First Name ___________________ Last Name ___________________

CIRCLE YOUR LECTURE BELOW:

Div. 3 – 08:30 a.m.  Div. 2 – 10:30 a.m.  Div. 1 – 02:30 p.m.

Prof. Chen            Prof. Naik            Prof. Goldenstein

ME 300 Final Exam  
May 1, 2019  
8:00 a.m. to 10:00 a.m.

INSTRUCTIONS

1. Please place all your electronics, including but not limited to cell phones, computers, watches, tablets, etc., into your bag and store your bag under your seat.
2. The only calculator that is permitted to be used during this exam is the TI-30X IIS basic scientific calculator.
3. This is a closed book and closed notes examination. You are provided with an equation sheet and all the necessary property tables.
4. Do not hesitate to ask the instructor if you do not understand a problem statement.
5. Start each problem on the same page as the problem statement. Write on only one side of the page. Materials on the back side of the page will not be graded.
6. Put only one problem on a page. Another problem on the same page will not be graded.
7. Use standard solution procedure for Problems 2, 3, and 5.
8. If you give multiple solutions, you will receive only a partial credit although one of the solutions might be correct. Cross out any solutions that you do not want to be graded.
9. For your own benefit, please write clearly and legibly. Maximum credit for each problem is indicated below.
10. After you have completed the exam, put your papers in order. This may mean that you have to remove the staple and then re-staple the exam. Do not turn in loose pages.
11. Once time is called you will have three minutes to turn in your exam. Points will be subtracted for exams turned in after these three minutes.

<table>
<thead>
<tr>
<th>Problem</th>
<th>Possible</th>
<th>Score</th>
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<tr>
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</table>
Problem 1 (40/200 points)

Please fill only ONE circle for your answer to each problem. Each problem is 4 points.

(1). Which of the following applies to a gas leaking from a tank at a constant rate?

- [ ] Steady state
- [x] Transient state

(2). The change in exergy of only the system (i.e., without its surroundings) is always positive.

- [ ] True
- [x] False

(3). Which of the following mixing processes does not generate entropy?

- [ ] Two chemically different gases but both at the same initial pressure and temperature
- [x] Two chemically identical gases but both at the same initial pressure and temperature
- [ ] Two chemically identical gases at the same initial temperature but at different initial pressures

(4). Which of the following is true for moist air at atmospheric pressure?

- [ ] Wet bulb temperature is nearly equal to dry bulb temperature
- [x] Wet bulb temperature is nearly equal to adiabatic saturation temperature
- [ ] Wet bulb temperature is nearly equal to dew point temperature

(5). Oxygen (O₂) can be a major product of “complete” combustion of methane (CH₄) with 80% theoretical air.

- [ ] True
- [x] False

(6). The equilibrium constant of a chemical reaction always increases with temperature.

- [ ] True
- [x] False
Problem 1 (Continued)

(7). Suppose the equilibrium constant for the reaction \( \text{H}_2 + 0.5\text{O}_2 \leftrightarrow \text{H}_2\text{O} \) at 5000 K and 1 atm is equal to \( K \). Which of the following reaction has a different equilibrium constant at the same temperature?

- \( \text{H}_2 + 0.5\text{O}_2 \leftrightarrow \text{H}_2\text{O} \) at 5 atm
- \( 2\text{H}_2 + \text{O}_2 \leftrightarrow 2\text{H}_2\text{O} \) at 1 atm
- \( \text{H}_2 + 0.5\text{O}_2 + 3\text{N}_2 \leftrightarrow \text{H}_2\text{O} + 3\text{N}_2 \) at 1 atm

(8). Which of the following is true for improving a gas turbine engine with an ideal Brayton cycle?

- Thermal efficiency will increase with regeneration
- Net power output will increase with regeneration
- Thermal efficiency will increase with intercooling

(9). Which of the following is true in a turbojet engine?

- Thermal energy converted to chemical energy
- Thermal energy converted to mechanical/kinetic energy
- Thermal energy converted to electrical energy

(10). Which of the following adiabatic processes is not correct in a turbojet engine?

