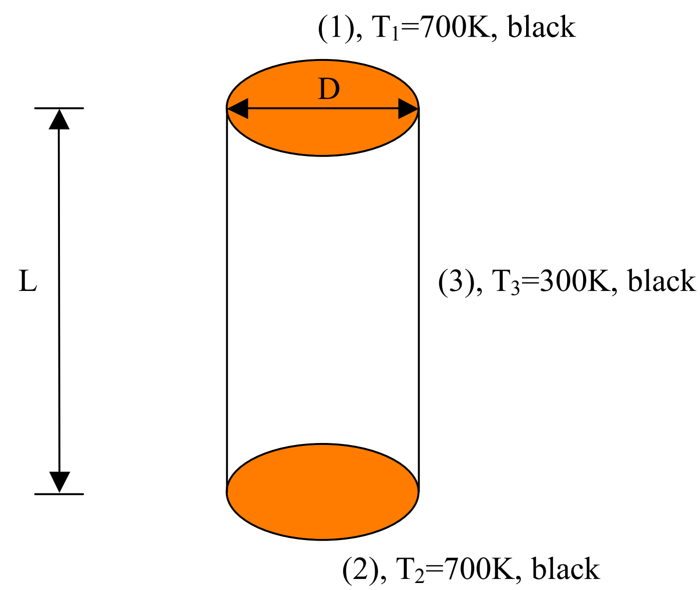
Tutorial # 11

Radiation Heat Transfer

Problem 1 Two parallel disks of diameter D=0.6m separated by L=0.4m are located directly on top of each other. Both disks are black, and are maintained at a temperature of 700K. The back sides of the disks are insulated, and the environment that the disks are in can be considered to be a blackbody at a temperature of 300K. Determine net rate of radiation heat transfer from the disks to the environment.

Solution:

Step 1: Draw a schematic diagram



Step 2: What to determine?

The net rate of radiation heat transfer from the disks to the environment, $\dot{Q}_3$

Step 3: The information given in the problem statement.

- The diameter of the disk D=0.6m and the distance of them L=0.4m;
- Disk temperature $T_1=T_2=700K$ and the environmental temperature $T_3=300K$.

Step 4: Assumptions

- Both the disks and the environment can be considerer as black;
- It's a steady-state condition.

Step 5: Solve

Since the back sides of the disks are insulated, the whole system could be considered to be three-surface enclosure. As shown in the figure, we consider the top disk surface to be surface one, the base disk surface as surface two and the environment (side surface) as the surface three.

This is a radiation heat transfer problem with black surfaces. In order to determine the radiation heat transfer from the disks to the environment, we just need to determine the heat transfer rate from either disk to the environment because of the symmetry.

Due to the surfaces involved are black,

$$\dot{Q}_{1\to 3} = A_1 F_{1\to 3}\sigma(T_1^4 - T_3^4)$$

As for the view factor, we can't determine it directly. However, from the Figure 12-43 in the textbook, we can get the view factor $F_{1\to 2} = 0.25$

Thus,

$$F_{1\to 3} = 1 - F_{1\to 1} - F_{1\to 2} = 1 - 0 - 0.25 = 0.75$$

Also,

$$A_1 = \frac{\pi D^2}{4}$$

So,

$$\dot{Q}_{1\to 3} = \frac{\pi D^2}{4} F_{1\to 3}\sigma(T_1^4 - T_3^4)$$

$$= \frac{\pi(0.6m)^2}{4}(0.75)[5.67\times 10^{-8} W/(m^2 \cdot K^4)][(700K)^4 - (300K)^4]$$

