Comparing Student Conceptual Understanding of Thermodynamics in Physics and Engineering

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Synopsis

We are undertaking a multi-disciplinary study on student learning of thermodynamics concepts across physics and engineering. Here we frame the study using existing research and conceptual emphases from both disciplines, and describe our plan for this study.

The literature on student conceptual understanding in thermodynamics shows areas of student difficulty among each population and provides conceptual questions to draw on from physics and mechanical engineering for research. We are evaluating these questions for efficacy across disciplines and categorizing questions as field-specific or interdisciplinary; we have also selected several concepts of interest.

Some key concepts and tools (algebraic, graphical, or tabular) are nearly exclusive to each discipline at the course levels we are investigating: senior year for physics and sophomore year for mechanical engineers.

Past Research

In physics, several identified student conceptual difficulties:

- **Heat, Work, & First Law** with processes on a *P-V* diagram [1]
- **First Law, work, & temperature changes** related to an adiabatic process [2]
- **Entropy** [3]

Engineers have also identified difficulties, some unique to engineering.

- **heat** vs. **temperature** [4]
- **steady-state** vs. **equilibrium** processes [4]
- **rate** vs. **amount** transferred during a process [4]
- **work** & **first Law** [5]
- **state process quantities** & **state functions** [5]
- **cycles** & **second law** [5]

Phase 1 – What to Collect

1. **Review Existing Concept Questions:** Determine concepts and methods required to successfully complete each task.
2. **Select Concepts**
   I. **Processes on *P-V* diagrams**
   II. **Power cycles & efficiencies**
   III. **Entropy**
3. **Choose Inter-Population Appropriate Questions:** See below

Phase 2 – Methods of Data Collection

1. **Classroom Observation**
2. **Short Answer Questions**
3. **Interviews**

Conceptual Highlights

Physics

- **Theoretical Limits of Ideal Processes**
- **Use of Integral and Differential Calculus to Find Closed-Form Solutions**
- **Maxwell Relations**

Common Ground

- **Use of *P-V-T* Relations and Phase Diagrams**
- **Use of Internal Energy and Enthalpy**
- **Cycles (Power, heat pump, refrigeration)**

Mechanical Engineering

- **Real Processes Modeled as Ideal**
- **Use of Steam Tables and Mollier Diagrams**
- **Open System Analysis – Mass Flow**
- **Exergy**

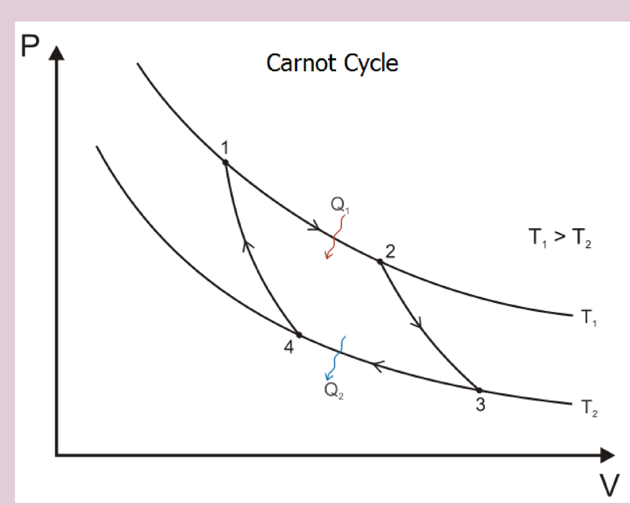
Tools of the Trade

$$dU = TdS - pdV$$

Total differential for thermodynamic potential of internal energy.

$$\left(\frac{\partial T}{\partial V}\right)_S = -\left(\frac{\partial P}{\partial S}\right)_V$$

Maxwell relation (one of two) derived from internal energy.



***P-V* diagram** of a Carnot power cycle. [6]

$$pV = nRT = NkT$$

Equation of state

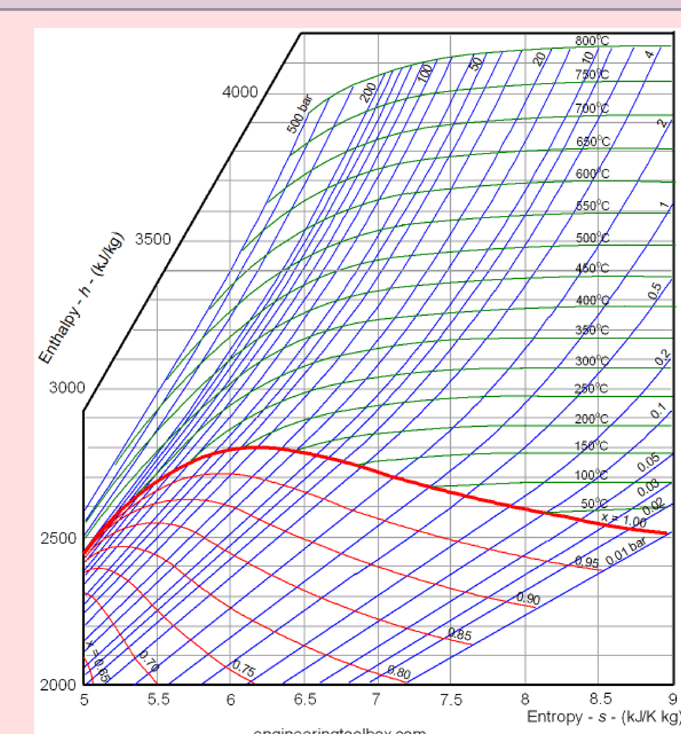
$$\eta = \frac{W}{Q_{in}} \le \eta_{carnot} = 1 - \frac{T_{low}}{T_{high}}$$