- Temperature at the exit of a “real” diffuser is always higher than the “isentropic” diffuser
- Temperature at the exit of a “real” compressor is always higher than the “isentropic” compressor
- Temperature at the exit of a “real” nozzle is always higher than the “isentropic” nozzle
Problem 2 (35/200 points)

Given:
A rigid tank of total volume 0.1 m³ initially contains saturated liquid-vapor mixture of water at pressure of 1 bar and quality of 1% (State 1). Heat transfer occurs to the tank at constant volume until the pressure increases to 20 bar (State 2). When the pressure reaches 20 bar, the valve on the top of the tank opens and saturated vapor at 20 bar exits from the tank until all the liquid in the tank evaporates and only saturated vapor at 20 bar remains in the tank (State 3).

Find:
(a) Show all the processes on T-v diagram. Label all three states correctly relative to the saturation vapor dome and indicate appropriate lines of constant pressure.
(b) What is the quality of the mixture at State 2, in %?
(c) Calculate the heat transfer during the transient process from State 2 to State 3, in kJ.

System Sketch:

Assumptions:
1. Uniform state
2. Negligible KE & PE
3. No work

Basic Equations:
\[
\frac{dm_{cv}}{dt} = \sum \dot{m}_l - \sum \dot{m}_e \\
\frac{dE_{cv}}{dt} = \dot{Q}_{cv} - \dot{W}_{cv} + \sum \dot{m}_l (h_l + KE + PE) - \sum \dot{m}_e (h_e + KE + PE)
\]
Solution:

(a)

(b)

State 1 → 2:

\[ m_2 = m_1 \]

because of the same volume of tank

\[ v_2 = v_1 + x_1(v_{g1} - v_{f1}) = 1.0432 \times 10^{-3} + 0.01(1.694 - 1.0432 \times 10^{-3}) \]

\[ = 0.0180 \text{ m}^3/\text{kg} \]

The quality of state 2 can be determined

\[ x_2 = \frac{v_2 - v_{f2}}{v_{g2} - v_{f2}} = \frac{0.0180 - 1.1767 \times 10^{-3}}{0.09963 - 1.1767 \times 10^{-3}} = 0.171 \text{ or } 17.1\% \]

(c)

State 2 → 3:

\[ \frac{dE_{cv}}{dt} = Q_{cv} + \dot{W}_{cv} + \sum m_i(h_i + KE + PE) - \sum m_e(h_e + KE + PE) \]

Integrate w.r.t. time

\[ U_3 - U_2 = Q_{cv} - m_e h_e \]

\[ m_3 u_3 - m_2 u_2 = Q_{cv} - (m_2 - m_3) h_e \]

\[ m_2 = m_1 = \frac{V}{v_1} = \frac{0.1 \text{ m}^3}{0.018 \text{ m}^3/\text{kg}} = 5.556 \text{ kg} \]

\[ u_2 = u_{f2} + x_2(u_{g2} - u_{f2}) = 906.44 + 0.171(2600.3 - 906.44) = 1196.09 \text{ kJ/kg} \]

\[ m_3 = \frac{V}{v_3} = \frac{0.1 \text{ m}^3}{0.09963 \text{ m}^3/\text{kg}} = 1.004 \text{ kg} \]
Problem 2 (continued)

\( u_3 = 2600.3 \text{ kJ/kg} \)
\( h_e = 2799.5 \text{ kJ/kg} \)

Therefore, the energy balance becomes

\[
1.004 \text{ kg} \times 2600.3 \frac{\text{kJ}}{\text{kg}} - 5.556 \text{ kg} \times 1196.09 \frac{\text{kJ}}{\text{kg}} = Q_{cv} - (5.556 - 1.004)\text{ kg} \times 2799.5 \frac{\text{kJ}}{\text{kg}}
\]

\( Q_{cv} = 8708.55 \text{ kJ} \)
Problem 3 (45/200 points)

Given:
Consider a regenerative steam power plant with one open feedwater heater. Superheated steam enters the turbine with a mass flow rate of 12 kg/s at 16 MPa and 560°C (State 1). Some fraction of the steam is extracted at 40 bar (State 2) and is supplied to the open feedwater heater. The remaining steam expands to the condenser pressure of 100 kPa (State 3). The isentropic efficiency of the turbine is 85%. Assume that saturated liquid water exits the condenser (State 4) and compressed liquid water exits the low-pressure pump (State 5). The low-pressure pump (Pump 1) is isentropic. Saturated liquid at 40 bar (State 6) exits the open feedwater heater, is compressed to 160 bar (State 7) in the high-pressure pump (Pump 2) before entering the boiler. The high-pressure pump (Pump 2) is isentropic. The environmental temperature is 27°C at 1 atm.

