Thermodynamics for Next Generation Engineers

Timothy J. Jacobs
Texas A&M University

Abstract

The traditional first thermodynamics course (FTC) has remained focused on classical, macroscale interpretations of the discipline; e.g., entropy is introduced in the context of a reversible (i.e., Carnot) heat engine. Such an approach is debilitating future engineers from understanding the impact of entropy of novel and advanced energy-conversion technologies such as wind, solar, and bio-based combustion / catalysis.

This effort seeks to redesign FTC such that it centers on concepts of exergy (available energy) so that future engineers can seamlessly couple energy and entropy in designing tomorrow's state-of-the-art energy technologies.

This activity fits into the "Innovation and expertise at teaching students leading edge engineering knowledge and skills" pedagogical topic.

Introduction and Objectives

The objective of this effort is to create challenge-based activities that allow students to develop deep conceptualizations of entropy and exergy (i.e., available energy) by seamlessly coupling micro and classical scales of thermodynamics so that they are equipped to design and develop tomorrow's state-of-the-art energy technologies.

The educational outcomes of this work are:

1) Preparing next generation engineers with improved understanding of thermodynamics and energy related issues,
2) Influencing many engineering students across several disciplines (e.g., mechanical, petroleum, civil, and nuclear engineering),
3) Improving student learning, success, and retention, including among underrepresented students, by using challenge-based learning modules, and
4) Disseminating course materials through an external advisory board, project web site, journal publications, conference presentations, and active engagement with ME department heads.

The first thermodynamics course is typically taken by second-year engineering students.

Developmental History of Innovation

Graduate students in graduate-level thermodynamics courses exhibited several conceptual short-comings on thermodynamics.

Upon reflection, it seemed the misunderstandings were induced by a conceptual disconnect between students' prior knowledge learned in chemistry and physics courses and the macroscale-oriented treatment of classical thermodynamics. FTC instructors ask students to ignore what they know about microscale physics (i.e., particle motion) and perceive thermodynamics entirely through abstractions (i.e., reversible heat engine) and mathematical proofs (e.g., Inequality of Clausius).

"The macroscopic point of view has been adopted throughout this text, though occasionally a few amplifying remarks are made from the microscopic point of view. . . The acid test of any thermodynamics textbook probably lies in the treatment of the second law. In this regard I followed a classical approach"

Gordon Van Wylen, preface to *Thermodynamics*, 1959.

Learning Activities and Materials

In addition to exposing students to microscopic discussions of entropy (see below), students will also learn from the following elements:

1) Learning modules linking energy and entropy to the concept of exergy, enabling students to recognize the degradation of energy due to entropy.
2) Challenge-based projects that require students to solve open-ended design problems and relate concepts of exergy to the designed solution.
3) Pre- and post-lecture "quizzes", along with "confidence ratings" to reinforce student learning and assess student grasp of material.

Example Execution of #3

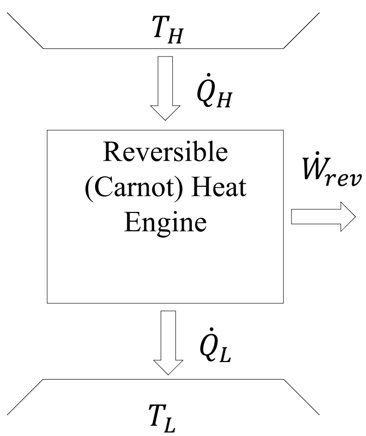
Suppose a turbine is expanding steam from 100 psia to 10 psia, as shown below. Which of the following statements are true (there could be more than one correct statement)?

a) If the turbine is adiabatic and reversible, then its exit state is State "b" and its isentropic efficiency is 100%.
b) If the turbine is adiabatic and irreversible, then its exit state could be State "c" and its isentropic efficiency less than 100%.
c) If the turbine is adiabatic, then State "a" is impossible.

10 - 1 Confidence Rating (10 – absolutely I know I'm right, 1 – total guess): _______________

Learning Activities and Materials: Discussions of Microscopic States

The most substantial learning material to be developed is the inclusion of microscopic discussions of entropy, in addition to the classical macroscopic approach. By doing so, students should gain a deeper appreciation of how entropy represents disorder, and thus affects the efficiency of energy conversion devices.



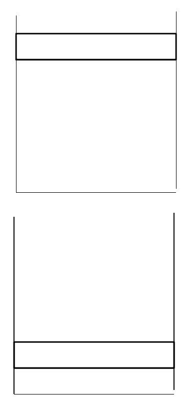
$$\oint \left(\frac{\delta Q}{T}\right)_{rev} = 0 \qquad dS = \left(\frac{\delta Q}{T}\right)_{rev}$$

OR → ?

$$S = k \ln W$$

(i.e., S = f(uncertainty))

$$(\Delta x)(\Delta m\vec{V}) \geq \frac{h}{2}$$



S_1: Low T (low thermal entropy) (low $\Delta m\vec{V}$) High V (high spatial entropy) (high Δx)

$S_1 = S_2$

In the ideal limit, uncertainty remains constant; Entropy can remain constant!

S_2: High T (high thermal entropy) (high $\Delta m\vec{V}$) Low V (low spatial entropy) (low Δx)

Discussion

The new materials are not yet implemented, but some of the learning activities (e.g., pre- and post-lecture quizzes with confidence rating) are executed this semester for the first time.

Hope to learn at FOEE:

1) Do you see shortcomings in students' basic understanding of energy and energy conversion technology?
2) Do you perceive thermodynamics to be important to your area of engineering?
3) Are the proposed changes to FTC beneficial to your area of engineering?
4) Do you feel the "confidence rating" assessment is insightful?

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