Power cycle efficiency equations. Carnot efficiency is the greatest allowed by the 2nd Law.

T °C	v m³/kg	u kJ/kg	h kJ/kg	s kJ/kg·K
p = 0.06 bar = 0.006 MPa (T_{sat} = 36.16 °C)				
Sat.	23.739	2425.0	2567.4	8.3304
80	27.132	2487.3	2650.1	8.5804
120	30.219	2544.7	2726.0	8.7840
160	33.302	2602.7	2802.5	8.9693

[7]

Steam Tables are used to rapidly determine state-variable values for commonly used fluids such as water and refrigerants.



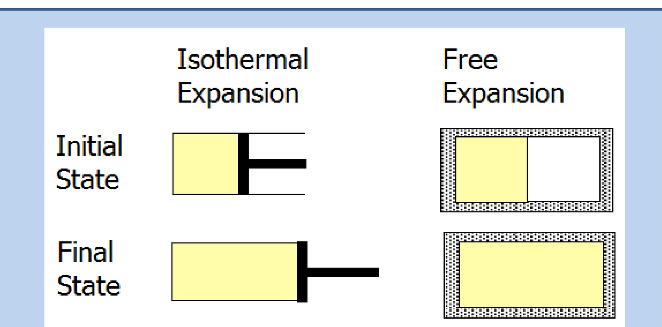
[8]

A **Mollier Diagram** is intended for evaluating state properties within the mixed liquid-vapor or gaseous phases.

Examples of Short Answer Questions

From Physics

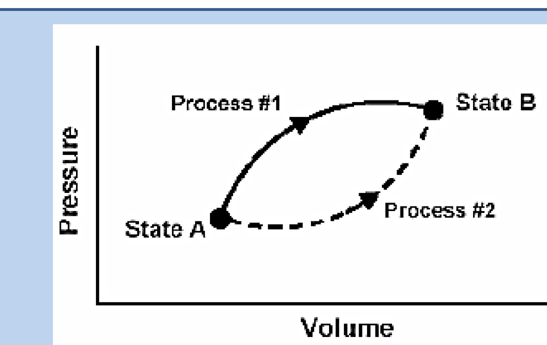
Discipline Specificity



[3]

Determine **sign of ΔS** for system & surroundings. **Compare** changes in **Δs_{sys}**.

Interdisciplinary Potential



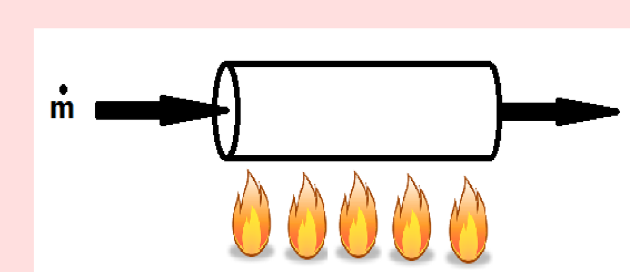
[1]

For the two processes shown on the *P-V* diagram, compare:

- **Work done**
- **Heat transferred**
- **Change in internal energy**

From Mechanical Engineering

Discipline Specificity

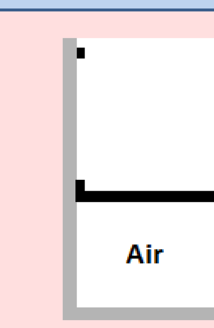


[9]

Air flows steadily through a heated pipe. Do the following increase, remain the same, decrease, or insufficient information:

- **Velocity of the air**
- **Mass flow rate of the air**
- **Energy of the air**
- **entropy of the air**

Interdisciplinary Potential



[9]

The high pressure air in an insulated piston-cylinder expands rapidly against the atmosphere. Do the following increase, remain the same, decrease, insufficient information?

- **Temperature of the air**
- **Energy of the air**

Work is done by the air. Agree, disagree, insufficient information.

Since **free expansion processes** and **open systems (mass flow)** are not typically part of introductory mechanical engineering and physics courses, respectively, we expect these to be unproductive for research.

***P-V* diagrams** and **isobaric expansions** are used across disciplines and should yield productive results for informing instruction.

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