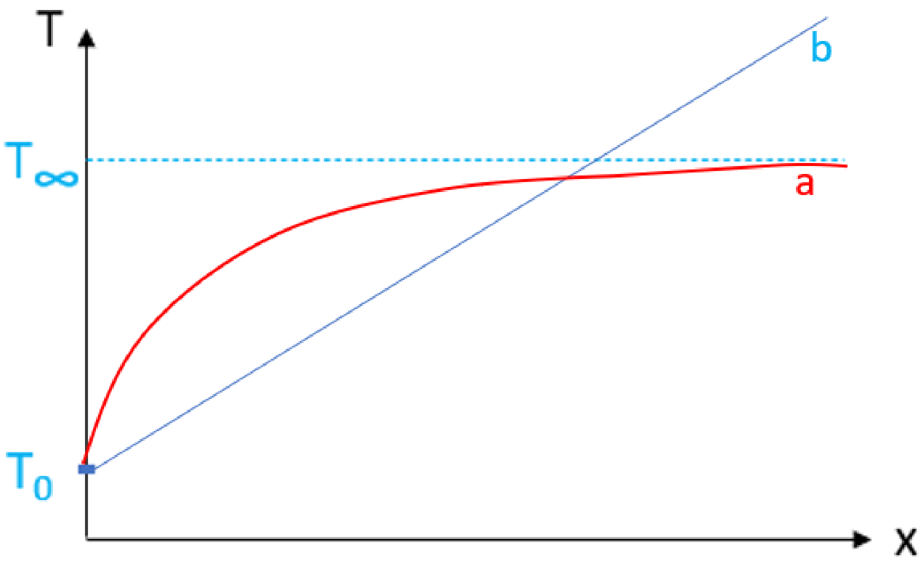
a) renewable if it is not harvested at a higher rate than it grows

b) sustainable if it is done in a way that preserves biodiversity, societal needs, etc

2. Draw the shape of the temperature curves, T(x), describing how a fluid with an inlet temperature T_0 is heated up is heated up in a tube when:

a) the tube belongs to a heat exchanger with the hot media being flue gas at a certain temperature, T_∞ **(1p)**

b) the tube belongs to a solar receiver (thus getting heat from solar irradiation) **(1p)**



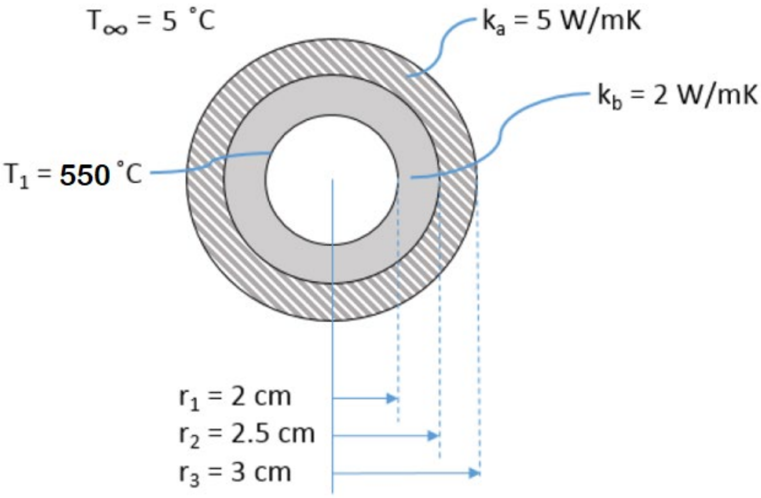
For which of the two curves above (a, b, both, or none) would be adequate to use the concept of logarithmic mean temperature difference (LMTD)? Motivate your answer. **(2p)**

Only for (a), since the LMTD method is derived and requires heat exchange through a temperature difference rather than the constant heating rate applying for (b).

3. Pressurized water flows inside an insulated tube in a room at 5 °C. Dimensions and properties of the tube and the insulation are given in the figure below. In a certain location in the tube, the pressurized water holds 550 °C and the convective and radiative heat transfer coefficients between the insulation and the surrounding are h_{conv} = 13 W/m^{2}K and h_{rad} = 54 W/m^{2}K, respectively. For this location in the tube:

a) What is the heat flow transferred from the pressurized water along 1 cm of tube? **(2p)**

b) What are the temperatures at the surface of the insulation and in the interface between the tubes and the insulation? **(3p)**



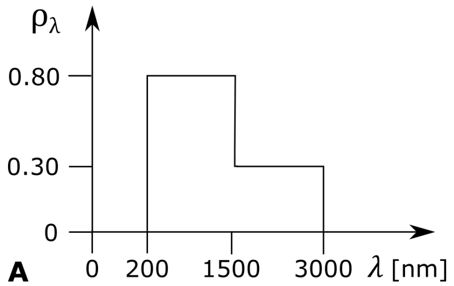
4. Energy systems characterized by fluctuating energy flows can have a more stable operation by being equipped with energy storage tanks. In our case, a cylindrical tank (r = 5m, h = 15m) is filled with hot water (C_p=4500 J/kgK, ρ=950 kg/m^3). The heat losses from the water tank to the surrounding (which holds 5 °C) can be described by a thermal resistance, R=2·10^{-4} K/W. At some point, the water in the full tank holds 85 °C and the water begins to be replaced by an incoming flow (1.5 m^3/s) of water at 60 °C.

