Kafrelsheikh University
Faculty of Engineering
Mech. Eng. Dept.
Year: First
Examiner: Assoc. Prof. Maher

Semester: 2nd Semester
Final Examination
May 20th, 2017
Time allowed: 3 hour
Full Mark: 60 Marks

Thermodynamics I (MEP1203)
Model Answer (نمــوذج الإجابـــــــــــــة)

(a) No. of pages: 11 -No. of questions: 6
(b) This is a close book exam. Only thermodynamics tables are allowed to be with students
(c) Clear, systematic answers and solutions are required. In general, marks will not be assigned for answers and solutions that require unreasonable (in the opinion of the instructor) effort to decipher.
(d) Ask for clarification if any question statement is not clear to you.
(e) Solve all questions.
(f) The exam will be marked out of 60. There are 36 marks bonus.

Question #1 (25 Marks)

Choose the correct answer. Justify your answer with calculations or explanations or both whenever possible. If answer requires justification, marks will not be given to the correct answer without justification.

1. In thermodynamics, a region in space selected for the purpose of study is called a
   (a) system
   (b) closed system
   (c) open system
   (d) control volume

2. A specific property is also:
   (a) an extensive property
   (b) the product of two extensive properties
   (c) an amount of mass dependent property
   (d) an intensive property

3. In order for a system to be in thermal equilibrium, which of the following properties must be the same throughout the system?
   (a) volume
   (b) mass
   (c) pressure
   (d) temperature

4. A cycle consists of a series of processes that:
   (a) are continually repeated
   (b) eventually return to the first state of the first process
   (c) are always in equilibrium or quasi-equilibrium
   (d) none of these

5. How many independent properties are required to completely specify the state of a simple compressible system?
   (a) 0
   (b) 1
   (c) 2
   (d) 3
6. Which temperature below is equivalent to an increase of 180°F?
   (a) 82°C
   (b) 100°C
   (c) 640°R
   (d) 355 K

7. On a day when the barometer reads 755 mmHg, a tire pressure gage reads 180 kPa. The absolute pressure in the tire is (i.e. ρ_{Hg}=13600 kg/m^3):
   (a) 100 kPa
   (b) 204 kPa
   (c) 2.10 mHg
   (d) 2.28 mHg

8. The interaction that occurs between a system and its surroundings as the system executes a process, which is the result of the system being at a temperature different from the surroundings, is:
   (a) Heat transfer
   (b) Mass transfer
   (c) Work transfer
   (d) None of these

9. The air contained in a room loses heat to the surroundings at a rate of 50 kJ/min while work is supplied to the room by computer, TV, and lights at a rate of 1.5 kW. What is the net amount of energy change of the air in the room during a 30-min period?
   (a) 0.36 kJ
   (b) 70 kJ
   (c) 660 kJ
   (d) 1200 kJ

10. At a pressure of 4.25 MPa, the temperature at which liquid water boils is:
    (a) 29.0°C
    (b) 145.8°C
    (c) 143.6°C
    (d) 250.4°C

11. Propane (C_3H_8) is an ideal gas is maintained at 6.50 MPa and 350 K. How much volume does 1 kg of this gas fill?
    (a) 15.7 liters
    (b) 13.1 liters
    (c) 12.3 liters
    (d) 10.2 liters

12. The specific volume of a system consisting of refrigerant-134a at -10 °C MPa is 0.1 m^3/kg. The quality of the R-134a is:

(a) 12.6 %
(b) 47.2 %
(c) 68.3 %
(d) Not applicable

13. A system contains water at 1.55 MPa, 200°C. The phase of this water is:
(a) Compressed liquid
(b) saturated mixture
(c) Superheated vapor
(d) Saturated liquid,
(e) Saturated vapor

14. A 10 m^3 tank contains air at pressure and temperature of 225 kPa, 127°C respectively. The weight for this system is:
(a) 93 N
(b) 127 N
(c) 192 N
(d) 256 N

15. Choose the correct statement according to what you studied throughout the course
(a) The slope of condensation curve is always negative
(b) The slope of condensation curve is always positive
(c) The slope of sublimation curve in negative for all pure substances
(d) The slope of fusion curve is positive for all pure substances

16. Dryness fraction of steam is defined as
(a) mass of water /(mass of water + mass of dry steam)
(b) mass of dry steam/mass of water
(c) mass of dry steam/(mass of dry steam + mass of water)
(d) mass of water /mass of dry steam.

