RYERSON UNIVERSITY

Department of Mechanical and Industrial Engineering

THERMODYNAMICS & FLUIDS - MEC511

FINAL EXAM (Sample)

DATE: April 17th, 2008
SECTIONS: 011-071
TIME: 2 hours

EXAMINERS: Prof. R.S. Budny
Dr. A. Fung

INSTRUCTIONS:

1. **OPEN TEXTBOOK EXAM.** You are permitted to bring in 1) **ONE** Thermodynamics course textbook, 2) **ONE** 8 ½" x 14" student-prepared aid sheet (both sides), 3) electronic calculator, and 4) writing and drawing instruments.
2. **Prohibited items include:** cell-phones (text and/or video display), pagers, and other wireless devices, Palm-pilots, laptop computers, radios/video/music players etc.. These must be switched off and left at the front of the exam room.
3. Leave all bags and brief cases at the front of the exam room. Travelling back and forth to bags and brief cases while the exam is in progress is **NOT** permitted.
4. Candidates may not borrow or lend any materials while the exam is in progress.
5. Answer all **FOUR (4)** questions. Questions are of equal percent value (25% each).
6. Answer questions in the space provided. You may use the back of the page if required.
7. Candidates must layout their work clearly and legibly at all times; otherwise, marks may be lost. Illegible answers will not be graded.
8. Work with equation symbols as long as possible before substituting in numbers. When using numbers use four (4) significant digits of accuracy to avoid rounding errors.
9. Full marks will be awarded for correct answers using the correct method. Marks will be deducted for incorrect units.
10. Use engineering judgment when answering questions. If you feel that there is a genuine error or omission in any question then make an assumption and draw this to the attention of the examiner right on the test paper and continue with the solution.

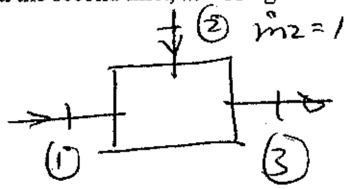
Student Name (Please Print) ⇨	**(Sample Exam)**	**Seat #**
Section Number ⇨	**Circle one: 011, 021, 031, 041, 051, 061, or 071**	
Student Number ⇨		

Question ⇨	**1.**	**2.**	**3.**	**4.**	**Total**
Mark ⇨					

QUESTION 1. For each of the following questions circle the (one) most appropriate answer which may be slightly rounded off. All questions are of equal value. Use the back of the page for rough work but this will not be marked.

A) A fluid mixer has two inlet streams and one outlet. At one inlet the flow properties are $V = 10$ m/s, $A = 1$ m^2, and $v = 0.5$ m^3/kg while at the second inlet, $\dot{m} = 10$ kg/s. The outlet mass flow rate $\dot{m}$ is:

- (i) 15 kg/s;
- (ii) 10.05 kg/s;
- [✓ (iii) 30 kg/s;]
- (iv) 12 kg/s;
- (v) 210 kg/s.



$\dot{m}_2 = 10$ kg/s

$\dot{m}_3 = ?$

$V_1 = 10$ m/s

$A_1 = 1$ m^2, $v_1 = 0.5$ m^3/kg

$\dot{m}_1 + \dot{m}_2 = \dot{m}_3$

$\dot{m}_1 = \rho_1 V_1 A_1 = \frac{A_1 V_1}{v_1}$

$= 20$

$\Rightarrow \dot{m}_3 = 10 + 20$

$= 30$ kg/s

B) 10 kg of water exists as a two-phase liquid-vapour mixture with $x = 30\%$:

- (i) The mass of vapour is 7 kg;
- [✓ (ii) The mass of vapour is 3 kg;]
- (iii) The mass of vapour is 33.3 kg;
- (iv) The mass of vapour is 14.3 kg;
- (v) The mass of liquid is 3 kg.

