HOMEWORK

David Malawey

ME 221 Applied Thermodynamics
Fall 2010

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D.44 A fuel oil has the following specifications:

$H/C = 1.7$
$MW = 200$ kg/kmol
$LHV_{liquid} = 42.5\times10^3$ kJ/kg
Heat of vaporization = 230 kJ/kg

a) Find the thermodynamically representative formula for the fuel, C_xH_y
b) Find the **stoichiometric** air-to-fuel ratio, A/F_{st}.
c) Find the heat of formation of **liquid** fuel oil (kJ/kmol)
d) Find the heat of formation of **gaseous** fuel oil (kJ/kmol)

$C_x H_y = \boxed{C_{14.6} H_{24.82}}$

$200 = 12(x) + 1(1.7x)$

$C_{14.6} H_{24.82} + a(O_2 + 3.76N_2) = bH_2O + 14.6CO_2 + dN_2$

$O_2: a = \frac{b}{2} + 14.6$ $\quad a = 20.81$

$H: 24.82 = 2b$

$\left(\frac{A}{F}\right)_{st} = \frac{20.81(4.76)(29)}{200} = \boxed{14.36}$

$\bar{h}^\circ_{f\,C_xH_y}$: $LHV = \sum_R n_i \bar{h}_f - \sum_P n_i \bar{h}^\circ_f$

$42.5\times10^3 \frac{kJ}{kg}(200\ kg/kmol) = \bar{h}^\circ_{f\,C_xH_y} - 14.60\,\bar{h}^\circ_{f\,CO_2} - 12.41\,\bar{h}^\circ_{f\,H_2O}$

$8.5\times10^6 \frac{kJ}{kmol} = \bar{h}^\circ_{f\,C_xH_y} - 14.6(-393{,}520) - 12.41(-241{,}820)$

$\boxed{\bar{h}^\circ_{f\,C_xH_y,l} = -246{,}378 \frac{kJ}{kmol}}$

$\bar{h}^\circ_{f\,C_xH_y,g}$: $\bar{h}^\circ_{f,l} = \bar{h}^\circ_{f,g} - \bar{h}_{fg}$

$\bar{h}^\circ_{f,g} = -246378 + 230(200)$

$\boxed{\bar{h}^\circ_{f,g} = -184{,}700}$

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D.45 A constant volume vessel is charged with a stoichiometric mixture of methane and air. The total pressure is 0.1 MPa and the temperature is 298 K before combustion. Combustion then occurs and the products are cooled to 1000 K. Assume complete combustion. Determine the final pressure and the heat released in kJ per kmol of fuel.

$$CH_4 + 2(O_2 + 3.76N_2) \rightarrow CO_2 + 2H_2O + 7.52N_2$$

$$-\cancel{W}^{0}\ \bar{Q} = \sum_P n_i(\bar{h}_f^\circ + \Delta\bar{h} - R_uT)_i - \sum_R n_i(\bar{h}_f^\circ + \Delta\bar{h} - R_uT)_i$$

$$Q = (\bar{h}_f^\circ + \Delta h - R_uT)_{CO_2} + 2(\bar{h}_f^\circ + \Delta\bar{h} - R_uT)_{H_2O}$$

$$+ 7.52(\bar{h}_f + \Delta\bar{h} - R_uT)_{N_2} - (\bar{h}_f + \Delta\bar{h} - R_uT)_{CH_4}$$

$$- 2(\bar{h}_f^\circ + \Delta h - R_uT)_{O_2} - 7.52(\bar{h}_f^\circ + \Delta\bar{h} - R_uT)_{N_2}$$

Prod	$\bar{h}_f^\circ$	$\Delta\bar{h}$ (1000 K)
CO_2	−393,520	42769 − 9364
H_2O	−241820	35882 − 9904
N_2	0	31389 − 8682
R		
CH_4	−74850	0
O_2	×	0
N_2	×	0

$$\bar{Q} = -368429 - 448312 + 108235 + 77328 + 2479 + 18631$$

$$\boxed{\bar{Q} = -6.1 \times 10^5\ \text{kJ/kmol f}}$$

$$P_f = \frac{n_f R_u T_f}{V} \qquad P_i = \frac{n_i R_u T_i}{V} \qquad P_f = P_i\left(\frac{n_f}{n_i}\right)\left(\frac{T_f}{T_i}\right)$$

$$n_f = 1 + 2 + 7.52 = 10.52 \qquad n_i = 1 + 2(4.76) = 10.52$$

$$P_f = 0.1\ \text{MPa}\left(\frac{10.52}{10.52}\right)\left(\frac{1000}{293}\right)$$

$$\boxed{P_f = .336\ \text{MPa}}$$

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D.42 Propane, C_3H_8, and air undergo rich combustion ($\phi>1$) and produce products consisting of **CO_2, CO, H_2O, H_2 and N_2**. Using a **dry gas analysis**, the following product composition is measured:

Product	Volume Percent
CO_2	11.41%
CO	3.355%

For these conditions, find:

a) The **stoichiometric** fuel-to-air ratio, F/A_{st}, for propane (C_3H_8).

b) The **actual** fuel-to-air ratio, F/A_{act}, given the species and product concentrations shown above.

c) The **equivalence ratio.**

d) If 5 kg of fuel are consumed, how much mass of water (kg) is produced in the actual combustion reaction?

a) $C_3H_8 + a(O_2 + 3.76N_2) \rightarrow bCO_2 + cH_2O + dN_2 +$

$C: 3 = b$ $\quad O_2: a = b + \frac{1}{2}c$ $\quad \frac{F}{A}_{st} = \frac{(12(3)+8)}{5(4.76)(29)} = \boxed{.0638}$

$H_2: 4 = c$ $\quad a = 3 + 4/2 = 5$

b) $aC_3H_8 + b(O_2 + 3.76N_2) \rightarrow 11.41\,CO_2 + 3.355\,CO + cH_2 + 3.76b\,N_2 + eH_2O$

$C: 3a = 11.41 + 3.355$ $\qquad a = 4.922$

$H_2: 4a = e + c$ $\qquad e = 19.688 - c$

$O_2: b = 11.41 + \frac{3.355}{2} + \frac{e}{2} =$

dry analysis: $11.41 + 3.355 + e + 3.76b = 100$

$\frac{F}{A}_{act} = \frac{a(44)}{22.9(29)(4.76)} = \boxed{.0701}$

$\phi = \frac{F/A_{act}}{F/A_{st}} = \frac{.0701}{.0638} = \boxed{\phi = 1.10}$

$c = 1.12 \quad e = 18.57$

$b = 22.37$

$\frac{5\,kg}{44\,kg/kmol} = .1136\,kmol \quad \frac{18.57\,kmol\,H_2O}{4.922\,kmol\,C_3H_8} \rightarrow .4544\,kmol\,H_2O\,(18\,kg/kmol) = \boxed{7.715\,kg\,H_2O}$

