Fill in your name and ID No. in the space above. There should be 11 pages (including this page and the last page which is a formula page).

RELAX, this is only an exam. Read over the whole exam, then decide which problem to work first.

The exam is closed book, and two double-sided sheets of notes are permitted in addition to the formula page attached to this exam. **No collaboration with others!**

For multiple choice questions, choose the single, **BEST** answer.

Properties and conversion factors are in the booklet provided.

Include a sketch and clearly state assumptions and equations used on problems requiring detailed analysis. If you use data from a table, indicate the **TABLE NUMBER** and the value read. Failure to do so will result in a lower score.

If you get stuck on a problem, go to another one. Pace yourself by the time and number of points. You should spend on average 3.6 minutes per multiple choice problem and 24 minutes per work-out problem.

Problems must be worked in the unit system in which they are specified. Failure to do so will result in a lower score.

You have **two hours** to complete the exam.

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<tr>
<th>Problem</th>
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<tr>
<td>Multiple choice:</td>
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<td>Workout problem 1:</td>
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Answers to the multiple choice questions. Circle the letter that corresponds to your answer for each of the multiple choice questions. Please note that only the answers you provide on this sheet will be graded.

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I. **(60 pts total) Multiple choice problems worth 2 points each.** Circle the answer that is the most appropriate or closest numerically to your answer and then select that answer on the answer sheet.

1. An ideal gas in a rigid container is initially at an absolute pressure of 400 kPa and a temperature of 318 K. If the gas is heated to a final temperature of 723 K, the final absolute pressure in MPa is:
   
   a. 0.5  
   b. 0.9  
   c. 2.0  
   d. 4.0  
   e. None of the above

2. A gas is contained in a vertical cylinder with a frictionless, heavy piston weighing 132 lb, and having a cross-sectional area of 62 in². The local atmospheric pressure is 14.7 psia. What is the absolute pressure inside the cylinder in psia?
   
   a. 12.6  
   b. 14.7  
   c. 16.8  
   d. 22.6  
   e. 83.2

3. Water at 400 kPa and 141 °C is a
   
   a. Subcooled liquid  
   b. Saturated liquid  
   c. Saturated liquid-vapor mixture  
   d. Saturated vapor  
   e. Superheated vapor

4. For any arbitrary process, an ideal gas in a rigid container always maintains
   
   a. Constant pressure  
   b. Constant enthalpy  
   c. Constant internal energy  
   d. Constant specific volume  
   e. Constant entropy
5. The quality of a vapor-liquid mixture of R-134A at 0.2 MPa and having a specific enthalpy of 150 kJ/kg is
   a. 0.00
   b. 0.55
   c. 0.65
   d. 0.75
   e. 1.00

6. The air conditioning system goes out in a well-insulated auditorium that contains 700 people and 1800 kg of air at 18 °C. The windows and doors are closed so that there is no significant exfiltration or infiltration of air. If the heat input from each person is 60 W, how long in minutes does it take for the air in the auditorium to reach 30 °C.
   a. 1
   b. 6
   c. 12
   d. 20
   e. 100

7. Consider a control volume in which occurs a steady flow process:
   a. Intensive properties may change with time
   b. Extensive properties may change with time
   c. All properties may change with time
   d. Properties do not change with location in the control volume
   e. Properties do not change with time

8. For an adiabatic compressor
   a. The enthalpy is unchanged between the inlet and outlet
   b. The potential energy change between the inlet and outlet is large
   c. The specific work input is equal to the enthalpy change
   d. The specific work output is equal to the enthalpy change
   e. The work input is equal to the heat exchange with the surroundings
9. Steam enters an adiabatic nozzle at 500 kPa, 400 °C and 20 m/s and exits at 80 m/s. The specific enthalpy change \((h_2 - h_1)\) between the inlet and the outlet of the nozzle in kJ/kg is
   a. -3000
   b. -6
   c. -3
   d. 3
   e. 3000