System sketch:

Find:
(a) Complete the table on the following page.
(b) Draw the processes on the T-s diagram on the following page. Label all the states on the T-s diagram.
(c) Determine the net power output of the cycle, in kW.
(d) Find the exergetic efficiency (2nd law efficiency) of the turbine, in %.
(e) Determine the rate of exergy destroyed in the open feedwater heater, in kW.

Assumptions:
1. Each component is analyzed as open system.
2. Steady state and steady flow
3. Neglect ΔKE and ΔPE.
4. No heat transfer for the turbine and pumps.
5. No work for the boiler and condenser.
6. No pressure drops for flow through the boiler, heaters and condenser
Problem 3 (continued)

Basic equations:
\[
\frac{d m_{cv}}{dt} = \sum \dot{m}_i - \sum \dot{m}_e
\]
\[
\frac{d E_{cv}}{dt} = \dot{Q}_{cv} - W_{cv} + \sum_i \dot{m}_i \left( h_i + \frac{v_i^2}{2} + g z_i \right) - \sum_e \dot{m}_e \left( h_e + \frac{v_e^2}{2} + g z_e \right)
\]
\[
\frac{d S_{cv}}{dt} = \frac{\dot{Q}_{cv}}{T_b} + \sum \dot{m}_i s_i - \sum \dot{m}_e s_e + \dot{\sigma}_{cv}
\]

Solution:

(a)

<table>
<thead>
<tr>
<th>State</th>
<th>P (MPa)</th>
<th>h (kJ/kg)</th>
<th>s (kJ/kg·K)</th>
<th>v (m³/kg)</th>
<th>Phase</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>16</td>
<td>3465.4</td>
<td>6.5132</td>
<td></td>
<td>SHV</td>
</tr>
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<td>2</td>
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<td>3113.1</td>
<td>6.6148</td>
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</tr>
<tr>
<td>3</td>
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<td>2505.2</td>
<td>6.900</td>
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<td>SLVM</td>
</tr>
<tr>
<td>4</td>
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<td>417.46</td>
<td>1.3026</td>
<td>1.043×10⁻³</td>
<td>SL</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td><strong>421.53</strong></td>
<td><strong>1.3026</strong></td>
<td></td>
<td>CL</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
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<td>2.7964</td>
<td></td>
<td>SL</td>
</tr>
<tr>
<td>7</td>
<td>16</td>
<td>1102.3</td>
<td></td>
<td></td>
<td>CL</td>
</tr>
</tbody>
</table>

(b)

![Diagram](image-url)
Problem 3 (continued)

(a) 
\[ h_b = h_i + v_i (P_3 - P_4) = 417.46 + 1.043 \times 10^3 (4 - 0.1) \times 10^3 = 421.53 \]

(c) 
To find a fraction \( y \), apply an energy balance for the open feedwater heater.

\[ \dot{m} y h_2 + \dot{m} (1 - y) h_5 - \dot{m} h_6 = 0 \]

\[ y \times 3113.1 + (1 - y) \times 421.53 - 1087.3 = 0 \]

\[ y = 0.247 \]

Now, apply an energy balance for each turbines and pumps, and sum them up. Then,

\[ \dot{W}_{net} = \dot{W}_{turb1} + \dot{W}_{turb2} + \dot{W}_{pump1} + \dot{W}_{pump2} \]

\[ = \dot{m} (h_1 - h_2) + \dot{m} (1 - y)(h_2 - h_3) + \dot{m} (1 - y)(h_4 - h_5) + \dot{m} (h_6 - h_7) \]

\[ = 12 \frac{kg}{s} \times [(3465.4 - 3113.1) + (1 - 0.247)(3113.1 - 2505.2) + (1 - 0.247)(417.46 - 421.53) + (1087.3 - 1102.3)] \frac{kJ}{kg} \]

\[ = 9504.3 \text{ kW} \]

(d) 
The exergetic efficiency can be written as

\[ \varepsilon_{turb} = \frac{\dot{W}_{turb}}{\dot{e}_{f, in} - \dot{e}_{f, out}} = \frac{(h_1 - h_2) + (1 - y)(h_2 - h_3)}{(h_1 - h_2) - T_o (s_1 - s_2) + (1 - y)[(h_2 - h_3) - T_o (s_2 - s_3)]} \]

\[ = \frac{3465.4 - 3113.1 + (1 - 0.247)(3113.1 - 2505.2)kJ/kg}{3465.4 - 3113.1 - 300(6.5132 - 6.6148) + (1 - 0.247)(3113.1 - 2505.2) - 300(6.6148 - 6.9000)} kJ/kg \]

\[ = 0.895 \]