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BOOK PROBLEM

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D.43 Ethanol (C_2H_6O) is used to fuel an engine. The engine operates slightly rich ($\phi > 1.0$). A **dry** exhaust gas analysis is made with the following mole fraction results:

$y_{CO} = 0.0489$
$y_{CO2} = 0.1177$

Other combustion products include H_20, N_2 and H_2.

a) Find the balanced, stoichiometric reaction **for 1 kmol of ethanol**.
b) Find the balanced, actual reaction **for 1 kmol of ethanol**.
c) Find the fuel to air ratio for the actual reaction
d) Find the equivalence ratio

$\boxed{15.59}$ find Q C_8H_{18} 25°C, $\bar{h}^\circ_f = -208,450$ air,

$C_8H_{18} + a[O_2 + 3.76 N_2] \rightarrow 8 CO_2 + 9 H_2O + a\, 3.76 N_2$ $a = 8 + \frac{9}{2}$ — stoich.

$C_8H_{18} + 25(O_2 + 3.76 N_2) \rightarrow 8 CO_2 + 9 H_2O + 25(3.76) N_2 + 12.5 O_2$ — 100% excess air

$$\bar{Q} - \overset{0}{\cancel{W}} = \Sigma N_p(\bar{h}^\circ_f + \bar{h} - \bar{h}_o)_P - \Sigma N_R(\bar{h}^\circ_f + \bar{h} - \bar{h}^\circ)_R$$

$O_2 < 298 >$

$$= 8(\bar{h}^\circ_f + \bar{h} - \bar{h}_o)_{CO_2} + 9(\bar{h}^\circ_f + \bar{h} - \bar{h}_o)_{H_2O} + 94(\overset{0}{\cancel{\bar{h}^\circ_f}} + \bar{h} - \bar{h}_o)_{N_2} + 12.5(\overset{0}{\cancel{\bar{h}^\circ_f}} + \bar{h} - \bar{h}_o)_{O_2}$$
$$- (\bar{h}^\circ_f + \bar{h} - \bar{h}_o)_{C_8H_{18}} - 25(\overset{0}{\cancel{\bar{h}^\circ_f}} + \bar{h} - \bar{h}_o)_{O_2} - 94(\overset{0}{\cancel{\bar{h}^\circ_f}} - \bar{h} - \bar{h}_o)_{N_2}$$

$$= 8(-393,520 + 19.029 - 9364) + 9(-241820 + 17889 - 9904) + (12.5)(0 + 15,708 - 8682) + (94)(0 + 15,469 - 8669)$$
$$- 1(-208450) - 0 - 0$$

$$\bar{Q} = -4,239,880 \text{ kJ/kmol } C_8H_{18}$$

$$Q = \frac{\bar{Q}}{m_{fuel}} = \frac{(-\ \ )}{114 \text{ kg/kmol}} = \boxed{-37,200 \text{ kJ/kg } C_8H_{18}}$$

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D40 | C_3H_8 equivalence ratio 0.9

a) $C_3H_8 + a(O_2 + 3.76N_2) \rightarrow b\,CO_2 + c\,H_2O + e\,N_2$

C: $3 = b$ $\qquad b = 3$

H: $8 = 2c$ $\qquad c = 4$

O: $2a = 2b + c$ $\qquad$ ~~2a =~~ $a = 5$

N_2: $3.76a = d$ $\qquad d = 18.8$

$$C_3H_8 + 5(O_2 + 3.76N_2) \rightarrow 3CO_2 + 4H_2O + 18.8N_2$$

MW/ $C_3H_8 = 36 + 8$ $\qquad$ Air = 29

$$\frac{F}{A}_{st} = \frac{(36+8)}{5(4.76)(29)} = \boxed{.0638}$$

b) find actual combustion reaction $\qquad \phi = .9 = \dfrac{F/A \text{ actual}}{F/A\ st} = \dfrac{(A/F)\ st}{(A/F) \text{ actual}}$

$0.9 = \dfrac{A\ st}{A \text{ actual}}$ $\qquad A_{act} = \dfrac{A\ st}{0.9}$

$$C_3H_8 + \frac{5}{0.9}(O_2 + 3.76N_2) \rightarrow 3CO_2 + 4H_2O + a\,O_2 + \frac{5}{.9}(3.76)N_2$$

O_2: $\dfrac{5}{.9} = 3 + 2 + a$

$a = .556$

$$\boxed{C_3H_8 + 5.56(O_2 + 3.76N_2) \rightarrow 3CO_2 + 4H_2O + .556O_2 + 20.89N_2}$$

D. 41 Natural gas $C_n H_{3.8n} N_{0.1n}$ MW = 18

dry gas analysis $Y_{O_2} = 0.1$

a) $F/A_{,st}$ $C_n H_{3.8n} N_{0.1n} \Rightarrow 12n + 3.8n + 14(0.1)n = 18$ $n = 1.0465$

$$C_{1.0465} H_{3.977} N_{.105} + a(O_2 + 3.76N_2) \rightarrow 1.0465\ CO_2 + \frac{3.977}{2} H_2O + \left(3.76a + \frac{1}{2}(.105)\right)N_2$$

O_2 bal : $a = 1.0465 + \frac{1}{2}\left(\frac{3.977}{2}\right) = 2.04$

$$\frac{F}{A_{,st}} = \frac{18}{2.04(4.76)(29)} = \boxed{.0639}$$

b) $\frac{F}{A_{,act}}$ $C_{1.0465} H_{3.977} N_{.105} + a(O_2 + 3.76N_2) \rightarrow 1.0465\ CO_2 + 1.988\ A_2O + bO_2$
$+ cN_2$

