ENGR 2010: Thermodynamics I (Fall 2010)
Exam II Study Guide

The exam will cover material from chapters 5, 6 and 7 in the text. Allowable materials on the exam are the appendices in the textbook (property tables) and three 8.5 × 11” pages of notes (front and back) in your own handwriting. The exam will begin promptly at 9:30, and will end at 10:40.

Study Points:

- At a minimum, you should be able to perform all of the assigned homework problems.
- Be able to work the problems front–to–back and back–to–front: exchange the given and required information and re–work the problems.
- Use the solutions only to check your completed work or to get you out of an intractable dead–end. If you study for this exam only by reviewing the solutions – and not actually working out problems – I can assure you that, most likely, you will do very poorly on the exam.
- Don’t stay up all night studying for the exam. Get an adequate amount of sleep. And don’t wake up at the last minute.

Concept Questions:

Be able to provide short (1–2 sentence) explanations/descriptions to the basic concepts covered in Chapters 5–7. Topics covered in previous chapters are still fair game. Here is a list of example questions and review topics:

1. The first law for a closed system (control mass) uses internal energy $u$ as the relevant state variable, whereas the first law for an open system (control volume) has enthalpy $h$ as the state variable. Briefly explain the reason for the difference.

2. Briefly explain the differences between steady–state, steady flow and unsteady–state, unsteady flow problems.

3. Air at $T_1 = 300$ K is throttled from $P_1 = 1$ MPa to $P_2 = 100$ kPa. Velocities are negligible on both sides of the valve. What is the temperature change of the gas?

4. Air at $T_1 = 300$ K, $P_1 = 1$ MPa, is fed from a supply line into an insulated, evacuated tank. What is the final temperature of the gas in the tank?

5. Consider the previous two problems. Why does one process result in no temperature change, whereas the other results in a large temperature change. That is, what is happening to the ‘energy’ of the flow?

6. In a sentence or two, explain why a heat engine cannot have a thermal efficiency of 100%.

7. A 100 MW power plant has a thermal efficiency of 45%. What is the rate of heat rejection to the environment?

8. An inventor claims to have a heat engine that receives heat from a geothermal source at 500°C and has a thermal efficiency of 70%. Do you believe the claim?
Problem examples

The test will have three problems that are similar to your homework exercises. In working the problems, remember the following points:

- Review the study points in the Exam I study guide. In particular, do not use ideal gas relations for substances that are not ideal gases.
- There will be at least two problems involving open systems. One of your first steps should be to apply the first law to the open system:
  - is the situation SSSF or USUF?
  - does the device produce or consume work?
  - is heat transfer present?
  - can kinetic energies be neglected (note: if there is no way of calculating velocities, then you have no choice but to neglect kinetic energy).
  - is the mass conservation equation needed (for multiple inlet, multiple outlet problems)?

The point is to get one equation for one unknown. The unknown typically is a transfer rate (work, heat) or a state variable at the exit (enthalpy, velocity).

Here are some example problems.

First Law Problems

1. Air at 300 K flows into a compressor at a rate of $\dot{m} = 1 \text{ kg/s}$. The work input to the compressor is 300 kW, and the rate of heat transfer from the compressor is 100 kW. Determine the outlet temperature of the air. Note: be sure you apply the correct sign (+/-) on work and heat in the first law. ($\sim 498$ K, using the tables).

2. Superheated steam at $T_1 = 500^\circ \text{C}$, $P_1 = 1 \text{ MPa}$ enters an adiabatic turbine. The exit is at $P_2 = 50 \text{ kPa}$ and a quality of 0.95. Calculate the specific work produced by the turbine. (948 kJ/kg).

3. Saturated liquid water at 1 MPa enters a $D = 5 \text{ cm}$ pipe at a rate of $\dot{m} = 2 \text{ kg/s}$. Heat is transferred to the water at a rate of $\dot{Q} = 5000 \text{ kW}$. The exit is at 1 MPa pressure.
   - (a) Neglecting kinetic energy, calculate the temperature at the pipe exit. (400°C)
   - (b) Using your answer in a), calculate the exit velocity of the water. (312 m/s)
   - (c) Based upon your answer, should kinetic energy be included in your analysis? (probably)
   - (d) Including the exit kinetic energy, recalculate the exit temperature. Iterate this procedure a couple of times. (378°C)

