ME-203

THERMODYNAMICS

PEQ

QUİZ

EXERCİSES

HOMEWORKS

PART-1 Sayfa 1-74
PART-2 Sayfa 75-183

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METU Department of Mechanical Engineering

ME 203 Thermodynamics 1

Fall 2021 Midterm Examination 1 SOLUTION

December 4, 2021, Saturday

150 minutes, open thermodynamic tables only

I confirm that I will not give or receive unauthorized help during the exam.

Sign: ______________________

Read the following first.

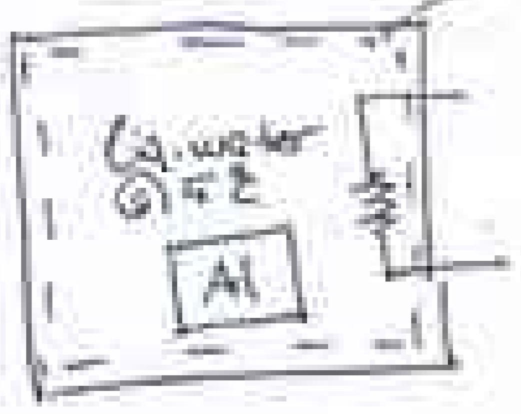
1. You are not allowed to ask any questions.
2. Read each problem carefully before solving it. The problems are not equally weighted.
3. Solve each problem on its own sheet(s). Ask for an extra sheet if necessary.
4. Follow the methodology we follow in class. You will lose significant points if this is not done properly.
   a. For all problems, indicate the system on a sketch, and show all information on the sketch.
   b. List all your relevant assumptions and write the necessary equations in symbolic form first.
   c. Show all your calculations and references (for example, Table A.1) clearly, and use units.
5. If you think your answer is wrong, but you do not have time to correct it, comment. Provide a short explanation on why you think it is wrong.
6. Use enough number of significant figures in intermediate steps and do proper interpolations when required (you don't have to show the interpolation calculations). The results should be rounded off to 2-3 significant figures.

GOOD LUCK

Problem 1 (33 points) An insulated rigid tank is filled with 20 kg of liquid water at 5 °C. A 5 kg aluminium block at 30 °C is dropped into the tank which is fitted with an electrical resistor supplying energy to the water for a period of time. After thermal equilibrium is attained, the pressure inside the tank is measured as 5 MPa. Neglecting the volume of the aluminium block, determine the energy transfer from the electrical resistor during the process.

Do not use the incompressible substance model for water.

closed system



- Use saturation tables to find liquid water internal energy and specific volume
- Neglect ΔKE and ΔPE for the system

Energy Balance for closed system:

$$\Delta E = Q - W$$

$$\underbrace{\Delta KE}_{0} + \underbrace{\Delta PE}_{0} + \Delta U = \underbrace{\cancel{Q}}_{0,\text{ insulated}} - W_{elec} \Rightarrow \Delta U_{water} + \Delta U_{Al} = -W_{elec}$$

$$\Rightarrow m_{water}(u_2 - u_1)_{water} + m_{Al} c_{Al} (T_2 - T_1)_{Al} = -W_{elec}$$

State 1 for water

liquid water, 5 °C

$v_1 = v_{f@5°C} = 1.0001 \times 10^{-3}\ m^3/kg$

$u_1 = u_{f@5°C} = 20.97\ kJ/kg$

State 2 for water

$v_2 = v_1 = 1.0001 \times 10^{-3}\ m^3/kg$

$P_2 = 5\ MPa$

→ compressed liquid table (A.5)

$\Rightarrow T_2 = 22\ °C$

$\Rightarrow u_2 = 91.81\ kJ/kg$

$c_{Al} = 0.903\ kJ/kgK$ (from Table A-19)

Energy Balance:

$$(20\ kg)(91.81 - 20.97)\frac{kJ}{kg} + (5\ kg)\left(0.903\ \frac{kJ}{kg}\right)(22 - 30) = -W_{elec}$$

$$\Rightarrow \boxed{W_{elec} = -1380.7\ kJ}$$

Problem 2 (33 points) The figure shows a piston/cylinder setup having two sets of stops and a linear spring. The volumes at the lower and upper stops are 1 and 3 m³, respectively. Initially the cylinder contains 1 kg of water at 1 bar. The lift pressure for the frictionless piston is 1.5 bar. At a volume of 2 m³, the piston starts to compress the spring. The spring constant and the piston area are 100 kN/m and 1 m². Heat is slowly transferred to the water until a total work of 250 kJ is done by the water. Calculate the heat transfer to the water during this process. You may need the following tables in addition to your copy of thermo tables.

Superheated Vapor Properties for Water

Temp °C	P=0.010 MPa (45.8°C) volume m³/kg	energy kJ/kg	enthalpy kJ/kg	entropy kJ/kg K	P=0.050 MPa (81.3°C) volume m³/kg	energy kJ/kg	enthalpy kJ/kg	entropy kJ/kg K	P=0.10 MPa (99.6°C) volume m³/kg	energy kJ/kg	enthalpy kJ/kg	entropy kJ/kg K
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Temp °C	P=0.20 MPa (120.2°C) volume m³/kg	energy kJ/kg	enthalpy kJ/kg	entropy kJ/kg K	P=0.30 MPa (133.5°C) volume m³/kg	energy kJ/kg	enthalpy kJ/kg	entropy kJ/kg K	P=0.40 MPa (143.6°C) volume m³/kg	energy kJ/kg	enthalpy kJ/kg	entropy kJ/kg K
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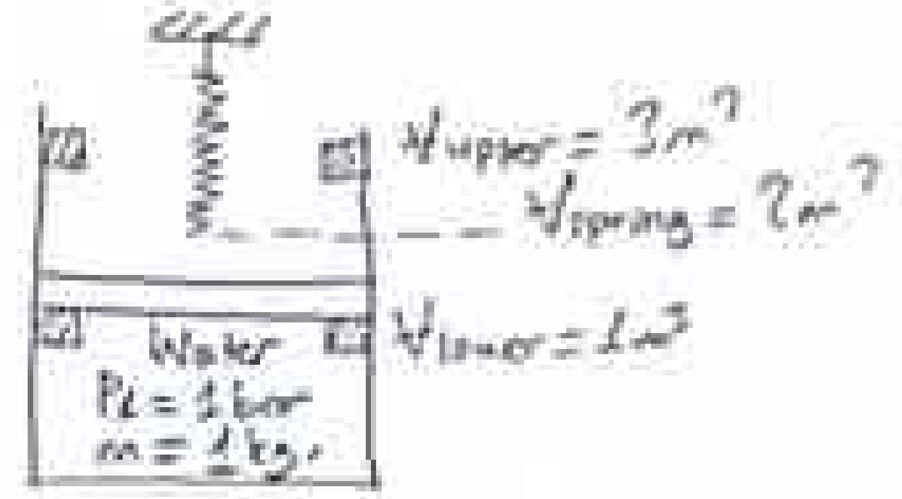
This page is for Problem 2 Solution only

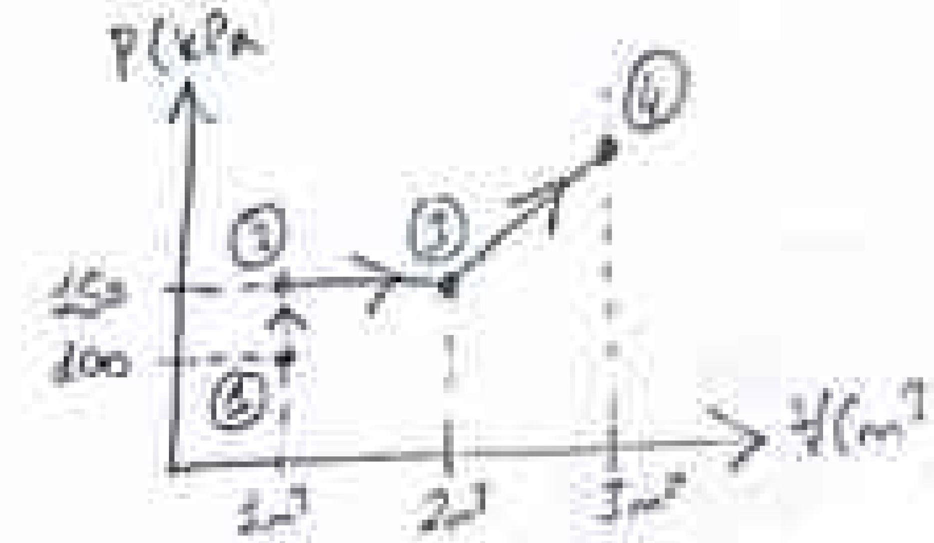


$k_s = 100$ kN/m

$A_p = 1\ m^2$

$W_{total} = 250$ kJ

$P_{lift} = 1.5$ bar



$$\frac{k_s}{A_p^2} = \frac{100}{1^2} = \frac{P_4 - P_3}{V_4 - V_3} = \frac{P_4 - 150}{3-2}$$

$P_4 = 250$ kPa

$W_{1,4} = W_{2,3} + W_{3,4}$
$= (150)(2-1) + \frac{1}{2}(150+250)(3-2)$
$= 150 + 200 = 350$ kJ

$W_{1,4} > W_{total} = 250$ kJ $\rightarrow$ final state is reached before state 4.

Final state is between states 3 and 4 and say the final state is 5.

$$\frac{k_s}{A_p^2} = \frac{100}{1^2} = \frac{P_5 - P_3}{V_5 - V_3} \rightarrow 100 = \frac{P_5 - 150}{V_5 - 2} \rightarrow P_5 = 150 + 100V_5 - 200$$

$\rightarrow P_5 = 100V_5 - 50$ --- (1)

$W_{1,5} = 250\text{ kJ} = W_{2,3} + W_{3,5} = 150 + \frac{1}{2}(P_3 + P_5)(V_5 - V_3)$

$\Rightarrow 100 = \frac{1}{2}(150 + P_5)(V_5 - 2) = \frac{1}{2}(150 + 100V_5 - 50)(V_5 - 2)$

$\Rightarrow 100 = (50V_5 + 50)(V_5 - 2) \rightarrow 50V_5^2 - 50V_5 - 100 = 100$

$V_5^2 - V_5 - 4 = 0$ --- (2)

Solution of equation (2) gives: $V_5 = 2.562\ m^3$

Then from (1): $P_5 = 206.2$ kPa

1st law: $Q_{1,5} - W_{1,5} = m(u_5 - u_1)$

This page is for Problem 2 Solution only

state 1
Water
$P_1 = 1\ bar$
$v_1 = \frac{V_1}{m} = 1\ m^3/kg$

T. A-3: $v_f = 0.0010432$
$v_g = 1.694$
$v_f < v_1 < v_g \rightarrow$ Saturated Mixture of Liquid and Vapor

$x_1 = \frac{v_1 - v_f}{v_g - v_f} = 0.59$

$u_1 = u_f + x_1 (u_g - u_f)$

$u_f = 417.36$ and $u_g = 2506.1$

$u_1 = 1649.72\ kJ/kg$

state 5
Water
$P_5 = 206.2\ kPa$
$v_5 = \frac{V_5}{m} = 2.562\ m^3/kg$

approximating $P_5 \sim 2\ bar$:
$v_g = 0.8857\ m^3/kg$
$v_5 > v_g \rightarrow$ superheated vapor

From the table suppied in the question: $P_5 \sim 0.2\ MPa$
$u_5 \sim 3736.4\ kJ/kg$

$\Rightarrow Q_{15} - .250 = (1)(3736.4 - 1649.72)$

$Q_{15} = 2336.68\ kJ$

of three processes in series.

Process 1-2: Adiabatic expansion from $p_1 = 700$ kPa and $T_1 = 207°C$ to $v_2 = 3\ v_1$

Process 2-3: Isothermal compression to the initial volume

Process 3-1: Constant volume heating, where 42.4 kJ of heat is transferred to air

system boundary

Assume air is an ideal gas and use Table A-22 for air.

List all your assumptions first.

a) Fill the missing values in the table below, showing all your calculations.

b) Sketch the cycle on a p-v diagram, showing all necessary features.

c) If you were to confirm the validity of the *ideal gas model (IGM)* for air by checking only one of the three states, which one would you choose and why? Check the validity of the *IGM* for the state you chose.

d) Is this a power cycle or refrigeration/heat pump cycle? Explain your reasoning. Then, calculate the performance measure (thermal efficiency or coefficient of performance) of this cycle, if possible.

State	p (kPa)	T (K)	u (kJ/kg)
1	700	480	344.70
2	139	285	203.37
3	416	285	203.37

Process	W (kJ)	Q (kJ)
1-2	42.4	0
2-3	-27.0	-27.0
3-1	0	42.4
Cycle, Net	15.4	15.4

System: Air, CM, assume ideal gas with variable specific heats
No KE/PE effects.

a) ① $T_1 \xrightarrow{A\text{-}22} \underline{u_1 = 344.70\ kJ/kg}$

use process 3→1: $Q_{31} - \underbrace{\cancel{W_{31}}}_{\text{isochoric, no work}} = m(u_1 - u_3) \rightarrow u_3 = u_1 - \frac{\overset{42.4\ kJ}{Q_{31}}}{\underset{0.5\ kg}{m}} = \underline{203.37\ kJ/kg}$ ↙A-22

$T_3 = \underline{285\ K}$

use process 2-3: isothermal, so $\underline{T_2 = T_3}$; $\underline{u_2 = u_3}$

find p_2: $\frac{p_1 V_1}{p_2 V_2} = \frac{\cancel{R} T_1}{\cancel{R} T_2} \rightarrow p_2 = p_1 \frac{V_1}{V_2} \cdot \frac{T_2}{T_1} = (700\ kPa)\left(\frac{1}{3}\right)\left(\frac{285}{480}\right) = \underline{139\ kPa}$

find p_3: $\frac{p_2 V_2}{p_3 V_3} = \frac{\cancel{R} T_2}{\cancel{R} T_3} \rightarrow p_3 = p_2 \frac{V_2}{V_3} = p_2 \underbrace{\frac{V_2}{V_1}}_{\text{isochoric}} = (139\ kPa)(3) = \underline{416\ kPa}$

energy balance for 1→2: $\underbrace{\cancel{Q_{12}}}_{\text{adiabatic, no HT}} - W_{12} = m(u_2 - u_1) \rightarrow W_{12} = m(u_1 - u_2) = \underline{42.4\ kJ}$

energy balance for 2→3: $Q_{23} - W_{23} = m\underbrace{(\cancel{u_3 - u_2})}_{=0,\ u_3 = u_2} \rightarrow Q_{23} = W_{23}$

isothermal compression is a polytropic process; with an ideal gas $T = const$ becomes $mRT = pV = const$.

$\rightarrow W_{23} = \int_2^3 p\,dV = p_2 V_2 \ln \frac{V_3}{V_2} = mRT \ln \frac{V_3}{V_2}$

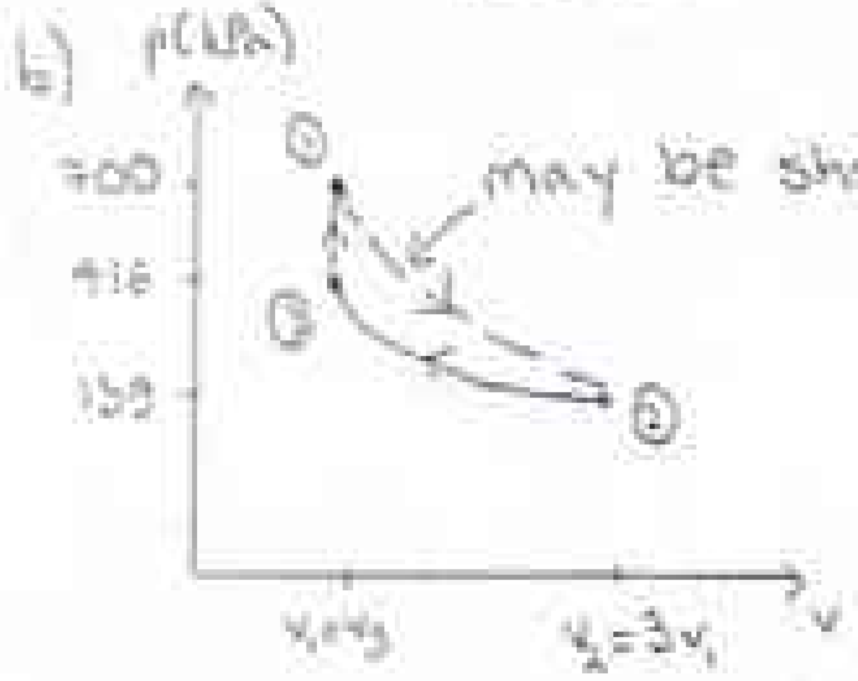
$= (0.5\ kg)(0.287 \frac{kJ}{kg K})(285\ K) \ln\left(\frac{1}{3}\right) = \underline{-27\ kJ = Q_{23}}$

This page is for Problem 3 Solution only.

check: $W_{cycle,net} = 42.4\ kJ - 27\ kJ = \underline{15.4\ kJ}$

$Q_{cycle,net} = -27\ kJ + 42.4\ kJ = \underline{15.4\ kJ}$

b)



may be shown solid or dashed

not known if quasi-eqlb.

c) Check IGM validity with State ① since other state properties are found by using IGM.

$p_{R1} = \frac{P_1}{P_c} = \frac{700\ kPa}{3770\ kPa} = 0.186$

Table A-1

$T_{R1} = \frac{T_1}{T_c} = \frac{480\ K}{133\ K} = 3.61$

Table A-1

Check Figure A-1, $Z \approx 1.0$

d) Power cycle since $W_{cycle,net} > 0$.

$\eta_{th} = \frac{W_{cycle,net}}{Q_{in}} = \frac{W_{cycle,net}}{Q_{21}} = \frac{15.4\ kJ}{42.4\ kJ} = 0.363$

$\underline{\eta_{th} = 36.3\ \%}$

$kJ := 1000J$ $\qquad$ $kmol := 1000mol$

MT2 Q1

1. 0.1 kg of ethanol (C_2H_5OH) in a piston-cylinder system is initially at 5.4 MPa and 270 °C undergoes a polytropic compression process to 12.75 MPa and 320 °C. Assuming real gas behavior, find the boundary work (kJ).

Given $\quad m_{eth} := 0.1kg \quad p_1 := 5.4MPa \quad T_1 := (270 + 273)K = 543\ K$

$p_2 := 12.75MPa \quad T_2 := (320 + 273)K = 593\ K$

Soln: We only need to find boundary work. Since the process is polytropic, p 1 V1^n = p 2 V2^n and we can model the boundary work as δWb = p dV.

$$W_b = \int_1^2 p dV \ \ \& \ \ p_1V_1^n = p_2V_2^n = \psi = \text{constant} \ \ \rightarrow p = \psi V^{-n} \ \ \rightarrow W_b = \psi \int_1^2 V^{-n} dV$$

To integrate we need to know if n = 1 or not. We note p1/p2 = (V2/V1)^n --> n = ln(p1/p2) / ln(V2/V1). To find n we need to find V1 and V2 using PMg.

TA.1: $\quad M_{eth} := 46\frac{kg}{kmol} \quad T_c := 516K \quad p_c := 63.8bar$

$\rightarrow \quad p_{r1} := \frac{p_1}{p_c} = 0.846 \quad T_{r1} := \frac{T_1}{T_c} = 1.052 \quad$ --> FA1 --> $\quad Z_1 := 0.7$

$p_{r2} := \frac{p_2}{p_c} = 1.998 \quad T_{r2} := \frac{T_2}{T_c} = 1.149 \quad$ --> FA2 --> $\quad Z_2 := 0.5$

From the cover of the Tables $\quad R_{bar} := 8.314\frac{kJ}{kmol \cdot K} \quad R_{eth} := \frac{R_{bar}}{M_{eth}} = 0.181\frac{kJ}{kg \cdot K}$

--> $\quad V_1 := Z_1\frac{m_{eth} \cdot R_{eth} \cdot T_1}{p_1} = 1.272 \times 10^{-3}\ m^3 \qquad V_2 := Z_2\frac{m_{eth} \cdot R_{eth} \cdot T_2}{p_2} = 4.203 \times 10^{-4}\ m^3$

$$n := \frac{\ln\left(\frac{p_1}{p_2}\right)}{\ln\left(\frac{V_2}{V_1}\right)} = 0.776$$

Since n not equal to 1 $\quad \rightarrow W_b = \psi \int_1^2 V^{-n} dV = \frac{(p_2V_2^n)V_2^{1-n} - (p_1V_1^n)V_1^{1-n}}{1-n} = \frac{p_1V_1 - p_2V_2}{n-1}$

$W_b := \frac{p_1 \cdot V_1 - p_2 \cdot V_2}{n-1} = -6.737\ kJ$ $\quad$ where Wb < 0 is consistent with a compression process.

MT2 Q2

ME 202 Fall 2018

kJ := 1000

1. As shown in the figure, a system executes an internally reversible refrigeration cycle with known information as follows:

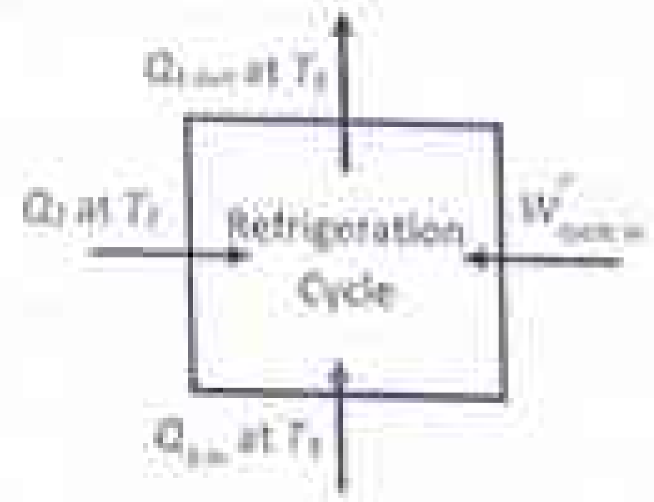
   $Q_{1,out}$ = 650 kJ at T_1 = 52 °C

   Q_2 = ? at T_2 = 12 °C where Q_2 may be <, =, > 0

   $Q_{3,in}$ = 825 kJ at T_3 = 2 °C

   $W_{cycle,in}$ = ?

What is the refrigeration cycle's Coefficient of Performance (COP), β?



Knowns: $Q_{1\,out} := 650kJ$ $\quad$ $T_1 := (52+273)K = 325\,K$ $\quad$ $T_2 := (12+273)K = 285\,K$

$Q_{3\,in} := 825kJ$ $\quad$ $T_3 := (2+273)K = 275\,K$

Solution: Since the cycle is internally reversible, σ = 0. We'll assume Q 2 is in. An SB for a cycle with σ = 0 is

SBcycle: 0 = Q 3 in/T3 + Q2 in/T2 - Q 1 out/T1

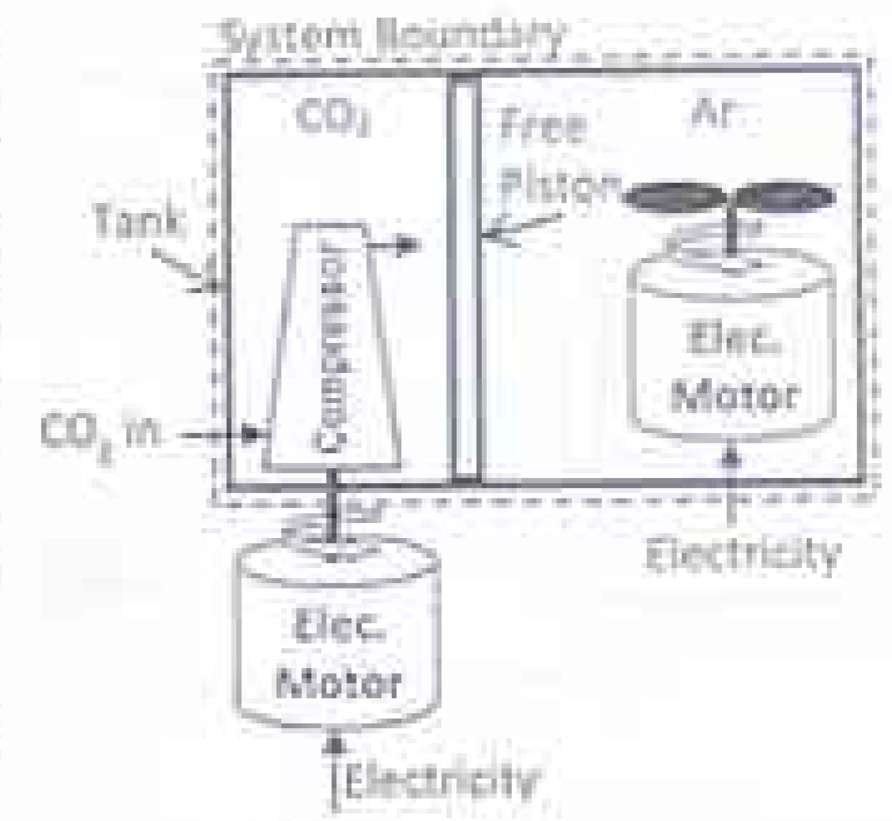
$$Q_2 := T_2\left(\frac{Q_{1\,out}}{T_1} - \frac{Q_{3\,in}}{T_3}\right) = -285\,kJ \qquad Q_{2\,out} := -Q_2 = 285\,kJ$$

EBcycle: 0 = (Q3 in + Wcycle in) - (Q1 out + Q2 out)

$$W_{cycle\,in} := Q_{1\,out} + Q_{2\,out} - Q_{3\,in} = 110\,kJ$$

Coefficient of Performance, β $\qquad$ $\beta := \dfrac{Q_{3\,in}}{W_{cycle\,in}} = 7.5$

1. The control volume defined by the system boundary in the figure undergoes a uniform-flow transient filling (charging) process. In this system, a free-floating piston separates carbon dioxide (CO_2) and argon (Ar) in a rigid and uninsulated tank. The compressor consumes 50 kJ to fill the system with CO_2. 200 kJ of shaft work is done to rotate the paddles to stir the argon. No argon crosses the system boundary. All processes occur slowly and effects of kinetic and potential energies can be neglected.



The solid parts of the system are special high-temperature materials that can be modeled as steel. The entire system can be modeled as consisting of the following three substances:

1. **Carbon Dioxide**: Model as an ideal gas using the most accurate ideal gas property model;
2. **Argon**: Model as an ideal gas using an appropriate ideal gas property model;
3. **Steel**: Model the tank walls, piston, compressor, stirring paddle, electric motor, shafts, etc. (i.e. everything except the CO_2 and Ar) as pure steel using an appropriate property model.

Known state information are as follows:

	Initial State			Final State			Inlet State	
	m (kg)	T (°C)	p (bar)	m (kg)	T (°C)	p (bar)	T (°C)	p (bar)
CO_2	0.2	7	1	0.3	507	?	7	1
Argon	0.4	7			507	?	-	-
Steel	0.5	7	-		507	-	-	-

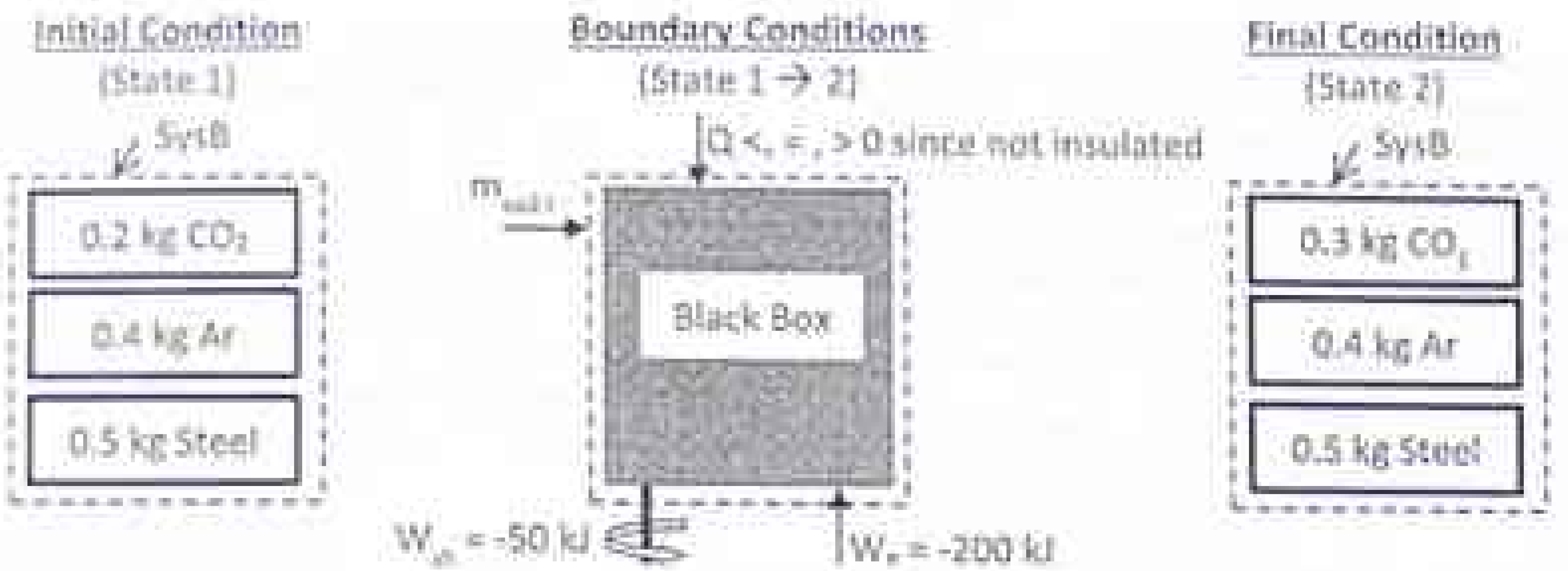
For the system boundary shown, find the following:

$p_{CO2,2}$ (kPa)	$p_{Ar,2}$ (kPa)	Q (kJ)	W_c (kJ)	W_{sh} (kJ)	W_e (kJ)

Sol'n: The simplest way to solve this problem is to pucker your lips and KISS (Keep It Simple Stupid) the problem by applying the Black Box Model (BBM) we discussed in class as follows.

1. Model the Initial Condition (IC) of the system, i.e. characterize the initial state (state 1) of the system inside the system boundary.
2. Put the system inside a Black Box, close the lid so you can't see what's happening inside the Black Box, and allow the system to evolve from the Initial Conditions to the Final Conditions. Characterize the boundary conditions during this process; specifically identify energy crossing the system boundary. Importantly here don't look at everything happening inside the system boundary, as this will just confuse things.
3. Open the Black Box and characterize the Final Condition of the system.

Visually, we have



After KISSing the Problem, the problem becomes more manageable. Pushing forward....

Given: $T_1 := (7 + 273)K = 280\,K$ $\quad T_2 := (507 + 273)K = 780\,K$

$m_{co2.1} := 0.2kg$ $\quad p_{co2.1} := 1bar$ $\quad m_{co2.2} := 0.3kg$ $\quad m_{ar} := 0.4kg$ $\quad m_s := 0.5kg$

$W_{sh} := -50kJ$ $\quad W_e := -200kJ$

Since the tank is rigid, the total volume is constant, and V.co2.1 + V.ar.1 = V.co2.2 + V.ar.2 = Vt.
Since at the the piston is free, p.co2.1 = p.ar.1 = p.1 and p.co2.2 = p.ar.2 = p.2. $\quad p_{ar.1} := p_{co2.1}$
Since we model both the CO2 and the Ar as an IG, p V = m R T.

From the cover page of the Tables, $\quad R_{bar} := 8.314\dfrac{kJ}{kmol\cdot K}$

From TA.1 $\quad M_{co2} := 44.01\dfrac{kg}{kmol}$ $\quad R_{co2} := \dfrac{R_{bar}}{M_{co2}} = 0.189\dfrac{kJ}{kg\cdot K}$

$M_{ar} := 39.94\dfrac{kg}{kmol}$ $\quad R_{ar} := \dfrac{R_{bar}}{M_{ar}} = 0.208\dfrac{kJ}{kg\cdot K}$

Therefore $\quad V_{co2.1} := \dfrac{m_{co2.1}\cdot R_{co2}\cdot T_1}{p_{co2.1}} = 0.106\,m^3$ $\quad V_{ar.1} := \dfrac{m_{ar}\cdot R_{ar}\cdot T_1}{p_{ar.1}} = 0.233\,m^3$ $\quad V_t := V_{co2.1} + V_{ar.1} = 0.339\,m^3$

So Vt = (m.co2 R.co2 T2)/p.2 + (m.ar R.ar T2)/p.2 $\quad p_2 := \dfrac{(m_{co2.2}\cdot R_{co2}\cdot T_2 + m_{ar}\cdot R_{ar}\cdot T_2)}{V_t} = 322.647\,kPa$

For the system boundary shown, there is no boundary work since the tank is rigid. There is electrical work since electricity crosses the sytem boundary to power the motor to turn the stirring paddles. There is shaft work since a rotating shaft crosses the system boundary to power the compressor. There may be heat transfer since the tank is not insulated. Therefore,

Wb = 0 $\quad$ —> Wt = Wsh + We
EB for a cv with NKP and mi > 0 and me = 0 $\quad$ —> ΔU.t = (Q + mi hi) - Wt
ΔU.t = ΔU.s + ΔU.co2 + ΔU.ar

We can find ΔU.t using appropriate PMs, we know the Wt, so we solve for the Q as

—> Q = ΔU.t + Wt - mi hi

We use PMics for the steel so ΔU.s = m.s c.s (T2 - T1) and we note c.s = c.p.s = c.v.s for PMics

TA.19 $\quad c_s := 0.480\dfrac{kJ}{kg\cdot K}$ $\quad \Delta U_s := m_s\cdot c_s\cdot(T_2 - T_1) = 120\,kJ$

CO2 is not a "simple" molecule since it contains 3 atoms and the change is temperature is relatively "large" (7 to 507 oC).

Therefore the most accurate PMig for CO2 is with variable specific heat, so ΔU_co2 = (m.co2.2 u.co2.2 - m.co2.1 u.co2.1)/M where u_co2 is molar specific.

TA.23 $\quad u_{co2.1} := 6369\dfrac{kJ}{kmol}$ $\quad u_{co2.2} := 24665\dfrac{kJ}{kmol}$ $\quad \Delta U_{co2} := \dfrac{(m_{co2.2}\cdot u_{co2.2} - m_{co2.1}\cdot u_{co2.1})}{M_{co2}} = 139.216\,kJ$

The specific heats for monatomic gases (i.e. Ar) are constant, and therefore PMig|cp is the "appropriate PM" and ΔU_ar = m_ar c_v.ar(T_ar.2 - T_ar.1). As emphasized in lecture, we look on the MT cover page and find cv.Ar = 3R/2

$c_{v.ar} := \dfrac{3\cdot R_{ar}}{2} = 0.312\dfrac{kJ}{kg\cdot K}$ $\quad \Delta U_{ar} := m_{ar}\cdot c_{v.ar}\cdot(T_2 - T_1) = 62.449\,kJ$

So $\quad \Delta U_t := \Delta U_s + \Delta U_{co2} + \Delta U_{ar} = 321.665\,kJ$

And $\quad m_{co2.i} := m_{co2.2} - m_{co2.1} = 0.1\,kg$ $\quad h_{co2.i} := \dfrac{8697\frac{kJ}{kmol}}{M_{co2}} = 197.614\dfrac{kJ}{kg}$

$Q_t := \Delta U_t + W_e + W_{sh} - m_{co2.i}\cdot h_{co2.i} = 51.903\,kJ$ $\quad$ > 0 which means heat transfer is to the system.

Discussion: Let's make sure this process is possible by the 2nd Law. Note this 2nd Law analysis for CO2 contains PMig ideas related to reference pressures covered in 204 but not in 203, and no attempt is made to explain these ideas here (i.e. I could not ask this solution in a 203 exam).

SBcvIr $\quad$ ΔS.sys = Q.j/Tj + mi si + σ —> $\quad$ σ = ΔS.sys - Q.j/Tj - mi si

The T of the system varies and Tj is not defined. However, we note as Tj decreases, σ also decreases, and a reasonable assumption for a "small" Tj is

$T_j := T_1$

$\Delta S_s := m_s\cdot c_s\cdot\ln\left(\dfrac{T_2}{T_1}\right) = 0.246\dfrac{kJ}{K}$

$c_{p.ar} := \dfrac{5}{2}\cdot R_{ar} = 0.52\dfrac{kJ}{kg\cdot K}$ $\quad \Delta S_{ar} := m_{ar}\left(c_{p.ar}\cdot\ln\left(\dfrac{T_2}{T_1}\right) - R_{ar}\cdot\ln\left(\dfrac{p_2}{p_{ar.1}}\right)\right) = 0.116\dfrac{kJ}{K}$

TA.23

$s_{co2.1.o} := \dfrac{1}{M_{co2}}\left(211.376\dfrac{kJ}{kmol\cdot K}\right) = 4.803\dfrac{kJ}{kg\cdot K}$ $\quad s_{co2.2.o} := \dfrac{1}{M_{co2}}\left(256.110\dfrac{kJ}{kmol\cdot K}\right) = 5.819\dfrac{kJ}{kg\cdot K}$

$p_o := 1bar$

$s_{co2.1} := s_{co2.1.o} - R_{co2}\cdot\ln\left(\dfrac{p_{co2.1}}{p_o}\right) = 4.803\dfrac{kJ}{K\,kg}$ $\quad S_{co2.1} := m_{co2.1}\cdot s_{co2.1} = 0.961\dfrac{kJ}{K}$

$s_{co2.2} := s_{co2.2.o} - R_{co2}\cdot\ln\left(\dfrac{p_2}{p_o}\right) = 5.598\dfrac{kJ}{K\,kg}$ $\quad S_{co2.2} := m_{co2.2}\cdot s_{co2.2} = 1.68\dfrac{kJ}{K}$

$\Delta S_{co2} := S_{co2.2} - S_{co2.1} = 0.719\dfrac{kJ}{K}$

$s_{co2.i} := s_{co2.1}$ $\quad S_{co2.i} := m_{co2.i}\cdot s_{co2.i} = 0.48\dfrac{kg}{K}\dfrac{kJ}{kg}$

$\Delta S_{sys} := \Delta S_{co2} + \Delta S_{ar} + \Delta S_s = 1.081\dfrac{kJ}{K}$

$\sigma := \Delta S_{sys} - \dfrac{Q_t}{T_j} - S_{co2.i} = 0.415\dfrac{kJ}{K}$ $\quad$ > 0 so the process is irrev.

Alternately, we may find the minimum Tj for which this process is possible by setting $\sigma = 0$ and we find

$$T_j := \frac{Q_j}{\left(\Delta S_{sys} - m_{co2,i} \cdot s_{co2,i}\right)} = 82.445\ \text{K}$$

i.e. this process becomes impossible for Tj < 82.4 K. Alternately, for all Tj > 82.4 K this process is irreversible, based on the T's of the system we expect Tj >> 82.4 K, and therefore this process is possible based on the 2nd Law.

The outlet pressure of the compressor varies from p1 to p2 by some unknown function. As a rough model for the compressor work, model the compressor as a combination of compressor + throttling valve, assume the compressor is isentropic and always produces CO2 at constant p2, while the throttling valve decreases the pressure to match the pressure of the system. Since the compressor is isentropic:

Δs = 0 = s co2,e,o - s co2,i,o - R ln(p2/p1)

$$s_{co2,i,o} := s_{co2,1,o} = 4.803\ \frac{kJ}{kg \cdot K}$$

$$s_{co2,e,o} := s_{co2,i,o} + R_{co2} \ln\left(\frac{p_2}{p_{co2,1}}\right) = 5.024\ \frac{kJ}{kg \cdot K} \qquad s_{co2,e,o} \cdot M_{co2} = 221.099\ \frac{kJ}{kmol \cdot K}$$

TA.23 the compressor exit T is ~ 300 K and

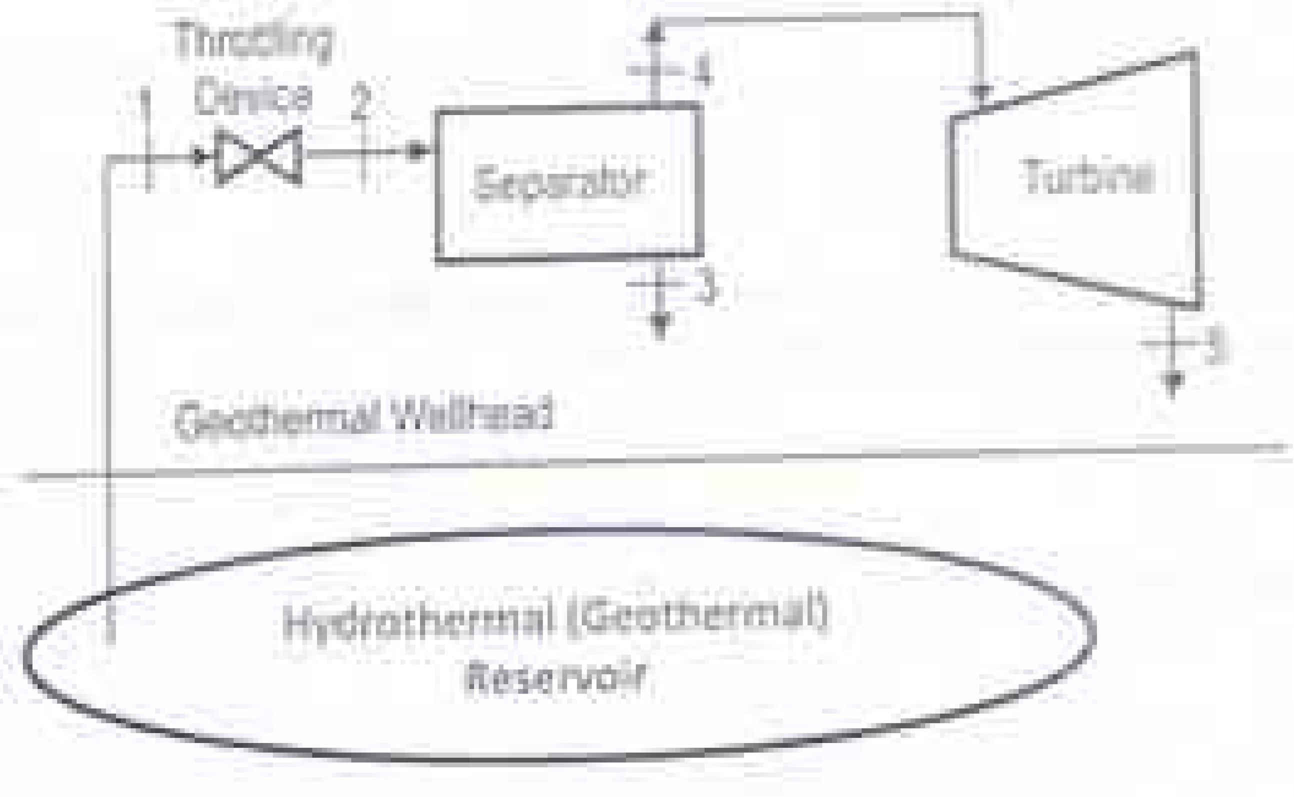
$$h_{co2,e} := \frac{11748\ \frac{kJ}{kmol}}{M_{co2}} = 266.939\ \frac{kJ}{kg}$$

$$W_{compr,in} := m_{co2,i} \cdot \left(h_{co2,e} - h_{co2,i}\right) = 6.933\ kJ$$

Therefore a compressor that consumes 50 kJ would be possible but very inefficient.

$kJ := 1000J$ $\qquad kmol := 1000mol$

1. A "flash" geothermal power plant is shown in the schematic. Note the schematic does not show heat transfers or works. Recall $\dot{W}_{cv} = \dot{W}_b + \dot{W}_{sh} + \dot{W}_e$. Assume steady-state operation and make **appropriate** assumptions to model the throttling device, separator, and turbine, noting that the turbine is not ideal (η_t < 100%).



Model the geothermal fluid as pure water. Known state information is as follows:

State	$\dot{m}$ (kg/s)	T (°C)	P (bar)	x	v (m³/kg)	u (kJ/kg)	h (kJ/kg)	s (kJ/kg K)	Phase
1	?	170		0					
2			4						
3									Sat. Liq.
4	10								Sat. Vap.
5		40		0.872	17	2 140	2 266	7.273	

a) For a system boundary drawn around the Throttling Device and Separator (i.e. process 1 → 2 → 3 & 4), find

$\dot{m}_1$ (kg/s)	$\dot{Q}$ (kW)	$\dot{W}_{cv}$ (kW)	σ (kW/K)

b) For a system boundary drawn around the turbine, find

$\dot{Q}$ (kW)	$\dot{W}_{cv}$ (kW)	η_t (%)	σ (kW/K)

Soln: SS cv problem. Therefore by definition the rate of boundary work is 0 since dV/dt = 0 and therefore pdV/dt = 0 at state state. Since there is no ke device and changes in elevation can be assumed negligible, nkp. As emphasized in class, adiabatic is an appropriate assumption for throttling devices and work devices (i.e., turbine). The separator is adiabatic. Therefore the rate EB and SB for a SS cv with nkp 1-inlet and >= 1 outlet

EB: 0 = mi hi - [Wcv - sum(me he)]

SB: 0 = mi si - [sum(me se)] + Sgen

where Wcv = Wsh + We.

Given: $m_4 := 10\ \frac{kg}{s}$

a) Draw the system boundary around both the throttling valve and the separator. Since we have 2-outlets, we need to write a MB

0 = m1 - (m3 + m4) --> m3 = m1 - m4 (1)

For the EB, we note there is no work so the EB becomes

0 = m1 h1 - (m3 h3 + m4 h4) (2)

(1) --> (2) ==> 0 = m1 h1 - [(m1 - m4) h3 + m4 h4] = m1(h1 - h3) + m4 (h3 - h4)

==> m1 = m4 (h4 - h3)/(h1 - h3) (3)

For the SB,

Sgen = [m3 s3 + m4 s4] - m1 s1 (4)

State 1 and State 3 are SL's, and State 4 is a SV. A separator is a thermal device and therefore being isobaric is an appropriate assumption and p3 = p4 = p2 = 4 bar.

TA.1 at 170 oC $h_1 := 719.21 \frac{kJ}{kg}$ $s_1 := 2.0419 \frac{kJ}{kg \cdot K}$

TA.3 at 4 bar $h_3 := 604.74 \frac{kJ}{kg}$ $s_3 := 1.7766 \frac{kJ}{kg \cdot K}$

$h_4 := 2738.6 \frac{kJ}{kg}$ $s_4 := 6.8959 \frac{kJ}{kg \cdot K}$

From Eqn. (3), $m_1 := m_4 \cdot \frac{(h_4 - h_3)}{(h_1 - h_3)} = 186.412 \frac{kg}{s}$

From Eqn. (1) $m_3 := m_1 - m_4 = 176.412 \frac{kg}{s}$

From Eqn. (4) $S_{gen} := (m_3 \cdot s_3 + m_4 \cdot s_4) - m_1 \cdot s_1 = 1.738 \frac{kW}{K}$ > 0 which makes sense as the throttling process (unrestrained expansion) is inherently irreversible

b) $\eta_s := 80\%$ ηs = W / Ws < 100% since Ws (ideal) > W (actual)

MB: m4 = m5 = m since 1-inlet and 1-outlet

EB: W = m (h4 - h5) & Ws = m (h4 - h5s)

SB: Sgen = m5 s5 - m4 s4 & s5s = s4 by defn

ηs = W / Ws = (h4 - h5) / (h4 - h5s) ⟹ h5 = h4 - ηs (h4 - h5s)

$h_5 := 2266 \frac{kJ}{kg}$ $W := m_4 \cdot (h_4 - h_5) = 4.726\ MW$

From TA.2 at 40 oC $v_f := 1.0078 \cdot 10^{-3} \frac{m^3}{kg}$ $u_f := 167.56 \frac{kJ}{kg}$ $h_f := 167.57 \frac{kJ}{kg}$ $s_f := 0.5725 \frac{kJ}{kg \cdot K}$

$v_g := 19.523 \frac{m^3}{kg}$ $u_g := 2430.1 \frac{kJ}{kg}$ $h_g := 2574.3 \frac{kJ}{kg}$ $s_g := 8.2570 \frac{kJ}{kg \cdot K}$

We note for consistency $x_5 := \frac{h_5 - h_f}{h_g - h_f} = 0.872$ $v_5 := v_f + x_5 \cdot (v_g - v_f) = 17.022 \frac{m^3}{kg}$

$u_5 := u_f + x_5 \cdot (u_g - u_f) = 2.14 \times 10^3 \frac{kJ}{kg}$ $s_5 := s_f + x_5 \cdot (s_g - s_f) = 7.273 \frac{kJ}{kg \cdot K}$ $S_{gen\ b} := m_4 \cdot (s_5 - s_4) = 3.767 \frac{kW}{K}$

Continuing w/ the soln. $s_{5s} := s_4$ $x_{5s} := \frac{s_{5s} - s_f}{s_g - s_f} = 0.823$ $h_{5s} := h_f + x_{5s} \cdot (h_g - h_f) = 2.148 \times 10^3 \frac{kJ}{kg}$

$W_s := m_4 \cdot (h_4 - h_{5s}) = 5.906\ MW$ $\eta_s := \frac{W}{W_s} = 0.8$

ME-203 MIDTERM-1

QUESTION 1 (20 Points) The density of mercury changes approximately linearly with temperature as ρ=13595-2.5T kg/m³ (T in Celcius), so the same pressure difference will result in a manometer reading that is influenced by temperature. If a pressure difference of 100 kPa is measured in the summer at 35°C and in the winter at -15°C, what is the difference in column heights between two measurements?

$$\rho = 13595 - 2.5T \ [kg/m^3]$$

$$\rho_s = 13595 - 2.5 \times 35 = 13507.5 \ kg/m^3$$

$$\rho_w = 13595 - 2.5 \times (-15) = 13632.5 \ kg/m^3$$

$$P = \rho g h \Rightarrow h = \frac{P}{\rho g}$$

$$h_s = \frac{P}{\rho_s g} = \frac{100{,}000}{13507.5 \times 9.81} = 0.7547\ m = 754.7\ mm$$

$$h_w = \frac{P}{\rho_w \cdot g} = \frac{100{,}000}{13632.5 \times 9.81} = 0.7477\ m = 747.7\ mm$$

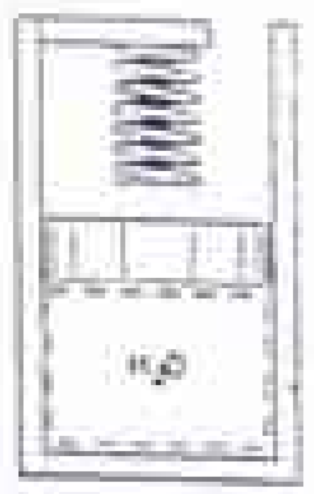
$$h_s - h_w = 754.7 - 747.7 = 7\ mm$$

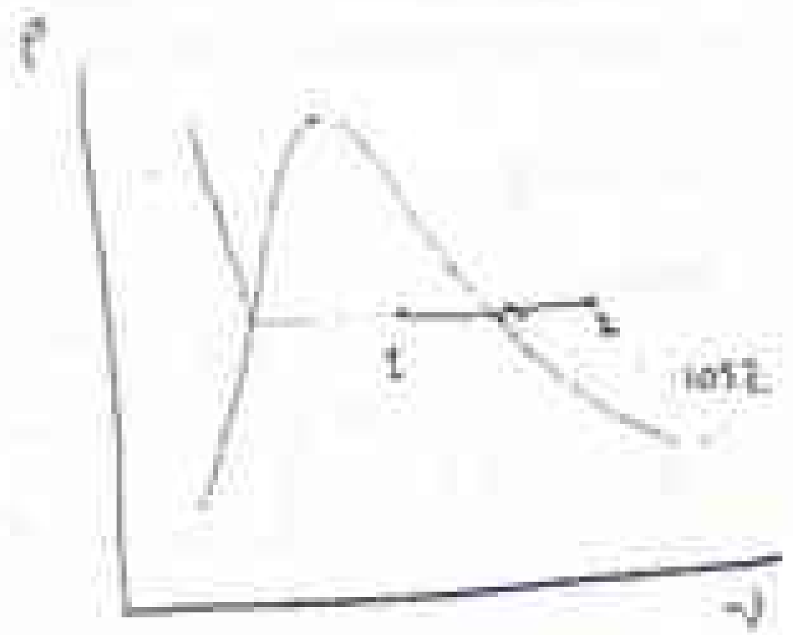
MIDTERM 1

QUESTION 2 (20 points) A cylinder/piston arrangement contains water at 105°C, 85% quality, with a volume of 1 liter. The system is heated, causing the piston to rise and encounter a linear spring, as shown in the figure. At this point the volume is 1.5 liters, the piston diameter is 150 mm, and the spring constant is 100 N/mm. The heating continues, so the piston compresses the spring. What is the cylinder temperature when the pressure reaches 200 kPa?

State (1):

$T_1 = 105\,°C$, $x_1 = 85\%$ $\Rightarrow \begin{cases} P_1 = 120.8\,kPa \\ v_1 = v_f + x_1 v_{fg} \end{cases}$





$v_1 = 0.001047 + 0.85 \times 1.41831$

$v_1 = 1.20661\ m^3/kg$

$V_1 = 1\ liter$

$m = \frac{V_1}{v_1} = \frac{0.001}{1.20661} = 8.288 \times 10^{-4}\ kg$

State (2):

$P_2 = P_1 = 120.8\ kPa$

$v_2 = \frac{V_2}{m} = 1.8099\ m^3/kg$

$v_2 > v_g\ (at\ P_2) \Rightarrow$ State (2) is superheated vapor

$T_2 = 204.5\,°C$

P = 100 kPa

$v\,[m^3/kg]$	$T\,[°C]$
1.69400	99.62
1.8099	T_2'
1.93636	150°C

$T_2' = 123.7\,°C$

P = 200 kPa

$v\,[m^3/kg]$	$T\,[°C]$
1.78139	500°C
1.8099	T_2''
2.01297	600°C

$T_2'' = 512.3\,°C$

$P\,[kPa]$	$T\,[°C]$
100	123.7
120.8	T_2
200	512.3

$\Rightarrow \underline{T_2 = 204.5\,°C}$

For linear spring:

$P_3 - P_2 = m \frac{k_s}{A_p^2}(v_3 - v_2) \Rightarrow v_3 = 2.1083\ m^3/kg$

$P_3 = 200\ kPa$

$A_p = \frac{\pi}{4} \times 0.15^2 = 0.01767\ m^2$

State (3)

$\begin{cases} P_3 = 200\ kPa \\ v_3 = 2.1083\ m^3/kg \end{cases}$

P = 200 kPa

$T\,[°C]$	$v\,[m^3/kg]$
600	2.01297
T_3	2.1083
700	2.24426

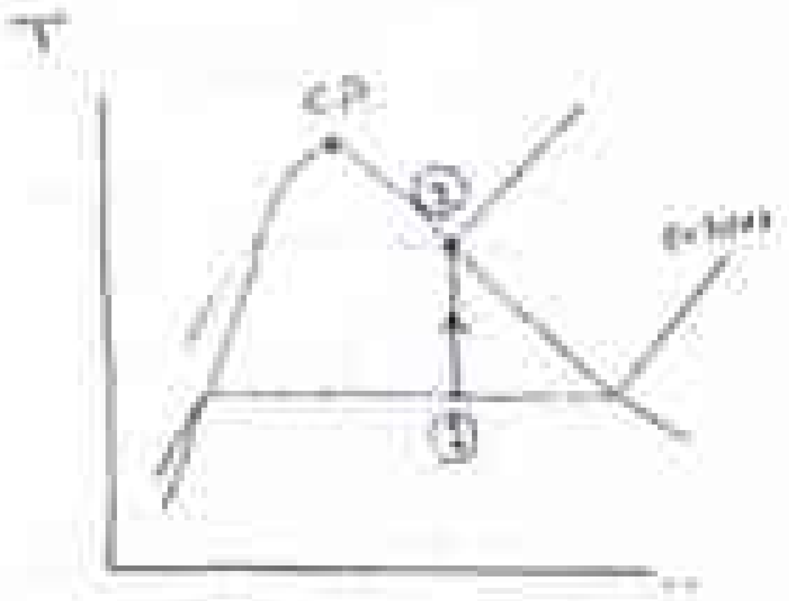
$\Rightarrow \underline{T_3 = 641.2\,°C}$

QUESTION 3(20 points) An insulated rigid vessel contains 1 kg of water at 300 kPa and 80% quality. A paddle-wheel inside the tank is turned by an external motor until all of the water becomes saturated vapor. Find the work necessary for this process and the final pressure and temperature. Plot the process on the T-v diagram showing the constant pressure lines and the vapor dome.

$m = 1\ kg$

$P_1 = 300\ kPa$

$x_1 = 80\%$



$v_1 = v_f + x_1 v_{fg} = 0.001073 + 0.80 \times 0.60475$

$v_1 = 0.48487\ m^3/kg$

$u_1 = u_f + x u_{fg} = 561.13 + 0.8 \times 1982.43$

$u_1 = 2146.73\ kJ/kg$

State (2):

$v_2 = v_1 = 0.48487\ m^3/kg$ (saturated vapor)

$v_g\ [m^3/kg]$	$P\ [kPa]$	$T\ [^\circ C]$	$u\ [kJ/kg]$
0.49137	375	141.32	2551.31
0.48487	P_2	T_2	u_2
0.46246	400	143.63	2553.55

$$\frac{0.48487 - 0.49137}{0.46246 - 0.49137} = \frac{P_2 - 375}{400 - 375} = \frac{\cancel{T_2 - 141.32}}{143.63 - 141.32} = \frac{\cancel{u_2 - 2551.31}}{2553.55 - 2551.31}$$

$$\begin{cases} P_2 = 380.62\ kPa \\ T_2 = 141.84\ ^\circ C \\ u_2 = 2551.81\ kJ/kg \end{cases}$$

$\cancel{Q_{1\to2}}^{\,0} - W_{1\to2} = m(u_2 - u_1) \Rightarrow W_{1\to2} = -1 \times (2551.81 - 2146.73)$

$W_{1\to2} = -405.08\ kJ$

QUESTION 4 (20 Points) A spherical balloon contains 2 kg of R-134a at 0°C, 6.8% quality. This system is heated until the pressure in the balloon reaches 600 kPa. For this process, it can be assumed that the pressure in the balloon is directly proportional to the balloon diameter. Calculate:

a) The final temperature
b) Total work done during the process in kJ
c) Total heat transfer during the process in kJ

$m = 2\ kg$

State (1)

$$\begin{cases} T_1 = 0^\circ C \\ x_1 = 6.8\% \end{cases} \Rightarrow \begin{cases} P_1 = 294.0\ kPa \\ v_1 = 0.000773 + 0.068 \times 0.06842 = 0.00542\ m^3/kg \\ u_1 = 199.77 + 0.068 \times 178.24 = 211.89\ kJ/kg \end{cases}$$

State (2)

$P_2 = 600\ kPa$

$P \propto D$

$V \propto D^3 \Rightarrow V^{1/3} \propto D \Rightarrow P \propto V^{1/3} \Rightarrow \frac{P}{V^{1/3}} = \text{constant}$

$\Rightarrow PV^{-1/3} = \text{constant}$

Polytropic process: $n = -1/3$ (polytropic index)

$P_1 V_1^{-1/3} = P_2 V_2^{-1/3} \Rightarrow V_2 = V_1 \left(\frac{P_2}{P_1}\right)^3 \Rightarrow v_2 = v_1 \left(\frac{P_2}{P_1}\right)^3$

$v_2 = 0.00542 \left(\frac{600}{294}\right)^3 \Rightarrow v_2 = 0.0461\ m^3/kg$

$$\begin{cases} P_2 = 600\ kPa \\ v_2 = 0.0461\ m^3/kg \end{cases} \Rightarrow v_2 > v_g \text{ (at 600 kPa)} \Rightarrow \text{state (2) is superheated vapor}$$

$P = 600\ kPa$

$T\ [^\circ C]$	$v\ [m^3/kg]$	$u\ [kJ/kg]$
80	0.04473	440.73
T_2	0.0461	u_2
90	0.04632	449.82

$$\Rightarrow \begin{cases} T_2 = 88.62\ ^\circ C \\ u_2 = 448.59\ kJ/kg \end{cases}$$

For polytropic process:

$$W_{1\to2} = \frac{P_2V_2 - P_1V_1}{1-n} = \frac{2\,(600\times0.0461 - 294\times0.00542)}{1-(-1/3)}$$

$$W_{1\to2} = 39.1\ \text{kJ}$$

1st law of thermodynamics:

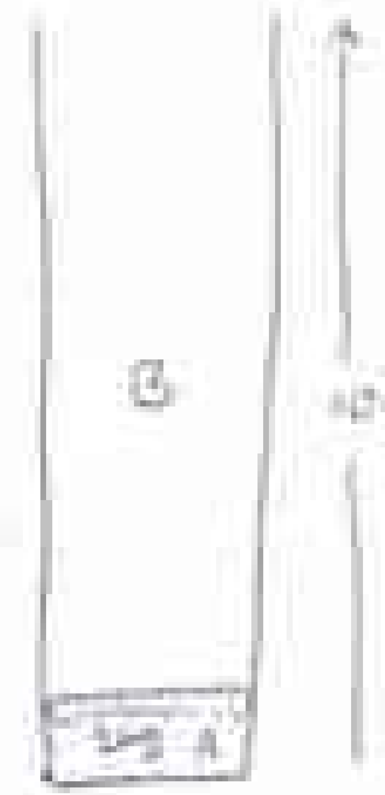
$$Q_{1\to2} - W_{1\to2} = m\,(u_2 - u_1)$$

$$Q_{1\to2} = 39.1 + 2\,(448.59 - 211.89)$$

$$Q_{1\to2} = 512.5\ \text{kJ}$$

Question 5 (20 Points) A 10 meters high open cylinder with a cylinder area of 0.1 m², contains 20°C compressed liquid water above and 2 kg of 20°C compressed liquid water below a 198.5 kg thin, insulated floating piston. Now heat is added to the water below the piston so that it expands, pushing the piston up, causing the water on top to spill over the edge. This process continues until the piston reaches the top of the cylinder. Find the final state of the water below the piston (T, P, v) and the heat added during the process. (g=9.81 m/s², P_{atm}=101.325 kPa)

System is the water below the piston.