10. The air conditioner unit in a student’s apartment has a COP\(\text{R}\) of 3.2. If heat is rejected to the outdoor high temperature reservoir at a rate of 750 kW, what is the rate of heat removal from the apartment in kW?
   a. 180
   b. 290
   c. 570
   d. 2400
   e. Indeterminate from the given information

11. The entropy change between states 1 and 2 of an internally reversible process is
   a. Always positive
   b. Always negative
   c. Always zero
   d. Dependent on the process path
   e. Independent of the process path

12. An isentropic process is one that is **always**
   a. Internally reversible
   b. Adiabatic
   c. At constant entropy
   d. Internally reversible and adiabatic
   e. Impossible in reality
13. The purpose of the reheat cycle in the Rankine cycle reheat is to

a. Make use of high temperature exhaust steam
b. Take advantage of higher boiler temperatures while maintaining high quality steam exiting the turbine
c. Provide power generation to the circulation pump
d. Lower the quality of the steam exiting the turbines
e. Give thermodynamics students more enthalpies to calculate

14. Steady, incompressible, frictionless flow in a horizontal, uniform-diameter pipe exhibits

a. Constant pressure
b. Steadily increasing pressure
c. Steadily decreasing pressure
d. Steadily increasing velocity
e. Steadily decreasing velocity

15. An ideal Otto cycle has a compression ratio of 8. At the beginning of the compression process, the air is at 100 kPa and 290 K; at the end of the compression process, the air is at 667 K. 800 kJ/kg of heat are transferred to the air during the constant-volume heat-addition process. Using the cold air assumptions, the maximum temperature in the cycle in K is:

a. 1190
b. 1275
c. 1460
d. 1780
e. 1990

16. For an ideal Brayton cycle with a compression ratio of 8, air enters the compressor at a temperature of 300 K. Using variable specific heats, the temperature of air exiting the compressor in K is

a. 180
b. 375
c. 480
d. 540
e. 760
17. Steam enters the isentropic turbine of an ideal Rankine cycle power plant at 3 MPa and 350 °C and exits at 75 kPa. The quality of steam exiting the turbine is

a. 0.7  
b. 0.8  
c. 0.9  
d. 1.0 (saturated vapor)  
e. Undefined (superheated steam)

18. Refrigerant-134A enters a condenser as superheated steam at 20 °F and 15 psia and exits as a saturated liquid. The heat rejected to the environment from the condenser during this process in Btu/lbm is

a. 6.68  
b. 14.1  
c. 82.3  
d. 90.0  
e. 98.9

19. A water tower is 35 m high and is drained by a 15 cm diameter pipe that runs down a hill a length of 1000 m and having an elevation decrease of 5 m (see figure below). The pressure in the water tower is 200 kPa gauge pressure and the pipe at the bottom of the hill exits to the atmosphere. Neglecting frictional losses, the velocity in m/s exiting the pipe at the bottom of the hill is

a. 0.6  
b. 16  
c. 34  
d. 49  
e. 1185

Figure 1: Sketch for multiple-choice question 19.
20. The velocity profile in a pipe is given by

\[ u(r) = u_{\text{max}} \left( 1 - \left( \frac{r}{R} \right)^2 \right) \]

where \( r \) is the radial distance from the pipe centerline, \( u_{\text{max}} \) is the maximum velocity in the pipe and \( R \) is the radius of the pipe. Given that the shear stress in radial coordinates is given by

\[ \tau (r) = \mu \frac{du}{dr} \]

where \( \mu \) is the dynamic viscosity, the shear stress at the pipe wall \( r = R \) is given by

a. \( \frac{2\mu u_{\text{max}}r}{R} \)

b. \( -\frac{2\mu u_{\text{max}}r}{R} \)

c. \( \frac{2\mu u_{\text{max}}}{R} \)

d. \( -\frac{2\mu u_{\text{max}}}{R} \)

e. none of the above
II. (40 pts total) Work-out problems worth 20 points each. Problem parts are valued as noted. State all important assumptions and indicate which tables you are reading values from.