N_2 : $c = \frac{1}{2}(.105) + 3.76a$

O_2 : $a = 1.0465 + \frac{1}{2}(1.988) + b$ $\Rightarrow A = 2.0405 + b$

$Y_{O_2} = b/(1.0465 + b + 3.76a + \frac{1}{2}(.105)) = 0.1$

$b = 0.1(1.0465 + b + 7.672 + 3.766 + .0525)$

$8.5246 = .8771 \Rightarrow b = 1.674$, $a = 3.714$

$$F/A_{act} = \frac{18}{(3.714)(4.76)(29)} = .0351$$

c) m_{CO_2} for 1 kg Nat-gas $1\text{ kg } C_xH_yN_2 \left(\frac{1\text{ kmol fuel}}{18\text{ kg}}\right)\left(\frac{1.0465\text{ kmol }CO_2}{1\text{ kmol fuel}}\right)\left(\frac{44\text{ kg }CO_2}{1\text{ kmol }CO_2}\right)$

$$\boxed{m_{CO_2} = 2.558\text{ kg}}$$

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15- 20, 25

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(75% extra air)

20) Propane C_3H_8 & air complete combustion. find A/F ratio

$$C_3H_8 + a(O_2 + 3.76N_2) \rightarrow b\,CO_2 + c\,H_2O + d\,N_2$$

balance:

$C: \; 3 = b$

$H_2: \; 4 = c$

$O_2: \; a = b + \frac{1}{2}c \qquad a = 3 + \frac{1}{2}(4) = 5$

$N_2 \; 3.76a = d \qquad d = 1.33$

MW

$C_3H_8 = 36 + 8 = 44$

air $= 29$

~~CO_2 44~~

~~H_2O =~~

$$(A/F)_{stoich} = \frac{29(5)(4.76)}{3(44)} = 15.69$$

$$(A/F)_{actual} = 1.75(15.69) = \boxed{27.46}$$

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25)

	mw	mf	y_i
CH_4	16	.2	.08
C_2H_6O	46	.8	.92
mix	40		

balance

$$.08\,CH_4 + .92\,C_2H_6O + a(O_2 + 3.76N_2) \rightarrow$$
$$b\,CO_2 + c\,H_2O + d\,N_2$$

$C: \; .08 + .92(2) = b \qquad b = 1.92$

$H_2: \; .08(2) + .92(3) = c \qquad c = 2.92$

$O: \; .92 + 2a = 2b + c \qquad a = 2.92$

$$\text{find A/F ratio} = \frac{2.92(4.76)(29)}{(.08 + .92)(40)} = 10.25$$

$\dot{m}_{fuel} = 31$ kg/s

$\dot{m}_{air} = 10.25(31) = 318$ kg/s

$$x\,CH_4 + y\,C_2H_6O + a_s[O_2 + 3.76N_2] \rightarrow B\,CO_2 + D\,H_2O + F\,N_2$$

$C: \quad x + 2y = B$

$H \quad 4x + 6y = 2D$

$O \quad 2a_{th} + y = 2B + D$

$N_2 \quad 3.76a_s = F$

$B = 1.582 \qquad x = .4$

$D = 2.582 \qquad y = .5818$

$F = 9.708 \qquad a_s = 2.582$

$$A/F = \frac{(2.582)(4.76)(29)}{(.4182)(12+4) + (.5818)(24 + 6 + 16)} = 10.64 \frac{\text{kg A}}{\text{kg F}}$$

$$\dot{m}_{air} = AF\,\dot{m}_{fuel} = 10.64(31) = \boxed{330 \text{ kg/s}}$$

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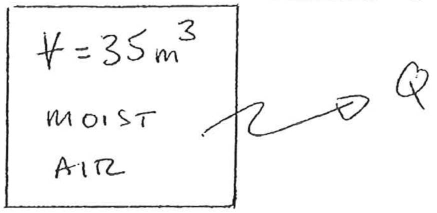
D.39 Air and water vapor are contained in a constant volume vessel with a volume of 35 m^3 at 150 kPa, 120 °C and a relative humidity of 9.548% (state 1). This system is cooled at a constant total volume until the temperature reaches 20 °C. T_2

$PV = mRT$

$Pv = RT$

$v = \frac{RT}{P}$



a) Find the partial pressure of the water vapor at state 1, P_{v1}.

b) Find the temperature at which condensation begins.

c) Find the mass of the vapor at state 1, m_{v1}.

d) Find the mass of the vapor at state 2, m_{v2}. You may assume that any volume taken up by the liquid water at this state is negligible (i.e. the volume of the water vapor-air mixture at state 2 is still 35 m^3)

e) Find the total heat transfer for the system between state 1 and state 2.

a)

$\phi = .09548 = \frac{P_v}{P_g\langle T_1\rangle} \quad P_g\langle T_1\rangle = 198.67 \Rightarrow \boxed{P_{V_1} = 18.97\,kPa}$

b) $T_{DP}: \quad v_{v_1} = v_g \quad v_{v_1} = \frac{R_v T_1}{P_{v_1}} = \frac{.4615(120+273)}{18.97} \quad v_{v_1} = 9.561\ m^3/kg \Rightarrow \boxed{T_{DP} = 55°C}$

c) $m_{v_1} = \frac{P_{v_1} V}{R_v T_1} = \frac{18.97(35)}{.4615(393)} = \boxed{3.661\ kg}$

d) $m_{v_2}: \quad P_{v_2} = P_{sat}\langle 20°C\rangle = 2.339 \quad \frac{P_{v_2} V}{R_v T} = \frac{2.339(35)}{.4615(293)} = \boxed{.6054\ kg}$

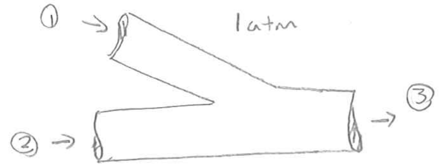
e) $Q = m_{v_2}u_{v_2} + m_{l_2}u_{l_2} - m_{v_1}u_{v_1} + m_a(u_2 - u_1)$

$.6054(2402) + 3.056(83.91) - 3.661(2529) + 40.66(0.718)(-100)$

$m_A = \frac{P_{A_1} V}{R_A T_1} = \frac{(150-18.97)(35)}{.2870(393)} = 40.66\,kg$

$\boxed{Q = -10{,}470\ kJ}$

14.107



① 32°C
$\phi = 40\%$
$\dot{V} = 20 m^3/min$
$h = 62 kJ/kg$
$\omega_1 = .012$
$v_1 = .88 m^3/kg$

② 12°C
$\phi = 90\%$
$\dot{V} = 25 m^3/min$
$h = 32 kJ/kg$
$\omega_2 = .008$
$v_2 = .818$

