

Thermodynamics
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Lecture 66
Tutorial Problems (1 numbers)

(Refer Slide Time: 00:18)

A reversible heat engine operates between two systems at constant temperatures of 600 degrees C and 40 degrees C. The engine drives a reversible refrigerator, which operates between systems at constant temperatures of 40 degrees C and -20 degrees C. The heat transfer to the engine is 2000 kJ and the net work output of the combined engine-refrigerator is 350 kJ. Evaluate the heat transfers involving the refrigerator.

$T_H = 600^\circ\text{C} = 873\text{ K}$
 $T_L = 40^\circ\text{C} = 313\text{ K}$
 $Q_H = 2000\text{ kJ}$
 $Q_{\text{net}} = 350\text{ kJ}$

Refr.
 $T_{H,L} = -20^\circ\text{C} = 253\text{ K}$
 $T_{e,H} = 40^\circ\text{C} = 313\text{ K}$

Heat engine: $\eta = 1 - \frac{|Q_L|}{Q_H} = 1 - \frac{T_L}{T_H}$
 $\frac{Q_L}{Q_H} = \frac{T_L}{T_H} \Rightarrow Q_L = 2000 \times \frac{313}{873} = 717\text{ kJ}$

$\Sigma Q = \Sigma W$
 $W = Q_H + Q_L$
 $W = Q_H - |Q_L|$

NPTEL

Figure 1.

$W = 2000 - 717\text{ kJ}$
 $W_{HE} = 1283\text{ kJ}$
 $W_R = 1283 - 350$
 $W_R = 933\text{ kJ}$

$1.24 Q_{e,L} - Q_{e,H} = 933$
 $\Rightarrow Q_{e,L} = 3882.5\text{ kJ}$
 $Q_{e,H} = 1.24 \times Q_{e,L}$
 $Q_{e,H} = 4820.5\text{ kJ}$

$\Sigma Q = \Sigma W$
 $Q_{e,H} + Q_{e,L} = W_R$
 $\Rightarrow W + Q_{e,L} = Q_{e,H}$
 $933 = |W| = |Q_{e,H} - Q_{e,L}|$

$\frac{Q_{e,H}}{Q_{e,L}} = \frac{T_{e,H} = 313}{T_{e,L} = 253}$
 $\frac{Q_{e,H}}{Q_{e,L}} = 1.24$
 $Q_{e,H} = 1.24 Q_{e,L}$

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Solution of the problem in Fig. 1:

For the reversible heat engine,

$$T_H = 600\text{ }^\circ\text{C} = 873\text{ K}, T_L = 40\text{ }^\circ\text{C} = 313\text{ K}, Q_H = 2000\text{ kJ}$$

For the reversible refrigerator,

$$T_{R,H} = 40\text{ }^\circ\text{C} = 313\text{ K}, T_{R,L} = -20\text{ }^\circ\text{C} = 253\text{ K}$$

The schematic of the entire of system is drawn in Fig. 1.

Since the heat engine is reversible,

$$\frac{Q_L}{Q_H} = \frac{T_L}{T_H} \rightarrow Q_L = 717\text{ kJ}$$

According to the first law for the heat engine,

$$W_{HE} = Q_H - |Q_L| = 2000 - 717 = 1283\text{ kJ} = \text{net work output of the heat engine alone (positive for the engine).}$$

Out of this net work output W_{HE} , some is used to run the refrigerator. The net work output of the combined heat engine-refrigerator system is 350 kJ.

Hence, the work input to the refrigerator is $W_R = W_{HE} - 350 = 933\text{ kJ}$ (this is negative for the refrigerator).

Now, we know the work input to the refrigerator. According to the first law for the reversible refrigerator,

$$W_R + Q_{R,L} = Q_{R,H} \rightarrow |W_R| = |Q_{R,H}| - Q_{R,L} \dots (1)$$

Since the refrigerator is reversible,

$$\frac{Q_{R,H}}{Q_{R,L}} = \frac{T_{R,H}}{T_{R,L}} = 1.24 \rightarrow Q_{R,H} = 1.24 Q_{R,L}$$

$$\text{Now, equation (1) implies } 933 = 1.24 Q_{R,L} - Q_{R,L} = 0.24 Q_{R,L} \rightarrow Q_{R,L} = 3887.5\text{ kJ and } Q_{R,H} = 4820.5\text{ kJ}$$