$x = \frac{m_g}{m_g + m_f} \Rightarrow 0.3 = \frac{m_g}{10}$

$\Rightarrow m_g = 3$ kg

C) Which of the following best describes a *Thermodynamic Cycle*:

- [✓ (i) The net cycle heat transfer must be equal to the net cycle work;]
- (ii) The process must be clockwise in the pressure-volume diagram;
- (iii) The process must be counter clockwise in the pressure-volume diagram;
- (iv) The device that performs the cycle must be insulated;
- (v) None of the above.

$Q_{cycle} = W_{cycle}$

D) Water at 100°C has a specific enthalpy of 2257.0 kJ/kg. At this state, the water is:

- (i) Superheated;
- (ii) Subcooled;
- (iii) Saturated vapour;
- (iv) Saturated liquid;
- [✓ (v) A two-phase liquid-vapour mixture.]

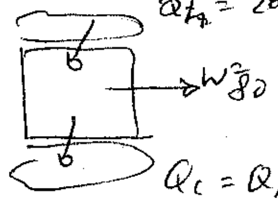
check Table A-2 for h_f & h_g @ 100°C

$h_f < 2257.0 < h_g$

E) An engine running at steady state takes in 200 kW of heat and produces 80 kW of shaft power output. If this engine obeys the laws of Thermodynamics it must:

- (i) Go through an ideal cycle;
- (ii) Be insulated;
- [✓ (iii) Reject 120 kW by heat transfer to its surroundings;]
- (iv) Absorb 120 kW by heat transfer from its surroundings;
- (v) All of the above.

$Q_H = 200$



$Q_C = Q_H - W$

$= 200 - 80$

$= 120$

F) A gas <u>expands</u> reversibly and adiabatically according to $pV^k = constant$ where k is the specific heat ratio. This process is best described by which pressure-volume figure below (i.e., p-V diagram):

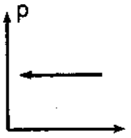


Fig. A

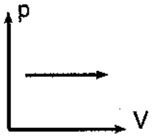


Fig. B

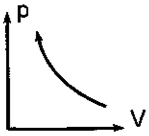
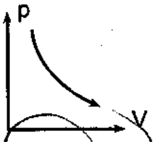


Fig. C



[✓ Fig. D]

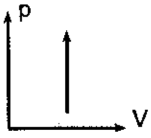


Fig. E

G) Gas in a piston-cylinder (closed system) undergoes a cycle that consists of three processes. From state 1 to state 2, 50 kJ of heat is added to the system in a constant volume process. The gas then expands in an adiabatic process from state 2 to state 3. From state 3 back to state 1, the system rejects 25 kJ of heat. The net work for the system over the cycle is:

- [✓ (i) 25 kJ;]
- (ii) -75 kJ;
- (iii) -25 kJ;
- (iv) 75 kJ;
- (v) insufficient information is provided.

$Q_{1-2} = 50$

$W_{1-2} = 0$ (V = const)

$Q_{2-3} = 0$ (adiabatic)

$Q_{3-1} = -25$

Since $W_{cycle} = Q_{cycle}$

$W_{1-2} + W_{2-3} + W_{3-1} = Q_{1-2} + Q_{2-3} + Q_{3-1}$

$W_{cycle} = 50 + 0 + (-25)$

$= 25$

H) Nitrogen at 100°C and an absolute pressure of 200 kPa expands in such a way that it can be represented by a polytropic process, pV^n=constant. The polytropic constant is n=1.3. If the final absolute pressure is 75 kPa, the final temperature is:

- (i) 195°C;
- [✓ (ii) 24°C;]
- (iii) 80°C;
- (iv) 38°C;
- (v) 28°C.

Since $\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}}$

$\Rightarrow T_2 = (273 + 100)\left(\frac{75}{100}\right)^{\frac{1.3-1}{1.3}}$

$= 297\text{k} = 24°\text{c}$

I) In the following properties, which one is NOT an *extensive* property:

- (i) Mass, in kg;
- (ii) Kinetic energy, in kJ;
- (iii) Volume, in m^3;
- [✓ (iv) Temperature, in °C;]
- (v) Internal energy, in J.