For compressed liquid we can assume:

$$v \cong v_f\ (\text{at } T_1 = 20^\circ C) = 0.001002\ \text{m}^3/\text{kg}$$

$$u \cong u_f\ (\text{at } T_{sat} = 20^\circ C) = 83.94\ \text{kJ/kg}$$

$$V_{total} = 10\times0.1 = 1\ \text{m}^3$$

$$m_{total} = \frac{V_{total}}{v} = \frac{1}{0.001002} = 998\ \text{kg}$$

$$m_{1A} = 2\ \text{kg} \Rightarrow m_{1B} = m_{total} - m_{1A} = 998 - 2 = 996\ \text{kg}$$

$m_{1B} = 996$ kg mass of water above the piston

$$P_{1A} = P_0 + \frac{(m_{1B} + m_p)\,g}{A_p} = 101.325 + \frac{(996 + 198.5)\times9.81}{0.1\times(1000)} = 218.5\ \text{kPa}$$

State 2:

$$P_{2A} = P_0 + \frac{m_p g}{A_p} = 101.325 + \frac{198.5\times9.81}{0.1\times(1000)} = 120.8\ \text{kPa}$$

$$v_{2A} = \frac{V_{total}}{m_A} = \frac{1}{2} = 0.5\ \text{m}^3/\text{kg}$$

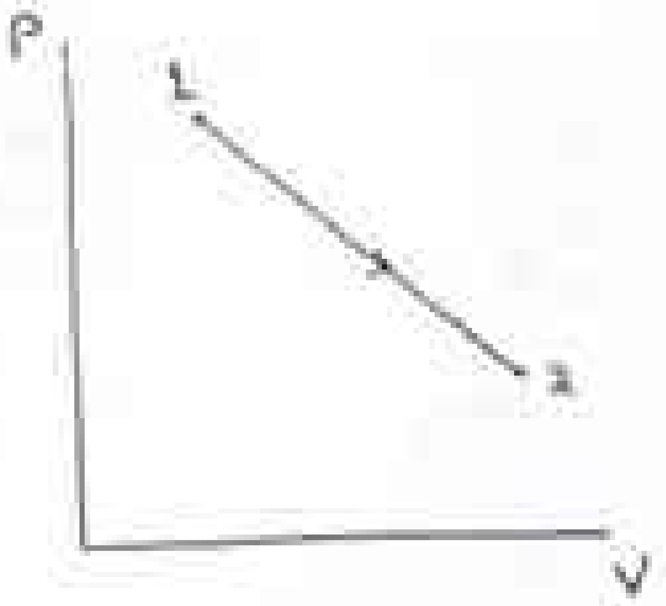
$v_f < v_{2A} < v_g$ at P=120.8 kPa $\Rightarrow$ two-phase state

$$x_{2A} = \frac{v_{2A} - v_f}{v_{fg}} = \frac{0.5 - 0.001047}{1.41831} = 0.352$$

$$T_{2A} = T_{sat}\ (\text{at } P = 120.8) = 105^\circ C$$

$$u_{2A} = u_f + x_{2A} u_{fg} = 440.0 + 0.352\times2072.34 = 1169.5\ \text{kJ/kg}$$

m_B decreases linearly while volume is changing, so P is linearly dependent to volume.



$$W_{1\to2} = \int_1^2 PdV = \frac{1}{2}(P_1+P_2)(V_2-V_1)$$

$$= \frac{1}{2}(218.5+120.82)(1-2\times0.001002)$$

$$W_{1\to2} = 169.32 \text{ kJ}$$

$$Q_{1\to2} = W_{1\to2} + m(u_2-u_1) = 169.32 + 2(1169.5-83.94)$$

$$Q_{1\to2} = 2340.44 \text{ kJ}$$

FINAL İÇİN ÇALIŞMA SORULARI

METU

MECHANICAL ENGINEERING DEPARTMENT

ME203 – Thermodynamics 1 Section 2

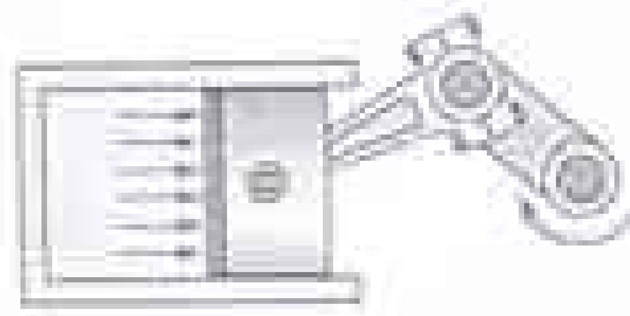
Homework 6

You should submit your homework just before your final examination (13.30 January 7,2013) in your examination classroom. No extensions will be given beyond the due time.

Q1) (2 points)
Using the tables for water, determine the specific entropy at the indicated states, in kJ/kg K. In each case, locate the state by hand on a sketch of the *T*–*s* diagram.
(a) p = 10.0 MPa, T = 400°C
(b) p = 10.0 MPa, T = 100°C
(c) p = 10.0 MPa, u = 1872.5 kJ/kg
(d) p = 10.0 MPa, saturated vapor.

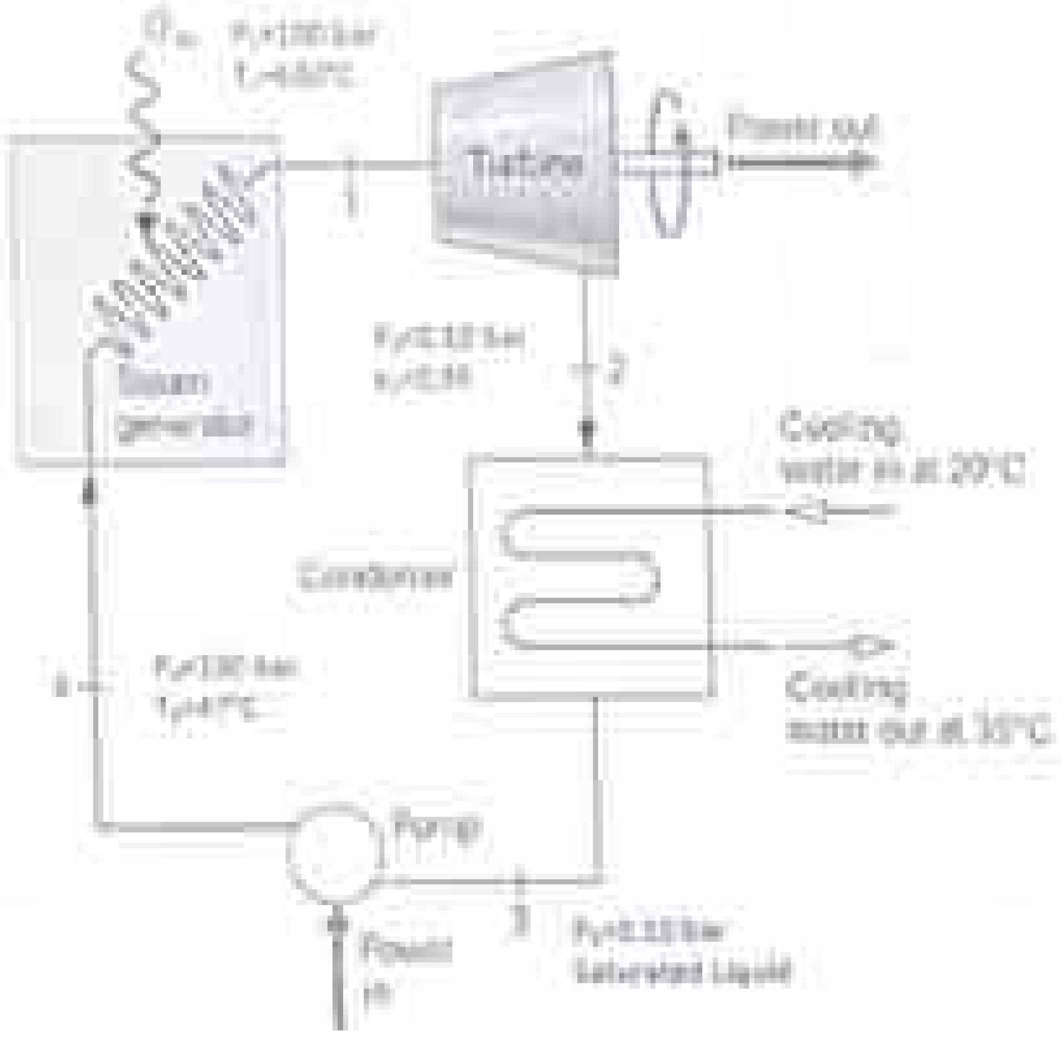
Q2) (2 points)
A 50-kg copper block initially at 80°C is dropped into an insulated tank that contains 120 L of water at 25°C. Determine the final equilibrium temperature and the total entropy change for this process.

Q3) (3 points)
The power stroke in an internal combustion engine can be approximated with a polytropic expansion. Consider air in a cylinder volume of 0.2 L at 7 MPa, 1800 K, shown in Figure. It now expands in a reversible adiabatic process with where k=1.35, through a volume ratio of 8:1 (expands until volume reaches 1.6 L). Find final temperature, pressure and work for the process and show this process on *P*–*v* and *T*–*s* diagrams. Use ideal gas model assuming constant specific heats.



Q4) (4 points)
A piston/cylinder has ammonia at 1800 kPa, 100°C with a volume of 0.1 m³. The piston is loaded with a linear spring, and the outside ambient air is at 20°C, shown in figure. The ammonia now cools down to 20°C, at which point it has a quality of 15%. Find the work, heat transfer, and total entropy generation in the process.

Q5) (4 points)
Figure below shows a simple vapor power plant operating at steady state with water as the working fluid. Data at key locations are given on the figure. The mass flow rate of the water circulating through the components is 120 kg/s. Stray heat transfer and kinetic and potential energy effects can be ignored. Determine,
(a) the net power developed, in MW.
(b) the thermal efficiency.
(c) the isentropic turbine efficiency.
(d) the isentropic pump efficiency.
(e) the mass flow rate of the cooling water, in kg/s.
(f) the rates of entropy production, each in kW/K, for the turbine, condenser, boiler and pump. Assume heat is transferred to boiler from a reservoir at 600°C. Do all the processes in the cycle satisfy 1st and 2nd law of thermodynamics? Explain.



Q6) (bonus question - 3 points)*

Answer the following true or false. Explain.

(a) A process that violates the second law of thermodynamics violates the first law of thermodynamics.

(b) When a net amount of work is done on a closed system undergoing an internally reversible process, a net heat transfer of energy from the system also occurs.

(c) One corollary of the second law of thermodynamics states that the change in entropy of a closed system must be greater than zero or equal to zero.

(d) A closed system can experience an increase in entropy only when irreversibilities are present within the system during the process.

(e) Entropy can never be produced in an internally reversible process of a closed system.

(f) If there is no change in enthalpy between two states of a closed system, the process is necessarily adiabatic and internally reversible.

(g) The energy of an isolated system must remain constant, but the entropy can only increase.

***Please note that it is quite obvious whether you are cheating in a verbal question and cheaters are going to recieve zero grade. Therefore, use your own word while answering the questions and explaining the underlying phenomena.**

Study Problems (Will not be collected)

From Fundamentals of Engineering Thermodynamics 7th Ed. Moran and Shapiro

6.14, 6.20, 6.27, 6.32, 6.48, 6.62, 6.66, 6.80, 6.83, 6.86, 6.106, 6.104, 6.114, 6.115, 6.116, 6.123, 6.150, 6.161, 6.163, 6.166, 6.187-189

2

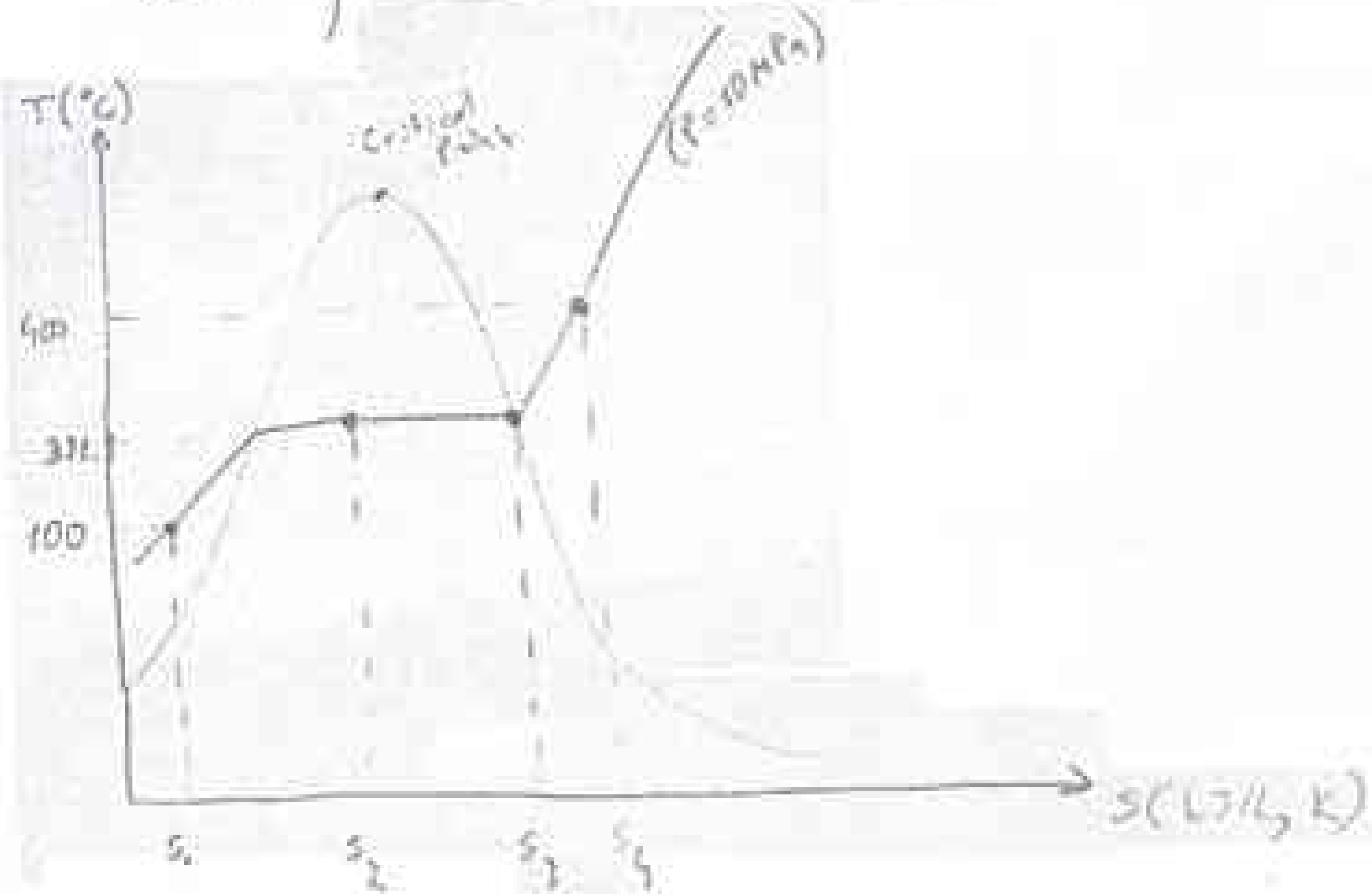
Q1)

a) $\left.\begin{array}{l} P = 10\ MPa \\ T = 400°C \end{array}\right\} \xrightarrow[\text{Superheated Vapor}]{\text{Table A.4}}$ $s_a = 6.212\ kJ/kgK$

b) $\left.\begin{array}{l} P = 10\ MPa \\ T = 100°C \end{array}\right\} \xrightarrow[\text{Compressed Liquid}]{\text{Table A.5}}$ $s_b = 1.2992\ kJ/kgK$

c) $\left.\begin{array}{l} P = 10\ MPa \\ u = 1872.5\ kJ/kg \end{array}\right\} \xrightarrow[\text{Saturated Mixture}]{\text{Table A.3}}$ $\left.\begin{array}{l} u_f = 1393\ kJ/kg \\ u_g = 2544.4\ kJ/kg \\ s_f = 3.3596\ kJ/kgK \\ s_g = 5.6141\ kJ/kgK \end{array}\right\} \xrightarrow{\text{interpolation}}$ $x = 0.416$, $s_c = 4.294\ kJ/kgK$, $T_c = 311.1\ °C$

d) $\left.\begin{array}{l} P = 10\ MPa \\ x = 1 \end{array}\right\} \xrightarrow{\text{Table A.3}}$ $s_d = 5.6141\ kJ/kgK$ $T_d = T_c$



Q2

Given

Copper: $m_c = 50\,kg$, $T_c = 90°C$

Tank (water): $V = 120L = 0.12\,m^3$, $T_w = 25°C$

Table A 19 $\Longrightarrow$ $c_{p_c} = 0.385\ kJ/kg\,K$, $c_{p_w} = 4.179\ kJ/kg\,K$, $\rho_w = 996.5\ m^3/kg$ (at 300 K)

$$m_w = \rho_w \cdot V_w = (0.12)(996.5) = 119.6\ kg$$

Energy Balance: $\cancel{\frac{dE}{dt}}^{0} = \Delta U + \cancel{Q}^{0} - \cancel{W}^{0} \Rightarrow \Delta U = 0$

$$\Rightarrow m_c c_{p_c}(T_c - T_f) + m_w c_{p_w}(T_w - T_f) = 0$$

$$\Rightarrow (50)(0.385)(90 - T_f) + (119.6)(4.179)(25 - T_f) = 0 \Rightarrow \boxed{T_f = 27°C}$$

Entropy Balance:

$$S_2 - S_1 = \cancel{\int \frac{\delta Q}{T}}^{0} + \sigma \Rightarrow \sigma = S_2 - S_1 = m_w c_{p_w} \ln\frac{T_f}{T_w} + m_c c_{p_c} \ln\frac{T_f}{T_c}$$

$$\Rightarrow \sigma = (50)(0.385)\ln\frac{27+273}{90+273} + (119.6)(4.179)\ln\frac{27+273}{25+273}$$

$$\Rightarrow \boxed{\sigma = 0.211\ kJ/K}$$

Q3

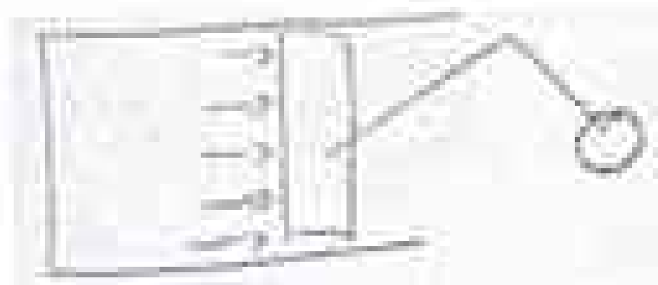
Given

Initial state: $V_1 = 0.2L = 0.2\times10^{-3}\,m^3$, $P_1 = 7\,MPa$, $T_1 = 1800K$

Final state: $V_2 = 1.6\times10^{-3}\,m^3$

PV^n = Constant

Reversible adiabatic process



Entropy balance for closed system

$$S_2 - S_1 = \cancel{\frac{Q}{T_1}}^{0} + \cancel{\sigma}^{0} \Rightarrow S_2 = S_1$$

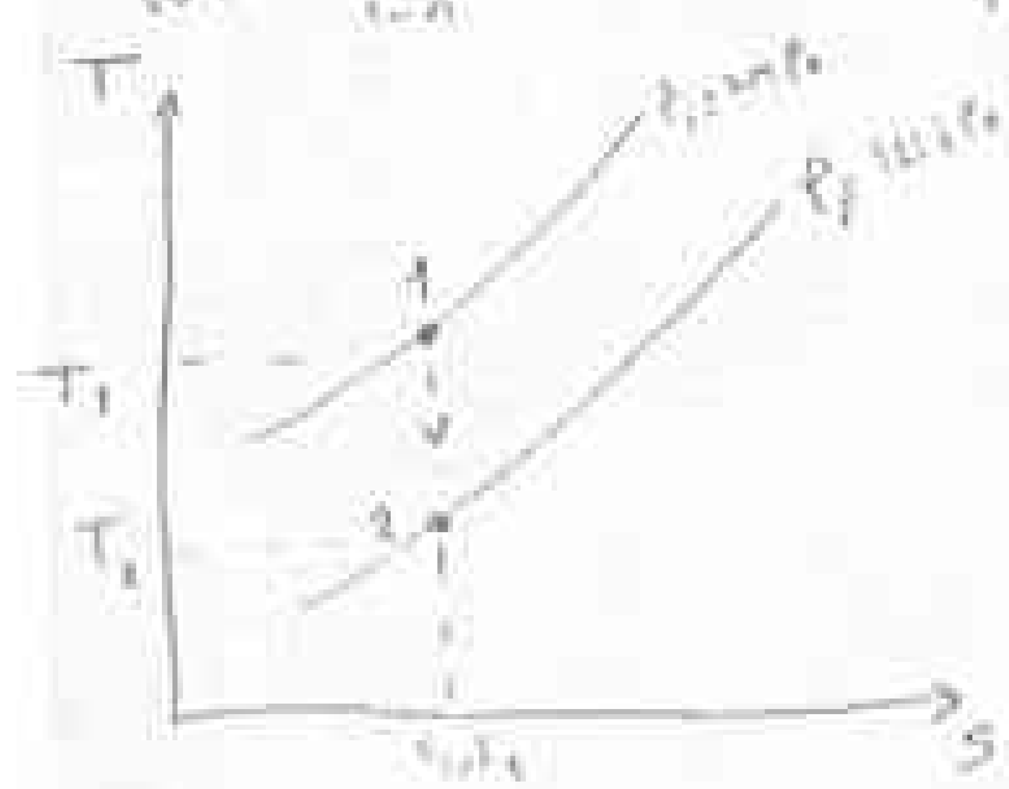
$$\Rightarrow c_v \ln\frac{T_2}{T_1} + R\ln\frac{v_2}{v_1} = 0 \quad \text{and} \quad c_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1} = 0$$

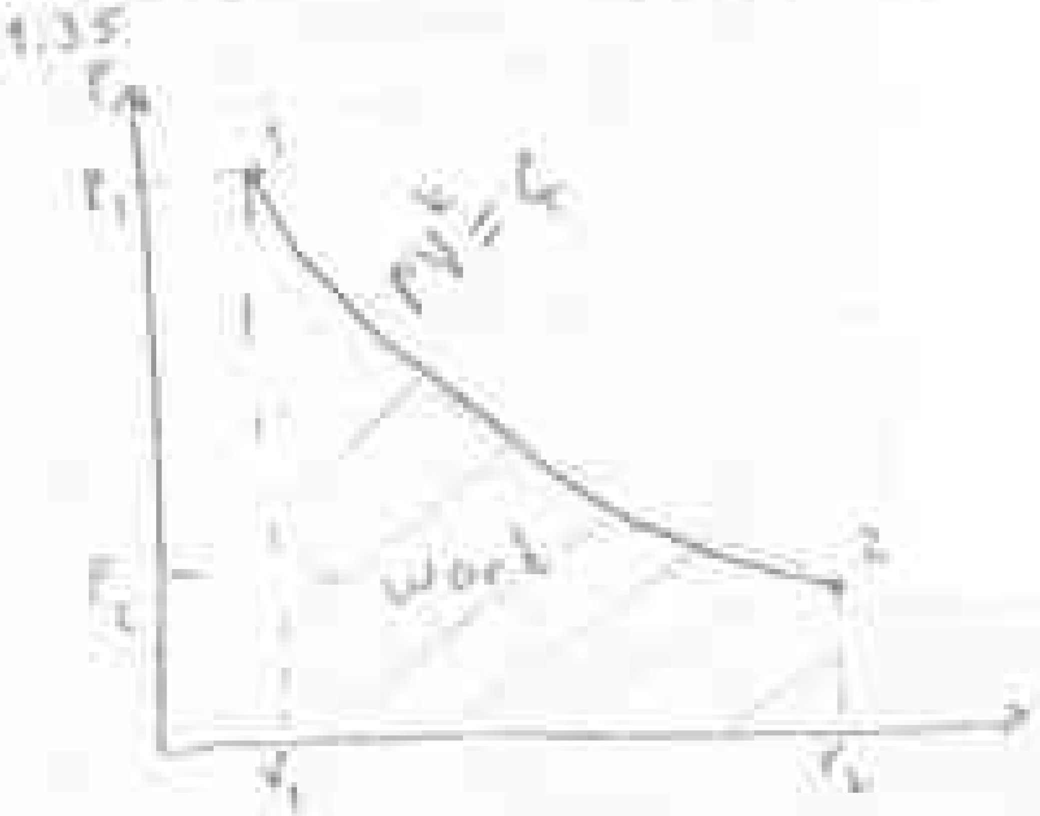
with $c_p = \frac{kR}{k-1}$ and $c_v = \frac{R}{k-1}$

$$\Rightarrow \frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{k-1} \Rightarrow \frac{T_2}{1800} = \left(\frac{1}{8}\right)^{1.35-1} \Rightarrow \boxed{T_2 = 869\,K}$$

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^{k} \Rightarrow \frac{P_2}{7000} = \left(\frac{1}{8}\right)^{1.35} \Rightarrow \boxed{P_2 = 423\ kPa}$$

$$W = \frac{P_2V_2 - P_1V_1}{1-n} = \frac{(423)(1.6\times10^{-3}) - (7000)(0.2\times10^{-3})}{1-1.35} = \boxed{2.07\ kJ}$$





Q4

Given

Initial state

$P_1 = 1400\,kPa$, $T_1 = 100^\circ C$, $V_1 = 0.1\,m^3$ $\xrightarrow{\text{Table A.15}}$ $s_1 = 5.2337\ kJ/kg\,K$, $v_1 = 0.09267\ m^3/kg$, $u_1 = 1470.37\ kJ/kg$

Final state

$T_2 = 20^\circ C$, $x = 0{,}15$ $\xrightarrow{\text{Table A.13}}$

$s_2 = 1.0405 + x_2(5.0849 - 1.0405) = 1.6471\ kJ/kg\,K$

$v_2 = (1.6386\times10^{-3}) + x_2(0.1492 - 1.6386\times10^{-3}) = 0.02377\ m^3/kg$

$u_2 = (272.86) + x_2(1331.94 - 272.86) = 431.722\ kJ/kg$

$P_2 = 857{,}6\ kPa$

Solution

$$m = \frac{V_1}{v_1} = \frac{0{,}1}{0.09267} = 1.08\ kg$$

$$V_2 = m v_2 = 0.0257\ m^3$$

$$_1W_2 = \frac{P_1 + P_2}{2}(V_2 - V_1) = \frac{(1400 + 857.6)}{2}(0.0257 - 0.1) = \boxed{-98.8\ kJ}$$

Energy Balance

$$Q - W = U_2 - U_1 \Rightarrow Q = m(u_2 - u_1) + W = (1.08)(431.722 - 1470.37) - 98.8$$

$$\Rightarrow \boxed{Q = -1221.2\ kJ}$$ (Heat is transferred to surrounding)

Entropy Balance

$$S_2 - S_1 = \frac{Q}{T_0} + \sigma \Rightarrow \sigma = \frac{-Q}{T_0} + m(s_2 - s_1)$$

$$\Rightarrow \sigma = \frac{+1221.2}{273 + 20} - (1.08)(5.2337 - 1.6471) = \boxed{0.225\ kJ/K}$$

Q5

Given

$P_1 = 100\ bar$

$T_1 = 600^\circ C$

$P_2 = 0.1\ bar$

$x_2 = 0.95$

$P_3 = P_2$

$x_3 = 0$

$P_4 = 100\ bar$

$T_4 = 47^\circ C$

Using Table A.3, A.4, A.5

$\dot m = 120\ kg/s$

State	h (kJ/kg)	s (kJ/kg K)
1	3625.3	6.9029
2	2464.99	7.7752
3	191.83	0.6493
4	205.51	0.6561

Solution

a) $\dot W = \dot m(h_1 - h_2) - \dot m(h_4 - h_3) = \dot m(h_1 + h_3 - h_2 - h_4) = \boxed{137.6\ MW}$

b) $\eta_{th} = \dfrac{\dot W_{net}}{\dot Q_H} = \dfrac{137600}{\dot m(h_1 - h_4)} = \boxed{33.53\%}$

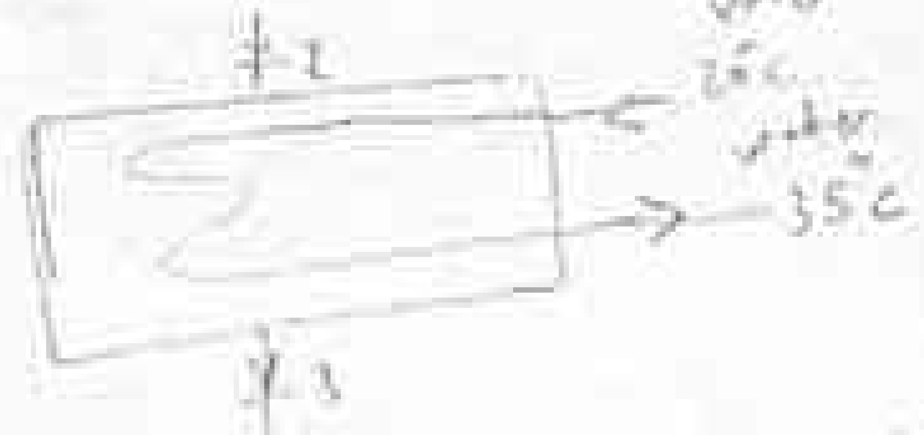
c) $\eta_t = \dfrac{h_1 - h_2}{h_1 - h_{2s}}$ at $\left.\begin{matrix} P = 0.1\ bar \\ s_2 = s_1 \end{matrix}\right\} \Rightarrow x_{2s} = 0.83 \Rightarrow h_{2s} = 2177.85\ kJ/kg$

$$\Rightarrow \eta_t = \frac{3625.3 - 2464.99}{3625.3 - 2177.85} = 0.553 = \boxed{55.3\ \%}$$

d) $\eta_p = \dfrac{h_{4s} - h_3}{h_4 - h_3}$ at $\left.\begin{matrix} P = 100\ bar \\ s = s_3 \end{matrix}\right\} \Rightarrow \begin{matrix} T_{4s} = 46.45^\circ C \\ h_{4s} = 203.24\ kJ/kg \end{matrix}$

$$\eta_p = \frac{203.24 - 191.83}{205.51 - 191.83} = \boxed{83.4\%}$$

e)



Energy Balance

$$\cancel{\dot Q} - \cancel{\dot W} = \dot H_3 - \dot H_2 + \Delta \dot H_w$$

0 0

$C_p = 4.18\ kJ/kg\,K$

$$\Rightarrow \dot H_2 - \dot H_3 = \dot m_w C_p(T_e - T_i) = \dot m(h_2 - h_3)$$

$$\Rightarrow \dot m_w = \frac{(120)(2464.99 - 191.83)}{(4.18)(35 - 20)} = \boxed{4350.5\ kg_{water}/s}$$

Q5-cont.

2) Turbine process (1 – 2)

$$\dot{S}_2 - \dot{S}_1 = \underbrace{\frac{\dot{Q}}{T}}_{0} + {}_1\dot{\sigma}_2 \Rightarrow \dot{\sigma} = \dot{S}_2 - \dot{S}_1 = \dot{m}(s_2 - s_1) = \boxed{104.676\ kW/K}$$

Condenser process (2 – 3)

$$\underbrace{\frac{dS_c}{dt}}_{0\ (\text{steady state})} = \underbrace{\sum \frac{\dot{Q}_j}{T_j}}_{0\ (\text{no heat transfer})} + \sum \dot{m}_i s_i - \sum \dot{m}_e s_e + \dot{\sigma}_{cv}$$

$$\Rightarrow {}_2\dot{\sigma}_3 = \sum \dot{m}_e s_e - \sum \dot{m}_i s_i = \dot{m}(s_3 - s_2) + \dot{m}_w \underbrace{(s_6 - s_5)}_{c_p \ln \frac{T_6}{T_5}}$$

$$\Rightarrow {}_2\dot{\sigma}_3 = (120)(0.6493 - 7.7752) + (4350.5)(4.179) \ln \frac{(273+35)}{(273+20)}$$

$$\Rightarrow \boxed{{}_2\dot{\sigma}_3 = 52.6\ kW/K}$$

Pump process (3 – 4)

$$\dot{S}_4 - \dot{S}_3 = \frac{\cancel{\dot{Q}}^{\,0}}{\cancel{T}} + {}_3\dot{\sigma}_4 \Rightarrow {}_3\dot{\sigma}_4 = \dot{m}(s_4 - s_3) = 0.816$$

Boiler process (4 – 1)

$$\dot{S}_1 - \dot{S}_4 = \frac{\dot{Q}}{T} + {}_4\dot{\sigma}_1 \Rightarrow {}_4\dot{\sigma}_1 = \dot{m}(s_1 - s_4) - \frac{\dot{Q}}{T} = \boxed{279.54\ kW/K}$$

4)

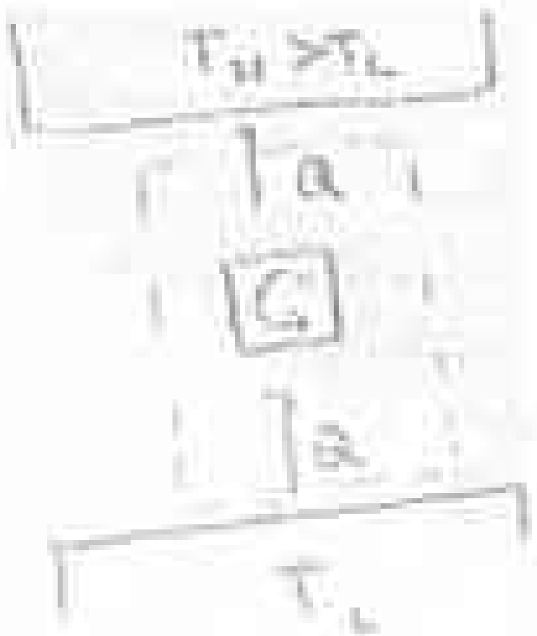
a) First law of thermodynamics states that energy can be neither generated nor destroyed but it is conserved in a process. It is also called conservation of energy

$$E_{gen} = 0 = (E_2 - E_1) - ({}_1Q_2 - {}_1W_2) = 0$$

2nd Law states the direction of a process and shows whether it is possible or not

$$S_{gen} = (S_2 - S_1) - \int \frac{\delta Q}{T} \geq 0$$

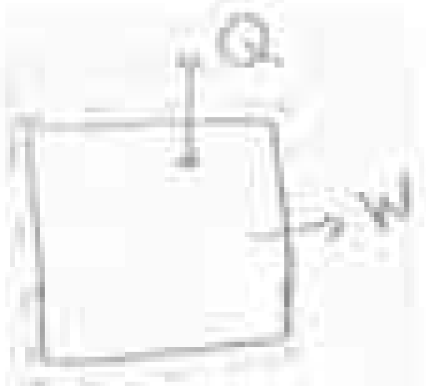
The heat transfer from a cold reservoir to a hot reservoir via a refrigerator whose work input is zero does not violate 1st law but it violates 2nd Law, hence, the statement of the problem is $\boxed{\text{False}}$. ✓



$$E_{gen} = \underbrace{(E_2 - E_1)}_{0} - \underbrace{(Q_{in} - Q_{out})}_{0} = 0 \ ✓$$

$$S_{gen} = \underbrace{(S_2 - S_1)}_{0} - \frac{Q}{T_L} + \frac{Q}{T_H} < 0 \ ✗$$

5)
b)



1st Law: $E_2 - E_1 = Q - W$

2nd Law: $S_{gen} = S_2 - S_1 - \int \frac{\delta Q}{T}$

i) assume no heat transfer

$E_2 - E_1 = -W \quad E_2 = E_1 - W$ } means that initial and final states are different

$S_{gen} = 0 = S_2 - S_1 \Rightarrow S_2 = S_1$ } means that initial and final states are same

Thus it is $\boxed{\text{not possible}}$ to have internally reversible process without heat transfer

ii) assume heat transfer from the system to surroundings

$E_2 - E_1 = Q - W \Rightarrow E_1 = E_2 - Q + W$ since $Q<0$

$\Rightarrow E_1 > E_2 \Rightarrow$ different initial and final state

$S_{gen} = 0 = S_2 - S_1 - \frac{Q}{T} \Rightarrow S_1 = S_2 - \frac{Q}{T}$ since $Q<0$

$\Rightarrow S_1 > S_2 \Rightarrow$ different initial and final state

so it is $\boxed{\text{possible}}$

iii) assume heat transfer to system

$E_2 - E_1 = Q - W \Rightarrow E_2 = E_1 + Q - W$ } different initial and final state

$S_{gen} = 0 = S_2 - S_1 - \frac{Q}{T} \Rightarrow S_2 = S_1 + \frac{Q}{T} \Rightarrow S_2 > S_1$ } different initial and final state

so it is $\boxed{\text{possible}}$ ✓

Hence, there must be a heat transfer to/from the system to have net amount of work in an internally reversible process.

4)
c) $\boxed{\text{False}}$ ✓ the second law of thermodynamics states that entropy generation of a system must be zero or positive. However, change of entrophy of a closed system can be negative as shown below.

$$S_{gen} = \underbrace{S_2 - S_1}_{\text{entrophy change}} - \frac{Q}{T}$$

$$\Rightarrow S_2 - S_1 = S_{gen} - \frac{Q}{T}$$

If heat is transfered from the system in a reversible process or when $S_{gen} < \frac{|Q|}{T}$, entrophy change of system becomes negative. ✓

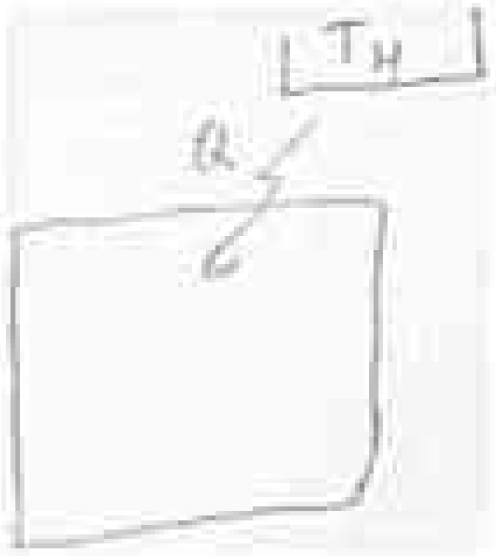
d) $\boxed{\text{False}}$ If there are irreversibilities other than heat transfer through finite temperature, there will be increase in entrophy such as

• Friction

• Unconstrained expansion

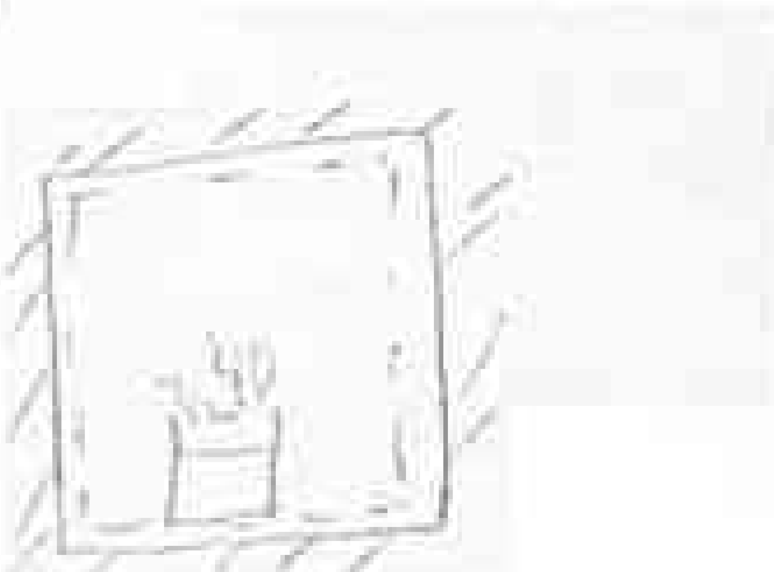
• Mixing

e) Entrophy can be produced by heat transfer through a finite temperature difference and internal irreversibilities such as friction, mixing of two different substances, mixing of same substance at different conditions and unrestrained expansion

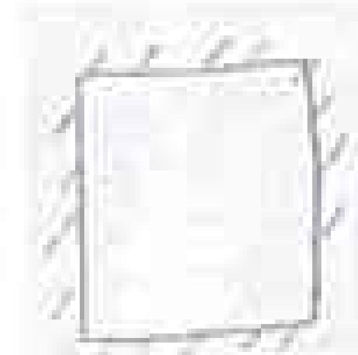


Thus, entrophy of a system can increase also with heat transfer and the result is $\boxed{\text{False}}$

f) $\boxed{\text{False}}$ Think of closed system where a fuel with air where the is going through combustion but it is not enthalphy is kept constant possible to reverse the process without external applications



4)
9)



isolated system: - no heat transfer
- no mass transfer

2nd Law: $S_{gen} = S_2 - S_1 - \cancel{\frac{Q}{T}}^{0}$

$\Rightarrow S_2 = S_1 + S_{gen}$

Since $S_{gen} \geq 0 \Rightarrow S_2 \geq S_1$

So the statement is correct. $\boxed{\text{True}}$

10/10

5) ... C: specific heat of liquid

Name, Surname: SOLUTION

ID:

Middle East Technical University Mechanical Engineering Department

ME 203 Thermodynamics – I Fall

Quiz 1 SOLUTION

Question 1: Describe the following:

(a) a system: A thermodynamic system, or simply system, is defined as a quantity of matter or a region in space chosen for study.

(b) an open system: An open system, or control volume, has mass as well as energy crossing the boundary, called a control surface.

(c) an isolated system: An isolated system is a general system of fixed mass where no heat or work may cross the boundaries.

(d) a closed system: A closed system consists of a fixed amount of mass and no mass may cross the system boundary. The closed system boundary may move.

(e) a property of a system: Any characteristic of a system in equilibrium is called a property. Properties are independent of the path used to arrive at the system condition.

Please state that the followings are properties (Y) or not properties (N) (in the bracelets). For the ones you have stated as properties, state that whether these properties are intensive (I) or extensive (E). *e.g. X (Y, E), for the extensive property X*

Pressure (Y, I), temperature (Y, I), mass (Y, E), volume (Y, E), density (Y, I), total energy (Y, E); kinetic energy (Y, E), potential energy (Y, E), heat transfer (N), work (N).

Question 2: As shown in Figure 1, a vertical piston-cylinder assembly containing a gas is placed on a hot plate. The piston initially rests on the stops. With the onset of heating, the gas pressure increases. At what pressure, in bar, does the piston start rising? The piston moves smoothly in the cylinder and $g = 9.81\ m/s^2$ *Hint: 1 bar = 100 kPa*

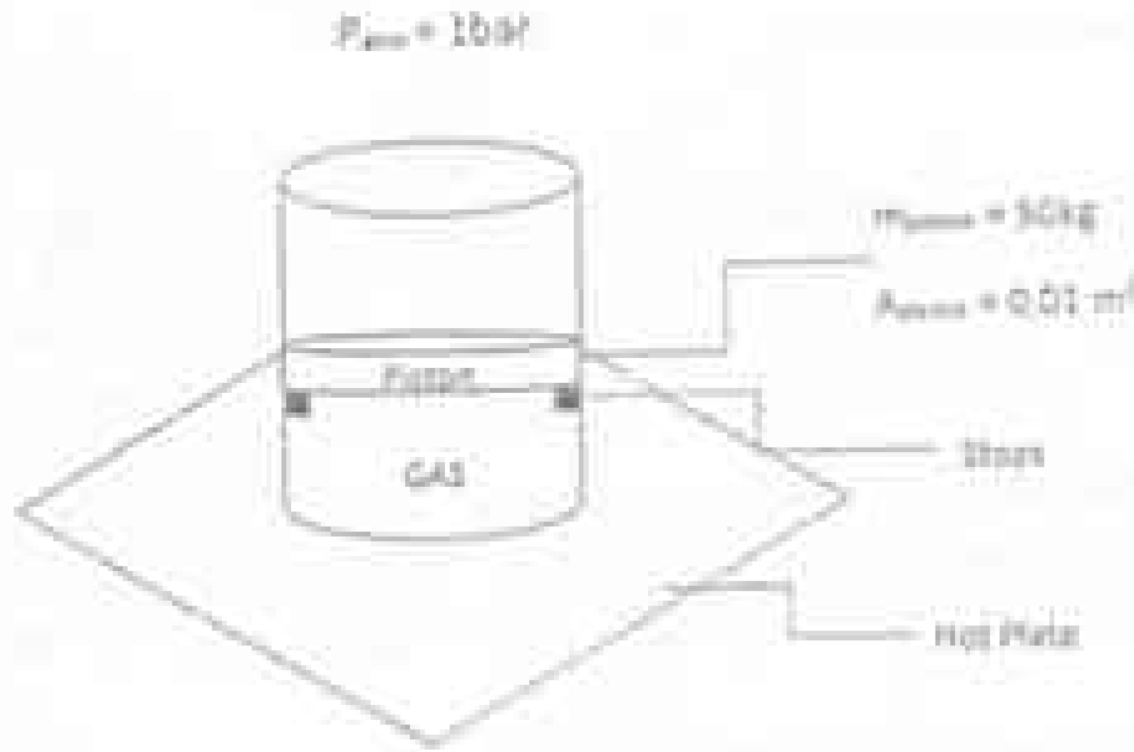


Figure 1. Piston-cylinder on hot plate

Question 2 Solution:

In order for piston to start moving, the pressure inside the cylinder should be equal to pressure acting on the piston.

Piston in mechanical equilibrium:

$P_{GAS}A_p = P_{atm} \cdot A_p + W$ where $W = m.g = (50kg).(9.81m/s^2) = 490.5\ N$

Divide both sides by A_p

$$P_{GAS} = P_{atm} + \frac{W}{A_p}$$

Substitute the numerical values

$$P_{GAS} = (1 bar) + \frac{490.5\,N}{0.01m^2}\frac{1\,bar}{(10^5 N/m^2)}$$

$$P_{GAS} = 1.49\ bar$$

Question 3: Oxygen (O_2) gas within a piston–cylinder assembly undergoes an expansion from a volume $V_1 = 0.01$ m^3 to a volume $V_2 = 0.03$ m^3. The relationship between pressure and volume during the process is $p = AV^{-1} + B$, where $A = 0.06$ bar.m^3 and $B = 3.0$ bar. For the O_2, determine

(a) the initial and final pressures, each in bar
(b) the work, in kJ.

Question 3 Solution:

(a) $P_1 = AV_1^{-1} + B = \frac{0.06\,bar.m^3}{0.01m^3} + 3.0bar = 9\ bar$

$$P_2 = AV_2^{-1} + B = \frac{0.06\,bar.m^3}{0.03m^3} + 3.0bar = 5\ bar$$

(b) $W = \int_{V_1}^{V_2} P.dV = \int_{V_1}^{V_2}\left(\frac{0.06}{V} + 3\right).dV = (0.06\ln(V) + 3.0V)|_{V_1}^{V_2} = 0.06\left(\ln\frac{V_2}{V_1}\right) + 3(V_2 - V_1)$

Substitute the values of V_1 and V_2

$$W = 0.06(bar.m^3)\left(\ln\frac{0.03m^3}{0.01m^3}\right) + (3.0bar)(0.03 - 0.01)(m^3) = 0.0659(bar.m^3) + 0.06bar.m^3$$

$$W = 0.1259\ bar.m^3 = 12.59\ kJ$$

Note that the unit conversion is done by:

$$(bar.m^3)\left(\frac{10^5 N/m^2}{1\,bar}\right)\left(\frac{1\,kJ}{10^3 N.m}\right)$$

Hint: $N/m^2 = Pa$ and $N = kg.m/s^2$ and $Joule(J) = Nm$

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ME 203 Thermodynamics - I

Quiz 2 SOLUTION

Question 1: A gas is contained in a vertical piston-cylinder assembly by a piston weighing 4,450 N and having a face area of 75 cm^2. The atmosphere exerts a pressure of 101.3 kPa on the top of the piston. An electrical resistor transfers energy to the gas in the amount of 5.3 kJ as the elevation of the piston increases by 0.6 m. The piston and cylinder are poor thermal conductors and friction can be neglected. Determine the change in internal energy of the gas in kJ, assuming it is the only significant internal energy of any component present. Clearly sketch the system showing all necessary information. Identify whether the system is an open or closed system (i.e. control volume or control mass.)

SOLUTION

Engineering Model

1. The system is the gas inside the piston cylinder (It is a closed system)
2. For the gas, ΔPE= 0, ΔKE= 0
3. Friction between piston and cylinder can be ignored.

1[st] Law for the system

$$(\Delta U)_{gas} = Q - W$$

The work done at the top of the piston in displacing the surrounding atmosphere

$$W = \int_{z_1}^{z_2}(P_{gas}A_{piston})dz = (P_{gas}A_{piston})(z_2 - z_1)$$

$$P_{gas} = P_{atm} + \frac{Piston\ weight}{Piston\ area} = 101.3kPa\left(\frac{1000Pa}{1kPa}\right) + \frac{4450N}{75cm^2}\left(\frac{10^4cm^2}{1m^2}\right) = 694.63\ kPa$$

$$W = (694.63kPa)(75cm^2)\left(\frac{1m^2}{10^4cm^2}\right)(0.6m) = 3.126kJ$$

Substitute the values into 1[st] Law

$$(\Delta U)_{gas} = 5.3kJ - 3.126kJ = 2.174kJ$$

Question 2: Figure 1 shows two power cycles, A and B, operating in series, with the energy transfer by heat into cycle B equal in magnitude to the energy transfer by heat from cycle A. All energy transfers are positive in the directions of the arrows. Determine an expression for the thermal efficiency of an overall cycle consisting of cycles A and B together in terms of their individual thermal efficiencies.

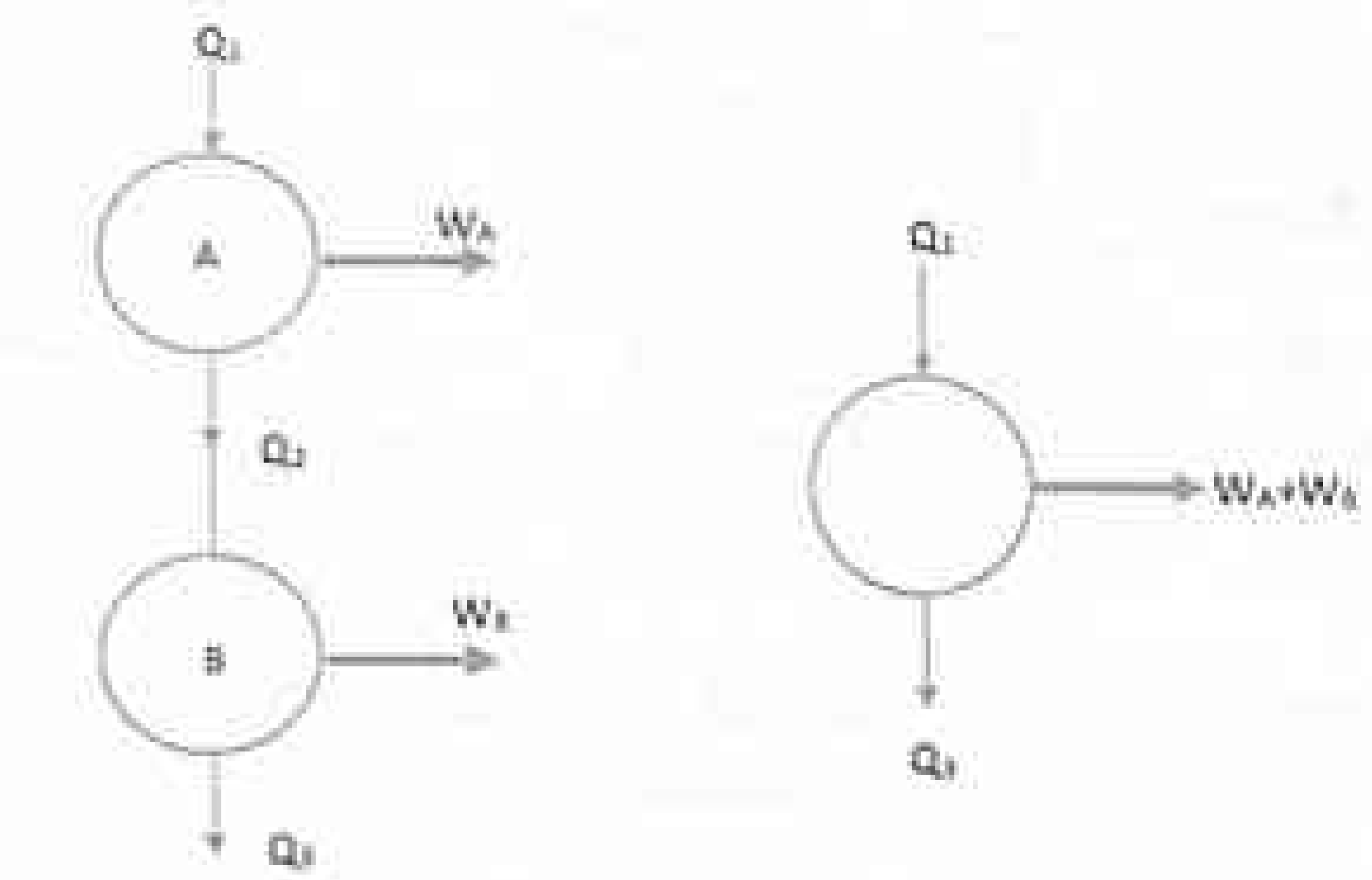

Figure 1. (a) A and B in series (b) Overall cycle

SOLUTION:

Efficiency of any cycle: $\frac{desired\ output}{required\ input}$ and for a power cycle: $\eta = \frac{work\ output}{heat\ input}$

Note that for a cycle ΔE = 0, so ΔQ=ΔW from 1st Law

Efficiency of cycle A:

$$\eta_A = \frac{W_A}{Q_1} = \frac{Q_1 - Q_2}{Q_1} = 1 - \frac{Q_2}{Q_1} \Rightarrow Q_2 = (1-\eta_A)Q_1 \tag{1}$$

Similarly,

$$\eta_B = \frac{W_B}{Q_2} = \frac{Q_2 - Q_3}{Q_2} = 1 - \frac{Q_3}{Q_2} \Rightarrow Q_2 = \frac{Q_3}{(1-\eta_B)} \tag{2}$$

By equating (1) & (2):

$$(1-\eta_A)Q_1 = \frac{Q_3}{(1-\eta_B)} \quad \Rightarrow \quad \frac{Q_3}{Q_1} = (1-\eta_A)(1-\eta_B) \tag{3}$$

Efficiency for overall cycle:

$$\eta_{overall} = \frac{W_A + W_B}{Q_1} = \frac{Q_1 - Q_3}{Q_1} = 1 - \frac{Q_3}{Q_1} \tag{4}$$

Substitute (3) in (4)

$$\eta_{overall} = (1-\eta_A)(1-\eta_B)$$

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ME 203 Thermodynamics – I

Quiz 3 SOLUTION

Question 1: Air contained in a piston–cylinder assembly, initially at 2 bar, 200 K, and a volume of 1 L, undergoes a process to a final state where the pressure is 8 bar and the volume is 2 L. During the process, the pressure–volume relationship is linear. Assuming the ideal gas model for the air, determine the work and heat transfer, each in kJ.

(a) By assuming constant specific heats (Use the specific heat value at 300K)
(b) By assuming varible specific heats
(c) Comment on the two results, which one is more accurate?

Sketch the system clearly. (Note that R_{air} = 287.058 J/kg K and 1bar = 100kPa)

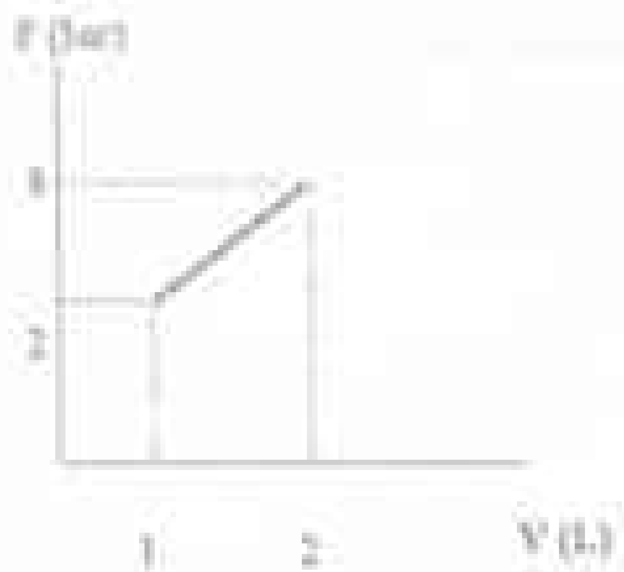
SOLUTION:

$$P_1V_1 = mR_{air}T_1 \Rightarrow m = \frac{P_1V_1}{R_{air}T_1} = \frac{(2bar)\left(\frac{100kPa}{1bar}\right)\left(\frac{10^3Pa}{1kPa}\right)(1L)\left(\frac{1m^3}{1000L}\right)}{\left(287.058\frac{J}{kgK}\right)(200K)} = 0.00348\ kg$$

$$Note\ that: J = Nm\ and\ Pa = \frac{N}{m^2}$$

Also,

$$P_2V_2 = mR_{air}T_2 \Rightarrow T_2 = \frac{P_2V_2}{mR_{air}} = \frac{(8bar)\left(\frac{100kPa}{1bar}\right)\left(\frac{10^3Pa}{1kPa}\right)(2L)\left(\frac{1m^3}{1000L}\right)}{\left(287.058\frac{J}{kgK}\right)(0.00348kg)} = 1600K$$



The area under the P-V graph gives us the work

$W = \frac{1}{2}(8+2)bar(2-1)L\left(\frac{100kPa}{1bar}\right)\left(\frac{1m^3}{1000L}\right)$

$W = \mathbf{0.5kJ}$

1[st] Law: $Q - W = \Delta U$

(a)

Assuming constant specific heats : $\Delta U = mc_v(T_2 - T_1)$

From Table A-20 for air @300 K c_v = 0.718 kJ/kg K

$$\Delta U = (0.00348\ kg)\left(0.718\frac{kJ}{kgK}\right)(1600 - 200)K = 3.502kJ$$

$$Q = W + \Delta U = 0.5 + 3.502 = \mathbf{4.002kJ}$$

(b) Assuming variable specific heats : : $\Delta U = m(u_{@T_2} - u_{@T_1})$

From Table A-22

$$u_{@1600K} = 1298.30kJ/kg$$

$$u_{@200K} = 142.56kJ/kg$$

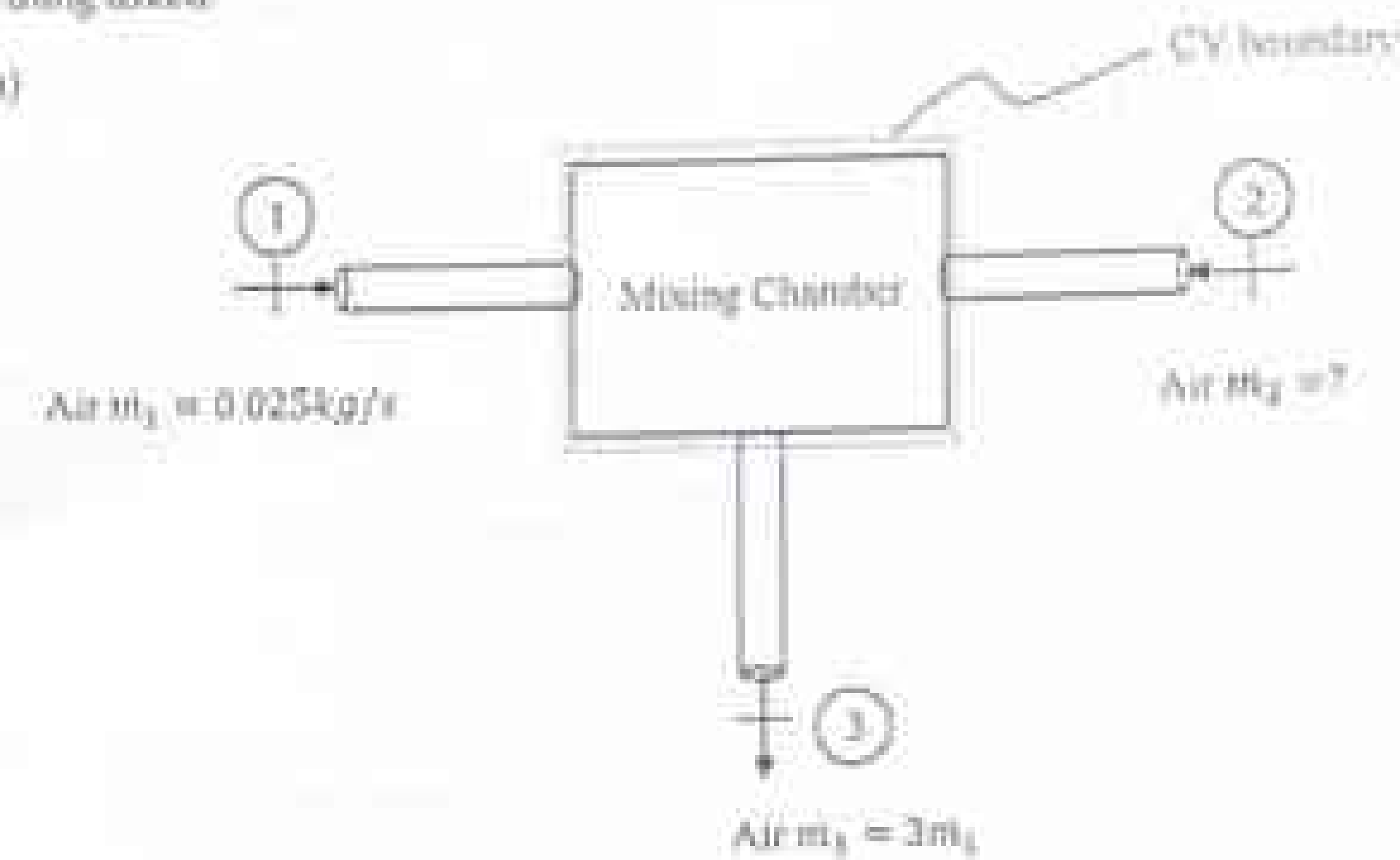
$$U = (0.00348\ kg)(1298.30 - 142.56)kJ/kg = 4.022kJ$$

$$Q = W + \Delta U = 0.5 + 4.022 = \mathbf{4.522kJ}$$

(c) Assuming variable specific heats gives more accurate result because specific heats are temperature dependent.