③
ω_3
ϕ_3
T_3
$\dot{V} = ?$

$$\cancel{\dot{Q}} - \cancel{\dot{W}} = \dot{m}_{a_3} h_{a_3} + \dot{m}_{v_3} h_{v_3} - \dot{m}_{a_1} h_{a_1} - \dot{m}_{v_1} h_{v_1} - \dot{m}_{a_2} h_{a_2} - \dot{m}_{v_2} h_{v_2}$$

$$\dot{m}_{a_3}(h_3 + \omega_3 h_3) - \dot{m}_{a_1}(h_1 - \omega_1 h_1) - \dot{m}_{a_2}(h_2 - \omega_2 h_2)$$

cons. mass: $\dot{m}_{a_3} = \dot{m}_{a_1} + \dot{m}_{a_2}$ $\quad \dot{m}_{v_3} = \dot{m}_{v_2} + \dot{m}_{v_1}$ $\quad \dot{m}_{a_3}\omega_3 = \dot{m}_{a_2}\omega_2 + \dot{m}_{a_1}\omega_1$

$$\omega_3 = \frac{\dot{m}_{a_2}}{\dot{m}_{a_3}}\omega_2 + \frac{\dot{m}_{a_1}}{\dot{m}_{a_3}}\omega_1 \qquad \dot{m}_{a_1} = \frac{\dot{V}_1}{v_1} = \frac{20 m^3/min}{.88 m^3/kg}\left(\frac{1 min}{60 sec}\right) = .3788 kg/s$$

$$\dot{m}_{a_2} = \frac{25}{.818(60)} = .5094 kg/s \qquad \dot{m}_{a_3} = .8882 kg/s \qquad \boxed{\omega_3 = .0097}$$

~~$\phi_3 = \frac{P_{v_3}}{P_s\langle T_3\rangle}$ $\quad P_g\langle T_3\rangle = 2.339$~~ chart.

$$.3788((62)(1 - .012)) + .5094(32)(1 - .008) = .8882(h_3(1 - .0097))$$

$h_3 = 44.76 \frac{kJ}{kg \text{ dry air}}$ $\quad \boxed{T_3 = 20 °C}$

$\boxed{\phi_3 = 65\%}$

$v_3 = .845 m^3/kg$ dry air

$$.845(.8882) = \boxed{.7505 m^3/s} \Rightarrow \boxed{45.03 m^3/min}$$

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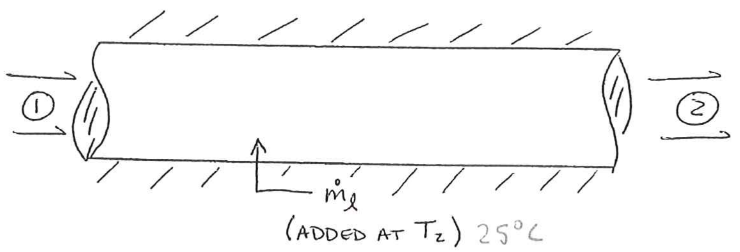
D.37 Hot air at 40 °C with 10% relative humidity passes through an adiabatic evaporative cooler. Water is added as the air passes through a series of wicks and the mixture exits at 25 °C.

$T_1 = 40°C$
$P_1 = 100$ kPa
$\phi_1 = 0.1$



$P_2 = P_1$
$T_2 = 25°C$
$\phi_2 = ?$

a) Find the humidity ratio at state 1, ω_1

b) Find the humidity ratio leaving the evaporative cooler, at state 2, i.e. ω_2

c) Find the relative humidity leaving the evaporative cooler, at state 2, i.e. ϕ_2

d) Find the mass flow rate of the liquid water added relative to the flow of dry air, i.e. $\frac{\dot{m}_\ell}{\dot{m}_{air}}$

a) $\phi = \frac{P_v}{P_g}$ $P_g\langle 40°C\rangle = 7.385 \Rightarrow P_v = .7385$ $\omega_1 = .622\left(\frac{.7385}{100-.7385}\right) = \boxed{.004628}$

b) $\cancel{\dot{Q}} = \dot{m}_A h_{A_2} + \dot{m}_v h_{v_2} - \dot{m}_A h_{A_1} - \dot{m}_{v_1} h_{v_1} - \dot{m}_\ell h_\ell$

$h_{A_2} - h_{A_1} + \omega_2 h_{v_2} - \omega_1 h_{v_1} - \frac{\dot{m}_\ell}{\dot{m}_A} h_\ell$

$0 = h_{A_2} - h_{A_1} + \omega_2 (h_{v_2} - h_\ell) - \omega_1 (h_{v_1} - h_\ell)$

$1.005(25-40) + \omega_2(\qquad) - .004628(2574 - 104.8)$

$\boxed{\omega_2 = .01085}$

$\dot{m}_\ell = \dot{m}_{v_2} - \dot{m}_{v_1}$

$\frac{\dot{m}_\ell}{\dot{m}_A} = \omega_2 - \omega_1$

$h_\ell = 104.8$

$h_{v_1} = 2574$

$h_{v_2} = 2547$

c) $\phi_2 = \frac{P_v}{P_g\langle T_2\rangle}$ $\frac{P_v}{100-P_v} = \frac{\omega}{.622}$ $P_v = (100-P_v)(.01744) \Rightarrow 1.744 = P_v(1.01744)$ $P_v = 1.714$

$P_g\langle 25\rangle = 3.170 \Rightarrow \boxed{\phi = \cancel{23.21\%}}$

Ans:
$\phi = .5047$

d) $\frac{\dot{m}_\ell}{\dot{m}_a} = \omega_2 - \omega_1 = .01085 - .004628 = \boxed{.00622}$

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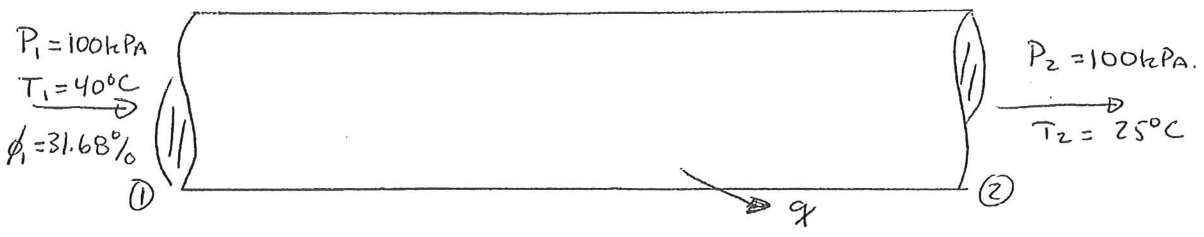
D.38 A flow of moist air at 100 kPa, 40 °C and a relative humidity of 31.68% enters a constant pressure, steady flow device. This moist air is cooled in the device to an exit temperature of 25°C.