J) A Carnot Cycle consists of which of the following four reversible processes:

- (i) Adiabatic Compression, Isobaric Heat Addition, Adiabatic Expansion, Isobaric Heat Rejection;
- (ii) Isothermal Compression, Adiabatic Heat Addition, Isothermal Expansion, Adiabatic Heat Rejection;
- (iii) Adiabatic Compression, Isobaric Heat Addition, Adiabatic Expansion, Isobaric Heat Rejection;
- (iv) Adiabatic Compression, Isobaric Heat Addition, Adiabatic Expansion, Constant Volume Heat Rejection;
- [✓ (v) Adiabatic Compression, Isothermal Heat Addition, Adiabatic Expansion, Isothermal Heat Rejection.]

✓ 2.6

QUESTION 2. A gas in a piston-cylinder assembly undergoes two processes in series. From state 1 to state 2 there is energy transfer by heat to the gas with a magnitude of 500 kJ, and the gas does work on the piston with a magnitude of 800 kJ. The second process, from state 2 to state 3, is a constant-pressure compression at 400 kPa during which there is a heat transfer from the gas with a magnitude of 450 kJ. The following data are also known: $U_1 = 2000$ kJ and $U_3 = 3500$ kJ. Neglecting changes in kinetic and potential energy, calculate:

(a) The internal energy at state 2, U_2, in kJ,

(b) The work done during process 2-3, $W_{2\text{-}3}$, in kJ, and state if the work is done ***by*** or ***on*** the gas, and,

(c) The change in volume of the gas during process 2-3, $\Delta V = V_3 - V_2$, in m^3.

Question 4 (25%):

A gas in a piston-cylinder assembly undergoes two processes in series. From state 1 to state 2 there is energy transfer by heat to the gas with a magnitude of 500 [kJ], and the gas does work on the piston with a magnitude of 800 [kJ]. The second process, from state 2 to state 3, is a constant-pressure compression at 400 [kPa] during which there is a heat transfer from the gas with a magnitude of 450 [kJ]. The following data are also known: $U_1 = 2000$ [kJ] and $U_3 = 3500$ [kJ]. Neglecting changes in kinetic and potential energy, calculate the change in volume of the gas during process 2-3, in [m^3].

Solution:

Given: A gas in piston-cylinder assembly, $\Delta PE = \Delta KE = 0$

Find: $\forall_3 - \forall_2$

Schematic:

process ①-②: $Q_{1-2} = +500\text{kJ}$, $W_{1-2} = 800\text{kJ}$

Process ②-③: $Q_{2-3} = -450\text{kJ}$, $P = 400\text{kPa}$

$U_1 = 2000\text{kJ}$, $U_3 = 3500\text{ kJ}$

Assumption: ① Closed system, ② $\Delta PE = \Delta KE = 0$, ③ Const Pressure process during ②-③.

Analysis:

Since $W_{2-3} = \int_{\forall_2}^{\forall_3} p\,d\forall = P_2(\forall_3 - \forall_2)$

or $\forall_3 - \forall_2 = \dfrac{W_{2-3}}{P_2}$ —①

Apply 1st Law b/w ② & ③:

$U_3 - U_2 = Q_{2-3} - W_{2-3}$ —②

~~U~~ Apply 1st Law b/w ① & ②:

$U_2 - U_1 = Q_{1-2} - W_{1-2}$

$\Rightarrow U_2 = Q_{12} - W_{1-2} + U_1$

$= 500 - 800 + 2000$

$U_2 = 1700\text{kJ}$

From Eq ②:

$W_{2-3} = Q_{2-3} - (U_3 - U_2)$

$= -450 - (3500 - 1700)$

$W_{2-3} = -2250\text{ kJ}$

From Eq ①:

$\forall_3 - \forall_2 = \dfrac{W_{2-3}}{P}$

$= \dfrac{-2250\text{ kJ}}{400\text{ kPa}}\left(\dfrac{10^3\text{ N.m}}{1\text{ kJ}}\right)\left(\dfrac{1k}{10^3}\right.$

$= -5.625\text{ m}^3$ #

There is a reduction in volume from ② to ③ of 5.625m^3 #

QUESTION 3. Steam enters a turbine steadily at 10 MPa and 560°C with a velocity of 60 m/s and leaves at 300 kPa with a quality of 100%. A heat loss of 30 kJ/kg occurs during the process. The inlet area of the turbine is 150 cm^2, and the exit area is 1400 cm^2. Do the following:

(a) Draw a schematic diagram of the system with all variables,

(b) Determine the mass flow rate of the steam, in kg/s,

(c) Determine the exit velocity, in m/s, and,

(d) Determine the power output, in kW.