(e) 
The rate of entropy generation in the open feedwater heater can be determined

\[ \frac{dS_{cv}}{dt} = \sum \frac{\dot{Q}_{cv}}{T_b} + \sum \dot{m}_i s_i - \sum \dot{m}_e s_e + \dot{\sigma}_{cv} \]

\[ 0 = \dot{m} y s_2 + \dot{m} (1 - y) s_5 + \dot{m} s_6 + \dot{\sigma}_{cv} \]

\[ \dot{\sigma}_{cv} = 12 \frac{kJ}{s} \left[ 2.7964 - (1 - 0.247) \times 1.3026 - 0.247 \times 6.6148 \right] \frac{kJ}{kgK} \]

\[ = 2.1802 \frac{kJ}{Ks} \]
Problem 3 (continued)

The rate of exergy destroyed in the open feedwater heater is

\[
\dot{E}_d = T_o \dot{\sigma}_{CV} = 300K \times 2.1802 \frac{kJ}{Ks}
\]

\[= 654.06 \text{ kW}\]
Problem 4 (35/200 points)

Given:
Gaseous octane (C₈H₁₈) reacts with 200% dry air in a combustor and an equilibrium mixture of H₂O(ｇ), CO₂, N₂, O₂, H₂, CO, and NO exits the furnace at an unknown temperature and a pressure of 1 atm. It is known that the equilibrium mixture contains 0.0082 moles of H₂, 7.967 moles of CO₂, and 93.68 moles of N₂.

Do not interpolate in the table; use the closest table value.

For 100% dry air: C₈H₁₈ + 12.5(O₂ + 3.76N₂) → 9H₂O + 8CO₂ + 47N₂

Find:
(a) Calculate the number of moles of H₂O(ｇ), O₂, CO, and NO in the equilibrium mixture.
(b) Determine the temperature of the equilibrium mixture, in K.
(c) Is it necessary to include atomic nitrogen (N) in the equilibrium mixture? You must justify your answer. No calculations are necessary.
(d) If the pressure is increased to 10 atm (with corresponding decrease in volume) at constant temperature, what happens to the number of moles of carbon monoxide (CO) in the equilibrium mixture? You must justify your answer. No calculations are necessary.

System Sketch:

(No standard solution procedure is requested for this problem)

Solution:

For 200% dry air:

C₈H₁₈ + 25(O₂ + 3.76N₂) → aH₂O + bCO₂ + cN₂ + dO₂ + eH₂ + fCO + gNO

(a)

Given b = 7.967, c = 93.68, and e = 0.0082

Atom balance:

C: 8 = 7.967 + f → f = 0.033 moles for CO
Problem 4 (continued)

H: \(18 = 2a + 2 \times 0.0082 \Rightarrow a = 8.9918\) moles for \(\text{H}_2\text{O}\)
N: \(25 \times 2 \times 3.76 = 2 \times 93.68 + g \Rightarrow g = 0.64\) moles for \(\text{NO}\)
O: \(50 = a + 2 \times 7.967 + 2d + f + g \Rightarrow d = 12.2006\) moles for \(\text{O}_2\)

(b)

Regarding any of the equilibrium equations below to determine the temperature

1. \(0.5\text{O}_2 + 0.5\text{N}_2 \rightleftharpoons \text{NO}\)
2. \(\text{CO}_2 \rightleftharpoons \text{CO} + 0.5\text{O}_2\)
3. \(\text{CO}_2 + \text{H}_2 \rightleftharpoons \text{CO} + \text{H}_2\text{O}\)

Note: \(\text{H}_2\text{O} \rightleftharpoons \text{H}_2 + 0.5\text{O}_2\) cannot be considered because it has the lowest equilibrium constant compared to others.

The total number of moles \(n_{tot} = \sum n_i\) is 123.521 moles.