a) Find the humidity ratio, ω_1, of the entering flow. (kg vapor per kg dry air)
b) Find the dew point temperature given the inlet conditions. Will water condense?
c) Find the humidity ratio, ω_2, of the exiting flow. (kg vapor per kg dry air)
d) Find the specific heat transfer (kJ/kg dry air) required to cool the flow from the entering conditions to the exiting conditions.

a) $\omega_1 = .622\,\phi\left(\frac{P_v}{P-P_v}\right)$ $P_g\langle 40°C\rangle = 7.385$ $P_A = 100 kPa$ $P_v = \phi P_g = 2.3396$ $\boxed{\omega_1 = .0149}$

b) $T_{DP} = P_{sat} = P_v = \boxed{20°C}$ $\boxed{\text{Will not condense}}$

c) $\omega_2 = \omega_1 = \boxed{.0149}$

d) $\dot{Q} - \cancel{\dot{W}}^{0} = \dot{m}_{a_0} h_{a_2} + \dot{m}_{v_0} h_{v_2} - \dot{m}_{a_i} h_{a_1} - \dot{m}_{v_i} h_{v_i}$

$\frac{\dot{Q}}{\dot{m}_a} = (h_{a_2} - h_{a_1} + \omega(h_{v_2} - h_{v_1}))$

$q = 1.005(25-40) + .0149(1.8723)(25-40)$

$\boxed{q = -15.49 \frac{kJ}{kg}}$ dry air

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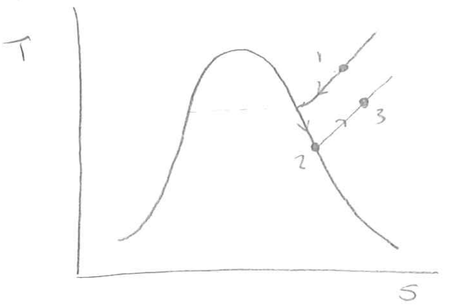
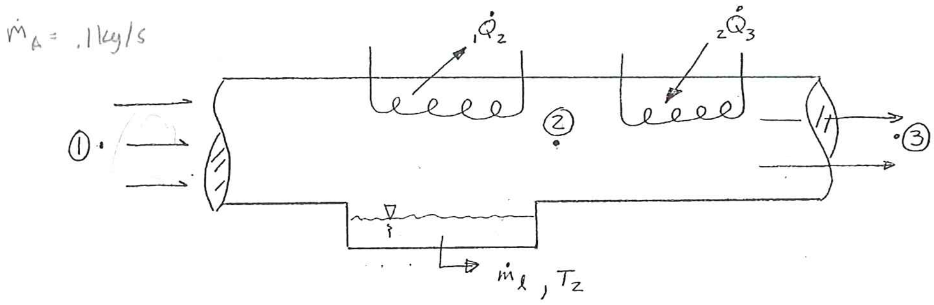


ME 221 Applied Thermodynamics
Fall 2010

D.35 A dehumidifying/heating unit operates at a steady state as shown below. The inlet conditions are 40°C, 100 kPa. The dry air mass flow rate is 0.1 kg/s. The moist air then passes over a cooling coil and some water is condensed. The condensate leaves the unit at T_2 at $\dot{m}_\ell = 0.00288$ kg/s. The moist air then passes through a heating unit, exiting at 20°C, 100 kPa and 37.3% relative humidity.

$T_1 = 40°C$
$P_1 = 100$ kPa
$\phi_1 = ?$



$P_3 = P_1$
$T_3 = 20°C$
$\phi_3 = 37.3\%$

a) Find the humidity ratio at state 3, ω_3
b) Find the temperature of the moist air at state 2 (leaving the dehumidifier and entering the heater).
c) Find the humidity ratio entering the unit, state 1. ω_1
d) Find the relative humidity entering the unit, state 1.
e) Find the rate of heat transfer across the entire unit, ${}_1\dot{Q}_3$ (kJ/s).

a) $\omega_3 = .622 \left(\frac{P_{v_3}}{P-P_{v_3}}\right)$ $\phi = .373 = \frac{P_{v_3}}{P_g\langle T_3\rangle}$ $P_g\langle T_3\rangle = 2.3392$ $P_{v_3} = .8725$

$\boxed{\omega_3 = .00548}$

$\boxed{T_2 = 5°C}$

b) $T_2 = T_{sat}\langle P_{v_2}\rangle = T$ where $P_3 = P_g$

$\dot{Q}_{in} = \dot{m}_{A_2} h_{A_2} + \dot{m}_{v_2} h_{v_2} + \dot{m}_\ell h_\ell - \dot{m}_a h_{a_1} - \dot{m}_{v_1} h_{v_1}$

$\dot{m}_\ell = \dot{m}_{v_1} - \dot{m}_{v_3}$

$\frac{\dot{Q}_{in}}{\dot{m}_a} = h_{A_2} + \omega_2 h_{v_2} + \frac{\dot{m}_\ell}{\dot{m}_a} - h_{a_1} - \omega_1 h_{v_1}$

$\frac{\dot{m}_\ell}{\dot{m}_a} = \omega_1 - \omega_3$

c)

$\omega_1 = \frac{.00288}{.1} + .00548 = \boxed{.03428}$

d) $\phi_1 = \frac{P_{v_1}}{P_g\langle T_1\rangle}$

$\boxed{\phi_1 = 70.72\%}$

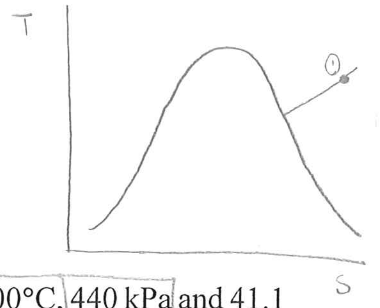
$P_g\langle T_1\rangle = 7.3851$

$.03428 = \frac{P_v}{P-P_v}(.622)$

$(100 - P_v).05511 = P_v$

$P_v = 5.223$

$100(.05511) = 1.05511 P_v$



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D.36 A closed rigid tank having a volume of $\boxed{3 \text{ m}^3}$ initially contains moist air at $\boxed{100°\text{C}}$, $\boxed{440 \text{ kPa}}$ and 41.1 % relative humidity. Neglect the volume of any liquid that might be present in your calculations below.