17. Volume of wet steam (per kg) with dryness fraction *x* is given by
(a) $x^3 v_g$
(b) $v_f + x v_{fg}$
(c) $x^2 (v_g - v_f)$
(d) $x^2 v_g$
(e) none of the above.

18. In throttling process
(a) $h_1^2 = h_2$
(b) $h_1 = h_2$
(c) $h_1 = h_2 + h_{fg} / T_s$
(d) $h_2 = h_1 + h_{fg} / T_s$

19. A heat engine has a thermal efficiency of 45%. How much power does the engine produce when heat is transferred into it at a rate of 10^9 kJ/Hr?
(a) 50 MW
(b) 75 MW

(c) 100 MW
(d) 125 MW

20. A refrigerator has a coefficient of performance of 1.6. How much work must be supplied to this refrigerator for it to reject 1000 kJ of heat?
(a) 385 kJ
(b) 627 kJ
(c) 836 kJ
(d) 1000 kJ

21. **26.** The thermodynamic efficiency of a heat engine that rejects heat at a rate of 20 MW when heat is supplied to it at a rate of 60 MW is:
(a) 33.3%
(b) 50%
(c) 66.7%
(d) 75%

22. A Carnot engine operates using a 527°C energy reservoir and a 27°C energy reservoir. The thermodynamic efficiency of this engine is:
(a) 50%
(b) 62.5%
(c) 73.6%
(d) 103%

23. A Carnot heat pump uses thermal reservoirs at -27°C and 57°C. How much power does this pump consume to produce a 100 kW heating effect?
(a) 9.1 kW
(b) 12.7 kW
(c) 15.3 kW
(d) 25.5 kW

24. An inventor claims to have created a heat engine which produces 10 kW of power for a 15 kW heat input while operating between energy reservoirs at 27°C and 427°C. Is this claim valid?
(a) Yes
(b) No

25. A manufacturer claims that its refrigerator has a COP of 1.4 when cooling food at 7°C using ambient air at 23°C as a heat sink. Is this claim valid?
(a) Yes
(b) No

26. According to Clausius, heat will transfer naturally from cold bodies to hot bodies
(a) Yes
(b) No

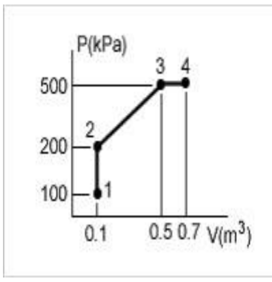
27. Air (c_p = 1.005 kJ/kg-k) is heated from 27°C to 327°C. How much does the specific internal energy of the air change as a result of this heating?
(a) 301.5 kJ/kg decrease
(b) 301.5 kJ/kg increase
(c) 215.4 kJ/kg decrease

(d) 215.4 kJ/kg increase

28. Air is expanded from 1 MPa, 327°C to 200 kPa in a closed piston-cylinder device executing a $PV^{1.2}$ = constant process. The work produced during this process is:

(a) 202.6 kJ/kg
(b) 263.4 kJ/kg
(c) 361.7 kJ/kg
(d) 422.8 kJ/kg

29. A closed system undergoes the series of quasi-equilibrium processes shown here.



(a) 40 kJ
(a) 140 kJ
(b) 240 kJ
(c) 340 kJ

30. A vertical circular cylinder holds a height of 1 cm of liquid water and 100 cm of vapor. If *P* = 200 kPa, the quality is nearest **(1.5 Marks)**

(a) 0.01
(b) 0.1
(c) 0.4
(d) 0.8

From saturated steam tables at 200 kPa

$v_f = 0.0.001061$ m³/kg

$v_g = 0.88578$ m³/kg

$$x = \frac{m_g}{m_g + m_f} = \frac{V_g / v_g}{V_g / v_g + V_f / v_f} = \frac{h_g A / v_g}{h_g A / v_g + h_f A / v_f} = \frac{h_g / v_g}{h_g / v_g + h_f / v_f}$$

$$x = \frac{1.00/0.88578}{1.00/0.88578 + 0.01/0.001061} = 0.107$$

Question #2 (18 Marks)

