

Thermodynamics
Professor Anand T N C
Department of Mechanical Engineering
Indian Institute of Technology, Madras
Lecture 68
Tutorial problems (2 numbers)

(Refer Slide Time: 00:13)

Carnot engine 1 works between temperature reservoirs A and B and **Carnot engine 2** works between reservoirs B and C. Temperature of reservoirs A, B and C are 850 K, 450 K and 250 K respectively. In any cycle, heat rejected by Carnot engine 1 to reservoir B is used by Carnot engine 2. For one cycle, Carnot engine 1 absorbs 150 MJ of heat from reservoir A. Calculate the heat rejected by Carnot engine 2 to reservoir C.

$Q_A = 150 \text{ MJ}$
 $Q_C = ?$

$\frac{Q_A}{Q_B} = \frac{850}{450} \Rightarrow Q_B = 150 \times \frac{450}{850} = 79.4 \text{ MJ}$

$\frac{Q_B}{Q_C} = \frac{450}{250} \Rightarrow Q_C = 79.4 \times \frac{250}{450}$

$Q_C = 44.1 \text{ MJ} \checkmark$



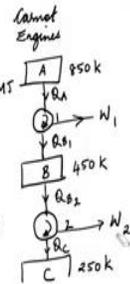




Figure 1.

Solution of the problem in Fig. 1:

$$T_A = 850 \text{ K}, T_B = 450 \text{ K}, T_C = 250 \text{ K}, Q_A = 150 \text{ MJ}$$

The schematic showing the engines and the temperature reservoirs is drawn in Fig. 1.

In any cycle, heat rejected by the Carnot's engine 1 equals the heat received by the Carnot's engine 2.

Since these are Carnot's engines,

$$\frac{Q_A}{Q_B} = \frac{T_A}{T_B} = \frac{850}{450} \rightarrow Q_B = 79.4 \text{ MJ} \quad (Q_A \text{ and } Q_B \text{ are the magnitudes of the heat transfers})$$

$$\text{Similarly, } \frac{Q_B}{Q_C} = \frac{T_B}{T_C} = \frac{450}{250} \rightarrow Q_C = 44.1 \text{ MJ}$$

(Refer Slide Time: 04:54)



A refrigerator has a COP of 2.5 and a power input of 500 W. It has to cool 7 big watermelons, which are at 25 degrees C initially, to 8 degrees C. The weight of each watermelon is 10 kg. Watermelon can be treated as water with specific heat of 4.2 kJ/kgK. How long will it take for this refrigerator to cool them to the required temperature? In reality, will the time taken by the refrigerator be greater or smaller than the time you calculated?

Handwritten solution and schematic:

$COP = 2.5$
 $\dot{W} = 500 \text{ W}$
 $T_i = 25^\circ\text{C} = 298 \text{ K}$
 $T_f = 8^\circ\text{C} = 281 \text{ K}$
 $m_w = 10 \text{ kg}$
 $m = 7 \times m_w = 70 \text{ kg}$
 $C = 4.2 \text{ kJ/kgK}$
 $Q_L = m C (T_f - T_i) = 70 \times 4.2 \times (25 - 8) = 4998 \text{ kJ}$
 $W = 4998 / COP = 1999.2 \times 10^3 \text{ J}$

Schematic diagram of a refrigerator cycle:

- A box labeled "Water melons" has an upward arrow labeled Q_L pointing to a circle representing the refrigerant.
- The circle has an upward arrow labeled Q_H pointing to a horizontal line representing the condenser.
- A horizontal arrow labeled $W = 500 \text{ W}$ points to the circle from the right, representing the work input.

Handwritten calculations for the schematic:

$COP = \frac{Q_L}{W} = 2.5$
 $\dot{W} = \frac{W}{t} \rightarrow t = \frac{W}{\dot{W}} = 3.99 \times 10^3 \text{ s}$



Figure 2.

Solution of the problem in Fig. 2:

$$COP = 2.5, \dot{W} = 500 \text{ W}, T_i = 25^\circ\text{C} = 298 \text{ K}, T_f = 8^\circ\text{C} = 281 \text{ K}, m_w = 10 \text{ kg}, m = 7 \times m_w = 70 \text{ kg}, C = 4.2 \frac{\text{kJ}}{\text{kg} \cdot \text{K}}$$

We are going to assume that the temperature of this refrigerator is the temperature of the watermelons. We are cooling only the watermelons and not the insides of the refrigerator or there is nothing else in the refrigerator other than the watermelons.

The schematic of the refrigerator is drawn in Fig. 2.

The magnitude of heat needed to be removed from the watermelons,

$$Q_L = m C \Delta T = 70 \times 4.2 \times (25 - 8) = 4998 \text{ kJ}$$

$$\text{Now, } COP = \frac{Q_L}{W} \rightarrow W = 1999.2 \text{ kJ}$$

$$\text{Now, } \dot{W} = \frac{W}{t} \rightarrow t = \frac{W}{\dot{W}} = 3.99 \times 10^3 \text{ s} = 1.1 \text{ h}$$

If the fridge was at the temperature of the watermelons initially, it is going to take longer than the time calculated above because there is some air around the watermelons which is also getting cooled along with the watermelons. Also, there are always heat losses as the insulation of the fridge is not perfect/ideal which also leads to consumption of more time for cooling.

However, if the fridge is already very cold, it might take less time to cool watermelons than what we calculated.