

Thermodynamics
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Lecture 18

Tutorial Problem on 'Modes of heat transfer'

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Q1 A normal household refrigerator has a black grille on the back. The surface temperature of the grille is 40°C and has a total surface area of 1m^2 . The room air is at 20°C and heat transfer takes place with an average convective heat transfer coefficient of $10\text{W}\cdot\text{m}^{-2}\cdot\text{K}^{-1}$. What is the maximum amount of thermal energy that can be removed from the grille during 15 minutes of operation?

$$\begin{aligned} A &= 1\text{m}^2 & t &= 15\text{min} & T_g &= 40^\circ\text{C} \\ T_g &= 40^\circ\text{C} & &= 15 \times 60 & &= 900\text{s} \\ T_a &= 20^\circ\text{C} & & & & \\ h &= 10\text{W}/(\text{m}^2\text{K}) & & & & \end{aligned}$$




Figure 1

Solution of the problem shown in Fig. 1:

$$A = 1\text{m}^2, T_g = 40^\circ\text{C}, T_a = 20^\circ\text{C}, h = 10\frac{\text{W}}{\text{m}^2\text{K}}, t = 15\text{min} = 900\text{s}$$

The grille loses heat to the surroundings by convection as well as radiation.

We assume that the refrigerator has reached steady state operation. Also, the temperature of the surroundings does not change.

Let's first calculate the heat lost due to convection.

$$\dot{Q}_c = hA\Delta T = 10 \times 1 \times (40 - 20) = 200\text{W}$$

$$\text{Hence, } Q_c = \dot{Q}_c \times t = 200 \times 900 = 180\text{kJ}$$

Let's calculate the heat lost due to radiation.

Assume that the grille is a black body. Hence, $\varepsilon = 1$.

$$\dot{Q}_R = \varepsilon \sigma A (T_g^4 - T_a^4) = 1 \times 5.67 \times 10^{-6} \times 1 \times (313^4 - 293^4) = 126.3 \text{ W} \text{ (temperatures are in kelvin)}$$

$$\text{Hence, } Q_R = 126.3 \times 900 = 113 \text{ kJ}$$

$$\text{Total heat lost} = Q_c + Q_R = 180 + 113 = 293 \text{ kJ}$$

Hence, the heat interaction for the grille, taking grille as a system, is -293 kJ while it is +293 kJ for the surroundings as the grille is losing heat and the surroundings is absorbing heat.