Question 2: For the following systems write the mass balance equation and determine everything asked.

(a)

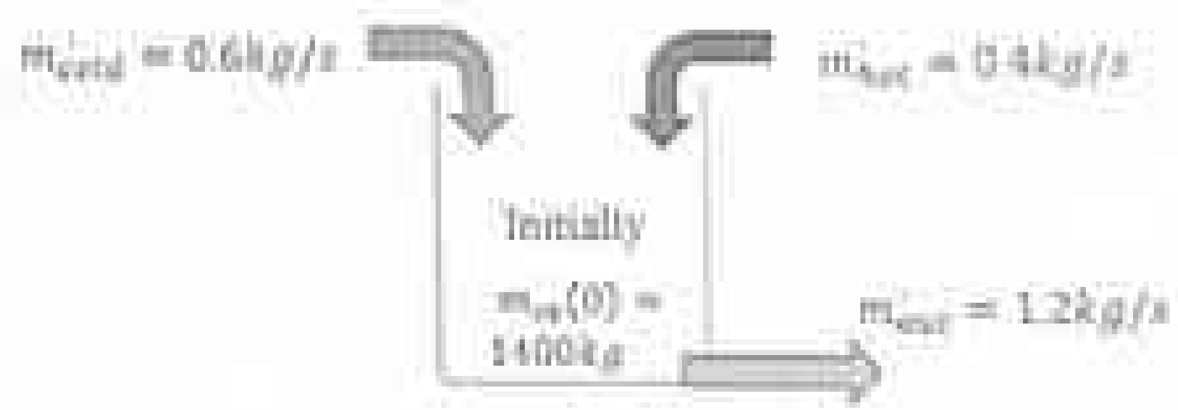


$$\frac{dm_{CV}}{dt} = \sum_i \dot m_i - \sum_e \dot m_e \quad \textit{The control volume is at steady state} \Rightarrow \frac{dm_{CV}}{dt} = 0$$

$$\Rightarrow \sum_i \dot m_i = \sum_e \dot m_e$$

$$\dot m_1 + \dot m_2 = \dot m_3 \Rightarrow \dot m_2 = \dot m_3 - \dot m_1 = 2\dot m_1 = \mathbf{0.05kg/s}$$

(b) A mixing tank initially contains 1400 kg of liquid water. The tank is fitted with two inlet pipes, one delivering hot water at a mass flow rate of 0.4 kg/s and other delivering cold water at a mass flow rate of 0.6 kg/s. Water exits through a single pipe at a mass flow rate of 1.2kg/s. Determine the amount of water in the tank, in kg, after one hour. Clearly sketch the problem and identify the system.



$$\frac{dm_{CV}}{dt} = \sum_i \dot m_i - \sum_e \dot m_e$$

Take the integral of both sides.

$$\int_0^t dm_{cv} = \int_0^t \left(\sum_i \dot m_i\right)dt - \int_0^t \left(\sum_e \dot m_e\right)dt$$

$$\int_0^t dm_{cv} = \int_0^t (\dot{m}_{cold} + \dot{m}_{hot} - \dot{m}_{out})dt$$

$$m_{cv}(t) - m_{cv}(0) = (\dot{m}_{cold} + \dot{m}_{hot} - \dot{m}_{out})\,t$$
$$\Rightarrow m_{cv}(t) = m_{cv}(0) + (\dot{m}_{cold} + \dot{m}_{hot} - \dot{m}_{out})\,t$$

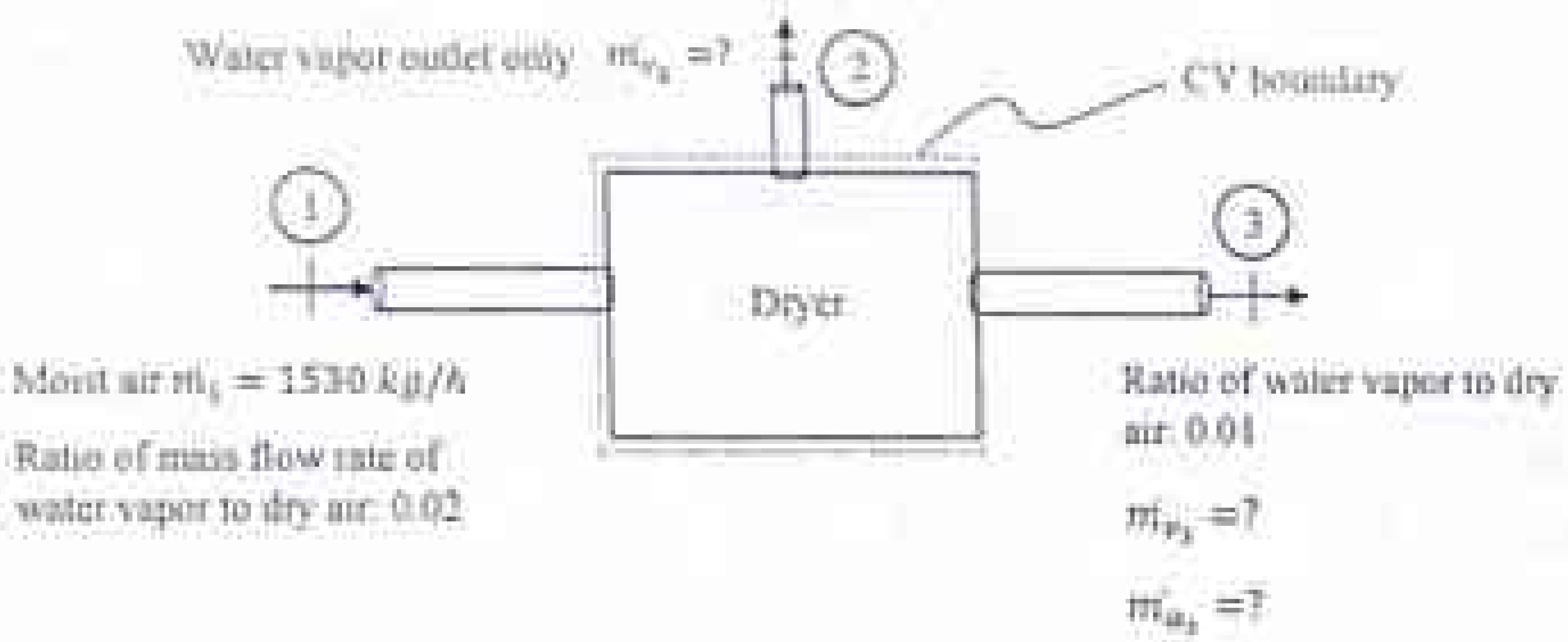
Note that $t = 1hour = 3600$ seconds

Substitute the known values:

$$m_{cv}(t) = 1400kg + (0.6 + 0.4 - 1.2)\left(\frac{kg}{s}\right)(3600s) = (1400 - 720)kg$$

$$m_{cv}(t) = \mathbf{680\ kg}$$

(c) As shown in figure below moist air gets into the dryer and in the dryer some of the water vapor is removed. Find the dry air and water vapor mass flow rate, in kg/h, at outlets 2 and 3.



$$\frac{dm_{CV}}{dt} = \sum_i \dot{m}_i - \sum_e \dot{m}_e \qquad \textit{The control volume is at steady state} \Rightarrow \frac{dm_{CV}}{dt} = 0$$

$$\Rightarrow \sum_i \dot{m}_i = \sum_e \dot{m}_e$$

We should write mass balance equation separately for dry air and water vapor

<u>For dry air:</u>

Through exit 2, only water vapor exits, therefore

$$\dot{m}_{1_{air}} = \dot{m}_{3_{air}} \qquad (1)$$

<u>For water vapor:</u>

$$\dot{m}_{1_{vapor}} = \dot{m}_{2_{vapor}} + \dot{m}_{3_{vapor}} \qquad (2)$$

For the inlet (1):

Moist air : dry air with water vapor

$$\dot{m}_1 = \dot{m}_{1_{vapor}} + \dot{m}_{1_{air}} = 1530\frac{kg}{h} \qquad (3)$$

$$\frac{\dot{m}_{1_{vapor}}}{\dot{m}_{1_{air}}} = 0.02 \Rightarrow \dot{m}_{1_{vapor}} = 0.02\dot{m}_{1_{air}} \qquad (4)$$

Substitute (4) into (3):

$$\dot{m}_{1_{air}} + 0.02\dot{m}_{1_{air}} = 1530kg/h \Rightarrow \dot{m}_{1_{air}} = \mathbf{1500}\boldsymbol{kg/h}$$
$$\Rightarrow \dot{m}_{1_{vapor}} = \mathbf{30}\boldsymbol{kg/h}$$

From equation (1):

$$\dot{m}_{1_{air}} = \dot{m}_{3_{air}} = \mathbf{1500}\boldsymbol{kg/h}$$

For the outlet (3):

$$\frac{\dot{m}_{3_{vapor}}}{\dot{m}_{3_{air}}} = 0.01 \qquad \Rightarrow \qquad \dot{m}_{3_{vapor}} = 0.01\dot{m}_{3_{air}} = (0.01)\left(1500\frac{kg}{h}\right) = \mathbf{15}\boldsymbol{kg/h}$$

From equation (2):

$$\dot{m}_{2_{vapor}} = \dot{m}_{1_{vapor}} - \dot{m}_{3_{vapor}} = (30 - 15)\,kg/h = \mathbf{15}\boldsymbol{kg/h}$$

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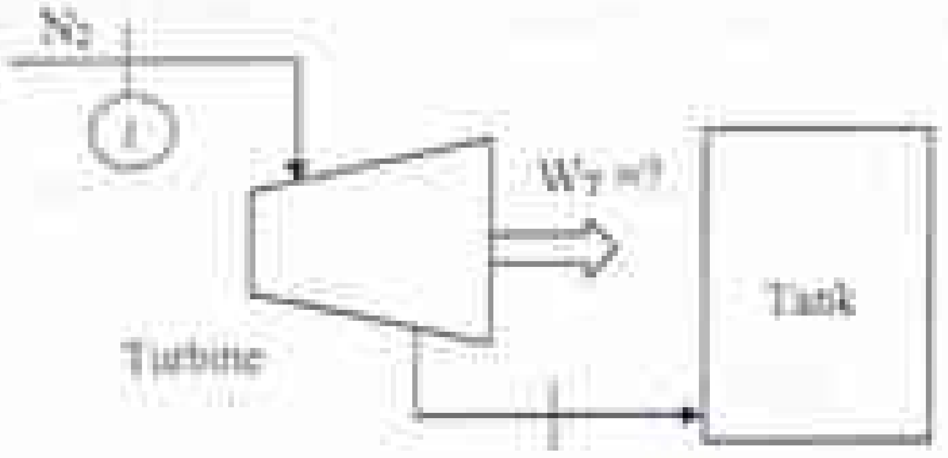
ME 203 Thermodynamics – 1

Quiz 4 SOLUTION

Question 1: A nitrogen line at 300 K, 0.6 MPa, shown in the figure, is connected to a turbine that exhausts to a closed, initially empty tank of 50 m^3. The turbine operates to a tank pressure of 0.6 MPa, at which point the temperature is 250 K. Assuming the entire process is adiabatic, determine the turbine work.
Write down the mass balance and energy balance equations. Clearly show your system

Note that the table for Nitrogen is given at the back page.



SOLUTION:

Given:

- Inlet properties: $P_i = 0.6MPa = 600kPa$
  $T_i = 300K$
- Initially the tank is empty
- Tank volume is constant and $V = 50m^3$
- Properties for the final state of the tank: $P_f = 0.6MPa = 600kPa$
  $T_f = 250K$

(Note that subscript f denotes the final state of the tank and subscript i denotes the inlet of the turbine)

Select control volume as turbine & tank together

Mass balance:

$$\frac{dm_{cv}}{dt} = \sum_i m_i - \sum_e m_e$$

$$\int_0^t dm_{cv} = \int_0^t \left(\sum_i m_i\right) dt - \int_0^t \left(\sum_e m_e\right) dt$$

Since we consider the turbine and the tank together, there is no exit flow.

Integrate both sides of the equation:

$$m_{cv}(t) = m_f = m_{inlet} = m$$

Energy balance

$$\frac{dE_{CV}}{dt} = Q_{CV} - W_{CV} + \sum_i m_i\left(h_i + \frac{V_i^2}{2} + gz_i\right) - \sum_e m_e\left(h_e + \frac{V_e^2}{2} + gz_e\right)$$

Assume KE and PE are negligible, system is adiabatic so $\dot{Q}_{CV} = 0$

Integrate both sides of the energy balance equation

$$E_2 - E_1 = m_i h_i - W_T$$

Since the tank is initially empty $E_1 = 0$ and there is no exit flow for the combined control volume

$$m_f u_f = m_i h_i - W_T$$

$$W_T = m(h_i - u_f)$$

From Table B.6.2

$\left.\begin{array}{l} P_i = 600\ kPa \\ T_i = 300\ K \end{array}\right\}$ $h_i = 310.06 kJ/kg$

$\left.\begin{array}{l} P_f = 600\ kPa \\ T_f = 250\ K \end{array}\right\}$ $u_f = 183.62\ kJ/kg$, $v_f = 0.12308\ m^3/kg$

$$m_f = m = \frac{V}{v_2} = \frac{50\ m^3}{0.12308\ m^3/kg} = 406.24\ kg$$

Substitute the numerical values to find work:

$$W_T = (406.2kg)(310.06 - 183.62)kJ/kg$$

$$W_T = 51365\ kJ = 51.37\ MJ$$

TABLE A-19 (continued)
Superheated Nitrogen

Temp. (K)	v (m^3/kg)	u (kJ/kg)	h (kJ/kg)	s (kJ/kg·K)	v (m^3/kg)	u (kJ/kg)	h (kJ/kg)	s (kJ/kg·K)
	400 kPa (91.22 K)				600 kPa (96.37 K)			
Sat.	0.05992	64.23	88.19	5.1264	0.03996	62.37	86.35	5.0411
100	0.06806	69.70	96.92	5.2466	0.04299	66.41	92.25	5.0957
120	0.08486	85.48	119.42	5.4156	0.05510	83.78	116.79	5.3204
140	0.10085	101.06	141.40	5.5250	0.06620	99.75	139.47	5.4453
160	0.11647	116.38	162.94	5.7090	0.07689	115.34	161.47	5.6422
180	0.13186	131.55	184.30	5.8447	0.08734	130.69	183.10	5.7696
200	0.14712	146.64	205.49	6.0563	0.09766	145.95	204.50	5.8823
220	0.16225	161.68	226.59	6.1005	0.10788	161.04	225.76	5.9837
240	0.17730	176.67	247.62	6.1998	0.11803	176.11	246.92	6.0757
260	0.19230	191.64	268.61	6.2854	0.12813	191.13	268.01	6.1601
280	0.20725	206.58	289.48	6.3460	0.13820	206.15	289.05	6.2383
300	0.22244	221.52	310.50	6.4322	0.14824	221.11	310.06	6.3109
350	0.25982	258.91	362.76	6.5934	0.17326	258.52	362.48	6.4722
400	0.29712	296.23	415.10	6.7331	0.19819	295.97	414.89	6.6121
450	0.33437	333.81	467.56	6.8567	0.22308	333.37	467.42	6.7359
500	0.37156	371.65	520.28	6.9678	0.24792	371.48	520.20	6.8471
600	0.44593	448.25	626.59	7.1622	0.29755	448.49	626.83	7.0416
700	0.52023	525.59	735.68	7.3299	0.34712	527.43	735.70	7.2093
800	0.59451	608.92	846.72	7.4781	0.39666	608.92	846.82	7.3576
900	0.66876	692.67	960.19	7.6117	0.44618	692.59	960.30	7.4912
1000	0.74302	778.68	1075.89	7.7335	0.49568	778.63	1076.22	7.6131
	800 kPa (100.38 K)				1000 kPa (103.73 K)			
Sat.	0.03038	62.21	87.52	4.9768	0.02416	63.19	87.35	4.9237
120	0.04017	81.49	114.02	5.2191	0.03157	79.94	111.06	5.1357
140	0.04886	98.43	137.30	5.4062	0.03845	97.02	135.47	5.3253
160	0.05710	114.28	159.95	5.5361	0.04522	113.20	158.42	5.4772
180	0.06509	129.82	181.89	5.6703	0.05173	128.94	180.67	5.6082
200	0.07293	145.13	203.51	5.7953	0.05809	144.43	202.52	5.7234
220	0.08067	160.40	228.94	5.8954	0.06436	159.76	224.11	5.8263
240	0.08835	175.54	246.23	5.9886	0.07055	174.98	245.53	5.9168
260	0.09599	190.67	267.45	6.0728	0.07670	190.13	266.83	6.0047
280	0.10358	205.68	288.54	6.1511	0.08281	205.23	288.04	6.0831
300	0.11115	220.70	309.62	6.2228	0.08889	220.29	309.18	6.1562
350	0.12998	258.19	362.17	6.3828	0.10401	257.86	361.87	6.3181
400	0.14875	295.69	414.68	6.5260	0.11905	295.42	414.47	6.4593
500	0.18609	371.29	520.12	6.7613	0.14899	371.14	520.04	6.6947
600	0.22335	448.24	626.93	6.9560	0.17883	448.09	626.92	6.8895
700	0.26056	527.34	735.79	7.1237	0.20862	527.19	735.85	7.0573
800	0.29773	608.79	846.91	7.2721	0.23837	608.83	847.00	7.2057
900	0.33488	692.52	960.43	7.4058	0.26810	692.48	960.54	7.3394
1000	0.37202	778.55	1076.18	7.5275	0.29782	778.45	1076.30	7.4644

QUİZ

Q1) A gas in a piston cylinder assembly undergoes an expansion process for which the relationship between pressure and volume is given by

$$pV^n = constant$$

The initial pressure is 4 *bar*. The initial volume is 0.2 m^3. The final volume is 0.5 m^3.

Determine the work for the process in *kJ* if

a) n = 1.2

b) n = 1

(Note: 1*bar* = 100*kPa*)

a) $W=\int_{V_1}^{V_2} p\,dV = \int_{V_1}^{V_2} cst\,V^{-n}\,dV = \frac{cst.\,V^{1-n}}{1-n}\Bigg|_{V=V_1}^{V=V_2} = \frac{cst\,V_2^{1-n} - cst\,V_1^{1-n}}{1-n}$

$W=\frac{(P_2V_2^n)V_2^{1-n} - (P_1V_1^n)V_1^{1-n}}{1-n} = \frac{P_2V_2 - P_1V_1}{1-n}$, P_2 is required to find W

$\underbrace{P_2}\underbrace{V_2}_{0.5m^3}^{n\to 1.2} = \underbrace{P_1}_{400kPa}\underbrace{V_1}_{0.2m^3}^{n\to 1.2} \Rightarrow P_2 = 133.2\,kPa$

$\Rightarrow \boxed{W = 67\,kJ}$ //

b) $W=\int_{V_1}^{V_2} p\,dV = \int_{V_1}^{V_2} cst\,\frac{dV}{V} = cst\,\ln(V)\Big|_{V=V_1}^{V=V_2} = (\underbrace{P_1}_{400kPa}\underbrace{V_1}_{0.2m^3})\,\ln\left(\frac{V_2}{V_1}\right)$ (V_2: 0.5 m^3, V_1: 0.2 m^3)

$\Rightarrow \boxed{W = 73.3\,kJ}$ //

e)

Air flowing in a converging nozzle

f)

Boiling water. The cup is open to surroundings.

Note: The system can be open or closed, depending on your system (CV) selection.

g)

Boiling water. The cup is not open to surroundings.

Q2) Classify as "extensive property", "intensive property" or "not property".

Mass → Extensive property

Volume → Extensive property

Work → Not property

Energy → Extensive property

Pressure → Intensive property

Temperature → Intensive property

Heat → Not property

Name Surname:

ID:

30.10.2019

Wednesday

ME203 THERMODYNAMICS 1

FALL 2019, Section 3

Quiz 2

Q1) A gas expands in a piston-cylinder assembly from $p_1 = 8\ bar$, $V_1 = 0.02\ m^3$ to $p_2 = 2\ bar$ in a process during which the relation between pressure and volume is $pV^{1.2} = constant$. The mass of the gas is $0.25\ kg$. If the specific internal energy of the gas decreases by $55\ kJ/kg$ during the process, determine the heat transfer, in kJ. Kinetic and potential energy effects are negligible. Sketch the schematic diagram of the question. Show your system and system boundary, clearly.

$$W = \int_{V_1}^{V_2} p\,dV = \int_{V_1}^{V_2} cst\,V^{-n}\,dV = cst\left.\frac{V^{1-n}}{1-n}\right|_{V=V_1}^{V=V_2}$$

$$W = \frac{cst\,V_2^{1-n} - cst\,V_1^{1-n}}{1-n} = \frac{(p_2V_2^n)V_2^{1-n} - (p_1V_1^n)V_1^{1-n}}{1-n}$$

$$W = \frac{p_2V_2 - p_1V_1}{1-n}$$, V_2 is required to find W.

$$p_1V_1^n = p_2V_2^n \quad (n \to 1.2) \Rightarrow V_2 = 0.0635\,m^3$$

$p_1 \to 8\,bar$, $V_1 \to 0.02\,m^3$, $p_2 \to 2\,bar$

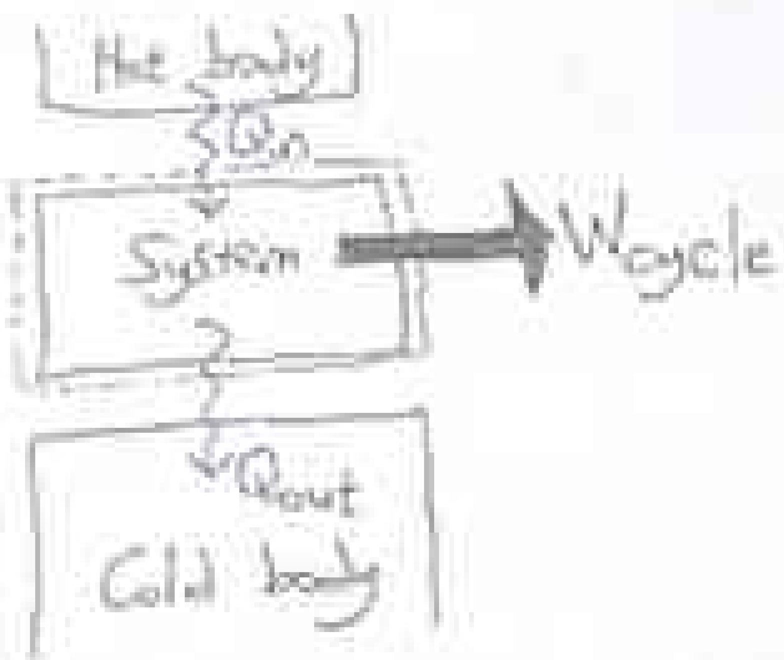
$$\Rightarrow W = 16.5\ kJ$$

Energy balance; $\Delta E = Q - W \to \underbrace{\Delta KE}_{\cong 0} + \underbrace{\Delta PE}_{\cong 0} + \Delta U = Q - W$

$$\underbrace{m}_{0.25\,kg}\underbrace{(u_2 - u_1)}_{-55\,kJ/kg} = Q - \underbrace{W}_{16.5\,kJ} \Rightarrow \boxed{Q = 2.75\ kJ}$$ //

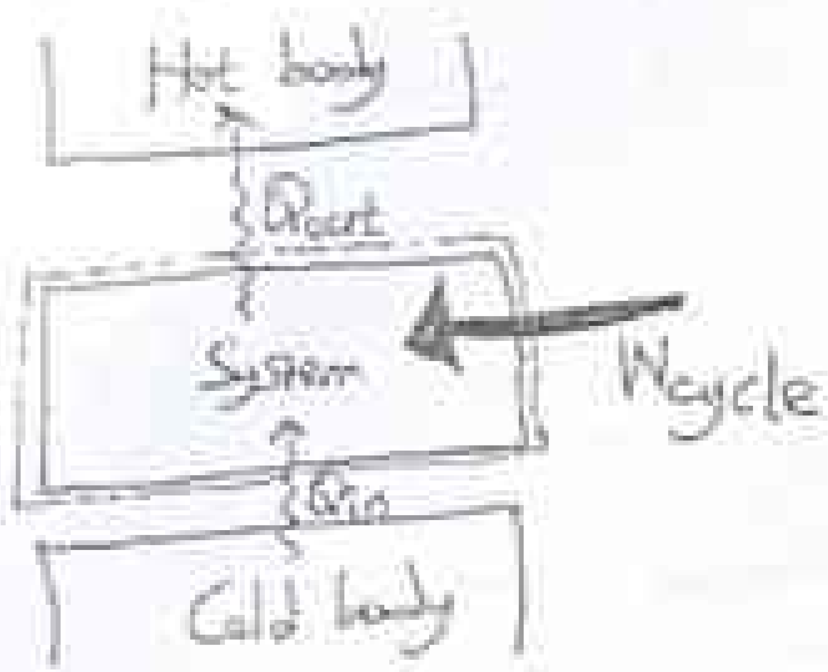
Q2)

a) Sketch the schematic diagram of a power cycle. What is the thermal efficiency of the system?



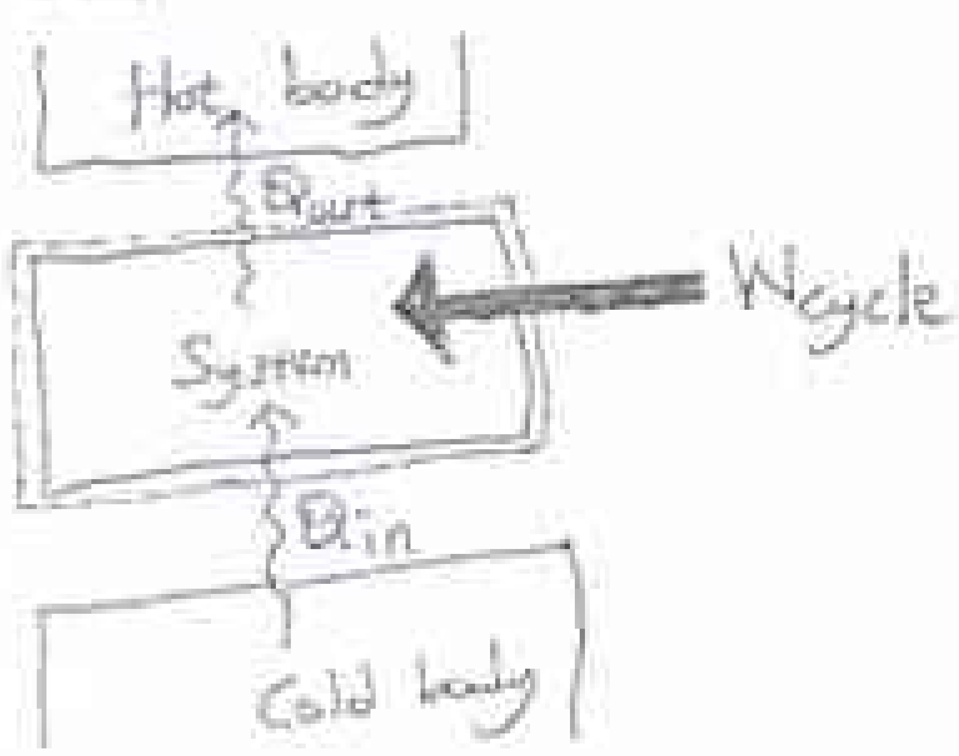
$$\eta = \frac{W_{cycle}}{Q_{in}}$$

b) Sketch the schematic diagram of a refrigeration cycle. What is the coefficient of performance of the system?



$$\beta = \frac{Q_{in}}{W_{cycle}}$$

c) Sketch the schematic diagram of a heat pump cycle. What is the coefficient of performance of the system?



$$\beta = \frac{Q_{out}}{W_{cycle}}$$

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Wednesday

ME203 THERMODYNAMICS 1

FALL 2019, Section 3

Quiz 3

Q1) A closed, rigid container of volume $0.6\ m^3$ is placed on a hot plate. Initially, the container holds a two-phase mixture of saturated liquid water and saturated water vapor at $p_1 = 2\ bar$ with a quality of 0.3. After the first heating, the pressure in the container is $p_2 = 5\ bar$. After the second heating, the pressure in the container is $p_3 = 10\ bar$. Kinetic and potential energy change can be neglected.

a) Indicate all three states on a $T - v$ diagram. Show all the temperature, pressure and specific volume values on the $T - v$ diagram.

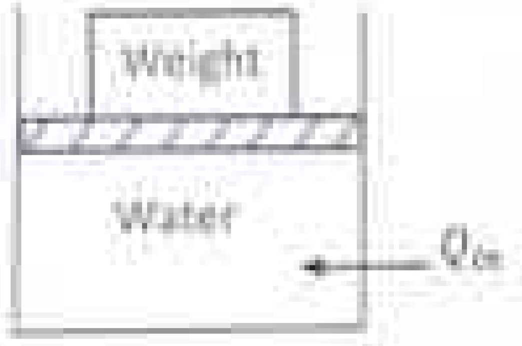
b) $u_3 = 1111.993\ kJ/kg$. Find the heat transfer per unit mass to the plate.

Q2) Water is placed in a piston-cylinder device at 20°C, 4 MPa. Weights are placed on the piston to maintain a constant force on the water as it is heated to 400°C. Kinetic and potential energy change can be neglected.

a) How much work does the water do on the piston, per unit mass?

b) Sketch the $P-v$ diagram and $T-v$ diagram. Show all the temperature, pressure and specific volume values on the diagrams.

c) Find the heat transfer per unit mass to the piston-cylinder system.



Q1) $P_1 = 2\,bar,\ x_1 = 0.3$

From TABLE A-3,

$$\left[\begin{array}{l} v_f = 1.0605\times10^{-3}\ \frac{m^3}{kg} \\ v_g = 0.8857\ \frac{m^3}{kg}\end{array}\right]$$

$$v_1 = v_f + x(v_g - v_f)$$

$$\boxed{v_1 = 0.26645\ \frac{m^3}{kg}}$$

$$\left[\begin{array}{l} u_f = 504.49\ kJ/kg \\ u_g = 2529.5\ kJ/kg\end{array}\right]$$

$$u_1 = u_f + x(u_g - u_f)$$

$$\boxed{u_1 = 1111.993\ kJ/kg}$$

State 1 is in the two-phase region

$P_2 = 5\,bar$

$v_2 = v_1$; closed, rigid container

From TABLE A-3,

State 2 is in the two-phase region.

$P_3 = 10\,bar$

$v_3 = v_1$; closed, rigid container

From TABLE A-4

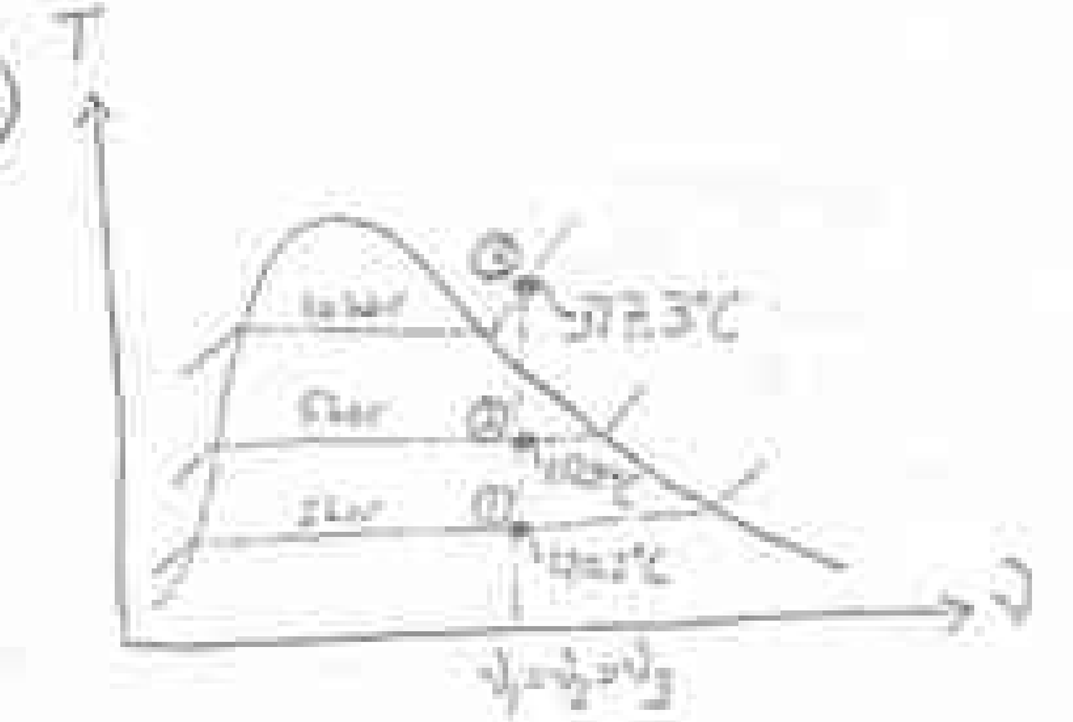
State 3 is in the superheated region.

Interpolation btw 280°C and 320°C ;

$v\ (m^3/kg)$	$u\ (kJ/kg)$
0.2480	2760.2
0.26645	u_3
0.2678	2826.1

$$\Rightarrow \boxed{u_3 = 2821.607\ kJ/kg}$$

c)



b) $\Delta E = Q - W$

$$\underbrace{\Delta KE}_{\cong 0} + \underbrace{\Delta PE}_{\cong 0} + \Delta U = Q - \underbrace{W}_{=0}$$

$$m(u_3 - u_1) = Q$$

$$u_3 - u_1 = \frac{Q}{\underbrace{m}_{\text{take } m = 1\,kg \text{ (per unit mass)}}} \Rightarrow \boxed{Q = 1709.614\ kJ} \text{ per unit mass}$$

Q2) 20°C, 4MPa

From TABLE A-5,

$P(MPa)$	$v\,(m^3/kg)$	$u\,(kJ/kg)$
2.5	1.0006×10^{-3}	83.80
4	v_1	u_1
5	0.9995×10^{-3}	83.65

$\Rightarrow v_1 = 0.9994\times10^{-3}\ m^3/kg$

$\Rightarrow u_1 = 83.71\ kJ/kg$

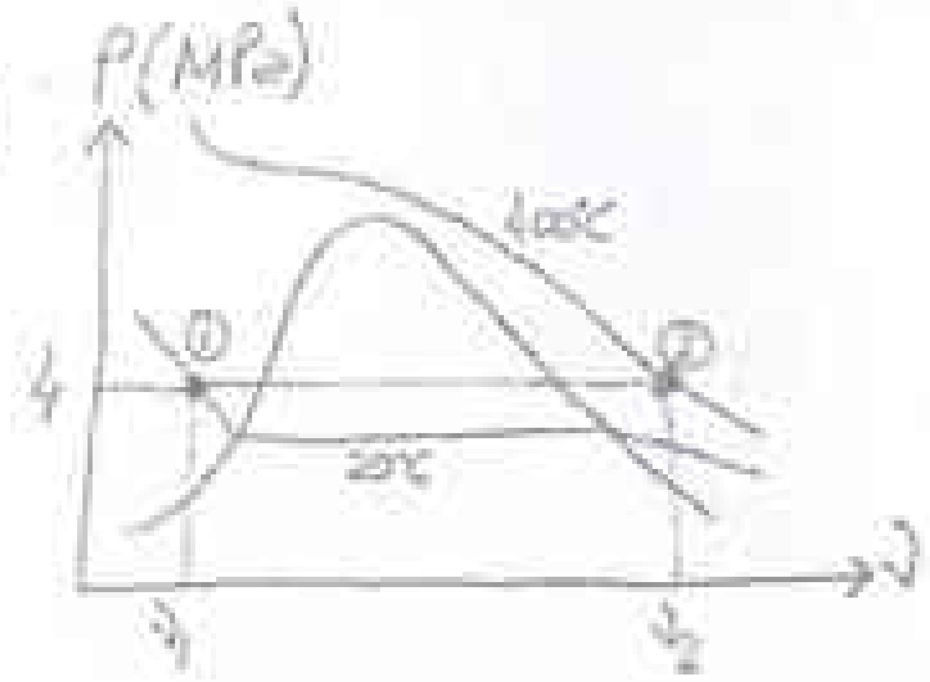
400°C, 4MPa

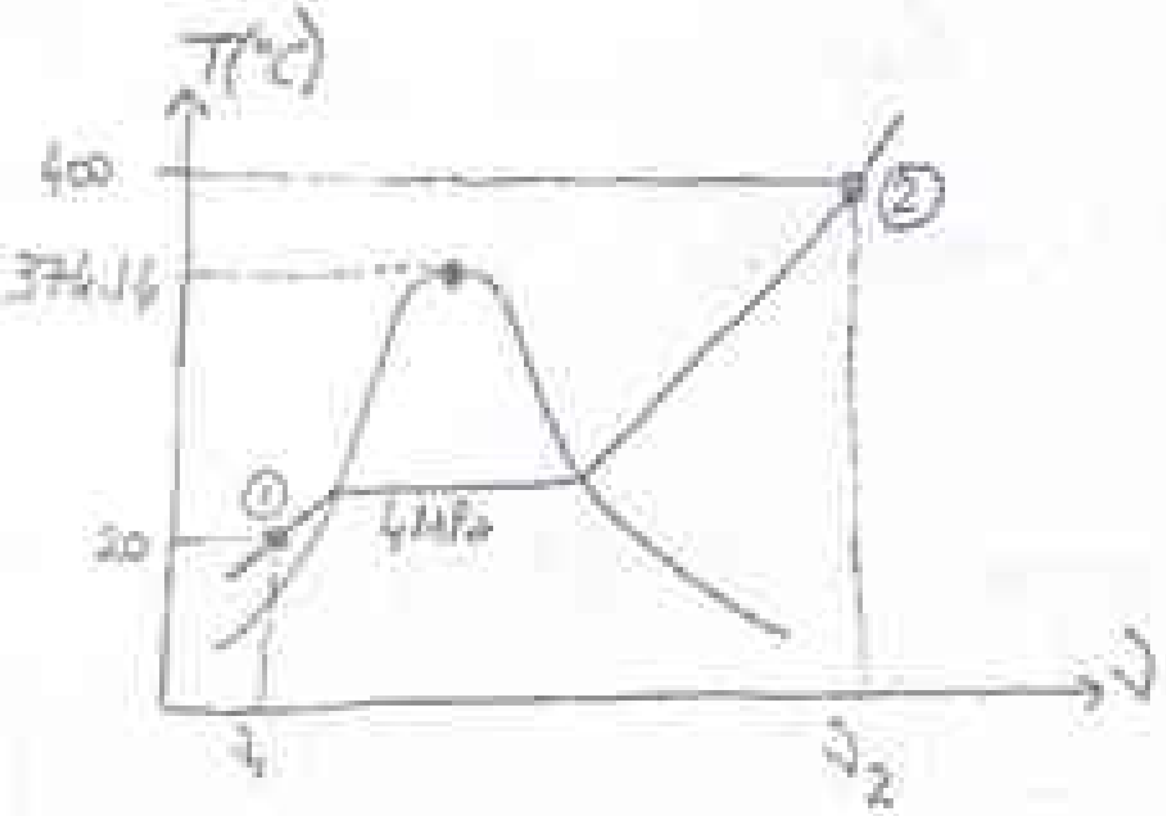
From TABLE A-4, $v_2 = 0.07341\ \frac{m^3}{kg}$, $u_2 = 2919.9\ \frac{kJ}{kg}$

---

a) $W = \int_{v_1}^{v_2} p\,dv = p(v_2 - v_1) = \boxed{289.64\ kJ}$ per unit mass

b)





c) $\Delta E = Q - W$

$\underbrace{\Delta KE}_{\cong 0} + \underbrace{\Delta PE}_{\cong 0} + \Delta U = Q - W$

$m(u_2 - u_1) = Q - p\,m(v_2 - v_1)$

$u_2 - u_1 = \frac{Q}{m} - p(v_2 - v_1) \Rightarrow \boxed{Q = 3125.83\ kJ}$ per unit mass

take m=1kg (per unit mass)

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Monday

ME203 THERMODYNAMICS 1

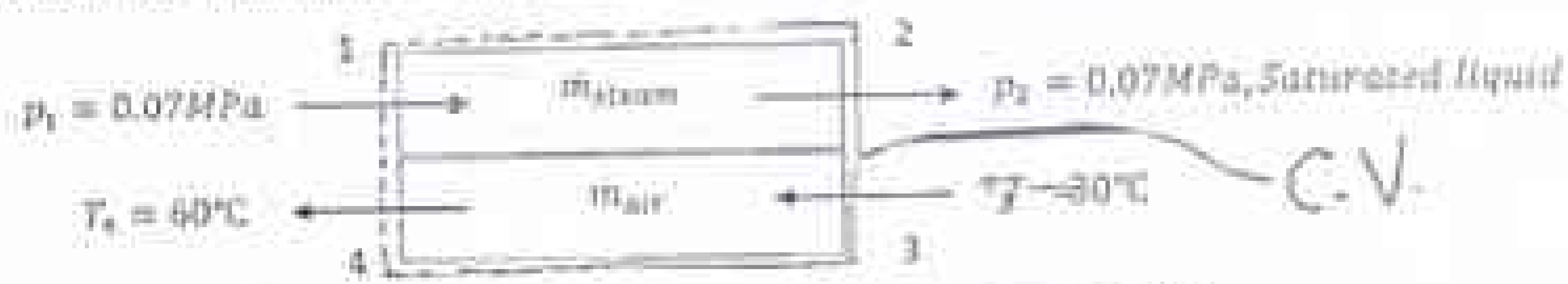
FALL 2019, Section 3

Quiz 4

Q1) Steam enters a heat exchanger operating at steady state at 0.07 MPa with a specific enthalpy of 2431.6 kJ/kg and exits at the same pressure as saturated liquid. The steam mass flow rate is 1.5 kg/min. A separate stream of air with a mass flow rate of 100 kg/min enters at 30 °C and exits at 60 °C. The ideal gas model with $c_p = 1.005\ \frac{kJ}{kg\,K}$ can be assumed for air. Kinetic and potential energy effects are negligible. Determine

a) the quality of the entering steam

b) the rate of heat transfer between the heat exchanger and its surroundings, in kW.



a) From TABLE A-3, at $p = 0.07$ MPa

$h_f = 376.7\ kJ/kg$, $h_g = 2660\ kJ/kg$

$\underbrace{h_1}_{2431.6\frac{kJ}{kg}} = h_f + x(h_g - h_f) \Rightarrow \boxed{x = 0.9}$ Quality of the entering steam

b) $0 = \dot{Q} - \dot{W} + \dot{m}_s\left[\underbrace{(h_1 - h_2)} + \underbrace{\left(\frac{V_1^2 - V_2^2}{2}\right)}_{\cong 0} + \underbrace{g(z_1 - z_2)}_{\cong 0}\right]$

$+ \dot{m}_a\left[(h_3 - h_4) + \underbrace{\left(\frac{V_3^2 - V_4^2}{2}\right)}_{\cong 0} + \underbrace{g(z_3 - z_4)}_{\cong 0}\right]$

$$\dot{Q} = \dot{m}_s(h_2 - h_1) + \dot{m}_a(h_4 - h_3)$$

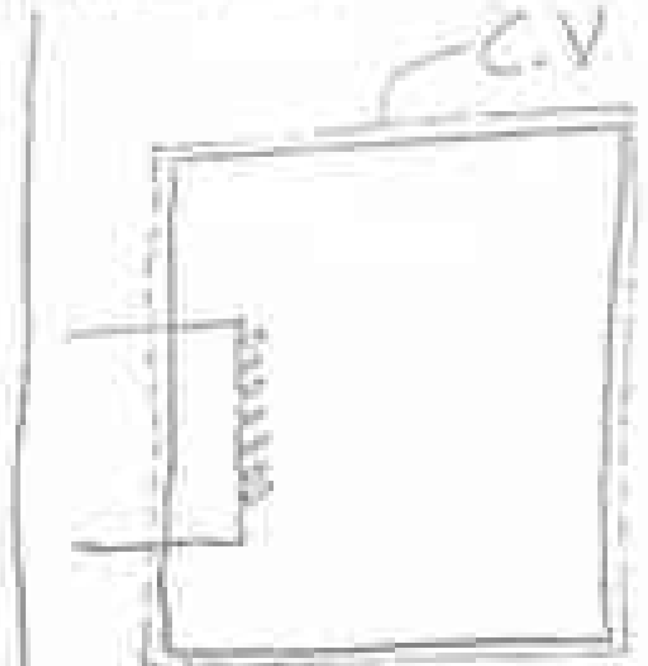
$$\dot{Q} = \dot{m}_s(h_2 - h_1) + \dot{m}_a\left[c_{p,air}(T_4 - T_3)\right]$$

$$\dot{Q} = \left[(1.5)\frac{kg}{min}\frac{1min}{60s}\right](376.7 - 2431.6)\frac{kJ}{kg}$$

$$+\left[(100)\frac{kg}{min}\frac{1min}{60s}\right]\left[(1.005)\frac{kJ}{kgK}(30K)\right]$$

$$\boxed{\dot{Q} = -1.1225 \text{ kW}}$$

Q2) A rigid, well-insulated tank of volume 0.5m³ is initially evacuated. At time t = 0, air from the surroundings at 1 bar, 21°C begins to flow in to the tank. An electric resistor transfers energy to the air in the tank at a constant rate of 100 W for 500 s, after which time the pressure in the tank is 1 bar. What is the temperature of the air in the tank, in °C, at the final time?



$$\frac{dU}{dt} = \underbrace{\dot{Q}}_{0} - \dot{W} + \dot{m}_i h_i$$

Integrating,

$$\Delta U = -\int_{t_1=0}^{t_2=500s} \dot{W}dt + \int_{t_1=0}^{t_2=500s} \dot{m}_i h_i dt$$

$$\Delta U = -\dot{W}(500s) + h_i \int_{t_i=0}^{t_2=500s} \dot{m}_i dt$$

$$m_2u_2 - \underbrace{m_1}_{0}u_1 = -\dot{W}(500s) + h_i(m_2 - \underbrace{m_1}_{0})$$

$$u_2 = \frac{-\dot{W}(500s)}{m_2} + h_i \quad \text{—— (1)}$$

Put $m_2 = \frac{P_2V}{RT_2}$ into eqn (1),

$$u_2 = \frac{-\overbrace{\dot{W}}^{(-0.1kW)}(500s)}{P_2V}RT_2 + h_i$$

P_2 → 100kPa, V → 0.5m³, R → $\left[\frac{8.314 \text{ kJ/kmol.K}}{28.97 \text{ kg/kmol}}\right]$

h_i → From TABLE A-22, T_i=294K, $h_i = 294.17 \frac{kJ}{kg}$

Given

$V = 0.5m^3$

$P_i = 1$ bar, $T_i = 294$ K

$\Delta t = 500$ s

$\dot{W} = -100$ W

$m_1 = 0$

$P_2 = 1$ bar, $T_2 = ?$

Assumptions

1- Air is modelled as an ideal gas

$$u_2 = 0.287\,T_2 + 294.17 \ \frac{kJ}{kg}$$

$\downarrow$ TABLE A-22

This equation is satisfied when

$$\boxed{T_2 = 665.3\ K}$$ //

A closed cylinder is divided into two rooms by a frictionless piston held in place by a pin, as shown in Fig. P5.138. Room A has 10 L air at 100 kPa, 30°C, and room B has 300 L saturated water vapor at 30°C. The pin is pulled, releasing the piston, and both rooms come to equilibrium at 30°C and as the water is compressed it becomes two-phase. Considering a control mass of the air and water, determine the work done by the system and the heat transfer to the cylinder.

Solution:

C.V. A + B, control mass of constant total volume.

Energy equation: $m_A(u_2 - u_1)_A + m_B(u_{B2} - u_{B1}) = {}_1Q_2 - {}_1W_2$

Process equation: $V = C \Rightarrow {}_1W_2 = 0$

$T = C \Rightarrow (u_2 - u_1)_A = 0$ (ideal gas)

The pressure on both sides of the piston must be the same at state 2.

Since two-phase: $P_2 = P_{g\,H_2O\text{ at }30°C} = P_{A2} = P_{B2} = 4.246$ kPa

Air, I.G.: $P_{A1}V_{A1} = m_A R_A T = P_{A2}V_{A2} = P_{g\,H_2O\text{ at }30°C}\,V_{A2}$

$$\rightarrow V_{A2} = \frac{100 \times 0.01}{4.246}\ m^3 = 0.2355\ m^3$$

Now the water volume is the rest of the total volume

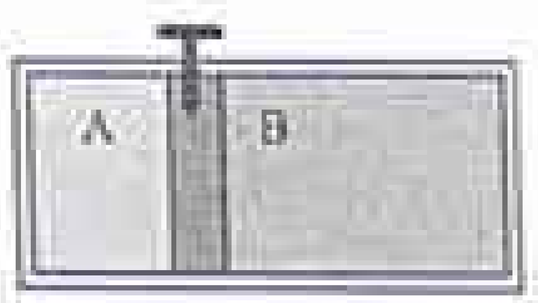
$$V_{B2} = V_{A1} + V_{B1} - V_{A2} = 0.30 + 0.01 - 0.2355 = 0.0745\ m^3$$

$$m_B = \frac{V_{B1}}{v_{B1}} = \frac{0.3}{32.89} = 9.121 \times 10^{-3}\ kg \ \Rightarrow \ v_{B2} = 8.166\ m^3/kg$$

$$8.166 = 0.001004 + x_{B2} \times (32.89 - 0.001) \ \Rightarrow \ x_{B2} = 0.2483$$

$$u_{B2} = 125.78 + 0.2483 \times 2290.8 = 694.5\ kJ/kg, \quad u_{B1} = 2416.6\ kJ/kg$$

$${}_1Q_2 = m_B(u_{B2} - u_{B1}) = 9.121 \times 10^{-3}(694.5 - 2416.6) = -15.7\ kJ$$



A piston/cylinder has 0.5 kg air at 2000 kPa, 1000 K as shown. The cylinder has stops so $V_{min} = 0.03$ m^3. The air now cools to 400 K by heat transfer to the ambient. Find the final volume and pressure of the air (does it hit the stops?) and the work and heat transfer in the process.

Solution:

We recognize this is a possible two-step process, one of constant P and one of constant V. This behavior is dictated by the construction of the device.

Continuity Eq.: $\quad m_2 - m_1 = 0$

Energy Eq.5.11: $\quad m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: $\quad P = \text{constant} = F/A = P_1 \quad \text{if} \quad V > V_{min}$

$\quad V = \text{constant} = V_{1a} = V_{min} \quad \text{if} \quad P < P_1$

State 1: (P, T) $\quad V_1 = mRT_1/P_1 = 0.5 \times 0.287 \times 1000/2000 = 0.07175$ m^3

The only possible P-V combinations for this system is shown in the diagram so both state 1 and 2 must be on the two lines. For state 2 we need to know if it is on the horizontal P line segment or the vertical V segment. Let us check state 1a:

State 1a: $\quad P_{1a} = P_1, V_{1a} = V_{min}$

$$\text{Ideal gas so } T_{1a} = T_1 \frac{V_{1a}}{V_1} = 1000 \times \frac{0.03}{0.07175} = 418 \text{ K}$$

We see that $T_2 < T_{1a}$ and state 2 must have $V_2 = V_{1a} = V_{min} = 0.03$ m^3.

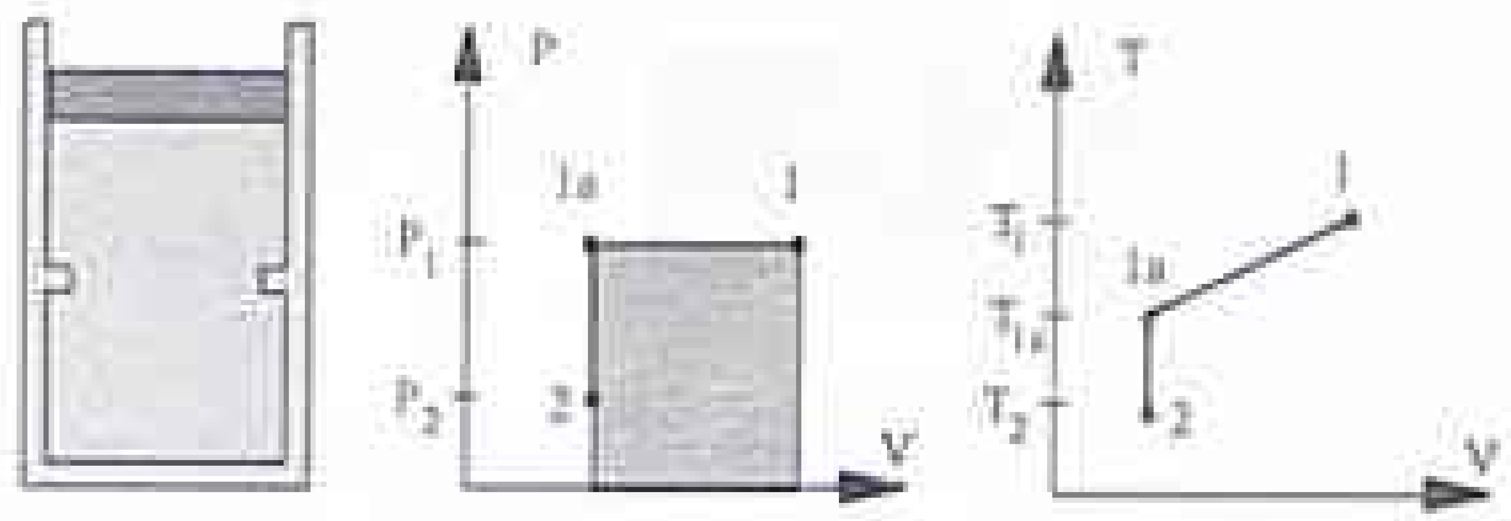
$$P_2 = P_1 \times \frac{T_2}{T_1} \times \frac{V_1}{V_2} = 2000 \times \frac{400}{1000} \times \frac{0.07175}{0.03} = 1913.3 \text{ kPa}$$

The work is the area under the process curve in the P-V diagram

$${}_1W_2 = \int_1^2 P\, dV = P_1 (V_{1a} - V_1) = 2000 \text{ kPa } (0.03 - 0.07175) \text{ m}^3 = \mathbf{-83.5 \text{ kJ}}$$

Now the heat transfer is found from the energy equation, u's from Table A.7.1,

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 0.5\,(286.49 - 759.19) - 83.5 = \mathbf{-319.85 \text{ kJ}}$$



A 10-m high open cylinder, $A_{cyl} = 0.1$ m^2, contains 20°C water above and 2 kg of 20°C water below a 198.5-kg thin insulated floating piston, shown in Fig. P5.59. Assume standard g, P_0. Now heat is added to the water below the piston so that it expands, pushing the piston up, causing the water on top to spill over the edge. This process continues until the piston reaches the top of the cylinder. Find the final state of the water below the piston (*T*, *P*, *v*) and the heat added during the process.

Solution:

C.V. Water below the piston.

Piston force balance at initial state: $F\uparrow = F\downarrow = P_A A = m_p g + m_B g + P_0 A$

State $1_{A,B}$: Comp. Liq. $\Rightarrow$ $v \cong v_f = 0.001002$ m^3/kg; $\quad u_{1A} = 83.95$ kJ/kg

$V_{A1} = m_A v_{A1} = 0.002$ m^3; $\quad m_{tot} = V_{tot}/v = 1/0.001002 = 998$ kg

mass above the piston $\quad m_{B1} = m_{tot} - m_A = 996$ kg

$$P_{A1} = P_0 + (m_p + m_B)g/A = 101.325 + \frac{(198.5+996)*9.807}{0.1*1000} = 218.5 \text{ kPa}$$

State 2_A: $\quad P_{A2} = P_0 + \frac{m_p g}{A} = \mathbf{120.8 \text{ kPa}}$; $\quad v_{A2} = V_{tot}/m_A = 0.5$ m^3/kg

$x_{A2} = (0.5 - 0.001047)/1.4183 = 0.352$; $\quad T_2 = \mathbf{105°C}$

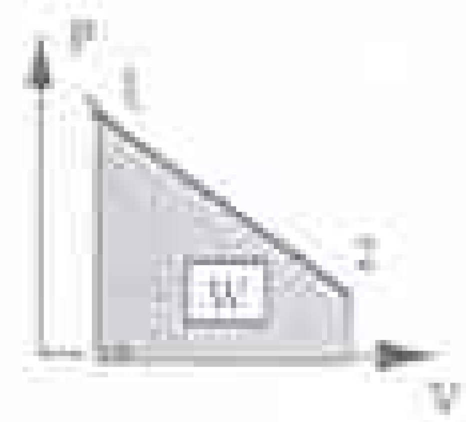
$u_{A2} = 440.0 + 0.352 \times 2072.34 = 1169.5$ kJ/kg

Continuity eq. in A: $\quad m_{A2} = m_{A1}$

Energy: $\quad m_A(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: $\quad$ P linear in V as m_B is linear with V

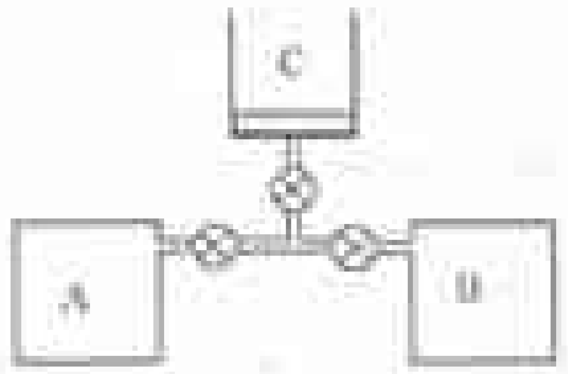
$${}_1W_2 = \int PdV = \frac{1}{2}(218.5 + 120.82)(1 - 0.002)$$
$$= \mathbf{169.32 \text{ kJ}}$$



$${}_1Q_2 = m_A(u_2 - u_1) + {}_1W_2 = 2170.1 + 169.3 = \mathbf{2340.4 \text{ kJ}}$$

A rigid tank A of volume 0.6 m^3 contains 3 kg water at 120^{0}C and the rigid tank B is 0.4 m^3 with water at 600 kPa, 200^{0}C. They are connected to a piston cylinder initially empty with closed valves. The pressure in the cylinder should be 800 kPa to float the piston. Now the valves are slowly opened and heat is transferred so the water reaches a uniform state at 250^{0}C with the valves open. Find the final volume and pressure and the work and heat transfer in the process.

C.V. A + B + C.
Only work in C, total mass constant.



$m_2 - m_1 = 0 \quad => \quad m_2 = m_{A1} + m_{B1}$

$U_2 - U_1 = {}_1Q_2 - {}_1W_2$;

${}_1W_2 = \int PdV = P_{lift}(V_2 - V_1)$

1A: $v = 0.6/3 = 0.2$ m^3/kg $=> x_{A1} = (0.2 - 0.00106)/0.8908 = 0.223327$

$u = 503.48 + 0.223327 \times 2025.76 = 955.89$ kJ/kg

1B: $v = 0.35202$ m^3/kg $=> m_{B1} = 0.4/0.35202 = 1.1363$ kg ; $u = 2638.91$ kJ/kg

$m_2 = 3 + 1.1363 = 4.1363$ kg and

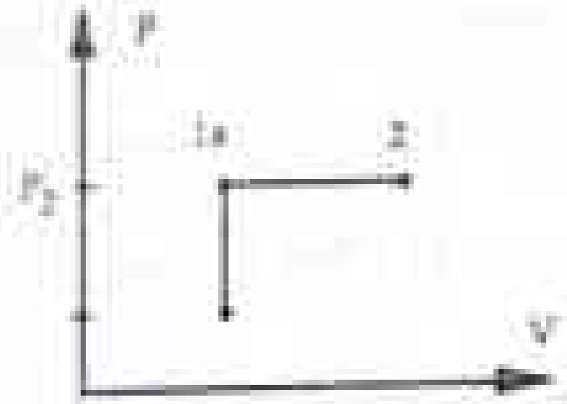
$V_2 = V_A + V_B + V_C = 1 + V_C$

Locate state 2: Must be on P-V lines shown

State 1a: 800 kPa,

$$v_{1a} = \frac{V_A + V_B}{m} = 0.24176 \text{ m}^3/\text{kg}$$

800 kPa, $v_{1a} \quad => \quad T = 173°C$ too low.



Assume 800 kPa: 250°C $\quad => \quad v = 0.29314$ m^3/kg $> v_{1a}$ OK

Final state is : **800 kPa;** 250°C $=> u_2 = 2715.46$ kJ/kg

$W = 800(0.29314 - 0.24176) \times 4.1363 = 800 \times (1.2125 - 1) =$ **170 kJ**

$Q = m_2u_2 - m_1u_1 + {}_1W_2 = m_2u_2 - m_{A1}u_{A1} - m_{B1}u_{B1} + {}_1W_2$

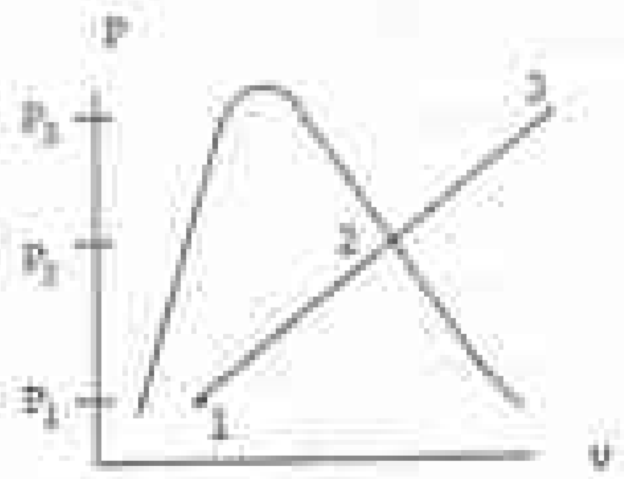
$= 4.1363 \times 2715.46 - 3 \times 955.89 - 1.1363 \times 2638.91 + 170$

$= 11\,232 - 2867.7 - 2998.6 + 170 =$ **5536 kJ**

A spring-loaded piston/cylinder arrangement contains R-134a at 20°C, 24% quality with a volume 50 L. The setup is heated and thus expands, moving the piston. It is noted that when the last drop of liquid disappears the temperature is 40°C. The heating is stopped when T = 130°C. Verify the final pressure is about 1200 kPa by iteration and find the work done in the process.