For \(0.5\text{O}_2 + 0.5\text{N}_2 \rightleftharpoons \text{NO}\)

\[
K_P = \frac{\prod_{\text{Products}} n_i^{\nu_i} \left( \frac{P}{P_{\text{tot}P_{\text{ref}}}} \right)^{\Delta
u}}{\prod_{\text{Reactants}} n_i^{\nu_i} \left( \frac{P}{P_{\text{tot}P_{\text{ref}}}} \right)^{\Delta
u}} = \frac{0.64}{12.2006^{0.5}93.68^{0.5}} \left( \frac{P}{n_{\text{tot}P_{\text{ref}}}} \right)^{1-0.5-0.5} = 0.01893
\]

\(\Rightarrow \log K_P = -1.7228\)

For \(\text{CO}_2 \rightleftharpoons \text{CO} + 0.5\text{O}_2\)

\[
K_P = \frac{0.033 \times 12.2006^{0.5}}{7.967} \left( \frac{1}{123.521 \times 1} \right)^{1+0.5-1} = 0.0013
\]

\(\Rightarrow \log K_P = -2.8855\)

For \(\text{CO}_2 + \text{H}_2 \rightleftharpoons \text{CO} + \text{H}_2\text{O}\)

\[
K_P = \frac{0.033 \times 8.9918}{7.967 \times 0.0082} \left( \frac{P}{n_{\text{tot}P_{\text{ref}}}} \right)^{1+1-1-1} = 4.5421
\]

\(\Rightarrow \log K_P = 0.6573\)

The temperature using Table A-27 gives 2000 K.
Problem 4 (continued)

(c) 
\( K_P \) of \( N_2 \rightleftarrows 2N \) is \( \sim 10^{-18} \) at \( T = 2000 K \). \( K_P \) is too small to consider the formation of \( N \) atoms.

(d) 
For \( CO_2 \rightleftarrows CO + 0.5O_2 \)

\[
K_P = \frac{n_{CO} n_{O_2}^{0.5}}{n_{CO_2}} \left( \frac{10 \text{ atm}}{123.521 \times 1 \text{ atm}} \right)^{0.5}
\]

\( K_P \) is constant due to the constant temperature. The increase in the second term on the right hand side makes the first term on the right hand side decrease. Consequently, \( n_{CO} \) decreases.

Note: For \( CO_2 + H_2 \rightleftarrows CO + H_2O \)

\[
K_P = \frac{n_{CO} n_{H_2O}}{n_{CO_2} n_{H_2}} \left( \frac{p}{n_{tot}^{P_{ref}}} \right)^{1+1-1-1}
\]

The second term on the right hand side is 1 so the pressure effect cannot be seen with this equilibrium equation. Thus, one should use the other equilibrium equation to judge the pressure effect.
Problem 5 (45/200 points)

Given:
A turbojet is traveling through the atmosphere of Mars at 225 m/s. Assume that the atmosphere is composed of pure CO\(_2\) with a temperature and pressure of 250 K and 0.6 kPa, respectively. The diffuser inlet has an area of 1 m\(^2\). The pressure ratio across the compressor is 100, and all of the turbine work is used to drive the compressor. A radiative heater is used to heat the gas to a turbine-inlet temperature of 2500 K. The nozzle expands the gas to atmospheric pressure (0.6 kPa). The diffuser, compressor, turbine, and nozzle are all isentropic. Assume constant specific heats with \(c_{p,CO_2} = 0.80\) kJ/kg·K and \(k_{CO_2} = 1.3\). The molecular weight of CO\(_2\) is 44 kg/kmol. The environmental temperature and pressure are 250 K and 0.6 kPa, respectively.

Hint: Recall \(KE = \frac{1}{2} v^2\) and 1 J/kg = 1 m\(^2\)/s\(^2\).

Find:
(a) Draw the processes on the T-s diagram on next page. Label all the states on the T-s diagram.
(b) Complete the table on the following page.
(c) Calculate the mass flow rate of CO\(_2\) in the turbojet, in kg/s.
(d) Determine the rate of heat addition provided by the radiative heater, in MW.
(e) Find the exergy rate supplied to the working fluid in the heater, in MW
(f) Calculate the thrust produced by the turbojet, in kN

System Sketch:

Assumptions:
1. Each component is an open system. 2. Steady state and steady flow.  3. No \(\Delta PE\)
4. The working fluid is CO\(_2\) modeled as an ideal gas
5. No heat transfer in diffuser, compressor, turbine, and nozzle.
6. No work in diffuser, heater, and nozzle.