$$= 2792W$$

Due to the symmetric condition, $\dot{Q}_{2\to 3} = \dot{Q}_{1\to 3}$

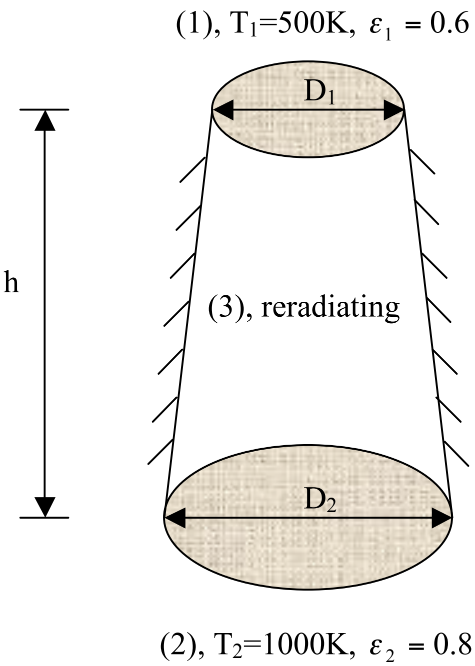
The total radiation heat transfer is

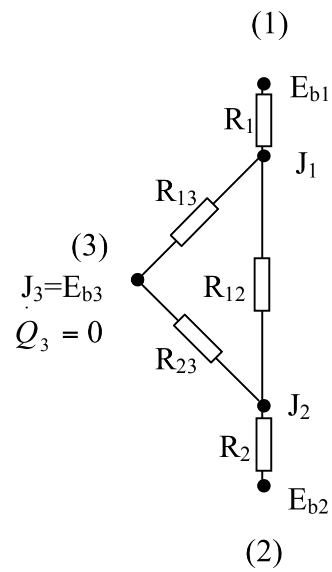
$$\dot{Q}_3 = \dot{Q}_{2\to 3} + \dot{Q}_{1\to 3} = 2\times(2792W) = 5584W$$

Step 6: Conclusion statement

The net rate of radiation heat transfer from the disks to the environment is about 5584W.

Problem 2 As shown in the figure, a furnace with reradiating side surfaces has a height of 2m. The diameters of the ceiling and floor surfaces are 2m and 4m. The ceiling (surface 1) and the floor surface (surface 2) have emissivities of 0.6 and 0.8, respectively, and the temperature of them are maintained at 500K and 1000K. Determine the net rate of radiation heat transfer between the ceiling and the floor surface of the furnace.





Solution:

Step 1: Draw a schematic diagram

As shown in the figure, the radiation network is described associated with the three-surface enclosure(furnace).

Step 2: What to determine?

The net rate of radiation heat transfer between the ceiling and the floor surface of the furnace, $\dot{Q}$

Step 3: The information given in the problem statement.

- Height of the furnace: h=2m;
- The ceiling and floor surface:
  - Diameter: D_1=2m, D_2=4m;
  - Temperature: T_1=500K, T_2=1000K;
  - Emissivity: $\varepsilon_1 = 0.6$, $\varepsilon_2 = 0.8$

Step 4: Assumptions

- The steady-state conditions exist.
- The surfaces are opaque, diffuse and gray if not specified.

Step 5: Solve

With the ceiling (surface 1), floor (surface 2) and the side (surface 3), the furnace can be considered as a three-surface enclosure with a radiation network as shown in the figure. Since the side surfaces (surface 3) are reradiating, the net heat transfer through this surface is zero. To maintain this steady-state condition, the entire heat loss from the ceiling must be gained by the floor. So, the heat transfer rate from the ceiling to floor in the whole furnace can be determined from

$$\dot{Q}_1 = \frac{E_{b1} - E_{b2}}{R_1 + (\frac{1}{R_{12}} + \frac{1}{R_{13} + R_{23}})^{-1} + R_2}$$

$$= \frac{\sigma(T_1^4 - T_2^4)}{\frac{1-\varepsilon_1}{A_1\varepsilon_1} + [A_1F_{12} + \frac{1}{(A_1F_{13})^{-1} + (A_2F_{23})^{-1}}]^{-1} + \frac{1-\varepsilon_2}{A_2\varepsilon_2}}$$

From the Figure 12-43 in the textbook, we can determine the view factors,

$$F_{12} = 0.44$$

Applying the summation rule, we can get,

$$F_{13} = 1 - F_{11} - F_{12} = 1 - 0 - 0.44 = 0.56$$

Applying the reciprocity rule, we can get,

$$F_{21} = F_{12}\frac{A_1}{A_2} = 0.44 \times \frac{\pi(1m)^2}{\pi(2m)^2} = 0.11$$

Again with summation rule, we can get,

$$F_{23} = 1 - F_{21} - F_{22} = 1 - 0.11 - 0 = 0.89$$

$$\dot{Q}_1 = \frac{[5.67\times10^{-8}W/(m^2\cdot K^4)]\times[(500K)^4 - (1000K)^4]}{\frac{1-0.6}{\pi(1m)^2\times0.6} + \{\pi(1m)^2\times0.44 + \frac{1}{[\pi(1m)^2\times0.56]^{-1} + [\pi(2m)^2\times0.89]^{-1}}\}^{-1} + \frac{1-0.8}{\pi(2m)^2\times0.8}}$$

Substituting,

$$= -92178W$$

Step 6: Conclusion statement

The net rate of radiation heat transfer is 92178W from the floor to the ceiling surface.