Solution:

C.V. R-134a. This is a control mass.



State 1: Table B.5.1 =>

$v_1 = 0.000817 + 0.24 * 0.03524 = 0.009274$

$P_1 = 572.8$ kPa,

$m = V/v_1 = 0.050 / 0.009274 = 5.391$ kg

Process: Linear Spring

$P = A + Bv$

State 2: $x_2 = 1, T_2 \quad \Rightarrow \quad P_2 = 1.017$ MPa, $\quad v_2 = 0.02002$ m^3/kg

Now we have fixed two points on the process line so for final state 3:

$$P_3 = P_1 + \frac{P_2 - P_1}{v_2 - v_1}(v_3 - v_1) = \text{RHS} \qquad \text{Relation between } P_3 \text{ and } v_3$$

State 3: T_3 and on process line $\Rightarrow$ iterate on P_3 given T_3

at $P_3 = 1.2$ MPa $=> v_3 = 0.02504 \quad => P_3 - \text{RHS} = -0.0247$

at $P_3 = 1.4$ MPa $=> v_3 = 0.02112 \quad => P_3 - \text{RHS} = 0.3376$

Linear interpolation gives :

$$P_3 \cong 1200 + \frac{0.0247}{0.3376 + 0.0247}(1400 - 1200) = 1214 \text{ kPa}$$

$$v_3 = 0.02504 + \frac{0.0247}{0.3376 + 0.0247}(0.02112 - 0.02504) = 0.02478 \text{ m}^3/\text{kg}$$

$$W_{13} = \int P\,dV = \frac{1}{2}(P_1 + P_3)(V_3 - V_1) = \frac{1}{2}(P_1 + P_3)\,m\,(v_3 - v_1)$$

$$= \frac{1}{2}\,5.391(572.8 + 1214)(0.02478 - 0.009274) = \mathbf{74.7\ kJ}$$

A closed cylinder is divided into two rooms by a frictionless piston held in place by a pin, as shown in Fig. P5.138. Room A has 10 L air at 100 kPa, 30°C, and room B has 300 L saturated water vapor at 30°C. The pin is pulled, releasing the piston, and both rooms come to equilibrium at 30°C and as the water is compressed it becomes two-phase. Considering a control mass of the air and water, determine the work done by the system and the heat transfer to the cylinder.

Solution:

C.V. A + B, control mass of constant total volume.

Energy equation: $m_A(u_2 - u_1)_A + m_B(u_{B2} - u_{B1}) = {}_1Q_2 - {}_1W_2$

Process equation: $V = C \Rightarrow {}_1W_2 = 0$

$T = C \Rightarrow (u_2 - u_1)_A = 0$ (ideal gas)

The pressure on both sides of the piston must be the same at state 2.

Since two-phase: $P_2 = P_{g\ H_2O\ at\ 30°C} = P_{A2} = P_{B2} = 4.246$ kPa

Air, I.G.: $P_{A1}V_{A1} = m_A R_A T = P_{A2}V_{A2} = P_{g\ H_2O\ at\ 30°C} V_{A2}$

$\rightarrow V_{A2} = \frac{100 \times 0.01}{4.246} m^3 = 0.2355\ m^3$

Now the water volume is the rest of the total volume

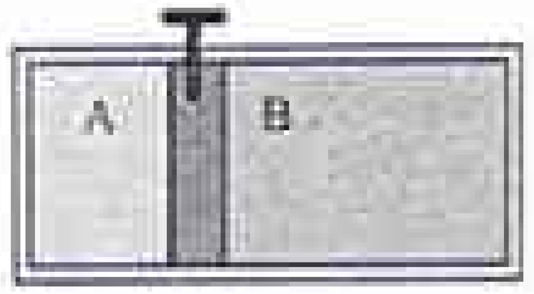
$V_{B2} = V_{A1} + V_{B1} - V_{A2} = 0.30 + 0.01 - 0.2355 = 0.0745\ m^3$

$m_B = \frac{V_{B1}}{v_{B1}} = \frac{0.3}{32.89} = 9.121 \times 10^{-3}$ kg $\rightarrow$ $v_{B2} = 8.166\ m^3/kg$

$8.166 = 0.001004 + x_{B2} \times (32.89 - 0.001) \Rightarrow x_{B2} = 0.2483$

$u_{B2} = 125.78 + 0.2483 \times 2290.8 = 694.5$ kJ/kg, $u_{B1} = 2416.6$ kJ/kg

${}_1Q_2 = m_B(u_{B2} - u_{B1}) = 9.121 \times 10^{-3}(694.5 - 2416.6) =$ **-15.7 kJ**



HOMEWORK 2 SOLUTION

1) R-134a enters to an insulated nozzle at 800 kPa, 120 °C and 20 m/s exits at 400 kPa and 30°C. Calculate the exit velocity and inlet-to-exit cross section area ratio of the nozzle.

$P_1 = 800\ kPa, T_1 = 120\ °C \rightarrow\ v_1 = 0.03762 \frac{m^3}{kg}, \quad h_1 = 358.40\ kJ/kg$

$P_2 = 400\ kPa, T_2 = 30\ °C \rightarrow\ v_2 = 0.05662 \frac{m^3}{kg}, \quad h_2 = 272.54\ kJ/kg$

Continuity Equation: $\dot{m}_1 = \dot{m}_2 = \dot{m}$

Energy Equation:

$$\dot{Q}_{CV} + \sum \dot{m}_i \cdot \left(h_i + \frac{V^2_i}{2} + g \cdot z_i\right) = \dot{W}_{CV} + \sum \dot{m}_e \cdot \left(h_e + \frac{V^2_e}{2} + g \cdot z_e\right)$$

Where $\dot{Q}_{CV} = 0$, $\dot{W}_{CV} = 0$ and $g \cdot z_i = g \cdot z_e$.

Then energy equation reduces to,

$V_2 = \sqrt{2 \cdot (h_1 - h_2) + V_1^2}$

$V_2 = \sqrt{2 \cdot (358.4 - 272.54) \cdot 1000 + 20^2} = 414.87\ m/s$

The ratio of the cross section area is determined from continuity equation.

$\dot{m}_1 = \dot{m}_2 = \rho_1 \cdot A_1 \cdot V_1 = \rho_2 \cdot A_2 \cdot V_2 \rightarrow \frac{A_1 \cdot V_1}{v_1} = \frac{A_2 \cdot V_2}{v_2} \rightarrow \frac{A_1}{A_2} = \frac{v_1 \cdot V_2}{v_2 \cdot V_1}$

$\frac{A_1}{A_2} = \frac{0.03762 \frac{m^3}{kg} \cdot 414.87\ m/s}{0.05662 \frac{m^3}{kg} \cdot 20\ m/s} = 13.783$

2) For the two stage turbine delineated below, find the total power output for the turbine. Consider that some of the steam extracted at the end of the first turbine.

$P_1 = 5\ MPa, T_1 = 600°C \rightarrow \quad h_1 = 3666.9\ kJ/kg$

$P_2 = 0.1\ MPa, x_2 = 1 \rightarrow \quad h_2 = 2675.5\ kJ/kg$

$P_3 = 10\ kPa, x_3 = 0.85 \rightarrow \quad h_3 = 2225.1\ kJ/kg$

Energy Equation for Turbine 1:

$$\sum \dot{m}_i \cdot \left(h_i + \frac{V^2_i}{2} + g \cdot z_i\right) = \dot{W}_{CV} + \sum \dot{m}_e \cdot \left(h_e + \frac{V^2_e}{2} + g \cdot z_e\right)$$

Where PE=KE=0

$\dot{W}_1 = \dot{m} \cdot (h_1 - h_2) = \frac{20kg}{s} \cdot \frac{(3666.9 - 2748.1)kJ}{kg} = 18376\ kW$

Energy Equation for Turbine 2:

$$\dot{W}_2 = \dot{m} \cdot (h_3 - h_2) = \frac{18kg}{s} \cdot \frac{(2748.1 - 2225.1)kJ}{kg} = 9414\ kW$$

$\dot{W} = \dot{W}_1 + \dot{W}_2 = 27790\ kW$

3) R-134a is throttled by a valve from 800 kPa and 25 °C to -20 °C. Calculate the pressure and internal energy after expansion.

$P_1 = 800\ kPa, T_1 = 25\ °C \rightarrow \ h_1 = 84.34\ kJ/kg$

Continuity Equation: $\dot{m}_1 = \dot{m}_2 = \dot{m}$

Energy Equation:

$$\dot{Q}_{CV} + \sum \dot{m}_i \cdot \left(h_i + \frac{V^2{}_i}{2} + g \cdot z_i\right) = \dot{W}_{CV} + \sum \dot{m}_e \cdot \left(h_e + \frac{V^2{}_e}{2} + g \cdot z_e\right)$$

Where $\dot{Q}_{CV} = 0, \dot{W}_{CV} = 0$ and $g \cdot z_i = g \cdot z_e$.

$A_1 = A_2 \ \rightarrow \ V_1 = V_2$

$h_1 = h_2$

$T_2 = -20°C,\ h_2 = 84.34\ kJ/kg$

$T_2 = -20°C\ \ h_f = 24.27\frac{kJ}{kg}, \quad h_g = 235.31\frac{kJ}{kg} \rightarrow h_f < h_2 < h_g$ *saturated mixture*

$$x = \frac{84.34 - 24.27}{211.04} = 0.2846$$

$u_2 = u_f + x \cdot u_{fg} = 24.167 + 0.2846 \cdot 191.67 = 78.72\ kJ/kg$

$P_2 = P_{sat@-20°C} = 133\ kPa$

5) The steam turbine derives both an air compressor and a generator as shown in figure. The steam flow rate is 25 kg/s and exits at 10 kPa and a quality of 92%. The air flow rate is 10 kg/s. Calculate the power delivered to generator.

$P_3 = 12.5\ MPa, T_3 = 500\ °C \rightarrow \ h_3 = 3343.6\ kJ/kg$

$P_4 = 10\ kPa; x_4 = 0.92 \rightarrow \ h_4 = 2392.5\ kJ/kg$

For the air

$T_1 = 295\ K \rightarrow \ h_1 = 295.17\ kJ/kg$

$T_2 = 620\ K \rightarrow \ h_2 = 628.38\ kJ/kg$

For the compressor:

$\dot{W}_{comp} = \dot{m}_{air} \cdot (h_1 - h_2) = 10 \cdot (628.38 - 295.17) = 3332.1\ kW$

For the turbine

$\dot{W}_{turb} = \dot{m}_{steam} \cdot (h_3 - h_4) = 25 \cdot (3343.6 - 2392.5) = 23777.5\ kW$

$\dot{W}_C = \dot{W}_{turb} - \dot{W}_{comp} = 23777.5 - 3332.1 = 20445.4\ kW$

6) Gaseous combustion products are discharged 20 kg/s at 600K. A system consist of a heat exchanger and a steam turbine is applied in order to utilize this heat for power generation as shown in figure. At steady state, combustion products exit heat exchanger at 440K and 100kPa. Water enters at 100 kPa and 30 °C with a mass flow rate of 10 kg/s. At the exit of the turbine, the pressure is 10 kPa at the saturated vapor. Heat exchanger and turbine are insulated. The combustion products can be modeled as air.

a) Find the power developed by the turbine,

b) Calculate the turbine inlet temperature.

Continuity equation:

$\dot{m}_1 = \dot{m}_2 ; \dot{m}_3 = \dot{m}_4 = \dot{m}_5$

$$\dot{Q}_{CV} + \dot{m}_1 \cdot h_1 + \dot{m}_3 \cdot h_3 = \dot{W}_{CV} + \dot{m}_2 \cdot h_2 + \dot{m}_4 \cdot h_5$$

Where $\dot{Q}_{CV} = 0$,

$\dot{W}_{CV} = \dot{m}_1 \cdot (h_2 - h_1) + \dot{m}_3 \cdot (h_3 - h_5)$

For the air:

$T_1 = 600\ K \rightarrow \ h_1 = 607.32\ kJ/kg$

$T_2 = 440\ K \rightarrow \ h_2 = 441.93\ kJ/kg$

For water:

$P_3 = 100\ kPa, T_3 = 30\ °C \rightarrow \ h_3 = 125.77\ kJ/kg$

$P_5 = 10\ kPa, x_5 = 1 \rightarrow \ h_5 = 2584.7\ kJ/kg$

$\dot{W}_{CV} = 20 \cdot (607.32 - 441.93) + 10 \cdot (125.77 - 2584.7) = -21281kW$

Control volume for the heat exchanger,

$\dot{m}_1 \cdot (h_2 - h_1) = \dot{m}_2 \cdot (h_4 - h_3) \rightarrow 20 \cdot (607.32 - 441.93) = 10 \cdot (h_4 - 125.77) \rightarrow h_4 = 456.6$

$P_4 = 100\ kPa, h_4 = 456.6\ kJ/kg \rightarrow \ T_4 = 30\ °C$

Added Q)

$P_1 = 5\ MPa, T_1 = 400\ °C \rightarrow \ h_1 = 3195.4\ kJ/kg$

$P_2 = 50\ kPa, x_2 = 0.95 \rightarrow \ h_2 = 2530.6\ kJ/kg$

$P_3 = 50\ kPa, x_3 = 0 \rightarrow \ h_3 = 340.5\ kJ/kg$

$P_4 = 3\ MPa, T_4 = 82\ °C \rightarrow \ h_4 = 344.4\ kJ/kg$

$$\eta = \frac{W_{net}}{Q_{in}} = \frac{W_{turb} - W_{pump}}{Q_{in}} = \frac{\dot{m} \cdot (h_1 - h_2) - \dot{m} \cdot (h_4 - h_3)}{\dot{m} \cdot (h_1 - h_4)} \rightarrow \eta = \frac{h_1 + h_3 - h_2 - h_4}{(h_1 - h_4)} = 0.232$$

$\eta = 23.2\%$

Energy equation for heat exchanger,

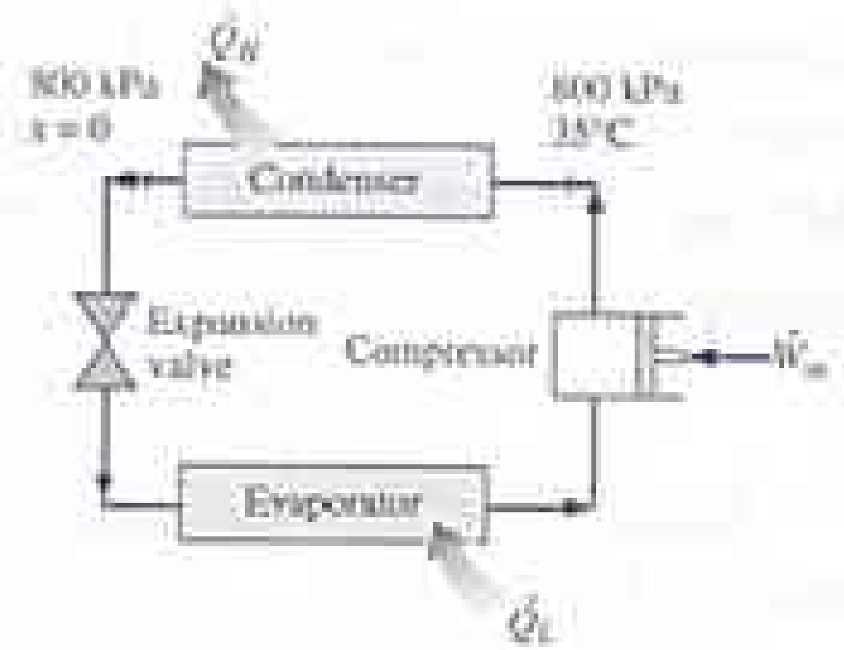
$$\dot{m} \cdot (h_2 - h_3) = \dot{m}_s \cdot (h_{out} - h_{in}) = \dot{m}_s \cdot \left(c_p \cdot (Tout - Tin)\right) \rightarrow \dot{m}_s = \dot{m} \cdot \frac{2530.6 - 340.5}{4.184 \cdot 15}$$

$\dot{m}_s = 34.8 \cdot \dot{m}$

ME 203 Thermodynamics Fall 2018

Homework 3

1) Refrigerant-134a enters the condenser of a residential heat pump at 800 kPa and 35°C at a rate of 0.02 kg/s and leaves at 800 kPa as a saturated liquid. If the compressor consumes 1.0 kW of power, determine
(a) the COP of the heat pump and
(b) the rate of heat absorption from the outside air.



The enthalpies of R-134a at the condenser inlet and exit are

$h_1 = 271.22\frac{kJ}{kg}$

$h_2 = 95.47\frac{kJ}{kg}$

$Q_H = m \cdot (h_1 - h_2) = \left(0.02\frac{kg}{s}\right) \cdot \left(175.75\frac{kJ}{kg}\right) = 3.515\ kW$

$COP = \frac{Q_H}{W} = \frac{3.515}{1} = 3.515$

$Q_L = Q_H - W = 3.515 - 1 = 2.515\ kW$

2) A geothermal power plant uses geothermal water extracted at 160°C at a rate of 520 kg/s as the heat source and produces 23 MW of net power. If the environment temperature is 25°C, determine
(a) the actual thermal efficiency,
(b) the maximum possible thermal efficiency, and
(c) the actual rate of heat rejection from this power plant.

$h_{source} = 675.47\ kJ/kg$

$h_{sink} = 104.83\ kJ/kg$

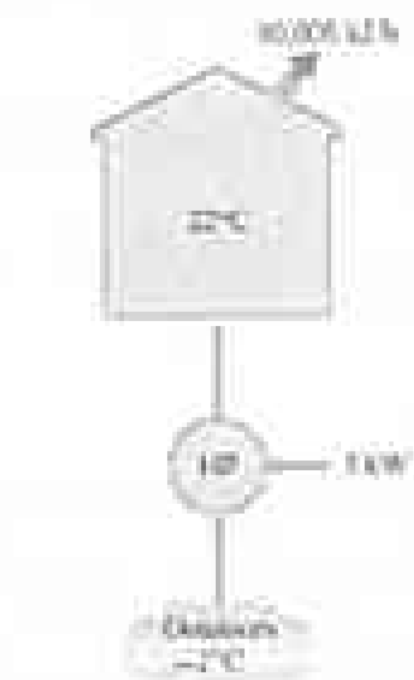
$Q_{in} = \dot{m}(h_{source} - h_{sink}) = 296.7\ MW$

$\eta_{th} = \frac{W_{net,out}}{Q_{in}} = \frac{23\ MW}{296.7\ MW} = 0.078 = 7.8\%$

$\eta_{th,max} = 1 - \frac{T_L}{T_H} = \frac{25+273.15}{160+273.15} = 0.312 = 31.2\%$

$Q_{out} = Q_{in} - W_{net,out} = 296.7 - 23 = 273.7\ MW$

3) A heat pump is used to maintain a house at 22°C by extracting heat from the outside air on a day when the outside air temperature is -2°C. The house is estimated to lose heat at a rate of 90,000 kJ/h, and the heat pump consumes 5 kW of electric power when running. Is this heat pump powerful enough to do the job?



$$COP_{HP,rev} = \frac{1}{1-(TL-TH)} = \frac{1}{1-(271/295)} = 12.29$$

$$W_{net,in,min} = \frac{Q_H}{COP_{HP}} = \frac{90000/3600}{12.29} = 2.03\ kW$$

This heat pump is powerful enough 5Kw > 2.03 kW

4) A heat pump with a COP of 2.4 is used to heat a house. When running, the heat pump consumes 7 kW of electric power. If the house is losing heat to the outside at an average rate of 42,000 kJ/h and the temperature of the house is 4°C when the heat pump is turned on, determine how long it will take for the temperature in the house to rise to 21°C. Assume the house is well sealed (i.e., no air leaks) and take the entire mass within the house (air, furniture, etc.) to be equivalent to 2000 kg of air.

Constant volume specific heat of air at room temperature is 0.718 kJ/kg*K

$Q_{loss} = 11.67\ kW$

$Q_H = COP_{HP} \cdot W_{net,in} = (2.4) \cdot (7\ kW) = 16.8\ kW$

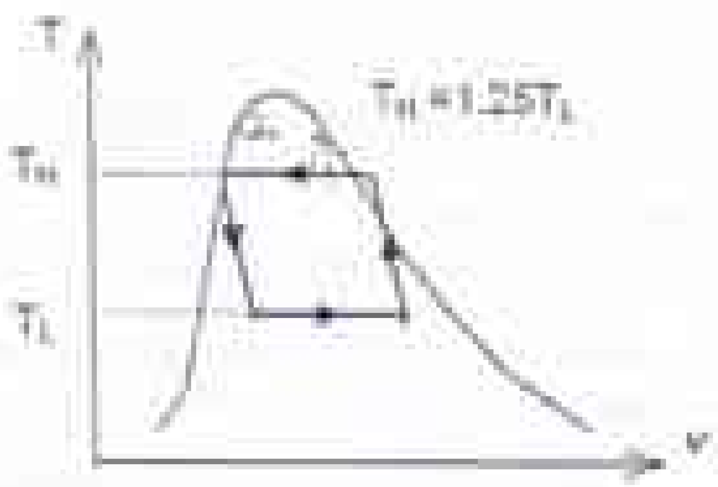
$E_{in} - E_{out} = \Delta E_{system} \rightarrow Q_{in} - Q_{out} = \Delta U = m \cdot (u_2 - u_1)$

$(Q_{in} - Q_{out}) \cdot \Delta t = m \cdot c_v \cdot (T_2 - T_1)$

$$(16.8 - 11.67) \cdot \Delta t = 2000 kg \cdot \frac{0.718 kJ}{kgK} \cdot (21 - 4)^{\circ}C \rightarrow \Delta t = 4759\ s$$

It will take 1.3 h for the temperature in the house to rise 21 °C

5) Consider a Carnot heat-pump cycle executed in a steady-flow system in the saturated liquid–vapor mixture region using refrigerant-134a flowing at a rate of 0.3 kg/s as the working fluid. It is known that the maximum absolute temperature in the cycle is 1.25 times the minimum absolute temperature, and the net power input to the cycle is 6 kW. If the refrigerant changes from saturated vapor to saturated liquid during the heat rejection process, determine the ratio of the maximum to minimum pressures in the cycle.



$$COP_{HP,rev} = \frac{1}{1 - (TL - TH)} = \frac{1}{1 - (1 - 1.25)} = 5$$

$$Q_H = COP_{HP} \cdot W_{net,in} = (5) \cdot (6) = 30\ kW$$

$$q_h = \frac{Q_H}{\dot{m}} = \frac{30\ kW}{0.3\ kg/s} = 100 \frac{kJ}{kg} = h_{fg@TH}$$

since the enthalpy of vaporization hfg at a given T or P represents the amount of heat transfer per unit mass as a substance is converted from saturated liquid to saturated vapor at that T or P. Therefore, TH is the temperature that corresponds to the hfg value of 100 kJ/kg, and is determined from the R-134a tables to be

$$T_H = 82.8\ ^{\circ}C = 355.8\ K$$

$$P_{max} = P_{@82.8} = 2790\ kPa$$

$$T_L = \frac{T_H}{1.25} = 284.64\ K = 11.64\ ^{\circ}C$$

$$P_{min} = P_{sat@11.64} = 457\ kPa$$

$$\frac{P_{max}}{P_{min}} = 6.1$$

PART-2

ME 203
Fall 2019
Sections 04 - 05

HOMEWORK #1
Assigned: 16.10.2019
Due: 23.10.2019

Guidelines for homework submission:

1. Use an A-4 sized, white paper. Staple papers when necessary.
2. Provide proper units for all dimensional quantities. Omission or incorrect usage of units will be penalized.
3. Your solution should be readable. Neatness may affect grading.
4. Cite all the references you used for the solution of the problems, such as tables, figures, other books, internet, etc.
5. If you want, you may work as a group at most 2 people (from the same section) and submit one solution. Do not forget to write the names of the group members on your solution if you work as a group.
6. **<u>Homework must be submitted at the beginning of the first class on the due date.</u>**
7. Late homework will not be accepted.

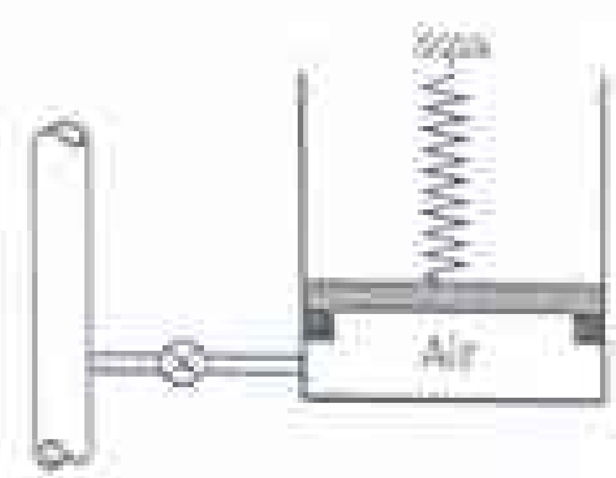
Q1) Determine the phase, quality x (if applicable), and the unknown properties of P, T, and v for the following pure substances at the specified states.

(a) Ammonia at T=170°C, P=6 bar
(b) R-22 at T=-25°C, P= 3 bar
(c) Water at T=350°C, v=0.2 m^3/kg
(d) R-134a at v=0.005 m^3/kg, x=0.5

Middle East Technical University
Department of Mechanical Engineering

Q2) A piston/cylinder system containing 0.005 kg of air is loaded with a linear spring as shown in the figure. Initially the piston (having a diameter of 0.1 m) is sitting on a set of stops located inside the cylinder. At this position, the cylinder volume is 1 L. Now the valve is opened and air enters the cylinder from the supply line. The piston starts to move up when the cylinder pressure reaches 1.5 bar. The valve is closed when the cylinder volume becomes 1.5 L. At this instant, the temperature in the cylinder is 80°C. Calculate the amount of air that enters the cylinder during this process. It is known that the spring has a constant of 80 kN/m.

Q2)



Q3) A closed rigid tank contains R-22 gas at 20°C. What is the initial pressure in the tank if small liquid droplets start to form on the walls when the gas inside is cooled to -20°C?

Middle East Technical University

Department of Mechanical Engineering

ME 203

Fall 2019

Sections 04-05

Solutions to Homework Assignment #1

Q1)

(a) @ 6 bar $\xrightarrow{\text{Table A.14}}$

Since T= 170 $\longrightarrow$ Superheated vapor

Table A.15: 6 bar, 170 $\longrightarrow$ v= 0.3554 m^3/kg

(b) R-22 @ -25 , 3 bar

@ 3 bar $\xrightarrow{\text{Table A.8}}$ = -14.66

T= -25 $\longrightarrow$ Compressed Liquid

v $\xrightarrow{\text{Table A.7}}$ $/kg$

(c) Water @ 350 , v= $/kg$

@ 350 $\xrightarrow{\text{Table A.2}}$ $/kg$

$/kg$

v= 0.2 $\longrightarrow$ Superheated vapor

From Table A.4: @ 350 °C , v= 0.3 m^3/kg $\longrightarrow$ P

(d) R-134a @ v= 0.005 $/kg$, x=0.5

State is saturated L+V mixture

$v = v_f + x(v_g - v_f)$ $\longrightarrow$ 0.005 = 5(v)

$0.005 = 0.5v_f + 0.5\,v$ $\longrightarrow$ = 0.01 $/kg$

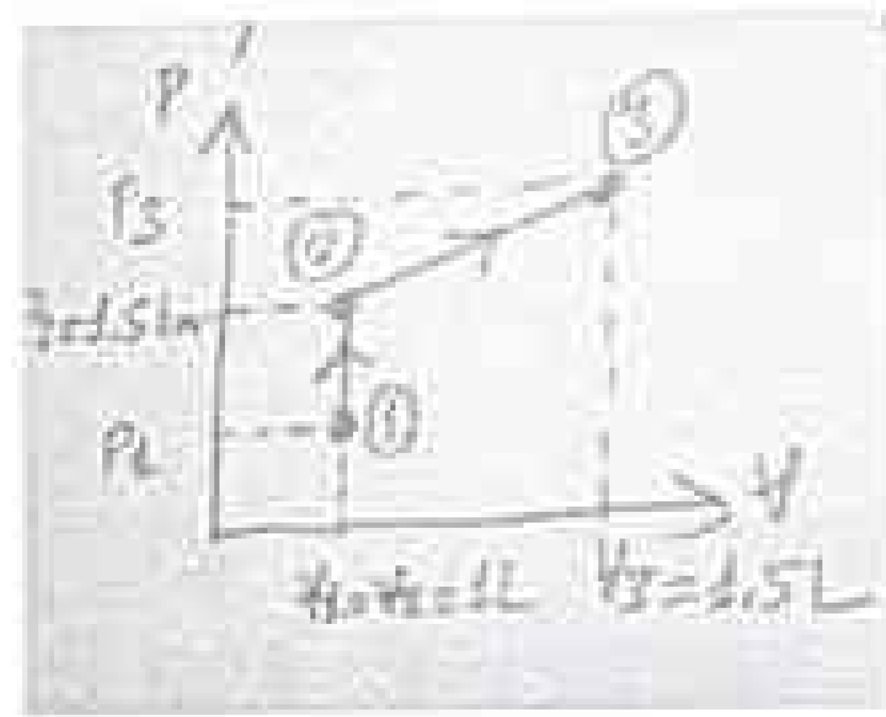
Table A.10: @ 60°C $\longrightarrow$ = 0.01233 $/kg$

@ 70°C $\longrightarrow$ = 0.0096 $/kg$

So T is between 60 and 70 $\longrightarrow$ T= (Linear - Interpolation)

P is 20.6 bar (Linear Interpolation)

Q2) The P-V diagram for the process



Between 1 and 2 : The pressure in the cylinder increases @ constant volume.

At P= 1.5 bar, piston starts to move.

Between 2 and 3: Due to linear spring, P changes linearly with V.

Between 2 and 3: P = C

—

— = (0 m)

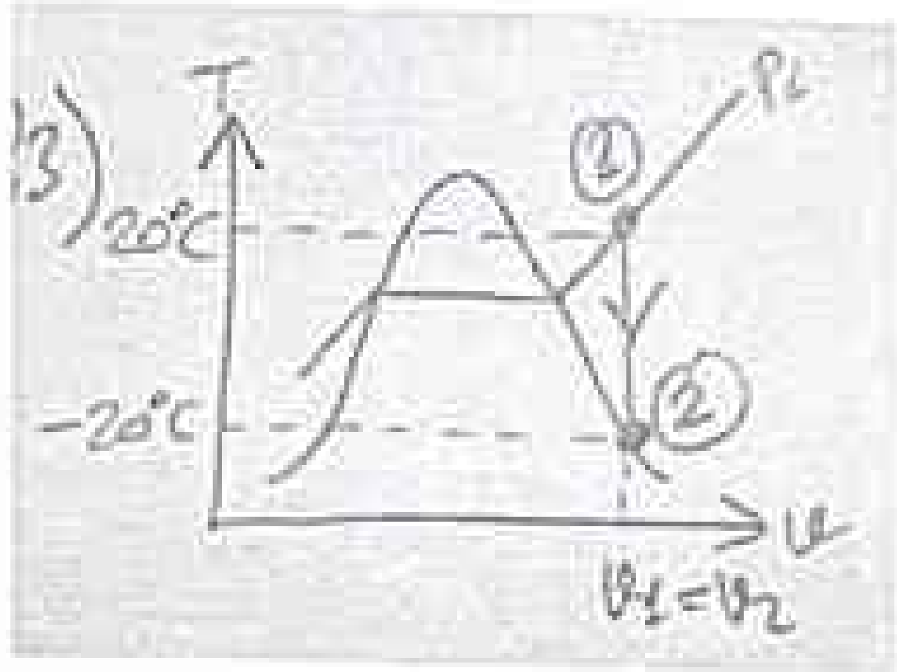
$\frac{kN/m}{(0.007854m)^2}$ = 1296905 kN/m

@ State 2: 150 kPa = (1296905 kN/m^3)(0.001m^3)

@ State 3: (1296905)(0.0015) − 1146.91= 798.45 kPa

$$= \frac{(798.45)(0.0015)}{(0.287)(353)}$$

Q3) The T-v diagram is given below:



Rigid tank $\longrightarrow$ V= constant

Closed system $\longrightarrow$ m = constant

Then, the process is constant specific volume process.

If small liquid droplets form @ state 2, state 2 must be saturated vapor !

@ -20°C $\xrightarrow{\text{Table A.7}}$ $v_2 = v_g = 0.0926\ m^3/kg$

<u>State1:</u>

R-22 ⎤ @ 20°C $\xrightarrow{A.7}$ $m\ /kg$

⎬ $\longrightarrow$ State is superheated vapor

From Table A.9: @ T_1 and $\longrightarrow$ P is between 2.5 and 3 bar

Linear Interpolation gives:

ME 203
Fall 2019
Sections 04 - 05

HOMEWORK #2
Assigned: 11.11.2019
Due: 18.11.2019

Guidelines for homework submission:

1. Use an A-4 sized, white paper. Staple papers when necessary.
2. Provide proper units for all dimensional quantities. Omission or incorrect usage of units will be penalized.
3. Your solution should be readable. Neatness may affect grading.
4. Cite all the references you used for the solution of the problems, such as tables, figures, other books, internet, etc.
5. If you want, you may work as a group at most 2 people (from the same section) and submit one solution. Do not forget to write the names of the group members on your solution if you work as a group.
6. **<u>Homework must be submitted at the beginning of the first class on the due date.</u>**
7. Late homework will not be accepted.

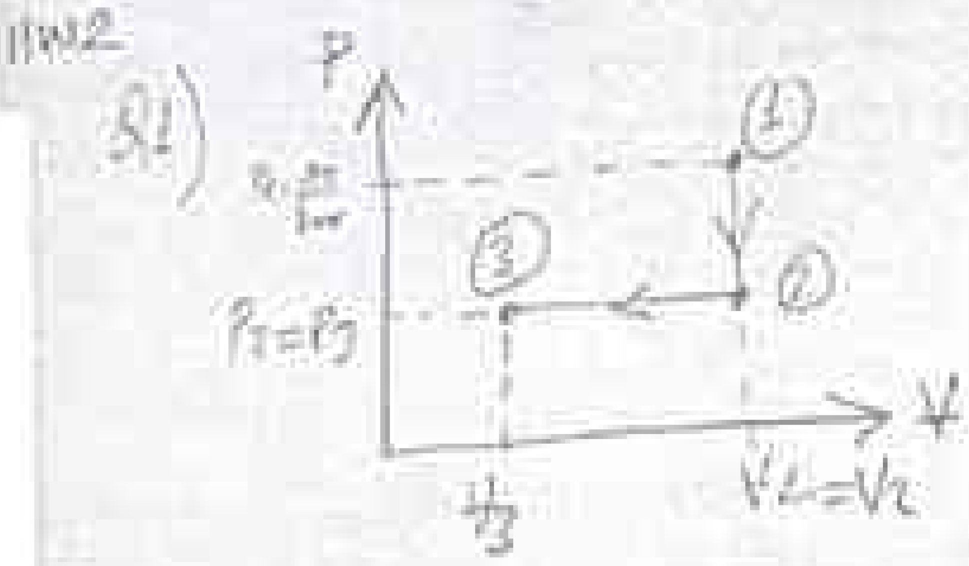
Q1) A piston-cylinder device contains refrigerant R-22 at 13 bar, 50°C. At this state, the piston is resting against a set of stops. Now, the refrigerant is cooled to a final state of 10°C with a volume of ½ of the initial volume. Find the specific heat transfer during the process.

Q2) Argon gas is contained in a piston-cylinder device initially at 10°C, 1.4 bar at a volume of 100 L. Now, the gas is compressed to a final state of 7 bar, 280°C. Find the heat transfer during the process if the process is polytropic.

Solutions to Homework #2

HW2

Q1)



$V_3 = \frac{V_1}{2}$ or $v_3 = \frac{v_1}{2}$

(1) → (2) : constant volume process

(2) → (3) : constant pressure process

State 1
R-22
$P_1 = 13$ bar
$T_1 = 50°C$

superheated vapor
$v_1 = 0.02014$
$u_1 = 248.49$

State 3
R-22
$T_3 = 10°C$
$v_3 = \frac{v_1}{2} = 0.01007$

saturated L+V mixture

$$x_3 = \frac{v_3 - v_f}{v_g - v_f} = \frac{0.01007 - 0.000802}{0.0346 - 0.000802} = 0.274$$

$$u_3 = \underset{56.6}{u_f} + x_3 \cdot (\underset{229.76}{u_g} - u_f) = 103.9 \text{ kJ/kg}$$

$P_3 = 6.8113$ bar

$$W_{13} = \cancelto{0}{W_{12}} + W_{23} = \underset{=P_2}{P_3}(V_3 - \underset{=V_1}{V_2})$$

$$w_{13} = \frac{W_{13}}{m} = P_3 \cdot (v_3 - \underset{v_1}{v_2}) = (681.13 \text{ kPa})(0.01007 - 0.02014)$$

$$= -6.86 \text{ kJ/kg}$$

$$Q_{13} - W_{13} = m(u_3 - u_1)$$

$$q_{13} - w_{13} = u_3 - u_1$$

$$q_{13} - (-6.86 \text{ kJ/kg}) = 103.9 - 248.49$$

$$q_{13} = -151.45 \text{ kJ/kg}$$

Q2)

Argon is an ideal monatomic gas → specific heats are constant

$$\frac{P_1 V_1 = \cancel{m}\cancel{R}T_1}{P_2 V_2 = \cancel{m}\cancel{R}T_2} \rightarrow \left(\frac{1.4}{7}\right)\left(\frac{0.1 m^3}{V_2}\right) = \frac{283K}{553K}$$

$$V_2 = 0.0391 \text{ m}^3$$

$$P_1 V_1^n = P_2 V_2^n \rightarrow n = \frac{\ln(P_2/P_1)}{\ln(V_1/V_2)} = 1.714$$

$$W_{12} = \frac{P_2 V_2 - P_1 V_1}{1-n} = \frac{(700 \text{ kPa})(0.0391 m^3) - (140 \text{ kPa})(0.1 m^3)}{1 - 1.714}$$

$$= -18.73 \text{ kJ}$$

$m = \frac{P_1 V_1}{R T_1}$ where $R = \frac{8.314 \text{ kJ/kmol·K}}{39.94 \text{ kg/kmol}} = 0.2081 \frac{\text{kJ}}{\text{kg·K}}$

$$m = (140)(0.1) / (0.2081)(283) = 0.2377 \text{ kg}$$

$$Q_{12} - W_{12} = m\underbrace{(u_2 - u_1)}_{c_v(T_2 - T_1)}$$

$$Q_{12} - (-18.73) = (0.2377)(0.3122 \text{ kJ/kg·K})(280 - 10)$$

$$Q_{12} = 1.31 \text{ kJ}$$

Note: from Table A.21: $\overline{c_p} = 2.5 R_u$ for monatomic gases

$\overline{c_p} - \overline{c_v} = R_u \rightarrow \overline{c_v} = 1.5 R_u = (1.5)(8.314) = 12.471$ kJ/kmol·K

$c_v = \overline{c_v} / MW_{argon} = 0.3122 \frac{\text{kJ}}{\text{kg·K}}$

ME 203

HW#1

Q1) A closed, rigid tank contains 4 kg of saturated mixture of liquid-vapor water at 100 kPa. Water is now heated to a pressure of 30 MPa. It is observed that water passes through its critical point during this heating process. Find:

(a) the initial quality of water,

(b) the volume of the tank,

(c) the final temperature of water,

(d) the pressure when the tank contains all saturated water vapor during the heating process.

(e) Show the process on T-v and P-v diagrams.

Q2) Ammonia vapor is compressed in a piston-cylinder assembly from saturated vapor at T_1=-20°C to a final state of P_2=900 kPa and T_2=88°C. During the process the pressure and specific volume are related by Pv^n=constant. Determine the work in kJ given that there are 2kg of ammonia in the cylinder.

ME 203

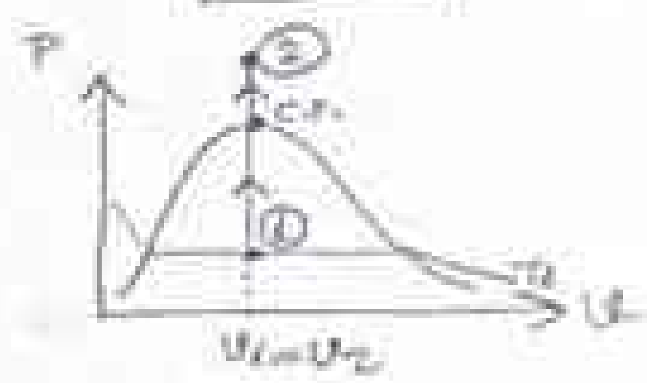
HW#1 Solution

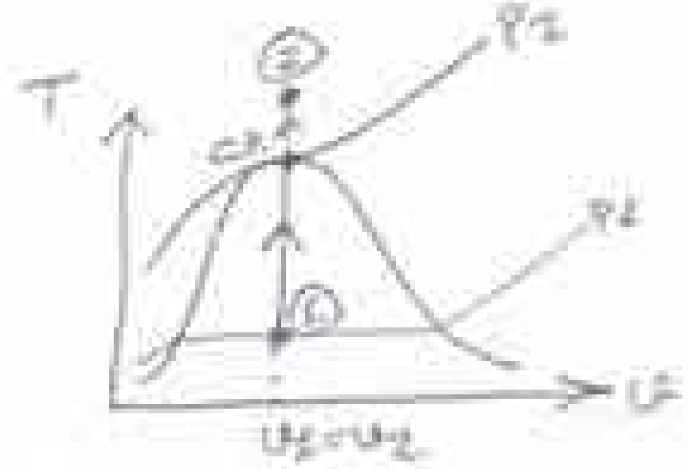
Q1)

Q1)

P_2 = 30 MPa

(e)





closed, rigid tank $\longrightarrow$ $\left.\begin{array}{l} V = \text{constant} \\ m = \text{constant} \end{array}\right\}$ v = constant

Table A.2 : For water, T_c = 647.3K
P_c = 22.12 MPa
v_c = 0.00317 m³/kg.

(a) state 1: $\left.\begin{array}{l}\text{Saturated mixture of Liquid} \\ \text{+Vapor water} \\ P_1 = 100 \text{ kPa} \\ v_1 = v_c = 0.00317 \text{ m}^3/\text{kg}\end{array}\right\}$ B.1.2: v_f = 0.001043
v_g = 1.69296

$$x_1 = \frac{v_1 - v_f}{v_{fg}} = \frac{0.00317 - 0.001043}{1.69296} = 0.001256$$

(b) $V_{tank} = m \cdot v_1 = (4\text{ kg})(0.00317 \text{ m}^3/\text{kg}) = 0.01268 \text{ m}^3$

(c) state 2: $\left.\begin{array}{l} P_2 = 30 \text{ MPa} \\ v_2 = v_1 = v_c = 0.00317 \text{ m}^3/\text{kg}\end{array}\right\}$ B.1.3: Interpolation between 400 and 425°C gives:
$T_2 \approx 404$°C

(d) The tank contains all saturated vapor (no liquid) at the critical point. Pressure at this instance is the critical point pressure : 22.12 MPa

Q2)

For saturated vapor at $T_1 = -20^\circ C$ (Ammonia) we can read P_1 value as $\underline{190.2\ kPa}$ from Table B.2.1 and also v_g is $\underline{0.62334}\ m^3/kg$.

$(\underline{P_1 = 190.2\ kPa}\ ,\ \underline{v_1 = 0.62334\ m^3/kg})$

For final state $(P_2 = 900\ kPa,\ T_2 = 88^\circ C)$, when we look at Table B.2.1 for $T = 88^\circ C$ we see that $P_{sat} > P_2$, so we understand that ammonia at the final state is at <u>superheated vapor</u> state.

<u>From Table B.2.2</u> :

$$v'(\text{at } 800kPa,\ 88^\circ C) \Rightarrow \frac{88-80}{100-80} = \frac{v' - 0.20530}{0.21849 - 0.20530}$$

$$\Rightarrow v'(\text{at } 800kPa,\ 88^\circ C) = \underline{\underline{0.211336}}\ m^3/kg$$

$$v''(\text{at } 1000kPa,\ 88^\circ C) \Rightarrow \frac{88-80}{100-80} = \frac{v'' - 0.16270}{0.17389 - 0.16270}$$

$$\Rightarrow v''(\text{at } 1000kPa,\ 88^\circ C) = \underline{\underline{0.167176}}\ m^3/kg$$

$$v(\text{at } 900kPa,\ 88^\circ C) \Rightarrow \frac{900-800}{1000-800} = \frac{0.211336 - v}{0.211336 - 0.167176}$$

$$\Rightarrow \boxed{v(\text{at } 900kPa,\ 88^\circ C) = 0.189256\ m^3/kg} = v_2$$

During compression of ammonia vapor from first state to final state;

$Pv^n = \text{constant} = P_1 v_1^n = P_2 v_2^n$

$P = \dfrac{\text{constant}}{v^n}$

$$_1w_2 = \int_1^2 P\,dv = \text{constant} \int_1^2 \frac{dv}{v^n} = \frac{Pv^n}{\text{constant}} \left(\frac{v^{1-n}}{1-n} \right) \Bigg|_1^2 = \frac{P_2 v_2 - P_1 v_1}{1-n}$$

To find $_1w_2$ we need to find n

$$P_1 v_1^n = P_2 v_2^n \Rightarrow (190.2\ kPa)\cdot(0.62334\ m^3/kg)^n = (900\ kPa)\cdot(0.189256\ m^3/kg)^n$$

$$\Rightarrow 3.2936^n = 4.7319$$

$$n = \frac{\log 4.7319}{\log 3.2936}$$

$$\boxed{n = 1.304}$$

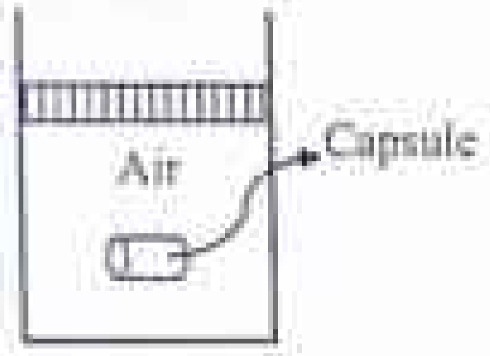
$$_1w_2 = \frac{P_2 v_2 - P_1 v_1}{1-n} = \frac{(900\ kPa)(0.189256\ m^3/kg) - (190.2\ kPa)(0.62334\ m^3/kg)}{1 - 1.304}$$

$_1w_2 = -170.3\ kj/kg$

$m = 2\,kg$ (given)

$$_1W_2 = m \cdot {_1w_2} = (2\ kg)(-170.3\ kj/kg) = \boxed{-340.6\ kj}$$

Q1) An insulated vertical cylinder is fitted with a frictionless piston. The cylinder initially contains air at 300 K, 150 kPa with a volume of 100 L. There is a small capsule in the cylinder with a volume of 5 L. The capsule initially contains air at 300 K, 500 kPa. Now the capsule breaks and the two gases mix together. Assume that the pressure in the cylinder stays constant at 150 kPa during the process. Treat air as an ideal gas and use constant specific heat approach in your solution. Calculate the:



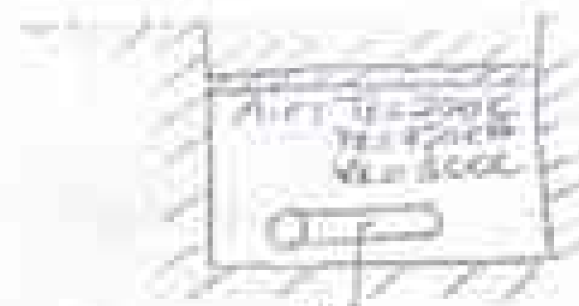
(a) final temperature in the cylinder,

(b) work done during the process in kJ.

Q2) Two rigid tanks (A and B) are connected by an initially closed valve. Tank A has a volume of 300 L and contains water at 1.4 MPa, 300°C. Tank B has a volume of 150 L and contains water at 200 kPa, 200°C. Now the valve is opened and the water in both tanks come to a uniform final state, which is in thermal equilibrium with the surroundings at T_{surr} = 25°C. Calculate the heat transfer during this process.

HW#2 Solution

Q1)



Capsule: Air @ $T_1 = 300K$
$P_1 = 500kPa$
$V = 5L$

• $P_{cylinder} = 150$ kPa (constant)

• Use constant specific heat approach.

Cylinder, Initial State

$$m_{air} = \frac{P_1 V_1}{R T_1} = \frac{(150)(100\times10^{-3})}{(0.287)(300K)}$$

$m_{air} = 0.1742$ kg

Capsule, Initial State

$$m_{air} = \frac{(500kPa)(5\times10^{-3})}{(0.287)(300)}$$

$m_{air} = 0.029$ kg

Final State:

$m_2 = 0.1742 + 0.029 = 0.2032$ kg

$P_2 V_2 = m_2 R T_2$

$150 V_2 = (0.2032)(0.287) T_2$

$V_2 = 0.0003888\, T_2$ ---- (1)

1st Law for the air in the cylinder (closed system):

$\cancel{Q_{1,2}}^{\,0} - W_{1,2} = m(u_2 - u_1)$

$W_{1,2} = \int_{V_1}^{V_2} P\, dV = P_1 (V_2 - V_1) = (150kPa)(V_2 - 0.105)$ (constant $= P_1$)

$-150(V_2 - 0.105) = m\, C_v (T_2 - T_1)$

$-150 V_2 + 15.75 = (0.2032)(0.717)(T_2 - 300)$

Insert equation (1):

$-150(0.0003888\, T_2) + 15.75 = 0.14569\, T_2 - 43.708$

$59.458 = 0.204\, T_2$

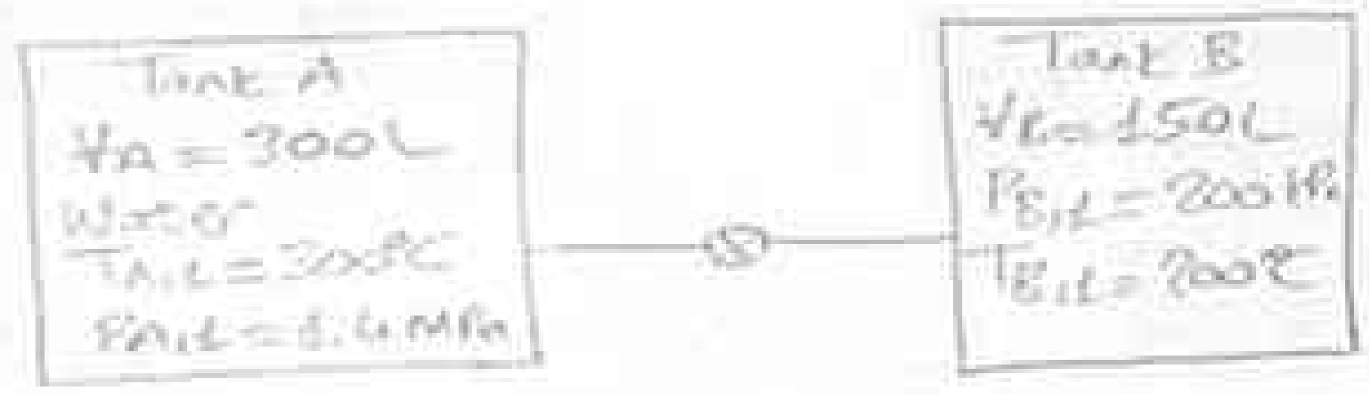
$T_2 = 291.46$ K

$V_2 = 0.1133\ m^3$

$W_{1,2} = P(V_2 - V_1) = 150(0.1133 - 0.105) = 1.245$ kJ

Q2)

3)



State 1 of A:

300°C, 1.6 MPa } Superheated steam, Tbl.3: $v_{A1} = 0.18228$, $u_{A1} = 2785.16$, $s_{A1} = 6.9533$

$$m_{A,1} = \frac{V_A}{v_{A1}} = \frac{0.3\,m^3}{0.18228\,m^3/kg}$$

$m_{A,1} = 1.646$ kg

State 1 of B:

200 kPa, 200°C } Superheated steam, $v_{B,1} = 1.08034$, $u_{B,1} = 2654.39$, $s_{B,1} = 7.5066$

$$m_{B,1} = \frac{V_B}{v_{B,1}} = \frac{0.15\,m^3}{1.08034\,m^3/kg}$$

$m_{B,1} = 0.139$ kg

$m_2 = m_{A,1} + m_{B,1} = 1.785$ kg

$$v_2 = \frac{V_A + V_B}{m_2} = \frac{0.45\,m^3}{1.785\,kg} = 0.2521\,m^3/kg$$

State 2

$T_2 = 25°C$, $v_2 = 0.2521\,m^3/kg$ }

$v_f < v_2 < v_g \rightarrow$ Saturated mixture of L+V

$$x_2 = \frac{v_2 - v_f}{v_{fg}} = \frac{0.2521 - 0.001003}{43.3583}$$

$x_2 = 0.00579$

$u_2 = 104.86 + (0.00579)(2304.9) = 118.21$ kJ/kg

1st Law for Tank A + Tank B (closed system):

$$Q - \cancel{W}^{\,0} = m_2 u_2 - (m_{A,1} u_{A,1} + m_{B,1} u_{B,1})$$

$$Q = (1.785)(118.21) - (1.646)(2785.16) - (0.139)(2654.39)$$

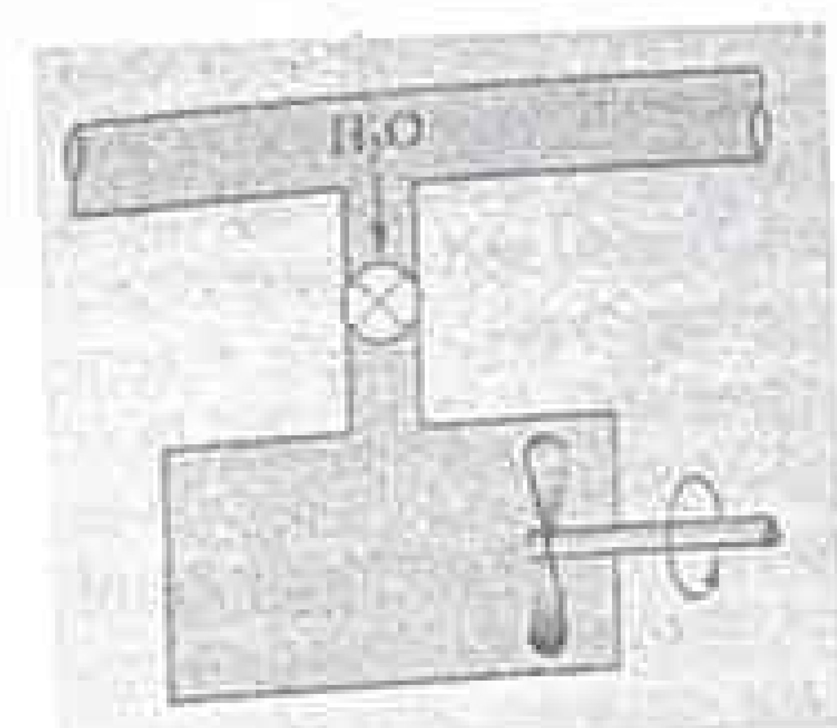
$= -4742.33$ kJ

$Q_{sur} = +4742.33$ kJ

HW#3

Q1) Steam turbine is used to steadily operate an R-134a centrifugal compressor. The inlet and exit states of the turbine are P_i = 10 MPa, T_i = 650°C, x_e = 0.96 and P_e = 10 kPa and the mass flow rate of the steam 10 kg/s. The inlet and exit states of the compressor are x_i = 1, P_i = 120 kPa and P_e = 800 kPa, T_e = 40.06°C. Assuming both the turbine and compressor are adiabatic devices, calculate the power supplied by the turbine and the mass flow rate of refrigerant that can be provided by the compressor.

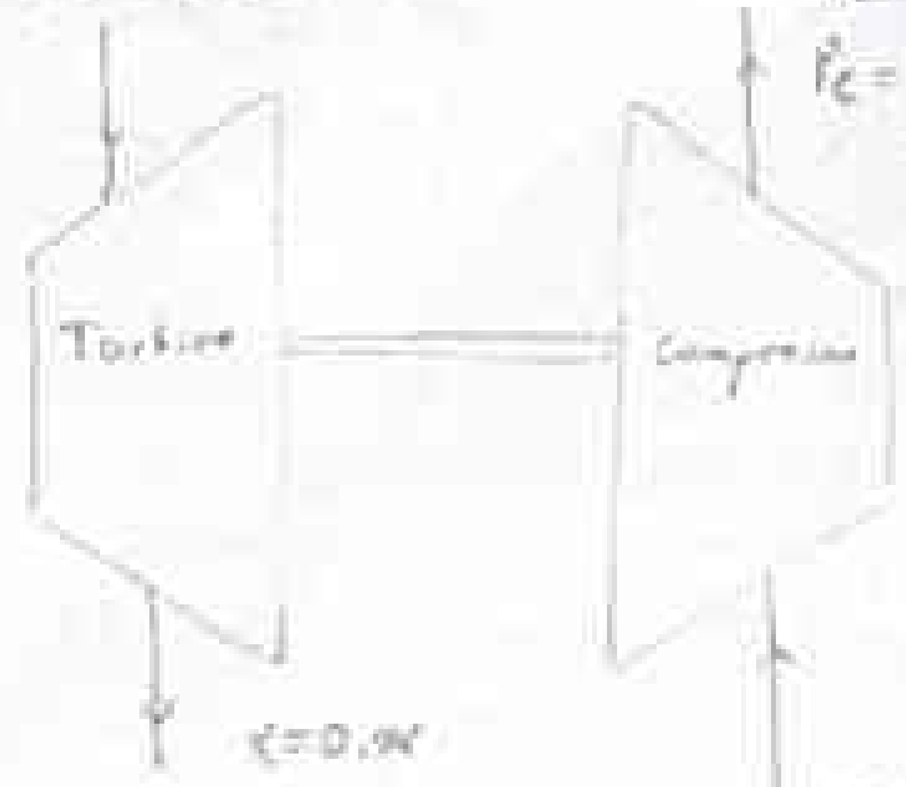
Q2) Water flows in a pipe at a pressure of 3.5 MPa and at a temperature 350°C.Attached to the pipe is an evacuated enclosure separated by a valve, as shown in the accompanying figure. An impeller is used to thoroughly mix the contents of the enclosure. The valve is opened and 10 kg of steam is allowed to enter the enclosure. At the end of the process the pressure inside the enclosure is found to be 3.5 MPa and during the process 700kJ of impeller work is required to mix the contents. The enclosure has a volume of 0.15 m³. Determine final temperature (if superheated) or quality (if saturated) of the steam inside the enclosure. Also, calculate the heat transfer from the enclosure during the process.



ME203 - HW#3

- SOLUTION -

Q1)



$$W_{turbine} = \dot{m}(h_i - h_e)$$

$$= 10\,(3717.9 - (0.96(2437.9) + 0.04(191.8)))$$

$$\boxed{W_{turbine} = 13998.6\ W}$$

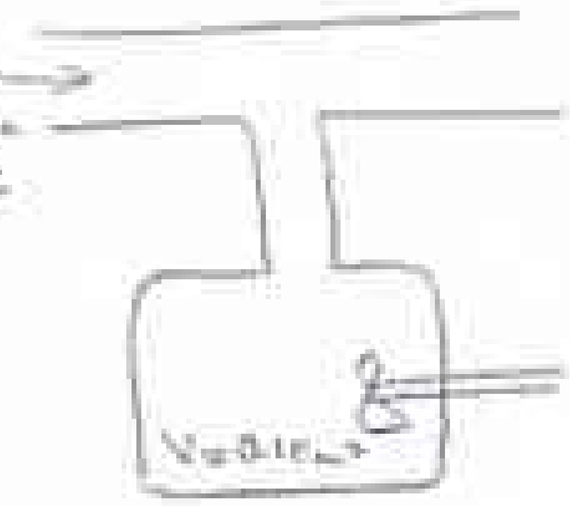
Same shaft $\rightarrow$ $W_{compressor} \Rightarrow 13998.6\ W$

$$W_{comp} = \dot{m}_{R134}\cdot(h_e - h_i)$$

$$13998.6 = \dot{m}\cdot(424.86 - 386.5)$$

$$\boxed{\dot{m}_{R\text{-}134a} = 346.85\ kg/s}$$

Q2:



Tank @ final state

$P = 3.5$ MPa

$v = \dfrac{0.15\,m^3}{10\,kg} = 0.015\,m^3/kg$

} saturated water

$x = 0.2666$

$T = 242.6°C$

$u = 1429.65$ kJ/kg

1st law of thermodynamics

$$Q - W = m u_{tank} - m h_{line}$$

$$Q = 10\,kg \cdot 1429.65\,kJ/kg - 10\,kg \cdot 3103.36\,kJ/kg + 700\,kJ$$

$Q = -16041.6$ kJ from the enclosure during the process

METU Department of Mechanical Engineering
ME 203 Thermodynamics I – Section 4 – Fall 2014 –Homework 1
DUE: 8:40am, October 27th, 2015

READ the instructions under the heading "Homework Policy" in the course outline, before you start solving the homework.