1. Steam enters a real turbine at 10 MPa and 500 °C at a rate of 2 kg/s and leaves at 20 kPa. The net power output from the turbine is 1.6 MW. Heat is also lost from the turbine at a rate of 0.4 MW due to imperfect insulation and irreversibilities in the turbine. Neglecting kinetic and potential energy changes, determine the following (5 points each):

   a. The temperature of the steam exiting the turbine in °C.
   b. The quality of the steam exiting the turbine.
   c. The specific entropy change in the turbine in kJ/(kg K).
   d. What would be the effect on the net work output of increasing the pressure at the outlet of the turbine? Please explain your answer.
2. A gas turbine power plant operates on the simple Brayton cycle with air as the working fluid and has a pressure ratio of 10. The air enters the compressor at 290 K and the turbine at 1115 K. Both the compressor and the turbine have an isentropic efficiency of 0.85. Using the cold air approximation, determine:

a. The air temperature at the compressor exit (7 points)
b. The back work ratio (percent of the total work output from the turbine that goes into the compressor). (7 points)
c. The cycle thermal efficiency (6 points).
\[ \Delta P = \rho gh \]  
\[ P_v = RT \]  
\[ PV = mRT \]  
\[ P_v = Z RT \]  
\[ R = R_v/M \]  
\[ W_{\text{elect}} = V \cdot I = I^2 R \]  
\[ w = \int P dv \]  
\[ W = m \int P dv \]  
\[ dh = c_v dT \]  
\[ \Delta s = s_2^r - s_1^r - R \ln \frac{P_2}{P_1} \]  
\[ \Delta s = C_v \ln \left( \frac{T_2}{T_1} \right) - R \ln \left( \frac{P_2}{P_1} \right) \]  
\[ \Delta s = C_v \ln \left( \frac{T_2}{T_1} \right) + R \ln \left( \frac{V_2}{V_1} \right) \]  
\[ \Delta s = C_v \ln \left( \frac{T_2}{T_1} \right) \]  
\[ \frac{P_2}{P_1} \]  
\[ \frac{V_1}{V_2} \]  
\[ (Q_\text{in}/Q_\text{out})_{\text{rev}} = T_H/T_L \]  
\[ \eta = W_{\text{net}}/Q_\text{in} \]  
\[ \text{COP} = Q_\text{out}/W_{\text{in}} \]  
\[ \frac{p_2}{\rho g} + \frac{V_2^2}{2g} + z_2 = \frac{p_1}{\rho g} + \frac{V_1^2}{2g} + z_1 \]  
\[ \left( z_1 + \frac{p_1}{\rho g} \right) - \left( z_2 + \frac{p_2}{\rho g} \right) = \frac{4l}{D \rho g} r_o = H_L \]  
\[ H_L = f \frac{V^2}{D^2} \]  
\[ \eta = \frac{W_s}{W_a}; \eta_i = \frac{W_s}{W_a}; \eta_d = \frac{(ke)_s}{(ke)_a}; \eta_f = \frac{(ke)_s}{(ke)_a} \]  
\[ \text{IDEAL GAS CONSTANT: } R_a = 8.314 \text{ kPa}\cdot\text{m}^3/(\text{kmol}\cdot\text{K}) \]  
\[ R_a = 8.314 \text{ kJ/(kmol}\cdot\text{K}) \]  
\[ R_a = 1.986 \text{ Btu/(lbmol}\cdot\text{°R}) \]  
\[ R_a = 1545 \text{ ft}^3\text{lbf}/(\text{lbmol}\cdot\text{°R}) \]  
\[ \Delta s = \int \left( \frac{\partial Q}{T} \right) + S_{\text{gen}} \frac{dS_{\text{ev}}}{dt} = \sum \frac{\dot{Q}_j}{T_j} + \sum \dot{m}_{\text{in}} s_{\text{in}} - \sum \dot{m}_{\text{out}} s_{\text{out}} + \dot{S}_{\text{gen}} \]  
\[ \text{for reservoir} \]  
\[ \Delta s = \left( \frac{Q}{T} \right)_{\text{rev}} \]