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Exercise 10: TMT4208

Hand out: 05.04.2021
Seminar: 12.04.2021
Hand in: 16.04.2021

In this exercise we will determine the *net radiation flow density* $\dot{q}_{1\rightleftarrows 2}$ in W per m^2 between two large, grey, planar, parallel surfaces 1 and 2 with emissivity $\varepsilon_1 = \alpha_1$ and $\varepsilon_2 = \alpha_2$, and temperatures T_1 and T_2 (Task 2), and then investigate the effect of inserting radiation shields between the two original surfaces. However, first (Task 1) we will find $\dot{q}_{1\rightleftarrows 2}$ in the extreme case that both surfaces are *black*, i.e. $\varepsilon_1 = \varepsilon_2 = 1$.

Task 1: Radiation exchange between two flat parallel black surfaces.

The calculation, in W/m^2, from surface 1 to surface 2 is with reference to Fig a) below can be formulated:

$$\underline{\underline{\dot{q}_{1\rightleftarrows 2}} = \dot{q}_{1\to 2} - \dot{q}_{2\to 1}} = \sigma {T_1}^4 - \sigma {T_2}^4 = \underline{E_{b1} - E_{b2}} \quad (\varepsilon_1 = \varepsilon_2 = 1)$$

a) What is the significance of the q-terms used here?
b) The constant σ has the value 5.67E-8; What is this constant called, and what is its dimension?
c) Using T_1 = 1800°C, T_2 = 50°C; determine the net radiation flow density between the two surfaces.

Task 2: Radiation exchange between two flat parallel grey surfaces

The net radiation flow density from surface 1 to surface 2 is generally given by:

$$\dot{q}_{1\rightleftarrows 2} = \dot{q}_{1\to 2} - \dot{q}_{2\to 1} = \frac{\varepsilon_1\alpha_2 E_{b1} - \varepsilon_2\alpha_1 E_{b2}}{1-(1-\alpha_1)(1-\alpha_2)} \qquad (1)$$

a) Given the geometric series and its solution: $A + Ak + Ak^2 + \ldots = \frac{A}{1\text{-}k}$ $(k < 1)$, sketch the derivation of equation (1) with reference to figure b) below.
b) Show that a simplified version of (1):

$$\underline{\dot{q}_{1\rightleftarrows 2}} = \frac{\varepsilon_1\varepsilon_2}{\varepsilon_1+\varepsilon_2-\varepsilon_1\varepsilon_2}(E_{b1} - E_{b2}) = \underline{\frac{E_{b1}-E_{b2}}{\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_2}-1}} \qquad (2)$$

can be written by using Kirchhoff's law for grey bodies.

c) Using T_1 = 1800°C, T_2 = 50°C, and $\varepsilon_1 = \varepsilon_2 = \varepsilon = 0.80$; determine the net radiation flow density between the two surfaces.

Task 3: Radiation exchange between multiple flat parallel surfaces

This task refers to the Fig c) below and deals with the radiation flow density from the grey surface I to the grey surface II with a number n of radiation shields placed in between them. All the shields have the same emissivity, ε, on both sides and are assumed to be grey. The heat conduction resistance in the shields is negligible such that the temperature is the same on both sides. TI and TII together with εI, εII and ε is assumed to be given.

a) Here we must assume $\dot{q}_{I\rightleftarrows 1} = \dot{q}_{1\rightleftarrows 2} = \dot{q}_{2\rightleftarrows 3} = \ldots = \dot{q}_{n\rightleftarrows \mathrm{II}} = \dot{q}_{I\rightleftarrows \mathrm{II}}$ =?What is the necessary condition for making this assumption?

b) Use equation (2) above for the radiation exchange between two parallel, planar, grey surfaces and formulate expressions for the fluxes: $\dot{q}_{I\rightleftarrows 1} = \dot{q}_{1\rightleftarrows 2} = \dot{q}_{2\rightleftarrows 3}$ and $\dot{q}_{n\rightleftarrows \mathrm{II}}$

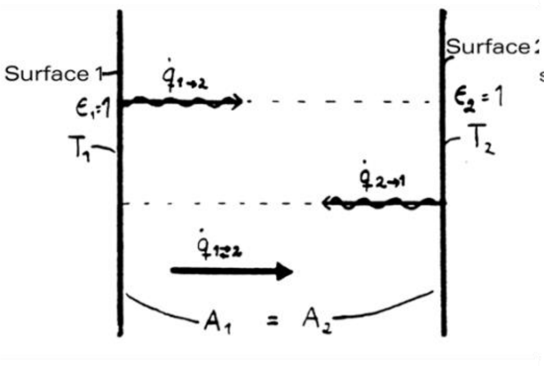
c) Sketch how the result in b) will lead to the expression: $\dot{q}_{I\rightleftarrows \mathrm{II}} = \dfrac{E_{\mathrm{bI}} - E_{\mathrm{bII}}}{\left[\frac{1}{\varepsilon_I} + \frac{1}{\varepsilon_{\mathrm{II}}} - 1 + \mathrm{n}\left(\frac{2}{\varepsilon} - 1\right)\right]}$ (3) for

the radiation flow density between grey surface I and grey surface II with n radiation shields placed in between them.

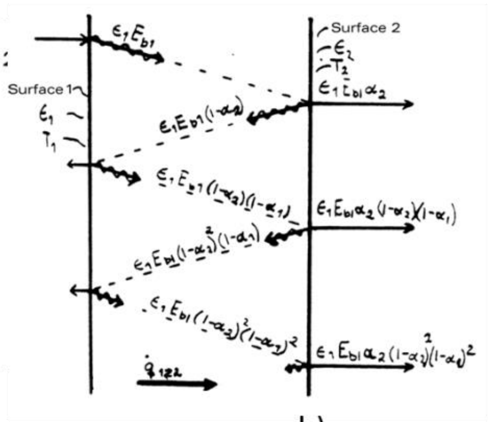
d) Show that In the special case of $\varepsilon_I = \varepsilon_{II} = \varepsilon$ we get:

$$\dot{q}_{I\rightleftarrows \mathrm{II}} = \frac{E_{\mathrm{bI}} - E_{\mathrm{bII}}}{(n+1)\left(\frac{2}{\varepsilon} - 1\right)} = \frac{\dot{q}_{I\rightleftarrows \mathrm{II}}\,(n=0)}{\mathrm{n}+1} \qquad (4)$$

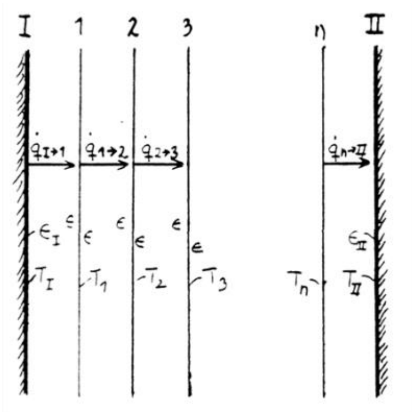
e) Using T_1 = 1800°C, T_2 = 50°C, and $\varepsilon_I = \varepsilon_{II} = \varepsilon = 0.80$; determine the net radiation flow density between the two surfaces with (n =) 0, 1 and 4 radiation shields.



a)



b)



c)