1. Describe the following terms in your own words:

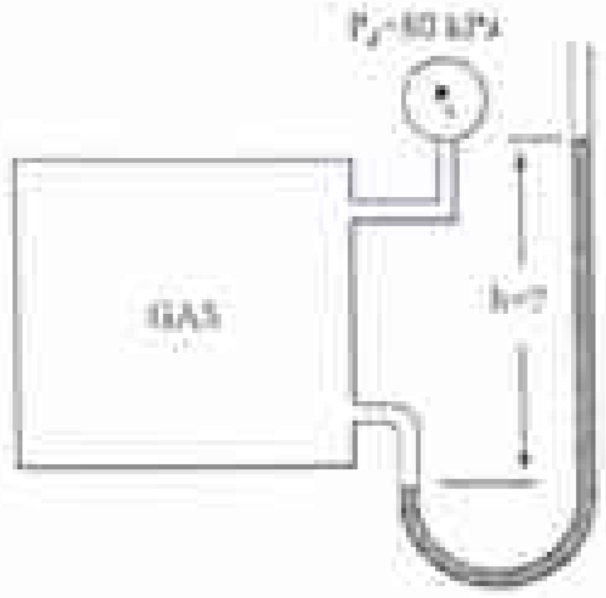
A) System	B) Closed System
C) Open System	D) Property
E) Intensive Property	F) Extensive Property
G) Thermodynamic Equilibrium	H) Process
I) Thermodynamic Cycle	J) Phase

2. Draw possible boundaries for the following systems (show inlet and outlet mass, heat, and work, if there is any):

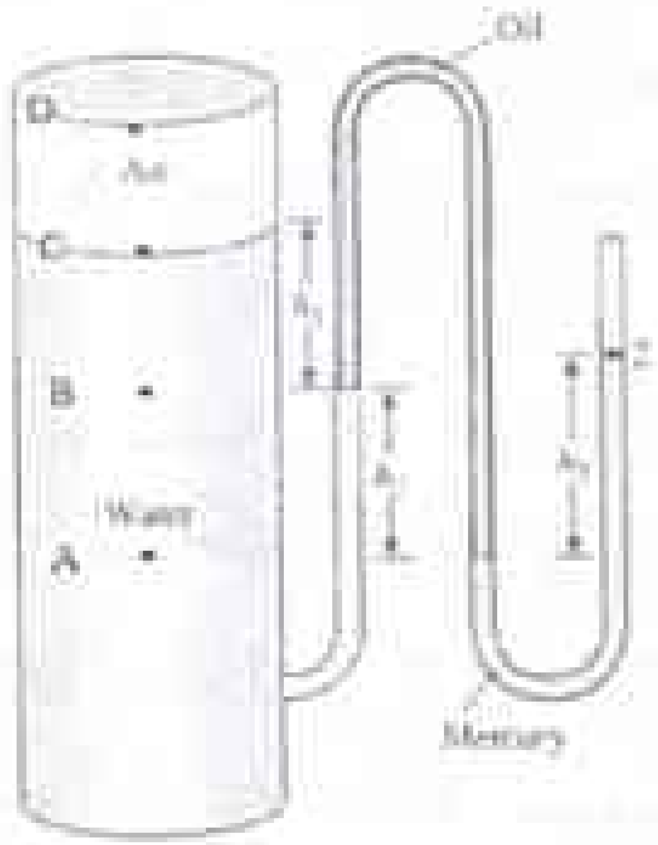
A) A bicycle tire inflating	B) A kettle of water boiling
C) A refrigerator	D) A jet engine
E) A gas furnace in operation	F) A rocket launching

3. Find the power required for a fixed pulley lifting a 500kg mass to 50 meters above the ground in 10 minutes.

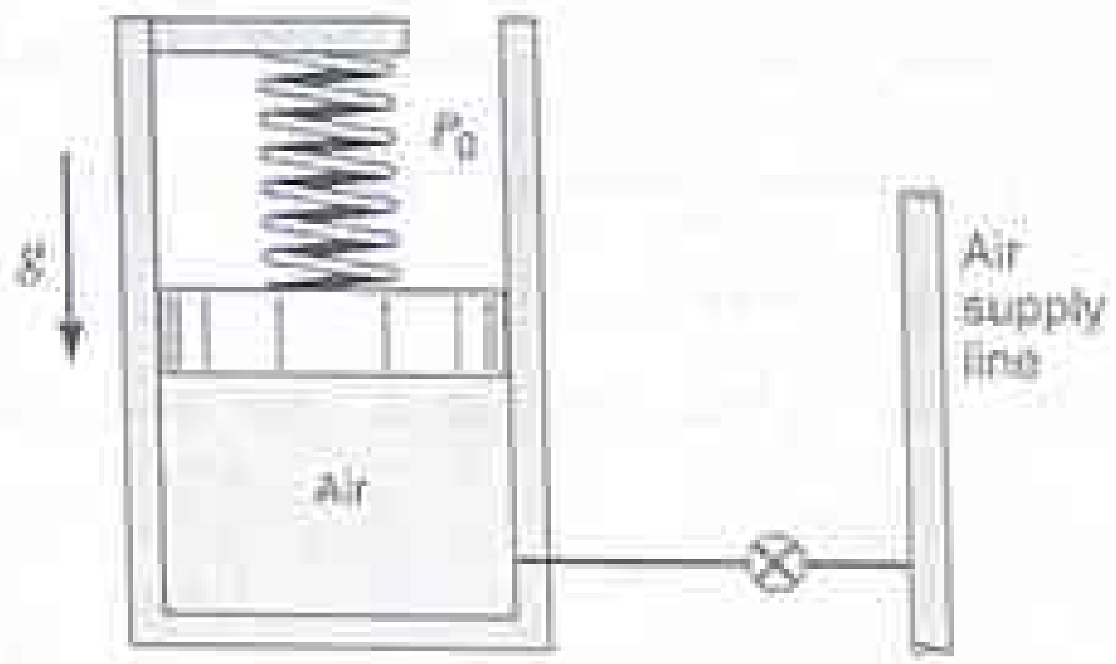
4. In order to obtain the pressure of a tank, a manometer and a gage are attached to it. If the gage indicator shows 80 kPa, determine the distance between the two fluid levels of the manometer. (The operating fluid is (a) mercury and (b) water).
ρ_{Hg} =13,600 kg/m3, ρ_w =1000 kg/m3



5. In the figure below, determine the absolute pressure of the points A, B, C and D inside the tank. (h1=0.2m, h2=0.3m, h3=0.46m; ρ_{Hg} =13,600 kg/m3, ρ_w =1000 kg/m3, ρ_{Oil} =850 kg/m3, P_{atm}=100kPa)



6. A piston in a cylinder with a diameter of 100 mm is loaded with a linear spring (K= 4kN/m) and the outside atmospheric pressure is 100 kPa. For the state shown, the spring exerts no force on the piston and the pressure is 200 kPa. The valve is opened to let some air in, causing the piston to rise 5 cm. Find the new pressure.



ME203 Thermodynamics I, section 2

Homework # 1 Solutions:

Problem 1.

A) System: The first step in the thermodynamics analysis of anything must be the definition of the entity that is subjected to analysis. This entity (collection of matter, region in space) is called a system.

B) Closed system: A closed system or control mass is a system defined by a boundary impermeable to mass flow. In other words, a closed system is a fixed quantity of matters.

C) Open system: A system whose defining boundaries can be crossed by the flow of mass are recognized as open system or flow system. Such thermodynamic system is also called as the control volume (prescribed volume).

D) Property: the condition, or the being, of a thermodynamic system at a particular point in time is described by an ensemble of quantities called thermodynamic properties. Thermodynamic properties are those quantities whose numerical values do not depend on the history of the system, as the system evolves between two different states.

E) Intensive property: Thermodynamic properties whose values do not depend on the mass (size) of the system are intensive properties.

F) Extensive property: Thermodynamic properties whose values depend on the mass (size) of the system are called extensive properties.

G) Thermodynamic Equilibrium: If for a system at the given state all three of the mechanical equilibrium (no pressure difference with the environment), thermal equilibrium (no heat interaction), and chemical equilibrium (uniform composition) are satisfied, it is said that the system is in thermodynamics equilibrium.

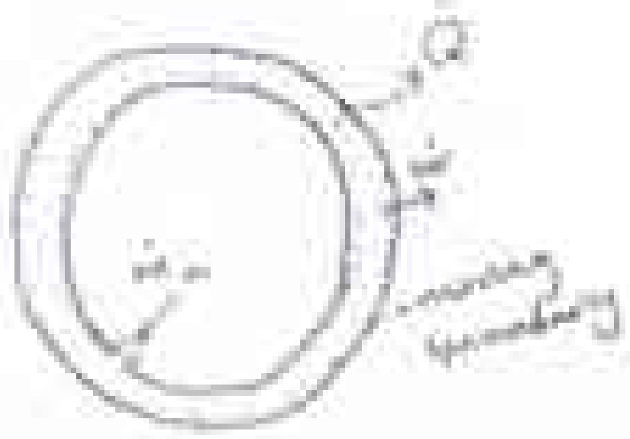
H) Process: The path of the succession states followed by the system from the initial to the final state is called process.

I) Thermodynamic cycle: It is a special process in which the final state coincides with the initial state.

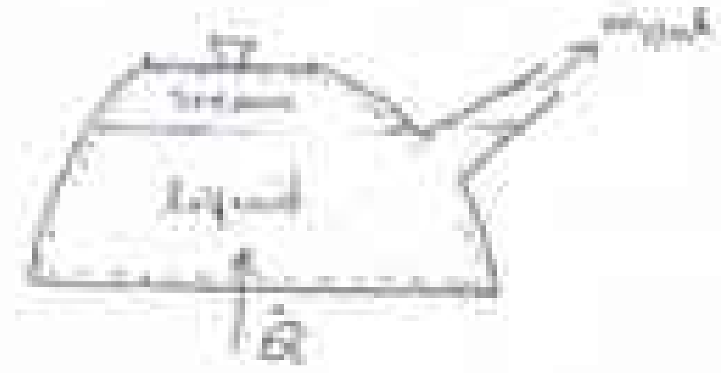
J) Phase: A certain phase of a system is the collection of all the parts of the system that have the same intensive properties and the same per-unit-mass values of the extensive properties.

Problem 2.

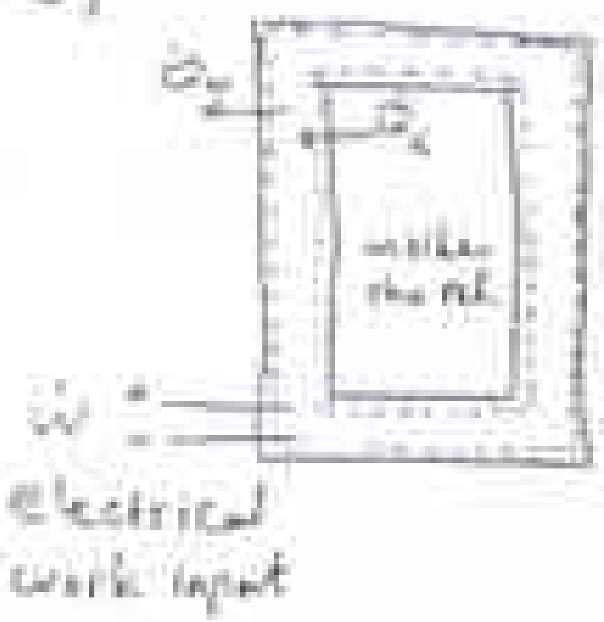
A)



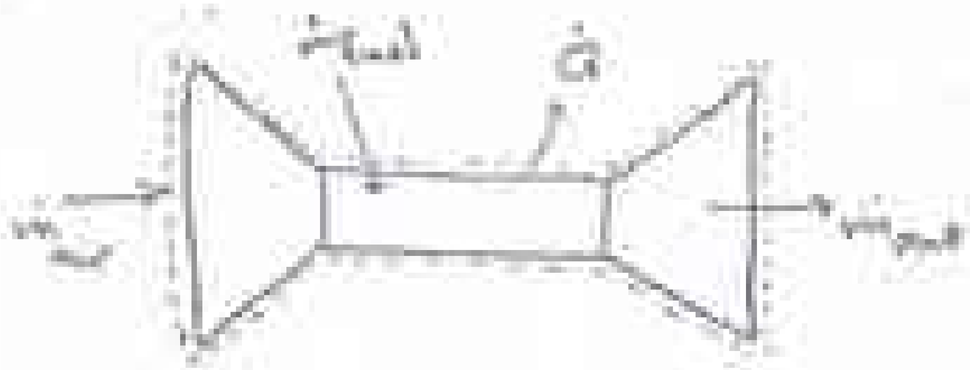
B)



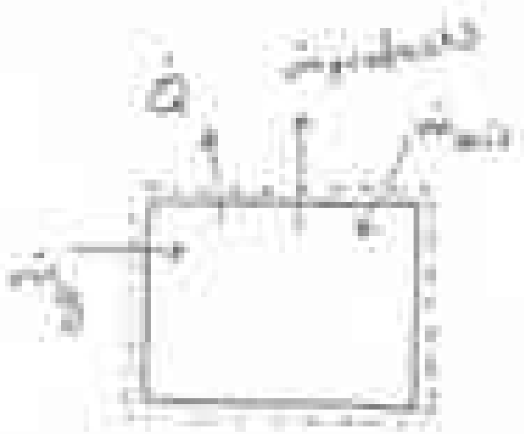
C)



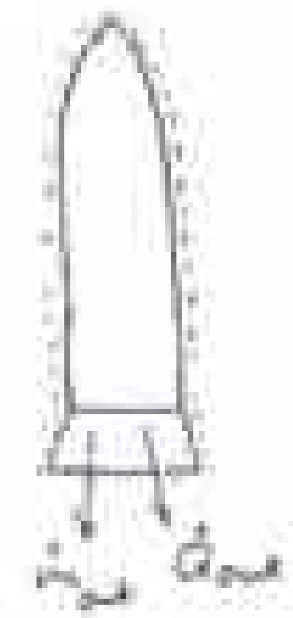
D)



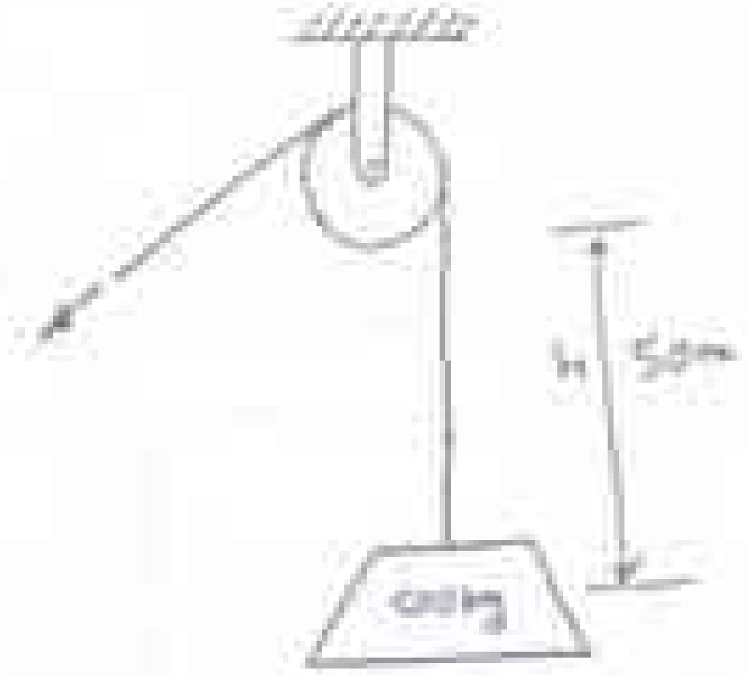
E)



F)



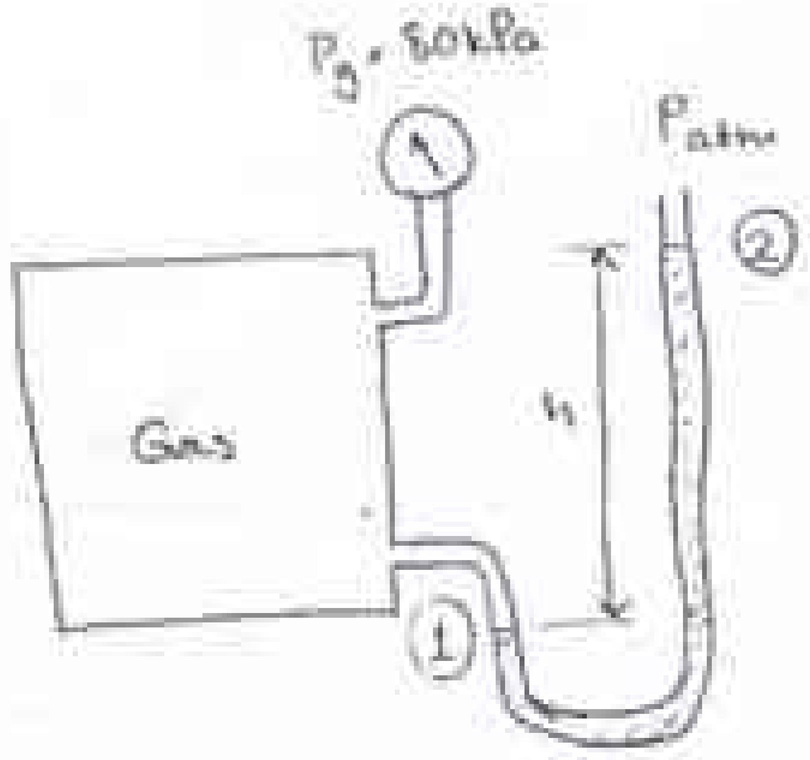
Problem 3.



$$W = mgh = 500 \times 9.81 \times 50 = 245.25 \text{ kJ}$$

$$\dot{W} = \frac{W}{t} = \frac{245.25}{10 \times 60} = 0.409 \text{ kW}$$

Problem 4.



$P_2 = P_{atm}$

As we know, the gage indicates pressure relative to the atmosphere.

Starting from P_g and moving along the tube from point 1 to point 2:

$$P_g - \rho g h = P_2 \Rightarrow \underbrace{P_g - P_2}_{P_{gage}\text{ (what we read in the pressure gage)}} = \rho g h$$

$$\Rightarrow 80\ kPa = \rho g h$$

a) Mercury:

$$80 \times 10^3 = 13600 \times 9.81 \times h_{Hg} \Rightarrow h_{Hg} = 0.600\ [m]$$

b) Water:

$$80 \times 10^3 = 1000 \times 9.81 \times h_w \Rightarrow h_w = 8.155\ [m]$$

Problem 5.

Point A:

$$P_A - \rho_w g h_2 - \cancel{\rho_{oil} g h_1} + \cancel{\rho_{oil} g h_1} + \rho_{oil} g h_2 - \rho_{Hg} g h_3 = P_2 = P_{atm}$$

$$P_A = 100 + \frac{1000 \times 9.81 \times 0.3}{1000} - \frac{850 \times 9.81 \times 0.3}{1000} + \frac{13600 \times 9.81 \times 0.46}{1000}$$

$$\Rightarrow P_A = 161.8\ kPa$$

Point B:

$$P_B - \rho_{oil} g h_1 + \rho_{oil} g h_1 + \rho_{oil} g h_2 - \rho_{Hg} g h_3 = P_2$$

$$P_B = 100 - \frac{850 \times 9.81 \times 0.3}{1000} + \frac{13600 \times 9.81 \times 0.46}{1000}$$

$$\Rightarrow P_B = 158.87\ kPa$$

Point C:

$$P_C + \rho_w g h_1 = P_B \Rightarrow P_C = P_B - \rho_w g h_1$$

$$P_C = 158.87 - \frac{1000 \times 9.81 \times 0.2}{1000}$$

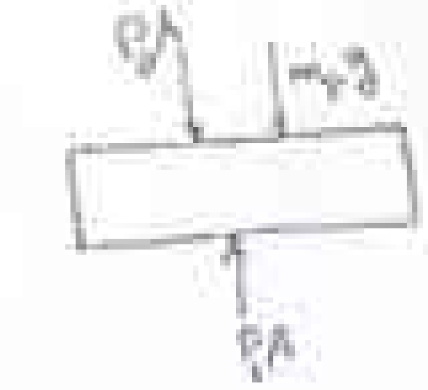
$$P_C = 156.9\ kPa$$

Point D:

$$P_D = P_C = 156.9\ kPa$$

Problem 6.

Before the valve is opened:



$$P_1 A = P_0 A + m_p g$$

$$\Rightarrow (P_1 - P_0) A = m_p g \Rightarrow m_p = \frac{(P_1 - P_0) A}{g}$$

$$\Rightarrow m_p = \frac{(200-100)\times 10^3 \times \frac{\pi}{4} \times 0.1^2}{9.81} \Rightarrow m_p = 80\,kg$$

After the valve is opened:

$$P_2 A = P_0 A + m_p g + KL$$

$$\Rightarrow P_2 = \frac{P_0 A + m_p g + KL}{A}$$

$$\Rightarrow P_2 = \frac{100\times 10^3 \times \frac{\pi}{4} \times 0.1^2 + 80 \times 9.81 + 4000 \times 0.05}{\frac{\pi}{4} \times 0.1^2}$$

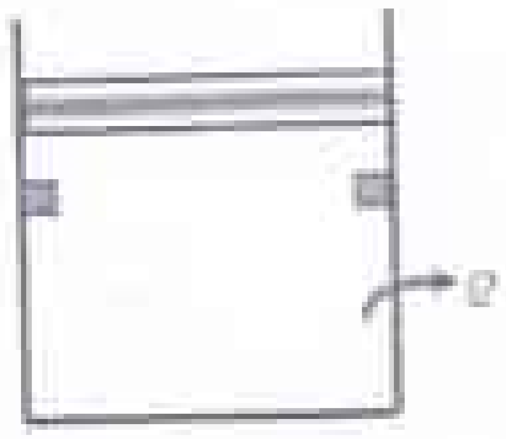
$$\Rightarrow P_2 = 225.4\ kPa$$

METU Department of Mechanical Engineering
ME 203 Thermodynamics I – Section 4 – Fall 2015 – Homework 2
DUE: 8:40am, November 24th, 2015

1- Find the boiling temperature of water in a piston cylinder setup with a 50 kg piston and the diameter of 15 cm. Calculate the temperature if the working fluid is R-134a.

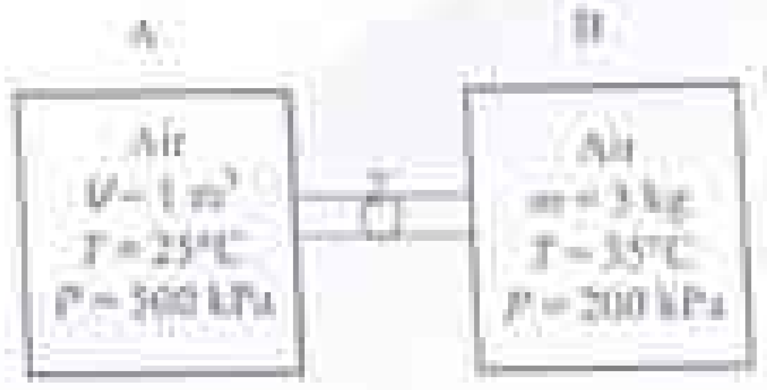
2- A 0.2 m^3 rigid tank that is filled with saturated liquid-vapor mixture of water at 200°C is heated until it crosses the critical point. Find the mass and volume of both liquid and vapor at the initial state. How much heat is required for this process? Imagine that the walls of this tank were transparent so we could observe the process. How the liquid/vapor portions would change during this process?

3- In a piston-cylinder setup that contains 4kg of steam at 3MPa and 400°C, heat is rejected until the piston reaches to the pin and stops. At this point, the volume of the cylinder is 0.2m^3. Heat loss continues until the temperature of the water inside the tank decreases to 150°C. Find the final pressure, specific internal energy and enthalpy and quality (if possible). Plot the process on a T-v diagram. Calculate the net heat transferred and net work done during the process.



4- A piston-cylinder setup contains R-134a at −20°C, x = 0.30 and the volume is 0.02 m^3. The piston weight is negligible and the area is 0.1 m^2. The spring force is zero when the piston reaches the bottom. The system is now heated until the pressure reaches to 150 kPa. Find the final temperature and specific volume of the fluid and plot the P–v diagram.

5- Two rigid tanks are connected to each other through a valve and contain air. The valve is now opened and both tanks reach to equilibrium. The tanks are not insulated, so at the final state the temperature of the tanks will be the same as the surrounding at 25°C. Calculate the final pressure and the mass for each tank.

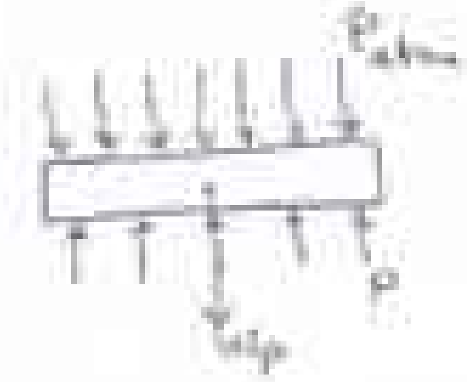


6- An insulated rigid vessel contains 1 kg of water at 300 kPa and 80% quality. A paddle-wheel inside the tank is turned by an external motor until all of the water becomes saturated vapor. Find the work necessary for this process and the final pressure and temperature. Plot the process on the T-v diagram.

ME203 Thermodynamics I , section 2

Homework #2 Solutions:

Problem 1:



$$P A_P = P_{atm} \cdot A_P + W_P$$

$$A_P = \frac{\pi}{4} \cdot 0.15^2 = 0.0177\,m^2$$

$$P = \frac{101325 \cdot 0.0177 + 50 \cdot 9.81}{0.0177} = 129037\ Pa$$

$\Rightarrow P = 129\ kPa$

Table B.1.2 :

$$\left.\begin{array}{ll} P\,[kPa] & T\,[°C] \\ 125 & 105.99 \\ 129 & T = ? \\ 150 & 111.37 \end{array}\right\} \Rightarrow \frac{T - 105.99}{111.37 - 105.99} = \frac{129 - 125}{150 - 125}$$

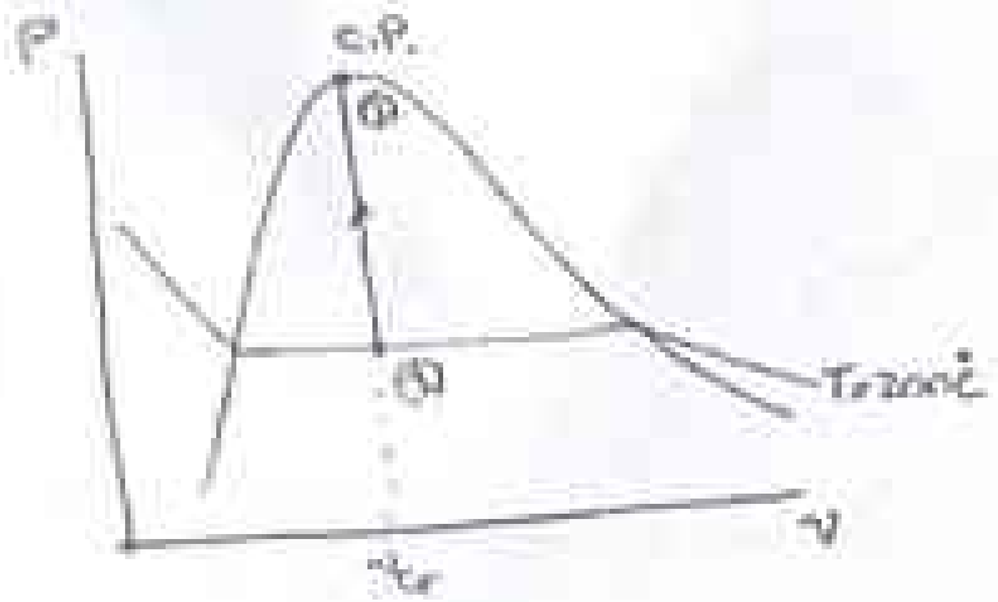
$\Rightarrow \underline{T = 106.85\ °C}$ (For water)

Table B.5.1 :

$$\left.\begin{array}{ll} T\,[°C] & P\,[kPa] \\ -25 & 107.2 \\ T = ? & 129 \\ -20 & 133.7 \end{array}\right\} \Rightarrow \frac{T - (-25)}{-20 - (-25)} = \frac{129 - 107.2}{133.7 - 107.2}$$

$\Rightarrow \underline{T = -20.89\ °C}$ (For R-134a)

Problem 2.



$T = 200°C$

$V = 0.2\ m^3$

$v_1 = v_{cr} = 0.003155\ m^3/kg$

At 200°C:

$v_f = 0.001156\ m^3/kg$

$v_g = 0.12736\ m^3/kg$

$v_{fg} = 0.12620\ m^3/kg$

$$m_{tot} = \frac{V}{v_1} = \frac{0.2}{0.003155} = 63.39\ kg$$

$$x_1 = \frac{v_1 - v_f}{v_{fg}} = \frac{0.003155 - 0.001156}{0.12620} = 0.0158$$

$$x_1 = \frac{m_g}{m_{tot}} \Rightarrow m_g = x_1 \cdot m_{tot} = 0.0158 \times 63.39 = 1.00\ kg$$

$$m_f = m_{tot} - m_g = 63.39 - 1.00 = 62.39\ kg$$

$$V_f = m_f \cdot v_f = 62.39 \times 0.001156 = 0.07212\ m^3$$

$$V_g = V - V_f = 0.2 - 0.7212 = 0.12788\ m^3$$

$$u_1 = u_f + x_1 u_{fg} = 850.64 + 0.0158 \times 1744.66 = 878.20\ kJ/kg$$

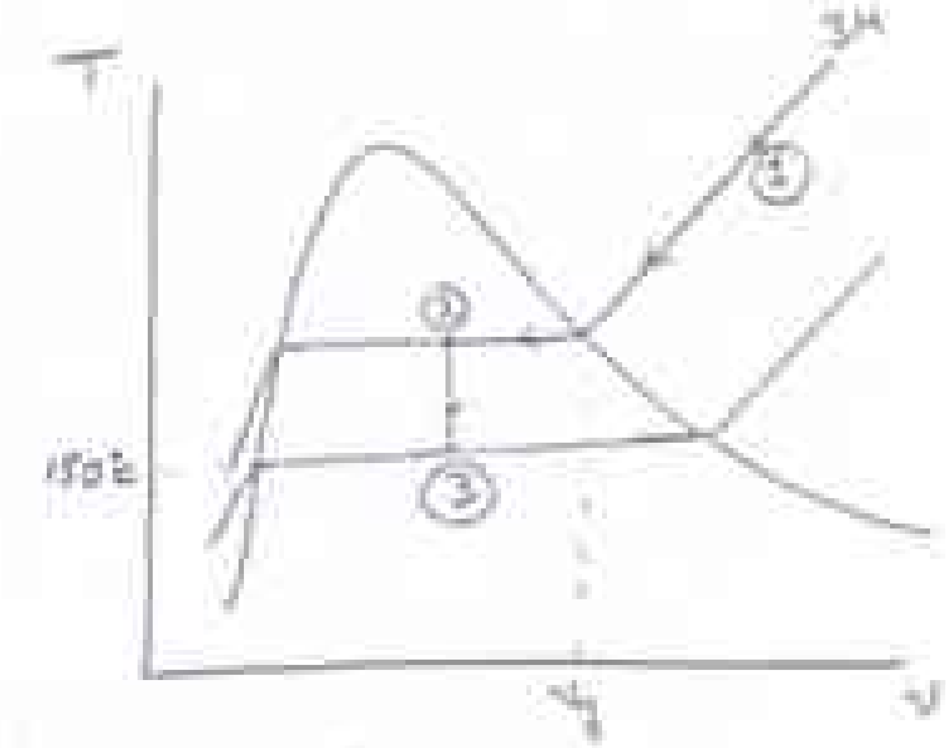
$$u_2 = u\ (\text{at critical point}) = 2029.58\ kJ/kg$$

1st law of thermodynamics:

$$Q_{1\to2} - \cancel{W_{1\to2}}^{\,0} = m(u_2 - u_1) \Rightarrow Q_{1\to2} = 63.39\,(2029.58 - 878.20)$$

$$\Rightarrow Q_{1\to2} = 72896\ kJ \approx 73\ MJ$$

Problem 3.



$$\left.\begin{array}{l} P_1 = 3\ MPa \\ T_1 = 400°C \end{array}\right\} \Rightarrow \left\{\begin{array}{l} v_1 = 0.09936\ m^3/kg \\ u_1 = 2932.75\ kJ/kg \end{array}\right.$$

$$V_1 = m \cdot v_1 = 4 \times 0.09936 = 0.3977\ m^3$$

$$V_g = m \cdot v_g (\text{at } 3MPa) = 4 \times 0.06668 = 0.26672\ m^3$$

$V_2 < V_g \Rightarrow$ two phase state

$$v_2 = \frac{V_2}{m} = \frac{0.2}{4} = 0.05\ m^3/kg \quad ; \quad x_2 = \frac{v_2 - v_f}{v_{fg}} = \frac{0.05 - 0.001216}{0.06546} = 0.7452$$

$$u_2 = u_f + x_2 u_{fg} = 1004.76 + 0.7452 \times 1599.34$$

$$u_2 = 2196.59\ kJ/kg$$

$T_3 = 150°C$

$v_3 = v_2 = 0.05\ m^3/kg$

$P_3 = P(\text{sat at } T_3) = 475.9\ kPa$

$$x_3 = \frac{v_3 - v_f}{v_{fg}} = \frac{0.05 - 0.001090}{0.39169} = 0.1249$$

$$u_3 = u_f + x_3 u_{fg} = 631.66 + 0.1249 \times 1927.87 = 842.45\ kJ/kg$$

$$h_3 = h_f + x_3 h_{fg} = 632.18 + 0.1249 \times 2114.26 = 896.25\ kJ/kg$$

Process 1→2 is constant pressure:

$$W_{1\to2} = m P_1 (v_2 - v_1) = 4 \times 3000\,(0.05 - 0.09936) = -592.32\ kJ$$

From the 1st law: $Q_{1\to2} - W_{1\to2} = m(u_2 - u_1)$

$$Q_{1\to2} = -592.32 + 4\,(2196.59 - 2932.75) = -3536.96\ kJ$$

Process 2→3 is constant volume:

$$W_{2\to3} = 0$$

$$Q_{2\to3} - W_{2\to3} = m(u_3 - u_2) \Rightarrow Q_{2\to3} = 4\,(842.45 - 2196.59) = -5416.56\ kJ$$

$$W_{1\to3} = W_{1\to2} + W_{2\to3} = -592.32\ kJ$$

$$Q_{1\to3} = Q_{1\to2} + Q_{2\to3} = -8953.52\ kJ$$

Problem 4.

$T_1 = -20^\circ C$, $x_1 = 0.3$ $\Rightarrow \begin{cases} P_1 = 133.7\ kPa \\ v_1 = v_f + x_1 v_{fg} \end{cases}$

$v_1 = 0.000738 + 0.3 \times 0.14576$

$v_1 = 0.0445\ m^3/kg$

$m = \dfrac{V_1}{v_1} = \dfrac{0.02}{0.0445} = 0.449\ kg$

$A_p = 0.1\ m^2 \Rightarrow L_1 = \dfrac{V_1}{A_p} = \dfrac{0.02}{0.1} = 0.2\ m$

$P_1 \cdot A_p = P_{atm} \cdot A_p + K_p \cdot L_1 \Rightarrow k_p = \dfrac{(P_1 - P_{atm})A_p}{L_1}$

$K_p = \dfrac{(133.7 - 101.3) \times 0.1}{0.2} = 16.2\ kN/m$

$P_2 = 150\ kPa$

$P_2 \cdot A_p = P_{atm} \cdot A_p + k_p L_2 \Rightarrow L_2 = \dfrac{(P_2 - P_{atm})A_p}{k_p}$

$L_2 = \dfrac{(150 - 101.3) \times 0.1}{16.2} = 0.3\ m$

$V_2 = A_p L_2 = 0.1 \times 0.3 = 0.03\ m^3$

$v_2 = \dfrac{V_2}{m} = \dfrac{0.03}{0.449} = 0.0668\ m^3/kg$

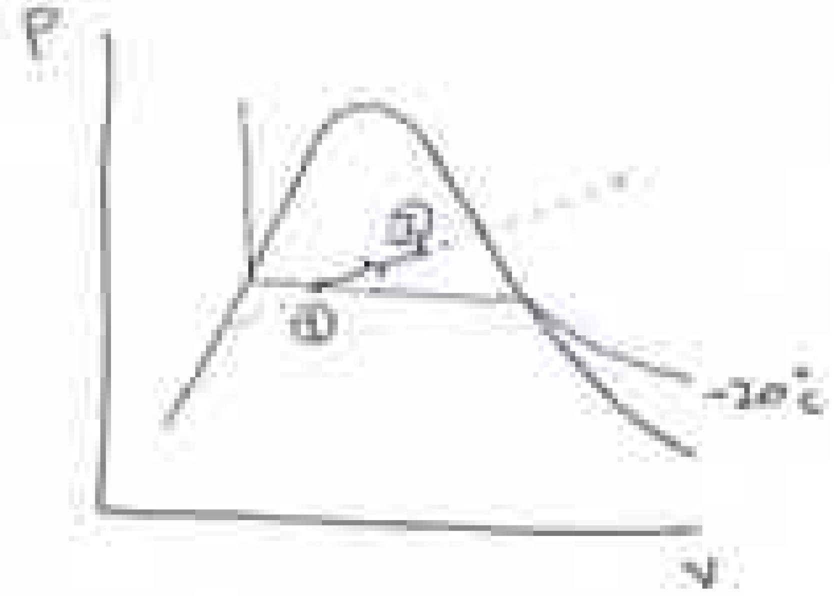
$v_f < v_2 < v_g$ → two phase region

$T_2 = T_{sat}$ (at $P = 150\ kPa$)

T [°C]	P [kPa]
-20	133.7
T_2=?	150
-15	165.0

$\Rightarrow \dfrac{T_2 - (-20)}{-15 - (-20)} = \dfrac{150 - 133.7}{165.0 - 133.7}$

$\Rightarrow T_2 = -17.40^\circ C$



Problem 5.

Air can be considered as an ideal gas.

$m_A = \left(\dfrac{P_1 V_1}{R T_1}\right)_A = \dfrac{500 \times 1.0}{0.287 \times 298} = 5.846\ kg$

$V_B = \left(\dfrac{m_1 R T_1}{P_1}\right)_B = \dfrac{5 \times 0.287 \times 308}{200} = 2.21\ m^3$

$V_{tot} = V_A + V_B = 1.0 + 2.21 = 3.21\ m^3$

$m_{tot} = m_A + m_B = 5.846 + 5.0 = 10.846\ kg$

$P_2 = \dfrac{m R T_2}{V} = \dfrac{10.846 \times 0.287 \times 293}{3.21} = 284.1\ kPa$

$m_{2A} = \left(\dfrac{P_2 V}{R T_2}\right)_A = \dfrac{284.1 \times 1.0}{0.287 \times 298} = 3.322\ kg$

$m_{2B} = 10.846 - 3.322 = 7.524\ kg$

Problem 6.

$m = 1\ kg$

$P_1 = 300\ kPa$

$x_1 = 80\%$

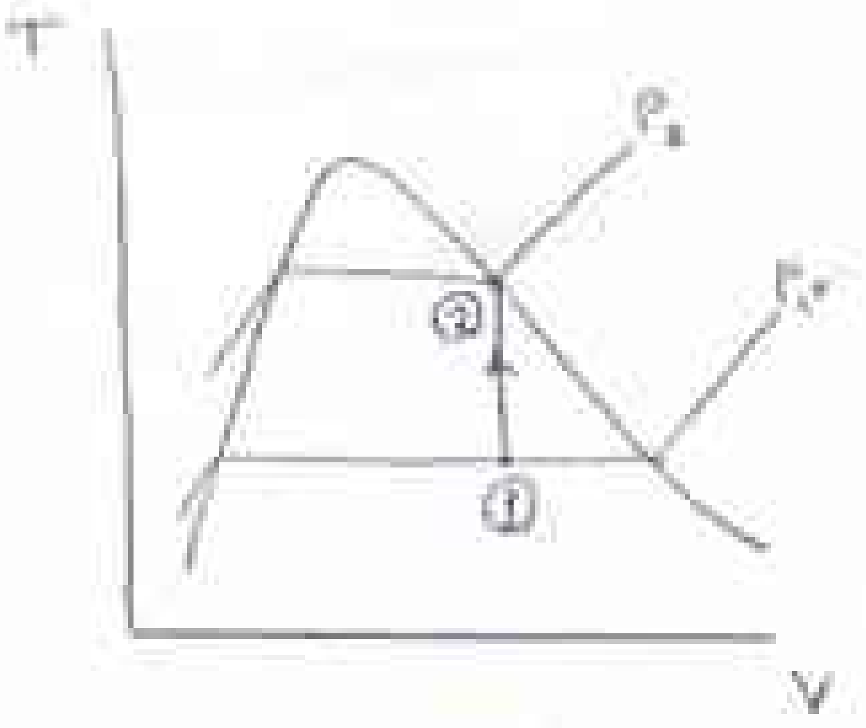
$v_1 = v_f + x_1 v_{fg} = 0.001073 + 0.80 \times 0.60475$

$\Rightarrow v_1 = 0.48487\ m^3/kg$

$u_1 = u_f + x_1 u_{fg} = 561.13 + 0.80 \times 1982.43$

$\Rightarrow u_1 = 2146.73\ kJ/kg$

$v_2 = v_1 = 0.48487\ m^3/kg$



State ② is saturated vapor.

$v_g\ [m^3/kg]$	$P\ [kPa]$	$T\ [°C]$	$u\ [kJ/kg]$
0.49137	375	141.32	2551.31
0.48487	P_2	T_2	u_2
0.46246	400	143.63	2553.55

$$\frac{0.48487-0.49137}{0.46246-0.49137} = \frac{P_2-375}{400-375} = \frac{T_2-141.32}{143.63-141.32} = \frac{u_2-2551.31}{2553.55-2551.31}$$

$$\Rightarrow \begin{cases} P_2 = 380.62\ kPa \\ T_2 = 141.84\ °C \\ u_2 = 2551.81\ kJ/kg \end{cases}$$

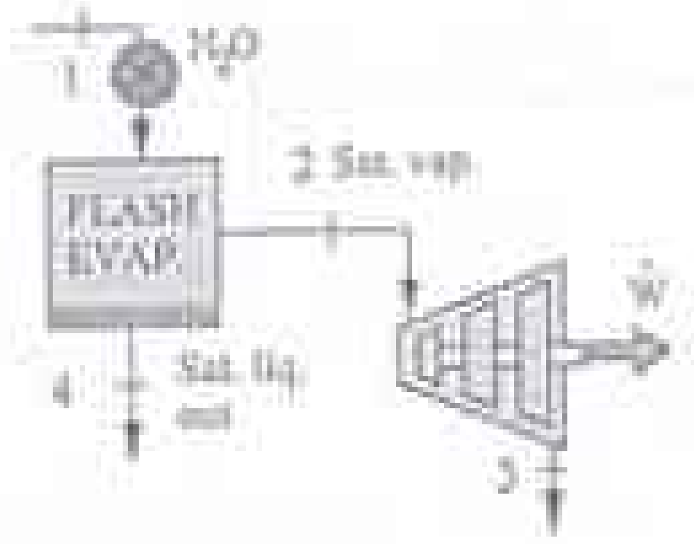
1st law of thermodynamics: $\cancel{Q}_{1\to 2} - \underset{0}{W_{1\to 2}} = m(u_2 - u_1)$

$W_{1\to 2} = -1 \times (2551.81 - 2146.73) = -405.08\ kJ$

METU Department of Mechanical Engineering
ME 203 Thermodynamics I – Section 2 – Fall 2015 –Homework 3
DUE: 21.12.2015 17:30

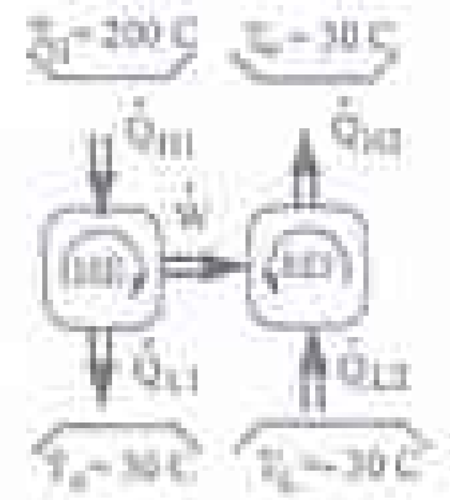
READ the instructions under the heading "Homework" in the course outline, before you start solving the homework.

Q1) A proposal is made to use a geothermal supply of hot water to operate a steam turbine, as shown in the figure. The high-pressure water at 2.5 MPa, 180°C, is throttled into a flash evaporator chamber, which forms liquid and vapor at a lower pressure of 400 kPa. The liquid is discarded while the saturated vapor feeds the turbine and exits at 10 kPa, 90% quality. If the turbine should produce 1 MW, find the required mass flow rate of hot geothermal water in kilograms per hour.



Q2) A 200 liter tank initially contains water at 100 kPa and a quality of 1%. Heat is transferred to the water thereby raising its pressure and temperature. At a pressure of 2 MPa a safety valve opens and saturated vapor at 2 MPa flows out. The process continues, maintaining 2 MPa inside until the quality in the tank is 90%, then stops. Determine the total mass of water that flowed out and the total heat transfer in kJ.

Q3) We wish to produce refrigeration at −30°C. A reservoir, shown below, is available at 200°C and the ambient temperature is 30°C. Thus, work can be done by a cyclic heat engine operating between the 200°C reservoir and the ambient. This work is used to drive the refrigerator. Determine the ratio of the heat transferred from the 200°C reservoir to the heat transferred from the −30°C reservoir, assuming all processes are reversible.



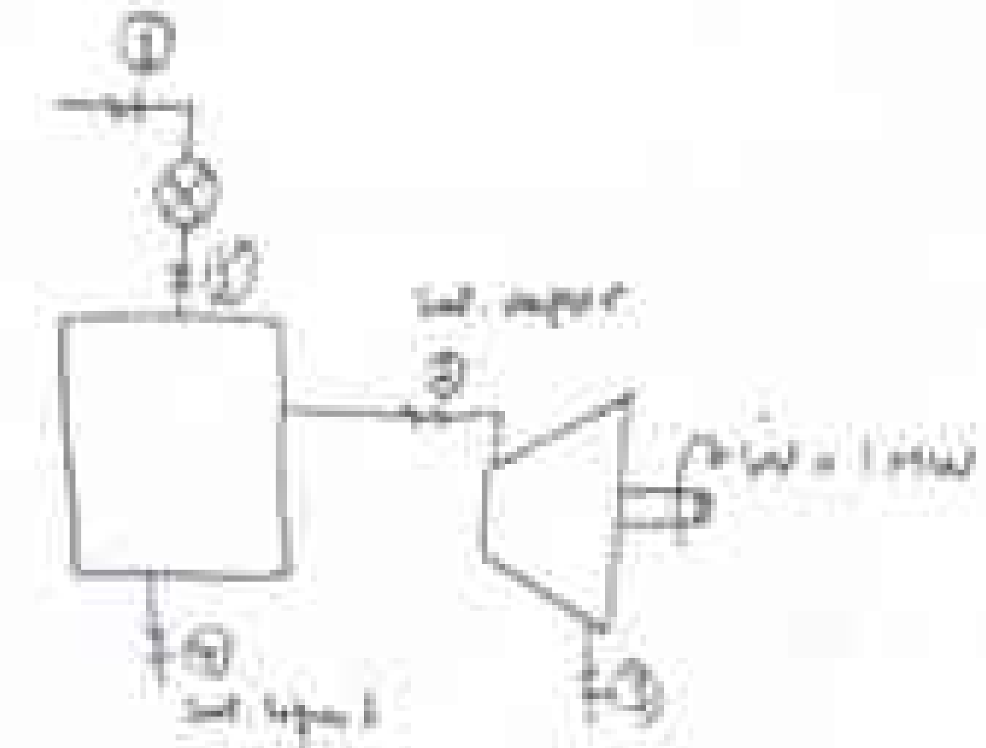
Q4) At steady state, a 750-MW power plant receives energy by heat transfer from the combustion of fuel at an average temperature of 300°C. The plant discharges energy by heat transfer to a river whose mass flow rate is 1.65×10^5 kg/s. Upstream of the power plant, the river is at 20°C. Determine the increase in the temperature of the river, ΔT, in °C, if the efficiency of the power plant is :
a) the maximum efficiency of the power cycle operating between hot and cold reservoirs at 300°C and 20°C, respectively
(b) half of the efficiency found in part (a)
(c) Comment on your results

Q3) A 4 liter pressure cooker has an operating pressure of 175 kPa. Initially, one half of the volume is filled with liquid and the other half with vapor. If it is desired that the pressure cooker not run out of liquid water for 1 hour, determine the highest rate of heat transfer allowed in kilowatts.

ME 203 Thermodynamics I, Section 2

Homework #3 Solutions

Problem 1



$P_2 = 400\,kPa$, sat. vapor $\Big\} \Rightarrow h_2 = 2738.53\ kJ/kg$

$P_3 = 10\,kPa$

$x_3 = 90\% \Rightarrow h_3 = 191.81 + 0.90 \times 2392.82 \Rightarrow h_3 = 2345.43\ kJ/kg$

$$\dot{W} = \dot{m}_2 (h_2 - h_3) \Rightarrow \dot{m}_2 = \frac{1000}{(2738.53 - 2345.43)} \Rightarrow \dot{m}_2 = 2.544\ kg/sec$$

$P_1 = 2.5\,MPa$, $T_1 = 180°C$ $\Big\} \Rightarrow$ compressed liquid

P [kPa]	2000	2500	5000
h [kJ/kg]	761.46	h_1	759.63

interpolation: $h_1 = 761.15\ kJ/kg$

For the throttling valve: $h_{1'} = h_1 = 761.15\ kJ/kg$

$P_{1'} = 400\,kPa$, $h_f < h_{1'} < h_g \Rightarrow$ liquid/vapor mixture

$$x_{1'} = \frac{761.15 - 604.73}{2133.31} = 0.0733$$

$$x_{1'} = \frac{\dot{m}_g}{\dot{m}_{tot}} \Rightarrow \dot{m}_{tot} = \frac{\dot{m}_g}{x_{1'}} \Rightarrow \dot{m}_{tot} = \frac{2.544}{0.0733} \Rightarrow \boxed{\dot{m}_{tot} = 34.707\ kg/sec}$$

$\dot{m}_g = \dot{m}_2 = 2.544\ kg/sec$

Problem 2.

$P_1 = 100kPa$ Process 1-2 is constant volume process in a closed system:

$x_1 = 0.01$

$P_2 = 2MPa$ $v_1 = v_f + x_1 v_{fg} = 0.001043 + 0.01 \times 1.69296$

$v_2 = v_1$ $v_1 = 0.01797 \ m^3/kg$

$P_3 = 2MPa$ $m_1 = \frac{V}{v_1} = \frac{0.2}{0.01797} = 11.13 \ kg$

$x_3 = 0.90$ $u_1 = 417.33 + 0.01 \times 2088.72 = 438.22 \ kJ/kg$

$m_2 = m_1 = 11.13 kg$

$\left.\begin{array}{l} v_2 = v_1 = 0.01797 \ m^3/kg \\ P_2 = 2MPa \end{array}\right\} \Rightarrow x_2 = \frac{0.01797 - 0.001177}{0.09845} = 0.1706$

$u_2 = 906.42 + 0.1706 \times 1693.84 = 1195.39 \ kJ/kg$

$Q_{1\to2} - \underbrace{W_{1\to2}}_{0} = m_1(u_2 - u_1) \Rightarrow Q_{1\to2} = 11.13(1195.39 - 438.22)$

$\boxed{Q_{1\to2} = 8427.3 \ kJ}$

$\left\{\begin{array}{l} P_3 = 2MPa \\ x_3 = 0.90 \end{array}\right. \Rightarrow v_3 = 0.001177 + 0.9 \times 0.09845 = 0.08978 \ m^3/kg$

$m_3 = \frac{V}{v_3} = \frac{0.2}{0.08978} = 2.228 \ kg$

$u_3 = 906.42 + 0.9 \times 1693.84 = 2430.88 \ kJ/kg$

$h_e = h_g$ (at 2MPa) $= 2799.51 \ kJ/kg$

$m_e = m_2 - m_3 = 11.13 - 2.228 = 8.902 \ kg$

$E_3 - E_2 = Q_{2\to3} - \underbrace{\cancel{W_{2\to3}}}_{0} + \underbrace{\cancel{\Sigma m_i}}_{0} h_i - \Sigma m_e h_e$

$Q_{2\to3} = m_3 u_3 - m_1 u_1 + m_e h_e = 2.228 \times 2430.88 - 11.13 \times 1195.39 + 8.902 \times 2799.51$

$\boxed{Q_{2\to3} = 17032.5 \ kJ}$

$Q_{CV} = Q_{1\to2} + Q_{2\to3} = 8427.3 + 17032.5 \Rightarrow \boxed{Q_{CV} = 25459.8 \ kJ}$

Problem 3.

$\frac{\dot{Q}_{H1}}{\dot{Q}_{L2}} = ?$

$\eta_{HE} = 1 - \frac{T_L}{T_H} = 1 - \frac{273.15 + 30}{273.15 + 200} = 0.3593$

$\eta_{HE} = \frac{\dot{W}}{\dot{Q}_{H1}} \Rightarrow \dot{Q}_{H1} = \frac{\dot{W}}{0.3593} \Rightarrow \dot{Q}_{H1} = 2.783 \dot{W}$

$COP_{REF} = \frac{T_L}{T_H - T_L} = \frac{273.15 - 30}{30 - (-30)} = 4.0525$

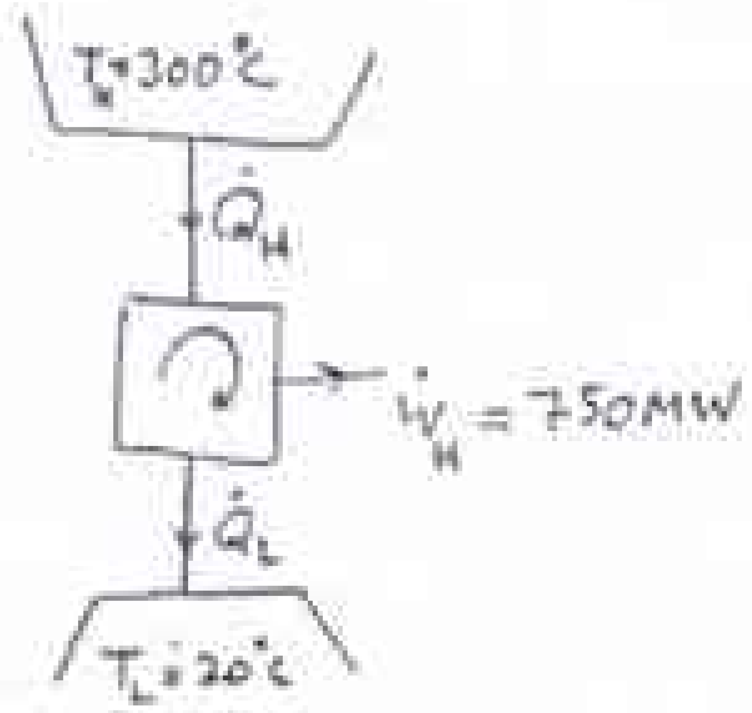
$COP_{REF} = \frac{\dot{Q}_{L2}}{\dot{W}} \Rightarrow \dot{Q}_{L2} = 4.0525 \dot{W}$

$\frac{\dot{Q}_{H1}}{\dot{Q}_{L2}} = \frac{2.783 \cancel{\dot{W}}}{4.0525 \cancel{\dot{W}}} \Rightarrow \boxed{\frac{\dot{Q}_{H1}}{\dot{Q}_{L2}} = 0.687}$

Problem 4.

$\dot{m}_{river} = 1.65 \times 10^5$ kg/sec

$\Delta T_{river} = ?$



a) $\eta_{max} = \eta_{carnot} = 1 - \frac{T_L}{T_H} = 1 - \frac{20+273.15}{300+273.15} \Rightarrow \eta_{max} = 0.4885$

$\eta = \frac{\dot{W}}{\dot{Q}_H} \Rightarrow \dot{Q}_H = \frac{750}{0.4885} = 1535.3 MW$

$\dot{Q}_L = \dot{Q}_H - \dot{W} = 785.3 MW$

$\dot{Q}_L = \dot{Q}_{river} = \dot{m}_{river} c_w \Delta T_{river} \Rightarrow \Delta T_{river} = \frac{785.3 \times 10^3}{1.65 \times 10^5 \times 4.18} = \underline{\underline{1.14°C}}$

$c_w = 4.18 \frac{kJ}{kg \cdot K}$

b) $\eta = \frac{1}{2} \eta_{max} = 0.2442$

$\eta = \frac{\dot{W}}{\dot{Q}_H} \Rightarrow \dot{Q}_H = \frac{750}{0.2442} = 3070.62 MW$

$\dot{Q}_L = \dot{Q}_H - \dot{W} = 2320.62 MW$

$\dot{Q}_L = \dot{Q}_{river} = \dot{m}_{river} c_w \Delta T_{river} \Rightarrow \Delta T_{river} = \frac{2320.62 \times 10^3}{1.65 \times 10^5 \times 4.18} = \underline{\underline{3.36°C}}$

Problem 5.

$P_1 = 175 kPa$

$V = 4$ Liter

$V_f = V_g = 2$ Liter

$m_1 = m_f + m_g = \frac{V_f}{v_f} + \frac{V_g}{v_g} = \frac{0.002}{0.001057} + \frac{0.002}{1.00363}$

$m_1 = 1.894$ kg

$v_1 = \frac{V}{m_1} = \frac{0.004}{1.894} = 0.00211$ m³/kg

$x_1 = \frac{0.00211 - 0.001057}{1.00257} = 0.001$

$u_1 = 486.78 + 0.001 \times 2038.12 = 488.82$ kJ/kg

$v_2 = v_g$ (at 175kPa) $= 1.00363$ m³/kg

$m_2 = \frac{V}{v_2} = \frac{0.004}{1.00363} = 0.004$ kg $\Rightarrow m_e = m_1 - m_2 = 1.890$ kJ/kg

$u_2 = u_g$ (at 175kPa) $= 2524.90$ kJ/kg

$h_e = h_g$ (at 175kPa) $= 2700.53$ kJ/kg

$E_2 - E_1 = Q_{cv} - \cancel{W_{cv}} + \cancel{\sum m_i h_i} - \sum m_e h_e$

$m_2 u_2 - m_1 u_1 = Q_{cv} - m_e h_e$

$Q_{cv} = 0.004 \times 2524.90 - 1.894 \times 488.82 + 1.890 \times 2700.53$

$Q_{cv} = 4188.3$ kJ

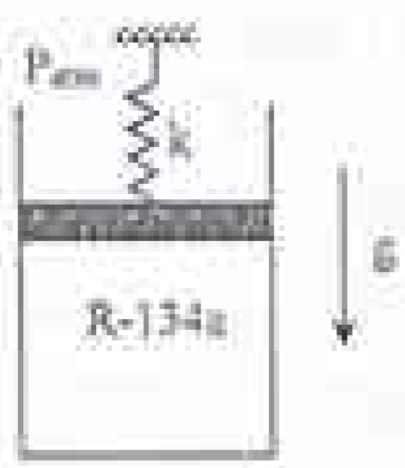
$\dot{Q}_{cv} = \frac{Q_{cv}}{\Delta t} = \frac{4188.3}{3600} \Rightarrow \dot{Q}_{cv} = 1.163$ kW

HW#1

Q1) A closed, rigid tank contains 4 kg of saturated mixture of liquid-vapor water at 100 kPa. Water is now heated to a pressure of 30 MPa. It is observed that water passes through its critical point during this heating process. Find:

(a) the initial quality of water,
(b) the volume of the tank,
(c) the final temperature of water,
(d) the pressure when the tank contains all saturated water vapor during the heating process.
(e) Show the process on T-v and P-v diagrams.

Q2) Refrigerant-134a is contained in a rigid cylinder that is fitted with a frictionless piston. The mass of the piston is 2 kg and is attached to a linear spring. The spring constant is k = 10 kN/m. The diameter of the piston is 200 mm and the atmospheric pressure P_{atm} is 110 kPa. At the initial state, R-134a occupies a volume of 0.2 L and has a temperature of 50°C. The spring touches the piston but does not exert any force on the piston. The R-134a is heated until its volume doubles. Determine:



(a) the initial pressure of R-134a,
(b) the mass of R-134a in the cylinder,
(c) the final pressure of R-134a, and
(d) Show the process on P-v and T-v diagrams with respect to saturation curve.

ME 203

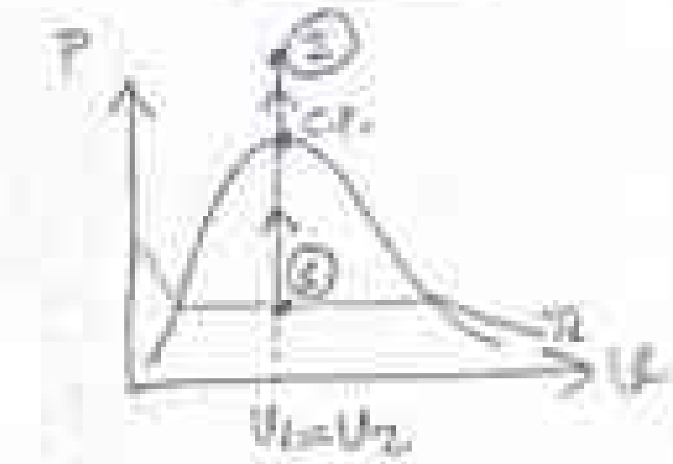
HW#1 Solution

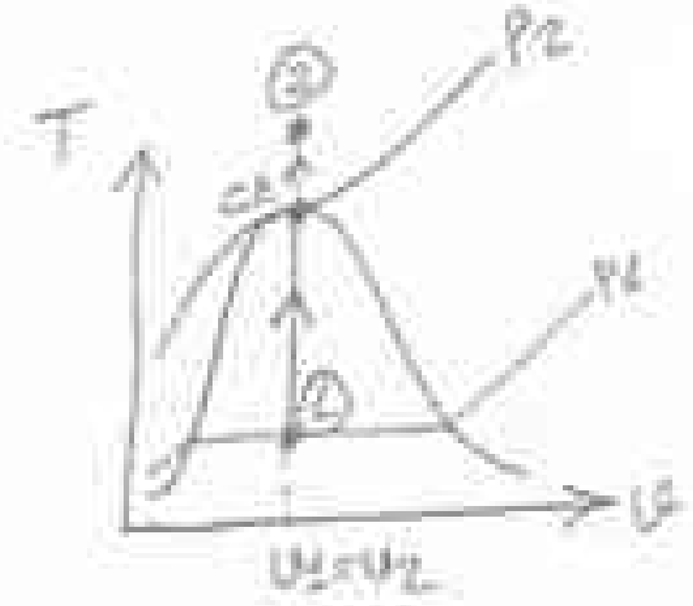
Q1)

Q1)

P_2 = 30 MPa

(e)





closed, rigid tank $\longrightarrow$ $\left.\begin{array}{l} V = \text{constant} \\ m = \text{constant} \end{array}\right\}$ v = constant

Table A.2 : For water, $T_c = 647.1$ K
$P_c = 22.12$ MPa
$v_c = 0.00317$ m³/kg.