a) Find the temperature at which condensation begins as the tank is cooled.
b) If the tank is cooled to 80 °C, determine the final tank pressure (kPa). (Assume **no** condensation) $\hookrightarrow 353\text{ K}$
c) If the tank is cooled to 20°C, determine the mass of water condensed out.

a) $\phi = 41.1\%$ Before sat, $P_v = \text{const}$ $\quad .411 = \frac{P_{v_1}}{P_g\langle T_1\rangle} = \frac{P_{v_1}}{101.4 \text{ kPa}} \Rightarrow P_{v_1} = 41.68 \text{ kPa}$

$$\boxed{T_{DP} = 76.75\,°C}$$

b) $P = P_v + P_A = \frac{m_v R_v T}{V_1} + \frac{m_A R_A T}{V_1}$ $\qquad m_v = \frac{P_v V}{R_v T} = \frac{41.68(3\text{m}^3)}{.4615(373\text{K})} = .7264 \text{ kg}$

$= \frac{.7264(.4615)(353\text{K}) + 11.16(.2870)(353)}{3}$ $\qquad m_A = \frac{P_A V}{R_A T} = \frac{(440-41.68)(3)}{.2870(373)} = 11.16 \text{ kg}$

$$\boxed{P\langle 80°C\rangle = 416.3 \text{ kPa}}$$

c) $P_g\langle 20°C\rangle = 2.3392 \text{ kPa}$ $\qquad \phi = 1 \Rightarrow P_v = 2.339$

$$m_v = \frac{P_v V}{R_v T} = \frac{2.339(3)}{.4615(293)} = .05189$$

$$m_v - m_{v_1} = m_l = .7264 - .05189$$

$$\boxed{m_l = .6745 \text{ kg}}$$

D 35 (continued)

$$\frac{\dot{Q}_{in}}{\dot{m}_a} = (h_{A_2} - h_{A_1}) + \frac{\dot{m}_\ell h_\ell}{\dot{m}_a} + \omega_3 h_{v_3} - \omega_1 h_{v_1}$$

$$C_{p_A}(T_2 - T_1) +$$

$$\dot{Q}_{in} = \left[1.005\,(20-40) + \frac{.00288(21.02)}{.1} + .00548\,(2537) - .03428(2574)\right] 0.1$$

$$[-20.1 + .6054 + 13.90 - 88.24]\ 0.1$$

$$\boxed{\dot{Q} = -9.383\ \mathrm{KJ/s}}$$

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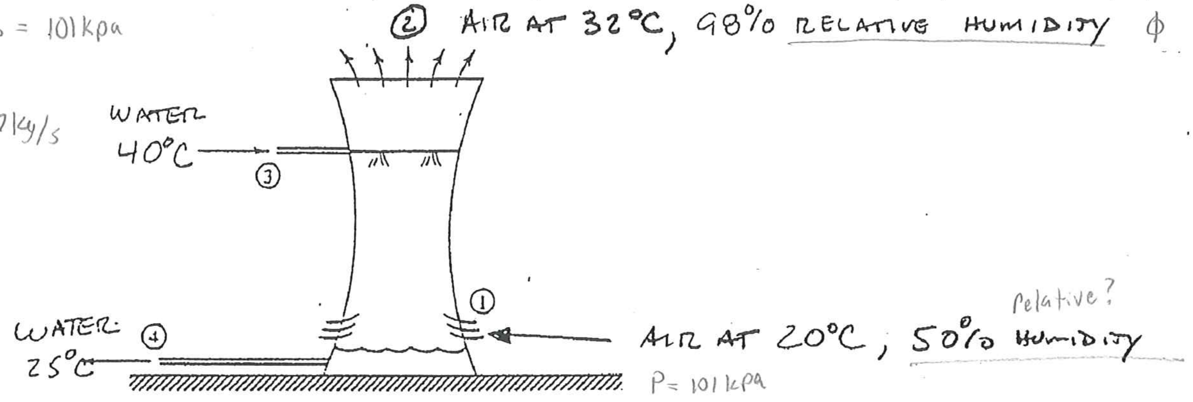
D.34 A "cooling tower" is used to remove heat from the condenser water of a power plant. Water enters at point 3 at 167 kg/s and 40°C and is sprayed in the upward flowing air. Liquid water is collected and leaves the system at point 4 at 25°C. The inlet air conditions at point 1 and outlet air conditions at point 2 are given. You may assume the tower is adiabatic and ambient pressure is 101 kPa. Also, treat the water vapor as an ideal gas.

$P_{amb} = 101 kpa$

$\dot{m} = 167 kg/s$



a) Find the humidity ratio at points 1 and 2 (i.e. ω₁ and ω₂).

b) Find the mass flow rate of dry air through the cooling tower. You may assume constant specific heats for air.

c) Find the mass flow of water that leaves at point 4.

a) $\omega_1 = .622\left(\frac{P_v}{P-P_v}\right)$ $\omega_2 = \phi \frac{.622 P_g}{P_A}$ $\phi = .98,\ P_A = .02(101)$

$P_v = (0.5) P_{sat,}\langle 20°C\rangle = .5(1.17) \Rightarrow \omega_1 = .622\left(\frac{1.17}{101-1.17}\right) = \boxed{0.0073}$

$(.98) P_{sat}\langle 32°C\rangle$ $\omega_2 = .622\left(\frac{4.66}{101-4.66}\right) = \boxed{0.03}$

$\dot{m}_{A_1} = \dot{m}_{A_2} = \dot{m}_a$

b) $\cancel{\dot{Q}}^0 - \cancel{\dot{W}}^0 = \Sigma\dot{m}(h_o - h_{in}) = [\dot{m}_{A_2}h_{A_2} + \dot{m}_{v_2}h_{v_2} + \dot{m}_{l_4}h_4 - \dot{m}_{l_3}h_{l_3} - \dot{m}_{A_1}h_{a_1} - \dot{m}_{v_1}h_{v_1}] \div \dot{m}_A$

$0 = C_{p_A}(T_2 - T_1) + \underbrace{\cancel{\frac{\dot{m}_{v_2}}{\dot{m}_A}}}_{\omega_2} h_{v_2} + \frac{\dot{m}_{l_4}}{\dot{m}_a}h_4 - \frac{\dot{m}_{l_3}}{\dot{m}_a}h_{l_3} - \underbrace{\cancel{\frac{\dot{m}_v}{\dot{m}_a}}}_{\omega_1} h_{v_1}$

