Chapter 5 - Second Law of Thermodynamics

Lecture 15
Sections 5.5-5.6

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:

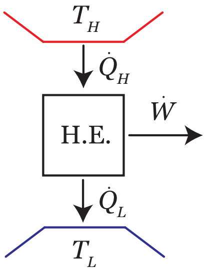
- Identify the two processes that comprise the Carnot Cycle
- Understand the implications of the Carnot Cycle, specifically, the efficiency of heat engines

Carnot

- Nicolas Léonard Said Carnot (June 1796 - August 1832) is known as the "father of thermodynamics," for his first and only publication outlined the theory of the maximum attainment of efficiency of heat engines
- His work, "Reflections on the Motive Power of Fire" (1824), laid the groundwork for the Second Law of Thermodynamics as proposed by Clausius and Kelvin
- Carnot's work was revolutionary, although not immediately, for it was not until 1845 that Joule provided values for specific heat of materials, and not until 1907 that the First Law of Thermodynamics (i.e. Conservation of Energy) was proposed

The Carnot Cycle

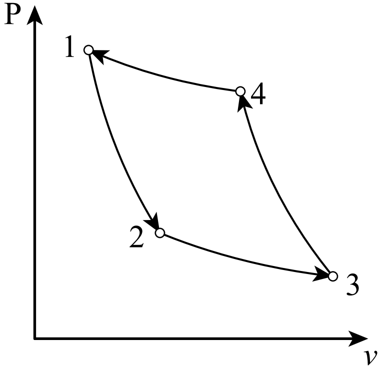
- If we break the heat engine down into reversible processes, we have the following



1. The first process is isothermal heat addition from T_H
2. The next process is reversible adiabatic (isentropic) expansion, W_{out}
3. Once expanded, the remained heat is rejected isotermally to T_L
4. Lastly, the cylinder is compressed in a reversible, adiabatic (isentropically) process, W_{in}

Example #1

- Identify the processes that constitute the Carnot Cycle:



The Carnot Cycle

- Each of these processes is assumed reversible, that is, the cycle is therefore reversible
- A reversible cycle (one without irreversibilities) will be the *most efficient* cycle when operating between two temperature reservoirs
- The Carnot Cycle is the most efficient heat engine operating between any two temperature reservoirs, and the efficiency is often denoted η_{Carnot}

Constraints of Carnot Cycle

- The **First Proposition** of the Carnot Cycle is that the efficiency of an irreversible cycle must be less than that of a reversible cycle

$$\eta_{\text{irr}} < \eta_{\text{rev}}$$

- This is seen as analyzing two heat engines operating between the same two temperature reservoirs

The First Proposition

- Assume an irreversible heat engine (H.E.$_{\text{irr}}$) operating between T_H and T_L that has greater efficiency than a reversible heat engine (H.E.$_{\text{rev}}$)

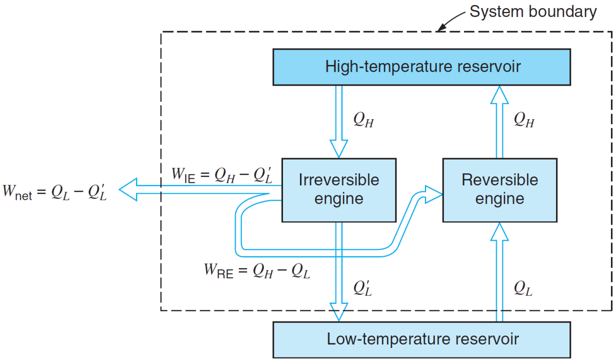
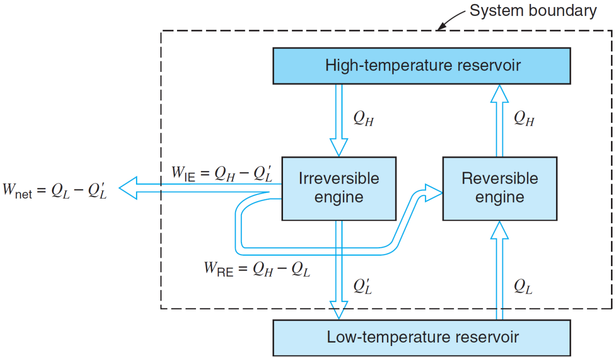


Image take from Sonntag, Borgnakke, Van Wylen, Fundamentals of Thermodynamics, 8E