(a) state 1: $\left.\begin{array}{l} \text{Saturated mixture of Liquid} \\ \text{+ Vapor water} \\ P_1 = 100 \text{ kPa} \\ v_1 = v_c = 0.00317 \text{ m}^3/\text{kg} \end{array}\right\}$ B.1.2: $v_f = 0.001043$
$v_{fg} = 1.69296$

$$x_1 = \frac{v_1 - v_f}{v_{fg}} = \frac{0.00317 - 0.001043}{1.69296} = 0.001256$$

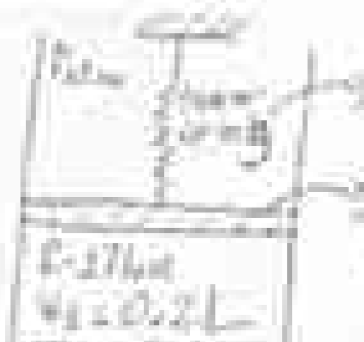
(b) $V_{tank} = m \cdot v_1 = (4 \text{ kg})(0.00317 \text{ m}^3/\text{kg}) = 0.01268 \text{ m}^3$

(c) state 2: $\left.\begin{array}{l} P_2 = 30 \text{ MPa} \\ v_2 = v_1 = v_c = 0.00317 \text{ m}^3/\text{kg} \end{array}\right\}$ B.1.3: Interpolation between 400 and 425°C gives:
$T_2 \sim 404$°C

(d) The tank contains all saturated vapor (no liquid) at the critical point. Pressure at this instance is the critical point pressure : 22.12 MPa

Q2)

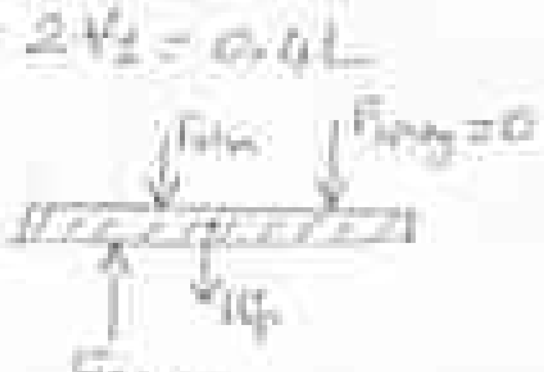
Q2)



$P_{atm} = 110\ kPa$

State 2: $V_2 = 2V_1 = 0.4\ L$

(a) FBD of piston at state 1:



$F_{R134a} = F_{atm} + W_p$

$P_1 \cdot A_p = P_{atm} \cdot A_p + m_p \cdot g$

$P_1 \frac{\pi}{4}(0.2m)^2 = (110\ kPa)\frac{\pi}{4}(0.2m)^2 + \frac{(2\ kg)(9.81\ m/s^2)}{1000\ N/kN}$

$\Rightarrow P_1 = 110.6\ kPa$

(b) $m = \frac{V_1}{v_1}$ State 1: $\left.\begin{matrix} P_1 = 110.6\ kPa \\ T_1 = 50°C \end{matrix}\right\}$ @ 110.6 kPa $\xrightarrow{\text{From Table}}$ $T_{sat} = -26.14°C$

$T_1 > T_{sat} \longrightarrow$ state 1 is superheated vapor

From Table: $v_1 = 0.2341\ m^3/kg$

$\Rightarrow m = \frac{0.2 \times 10^{-3}\ m^3}{0.2341\ m^3/kg} = 8.54 \times 10^{-4}\ kg$

(c)

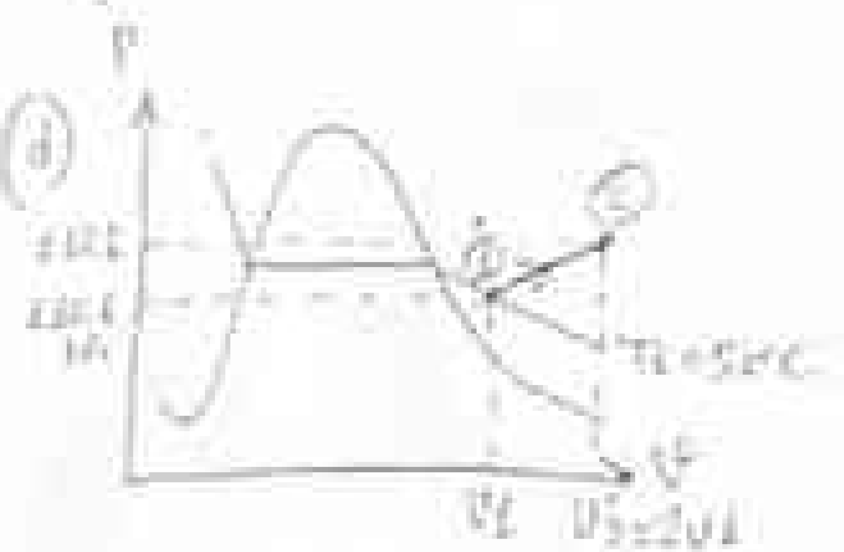
linear spring $\longrightarrow$ $P = C_1 V + C_2$ ---- a line

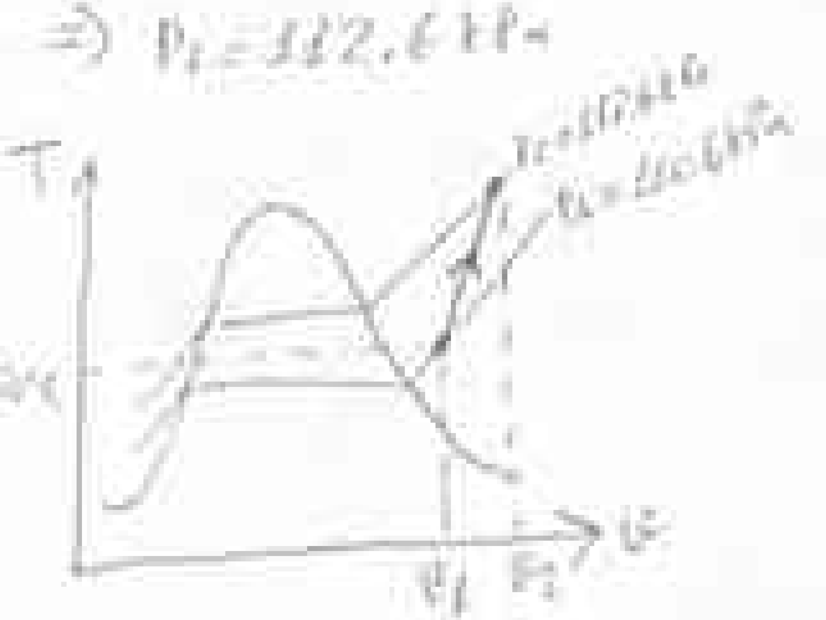
slope $= C_1 = \frac{k}{A_p^2} = \frac{P_2 - P_1}{V_2 - V_1}$

$\Rightarrow \frac{10\ kN/m}{\left[\frac{\pi}{4}(0.2)^2\right]^2} = \frac{P_2 - 110.6}{(0.4 - 0.2) \times 10^{-3}}$

$\Rightarrow P_2 = 112.6\ kPa$

(d)





ME 203

HW#2

Guidelines for homework submission:

1. Use an A-4 sized, white paper. Staple papers when necessary.
2. Provide proper units for all dimensional quantities. Omission or incorrect usage of units will be penalized.
3. Your solution should be readable. Neatness may affect grading.
4. Cite all the references you used for the solution of the problems, such as, tables, figures, appendices, other books, internet, etc.
5. The following information must be provided on the submitted homework: Name, Last name, ID number.

Q1) Diatomic nitrogen, N_2, exists at P = 2.9 MPa and T = 180 K. Estimate its specific volume with three different methods:

(a) an ideal gas assumption,

(b) the thermodynamic tables,

(c) the generalized compressibility chart.

Q2) Two separate tanks contain the same amount of oxygen. The pressure, temperature, and volume of the first tank are 400 kPa, 20°C, and 1m³ respectively. The pressure and temperature of the second tank are 200 kPa and 40°C respectively. Determine the volume of the second tank.

Q3) Ammonia vapor is compressed in a piston-cylinder assembly from saturated vapor at T_1=-20°C to a final state of P_2=900 kPa and T_2=88°C. During the process the pressure and specific volume are related by Pv^n=constant. Determine the work in kJ given that there are 2kg of ammonia in the cylinder.

ME 203

HW#2 Solution

Q1) a) an ideal gas assumption :

$P v = RT$

for N_2 : $P = 2.9 MPa = 2900 kPa$ $T = 180K$ $R = 0.2968 \, kj/kg.K$ (Appendix A.5 for N_2)

$$\Rightarrow v = \frac{RT}{P} = \frac{(0.2968 \, kj/kg.K)(180 K)}{2900 kPa}$$

$$\boxed{v = 0.0184 \, m^3/kg}$$

b) the thermodynamic tables :

When we look at the saturated Nitrogen table (Appendix B.6.1), we can understand that for the given conditions of N_2 ($P = 2900 kPa$, $T = 180K$) N_2 is at superheated vapor state. So, in the superheated Nitrogen table (Appendix B.6.2) by interpolating between 2000 kPa (T=180K) and 3000 kPa (T=180K) we can find the specific volume of N_2.

$$\frac{3000-2900}{3000-2000} = \frac{v - 0.01614}{0.02503 - 0.01614} \Rightarrow \boxed{v = 0.017029 \, m^3/kg}$$

c) the generalized compressibility chart :

Firstly, we look at Table A.2 for P_c and T_c

$P_c = 3.39 MPa$ $T_c = 126.2 K$

the given conditions are $P = 2.9 MPa$ and $T = 180K$

So, $P_r = \frac{P}{P_c} = \frac{2.9}{3.39} = 0.855$

$T_r = \frac{T}{T_c} = \frac{180}{126.2} = 1.426$

For $P_r = 0.855$ and $T_r = 1.426$, in Figure D.1 we can read compressibility factor, Z, as $\underline{0.88}$. ($Z \sim 0.88$)

From Table A.5, $R_{N_2} = 0.2968 \, kj/kg.K$

$$v = \frac{ZRT}{P} = \frac{(0.88)(0.2968 \, kj/kg.K)(180K)}{2900 kPa}$$

$$\Rightarrow \boxed{v = 0.0162 \, m^3/kg}$$

Q2) "Two seperate tanks contain the same amount of oxygen" means that in both of the tanks the masses of oxygen are same. ($m_{1_{O_2}} = m_{2_{O_2}}$)

To make an ideal gas assumption, the critical constants must be checked from Table A.2

For O_2 : $P_c = 5.04 MPa$ $T_c = 154.6 K$

In both of the tanks pressures are under P_c and temperatures are over T_c. So low P and high T condition provides us assuming oxygen in the tanks as an ideal gas.

$PV = mRT \Rightarrow m = \frac{PV}{RT}$ $R_{O_2} = 0.2598 \, kj/kg.K$ (Table A.5)

$$m_1 = \frac{P_1 . V_1}{R_{O_2} . T_1} = \frac{(400 kPa)(1 m^3)}{(0.2598 \, kj/kg.K)(293.15K)} = 5.25 \, kg$$

$$m_1 = m_2 \Rightarrow V_2 = \frac{m_2 . R_{O_2} . T_2}{P_2} = \frac{(5.25 kg)(0.2598 \, kj/kg.K)(313.15K)}{(200 kPa)}$$

$$\boxed{V_2 = 2.136 \, m^3}$$

Q3) For saturated vapor at $T_1 = -20°C$ (Ammonia) we can read P_1 value as 190.2 kPa from Table B.2.1 and also v_g is 0.62334 m^3/kg.

($P_1 = 190.2 kPa$, $v_1 = 0.62334 m^3/kg$)

For final state ($P_2 = 900 kPa$, $T_2 = 88°C$), when we look at Table B.2.1 for $T = 88°C$ we see that $P_{sat} > P_2$, so we understand that ammonia at the final state is at superheated vapor state.

From Table B.2.2 :

v (at 800kPa, 88°C) $\Rightarrow \dfrac{88-80}{100-80} = \dfrac{v - 0.20590}{0.21849 - 0.20590}$

$\Rightarrow v$ (at 800kPa, 88°C) $= 0.211336 \ m^3/kg$

v (at 1000kPa, 88°C) $\Rightarrow \dfrac{88-80}{100-80} = \dfrac{v - 0.16270}{0.17389 - 0.16270}$

$\Rightarrow v$ (at 1000kPa, 88°C) $= 0.167176 \ m^3/kg$

v (at 900kPa, 88°C) $\Rightarrow \dfrac{900-800}{1000-800} = \dfrac{0.211336 - v}{0.211336 - 0.167176}$

$\Rightarrow \boxed{v \text{ (at 900kPa, 88°C)} = 0.189256 \ m^3/kg} = v_2$

During compression of ammonia vapor from first state to final state;

$P v^n = \text{constant} = P_1 v_1^n = P_2 v_2^n$

$P = \dfrac{\text{constant}}{v^n}$

$w_2 = \int_1^2 P dv = \text{constant} \int_1^2 \dfrac{dv}{v^n} = \underbrace{\text{constant}}_{P v^n} \left(\dfrac{v^{1-n}}{1-n} \right) \Big|_1^2 = \dfrac{P_2 v_2 - P_1 v_1}{1-n}$

To find w_2 we need to find n.

$P_1 v_1^n = P_2 v_2^n \Rightarrow (190.2 kPa)(0.62334 m^3/kg)^n = (900 kPa)(0.189256 m^3/kg)^n$

$\Rightarrow 3.2936^n = 4.7319$

$n = \dfrac{\log 4.7319}{\log 3.2936}$

$\boxed{n = 1.304}$

$w_2 = \dfrac{P_2 v_2 - P_1 v_1}{1-n} = \dfrac{(900 kPa)(0.189256 m^3/kg) - (190.2 kPa)(0.62334 m^3/kg)}{1 - 1.304}$

$w_2 = -170.3 \ kJ/kg$

$m = 2kg$ (given)

$W_2 = m \cdot w_2 = (2 kg)(-170.3 kJ/kg) = \boxed{-340.6 \ kJ}$

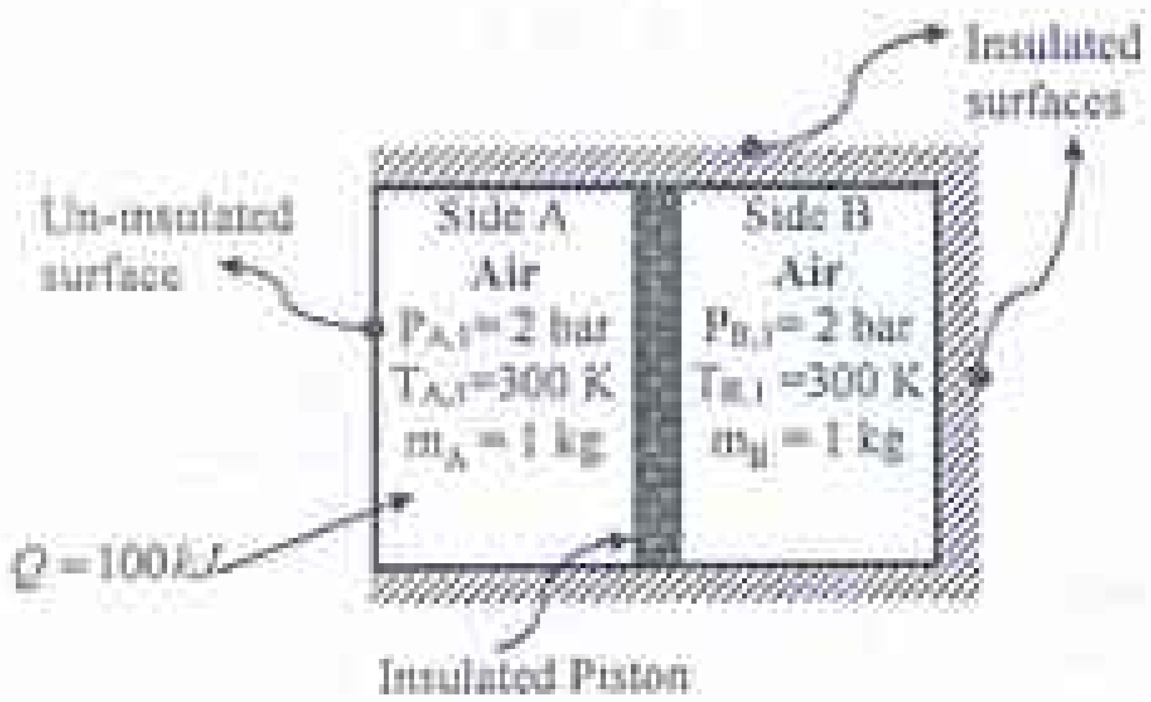
ME 203

HW#3

Guidelines for homework submission:

1. Use an A-4 sized, white paper. Staple papers when necessary.
2. Provide proper units for all dimensional quantities. Omission or incorrect usage of units will be penalized.
3. Your solution should be readable. Neatness may affect grading.
4. Cite all the references you used for the solution of the problems, such as, tables, figures, appendices, other books, internet, etc.
5. The following information must be provided on the submitted homework: Name, Last name, ID number.

Q1) An insulated, frictionless piston separates a rigid cylindrical tank into two volumes, each having 1 kg of air. The initial pressure and temperature in each side are equal, 2 bar and 300 K, respectively. The tank is insulated except the left wall. An amount of 100 kJ of heat is transferred to the air in side A through the un-insulated left wall of the tank. As a result of this heat transfer, the temperature in side A becomes 400 K. Assume air is an ideal gas and use the variable specific heat approach.



(a) How much work is done on the air in side B?

(b) What is the final temperature and pressure of the air in side B?

Q2) A cylinder fitted with a frictionless piston contains 0.1 kg of R-134a at 200 kPa, 50°C (state 1). An external force on the piston is such that the pressure inside the cylinder is related to the volume by the following expression: $P = C \cdot V^{-1.16}$, where C is a constant. There is a set of stops in the cylinder at a volume of 1/4 of the initial volume (i.e., V_{stops} = $0.25V_1$). Consider the following two processes.

Process 1: Compression process until the piston hits the stops (state 2).
Process 2: With the piston resting against the stops, the R-134a cools to 20°C (state 3).

(a) Calculate the total work and total heat transfer.

(b) Draw the P-V and T-V diagrams with respect to the saturation curve. Indicate all the states.

ME 203

HW#3 Solution
Q1)

1st law for air in volume A:

$Q_A - W_A = m_A (u_2 - u_1)_A$

$T_{A,1} = 300K \xrightarrow{A.22} u_{A,1} = 214.07$

$T_{A,2} = 400K \xrightarrow{A.22} u_{A,2} = 286.16$

$\Rightarrow (100\,kJ) - W_A = (1\,kg)(286.16 - 214.07)$

$W_A = 27.91\,kJ$

(a) $W_B = -W_A = -27.91\,kJ$

1st law for air in volume B:

$\cancel{Q_B}^{0} - W_B = m_B (u_2 - u_1)_B$

insulated

$\Rightarrow -(-27.91) = (1\,kg)(u_2 - 214.07)$

$u_2 = 241.98\,kJ/kg$

$\downarrow A.22$

$T_{2_B} \simeq 338.8\,K$

$V_{A,1} = \dfrac{m_A R_{air} T_{A,1}}{P_{A,1}} = \dfrac{(1)(0.287)(300)}{200} = 0.4305\,m^3$

$V_{B,1} = \dfrac{m_B R_{air} T_{B,1}}{P_{B,1}} = \dfrac{(1)(0.287)(300)}{200} = 0.4305\,m^3$

$V_{total} = V_{A,1} + V_{B,1} = 0.861\,m^3$

$$\frac{\cancel{P_{A,2}}\, V_{A,2} = \cancel{m_A}\, \cancel{R_{air}}\, T_{A,2}}{\cancel{P_{B,2}}\, V_{B,2} = \cancel{m_B}\, \cancel{R_{air}}\, T_{B,2}}$$

$P_{A,2} = P_{B,2}$

$\Rightarrow \dfrac{V_{A,2}}{V_{B,2}} = \dfrac{400K}{338.8\,K} = 1.1806$

$V_{A,2} + V_{B,2} = 0.861\,m^3$

$1.1806\, V_{B,2} + V_{B,2} = 0.861$

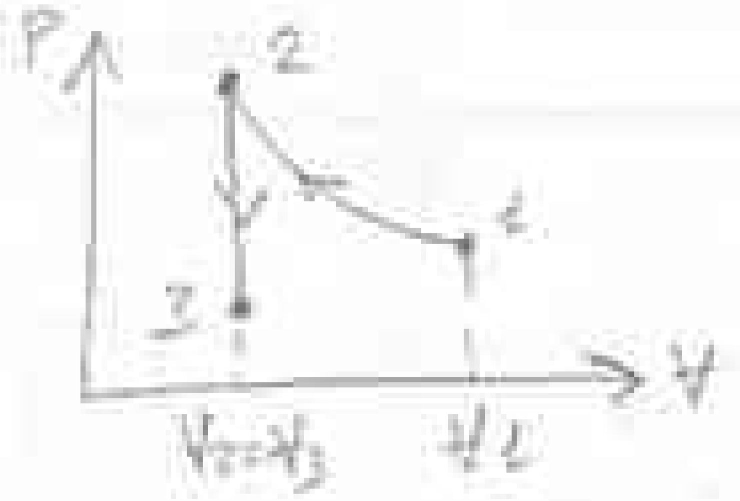
$V_{B,2} = 0.3948\,m^3$

$P_{B,2} = \dfrac{m_B R_{air} T_{B,2}}{V_{B,2}} = \dfrac{(1)(0.287)(338.8K)}{0.3948}$

$P_{B,2} = 246.29\,kPa = P_{A,2}$

Q2)

Q2) (a) 1st Law: $Q_{1,3} - W_{1,3} = m(u_3 - u_1)$



$\text{Area} = W_{1,3} = \int P \, dV$

$= \int C \, V^{-1.16} \, dV$

$= C \left. \dfrac{V^{-0.16}}{-0.16} \right|_{V_1}^{V_2}$

$\Rightarrow W_{1,3} = \dfrac{C}{0.16} \left(\dfrac{1}{V_1^{0.16}} - \dfrac{1}{V_2^{0.16}} \right)$

$= \dfrac{P_1}{0.16 \, V_1^{-1.16}} \left(\dfrac{1}{V_1^{0.16}} - \dfrac{1}{V_2^{0.16}} \right)$

state 1: $\left.\begin{array}{l} R\text{-}134a \\ P_1 = 200 \text{ kPa} \\ T_1 = 50°C \end{array}\right\}$ $T_1 > T_{sat@200kPa} \rightarrow$ superheated vapor

B.5.2: $v_1 = 0.12776 \text{ m}^3/\text{kg}$

$u_1 = 419.11$

$V_1 = m \cdot v_1 = (0.1)(0.12776) = 0.012776 \text{ m}^3$

$V_2 = 0.25 \, V_1 = 0.003194 \text{ m}^3$

$W_{1,3} = \dfrac{200}{(0.16)(0.012776)^{-1.16}} \left(\dfrac{1}{0.012776^{0.16}} - \dfrac{1}{0.003194^{0.16}} \right)$

$= -3.966 \text{ kJ}$

state 2: $P_1 V_1^{1.16} = P_2 V_2^{1.16} \longrightarrow P_2 \cong 1000 \text{ kPa}$

$\left.\begin{array}{l} P_2 = 1000 \text{ kPa} \\ v_2 = \dfrac{V_2}{m} = 0.03194 \text{ m}^3/\text{kg} \end{array}\right\}$ superheated vapor $T_2 \cong 150°C$

State 3: $\left.\begin{array}{l} T_3 = 20°C \\ v_3 = v_2 = 0.03194 \text{ m}^3/\text{kg} \end{array}\right\}$ $v_f < v_3 < v_g$ Saturated mixture $P_3 = 573 \text{ kPa}$

$x_3 = \dfrac{v_3 - v_f}{v_{fg}} = \dfrac{0.03194 - 0.000817}{0.03524} = 0.883$

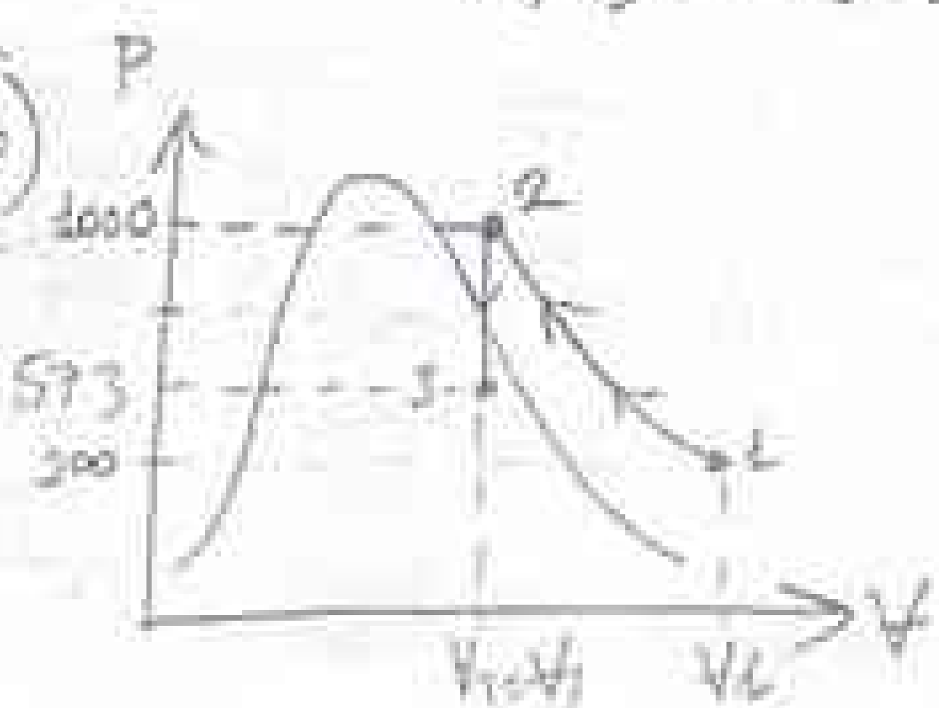
$u_3 = u_f + x_3 \, u_{fg} = 227.03 + (0.883)(162.16)$

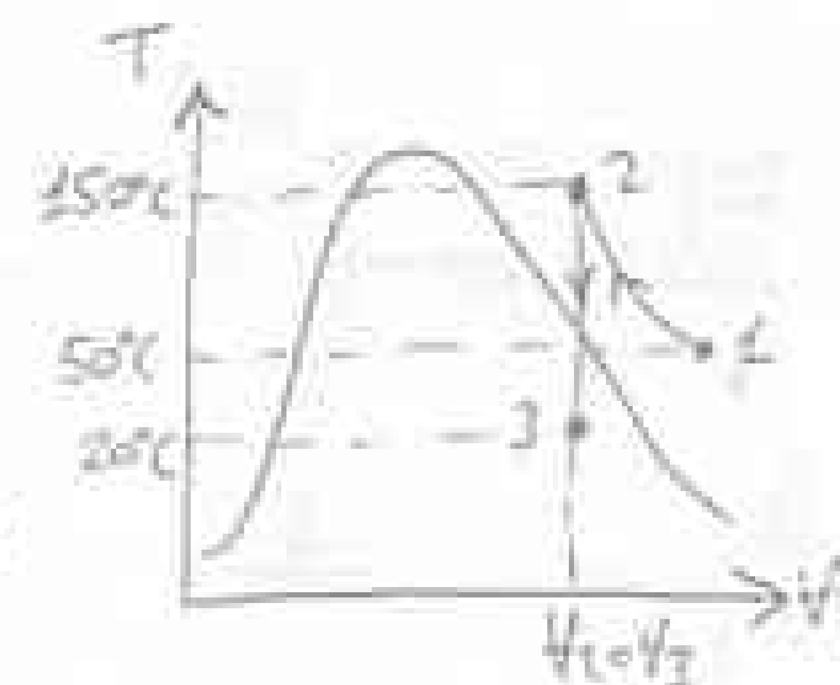
$= 370.2 \text{ kJ/kg}$

$Q_{1,3} - (-3.966) = (0.1)(370.2 - 419.11)$

$Q_{1,3} = -8.85 \text{ kJ}$

(b)





ME 203

HW#1

Q1) In a vertical piston-cylinder arrangement, the internal cross-sectional area of the cylinder is 0.0981 m^2, and the total mass of the piston and the load it carries is 1000 kg. Atmospheric pressure is 1 bar. The cylinder contains 0.05 kg of water, initially at a temperature of 200 °C. A heat transfer takes place from the water to the surroundings in a quasi-equilibrium process, during which the piston descends until the volume of the cylinder contents reaches V_2=0.03102 m^3.

(a) Find the final temperature of water.

(b) Calculate the work.

Q2) A closed system contains 0.15 kg of saturated water vapor initially at 205°C. The water undergoes the following sequence of quasi-equilibrium processes. The water is first cooled at constant volume until the temperature reaches 150°C. Then the water is further cooled at constant temperature until the volume is reduced to one-half of the initial volume.

(a) Show the processes on P-v and T-v diagrams with respect to saturation curve.

(b) Find the final pressure of the water.

(c) Find the total work for the two processes.

ME 203

HW#1 Solution

ME 203 FALL 2013 HW1 Solution

Q1)

piston weight + external weight = 1000kg
= 9810 N

$$P_1 = P_{atm} + \frac{9810 N}{A_p} \cdot \frac{1 kN}{1000 N} = 100 kPa + \frac{9.81}{0.0981} = 200 kPa$$

State 1

$P_1 = 200 kPa$
$T_1 = 200°C$

superheated vapor
A.4: Linear interpolation between 150 and 300kPa gives:

$v_1 = 1.201$ m³/kg
$u_1 = 2656.6$ kJ/kg
$V_1 = m.v_1 = (0.05)(1.201) = 0.06005 m^3$

State 2

$P_2 = P_1 = 200 kPa$

$$v_2 = \frac{V_2}{m} = \frac{0.03102 m^3}{0.05 kg} = 0.6204 \frac{m^3}{kg}$$

A.3: @ 200 kPa
$v_g = 0.8857$
$v_f = 0.001605$

$v_f < v_2 < v_g \rightarrow$ Saturated mixture of L+V

(a) $T_2 = T_{sat @ 200kPa} \overset{A.3}{=} 120.2°C$

(b) $W_{12} = \int_1^2 P.dV = P(V_2 - V_1)$

$= (200 kPa)(0.03102 - 0.06005) = -5.81 kJ$

Q2)

State 1

Water
$T_1 = 205°C$
$x_1 = 1$

A.2: Linear interpolation between 200 and 210°C gives:
$v_1 = 0.1159\ m^3/kg$
$P_1 = 1730\ kPa$

State 2

Water
$V_2 = V_1$ same amount, $v_2 = v_1 = 0.1159\ m^3/kg$
$T_2 = 150°C$

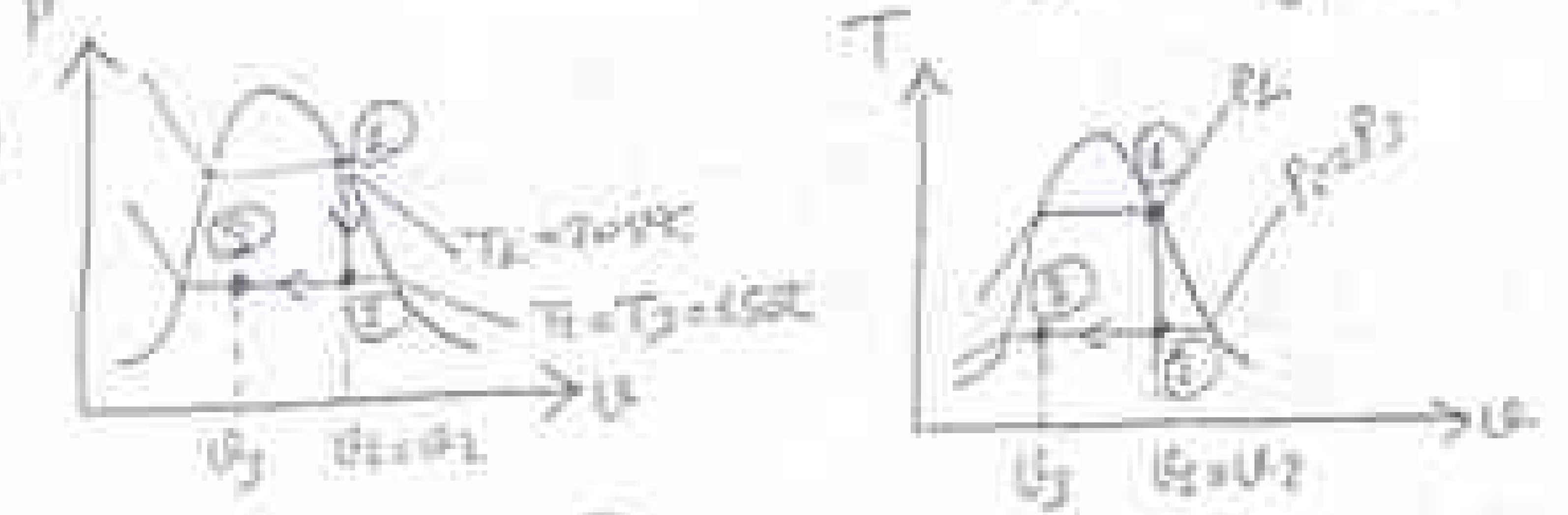
A.2: $v_f = 0.001090 5$
$v_g = 0.3928$
Saturated mixture of L+V

State 3

Water
$T_3 = T_2 = 150°C$
$v_3 = \frac{V_3}{m} = \frac{0.5 V_1}{m} = (0.5) v_1 = 0.05795\ \frac{m^3}{kg}$

Saturated mixture of L+V.

(a)



(b) $T_3 = 150°C$
$v_3 = 0.05795\ m^3/kg$

Saturated mixture
$P_3 = P_{sat@150°C} \overset{A.7}{=} 475.8\ kPa.$

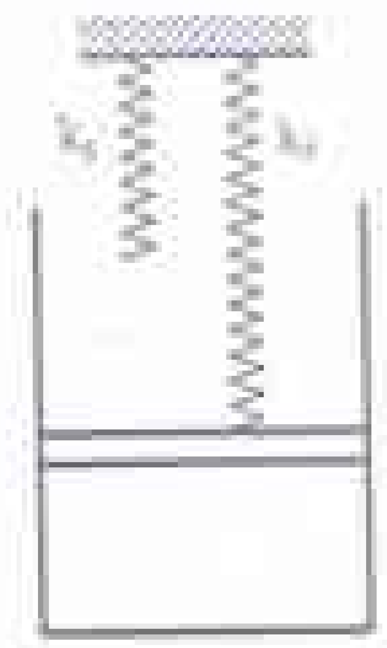
(c) $W_{1,3} = \cancel{W_{1,2}}^{0} + W_{2,3} = P_3 \cdot (V_3 - V_2)$
$V = \text{constant}$
$= P_2 \cdot m \cdot (v_3 - v_2)$

$W_{1,3} = (475.8\ kPa)(0.05795 - 0.1159)(0.15\ kg)$
$= -4.24\ kJ$

ME 203

HW#2

Q1) Two linear springs with the same spring constant are installed in a massless piston/cylinder with the outside air at 100 kPa. If the piston is at the bottom, both springs are relaxed, and the second spring comes in contact with the piston at $V = 2\ m^3$. The cylinder contains ammonia initially at -5°C, $x = 0.13$, $V = 1\ m^3$, which is then heated until the pressure finally reaches 1200 kPa. Calculate:

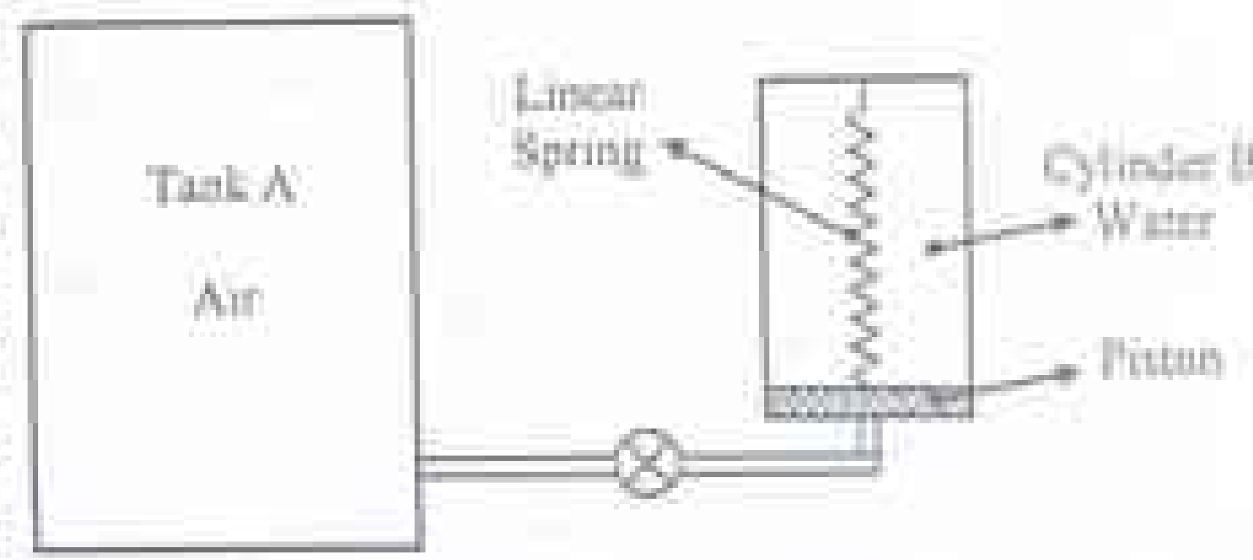


(a) the final temperature of the ammonia,

(b) total work done by ammonia,

(c) total heat transfer during the process.

Q2) A rigid tank is connected to a cylinder by an initially closed valve. Tank A initially contains air at 300 kPa, 30°C with a volume of 0.01 m^3. Cylinder B initially contains saturated water vapor at 30°C with a volume of 0.003 m^3. There is a frictionless and massless piston with area $A_p = 0.01\ m^2$ in cylinder B, which is initially at the bottom of the cylinder. A linear spring with a spring constant of $k_s = 10$ kN/m is attached to the piston. Spring force is zero when the piston is at the bottom of the cylinder. Now the valve is opened slowly and air pushes the piston up. Air and water is always at 30°C during the process due to continuous heat transfer. It is known that as the water is compressed it becomes two-phase mixture. The air can be assumed to be ideal gas with constant specific heats. Calculate the:



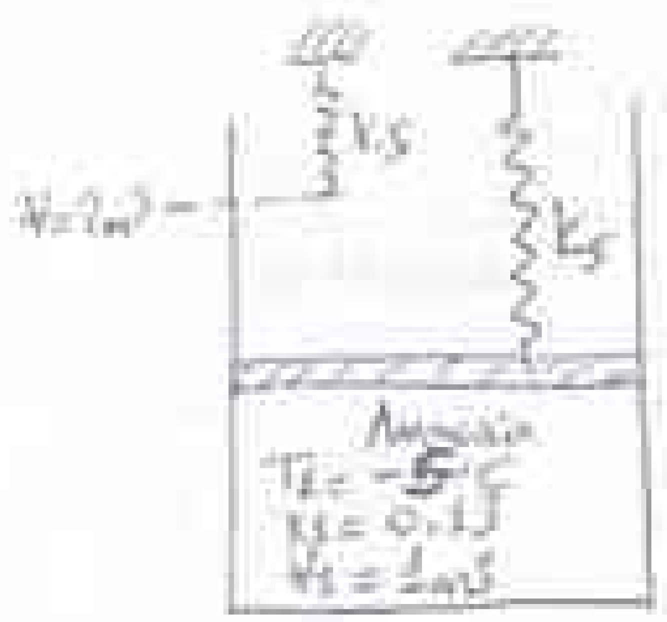
(a) final pressure of the air,

(b) work done by air and work done on water,

(c) heat transfer for air and water.

ME 203
HW#2
Solution

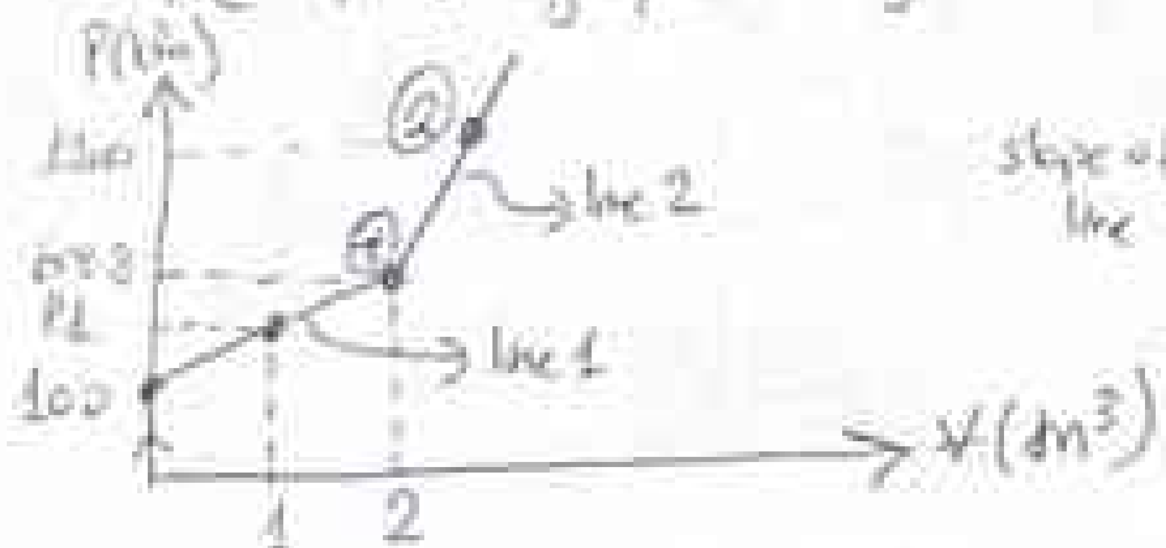
Q1)



$P_2 = 1200$ kPa

Find: T_2, $W_{1,2}$, $Q_{1,2}$

The P-V graph may look like:



slope of line 2 = 2 [slope of line 1]

State 1
Ammonia
$T_1 = -5°C$
$x_1 = 0.13$

$P_{sat} = 354.9$ kPa

$v_1 = v_f + x_1 \cdot v_{fg}$
$= 0.00155 + (0.13)(0.34497)$
$= 0.04639\ m^3/kg$

$u_1 = u_f + x_1 \cdot u_{fg}$
$= 156.76 + (0.13)(1157) = 307.17$ kJ/kg

$m = \frac{V_1}{v_1}$

$m = \frac{1m^3}{0.04639} = 21.556$ kg

State 2 could be on line 1 or on line 2.
Check the state when the piston first touches the 2nd spring at $V = 2m^3$ (state * on the graph)

State *

$v^* = \frac{2m^3}{21.556kg} = 0.09278\ m^3/kg$

$P^* = ?$ From line 1: $\frac{P^* - 100}{2-0} = \frac{354.9-100}{1-0}$

$P^* = 609.8$ kPa

$P^* < P_2 \longrightarrow$ piston has reached the second spring

State 2

slope of line 1 $= \frac{354.9-100}{1-0} = 254.9$

slope of line 2 $= (2)(254.9) = 509.8$

$509.8 = \frac{1200 - 609.8}{V_2 - 2} \rightarrow V_2 = 3.158\ m^3$

$v_2 = \frac{3.158}{21.556} = 0.1465\ m^3/kg$

State 2
$v_2 = 0.1465$
$P_2 = 1200$ kPa

superheated vapor
$T_2 = 106.5°C$
$u_2 = 1498$ kJ/kg

$$W_{1,2} = \text{area}$$

$$= \frac{1}{2}(571.9 + 600.8)(2-1) + \frac{1}{2}(600.8 + 1120) \cdot (3.155-2)$$

$$= 1530.2 \text{ kJ}$$

1st Law: $Q_{1,2} - W_{1,2} = m(u_2 - u_1)$

$$Q_{1,2} - (1530.2) = (21.556)(1198 - 327.17)$$

$$Q_{1,2} = 27199.7$$

Q2)

State 1 of H_2O: $x_1 = 1$, $T_1 = 30C \xrightarrow{B.1.1} P_1 = 4.246\,kPa$

State 2 of H_2O: $T_2 = 30C$, Saturated Mixture $\Big\}$ $P_2 = 4.246\,kPa$.

Therefore, for H_2O, the process is isobaric. (P_{H_2O} = constant)

Free body diagram of piston:

$$F_{air} = \underbrace{F_{H_2O}}_{\text{constant}} + F_{spring}.$$

$$P_{air} \cdot A_p = P_{H_2O} \cdot A_p + k_s \cdot X$$

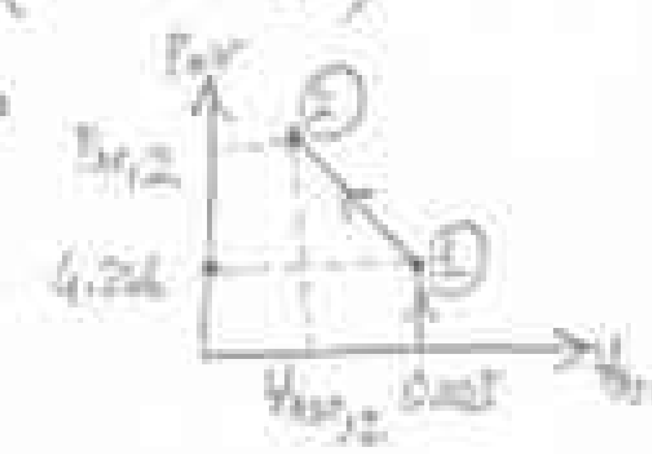
$$X = \frac{V_{cylinder} - V_{H_2O}}{A_p}$$

$$P_{air} = P_{H_2O} + \frac{k_s}{A_p^2}(V_{cylinder} - V_{H_2O})$$ --- linear relationship between P_{air} and V_{H_2O}

$$\frac{k_s}{A_p^2} = \frac{10\,kN/m}{(0.01)^2\,m^4} = 10^5\,kN/m^5$$

$$\Rightarrow P_{air} = 4.246\,kPa + 10^5 \cdot (0.003 - V_{H_2O})$$

$$= 304.246 - 10^5\,V_{H_2O}$$



at state 2: $P_{air,2} = 304.246 - 10^5\, V_{H_2O,2}$ -- ①

$$m_{air} = \frac{P_{A1} \cdot V_A}{R_{air}\, T_{A1}} = \frac{(300)(0.01)}{(0.287)(303)} = 0.0345 \text{ kg.}$$

at state 2: $m_{air} = \dfrac{P_{air2} \cdot V_{air,2}}{R_{air} \cdot T_2}$

$$V_{air,2} = V_A + V_{cylinder} - V_{H_2O,2} = 0.01 + 0.003 - V_{H_2O,2}$$
$$= 0.013 - V_{H_2O,2}$$

$$\Rightarrow 0.0345 \text{ kg} = \frac{P_{air,2} \cdot (0.013 - V_{H_2O,2})}{(0.287)(303)}$$

$$P_{air,2} \cdot (0.013 - V_{H_2O,2}) = 3 \quad \text{---} ②$$

2 equations, 2 unknowns ($P_{air,2}$ and $V_{H_2O,2}$)

Put ① into ②: $(304.246 - 10^5 V_{H_2O,2}) \cdot (0.013 - V_{H_2O,2}) = 3$

$$3.955 - 304.246\, V_{H_2O,2} - 1300\, V_{H_2O,2} + 10^5 V_{H_2O,2}^2 = 3$$

$$10^5 V_{H_2O,2}^2 - 1604.246\, V_{H_2O,2} + 0.955 = 0$$

$$V_{H_2O,2} = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

Two solutions: $V_{H_2O,2} = 0.0006192 \text{ m}^3$

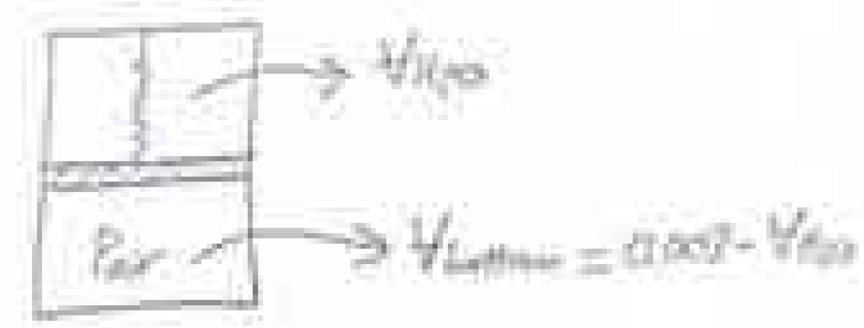
or

$V_{H_2O,2} = 0.0154 \text{ m}^3$ X cannot be a solution

So $V_{H_2O,2} = 0.0006192 \text{ m}^3$

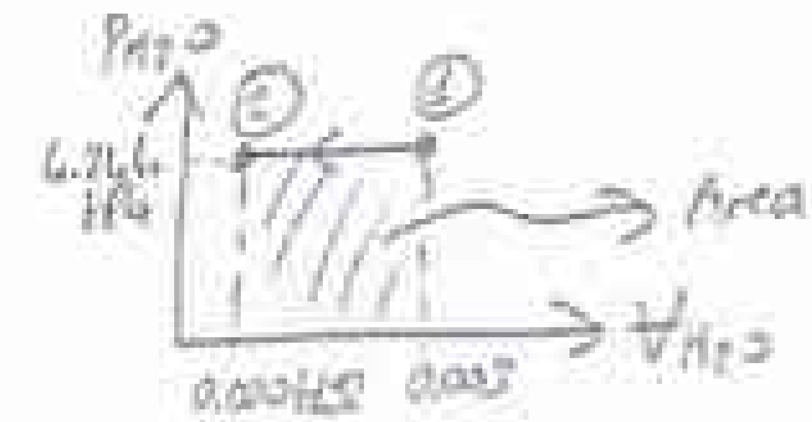
$$P_{air,2} = 304.246 - (10^5)(0.0006192 \text{ m}^3) = 242.3 \text{ kPa.}$$

(b) For the cylinder:



$$\text{Area} = W_{air,1,2} = \frac{1}{2}(4.246 + 242.3)(0.00238 - 0)$$
$$= 0.2935 \text{ kJ}$$

For H_2O:



→ Area $= W_{H_2O\,1,2}$

$$W_{H_2O,1,2} = (4.246 \text{ kPa})(0.0006192 - 0.003) = -0.01 \text{ kJ}$$

(c) 1st Law for air: $Q_{1,2} - W_{1,2} = m\,\cancel{(u_2 - u_1)}^{\,0}$ $T_1 = T_2$

$$Q_{1,2} = W_{1,2} = 0.2935 \text{ kJ}$$

1st Law for water: $Q_{1,2} - W_{1,2} = m\,(u_2 - u_1)$

state 1 of H_2O: $\left.\begin{array}{l} x_1 = 1 \\ T_1 = 30°C \end{array}\right\}$ $\begin{array}{l} u_1 = 2416.58 \text{ kJ/kg} \\ v_1 = 32.8932 \text{ m}^3/\text{kg} \end{array}$

state 2 of water: $T_2 = 30C$

$$v_2 = \frac{V_{H_2O,2}}{m}$$

$$m_{H_2O} = \frac{V_{H_2O,2}}{v_f} = \frac{0.003\,m^3}{32.8932} = 9.12\times10^{-5}\ kg$$

$$v_2 = \frac{0.0006192\,m^3}{9.12\times10^{-5}\,kg} = 6.789\ m^3/kg$$ } saturated mixture

$T_2 = 30C$

$$x_2 = \frac{v_2 - v_f}{v_{fg}} = \frac{6.789 - 0.001004}{32.8922} = 0.2064$$

$$u_2 = u_f + x_2 \cdot u_{fg} = 125.73 + (0.2064)(2290.82)$$
$$= 538.53\ kJ/kg.$$

$$Q_{12,H_2O} - (-0.02) = (9.12\times10^{-5}\,kg)(538.55 - 206.9)$$

$$Q_{12,H_2O} = -0.176\ kJ.$$

ME 203

HW#3

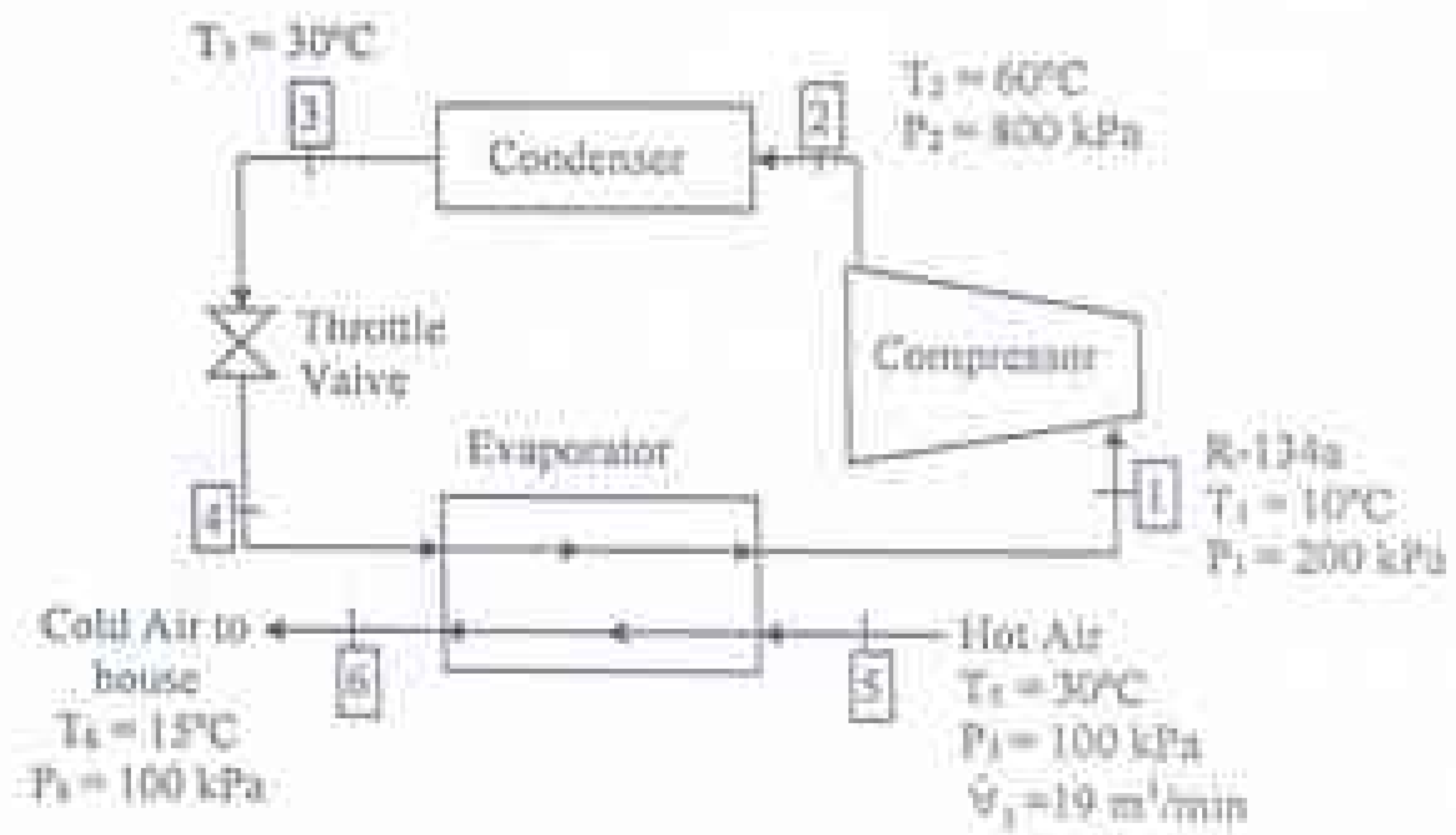
Q1) An air conditioning system operates at steady state as shown in the figure. R-134a is used in the cycle. There are no pressure drops in the condenser and evaporator. The compressor is adiabatic. The volumetric flow rate of air at the inlet of evaporator is 19 m^3/minute. Assume air is an ideal gas with constant specific heats. Using the properties given on the figure, calculate:

(a) the power input to the compressor in kW,

(b) the coefficient of performance of the air conditioner,

(c) the temperature at state 4.

(d) Plot the P-v and T-v diagrams of the cycle with respect to the saturation curve. Indicate all the states.



Q2) An industrial operation requires a supply of argon gas at a constant temperature of 93°C. To satisfy this requirement, a large supply tank having a volume of 1.2 m^3 containing argon at 25°C and 2 MPa is heated until the temperature of the argon reaches 93°C. Then, a valve on the tank is opened and argon gas at 93°C is supplied for the industrial process. While the valve is open, the heating of the argon gas continues so that the temperature of the argon in the tank remains constant at 93°C. When the valve is closed, the mass of the argon in the tank has been reduced by 80%. Assuming argon is an ideal gas with constant specific heats, calculate:

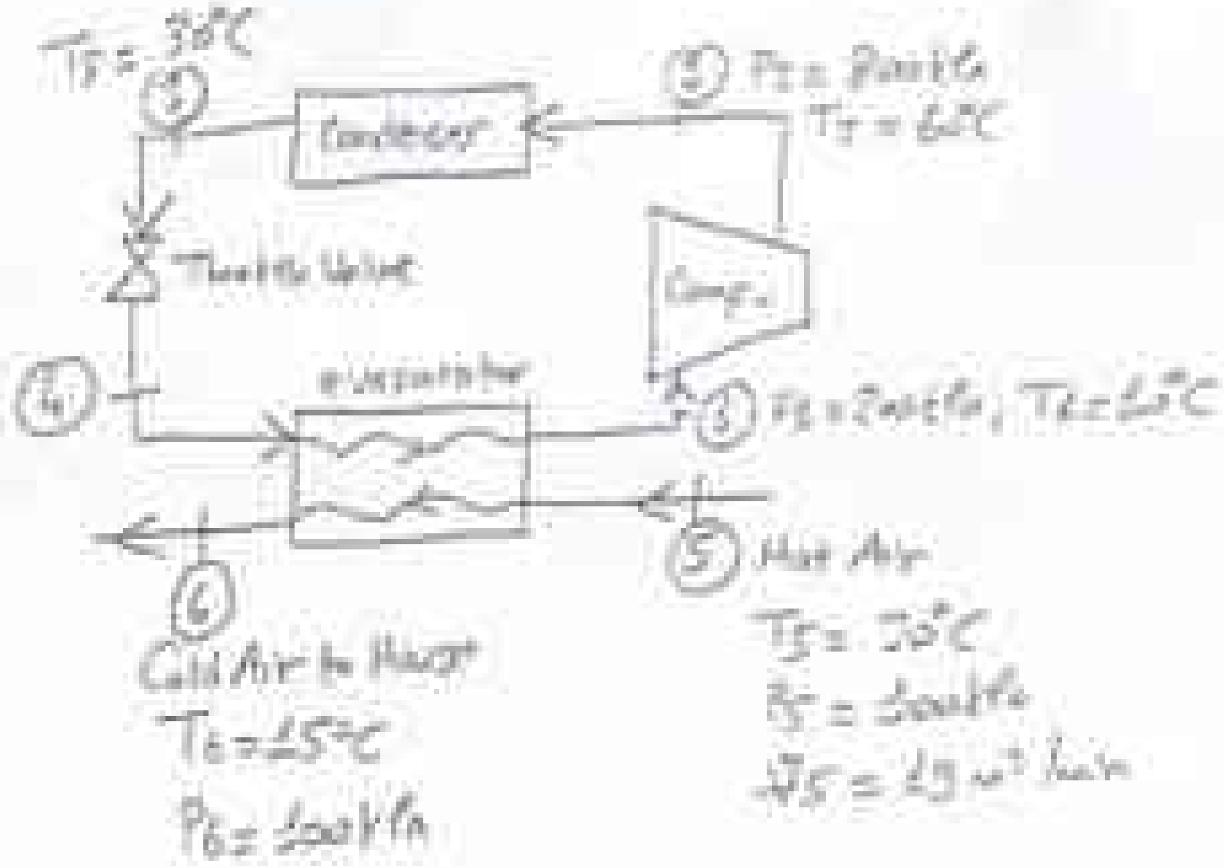
(a) the final pressure of argon in the tank,

(b) the total heat transfer required for the overall process.

ME 203

HW#3
Solution

Q1)



(a) 1st Law to adiabatic compressor: SSSF process

$$\cancel{\dot{Q}}^{0} - \dot{W} + \dot{m}_{R\text{-}134a}(h_1 - h_2) = 0$$

$$\dot{W} = \dot{m}_{R\text{-}134a}(h_1 - h_2)$$

State 1: R-134a, $P_1 = 200$ kPa, $T_1 = 10°C$ } superheated $h_1 = 403.5$ kJ/kg.

State 2: $P_2 = 800$ kPa, $T_2 = 60°C$ } superheated $h_2 = 445.22$ kJ/kg.