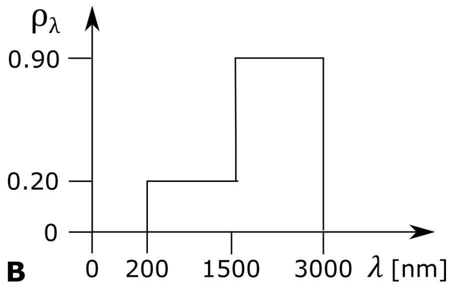
a) Calculate the tank temperature after one hour. **(3p)**

b) Do you consider this tank to be well-dimensioned for acting as a dampener of hourly temperature fluctuations in the system? **(1p)**

5. In a solar power plant building project:

a) You are in charge of selecting the mirrors and your boss hands you two options to choose from. Alternative A is the mirror commonly used, and alternative B is a considerably cheaper option that your boss has found. Your boss is eager to go for alternative B due to large savings. Based on the spectral reflectivities shown below, what is your response? Which alternative would you choose? Motivate your answer. **(1p)**





b) Both mirror alternatives are opaque. Calculate the total reflectivity of the incident solar radiation for the mirror alternative of your choice in a). The sun irradiation at your mirrors can be considered as blackbody radiation at a temperature of 5800 K. **(3p)**

A sunny day, the direct irradiation from the sun is 1000 W/m^2 at your plant, in which you have installed 2000, sun tracking, quadratic mirrors with a side of 1.2 m. Your absorber has an absorptivity of 0.85, an area of 6 m^2 and the absorbing medium holds a temperature of 700°C.

c) Calculate the absorber efficiency of your solar park. You can consider the mirror reflections of the direct irradiation from the sun as the only source of irradiation to your absorber, and that all the reflected radiation reaches your absorber (mirrors are not diffusive). **(2p)**

a) The more expensive alternative A has a much more suitable spectral reflectivity. Comparing the different intervals, the main part of the irradiation from the sun lies between 200 and 1500 nm. For a mirror you would desire a material that reflects well within this interval. Therefore, if you are set for a certain number of mirrors in the solar park, you should choose alternative A even though it is more expensive.

b) Assume that the reflectivity is independent on the solar direction. The total reflectivity can then be expressed as:

$$\rho = \frac{\int_0^\infty \rho_\lambda G_\lambda(T) d\lambda}{\int_0^\infty G_\lambda (T) d\lambda}$$

Given that the solar radiation is blackbody radiation we can calculate the total reflectivity as:

$$\rho = 0 + \rho_2 \frac{\int_{0.2}^{1} E_{\lambda b}(\lambda, T)\, d\lambda}{E_b(T)} + \rho_3 \frac{\int_{1}^{2} E_{\lambda b}(\lambda, T)\, d\lambda}{E_b(T)} + 0$$

$$\rho_A = 0.80 * F_{0.2\to 1} + 0.30 * F_{1\to 2}$$

$$\rho_B = 0.20 * F_{0.2\to 1} + 0.90 * F_{1\to 2}$$

From table 12.2 in the course book, the portion of the blackbody radiation corresponding to each interval can be found. First, from $\lambda = 0$, to each wavelength:

$$F_{0\to\lambda} = \frac{\int_0^{\lambda} E_{\lambda b}(\lambda, T)\, d\lambda}{E_b(T)}$$

$$\left.\begin{array}{ll} \lambda_1 T = 0{,}2 * 5800 = 1160\ \mu mK & \to \quad F_{0\to\lambda_1} = 0.0018 \\ \lambda_2 T = 1.5 * 5800 = 8700\ \mu mK & \to \quad F_{0\to\lambda_2} = 0.8808 \\ \lambda_3 T = 3 * 5800 = 17400\ \mu mK & \to \quad F_{0\to\lambda_3} = 0.9739 \end{array}\right\}$$

Calculate the portion of the blackbody radiation that corresponds to each wavelength interval:

$$F_{\lambda_1\to\lambda_2} = F_{0\to\lambda_2} - F_{0\to\lambda_1} = 0.8790$$

$$F_{\lambda_2\to\lambda_3} = F_{0\to\lambda_3} - F_{0\to\lambda_2} = 0.0931$$

The total reflectivity becomes:

$$\rho_A = 0.80 * 0.8790 + 0.30 * 0.0931 = 0.7311 \approx 0.73$$

$$\rho_B = 0.20 * 0.8790 + 0.90 * 0.0931 = 0.2596 \approx 0.26$$

c) All solar radiation is assumed to be reflected towards the absorber, the reflectivity we calculated above tells us how much solar radiation that is directed towards the absorber.

We neglect the emission from the mirrors. We assume that the absorber is grey $(\alpha = \varepsilon)$.