Student Name:______________________________ Section # _________ Student ID: ____________

Question #3 (25%):

Steam enters a turbine steadily at 10 [MPa] and 560 [°C] with a velocity of 60 [m/s] and leaves at 300 [kPa] with a quality of 100%. A heat loss of 30 [kJ/kg] occurs during the process. The inlet area of the turbine is 150 [cm^2], and the exit area is 1400 [cm^2].

Determine:

a) draw a schematic diagram of the system with all variables,

b) the mass flow rate of the steam in [kg/s],

c) the exit velocity in [m/s], and

d) the power output in [kW].

Solution:

Given: $P_1 = 10 MPa$, $T_1 = 560°c$

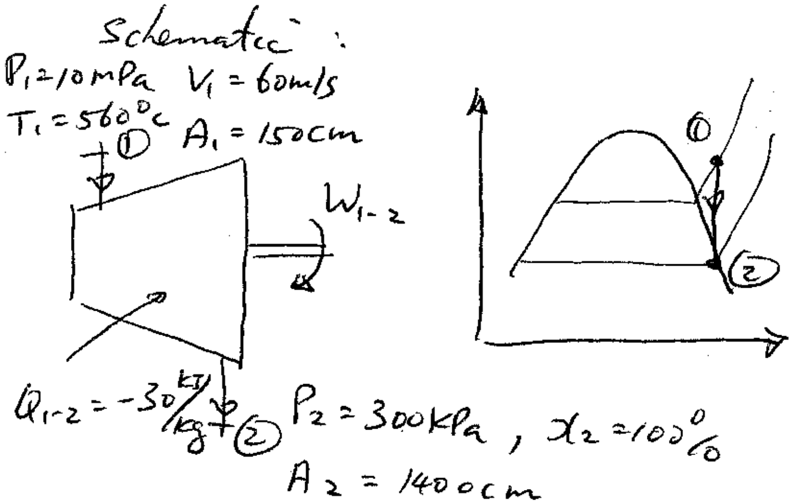
$V_1 = 60 m/s$, $A_1 = 150 cm^2$

$P_2 = 300 kPa$, $x_2 = 100\%$

$A_2 = 1400 cm^2$, $\frac{Q_{1-2}}{m} = -30 kJ/kg$

Find: $\dot{m}$, V_2, W_{1-2}

Schematic:



Assumption: steady-flow process, $\Delta PE = 0$

Analysis:

From Table A-4: (T_1 & P_1)

$v_1 = 0.03619$, $h_1 = 3526$

From Table A3: (P_2, x_2):

$v_2 = v_g = 0.6058$, $h_2 = h_g = 2725.3$

$\dot{m} = \frac{1}{v_1} V_1 A_1 = \frac{1}{0.03619} (60)\left(\frac{150}{100 \times 100}\right)$

$\dot{m} = 24.87 kg/s$ #

Since $\dot{m}_1 = \dot{m}_2 = \frac{1}{v_2} V_2 A_2$

$\Rightarrow 24.87 = \frac{1}{0.6058} V_2 \left(\frac{1400}{100 \times 100}\right)$

$\Rightarrow V_2 = 107.6 m/s$ #

Apply 1st Law:

$Q - W = \Delta E = \Delta H + \overset{0}{\cancel{\Delta PE}} + \Delta KE$

$\Rightarrow -30(24.87) - W = 24.87(2725.3 - 3526)$

$+ \frac{24.87(\frac{1}{2})(107.6^2 - 60}{1000}$

$\Rightarrow W = 19913 - \overset{99.2}{1\cancel{}7} - 746$

$= 19068 kW$ #

QUESTION 4. A Carnot engine, using ideal air as the working fluid, accepts heat from a reservoir at 800 K and rejects heat to a reservoir at a temperature of 400 K. The heat transfer from the high-temperature reservoir is 5000 kJ. The pressure at the end of the isothermal-compression process is 500 kPa (abs), and the pressure at the end of the heat addition process is 400 kPa (abs). The cycle is a <u>closed system</u> and assume that air has constant properties $R = 0.287$ kJ/(kg·K), $k = 1.4$, and $c_v = 0.717$ kJ/(kg·K). Calculate:

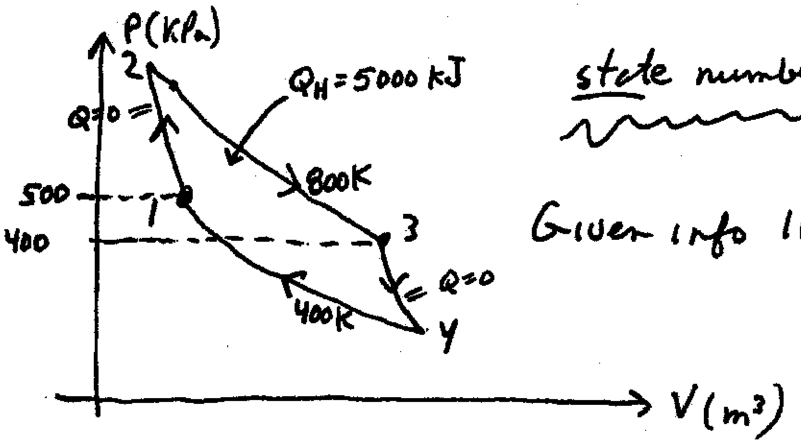
(a) The thermal efficiency of the cycle, η_{TH}, in percent,

(b) The net work provided by the cycle, W_{net}, in kJ,

(c) The pressure at the beginning of the heat addition process, in kPa (abs), and,

(d) The specific work done during the isothermal expansion, (W/m), in kJ/kg.

(2) Carnot cycle
in Air



state numbering as in Moran + Shapiro

Given info located on p-V diagram
(V's unknown)

Solution

(a) $\eta_{TH} = 1 - \frac{T_c}{T_H} = 1 - \frac{400}{800} = 0.5$ $\boxed{(50\%)}$

b) $W_{net} = Q_{in}\,\eta_{TH} = (5000\text{ kJ})(0.5) = \boxed{2500\text{ kJ}}$

c) find p_2: Use adiabatic (+isentropic) process for 1 → 2 ie $pV^k = C$

$$\frac{P_2}{P_1} = \left(\frac{T_2}{T_1}\right)^{\frac{k}{k-1}} \therefore P_2 = P_1\left(\frac{T_2}{T_1}\right)^{\frac{k}{k-1}} = (500)\left(\frac{800}{400}\right)^{\frac{1.4}{0.4}} = \boxed{5657\text{ kPa}}$$

d) Isothermal expansion 2 → 3 (ie T = const)

$pV^n = C$
$\Rightarrow PV = C$

$$\therefore w_{2\to3} = \left(\frac{W}{m}\right)_{2-3} = RT_2 \ln\left(\frac{P_2}{P_1}\right) = (0.287)(800)\ln\left(\frac{5657}{400}\right)$$

$$\therefore w_{2-3} = \boxed{608.3}\text{ kJ/kg}$$

$\Rightarrow PV = mRT$
$p = \frac{mRT}{V}$

x (e) Can't use $pV = mRT$ since V's not given
Can use $q_{2-3} = \frac{Q_{2-3}}{m}$ or $m = Q_{2-3}/q_{2-3}$

of $\underset{0\text{ isothermal}}{\Delta u_{2-3}} = q_{2-3} - w_{2-3}$ $\therefore q_{2-3} = w_{2-3} = 608.3$ kJ/kg

$\therefore m = \frac{5000}{608.3} = \boxed{8.22\text{ kg}}$ of Air