$h_{v_2} = h_g\langle T_2\rangle = 2560$

$h_{v_1} = h_g\langle T_1\rangle = 2538$

$h_{l_4} = h_f\langle T_4\rangle = 104.8$

$h_{l_3} = h_f\langle T_3\rangle = 167.5$

$\dot{m}_{l_4} + \dot{m}_{v_2} = \dot{m}_{l_3} + \dot{m}_{v_1}$ $\frac{\dot{m}_{l_4}}{\dot{m}_a} = \frac{\dot{m}_3}{\dot{m}_a} + (\omega_1 - \omega_2)$

$0 = C_{p_A}(T_2 - T_1) + \omega_2 h_{v_2} - \omega_1 h_{v_1} + (\omega_1 - \omega_2)h_{l_4} + \frac{\dot{m}_{l_3}}{\dot{m}_a}(h_{l_4} - h_{l_3})$

$\frac{\dot{m}_{l_3}}{\dot{m}_a} = 1.084$

$\dot{m}_a = \frac{1}{1.084}(167) = \boxed{154.1\ kg/s}$

c) $\dot{m}_{l_4} = \dot{m}_3 + \dot{m}_a(\omega_1 - \omega_2)$

$= 167 + 154.1(.0073 - .03)$

$\boxed{\dot{m}_{l_4} = 163.5\ kg/s}$

14.33

$P = 100\,\text{kPa}$

"T_2" = $T = 22°C$ (dry bulb)

"T_1" = $T_{wb} = 16°C$

$$\omega_1 = \frac{C_p(T_2 - T_1) + \omega_2 h_{fg2}}{h_g \langle T_1 \rangle - h_f \langle T_{2s} \rangle}$$

$$\omega_2 = .622\left(\frac{P_{g2}}{P_2 - P_{g2}}\right) = \frac{(.622)(1.819)}{(100 - 1.819)\ \text{kPa}} = \boxed{.01152}$$

$$\omega_1 = \frac{(1.005)(16-22) + (.01152)(2463)}{(2541 - 67.17)} = \boxed{9.03 \times 10^{-3}}$$

b) $$\phi_1 = \frac{\omega_1 P_1}{(.622 + \omega_1) P_{g1}} = \frac{9.03E{-3}\ (100\,\text{kPa})}{(.622 + .0091)(2.645)} = \boxed{0.541}$$

c) $$P_{v_1} = \phi_1 P_{g_1} = \phi_1 P_{sat}\langle T_2 \rangle = .541(2.645) = \boxed{1.432\ \text{kPa}}$$

$$T_{dp} = T_{sat}\langle P_v \rangle = \boxed{12.3°C}$$

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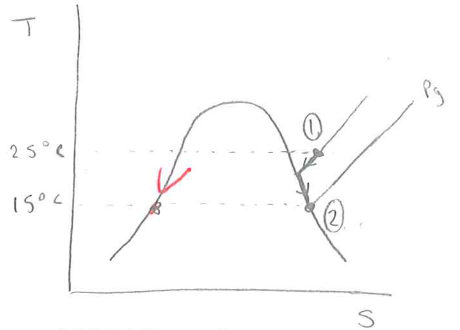

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D.33 The moist air in a 150 m^3 vessel has a temperature of 25°C, pressure of 100 kPa and a relative humidity of 53.8%. Assume water vapor behaves as an ideal gas.

P_v partial pressure of vapor
P_A partial pressure of dry air $= P - P_v$
P_g saturation pressure

a) Find the dew point temperature.
b) Find the humidity ratio.
c) If the temperature is cooled to 10°C at constant pressure, calculate the amount of water condensed.
d) Sketch the process described in c) on a T-S diagram, showing the initial and final states as well as the path.

a) $\phi = \dfrac{\omega P_A}{.622 P_g} = .538$ $\quad P_g = 3.1698$ $\quad P = 100\text{kPa} = P_A + P_v$

$T_{DP} =$ T where $P_v = P_{sat}\langle 25°C\rangle$ $\quad P_v = .538(3.1698) = 1.705$ kPa

$\boxed{T_{DP} = 15°C}$

b) $\omega = 0.622 \dfrac{P_v}{P_A} = .622\left(\dfrac{1.705}{100-1.705}\right) = \boxed{.01079 = \omega_1}$

c) $\phi_2 = 100\%$ $\quad 10°C < T_{DP}$ $\quad P_{v_2} = P_g\langle T_2\rangle = 1.2281$ kPa

$\omega_2 = .622 \dfrac{P_{v_2}}{P_A} = .622\left(\dfrac{1.228}{100-1.228}\right) = \boxed{.00773 = \omega_2}$

$m_l = m_a(\omega_1 - \omega_2)$ $\quad m_a = \dfrac{P_A V_1}{R_A T_1} = \dfrac{(100-1.705)(150)}{(.287)(298)} = 172.4$ kg

$\Rightarrow m_l = 172.4(.01079 - .00773)$

$\boxed{m_l = .5275 \text{ kg}}$

T Dupont?

$\boxed{14.28}$ air 25°C $\phi = .65$ Windows drop to 10°C

$P_g = 3.1698$ $\quad .65 = \left.\frac{P_v}{P_g}\right|_{T,P}$ $\Rightarrow P_v = 2.060$ kPa

$T_{DP} = T_{\text{where}}\ P_g = 2.060$ kPa

$17.5° < T_{DP} < 21.1°C$ Yes, moisture will condense

$10° < T_{DP}$

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② $600°C = 873K$
$1\ kg\ H_2O$
$1.2\ kg$ air

D.32 A tank has two sides initially separated by a diaphragm. Side A contains 1 kg of water and side B contains 1.2 kg of air, both initially at 20°C, 100 kPa. The diaphragm is broken and the entire tank is heated to 600°C by the ambient which is at 700°C (i.e. the heat transfer comes from a source at a constant 700°C). You may assume that air is an ideal gas with constant specific heats evaluated at 300K. However, use the steam tables for water.

a) Determine the volume of the entire tank.
b) Find the final total pressure (hint: this is the sum of the partial pressures)
c) Find the heat transfer into the tank.
d) Find the total entropy generation.

a) $V_{H_2O} = .001002\,(1\,kg) = .001\,m^3$ $\quad V_{air,1} = \frac{m R_{air} T_1}{P_1} = \frac{.2870(1.2)(293)}{100} = 1.010\,m^3$

