Heat transfer - RADIATION

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30th Oct. 2019: SUMMARY

Emissivity ε = how much emissive power a surface has, with respect to a blackbody

The emissivity ε of a blackbody is 1 and the emissivity of real surfaces can vary between 0 and 1. In the calculations, to find the emissivity of a surface, we have to divide the emissive power of the surface by σT^4.

Emissivity can vary with respect to temperature, wavelength and direction. Knowing this this we can define it as **spectral emissivity ε_λ** when it is related to a specified wavelength and **directional emissivity ε_θ** when it is related to a specified directional angle. We know now that in diffused surfaces, which emit the same radiation in every direction, **ε_θ** is constant, while in gray surfaces, which have the same emissivity for every wavelength, **ε_λ** is constant. In real surfaces, we have variations both in the spectral and in the directional emissivity.

As many surfaces can be approximated as diffuse, we can say that their **radiation intensity** is independent from direction, and thus their emissivity is constant (**$E = \pi I_e$**)

All surfaces receive radiation emitted or reflected by other surfaces. The intensity of incident radiation is called **irradiation G** (**$G = \pi I_i$** for diffuse surfaces)

We need to know the total intensity of radiation energy in a certain direction to calculate the rate of heat transfer between two surfaces. The total radiation leaving a surface has two different components: emitted radiation and reflected radiation. **Radiosity J** is the total power leaving a certain surface (EMISSIVE POWER + REFLECTION). For diffuse surfaces we have (**$J = \pi I_{e+r}$**).

Absorptivity α = the capacity of a surface to absorb incident radiations

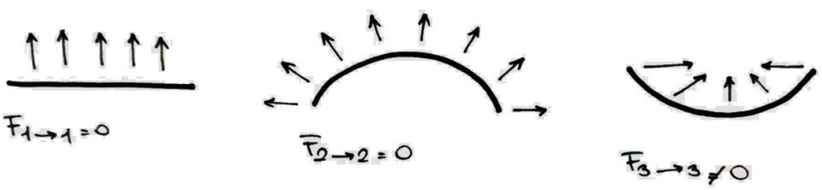
Reflectivity ρ = the capacity of a surface to reflect incident radiations

For opaque surfaces **$\alpha + \rho = 1$** (for transparent surfaces we need to add the transmittivity τ: $\alpha + \rho + \tau = 1$)

Kirchhoff's Law states that the total emissivity of a surface at temperature T, is equal to the total absorptivity for radiation coming from a blackbody at the same temperature: **$\varepsilon(T) = \alpha(T)$**.

The **view factor F** is a geometrical quantity that represents the fraction of radiation leaving surface 1 that is intercepted by surface 2. It doesn't depend on the surface properties.

According to their shape, some surfaces can have a view factor not only to other surfaces but also to themselves.



$F_{12} = q_{12} / q_1 \dashrightarrow q_{12} = F_{12} \times q_1$

If S_1 is a blackbody at T_1: $q_{12} = F_{12} \times \sigma T^4$ ---> **$Q_{12} = F_{12} \times A_1 \times \sigma T^4$**

(repeat process for Q_{21})

To find the **rate of radiative heat exchange between two balck surfaces** we simply have to subtract the total radiation coming from surface 2 and intercepting surface 1 from the total radiation coming from surface 1 and intercepting surface 2. Since we are talking about perfect absorbers, reflected radiation doesn't have to be taken in account; that's why we take in consideration just the emissive power.

$A_1 F_{12} = A_2 F_{21}$ is the reciprocity law that allows us to simplify the equation:

$Q_{1<->2} = F_{12}\ A_1\ \sigma T_1^4 - F_{21}\ A_2\ \sigma T_2^4$

$Q_{1<->2} = F_{12}\ A_1\ \sigma\ (T_1^4 - T_2^4)$

For **opaque grey surfaces** we have to take in account, not only the radiation emitted by the two surfaces, but also the radiation reflected by the two surfaces. That's why we use radiosity in the equation instead of the emissive power.

$J = \varepsilon E_b + \rho G = \varepsilon E_b + (1-\varepsilon)G$

$Q = A (J-G) = A\varepsilon / (1-\varepsilon) \times (E_b-J)$ ---> $Q = (E_b-J) / R$ dove $R = (1-\varepsilon) / A\varepsilon$

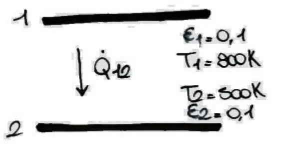
$Q_{1<->2} = F_{12} A_1 J_1 - F_{21} A_2 J_2$ ma $A_1 F_{12} = A_2 F_{21}$

$\mathbf{Q_{1<->2} = F_{12} A_1 (J_1 - J_2)}$

$Q_{1<->2} = (J_1 - J_2) / R_{1<->2}$ dove $\mathbf{R_{1<->2} = 1 / (F_{12} A_1)}$ **= radiative resistance**

EXERCISE:

RADIATION HEAT TRANSFER BETWEEN TWO PARALLEL PLATES



$$\dot{Q}_{12} = \frac{\sigma (T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

$$\dot{Q}_{12} = \frac{5,67 \cdot 10^{-8} (800^4 - 500^4)}{\frac{1}{0,1} + \frac{1}{0,1} - 1} = \frac{19680,57}{19} = 1035,8 \text{ W}$$

Reducing the emissivity of the surfaces materials from 0.2 and 0.7 to 0.1 reduced the radiation heat transfer almost to the third (with respect to the exercise we did in class).