Chapter 5 - Second Law of Thermodynamics

Lecture 17

Sections 5.9

MEMS 0051 Introduction to Thermodynamics

Mechanical Engineering and Materials Science Department
University of Pittsburgh

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