Chapter 5 - Second Law of Thermodynamics

Lecture 17
Section 5.9

MEMS 0051 Introduction to Thermodynamics

Mechanical Engineering and Materials Science Department
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Student Learning Objectives

At the end of the lecture, students should be able to:

- Analyze real and ideal machines (heat engines, refrigerators, heat pumps) using the thermodynamic temperature scale

Ideal Machines

- Using the thermodynamic temperature scale, we can express the efficiency of the following devices in terms of temperature
- Heat engine:

$$\eta_{\text{Carnot}} = 1 - \frac{T_L}{T_H}$$

- Refrigerator:

$$\beta_{\text{Carnot}} = \frac{T_L}{T_H - T_L}$$

- Heat pump:

$$\beta'_{\text{Carnot}} = \frac{T_H}{T_H - T_L}$$

Real Machines

- Real machines have irreversibilities, which means the efficiency is less than that of ideal machines
- Heat engine:

$$\eta_{\text{real}} = 1 - \frac{Q_L}{Q_H} \leq 1 - \frac{T_L}{T_H}$$

- Refrigerator:

$$\beta_{\text{real}} = \frac{Q_L}{Q_H - Q_L} \leq \frac{T_L}{T_H - T_L}$$

- Heat pump:

$$\beta'_{\text{real}} = \frac{Q_H}{Q_H - Q_L} \leq \frac{T_H}{T_H - T_L}$$

Example #1

- An inventor claims to have developed a power cycle that outputs 410 [kJ] of work for an energy input of 1,000 [kJ]. The system operates between a high-temperature reservoir of 500 [K] and rejects heat to a low temperature reservoir of 300 [K]. Evaluate the inventor's claim.

Example #2

- A refrigerator maintains the cold compartment at -5 °C while the ambient air is 22 °C. The rate of heat removed from the cold compartment is 8,000 [kJ/hr] while the power input is 3,200 [kJ/hr]. Determine C.O.P. of the real and ideal refrigerator.

Example #3

- A building uses a heat pump to maintain a temperature of 22 °C while the ambient temperature is 10 °C. The heat delivered by the heat pump is 500 [MJ] per day. Determine the minimum theoretical work required for this heat pump to operate.

Student Learning Objectives

At the end of the lecture, students should be able to:

- Analyze real and ideal machines (heat engines, refrigerators, heat pumps) using the thermodynamic temperature scale
  - The performance of a real machine is quantified in terms of heat inputs/outputs, whereas that of an ideal machine is quantified using the Carnot efficiency via the thermodynamic temperature scale.

Suggested Problems

- 5.101, 5.104, 5.106, 5.107, 5.109, 5.110, 5.112, 5.114, 5.120