ME 322 – Mechanical Engineering Thermodynamics (Exam 2)

Spring 2022

THIS IS A TAKE-HOME EXAM. YOU HAVE SEVERAL DAYS TO WORK ON THIS EXAM, AND SEVERAL CLASS PERIODS WHERE YOU CAN ASK QUESTIONS. THE WORK PRESENTED ON THIS EXAM NEEDS TO BE YOURS, AND YOURS ALONE. PRESENTING SOLUTIONS FROM SOMEONE ELSE WILL RESULT IN A GRADE OF F IN THE COURSE.

Please read the following statement:

Article II, Section 1 of the University of Idaho Student Code of Conduct states,

> *Cheating on classroom or outside assignments, examinations, or tests is a violation of this code. Plagiarism, falsification of academic records, and the acquisition or use of test materials without faculty authorization are considered forms of academic dishonesty and, as such, are violations of this code. Because academic honesty and integrity are core values at a university, the faculty finds that even one incident of academic dishonesty seriously and critically endangers the essential operation of the university and may merit expulsion.*

Passing on exam information to someone who has not taken the exam constitutes cheating on an examination. Such action is a violation of the University of Idaho Student Code of Conduct.

I have read and understand the above statement.

____ ______________

Signature Date

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Printed Name

EXAM INSTRUCTIONS – PLEASE READ THIS CAREFULLY

You need to show your work for each of the problems to get credit.

- **If values from a table are cited, you need to indicate which table was used, and what inputs were used to find the value.**
- **Equations used should be written down, and the numbers used in those equations should also be shown.**
- **You should include units in your calculations, as many times there will be unit conversions necessary.**
- **You may work your problems on these pages or work them on separate pages.**
- **If you have questions about problems on the exam you should ask those of the instructor.**
- **You are not allowed to work with other people (in person, or online) on this exam.**
- **Many problems on this exam are similar to past homework problems. You can certainly work with other students to make sure you know how to solve past homework problems** 😉
- **Remember that you can check your past homework against the posted solutions on Canvas.**

Part 1: Engineering Calculations – 75 Points

For this section you may do problems by-hand or using EES.

1. Open-System 2nd Law Analysis

   (25 points) A medium-size home-shop air compressor operates under the following conditions:

   - State 1 is air entering the compressor at 14.7 psia and 75 °F.
   - State 2 is air leaving the compressor at 104.0 psia.
   - Steady-State volume flow rate **leaving** the compressor is 6.75 ft^3/min
   - Isentropic efficiency of the 'Real' compressor under these conditions is 75%

   Note: The steady-state volume flow rate will be the same for 'Ideal' and 'Real' conditions. However, calculated mass flow rates will not be the same between the 'Ideal' and 'Real' conditions.

   a. Decide if you are going to assume specific heat capacity is constant or variable from State 1 to State 2. Provide a justification (and possibly sample calculations) to support your decision.
   b. If the compressor were 'Ideal' (read that as: isentropic) calculate the outlet temperature [°F] of the air.
   c. If the compressor were 'Ideal' (read that as: isentropic) calculate the power input [hp] required to operate the compressor under these conditions.
   d. If the compressor is modeled as 'Real' calculate the outlet temperature [°F] of the air.
   e. If the compressor is modeled as 'Real' calculate the power input [hp] required to operate the compressor under these conditions.

2. Transient System Analysis

   (25 points) You are going to rapidly empty a small (portable) air storage tank. Assume the small portable tank is rigid. There is no turbine or work-capturing device so you may consider this system aergonic.

   a. Simplify the two equations below as they pertain to this problem. Cross out terms that do not apply.

$$\dot{Q} - \dot{W} + \sum_i \dot{m}_i \left(h_i + \frac{V_i^2}{2g_c} + \frac{g}{g_c} z_i \right) - \sum_e \dot{m}_e \left(h_e + \frac{V_e^2}{2g_c} + \frac{g}{g_c} z_e \right) = \frac{d}{dt}(U + KE + PE)$$

$$\sum_i \dot{m}_i - \sum_e \dot{m}_e = \frac{dm}{dt}$$

   b. Use substitution, then separate and integrate the equation to get rid of the time derivatives. You should end up with an equation that relates Q_{12}, h_{out}, u_1, u_2, m_1, and m_2. What is this relationship?

   c. The small storage tank has a volume of 5 gallons and the air inside is initially at 145 [psia] and 75 [°F]. You are going to release air from the small tank until it reaches a pressure of 20 [psia]. Calculate the amount of heat [Btu] you will need to add to the system to make sure the air in the tank stays at constant specific enthalpy.

3. Closed-System 2nd Law Analysis
   (25 points) I want you do perform another calculation about problem 2. You probably won't be able to add the amount of heat you need (especially over a short amount of time) to keep the tank in problem 2 at constant specific enthalpy. As a way to approximate the final outlet conditions of problem 2 if you didn't add any heat I would like you to calculate the following:

   a. If you start with the tank at its initial condition, then remove 18 Btu of heat from it – calculate the temperature [°F] and pressure [psia] of the final state. Treat the tank as being rigid and sealed.
   Note: 18 Btu is *not* the answer to problem 2c
   b. Using 2nd law analysis, determine the boundary temperature that would be necessary for the entropy production [Btu/°R] to be zero for the case in part a.

Part 2: Short Calculations and Conceptual Problems – 25 Points

4. (5 points) You purchase a portable refrigerator for camping. The specs say that when outside temperature is 100 °F the inside of the cooler can be kept at 46 °F. Calculate the maximum theoretical COP for this refrigerator.

5. (5 points) Rank the following devices in order of least efficient to most efficient. Consider all devices to be operating between the same high and low temperature reservoirs.
   Heat pump   Carnot heat engine   Refrigerator   Real heat engine

True/False in regards to entropy and entropy production (5 point each):

6. T / F Entropy is always conserved

7. T / F Some real processes can have zero entropy production

8. T / F Some real processes can have a decrease in entropy