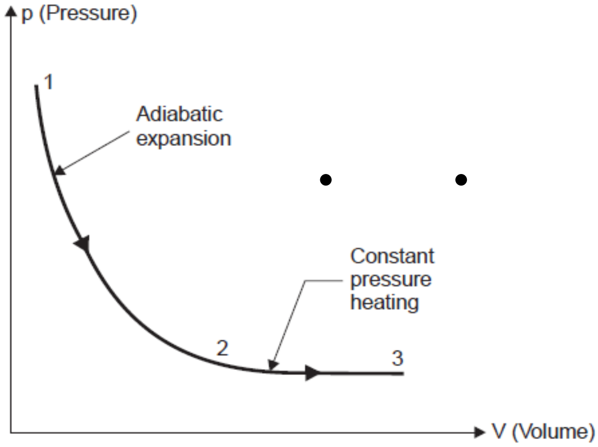
1) Prove that for an ideal gas, the work for a polytropic process ($pv^n = c$) is represented by: **(4 Marks)**

$$W = \frac{R(T_1 - T_2)}{n-1}$$

a. A 0.2 m³ of air (i.e. ideal gas with *R*=0.287 kJ/kg.K) at 0.4 MPa and 130°C is contained in a system. A reversible **adiabatic** expansion that follow the relation $pv^{1.4} = c$ takes place till the pressure falls to 0.1 MPa. The gas is then heated at constant pressure till temperature rises by 72 °C. Calculate:

2) Mass of air in the system **(3 Marks)**
3) The work done in processes 1-2 and 2-3. **(6 Marks)**
4) The index of expansion, *n* ($pv^n = c$) if the above processes are replaced by a single polytropic process giving the same work between the same initial and final states. **(5 Marks)**

Solution


p (Pressure)
1
Adiabatic
expansion
Constant
pressure
heating
2
3
V (Volume)

Question #3 (10 Marks)

A fluid system, contained in a piston and cylinder machine, passes through a complete cycle of four processes. The sum of all heat transferred during a cycle is – 340 kJ. The system completes 200 cycles per min. Complete the following table showing the method for each item, and computes the net rate of work output in kW. **(10 Marks)**

Process	Q (kJ/min)	W (kJ/min)	ΔE (kJ/min)
1—2	0	4340	_______
2—3	42000	0	_______
3—4	-4200	_______	– 73200
4—1	_______	_______	_______
Cycle	_______	_______	_______

Solution. Sum of all heat transferred during the cycle = – 340 kJ.

Number of cycles completed by the system = 200 cycles/min.

Process 1—2 :

$$Q = \Delta E + W$$
$$0 = \Delta E + 4340$$
$$\therefore \quad \Delta E = -4340 \text{ kJ/min.}$$

Process 2—3 :

$$Q = \Delta E + W$$
$$42000 = \Delta E + 0$$
$$\Delta E = 42000 \text{ kJ/min.}$$

Process 3—4 :

$$Q = \Delta E + W$$
$$-4200 = -73200 + W$$
$$\therefore \quad W = 69000 \text{ kJ/min.}$$

Process 4—1 :

$$\sum_{\text{cycle}} Q = -340 \text{ kJ}$$

The system completes 200 cycles/min

$$\because \quad Q_{1-2} = Q_{2-3} + Q_{3-4} + Q_{4-1} = -340 \times 200 = -68000 \text{ kJ/min}$$
$$0 + 42000 + (-4200) + Q_{4-1} = -68000$$
$$Q_{4-1} = -105800 \text{ kJ/min.}$$

Now, $\int dE = 0$, since cyclic integral of any property is zero.

$$\Delta E_{1-2} + \Delta E_{2-3} + \Delta E_{3-4} + \Delta E_{4-1} = 0$$
$$-4340 + 42000 + (-73200) + \Delta E_{4-1} = 0$$
$$\therefore \quad \Delta E_{4-1} = 35540 \text{ kJ/min.}$$
$$\therefore \quad W_{4-1} = Q_{4-1} - \Delta E_{4-1}$$
$$= -105800 - 35540 = -141340 \text{ kJ/min}$$

The completed table is given below :

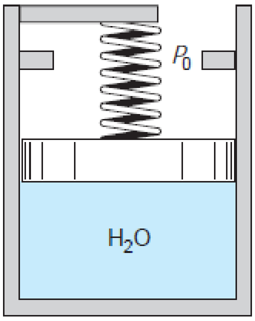
Process	*Q(kJ/min)*	*W(kJ/min)*	ΔE*(kJ/min)*
1—2	0	4340	– 4340
2—3	42000	0	42000
3—4	– 4200	69000	– 73200
4—1	– 105800	– 141340	35540

Since $\sum_{\text{cycle}} Q = \sum_{\text{cycle}} W$

Rate of work output = – 68000 kJ/min $= -\dfrac{68000}{60}$ kJ/s or kW

= 1133.33 kW. (Ans.)