The absorber efficiency can be expressed as:

$$\eta = \frac{Q_{medium}}{Q_{in}} = \frac{\alpha Q_{in} - Q_{loss}}{Q_{in}} = \alpha - \frac{Q_{loss}}{Q_{in}}$$

Where the incident heat flux to the absorber surface can be calculated as:

$$Q_{in} = A_{mirror}\rho G_{dir}$$

And the heat loss for the absorber (grey assumption):

$$Q_{loss} = A_{absorber}\varepsilon\sigma T_{medium}^4$$

Gives the absorber efficiency as:

$$\eta = \alpha - \frac{A_{absorber}\alpha\sigma T_{medium}^4}{A_{mirror}\rho G_{dir}}$$

$$\eta_A = 0.85 - \frac{6 * 0.85 * 5.67 * 10^{-8} * (700 + 273)^4}{2000 * 1.2^2 * 0.73 * 1000} = 0.7267$$

$$\eta_B = 0.85 - \frac{6 * 0.85 * 5.67 * 10^{-8} * (700 + 273)^4}{2000 * 1.2^2 * 0.26 * 1000} = 0.5039$$

6. It is the middle of the winter but you just found some blueberries laying in your freezer and you decide to make a pie. You set the pie tin on a very thin wire rack in the middle of a cubic shaped oven without windows. The side of the oven is 30 cm and the pie tin has a diameter of 20 cm and a height of 7 cm, with smooth surfaces. On top of your pie, you have placed a smooth layer of dough, in line with the top of the pie tin.

a) Calculate all view factors between pie tin (1), dough (2) and oven (3), you can neglect the thin wire rack in your calculations. (**2p**)

b) To avoid burning your pie, when the pie is almost done, you place a sheet of aluminum sheet on top of the pie. The emissivities of the dough and aluminum are 0.85 and 0.10, respectively. Explain why adding this sheet protects your pie dough from getting burned. (**1p**)

a) We must calculate $3^2 = 9$ view factors.

The pie tin doesn't see itself or the dough, only the oven.

$F_{11} = 0;\ F_{12} = 0; F_{13} = 1$

The dough doesn't see itself or the pie tin, only the oven.

$F_{21} = 0;\ F_{22} = 0;\ F_{23} = 1$

The oven sees the pie tin, the dough and it sees itself.

$$A_1 = \frac{\pi D_1^2}{4} + \pi D_1 h_1 = \frac{\pi * 0.20^2}{4} + \pi * 0.20 * 0.07 \approx 0.0754\, m^2$$

$$A_2 = \frac{\pi D_2^2}{4} = \frac{\pi * 0.20^2}{4} \approx 0.0314\, m^2$$

$$A_3 = D_3^2 * 6 = 0{,}3^2 * 6 = 0{,}54\ m^2$$

$$F_{31} = F_{13} * \frac{A_1}{A_3} \approx 0.140$$

$$F_{32} = F_{23} * \frac{A_2}{A_3} \approx 0.058$$

$$F_{33} = 1 - F_{31} - F_{32} = 0.745$$

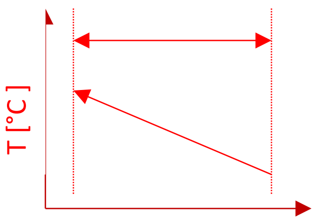
b) The aluminum has a very reflective surface (high ρ) and most of the irradiation will be reflected from the surface, and it won't burn the pie dough. The aluminum acts as a radiation shield for the pie and, radiation is exchanged between the dough and the aluminum sheet instead. The pie is instead finished mainly due to conduction through the pie tin and aluminum sheet.

7. As a new employee in a plant, you are trying to map the flows in the heat exchanger network. You see the following readings on the screen for a tube heat exchanger:

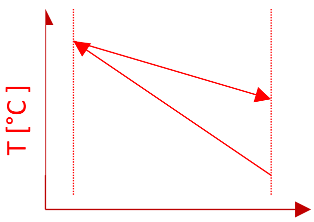
name	Temp. [°C]
Ti_H2O_r	50
Ti_H2O_q	70
Ti_H2O_t	110
Ti_H2O_a	110

Indicate the theoretically possible options by drawing, for each of them, the temperature profiles and flow directions in a diagram as shown below. Comment under which conditions each option is viable and if it is realistic. **(2p)**

a) condensation, flow direction of the condensing flow could go both directions!



b) Counter flow with either Chot >>>Ccold or a infinitesimal large exchanger area (not realistic in an industrial setting if the heat exchanger is in operation)



8. Consider a co-current heat exchanger in parallel flow with the following characteristic.

	$\dot{m}$ [kg/s]	C_p [J/kgK]	T_{in} [°C]	T_{out} [°C]
cold (water)	25	4200	105	148
hot (gas)	11	1700	800	560
$A = 58\ m^2$ $U = 144\ W/m^2K$				

a) What are the new outlet temperatures if you increase the flow of water to 32 kg/s? **(3p)**

For the calculation, assume that the overall heat transfer coefficient will not change.

b) Argue if the assumption to keep the overall heat transfer coefficient constant is reasonable or not. **(1p)**