To find $\dot{m}_{R\text{-}134a}$, apply 1st Law to evaporator (SSSF):

$$\cancel{\dot{Q}}^{0} - \cancel{\dot{W}}^{0} + (\dot{m}_{R\text{-}134a} \cdot h_4 + \dot{m}_{air} \cdot h_5) - (\dot{m}_{R\text{-}134a} \cdot h_1 + \dot{m}_{air} \cdot h_6) = 0$$

$$\Rightarrow \dot{m}_{R\text{-}134a} = \frac{\dot{m}_{air}(h_6 - h_5)}{h_4 - h_1} = \frac{\dot{m}_{air}\, c_p (T_6 - T_5)}{h_4 - h_1}$$

State 3: $P_3 = 800$ kPa, $T_3 = 30°C$ } compressed liquid $h_3 \cong h_{f@30°C} = 241.79$ kJ/kg

State 4: $h_4 = h_3 = 241.79$ kJ/kg for throttling process.

$$\dot{m}_{air} = \frac{\dot{V}_5}{v_5} \qquad v_5 = \frac{R \cdot T_5}{P_5} = \frac{(0.287)(303K)}{100\ kPa}$$

$$v_5 = 0.869\ m^3/kg$$

$$\Rightarrow \dot{m}_{air} = \frac{15\frac{m^3}{min} \cdot \frac{1\ min}{60\ s}}{0.869\ m^3/kg} = 0.264\ kg/s$$

$$\dot{m}_{R\text{-}134a} = \frac{(0.264)(1.005\ kJ/kg \cdot K)(15-30)}{241.73 - 403.5} = 0.0327\ kg/s$$

$$\dot{W}_{comp} = (0.0327)(403.5 - 445.22) = -1.17\ kW$$

(b) $COP_{refrigerator} = \frac{\dot{Q}_L}{\dot{W}_{comp}}$

1st law for R-134a in the evaporator:

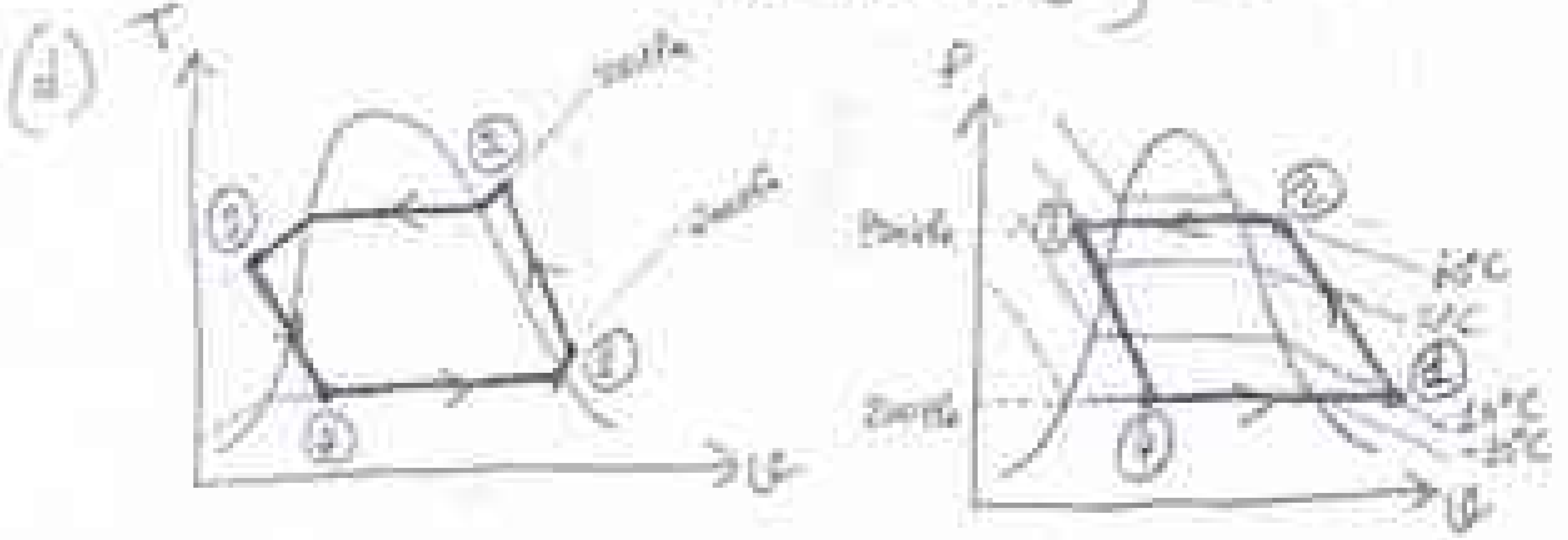
$$\dot{Q}_L - \cancel{\dot{W}}^{0} + \dot{m}_{R\text{-}134a}(h_4 - h_1) = 0$$

$$\dot{Q}_L = \dot{m}_{R\text{-}134a}(h_1 - h_4) = (0.0327)(403.5 - 246.79) = 5.48\ kW$$

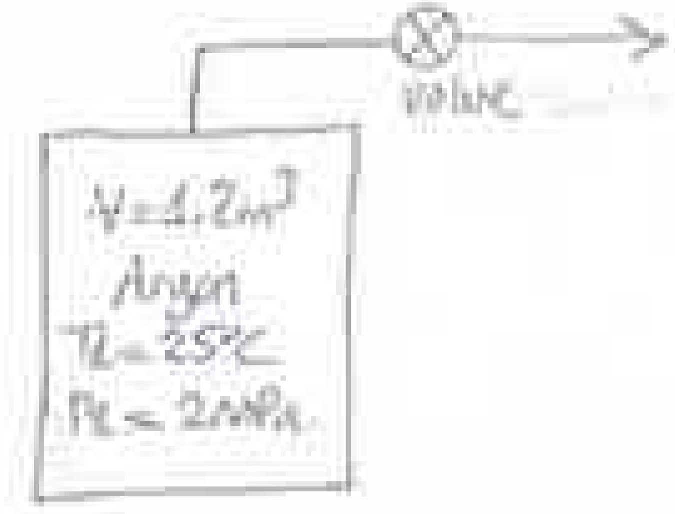
$$COP = \frac{5.48}{1.17} = 4.68$$

(c) state 4: R-134a @ $P_4 = 200\ kPa$, $h_4 = 246.79\ kJ/kg$ $\Big\}$ Saturated mixture $T_4 = T_{sat} = -10°C$.

(d)



Q2)



process 1 → 2: constant volume heating from $T_1 = 25°C$ to $T_2 = 93°C$ while the valve is closed.

process 2 → 3: USUF discharging process until the mass has been reduced by 80%

(a) pressure ~~mass~~ of argon at final state 3 = ?

$$m_1 = \frac{P_1 V_1}{R_{argon} T_1} = \frac{(2000\ kPa)(1.2\ m^3)}{\left(0.2081 \frac{kJ}{kg \cdot K}\right)(298\ K)} = 38.7\ kg$$

$m_1 = m_2$

$$P_2 = \frac{m_2 R T_2}{V} = \frac{(38.7)(0.2081)(366K)}{1.2\ m^3} = 2456.3\ kPa$$

Final mass: $m_3 = 0.20 \cdot m_1 = (0.2)(38.7) = 7.74\ kg$

$$P_3 = \frac{m_3 R T_3}{V} = \frac{(7.74)(0.2081)(366K)}{1.2} = 491.3\ kPa$$

(b) The total heat transfer $= Q_{1,3}$

$$Q_{1,3} = Q_{1,2} + Q_{2,3}$$

Instead of finding $Q_{1,2}$ and $Q_{2,3}$ separately, write the first law for process 1 to 3 and find $Q_{1,3}$ directly:

1st law for process $1 \to 3$: USUF process

$$Q_{1,3} - \cancel{W_{1,3}}^{0} + \cancel{m_i h_i}^{0} - m_e h_e = m_3 u_3 - m_1 u_1$$

$$Q_{1,3} = m_3 u_3 - m_1 u_1 + m_e h_e$$

conservation of mass: $\cancel{m_i}^{0} - m_e = m_3 - m_1$

$$m_e = m_1 - m_3 = 38.7 - 7.74 = 30.96 \text{ kg.}$$

$$Q_{1,3} = m_3 u_3 - m_1 u_1 + (m_1 - m_3)(u_e + \underbrace{P_e v_e}_{R_{oxygen} T_e})$$

$$= m_3 u_3 - m_1 u_1 + m_1 u_e - m_3 u_e + m_e R_{oxygen} T_e$$

$$= m_3 \underbrace{(u_3 - u_e)}_{C_v(T_3 - T_e)} + m_1 \underbrace{(u_e - u_1)}_{C_v(T_e - T_1)} + m_e R_{oxygen} T_e$$

$$= (7.74)\left(0.312 \frac{kJ}{kg.K}\right)\cancel{(93-93)}^{0} + (38.7)(0.312)(93-25) + (30.96)(0.2082)(366K)$$

$$Q_{1,3} = 0 + 821.06 + 2358 \text{ kJ} = 3179.12 \text{ kJ}$$

ME 203

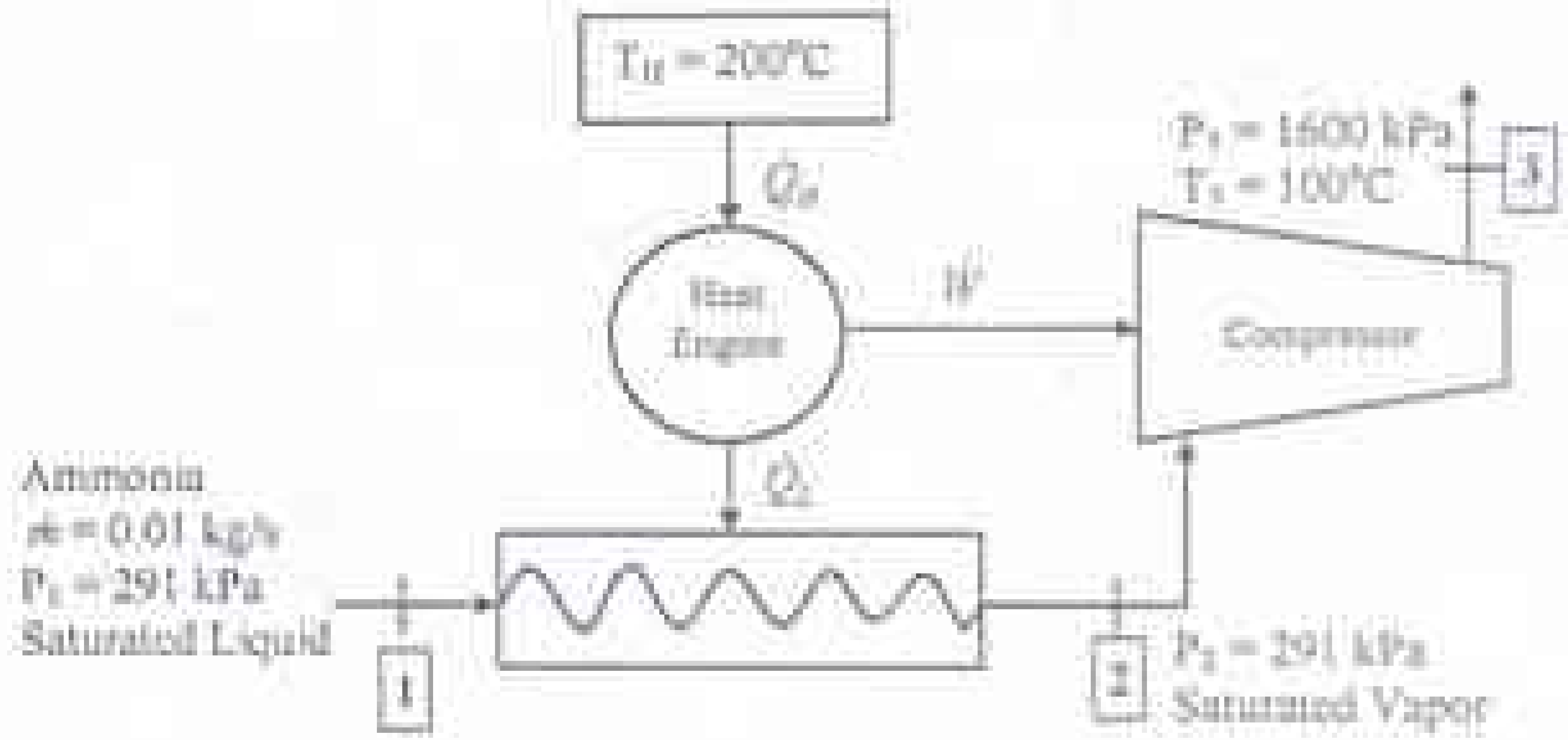
HW#4

The power output of a heat engine is used to derive the compressor of a refrigerator. The heat is supplied to the heat engine from a reservoir at T_H = 200°C.

The rejected heat Q_L is used to heat ammonia in a heat exchanger. Using the properties given on the figure:

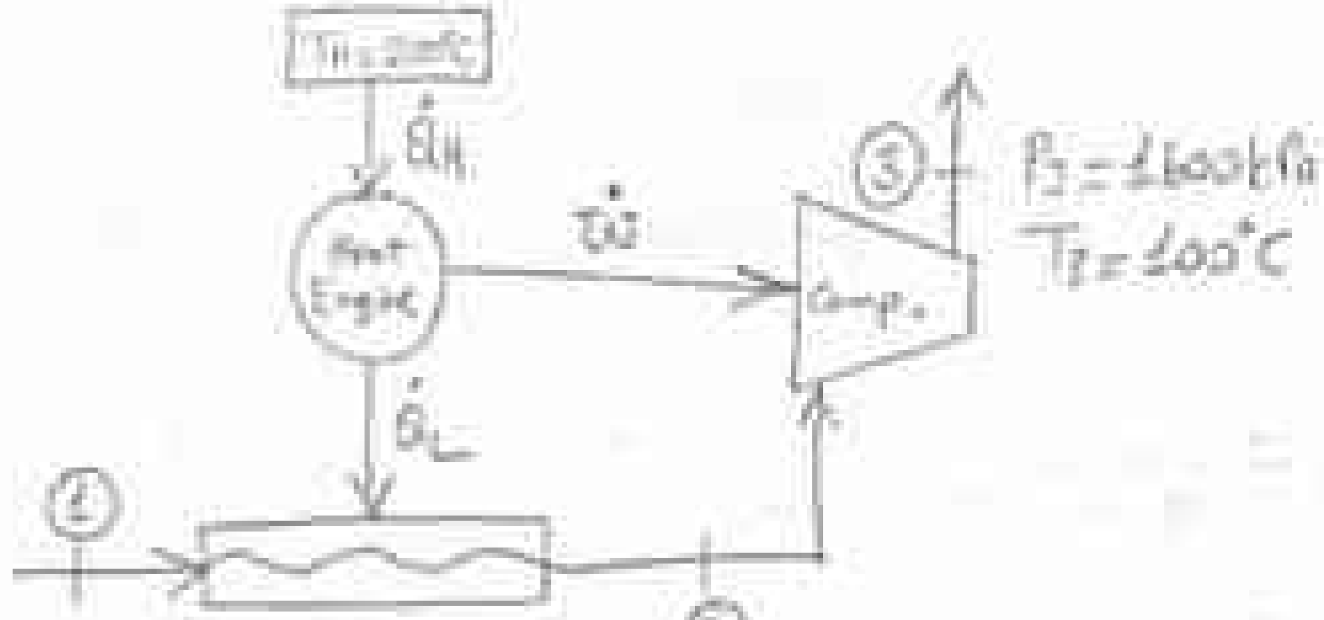
(a) calculate the thermal efficiency of the heat engine.

(b) Is this a reversible, irreversible, or impossible heat engine?



ME 203

HW#4
Solution



Ammonia
$\dot{m} = 0.01 kg/s$
$P_1 = 291 kPa$
Saturated liquid

$P_2 = 291 kPa$
Saturated Vapor

(a) $\eta_{th,\ \text{Heat Engine}} = \dfrac{\dot{W}}{\dot{Q}_H} = \dfrac{\dot{W}}{\dot{Q}_L + \dot{W}}$

1st Law for the SSSF Heat Exchanger:

$$\dot{Q}_L + \dot{m}(h_1 - h_2) = 0 \rightarrow \dot{Q}_L = \dot{m}(h_2 - h_1)$$

State 1: Ammonia, $P_1 = 291 kPa$, $x_1 = 0$ $\Big\}$ $T_1 = -10°C$, $h_1 = 134.41\ kJ/kg$

State 2: $P_2 = 291 kPa$, $x_2 = 1$ $\Big\}$ $h_2 = 1430.8$

$$\dot{Q}_L = (0.01\ kg/s)(1430.8 - 134.41) = 12.96\ kW$$

1st Law for the SSSF Compressor:

$$\cancel{\dot{Q}}^{\,0} - \dot{W} + \dot{m}(h_2 - h_3) = 0 \rightarrow \dot{W} = \dot{m}(h_2 - h_3)$$

State 3: $P_3 = 1600 kPa$, $T_3 = 100°C$ $\Big\}$ superheated $h_3 = 1644.8$

$$\dot{W} = (0.01)(1430.8 - 1644.8) = -2.14\ kW$$

$$\eta_{th,\ \text{Heat Engine}} = \frac{|-2.14|}{12.96 + |-2.14|} = 0.142 \rightarrow 14.2\%$$

(b) $\eta_{th,\ \text{Carnot Heat Engine}} = 1 - \dfrac{T_L}{T_H} = 1 - \dfrac{263K}{473K} = 0.444 \rightarrow 44.4\%$

Since $\eta_{th,\ \text{Carnot H.E.}} > \eta_{th,\ \text{Heat Engine}} \rightarrow$ Irreversible Heat Engine.

TWO CTFS QUESTIONS

Q1. Determine the average power of

$$x(t) = 1 - \cos(\pi t) + 2\sin(\pi t) + \cos(3\pi t),$$

using the Parseval's relation. Also compute the second and third harmonic powers in $x(t)$.

Answer: $P = 4$, the second harmonic power is 0, the third harmonic power is 1/2.

Q2. Let one period of a rectangular pulse train $x(t)$ be defined as $\tilde{x}(t) = \begin{cases} 1, & 0 \le t < 1 \\ -1, & 1 \le t < 2 \end{cases}$.

a) Find the FS coefficients of $x(t)$.

Answer: $a_k = \begin{cases} 0, & \text{for } k \text{ even} \\ 2/jk\pi, & \text{for } k \text{ odd} \end{cases}$

b) Show that $\pi = \sqrt{8\sum_{n=0}^{\infty} \frac{1}{(2n+1)^2}}$, using the Parseval's relation for the signal defined above.

c) Show that $x(t) = \frac{4}{\pi} \sum_{k=1,\, k \text{ odd}}^{\infty} \frac{1}{k}\sin(k\pi t)$. This expression is not valid at points of discontinuity. The sum on the right converges to midpoint (0) of the two values (± 1) at discontinuity points.

d) Let $y(t) = x(t + \frac{1}{2})$, find the FS coefficients of $y(t)$ and obtain an expression for it, similar to the expression in part c.

Answer: $b_k = a_k e^{jk\omega_0 \frac{1}{2}} = a_k e^{jk\frac{2\pi}{2}\frac{1}{2}} = a_k e^{jk\frac{\pi}{2}} = \begin{cases} 0, & \text{for } k \text{ even} \\ 2/k\pi, & \text{for } k = \dots, -7, -3, 1, 5, 9, 13, \dots \\ -2/k\pi, & \text{for } k = \dots, -5, -1, 3, 7, 11, \dots \end{cases}$

Hence,

$$y(t) = \sum_{\substack{k=-\infty \\ k \text{ odd}}}^{\infty} e^{jk\pi/2} a_k e^{jk\pi t} = \sum_{\substack{k=-\infty \\ k \text{ odd}}}^{\infty} e^{jk\pi/2} \frac{2}{jk\pi} e^{jk\pi t}$$

$$= \dots - j\frac{2}{j(-5)\pi}e^{-j5\pi t} + j\frac{2}{j(-3)\pi}e^{-j3\pi t} - j\frac{2}{j(-1)\pi}e^{-j\pi t} + j\frac{2}{j\pi}e^{j\pi t} - j\frac{2}{j(3)\pi}e^{j3\pi t} + j\frac{2}{j(5)\pi}e^{j5\pi t} - \dots$$

$$= \frac{4}{\pi}\cos(\pi t) - \frac{4}{3\pi}\cos(3\pi t) + \frac{4}{5\pi}\cos(5\pi t) - \dots = \frac{4}{\pi}\sum_{k=1,\, k \text{ odd}}^{\infty} \frac{(\pm 1)}{k}\cos(k\pi t)$$

Summary for a rectangular pulse train with an arbitrary period T_0:

If $x(t) = \begin{cases} 1, & 0 \le t < T_0/2 \\ -1, & T_0/2 \le t < T_0 \end{cases}$ (an odd function), its FS expansion is $x(t) = \frac{4}{\pi}\sum_{k=1,\, k \text{ odd}}^{\infty} \frac{1}{k}\sin(k\frac{2\pi}{T_0}t)$.

If $y(t) = \begin{cases} 1, & -T_0/4 \le t < T_0/4 \\ 0, & T_0/4 \le t < 3T_0/4 \end{cases}$ (an even function), its FS expansion is $y(t) = \frac{1}{2} + \frac{2}{\pi}\sum_{k=1,\, k \text{ odd}}^{\infty} \frac{(\pm 1)}{k}\cos(k\frac{2\pi}{T_0}t)$.

ME 203

Section 01

HW#1
Assigned:

Q1) Air is contained in a piston/cylinder assembly at 0.5 m^3, 150 kPa, and 300 K. It is then compressed by a polytrophic process ($P.V^n$ =constant) to a pressure of 600 kPa and a temperature of 400 K. Find the followings:

a) the final volume of the air,
b) the polytropic exponent n,
c) the work done during the process in kJ,
d) show the process on P-V and T-V diagrams.

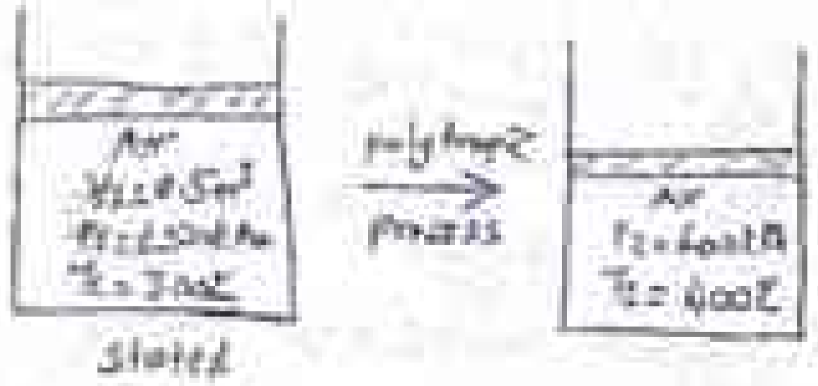
Q2) In a frictionless piston/cylinder system loaded with a linear spring, the cross-sectional area of the piston is 0.05 m^2. The cylinder contains ammonia initially at P_1 = 1MPa, T_1 = 60°C with V_1 = 1 m^3. The spring constant is 150 kN/m. Now the system cools by transferring heat to the surrounding. During this process, 6.25 kJ of work has been done on the ammonia.

a) Find the final temperature of the ammonia.
b) Show the process on P-v and T-v diagrams with respect to saturation lines.

ME 203

HW#1 Solution

Q1)



$PV^n = const$

a-) $m_1 = \dfrac{P_1 V_1}{R T_1} = \dfrac{(150)(0.5)}{(0.287)(300)} = 0.871\ kg$

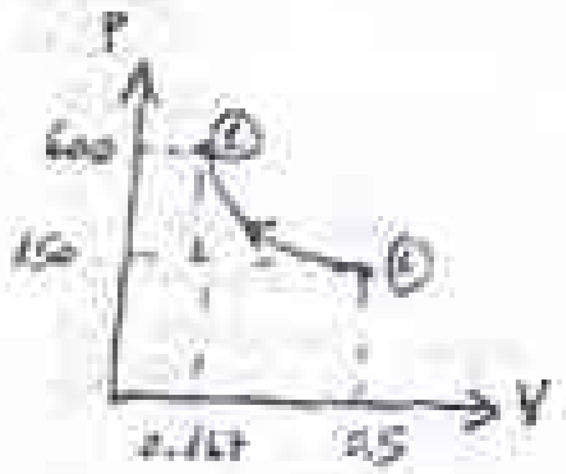
$P_2 V_2 = m R T_2 \Rightarrow V_2 = \dfrac{(0.871)(0.287)(600)}{600} = 0.167\ m^3$

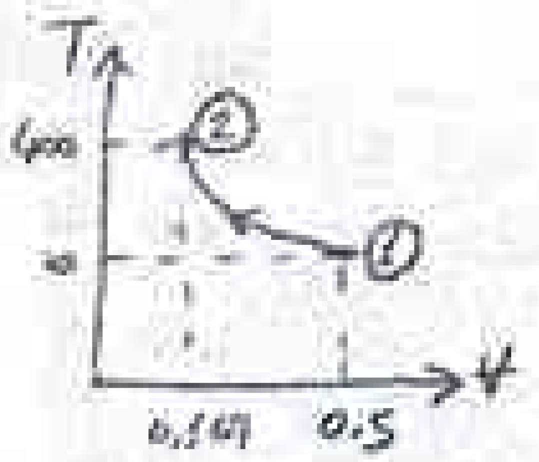
b-) $\dfrac{P_1 V_1^n = C}{P_2 V_2^n = C} \Rightarrow \left(\dfrac{V_1}{V_2}\right)^n = \dfrac{P_2}{P_1} \Rightarrow n \ln \dfrac{V_1}{V_2} = \ln \dfrac{P_2}{P_1}$

$\Rightarrow n = \dfrac{\ln P_2/P_1}{\ln V_1/V_2} = \dfrac{\ln 600/150}{\ln 0.5/0.167} \Rightarrow n = 1.264$

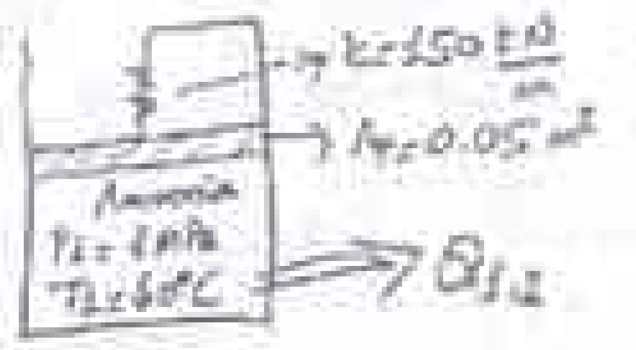
c-) $W_{1,2} = \dfrac{P_2 V_2 - P_1 V_1}{1-n} = \dfrac{(600)(0.167)-(150)(0.5)}{1-1.264} = -95.45\ kJ$

d-)





Q2)



Given: $W_{12} = -6.25\ kJ$
$V_1 = 1\ m^3$

a-) state 1: NH_3, $P_1 = 1\ MPa$, $T_1 = 60°C$ } superheated: $v_1 = 0.15106$, $h_1 = 1563.1$, $u_1 = 1412.04$

$P = C_1 V + C_2$ $\quad C_1 = \text{Slope} = \dfrac{k}{A_p^2} = \dfrac{150}{0.05^2} = 60000\ kN/m^5$

$P_1 = C_1 V_1 + C_2 \Rightarrow C_2 = -59000\ kPa \Rightarrow \boxed{P = 60000V - 59000}$

$W_{12} = -6.25 = \dfrac{1}{2}(P_1 + P_2)(V_2 - V_1) = \dfrac{1}{2}(1000 + 60000V_2 - 59000)(V_2 - 1)$

$\Rightarrow 60000 V_2^2 - 118000V_2 + 58012.5 = 0 \Rightarrow V_2 = 0.9917$ or $V_2 = 0.975$

$V_2 = 0.975$ gives negative P_2, so $\boxed{V_2 = 0.9917\ m^3}$

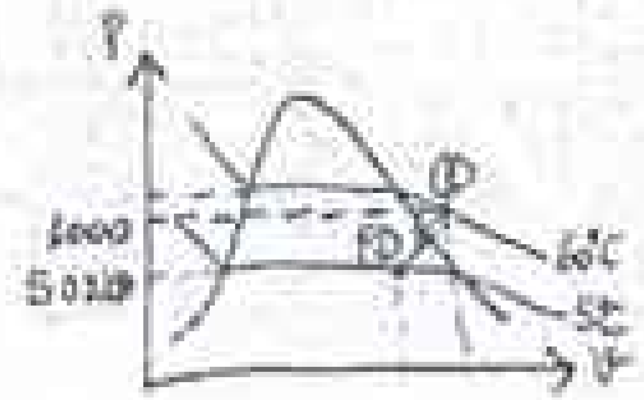
$P_2 = (60000)(0.9917) - 59000 = 502\ kPa$

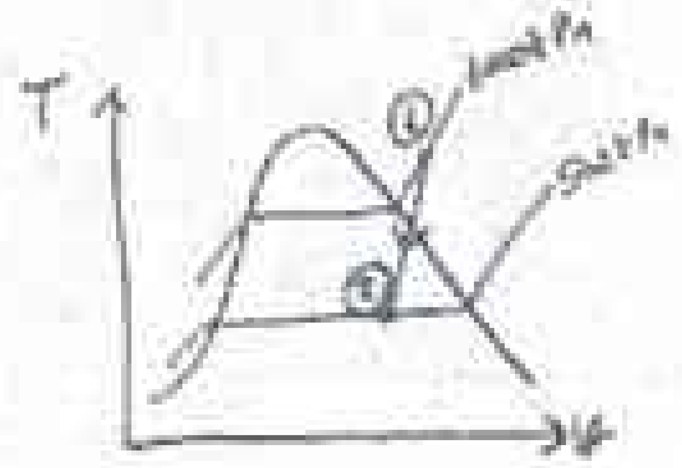
$m = \dfrac{V_1}{v_1} = 6.62\ kg \qquad v_2 = \dfrac{V_2}{m} = 0.1498\ m^3/kg$

state 2: $v_2 = 0.1498\ m^3/kg$, $P_2 = 502\ kPa$ } $T_2 \cong 5°C$ 2-phase mix. $\quad x_2 = \dfrac{v_2 - v_f}{v_{fg}}$ $\Rightarrow x_2 = 0.614$

$u_2 = 202.77 + (0.614)(1128.3) = 895.86\ kJ/kg$

b-)





ME 203

Section 01

HW#2

Q1) One kilogram of air undergoes a cycle in a piston/cylinder device consisting of the following three processes:

Process 1-2: expansion at constant pressure from an initial state of 800 kPa, 300 K.

Process 2-3: expansion at constant temperature to a pressure of 100 kPa.

Process 3-1: a process which can be represented by a straight line on the P-v diagram. Assume air as an ideal gas. Use constant specific heat approach.

(a) Sketch the cycle on a pressure- specific volume (P-v) diagram.

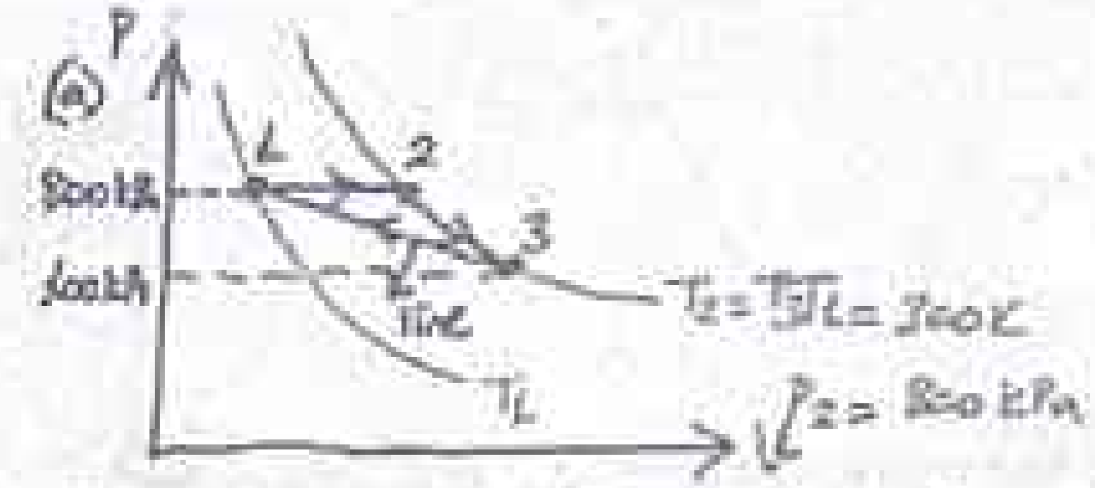
(b) Find T_2 if the heat transfers in processes 1-2 and 2-3 are equal.

(c) Find the heat transfer in process 3-1.

Q2) A frictionless piston-cylinder initially contains water at 100 kPa and with a quality of 0.8 and volume of 8 L (state 1). An external force now slowly compresses the water in a polytropic process of $PV^{1.44}$ = ***Constant*** until the piston reaches a set of stops (state 2). At the stops, the cylinder volume is 1 L. After the piston reaches the stops, the water is cooled to the ambient temperature, 20°C (state 3). Find the work and the heat transfer for the overall process.

HW#2 Solution Q1)

(a)



Air → ideal gas with constant specific heats

(b) $Q_{1,2} = Q_{2,3}$

1st Law for process 1→2: $Q_{1,2} - W_{1,2} = m(u_2 - u_1)$

$W_{1,2} = P_1(v_2 - v_1)m$ and $u_2 - u_1 = C_{v_0}(T_2 - T_1)$, $P_1 = P_2$

Substitute these into 1st Law, $Q_{1,2} = m(h_2 - h_1)$

$h_2 - h_1 = C_{p_0}(T_2 - T_1) \Rightarrow Q_{1,2} = m\,C_{p_0}(T_2 - T_1)$ --- (1)

1st Law for process 2→3: $Q_{2,3} - W_{2,3} = m(u_3 - u_2) = m\,C_{v_0}(T_3 - T_2)$, $T_2 = T_3$, $= 0$

$\Rightarrow Q_{2,3} = W_{2,3}$ --- (2)

$T_2 = T_3$: $P\forall = \underbrace{mRT}_{constant}$ $\Rightarrow W_{2,3} = \int P\,d\forall = mRT_2 \ln\frac{\forall_3}{\forall_2}$

$\downarrow$

$P_2\forall_2 = P_3\forall_3 \longrightarrow \frac{\forall_3}{\forall_2} = \frac{P_2}{P_3} = 8$

$\Rightarrow W_{2,3} = mRT_2 \ln 8$ --- (3)

Substitute Equation (3) into (1) and since $Q_{1,2} = Q_{2,3}$:

$m\,C_{p_0}(T_2 - T_1) = mRT_2 \ln 8$

$\Rightarrow (1)(1.004)(T_2 - 300) = (1)(0.287)(T_2)\ln 8 \Rightarrow T_2 = 739.7\,K$

(c) 1st law for process 3→1: $Q_{3,1} - W_{3,1} = m(u_1 - u_3)$

$u_1 - u_3 = C_{v_0}(T_1 - T_3)$ and $W_{3,1} = \frac{1}{2}(P_1 + P_3)(\forall_1 - \forall_3)$

$\forall_1 = \frac{mRT_1}{P_1} = 0.1076\,m^3$ $\quad \forall_3 = \frac{mRT_3}{P_3} = 2.123\,m^3$

$\Rightarrow W_{3,1} = -906.87\,kJ$

$\Rightarrow Q_{3,1} - (-906.87\,kJ) = (1)(0.717)(300 - 739.7) \Rightarrow Q_{3,1} = -1222\,kJ$

Q2)

Control mass: water in cylinder

state 1

H_2O, $P_1 = 100\,kPa$, $x_1 = 0.8$, $V_1 = 8L$ } B.1.2, $v_f = 0.001043$, $v_{fg} = 1.69296$, $u_f = 417.33$, $u_{fg} = 2088.72$

$v_1 = v_f + x_1 v_{fg} = 1.3554\ m^3/kg$ and $u_1 = u_f + x_1 u_{fg} = 2088.31\ kJ/kg$

$m_1 = \frac{V_1}{v_1} = 5.9 \times 10^{-3}\ kg$

state 2

$v_2 = \frac{V_2}{m} = 0.16949$

$P_1 V_1^{1.4} = P_2 V_2^{1.4}$

$(100)(8)^{1.4} = P_2 (1)^{1.4} \Rightarrow P_2 \cong 2000\,kPa$

$\underbrace{P_2 = 2000\,kPa}_{\text{superheated}} \xrightarrow{B.1.3} T_2 = 494.5°C,\ u_2 = 3072\ kJ$

state 3

$v_3 = v_2$, $T_3 = 20°C$ } Sat. Mixture, $P_3 = P_{sat} = 2.339\,kPa$, $v_f = 0.001002$, $v_{fg} = 57.7887$, $u_f = 83.94$, $u_{fg} = 2318.98$

$x_3 = \frac{v_3 - v_f}{v_{fg}} = 2.9256 \times 10^{-3}$ $u_3 = u_f + x_3 u_{fg} = 90.7\ kJ/kg$

$W_{1,2} = \frac{P_2 V_2 - P_1 V_1}{1-n} = -2.72\ kJ$

$Q_{1,2} - W_{1,2} = m(u_2 - u_1) \longrightarrow Q_{1,2} = 3.09\ kJ$

$Q_{2,3} - \cancel{W_{2,3}}^{0} = m(u_3 - u_2) \longrightarrow Q_{2,3} = -17.59\ kJ$

constant volume process

$Q_{tot} = Q_{1,2} + Q_{2,3} = -14.5\ kJ$

$W_{tot} = W_{1,2} + W_{2,3} = -2.72\ kJ$

HW#3

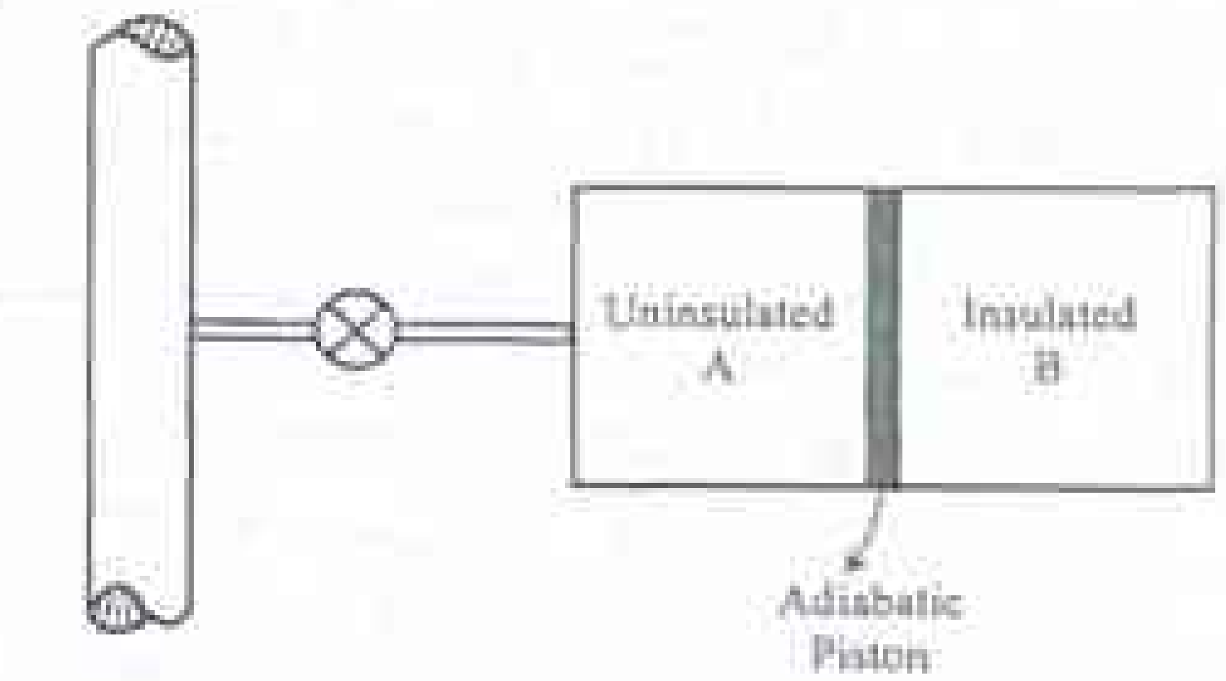
Assigned:

Due:

Q1) Air enters a compressor at 90 kPa, 280 K and with a velocity of 30 m/s. The inlet diameter of the compressor is 50 cm. The air is compressed to 560 kPa, 580 K. The compressed air then enters a constant-pressure heat exchanger where 950 kJ/kg of energy is transferred to the air. The hot compressed air then expands through a turbine. The exit state of the turbine is 90 kPa, 950 K. Using ideal gas table for air:

a) Show the 3 processes on a P-v diagram.
b) Find the compressor power in kW.
c) Find the maximum temperature of the air during the 3 processes.
d) Find the turbine power in kW.

Q2) A cylinder is divided into two regions by an adiabatic piston that is free to move. Region A is uninsulated and has sufficient heat transfer with surroundings so that its contents are always at 25°C. Region B is insulated such that it may be considered adiabatic. Both regions initially contain air at 25°C, 150 kPa with volume $V_{A,1} = V_{B,1} = 0.1\ m^3$. A valve connecting A to a supply line at $P_{supply} = 1000$ kPa is opened and air is allowed to enter until the air in B reaches $T_{B,2} = 67°C$, $P_{B,2} = 260$ kPa. During the process 100 kJ of heat is transferred from A to the surroundings. Find the temperature of the supply line. Assume air is an ideal gas with variable specific heats.

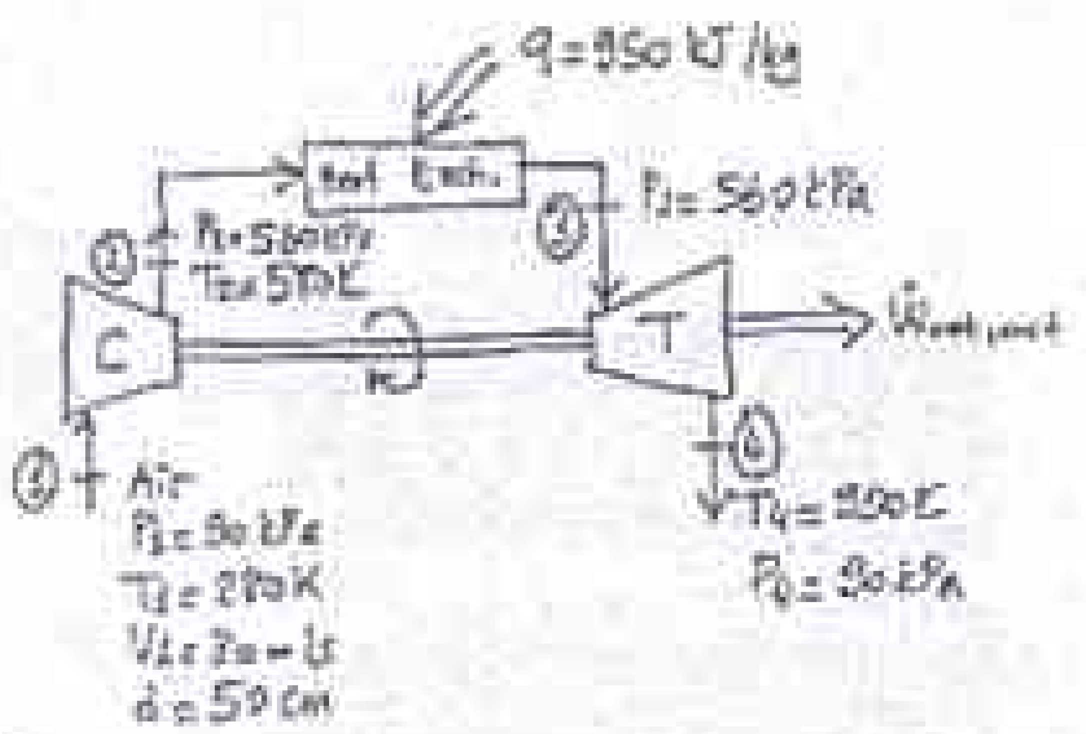


ME 203

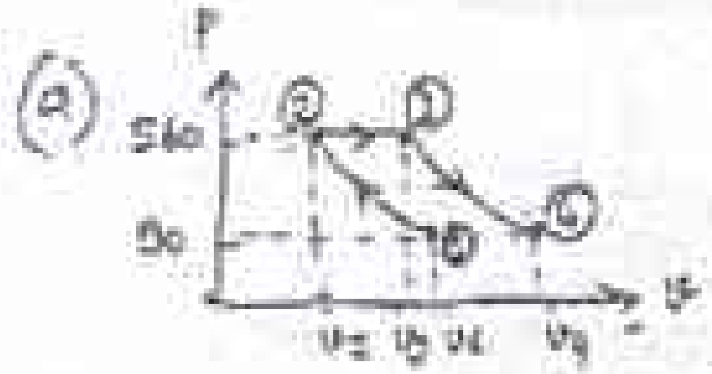
HW#3 Solution

Q1)

Q2:



(a)



(b) C.V. = compressor (SSSF) 1^{st} Law: $\dot{W}_{12} = \dot{m}(h_1 - h_2)$

$\dot{m} = \rho_1 A_1 V_1$ $\qquad A_1 = \frac{\pi}{4} d^2 = \frac{\pi}{4}(0.5)^2 = 0.196\ m^2$

$\Rightarrow \dot{m} = (1.12)(0.196)(30) = 6.58$ kg/s $\qquad \rho_1 = \frac{P_1}{R\,T_1} = \frac{80\text{ kPa}}{(0.287\frac{kJ}{kg\,K})(280K)} = 1.12\ kg/m^3$

$T_1 = 280\ K \xrightarrow{\text{Table A.7}} h_1 = 280.35$ kJ/kg

$T_2 = 580\ K \longrightarrow h_2 = 586.35$ "

$\Rightarrow \dot{W}_{1,2} = (6.58)(280.35 - 586.35) = -2016.3$ kW

(c) C.V. = Heat exchanger (SSSF) 1^{st} Law: $q = h_3 - h_2$

$\Rightarrow 950\ \frac{kJ}{kg} = h_3 - 586.35\ \frac{kJ}{kg} \Rightarrow h_3 = 1536.35$ kJ/kg $\xrightarrow{A.7} T_3 = 1417.5K = T_{max}$

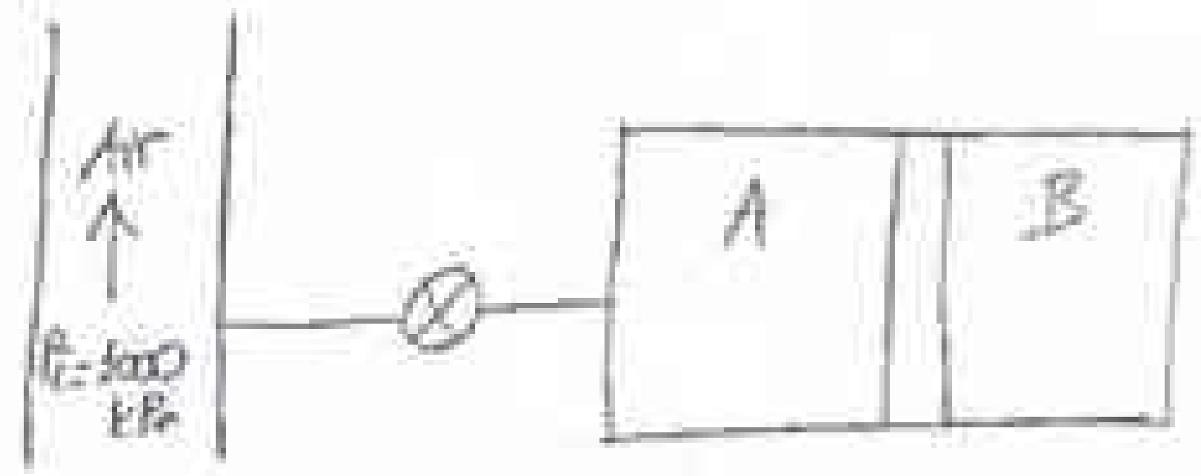
(d) C.V. = Turbine (SSSF) 1^{st} Law: $\dot{W}_{34} = \dot{m}(h_3 - h_4)$

$T_4 = 950K \longrightarrow h_4 = 989.436$ kJ/kg.

$\dot{W}_{34} = (6.58)(1536.35 - 989.436) = +3604.2$ kW

Q2)

Q3)



Given:

State 1		State 2	
A	B	A	B
$T_{A,1} = 25°C$	$T_{B,1} = 25°C$	$T_{A,2} = 25°C$	$T_{B,2} = 67°C$
$P_{A,1} = 150$ kPa	$P_{B,1} = 150$ kPa	$Q_A = -100$ kJ	$P_{B,2} = 260$ kPa
$V_{A,1} = 0.1\ m^3$	$V_{B,1} = 0.1\ m^3$		

B : Closed System

$m_B = \frac{P_{B,1} V_{B,1}}{R_{air} T_{B,1}} = \frac{(150)(0.1)}{(0.287)(298)} = 0.1754$ kg.

$V_{B,2} = \frac{m_B R_{air} T_{B,2}}{P_{B,2}} = \frac{(0.1754)(0.287)(340)}{260} = 0.0658\ m^3$

$V_{A,2} = V_{tot} - V_{B,2} = (0.1 + 0.1) - (0.0658) = 0.1342\ m^3$

$P_{A,2} = P_{B,2} = 260$ kPa (mechanical equilibrium)

1^{st} law for B: $\cancel{Q_B}^{\,0} - W_B = m_B (u_2 - u_1)_B$

adiabatic

state B,1 : $T_{B,1} = 25°C \xrightarrow{A.7} u_{B,1} = 213.04$ kJ/kg

state B,2 : $T_{B,2} = 67°C \longrightarrow u_{B,2} = 243.11$ kJ/kg

$W_B = m_B (u_{B,1} - u_{B,2}) = (0.1754)(213.04 - 243.11) = -5.27$ kJ

A: USUF process, open system

$$m_{A,1} = \frac{P_{A,1} V_{A,1}}{R_{air} T_{A,1}} = \frac{(150)(0.1)}{(0.287)(298)} = 0.1754 \text{ kg.}$$

$$m_{A,2} = \frac{P_{A,2} V_{A,2}}{R_{air} T_{A,2}} = \frac{(260)(0.1342)}{(0.287)(298)} = 0.408 \text{ kg}$$

$$m_i = m_{A,2} - m_{A,1} = 0.2326 \text{ kg}$$

1st law for A:

$$Q_A - W_A + m_i h_i = m_{A2} u_{A2} - m_{A1} u_{A1}$$

state A,1: $T_{A,1} = 25°C \xrightarrow{A.7} u_{A,1} = 213.04 \text{ kJ/kg}$

state A,2: $T_{A,2} = 75°C \longrightarrow u_{A,2} = 213.04$ "

$$W_A = -W_B = +5.27 \text{ kJ}$$

$$Q_A = -100 \text{ kJ}$$

$$\Rightarrow (-100 \text{ kJ}) - (5.27) + (0.2326) h_i = (213.04)(0.408 - 0.1754)$$

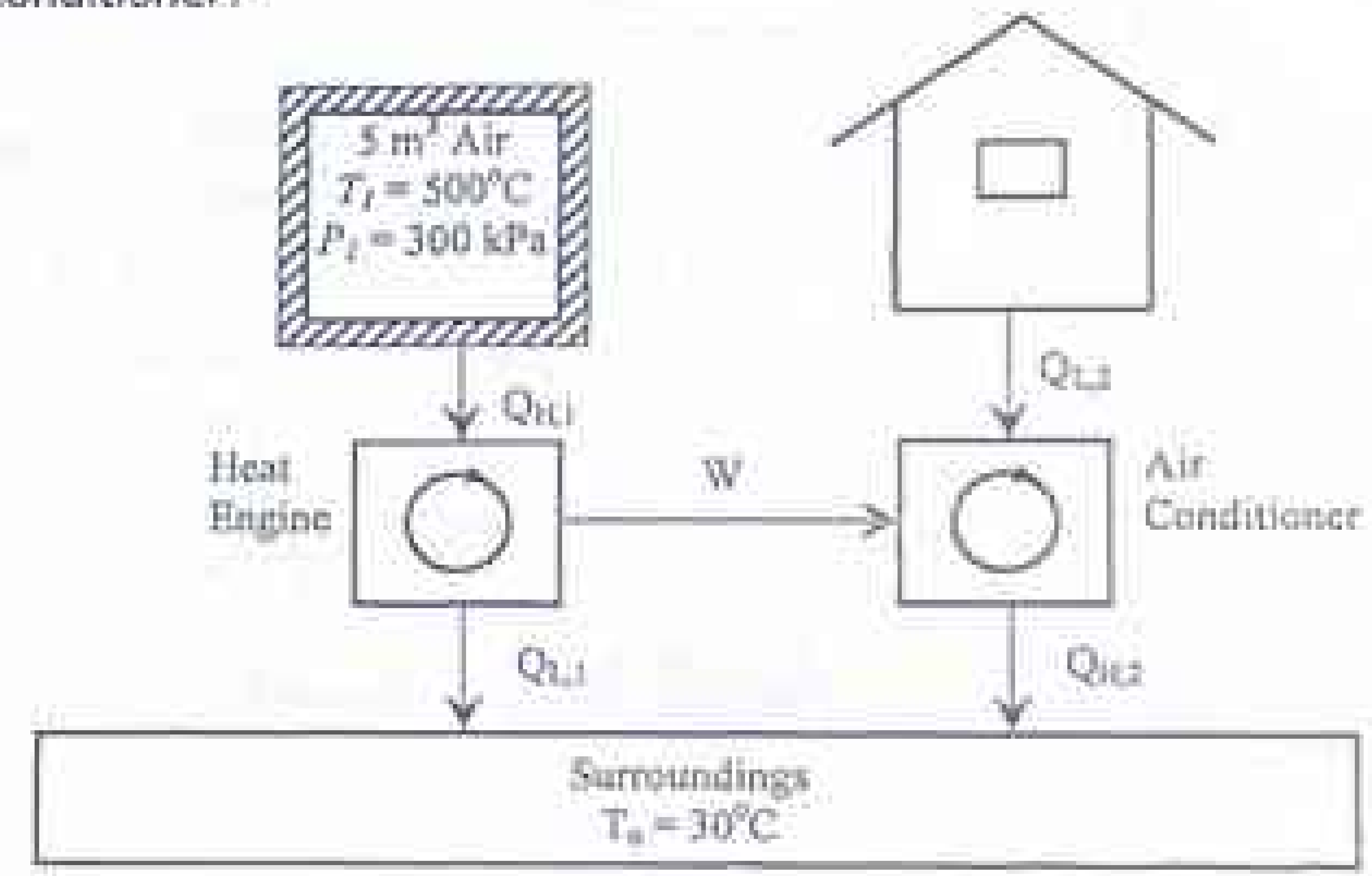
$$h_i = 665.62 \text{ kJ/kg}$$

$$\Big\downarrow A.7$$

$$T_i = 655 \text{ K} = 382 °C$$

HW#4
Assigned:
Due:

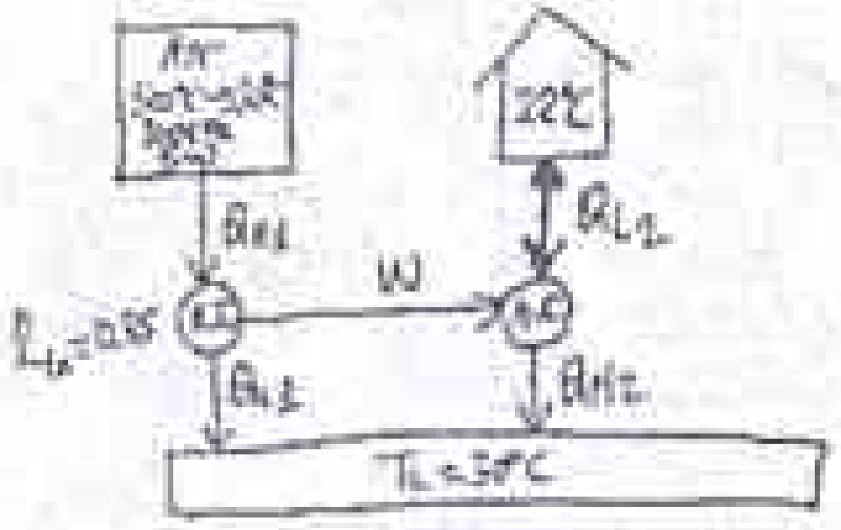
Q1) A heat engine with a thermal efficiency of 35% employs a rigid insulated tank as its high-temperature reservoir and rejects heat to the surroundings at 30°C. The air in the tank is initially at 500°C, 300 kPa and it is cooled to 30°C. The volume of the tank is 5 m³. The work produced from the heat engine is used to drive an air conditioner. The air conditioner is used to keep the air in a house at 22°C while rejecting energy to the surroundings at 30°C. What is the maximum cooling ($Q_{L,2}$) that can be accomplished by the air conditioner?



HW#4 Solution

Q1)

Q1:



$Q_{H1} = U_2 - U_1 = m C_{vo} (T_2 - T_1)$ $\qquad m = \frac{P_1 V}{R T_1} = \frac{(300)(5)}{(0.287)(773)} = 6.76 \text{ kg}$

$\Rightarrow Q_{H1} = (6.76)(0.717)(30-500) = -2278 \text{ kJ}$

$W = \eta_{th_{H.E.}} Q_{H1} = (0.35)(2278) = 797.3 \text{ kJ}$

$\beta_{Carnot_{A.C.}} = \frac{Q_{L2}}{W} = \frac{T_L}{T_H - T_L}$ $\qquad \Rightarrow \beta_{Carnot_{H.E.}} = \frac{295 \text{ K}}{303-295} = 36.875$

$\Rightarrow Q_{L2} = \beta_{Carnot_{A.C.}} W = (36.875)(797.3) = 29400 \text{ kJ}$

Section 03

HW#1

Q1) Water is contained in a closed piston/cylinder assembly. There is no friction between the piston and cylinder walls. The piston has a mass of 2040 kg and the cross-sectional area of the piston is 0.4 m². The atmospheric pressure is 100 kPa. The initial temperature and volume of the water are 50°C and 2 m³. The water is heated until its temperature reaches 200°C. Calculate:

(a) the initial and the final pressure of the water,
(b) the mass of the water,
(c) the internal energy change of the water during the process, and
(d) show the process on P-v and T-v diagrams with respect to saturation curve .

Q2) Refrigerant-134a is contained in a rigid cylinder that is fitted with a frictionless piston. The mass of the piston is 2 kg and is attached to a linear spring. The spring constant is k = 10 kN/m. The diameter of the piston is 200 mm and the atmospheric pressure P_{atm} is 110 kPa. At the initial state, R-134a occupies a volume of 0.2 L and has a temperature of 50°C. The spring touches the piston but does not exert any force on the piston. The R-134a is heated until its volume doubles. Determine:

(a) the initial pressure of R-134a,
(b) the mass of R-134a in the cylinder,
(c) the final pressure of R-134a, and
(d) Show the process on P-v and T-v diagrams with respect to saturation curve.

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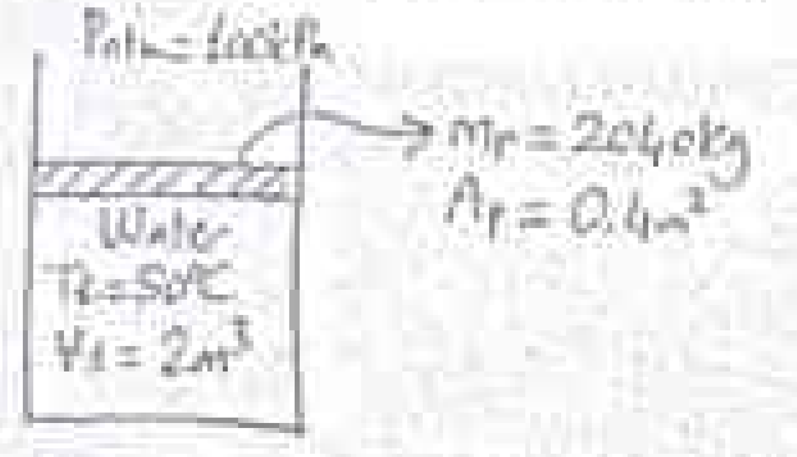
HW#1 Solution

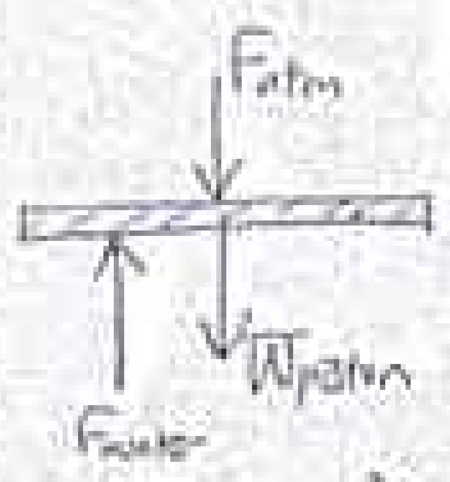
Q1)



State 2

$T_2 = 200°C$

(a) Free Body Diagram of piston:



$F_{water} = F_{atm} + W_{piston}$

$P_1 . A_P = P_{atm} . A_P + m_P . g$

$$P_1 \left(0.4m^2\right) = (100kPa)\left(0.4m^2\right) + \frac{(2040kg)\left(9.81\ m/s^2\right)}{1000\ N/kN} \Rightarrow P_1 = 150kPa$$

Since atmospheric pressure and piston weight is constant, initial and final pressures of water are constant in order to have mechanical equilibrium. $\Rightarrow P_1 = P_2 = 150kPa$

(b) $m = \frac{V_1}{v_1}$ at $150kPa \xrightarrow{A.3\ Moran} T_{sat} = 111.4°C > T_1$

$\Downarrow$

state 1 is compressed liquid

$v_1 \cong v_{f@T_1=50°C} \overset{A.2\ Moran}{=} 0.001012\ m^3/kg$.