The First Proposition

- The work of H.E.$_{\text{IE}}$ is $W_{\text{IE}} = Q_H - Q_L'$
- The reversible H.E. is operated as a refrigerator, and $W_{\text{RE}} = Q_H - Q_L$



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The First Proposition

- It follows that $Q'_L < Q_L$ since $\eta_{\mathrm{IE}} > \eta_{\mathrm{RE}}$
- It also follows $W_{\mathrm{IE}} > W_{\mathrm{RE}}$

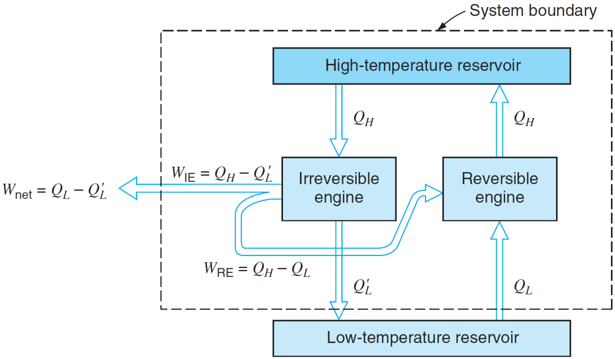
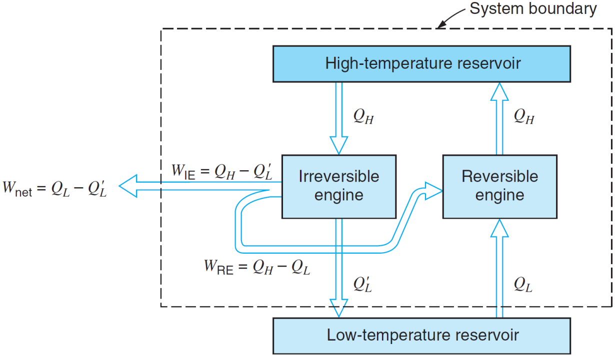


Image take from Sonntag, Borgnakke, Van Wylen, Fundamentals of Thermodynamics, 8E

The First Proposition

- The irreversible H.E. can power the reversible H.E. and deliver net work W_{net}, which is difference of the irreversible less the reversible work, (Q_H is the same), $Q_L - Q'_L$



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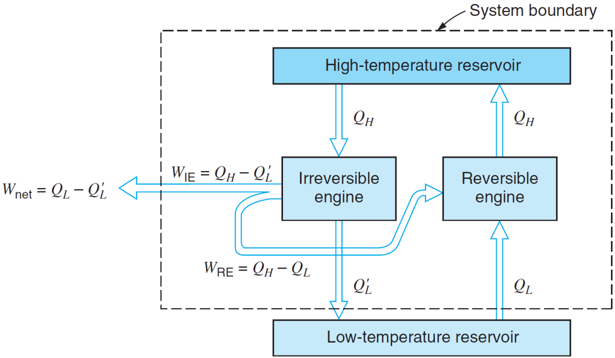
The First Proposition

- We notice that the net work is the result of heat exchange with a single reservoir, violating the K.P. statement, which invalidates our assumption that $\eta_{\text{IE}} > \eta_{\text{RE}}$



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Constraints of Carnot Cycle

- The **Second Proposition** of the Carnot Cycle is that if two reversible heat engines operated between the same temperature reservoirs, they have the same efficiency

$$\eta_{\text{rev},1} = \eta_{\text{rev},2}$$

- This is seen as analyzing two reversible heat engines operating between the same two temperature reservoirs (both can be heat engines, or one a heat engine and the other a refrigerator)

Student Learning Objectives

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

- Identify the two processes that comprise the Carnot Cycle
  - The Carnot cycle is comprised two isothermal processes (heat addition and heat rejection), and two reversible, adiabatic (i.e. isentropic) processes (expansion and compression).

Student Learning Objectives

- Understand the implications of the Carnot Cycle, specifically, the efficiency of heat engines
  - The Carnot Cycle is the most efficient cycle a heat engine, refrigerator and heat pump, can follow. The propositions of the Carnot Cycle state that an irreversible cycle is less efficient than a reversible, and two reversible heat engines operating between the same temperature reservoirs must have the same efficiency.

Suggested Problems

- 5.34, 5.37, 5.38, 5.41, 5.42