ME 322 – Mechanical Engineering Thermodynamics (Exam 2)

Fall 2021

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. You will scan and upload a PDF of your submission to BbLearn.**
- **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 BbLearn.**

Part 1: Engineering Calculations – 50 Points

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

1. (25 points) A large 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 19 ft^3/min
   - Isentropic efficiency of the compressor under these conditions is 80 %

   Note: While the volume flow rate will be the same for 'Ideal' and 'Real' conditions, calculated mass flow rates will not be the same.

   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. (25 points) You are going to use your compressor from Problem 1 to fill a smaller (portable) air storage tank. Assume the small portable tank is rigid.

   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_{in}, 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 30 [psia] and 75 [°F]. You are going to add air to the small tank until it reaches a pressure of 139.7 [psia], but you also want to make sure the temperature of the air in the tank doesn't get above 100 [°F]. When your large compressor tank is full it has pressure and temperature of 150 [psia] and 75 [°F] (assume it is large enough for these to remain constant as you fill the little tank).
   Calculate the amount of heat [Btu] you will need to remove from the system to make sure the air stays below 100 [°F]

Part 2: Short Calculations – 20 Points

3. You purchase a portable refrigerator for camping. The specs say that the inside can be kept at 40 °F when the outside temperature is 90 °F. Calculate the maximum theoretical COP for this freezer.

4. 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

5. Using your supplemental tables, find the specific internal energy [Btu/lbm] of R-134a at 400.22 psia and 29.04 °F? Make sure to note which table(s) you used, and what inputs you used to find the value.

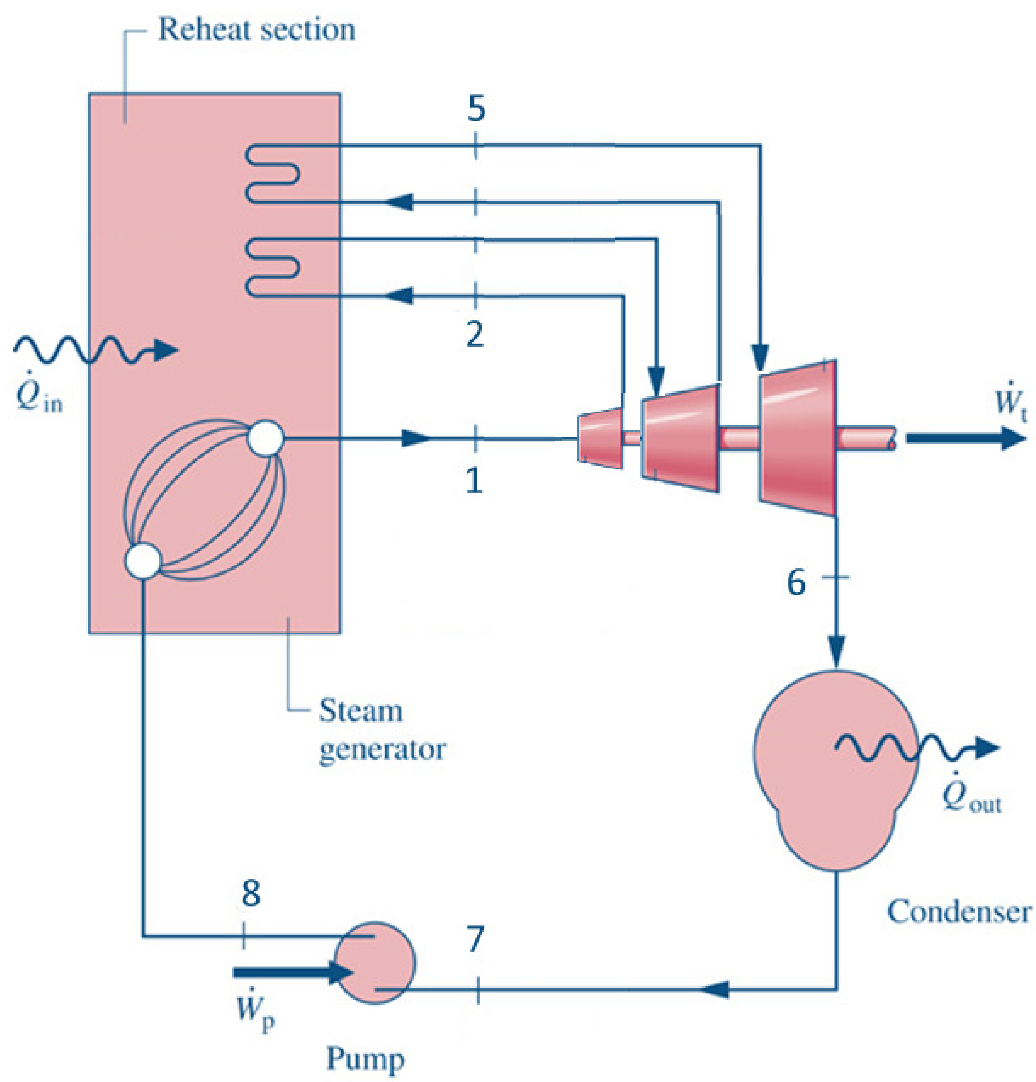
True/False in regards to entropy and entropy production (1 point each):

6. T / F Entropy is a conserved quantity
7. T / F Entropy is highest for solids, and lowest for gases
8. T / F Friction, heat addition, mixing, and chemical reactions each increase entropy
9. T / F Some real processes have no entropy production
10. T / F In some real processes the system experiences no change in entropy

Part 3: EES Problems – 30 Points

For this problem you *must* use EES to solve it. You will need to make a PDF print from your EES code that includes:

11. The UI Steam Plant is considering adding a three-stage turbine for power generation. In this problem you will explore the ideal pressures to for two reheat paths, as shown in the sketch below. These parameters are important when selecting an appropriate turbine for this application. Steam from the boiler enters the first turbine stage at 600 psia and 1000 °F (old pipes and boiler don't let us go as high as most steam plants). The steam leaves the first turbine stage at P[2] and then enters the reheat section of the boiler where it is reheated back to 800 °F. The steam then enters the second turbine stage, and leaves at P[4] to a second reheat section where it increases temperature to 650 °F. It enters the third turbine stage where it expands to 5 psia. It leaves the condenser as a saturated liquid. Each stage of the turbine has an isentropic efficiency of 85% and the pump has an isentropic efficiency of 80%. The net power output of the cycle is 1,000 hp. Assume no pressure drop through the boiler (or the reheat sections) and condenser.



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For this problem you need to build a parametric table that explores ranges for both P[2] and P[4] as a means to maximize plant efficiency.
For P[2]: explore values from 175 psia to 75 psia in increments of 25 psia (5 values).
For P[4]: explore values from 100 psi to 20 psia in increments of 20 psia (5 values).

To explore all possibilities, you will have a parametric table that has 25 runs in it. This means that for each value of P[2] you need to explore all values of P[4].

After you've completed this analysis, at the combination of most efficient P[2] and P[4]

Determine the following:

a) P[2] [psia] ______________________

b) b) P[4] [psia] ____________________________

c) $\dot{m}_{steam}$[lbm/hr] ________________

d) Peak efficiency (5 sig figs) ______________

Tip: Remember that Q_dot_in includes more than just the heat between states 8 and 1.