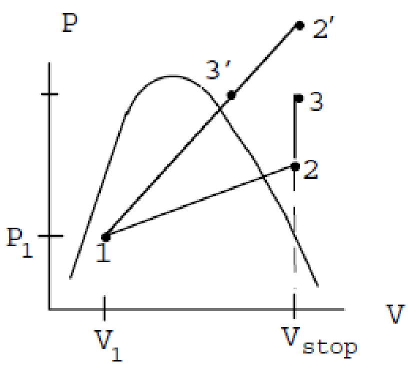
Question #4 (13 Marks)



Two kilograms of water is contained in a piston/cylinder (shown in the Fig.) with a massless piston loaded with a linear spring and outside atmosphere. Initially the spring force is zero and P_1=P_0= 100 kPa with a volume of 0.2 m³. If the piston just hits the upper stops, the volume is 0.8 m³ and T = 600°C. Heat is now added until the pressure reaches 1.2 MPa.

1. Find the final temperature. **(4 Marks)**
2. Show the P-V diagram **(3 Marks)**
3. Find the work done and heat added during this/these process **(6 Marks)**

Solution



State 1: $v_1 = V/m = 0.2 / 2 = 0.1 \text{ m}^3/\text{kg}$

Process: $1 \rightarrow 2 \rightarrow 3$ or $1 \rightarrow 3'$

State at stops: 2 or 2'

$v_2 = V_{stop}/m = 0.4 \text{ m}^3/\text{kg}$ & $T_2 = 600°C$

Table B.1.3 $\Rightarrow$ $P_{stop} = 1 \text{ MPa} < P_3$

since $P_{stop} < P_3$ the process is as $1 \rightarrow 2 \rightarrow 3$

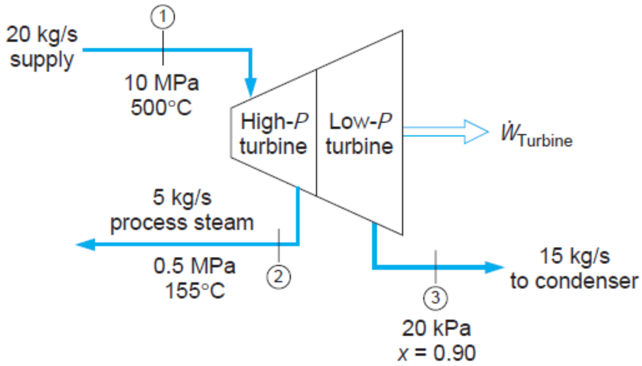
State 3: $P_3 = 1.2$ MPa, $v_3 = v_2 = 0.4 \text{ m}^3/\text{kg}$ $\Rightarrow$ $T_3 \cong$ **770°C**

$$W_{13} = W_{12} + W_{23} = \frac{1}{2}(P_1 + P_2)(V_2 - V_1) + 0 = \frac{1}{2}(100 + 1000)(0.8 - 0.2)$$

$= \mathbf{330 \text{ kJ}}$

Question #5 (10 Marks)

Cogeneration is often used where a steam supply is needed for industrial process energy. Assume that a supply of 5 kg/s steam at 0.5 MPa is needed. Rather than generating this from a pump and boiler, the setup in the figure shown is used to extract the supply from the high-pressure turbine. Find the power the turbine now cogenerates in this process.