Basic Equations:

\[
\frac{dm_{cv}}{dt} = \sum \dot{m}_i - \sum \dot{m}_e
\]

\[
\frac{dE_{cv}}{dt} = \dot{Q}_{cv} - \dot{W}_{cv} + \sum \dot{m}_i (h_i + KE + PE) - \sum \dot{m}_e (h_e + KE + PE)
\]
Problem 5 (continued)

(a)

State 1:

\[ h_1 = h_a + \frac{v_a^2}{2} \]

\[ C_p T_1 = C_p T_a + \frac{v_a^2}{2} \]

\[ 0.8 \frac{kJ}{kgK} T_1 = 0.8 \frac{kJ}{kgK} 250 K + \frac{(225 m/s)^2}{2 \times 1000} \]

\[ \Rightarrow T_1 = 281.64 K \]

\[ \frac{T_1}{T_a} = \frac{281.64 K}{250 K} = \left( \frac{P_1}{P_a} \right)^{k-1/k} = \left( \frac{P_1}{0.6 kPa} \right)^{0.3/1.3} \]

\[ \Rightarrow P_1 = 1.006 kPa \]

State 2:

\[ \frac{T_2}{T_1} = \frac{T_2}{281.64 K} = \left( \frac{P_2}{P_1} \right)^{k-1/k} = \left( 100 \right)^{0.3/1.3} \]

\[ \Rightarrow T_2 = 815.14 K \]

\[ P_2 = 100 \times P_1 = 100.6 kPa \]

State 4:

\[ h_2 - h_1 = h_3 - h_4 \]

\[ T_2 - T_1 = T_3 - T_4 \]

\[ 815.14 - 281.64 = 2500 - T_4 \]

\[ \Rightarrow T_4 = 1966.5 K \]

\[ \frac{T_4}{T_3} = \frac{1966.5 K}{2500 K} = \left( \frac{P_4}{P_3} \right)^{k-1/k} = \left( \frac{P_4}{100.6} \right)^{0.3/1.3} \]

\[ \Rightarrow P_4 = 35.55 kPa \]
Problem 5 (continued)

State 5:
\[
\frac{T_5}{T_4} = \frac{T_5}{1966.5 \, K} = \left( \frac{p_5}{p_4} \right)^{\frac{k-1}{k}} = \left( \frac{0.6}{35.55} \right)^{0.3/1.3} \Rightarrow T_5 = 766.68 \, K
\]

(c)
\[
P\dot{V} = mRT
\]
\[
0.6 \, kPa \left( 1 \, m^2 \times 225 \frac{m}{s} \right) = m \left( \frac{8.314 \, kJ}{44 \, kJ/kK} \right) \times 250 \, K \Rightarrow m = 2.858 \, kg/s
\]

(d)
Apply an energy balance to the heater.
\[
Q_{in} = \dot{m}(h_3 - h_2) = \dot{m}C_p(T_3 - T_2) = 2.858 \frac{kg}{s} \times 0.8 \frac{kJ}{kgK} \times (2500 - 815.14)K
\]
\[
= 3852.3 \, kW \text{ or } 3.85 \, MW
\]

(e)
\[
\dot{E}_q = \dot{m}\Delta\bar{e}_f = \dot{m}[(h_3 - h_2) - T_0(s_3 - s_2)] = \dot{m} \left[ C_p(T_3 - T_2) - T_0 \left( C_p \ln \frac{T_3}{T_2} - R \ln \frac{P_3}{P_2} \right) \right]
\]
\[
= 2.858 \frac{kg}{s} \times 0.8 \frac{kJ}{kgK} \times (2500 - 815.14)K - 250K \left( 0.8 \frac{kJ}{kgK} \times \ln \frac{2500}{815.14} \right)
\]
\[
= 3.212 \, MW
\]

(f)
\[
v_5 = \sqrt{2 \left( h_4 - h_s \right)} = \sqrt{2C_p(T_4 - T_5)} = \sqrt{2 \times 0.8 \frac{kJ}{kgK} \times (1966.5 - 766.68)K \times 1000 \frac{J}{kJ}}
\]
\[
= 1385.54 \, m/s
\]
\[
\text{Thrust} = \dot{m}(v_5 - v_a) = 2.858 \frac{kg}{s} \times (1385.54 - 225) \frac{m}{s}
\]
\[
= 3316.82 \, N \text{ or } 3.317 \, kN
\]