$\Rightarrow m = \frac{2m^3}{0.001012\ m^3/kg} = 1976\ kg$

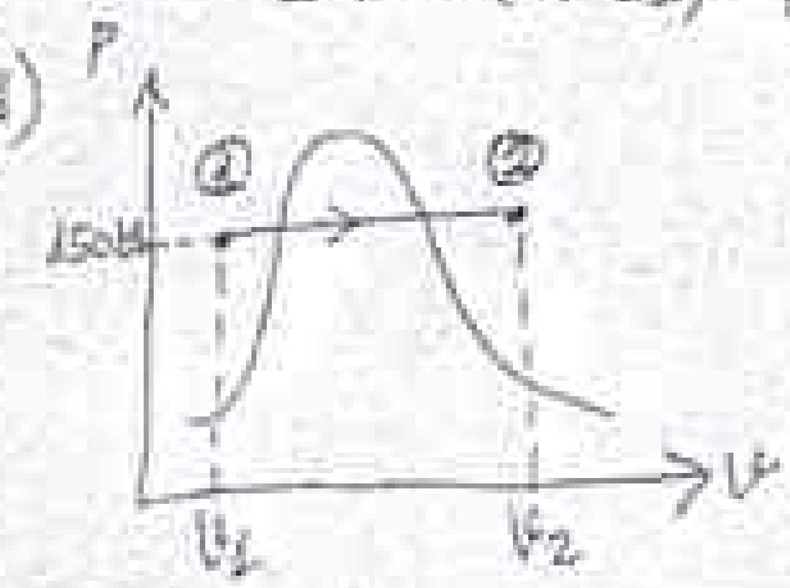
(c) state 1: compressed liquid $\longrightarrow u_1 \cong u_{f@T_1=50°C} \overset{A.2\ Moran}{=} 209.3\ kJ/kg$

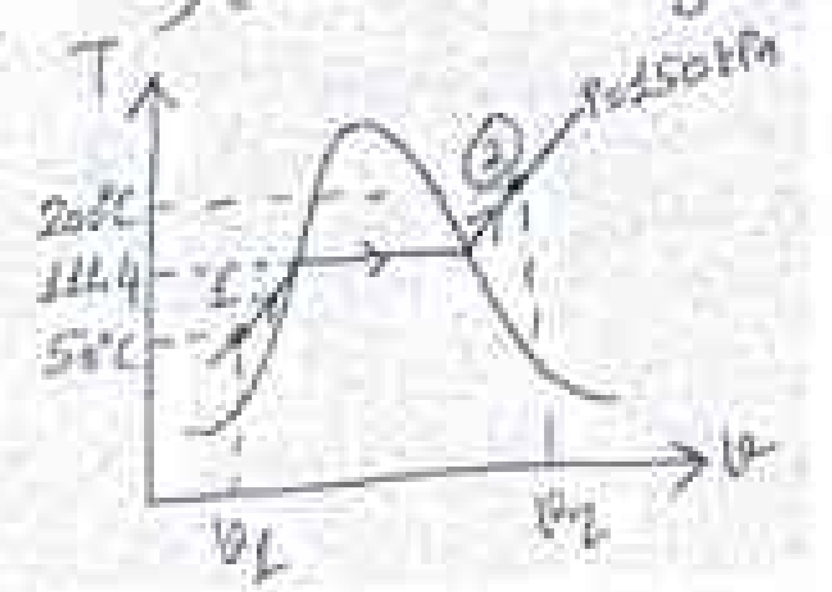
state 2: $\left.\begin{array}{l} T_2 = 200°C \\ P_2 = 150kPa \end{array}\right\}$ $T_2 > T_{sat@150kPa} \longrightarrow$ state 2 is superheated vapor

A.4 Moran: $u_2 = 2656\ kJ/kg$

$$\Delta U = m(u_2 - u_1) = (1976kg)(2656 - 209.3)\frac{kJ}{kg} = 4835 294\ kJ$$

(d)





ME 203

Section 03 **HW#2**

Q1) A piston/cylinder arrangement contains two sets of stops, between which the piston is free to move. The mass of the piston is such that a pressure of 200 kPa is required to displace it, and when the piston is resting on the lower stops, the volume contained in the cylinder is 0.4 m³. The cylinder is initially filled with water at 100°C with a quality of 0.25. Heat is slowly added until all of the liquid water has just vaporized. At this condition the pressure in the cylinder is 300 kPa.

(a) Sketch the process on a P-v diagram with respect to saturation lines (labeling each state and showing process paths and directions), and calculate:

(b) the mass of water in cylinder,

(c) the temperature when the piston first moves,

(d) the volume at the final state,

(e) the work done during the process,

(f) the heat transfer during the process.

Q2) A cylinder fitted with a frictionless piston that is restrained by a linear spring contains refrigerant R-22 at 20°C, quality 60 % with a volume of 8 liters. The piston cross-sectional area is 0.04 m² and the spring constant is 500 kN/m. During a process, 2.76 kJ of work is done by R-22. Find:

(a) the final pressure and temperature in the cylinder,

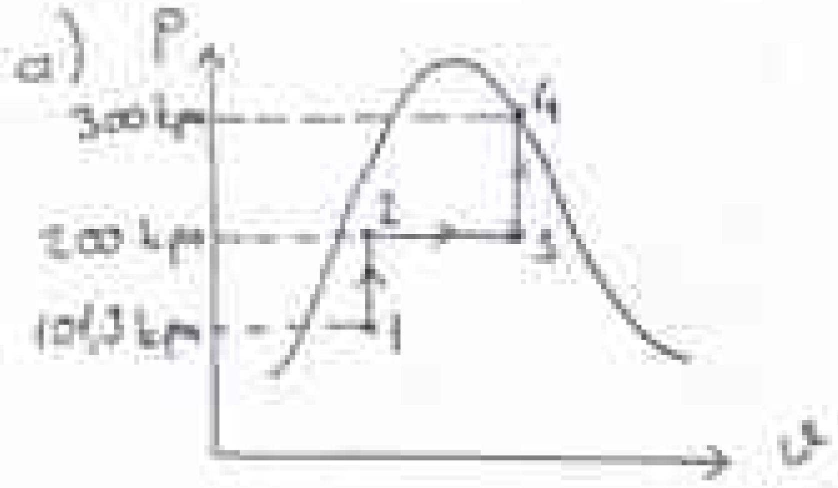
(b) the heat transfer during the process.

Me 203 sec 03 Hw Sol 2

(Q1)

Initial State	Final State
$T = 100°C$	$P = 300\,kPa$
$x = 0{,}25$	$x = 1$
$V = 0{,}4\,m^3$	

a)



b) State 1: $T_1 = 100°C$, $x_1 = 0{,}25$ } Table B.1.1: $P_1 = P_{sat} = 101{,}3\,kPa$, $v_f = 0{,}001044$, $v_{fg} = 1{,}67185$, $u_f = 418{,}91$, $u_{fg} = 2087{,}58$

$m = ?$

$v_1 = v_f + x_1 v_{fg} = 0{,}419\ m^3/kg$

$u_1 = u_f + x_1 u_{fg} = 340{,}805\ kJ/kg$

$m = \frac{V_1}{v_1} = \frac{0{,}4\,m^3}{0{,}419\,m^3/kg} = 0{,}955\,kg$

c) State 2: $P_2 = 200\,kPa$, $v_2 = v_1 = 0{,}419$ } Table B.1.2: $v_{f\,at\,200kPa} < v_2 < v_{g\,at\,200\,kPa}$

saturated liquid-vapor mixture

$T_2 = T_{sat\,@200kPa} = 120{,}23\,°C$

d) State 4: $P_4 = 300\,kPa$, $x_4 = 1$ } Table B.1.2: $v_4 = v_g = 0{,}60582$, $u_4 = u_g = 2543{,}55$

$V_4 = m v_4 = 0{,}579\,m^3$

e) $W_{1,4} = \underbrace{W_{1,2}}_{0} + W_{2,3} + \underbrace{W_{3,4}}_{0}$

$= P_2(V_3 - V_2)$

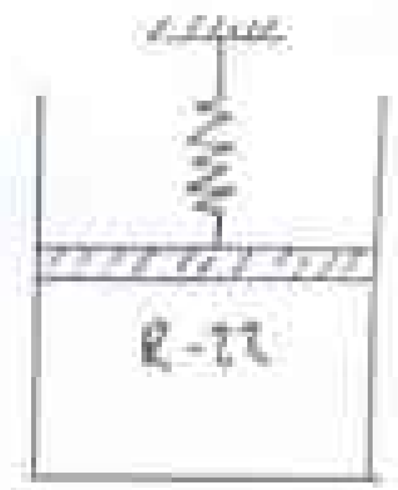
$W_{1,4} = 200\,kPa\,(0{,}579 - 0{,}4) = 35{,}71\,kJ$

f) 1st law: $Q_{1,4} - W_{1,4} = m(u_4 - u_1)$

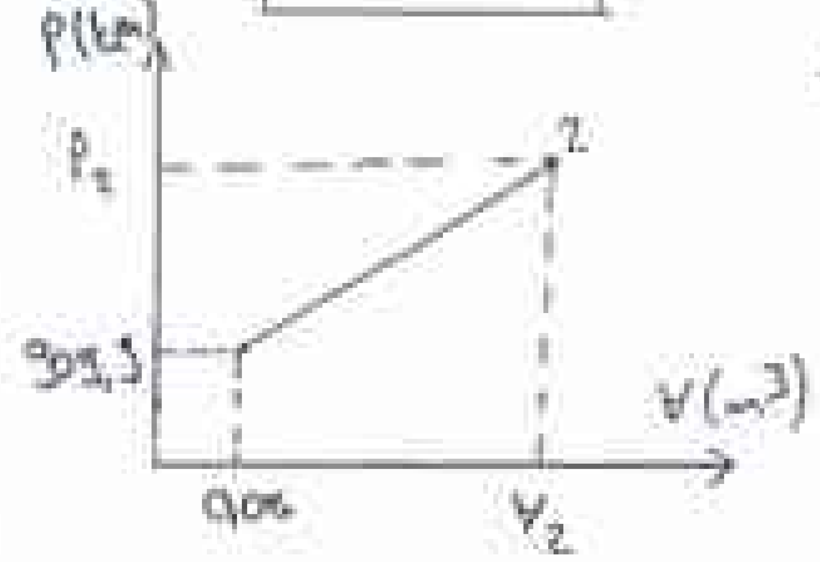
$Q_{1,4} - (35{,}71) = 0{,}955(2543{,}55 - 340{,}805)$

$Q_{1,4} = 1566{,}3\,kJ$

(Q2)



Given: $k_s = 500\,kN/m$, $A_p = 0{,}04\,m^2$, $T_1 = 20°C$, $x_1 = 0{,}6$, $V_1 = 8\,L$, $W_{1,2} = 2{,}76\,kJ$



State 1: R-22, $T_1 = 20°C$, $x_1 = 0{,}6$ } Table B.4.1: $P_1 = 909{,}9\,kPa$, $v_f = 0{,}000824$, $v_{fg} = 0{,}02518$, $u_f = 67{,}92$, $u_{fg} = 164{,}92$

$v_1 = v_f + x_1 v_{fg} = 0{,}01593\ \frac{m^3}{kg}$

$u_1 = u_f + x_1 u_{fg} = 166{,}872\ \frac{kJ}{kg}$

linear spring $\Rightarrow P = c_1 V + c_2$ where $c_1 = \frac{k_s}{A_p^2}$ ... slope of the line

$\Rightarrow c_1 = \frac{500\,kN/m}{(0{,}04)^2\,m^4} = 312500\ \frac{kN}{m^5} = \frac{kPa}{m^3}$

$312500\ \frac{kPa}{m^3} = \frac{P_2 - P_1}{V_2 - V_1} = \frac{P_2 - 909{,}9}{V_2 - 0{,}008} \Rightarrow \boxed{P_2 = 312500\,V_2 - 1590{,}1}$ ... (1)

$W_{1,2} = 2{,}76\,kJ = \frac{1}{2}(P_1 + P_2)(V_2 - V_1)$ ... (2)

substitute eqn (1) into (2): $2{,}76 = \frac{1}{2}(909{,}9 + 312500V_2 - 1590{,}1)(V_2 - 0{,}008)$

solving this quadratic function for V_2 gives: $V_2 = 0{,}0102\,m^3$

from equation (1) $\Rightarrow P_2 = 1598\,kPa$

mass of R-22 $m = \frac{V_1}{v_1} = 0{,}502\,kg \Rightarrow v_2 = \frac{V_2}{m} = 0{,}0203\ \frac{m^3}{kg}$

a) State 2: $P_2 = 1600\,kPa$, $v_2 = 0{,}0203\ m^3/kg$ } Superheated R-22, Table B.4.2: $T_2 \sim 110°C$, $u_2 = 288{,}12\ \frac{kJ}{kg}$

b) 1st law: $Q_{1,2} - W_{1,2} = m(u_2 - u_1)$

$Q_{1,2} - (2{,}76) = (0{,}502)(288{,}12 - 166{,}872)$

$\Rightarrow Q_{1,2} = 63{,}6\,kJ$

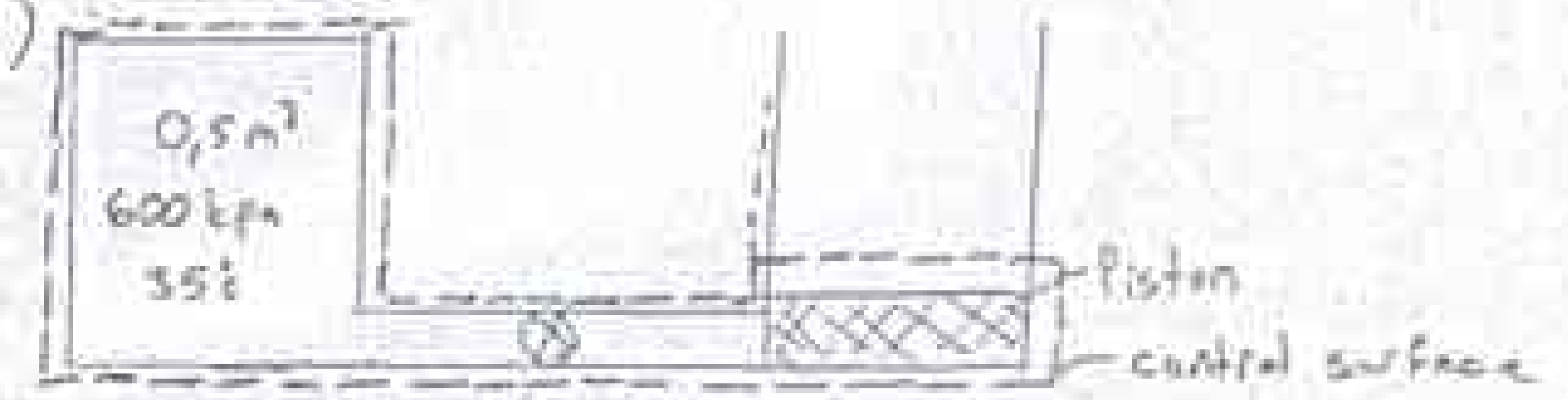
ME 203

HW#3

Q1) A rigid tank, which contains 0.5 m^3 of air at 600 kPa and 35°C, is connected by a valve to an initially empty piston-cylinder device. The mass of the piston and the atmospheric pressure are such that a pressure of 300 kPa is required to raise the piston. The valve is now opened slowly and air is allowed to flow in the cylinder until the pressure in the tank drops to 300 kPa. During this process heat is exchanged with the surrounding such that the entire air remains at 35°C at all times. Determine the heat transfer for this process. Assume air is an ideal gas with varying specific heats.

Me 203 HW3 Solution Sec 03

Q1)



Initial State

$P_1 = 600$ kPa

$V_1 = 0{,}5\ m^3$

$T_1 = 35°C = 308$ K

$R_{air} = 0{,}287\ \frac{kJ}{kg\,K}$

$P_1 V_1 = m R T_1$

$600\ 0{,}5 = m\ 0{,}287\ 308$

$m = 3{,}3938$ kg

m = constant $= m_1 = m_2$

State 2

$P_2 = 300$ kPa

$T_2 = 35°C = 308$ K

$V_2 = ?$

$P_2 V_2 = m R T_2$

$300\ V_2 = (3{,}3938)(0{,}287)(308\text{ K})$

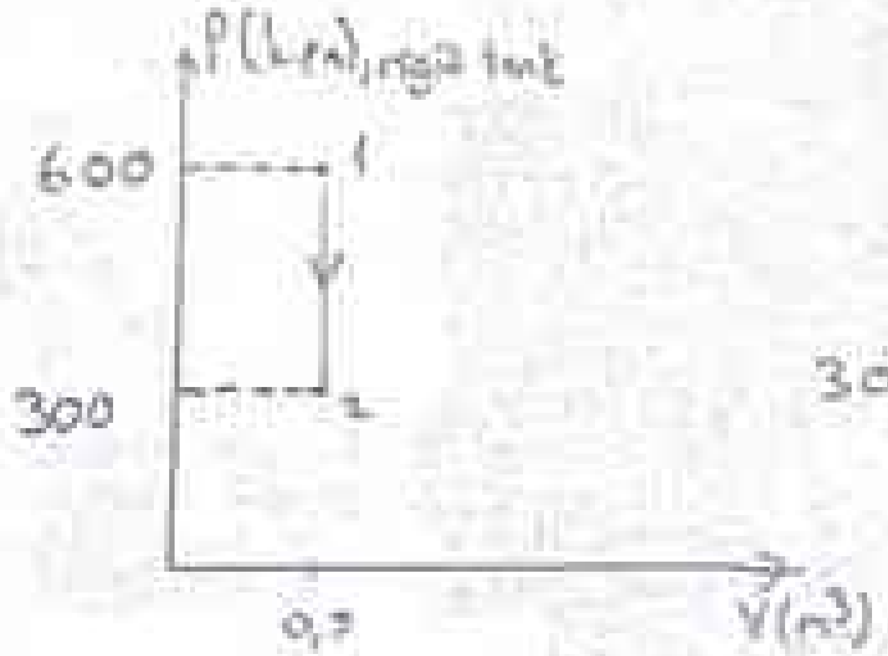
$V_2 = 1\ m^3$ (all control volume)

$W_{total} = \cancel{W_{rigid\ tank}}^{\,0} + W_{piston}$

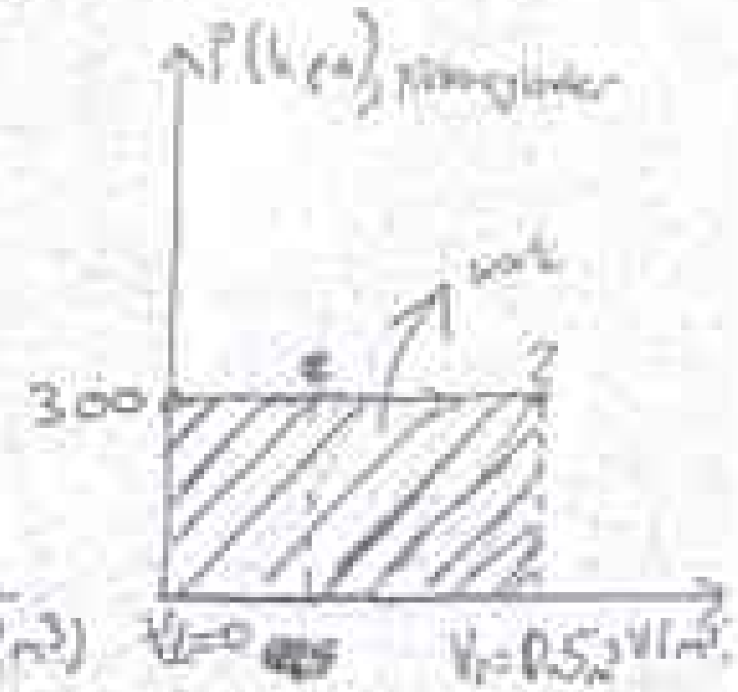
$W = P(V_2 - V_1)$

$= 300\text{ kPa}\,(1 - 0{,}5)\,m^3$

$= 150$ kJ



$W_{rigid\ tank} = 0$ (V is constant)



PV diagram for piston cylinder

$Q - W = m(u_2 - u_1) + \frac{1}{2} m \cancel{(V_2^2 - V_1^2)} + mg\cancel{(z_2 - z_1)}$

neglected neglected

$u_2 = u_1$ (isothermal process $T_1 = T_2 = 35°C$) air is ideal gas $u = f(T)$

$Q = W = 150$ kJ

ME 203

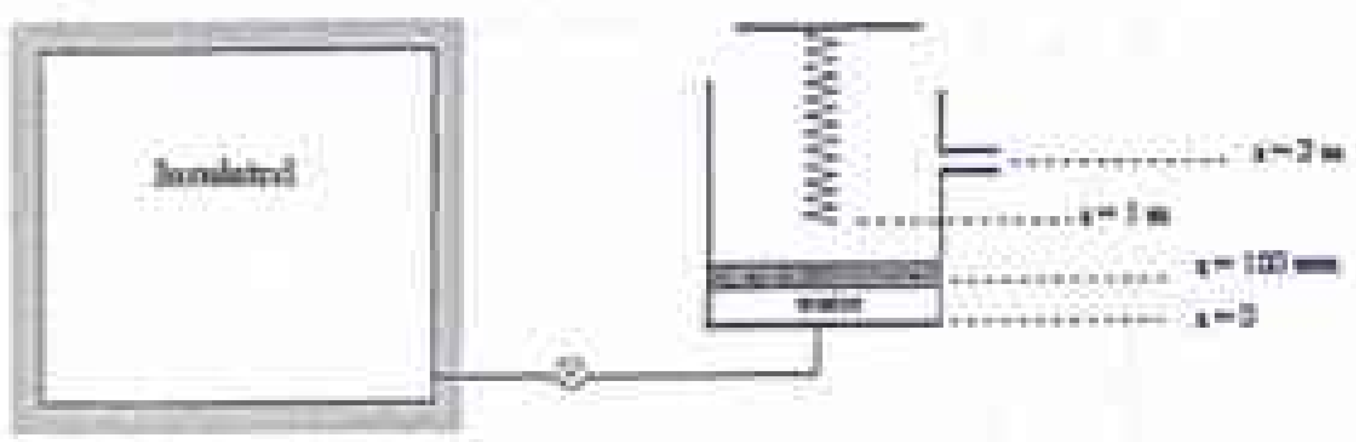
HW#4

Q1) Consider the following piston/cylinder that is connected to an insulated, rigid tank by a valve. Tank A has a volume of 8 m^3. The piston has a cross-sectional area of 1 m^2. Near the top of the cylinder there is an opening, which is located 2 m from the bottom of the cylinder. The excess fluid is discharged from the cylinder when the piston reaches this opening (in this way, the piston cannot rise above this height).

Initially, tank A contains saturated water mixture at 20 MPa, with the liquid volume ½ of the tank volume. Piston is initially 100 mm above the bottom of the cylinder. Initial pressure in the cylinder is 200 kPa. There is a linear spring with a constant of k = 600 kN/m as shown in the figure.

Now the valve is opened slowly. The flow continues until the state in the tank becomes T_{A2} = 200°C, quality x_{A2} = 0.468. Then the valve is closed. During the process there is sufficient heat transfer from the cylinder such that its contents are always in thermal equilibrium with the surroundings at T_{surr} = 20°C. Find:

a) the mass loss through the opening during this process,
b) the work done by water during this process,
c) the heat transfer during this process.



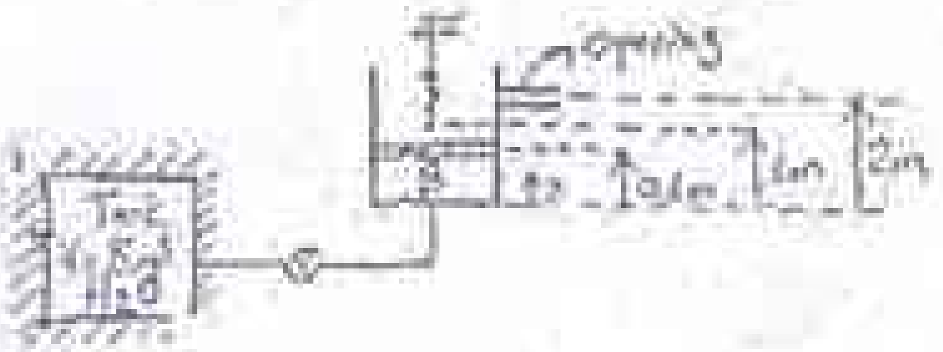
Q2) Air enters a compressor at 90 kPa, 280 K and with a velocity of 30 m/s. The inlet diameter of the compressor is 50 cm. The air is compressed to 560 kPa, 580 K. The compressed air then enters a constant-pressure heat exchanger where 950 kJ/kg of energy is transferred to the air. The hot compressed air then expands through a turbine. The exit state of the turbine is 90 kPa, 950 K. Using ideal gas table for air:

a) Show the 3 processes on a P-v diagram.

b) Find the compressor power in kW.
c) Find the maximum temperature of the air during the 3 processes.
d) Find the turbine power in kW.

W4 Solution

Q1:



Initial state 1; Tank A: $P_{A1} = 20000\,kPa$ Saturated mixture $V_f = 4m^3$, $V_g = 4m^3$

$$m_{f1} = \frac{V_{f1}}{v_{f1}} = \frac{4}{0.002035} = 1965.6\,kg \qquad m_{g1} = \frac{V_{g1}}{v_{g1}} = \frac{4}{0.00583} = 686\,kg$$

$$x_{A1} = \frac{m_{g1}}{m_{f1}+m_{g1}} = 0.2587 \qquad u_{A1} = u_f + x_{A1} u_{fg} = 1916.75\,kJ/kg.$$

$$m_{A1} = m_{f1} + m_{g1} = 2651.7\,kg$$

Initial state 1, Cylinder: $P_{B1} = 200\,kPa$, $T_B = 20°C \Rightarrow$ compressed liquid

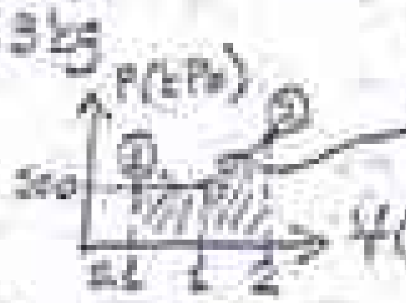
$$m_{B1} = \frac{V_{B1}}{v_{f@20°C}} = \frac{0.1m^3}{0.001002} = 99.8\,kg \qquad u_{B1} = u_{f@20°C} = 83.94\,kJ/kg.$$

Final State 2, Tank A: $T_{A2} = 200°C$, $x_{A2} = 0.468 \Rightarrow$ Saturated Mixture

$P_{A2} = 1553.8\,kPa$; $v_{A2} = v_f + x_{A2} v_{fg} = 0.0602\,\frac{m^3}{kg}$, $u_{A2} = u_f + x_{A2} u_{fg} = 1643.14\,\frac{kJ}{kg}$

$$m_{A2} = \frac{8m^3}{0.0602\,\frac{m^3}{kg}} = 132.9\,kg$$

Final State 2, Cylinder:



$\text{slope} = \frac{k}{A_p^2} = 600\,\frac{kN}{m^5}$

$P_{B2} = (200\,kPa) + \left(600\,\frac{kN}{m^5}\right)(2-1)m^3$

$\Rightarrow P_{B2} = 800\,kPa$

$\left.\begin{array}{l} P_{B2} = 800\,kPa \\ T_{B2} = 20°C \end{array}\right\}$ compressed liquid

$v_{B2} = v_{f@20°C} = 0.001002\,m^3/kg$, $u_{B2} = u_{f@20°C} = 83.94\,kJ/kg$.

$m_{B2} = 2m^3/0.001002 = 1996\,kg$.

(a) Continuity $\Rightarrow$ $m_{A1} + m_{B1} = m_{A2} + m_{B2} + m_{exit}$ $\Rightarrow m_{exit} = 622.6\,kg$

(b) $W_{12} = \text{Area} = (200\,kPa)(1-0.1)m^3 + \frac{1}{2}(200+800)(2-1)m^3 = 680\,kJ$

(c) For the Tank + Cylinder Control Volume : process $\rightarrow$ USUF

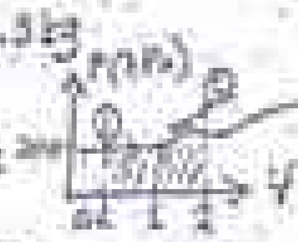
$$Q_{12} - W_{12} - m_e h_e = (m_{A2} u_{A2} + m_{B2} u_{B2}) - (m_{A1} u_{A1} + m_{B1} u_{B1})$$

$$h_e = h_{f@20°C} = 83.94\,kJ/kg.$$

$$\Rightarrow Q_{12} - (680) - (622.6)(83.94) = \left[(132.9)(1643.14) + (1996)(83.94)\right] - \left[(2651.7)(1916.8) + (99.8)(83.94)\right]$$

$$\Rightarrow Q_{12} = -4\,649\,158\,kJ \approx -4650\,MJ$$

Q1:
Initial state 1; Tank A: $P_{A1} = 20000\,kPa$ Saturated mixture $V_f = 4m^3$, $V_g = 4m^3$
$m_{f1} = \frac{V_{f1}}{v_{f1}} = \frac{4}{0.002035} = 1965.6\,kg$ $m_{g1} = \frac{V_{g1}}{v_{g1}} = \frac{4}{0.00583} = 686\,kg$
$x_{A1} = \frac{m_{g1}}{m_{f1}+m_{g1}} = 0.2587$ $u_{A1} = u_f + x_{A1} u_{fg} = 1916.75\,kJ/kg.$
$m_{A1} = m_{f1} + m_{g1} = 2651.7\,kg$
Initial state 1, Cylinder: $P_{B1} = 200\,kPa$, $T_B = 20°C \Rightarrow$ compressed liquid
$m_{B1} = \frac{V_{B1}}{v_{f@20°C}} = \frac{0.1m^3}{0.001002} = 99.8\,kg$ $u_{B1} = u_{f@20°C} = 83.94\,kJ/kg.$
Final State 2, Tank A: $T_{A2} = 200°C$, $x_{A2} = 0.468 \Rightarrow$ Saturated Mixture
$P_{A2} = 1553.8\,kPa$; $v_{A2} = v_f + x_{A2} v_{fg} = 0.0602\,\frac{m^3}{kg}$, $u_{A2} = u_f + x_{A2} u_{fg} = 1643.14\,\frac{kJ}{kg}$
$m_{A2} = \frac{8m^3}{0.0602\,\frac{m^3}{kg}} = 132.9\,kg$
Final State 2, Cylinder:

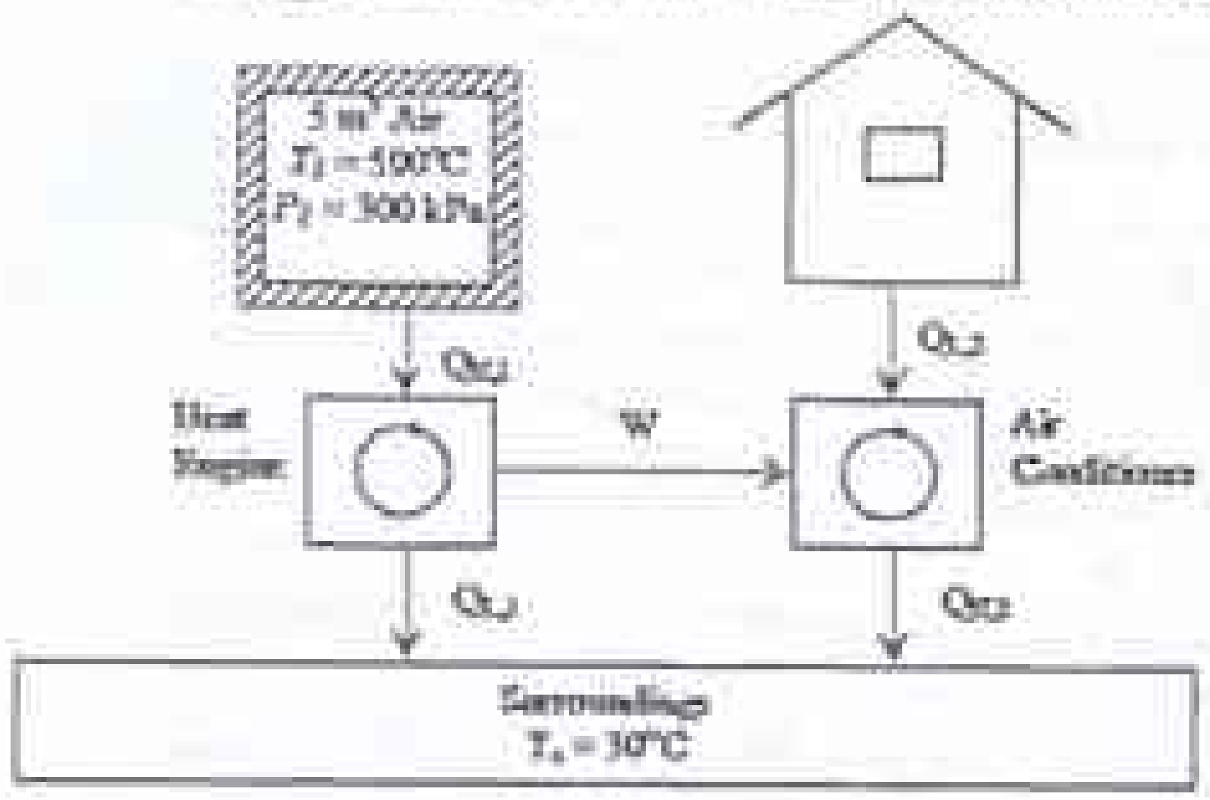


$\text{slope} = \frac{k}{A_p^2} = 600\,\frac{kN}{m^5}$
$P_{B2} = (200\,kPa) + \left(600\,\frac{kN}{m^5}\right)(2-1)m^3$
$\Rightarrow P_{B2} = 800\,kPa$
$P_{B2} = 800\,kPa$, $T_{B2} = 20°C$ compressed liquid
$v_{B2} = v_{f@20°C} = 0.001002\,m^3/kg$, $u_{B2} = u_{f@20°C} = 83.94\,kJ/kg$.
$m_{B2} = 2m^3/0.001002 = 1996\,kg$.
(a) Continuity $\Rightarrow$ $m_{A1} + m_{B1} = m_{A2} + m_{B2} + m_{exit}$ $\Rightarrow m_{exit} = 622.6\,kg$
(b) $W_{12} = \text{Area} = (200\,kPa)(1-0.1)m^3 + \frac{1}{2}(200+800)(2-1)m^3 = 680\,kJ$
(c) For the Tank + Cylinder Control Volume : process $\rightarrow$ USUF
$Q_{12} - W_{12} - m_e h_e = (m_{A2} u_{A2} + m_{B2} u_{B2}) - (m_{A1} u_{A1} + m_{B1} u_{B1})$
$h_e = h_{f@20°C} = 83.94\,kJ/kg.$
$\Rightarrow Q_{12} - (680) - (622.6)(83.94) = \left[(132.9)(1643.14) + (1996)(83.94)\right] - \left[(2651.7)(1916.8) + (99.8)(83.94)\right]$
$\Rightarrow Q_{12} = -4\,649\,158\,kJ \approx -4650\,MJ$

ME 203

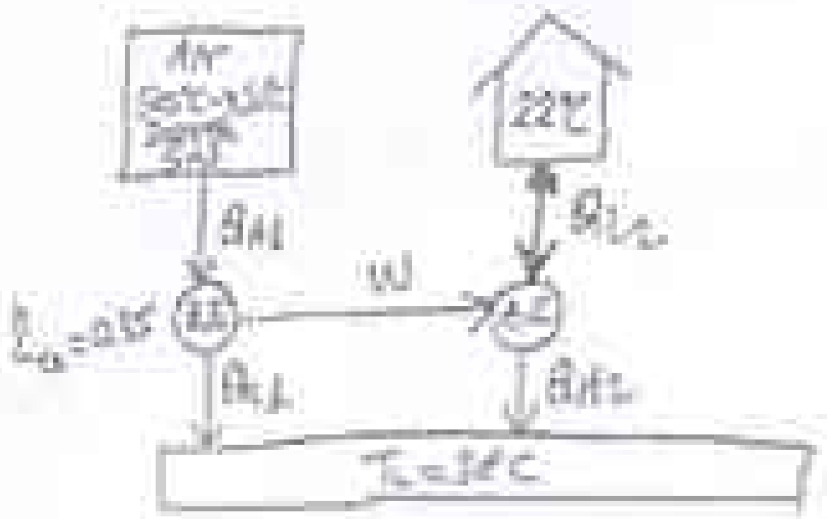
HW#5

Q1) A heat engine with a thermal efficiency of 35% employs a rigid insulated tank as its high-temperature reservoir and rejects heat to the surroundings at 30°C. The air in the tank is initially at 500°C, 300 kPa and it is cooled to 30°C. The volume of the tank is 5 m^3. The work produced from the heat engine is used to drive an air conditioner. The air conditioner is used to keep the air in a house at 22°C while rejecting energy to the surroundings at 30°C. What is the maximum cooling (Q_{L2}) that can be accomplished by the air conditioner?



Q2) Consider a Carnot heat engine cycle executed in a closed system (piston-cylinder) using 0.103 kg of steam as the working fluid. It is known that the maximum absolute temperature in the cycle is twice the minimum absolute temperature, and the net work output of the cycle is 246.46 kJ. If the steam changes from saturated vapor to saturated liquid during heat rejection, determine the temperature of the steam during the heat rejection process. Also show the cycle on a P-v diagram with respect to saturation lines.

Q1:



$$Q_{H1} = U_2 - U_1 = m\,c_{v0}\,(T_2 - T_1) \qquad m = \frac{P_1 V}{R\,T_1} = \frac{(300)(5)}{(0.287)(773)} = 6.76\,\text{kg}$$

$$\Rightarrow Q_{H1} = (6.76)(0.717)(30-500) = -2278\ \text{kJ}$$

$$W = \eta_{th_{H.E.}}\, Q_{H1} = (0.35)(2278) = 797.3\ \text{kJ}$$

$$\beta_{\substack{Carnot\\A.C.}} = \frac{Q_{L2}}{W} = \frac{T_L}{T_H - T_L} \qquad \Rightarrow \beta_{\substack{Carnot\\H.E.}} = \frac{295\,K}{303-295} = 36.875$$

$$\Rightarrow Q_{L2} = \beta_{\substack{Carnot\\A.C.}}\, W = (36.875)(797.3) = 29400\ \text{kJ}$$

Q2)

: Piston-cylinder type Carnot heat engine

K

1→2: reversible + isothermal heat addition

2→3: reversible + adiabatic expansion

3→4: reversible + isothermal heat rejection

4→1: reversible + adiabatic compression

$$\eta_{th,Carnot} = 1 - \frac{T_L}{T_H} \quad , \quad T_H = 2T_L$$

$$\Rightarrow \eta_{th,Carnot} = 1 - \frac{T_L}{2T_L} = 0.5 = \frac{W_{net,out}}{Q_H}$$

$$\Rightarrow Q_H = \frac{W_{net,out}}{0.5} = \frac{246.46\ kJ}{0.5} = 492.92\ kJ$$

$$Q_L = Q_H - W_{net,out} = 246.46\ kJ$$

1st Law for 3→4: $Q_{3,4} - W_{3,4} = U_4 - U_3$

$$W_{3,4} = P(V_4 - V_3)$$

$$\Rightarrow Q_{3,4} - P(V_4 - V_3) = U_4 - U_3$$

$$\Rightarrow Q_{3,4} = H_4 - H_3 \Rightarrow q_{3,4} = \frac{Q_{3,4}}{m} = h_4 - h_3$$

$$\Rightarrow q_{3,4} = h_f - h_g = -h_{fg}$$

$$q_{3,4} = \frac{-246.46\ kJ}{0.103\ kg} = -2392.8\ kJ/kg$$

$$\Rightarrow h_{fg} = 2392.8\ kJ/kg \Rightarrow T_L \simeq 45°C$$

(45.81°C @ 10kPa)

Section 01
HW#2

Q1) Air enters a compressor at 90 kPa, 280 K and with a velocity of 30 m/s. The inlet diameter of the compressor is 50 cm. The air is compressed to 560 kPa, 580 K. The compressed air then enters a constant-pressure heat exchanger where 950 kJ/kg of energy is transferred to the air. The hot compressed air then expands through a turbine. The exit state of the turbine is 90 kPa, 950 K. Using ideal gas table for air:

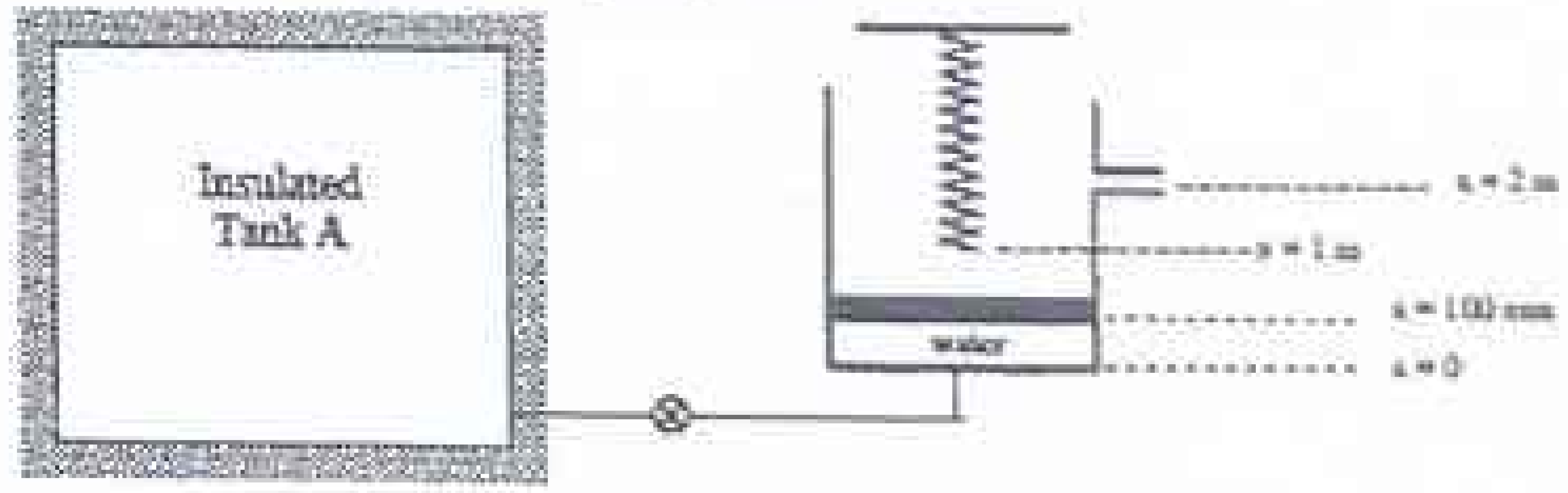
a) Show the 3 processes on a P-v diagram.
b) Find the compressor power in kW.
c) Find the maximum temperature of the air during the 3 processes.
d) Find the turbine power in kW.

Q2) Consider the following piston/cylinder that is connected to an insulated, rigid tank by a valve. Tank A has a volume of 8 m^3. The piston has a cross-sectional area of 1 m^2. Near the top of the cylinder there is an opening, which is located 2 m from the bottom of the cylinder. The excess fluid is discharged from the cylinder when the piston reaches this opening (in this way, the piston cannot rise above this height).

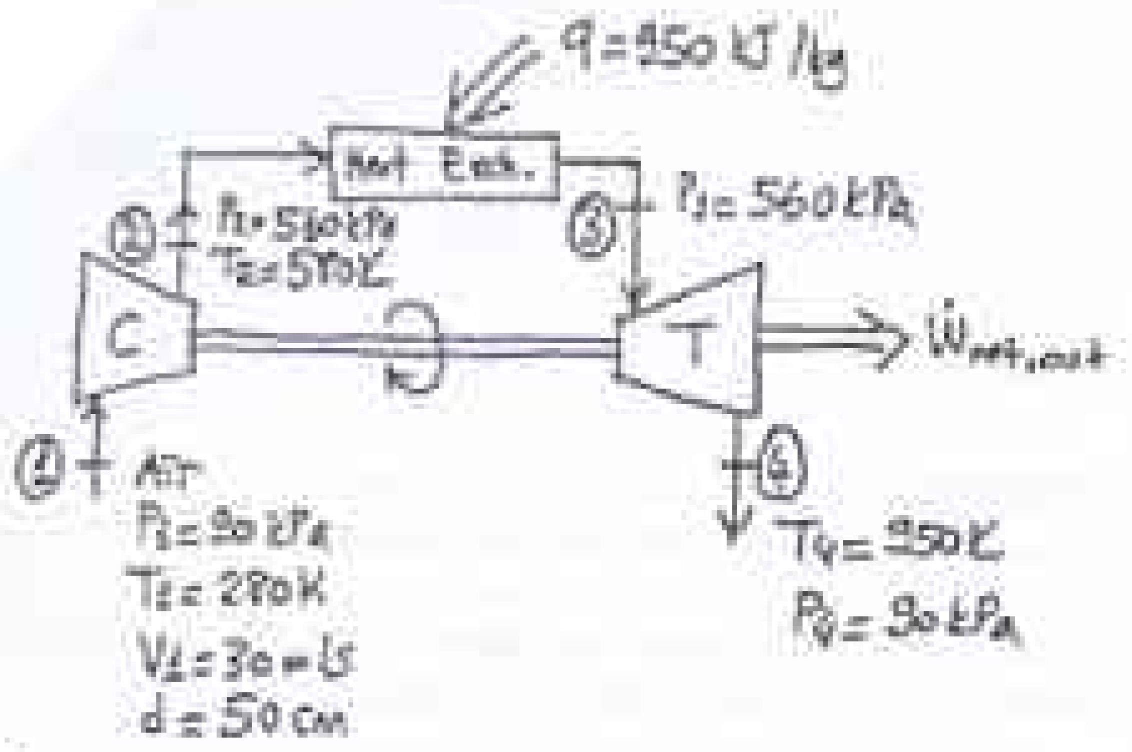
Initially, tank A contains saturated water mixture at 20 MPa, with the liquid volume ½ of the tank volume. Piston is initially 100 mm above the bottom of the cylinder. Initial pressure in the cylinder is 200 kPa. There is a linear spring with a constant of k = 600 kN/m as shown in the figure.

Now the valve is opened slowly. The flow continues until the state in the tank becomes T_{A2} = 200°C, quality x_{A2} = 0.468. Then the valve is closed. During the process there is sufficient heat transfer from the cylinder such that its contents are always in thermal equilibrium with the surroundings at T_{surr} = 20°C. Find:

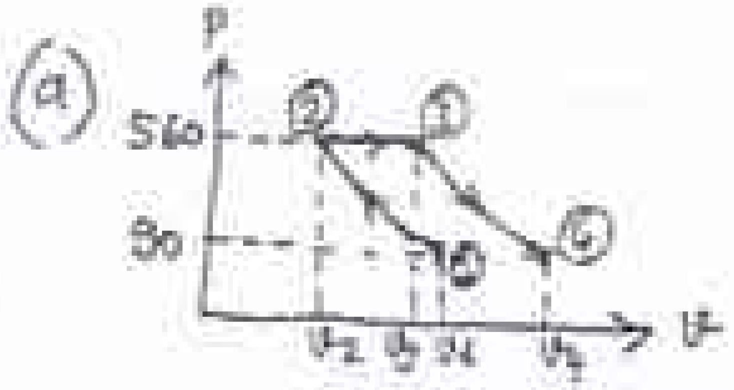
a) the mass loss through the opening during this process,
b) the work done by water during this process,
c) the heat transfer during this process.



Q1)



(a)



(b) C.V. = compressor (SSSF) 1^{st} Law: $\dot{W}_{1,2} = \dot{m}(h_1 - h_2)$

$\dot{m} = \rho_1 A_1 V_1$ $\qquad A_1 = \frac{\pi}{4} d^2 = \frac{\pi}{4}(0.5)^2 = 0.196\ m^2$

$\Rightarrow \dot{m} = (1.12)(0.196)(30)$ $\qquad \rho_1 = \frac{P_1}{R T_1} = \frac{90\ kPa}{(0.287 \frac{kJ}{kg.K})(280K)} = 1.12\ kg/m^3$

$= 6.58\ kg/s$

$T_1 = 280\ K \xrightarrow{\text{Table A.7}} h_1 = 280.13\ kJ/kg$

$T_2 = 580\ K \longrightarrow h_2 = 586.35$ "

$\Rightarrow \dot{W}_{1,2} = (6.58)(280.13 - 586.35) = -2016.3\ kW$

(c) C.V. = Heat exchanger (SSSF) 1^{st} Law: $q = h_3 - h_2$

$\Rightarrow 950 \frac{kJ}{kg} = h_3 - 586.35 \frac{kJ}{kg} \Rightarrow h_3 = 1536.35\ kJ/kg$

$\downarrow A.7$

$T_3 = 1417.5K = T_{max}$

(d) C.V. = Turbine (SSSF) 1^{st} Law: $\dot{W}_{3,4} = \dot{m}(h_3 - h_4)$

$T_4 = 950K \longrightarrow h_4 = 989.436\ kJ/kg.$

$\dot{W}_{3,4} = (6.58)(1536.35 - 989.436) = +3604.2\ kW$

Q2

Initial state 1, Tank A: $P_{A1} = 20000\ kPa$ Saturated Mixture $\qquad V_f = 4m^3$, $V_g = 4m^3$

$m_{f1} = \frac{V_{f1}}{v_{f1}} = \frac{4}{0.002035} = 1965.6\ kg$ $\qquad m_{g1} = \frac{V_{g1}}{v_{g1}} = \frac{4}{0.00583} = 686.1\ kg$

$x_{A1} = \frac{m_{g1}}{m_{f1} + m_{g1}} = 0.2587$ $\qquad u_{A1} = u_f + x_{A1} u_{fg} = 1916.75\ kJ/kg.$

$m_{A1} = m_{f1} + m_{g1} = 2651.7\ kg$

Initial state 1, Cylinder: $P_{B1} = 200\ kPa$, $T_1 = 20°C \Rightarrow$ compressed liquid

$m_{B1} = \frac{V_{B1}}{v_{f@20°C}} = \frac{0.1\ m^3}{0.001002} = 99.8\ kg$ $\qquad u_{B1} = u_{f@20°C} = 83.94\ kJ/kg.$

Final State 2, Tank A: $T_{A2} = 200°C$, $x_{A2} = 0.468 \Rightarrow$ Saturated Mixture

$P_{A2} = 1553.8\ kPa$, $v_{A2} = v_f + x_{A2} v_{fg} = 0.0602 \frac{m^3}{kg}$, $u_{A2} = u_f + x_{A2} u_{fg} = 1462.16 \frac{kJ}{kg}$

$m_{A2} = \frac{8m^3}{0.0602 \frac{m^3}{kg}} = 132.9\ kg$

Final State 2, Cylinder:

slope $= \frac{k}{A_p^2} = 600 \frac{kN}{m^5}$

$P_{B2} = (200\ kPa) + (600 \frac{kN}{m^5})(2-1)m^3$

$\Rightarrow P_{B2} = 800\ kPa$

$\left.\begin{array}{l} P_{B2} = 800\ kPa \\ T_{B2} = 20°C \end{array}\right\}$ compressed liquid $v_{B2} = v_{f@20°C} = 0.001002\ m^3/kg$, $u_{B2} = u_{f@20°C} = 83.94\ kJ/kg.$

$m_{B2} = 2m^3/0.001002 = 1996\ kg.$

(a) Continuity $\Rightarrow m_{A1} + m_{B1} = m_{A2} + m_{B2} + m_{exit} \Rightarrow m_{exit} = 622.6\ kg$

(b) $W_{12} = Area = (200\ kPa)(1-0.1)m^3 + \frac{1}{2}(200+800)(2-1)m^3 = 680\ kJ$

(c) For the Tank + Cylinder Control Volume; process $\rightarrow$ USUF

$Q_{12} - W_{12} - m_e h_e = (m_{A2} u_{A2} + m_{B2} u_{B2}) - (m_{A1} u_{A1} + m_{B1} u_{B1})$

$h_e = h_{f@20°C} = 83.94\ kJ/kg.$

$\Rightarrow Q_{12} - (680) - (622.6)(83.94) = [(132.9)(1462.16) + (1996)(83.94)]$

$- [(2651.7)(1916.8) + (99.8)(83.94)]$

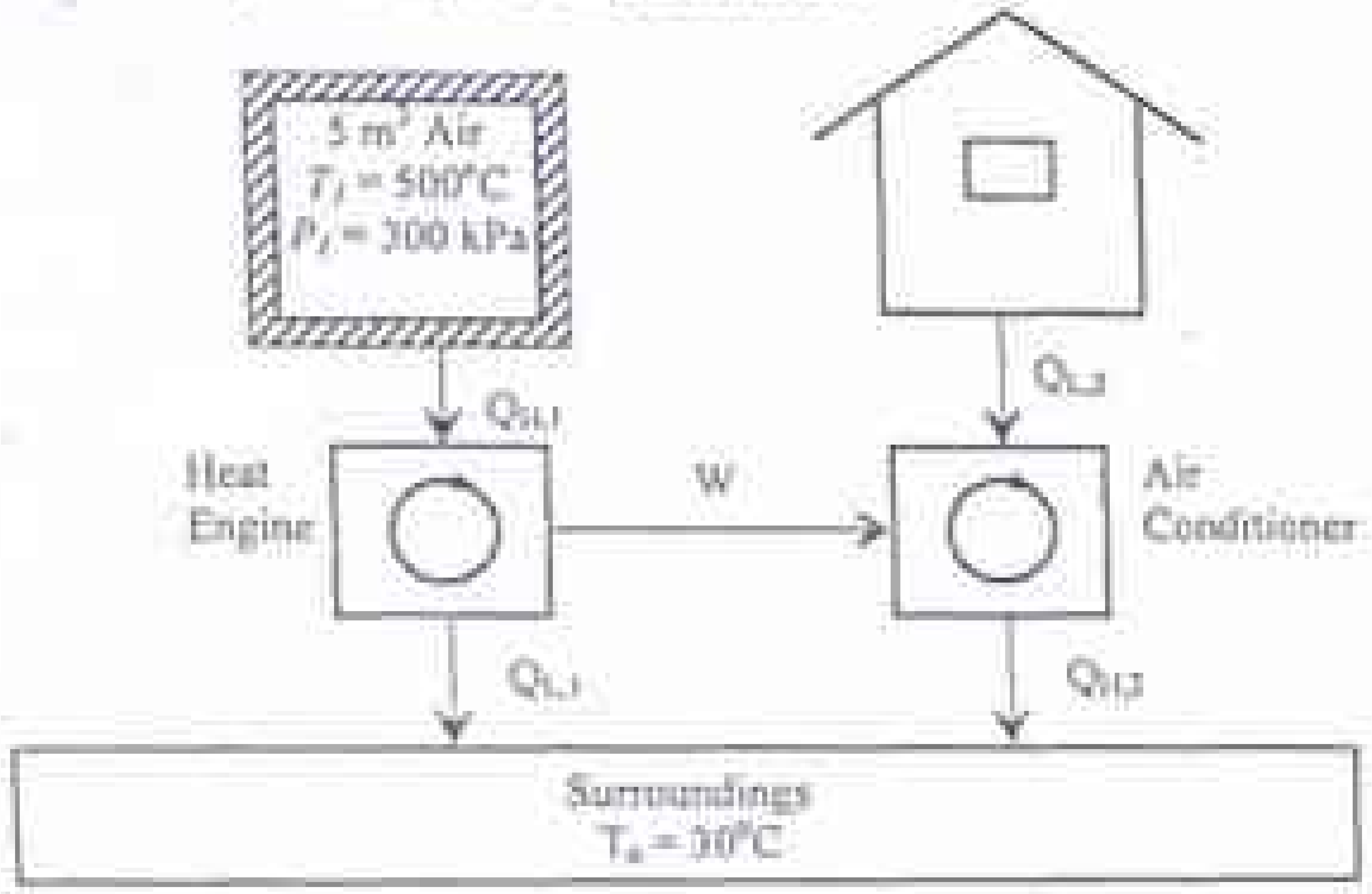
$\Rightarrow Q_{12} = -4\ 649\ 158\ kJ \approx -4650\ MJ$

Middle East Technical University
Department of Mechanical Engineering

ME 203

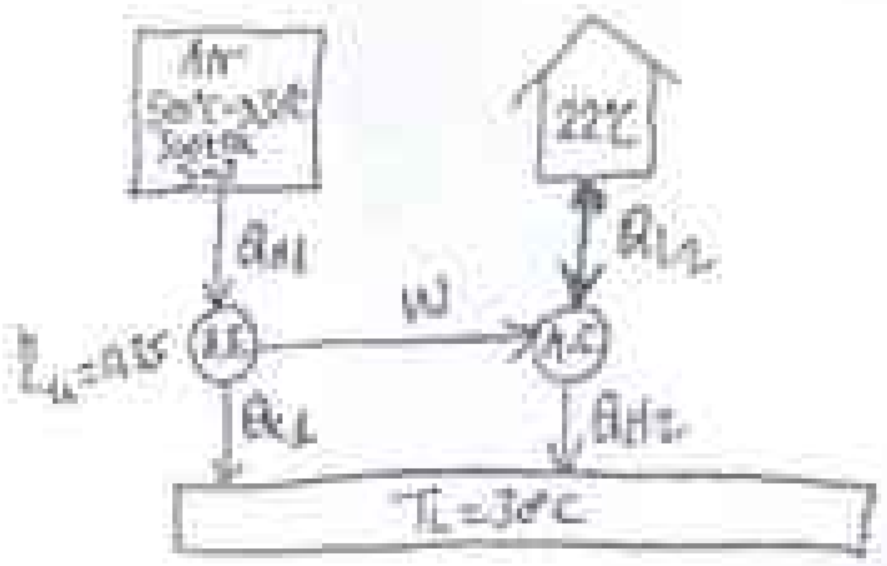
Section 01
HW#3

Q1) A heat engine with a thermal efficiency of 35% employs a rigid insulated tank as its high-temperature reservoir and rejects heat to the surroundings at 30°C. The air in the tank is initially at 500°C, 300 kPa and it is cooled to 30°C. The volume of the tank is 5 m³. The work produced from the heat engine is used to drive an air conditioner. The air conditioner is used to keep the air in a house at 22°C while rejecting energy to the surroundings at 30°C. What is the maximum cooling ($Q_{L,2}$) that can be accomplished by the air conditioner?



Q2) Consider a Carnot heat engine cycle executed in a closed system (piston-cylinder) using 0.103 kg of steam as the working fluid. It is known that the maximum absolute temperature in the cycle is twice the minimum absolute temperature, and the net work output of the cycle is 246.46 kJ. If the steam changes from saturated vapor to saturated liquid during heat rejection, determine the temperature of the steam during the heat rejection process. Also show the cycle on a P-v diagram with respect to saturation lines.

Q1:



$$Q_{H1} = U_2 - U_1 = m C_{v0} (T_2 - T_1) \qquad m = \frac{P_1 V}{R T_1} = \frac{(300)(5)}{(0.287)(773)} = 6.76 \text{ kg}$$

$$\Rightarrow Q_{H1} = (6.76)(0.717)(30-500) = -2278 \text{ kJ}$$

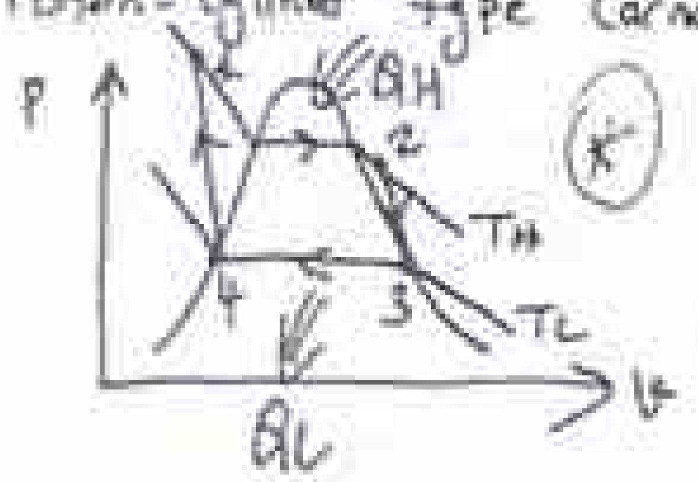
$$W = \eta_{th_{H.E.}} Q_{H1} = (0.35)(2278) = 797.3 \text{ kJ}$$

$$\beta_{Carnot_{A.C}} = \frac{Q_{L2}}{W} = \frac{T_L}{T_H - T_L} \qquad \Rightarrow \beta_{Carnot_{H.E.}} = \frac{295 \text{ K}}{303-295} = 36.875$$

$$\Rightarrow Q_{L2} = \beta_{Carnot_{A.C.}} W = (36.875)(797.3) = 29400 \text{ kJ}$$

Q2)

: Piston-cylinder type Carnot heat engine



(*)

1→2: reversible + isothermal heat addition

2→3: reversible + adiabatic expansion

3→4: reversible + isothermal heat rejection

4→1: reversible + adiabatic compression

$$\eta_{th,carnot} = 1 - \frac{T_L}{T_H} \quad , \quad T_H = 2T_L$$

$$\Rightarrow \eta_{th,carnot} = 1 - \frac{T_L}{2T_L} = 0.5^{(*)} = \frac{W_{net,out}}{Q_H}$$

$$\Rightarrow Q_H = \frac{W_{net,out}}{0.5} = \frac{246.46\,kJ}{0.5} = 492.92\,kJ \ (*)$$

$$Q_L = Q_H - W_{net,out} = 246.46\,kJ \ (*)$$

1st law for 3→4: $Q_{3,4} - W_{3,4} = U_4 - U_3$

$$W_{3,4} = P(V_4 - V_3)$$

$$\Rightarrow Q_{3,4} - P(V_4 - V_3) = U_4 - U_3$$

$$\Rightarrow Q_{3,4} = H_4 - H_3 \Rightarrow q_{3,4} = \frac{Q_{3,4}}{m} = h_4 - h_3$$

$$\Rightarrow q_{3,4} = h_f - h_g = -h_{fg}$$

$$q_{3,4} = \frac{-246.46\,kJ}{0.103\,kg} = -2392.8\,kJ/kg$$

*

$$\Rightarrow h_{fg} = 2392.8\,kJ/kg \Rightarrow T_L \cong 45°C$$

(45.81°C)

* 10kPa