Solution

C.V. Turbine, steady state, 1 inlet and 2 exit flows, assume adiabatic, $\dot{Q}_{CV} = 0$

Continuity Eq.6.9: $\dot{m}_1 = \dot{m}_2 + \dot{m}_3$

Energy Eq.6.10: $\dot{Q}_{CV} + \dot{m}_1 h_1 = \dot{m}_2 h_2 + \dot{m}_3 h_3 + \dot{W}_T$;

Supply state 1: 20 kg/s at 10 MPa, 500°C

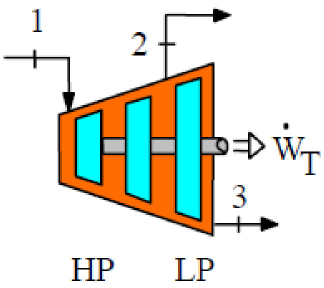
Process steam 2: 5 kg/s, 0.5 MPa, 155°C,

Exit state 3: 20 kPa, $x = 0.9$

Table B.1.3: $h_1 = 3373.7$, $h_2 = 2755.9$ kJ/kg,

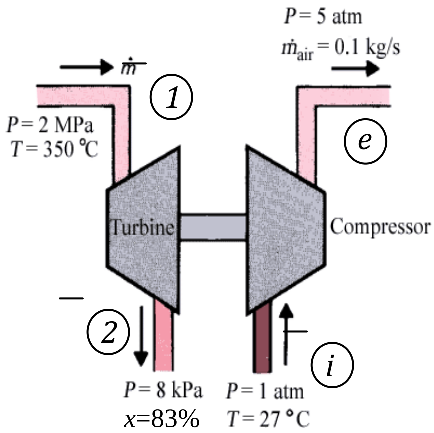
Table B.1.2: $h_3 = 251.4 + 0.9 \times 2358.3$

$= 2373.9$ kJ/kg



$$\dot{W}_T = 20 \times 3373.7 - 5 \times 2755.9 - 15 \times 2373.9 = \mathbf{18.084\ MW}$$

Question #5 (10 Marks)



A small steam turbine drives an air compressor as shown in the figure. What mass flow rate of steam, in kilograms per hour, must be supplied to the turbine?

Solution

- For compressor

$$\dot{W}_c = \dot{m}_a(h_e - h_i) = \dot{m}_a c_p (T_e - T_i)$$
$$= 0.1 \times 1.005 \times (202\text{-}27)$$
$$= 17.59 \text{ kW}$$

- For air turbine

From saturated steam tables at 2 MPa (Table A-5),

$$T_s = 212\ 4\ ^{\circ}\text{C}$$

Since $T_1 > T_s$, then state 1 is superheated

From superheated steam (Table A-6) tables at 2 MPa, 350 ºC

$$h_1 = 3137 \text{ kJ/kg}$$

From saturated steam tables at 8 kPa (Table A-5),

$$h_f = 173.9 \text{ kJ/kg}$$
$$h_g = 2577 \text{ kJ/kg}$$

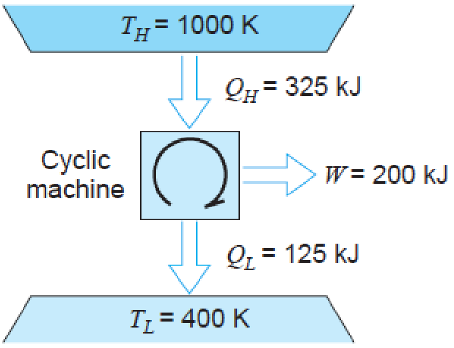
$$h_2 = h_f + x_2(h_g\text{-}h_f) = 173.9 + 0.83 \times (2577 - 173.8) = 2168.5 \text{ kJ/kg}$$

Since steam turbine is only for drive the air compressor

$$\dot{W}_T = \dot{W}_c$$
$$= \dot{m}_s(h_2 - h_1)$$
$$17.59 \text{ kW} = \dot{m}_s \times (3137 - 2168.5)$$
$$\dot{m}_s = 0.018 \text{ kg/s}$$

Question #6 (10 Marks)

A cyclic machine, shown in the figure, receives 325 kJ from a 1000 K energy reservoir. It rejects 125 kJ to a 400 K energy reservoir, and the cycle produces 200 kJ of work as output. Is this cycle reversible, irreversible, or impossible?



Solution

$$\eta_{\text{Carnot}} = 1 - \frac{T_L}{T_H} = 1 - \frac{400}{1000} = 0.6$$

$$\eta_{\text{Engine}} = \frac{W}{Q_H} = \frac{200}{325} = 0.615$$

Since $\eta_{\text{Engine}} > \eta_{\text{Carnot}}$, the engine is **impossible**