4. 2 kg/s of water is brought from a saturated liquid at 1 MPa to 400 °C, 1 MPa by transfer of heat from an air stream. The air enters the heat exchanger at 1200 K and exits at 50°C above the water inlet temperature. Calculate the required mass flow rate of the air. (6.486 kg/s, using the air tables).
5. R–134 enters a throttle valve as a saturated liquid at 1 MPa and exits at 200 kPa. Find the exit
temperature and quality. (enthalpy is constant for this device: \(h_2\) and \(P_2\) fix state 2)

6. Two water flows are mixed in an insulated chamber to form a single flow. Flow at state 1 is 1.5 kg/s
at 400 kPa and 200°C, and flow at state 2 is at 500 kPa and 100°C. The exit is at 300 kPa and 150°C.
Find the required mass flow rate at state 2. (0.0637 kg/s).

7. An insulated, initially empty bottle is filled with steam from a line at 0.8 MPa, 350°C. The valve is
closed when the pressure in the bottle reaches the line pressure. If the final mass in the bottle is 0.75
kg, determine the final temperature and the volume of the bottle. (521°C, 0.342 m³).

8. A 1 m³ tank contains ammonia at 150 kPa and 25°C. The tank is connected to an ammonia supply
line at 1200 kPa, 60°C and filled until the tank is half full (by volume) of liquid at 25°C. Calculate
the heat transfer during the process. (-380 MJ (from the system)).

**Second Law Problems/heat engine/heat pump**

9. One kg of water is water is contained in a piston–cylinder device. The initial state of the water is
\(P_1 = 1\) MPa, \(T_1 = 300°C\). The water is then expanded in an adiabatic and reversible process to a final
pressure of \(P_2 = 50\) kPa. Find the final temperature and quality (if saturated) and the work done.
The key here is that adiabatic + reversible = isentropic, so \(s_2 = s_1\). \(P_2\) and \(s_2\) fix state 2, and the
work is obtained from the first law for the adiabatic, closed system.

10. An inventor claims to have a device that can compress one kg of water from an initial state of \(T_1 = 200°C, P_1 = 50\) kPa in an adiabatic process to a final pressure of \(P_2 = 200\) kPa. It is claimed that the
device uses 250 kJ of work to accomplish this task. Is the inventor’s claim valid? (no)

11. A house looses heat at a rate of \(\dot{Q}_{loss} = 40\) kW. If the inside and outside temperatures are 20°C and
−5°C, find the minimum power requirement to a heat pump that would maintain the house at the
given temperature. (3.4 kW: note that \(\dot{Q}_H = 40\) kW; this is the heat from the heat pump that is
needed to keep the house at 20°C).

12. Consider a building whose annual air–conditioning load is estimated to be 120,000 kWh (kilowatt-
hours) in an area where the unit cost of electricity is $0.10/kWh. Two air conditioners are considered
for the building. Air conditioner A has a seasonal average COP of 3.2 and costs $5500 to purchase and
install. Air conditioner B has a seasonal average COP of 5.0 and costs $7000 to purchase and install.
Both units have an expected lifetime of 10 years. All else being equal, determine which air conditioner
is a better buy. (The AC load is the amount of heat that needs to be removed from the building. The
electrical energy would be the load/COP. The cost, over a 10 year lifetime, would be

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10 \text{ years} \times \frac{1.2 \times 10^5}{COP} \text{kWh/year} \times 0.1 \$/\text{kWh} + \text{purchase cost}
\]

System A turns out to be better in the long run).

13. A heat engine receives heat from a 200 kg slab of concrete \((C = 0.65 \text{ kJ/kg K})\) that is initially at
a temperature of \(T_1 = 200°C\). The engine rejects heat to the environment, which is at a steady
temperature of \(T_L = 25°C\). As the engine operates, the concrete slab cools off due to the transfer of
heat from it. Determine the theoretical maximum amount of work (in kJ) that could be produced from the engine. To do this, write the efficiency equation in a differential form,

$$\delta W_{\text{rev}} = \eta_{\text{rev}} \delta Q_H = \left(1 - \frac{T_L}{T_B}\right) \delta Q_H$$

and use the fact that $\delta Q_H = -mC dT_B$, where $T_B$ is the temperature of the block. Integrate the resulting DE from $T_B = T_1$ to $T_L$ to get the total work.

14. I may think of more problems over the weekend.