$V_{total} \approx 1.01\,m^3$

b) $P_{total} = \Sigma P_i$ $\quad \frac{m_i R_i T}{V} =$ (Air) $\frac{1.2\,(.2870)(873)}{1.01\,m^3} = 297.7\,kPa$

(water) $\frac{(1)(.4615)(873)}{(1.01)} = 398.9\,kPa$

$\boxed{P_2 = 696.6\,kPa}$

c) $Q - \overset{0}{\cancel{W}} = U_2 - U_1 = \Sigma m_i c_{p_i} (\Delta T) =$

air, $1.2\,kg\,(.717)(600 - 20°C) = 499.0\,kJ$
h_2o, $\Delta u = 1\,kg\,(3299 - 83.91) = 3215\,kJ$

$\boxed{Q_{in} = 3715}\ kJ$

d) $S_2 - S_1 = \int \frac{dQ}{T} + S_{Gen}$ $\quad \frac{Q}{T} = \frac{3715}{(700+273)} = 3.818\,\frac{kJ}{\cdot K}$ ✓

$(S_2 - S_1)_{air} = c_p \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{P_2}{P_1}\right) = 1.005 \ln\left(\frac{873}{293}\right) - .2870 \ln\left(\frac{297.7}{100}\right) = .783\,\frac{kJ}{kg \cdot K}\,(1.2\,kg)$

$(S_2 - S_1)_{h_2o} =$ $S_2 = 8.458$, $S_1 = .2965$ $\quad (\Delta S, h_2o) = 8.162\,\frac{kJ}{kg \cdot K}\,(1\,kg)$

$(S_2 - S_1)_{total} = 9.102\,\frac{kJ}{K} - 3.818$

$S_{Gen} = (S_2 - S_1) - \frac{Q}{T} = \boxed{5.284\,\frac{kJ}{K}}$

Text p $\underline{14.41}$

$\underline{m_A, m_v\,?}$ $\quad V = 240\,m^3 \quad P = 98\,kPa \quad T = 23°C \quad \phi = 50\% = \frac{P_v}{P_g} = \frac{\omega P_A}{.622 P_g}$

$P_g = P_{sat}(23°C) = 2.811\,kPa$

$P_v = .5 P_g = 1.41\,kPa$

$P_a = P - P_v = 98 - 1.41 = 96.59$

$$m_A = \frac{P_A V}{R_A T} = \frac{(96.59)(240)}{(.287)(296)} = \boxed{272.9\,kg}$$

$$m_v = \frac{P_v V}{R_v T} = \frac{1.41\,kPa\,(240)}{.4615\,(296)} = \boxed{2.47\,kg}$$

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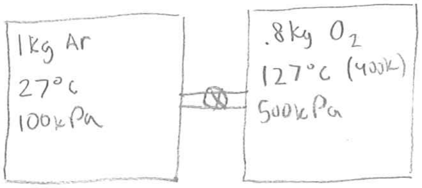

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D.30 One kg of argon at 27°C, 100 kPa, is contained in a rigid tank connected by a valve to another rigid tank containing 0.8 kg of O_2 at 127°C, 500 kPa. The valve is opened and the gasses are allowed to mix, reaching equilibrium at 77°C. Given MW_{AR} = 40 kg/kmol and MW_{O2} = 32 kg/kmol, determine:

- a) The volume of each tank (m^3)
- b) The final pressure (kPa)
- c) The heat transfer to or from the system during the process (kJ). Assume constant specific heats.
- d) The entropy change of the argon (kJ/K)

a) $PV = nRT \quad V_{Ar} = \frac{8.314(300)}{100\,kPa}\left(\frac{1kg}{40\,kg/kmol}\right) = \boxed{.6236\ m^3}$

$V_{O_2} = \frac{8.314(400K)}{500\,kPa}\left(\frac{.8}{32}\right) = \boxed{.1663\ m^3} \qquad V_{total} = \underline{.7899}$

b) $P\forall = mR_{mix}T \qquad R_{mix} = \sum_i m_{fi}R_i = \frac{1}{1.8}(.2081) + \frac{.8}{1.8}(.2598) = \underline{.2311}$

$P_{mix} = \frac{1.8kg(.2311\ \frac{kJ}{kg \cdot K})(77+273)K}{.7899\ m^3} = \boxed{184.3\ kPa}$

c) $Q - \cancel{W}^{0} = U_2 - U_1 = mc_v(T_2 - T_1) = 1kg(.3122)(77-27) + .8kg(.658)(77-127)$

$\boxed{Q = -10.71\ kJ}$

d) $S_2 - S_1 = C_p \ln\left(\frac{T_2}{T_1}\right) - R\ln\left(\frac{P_2}{P_1}\right) =$ where $P_{2,Ar} = \left[\frac{1}{40kg/kmol} \Big/ \left(\frac{1}{40} + \frac{.8}{32}\right)\right] P_2$

$= .5203\ln\left(\frac{350}{300}\right) - .2081\ln\left(\frac{184(.5)}{100}\right)$

$\boxed{\Delta S_{,Ar} = .0976\ \frac{kJ}{\cancel{kg} \cdot K}} * (1\cancel{kg})$

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D.31 An insulated rigid tank is divided into two compartments by a partition. One compartment contains 7 kg of oxygen (0_2) gas at 40°C and 100 kPa and the other compartment contains 4 kg of nitrogen (N_2) gas at 20°C and 150 kPa. The partition is removed and the gases are allowed to mix. Assume ideal gas behavior and constant specific heats.

$R_{O_2} = .2598$ $C_{P O_2} = .918$

$R_{N_2} = .2968$ $C_{P N_2} = 1.039$

a) Determine the final mixture temperature (K)
b) Find the total volume of the tank (m^3)
c) Find the final system pressure (kPa)
d) Find the entropy generated in the process (kJ/K)

a)

$$Q - W = \Delta U = m_{O_2} C_{v_{O_2}} (T_2 - T_1) + m_{N_2} C_{v_{N_2}} (T_2 - T_1)$$

$$7kg(.658)(T_2 - 313) + 4kg(.743)(T_2 - 293) = 0 \Rightarrow 7.578\, T_2 - 2313 = 0$$

$$\boxed{T_2 = 305.2\,K}$$

b)

$$V_{O_2} = \frac{m R_{O_2} T}{P} = \frac{7kg(.2598)(40+273)}{100} = 5.692\,m^3$$

$$V_{N_2} = \frac{4kg(.2968)(293)}{150} = 2.319\,m^3$$

$$\boxed{V_{total} = 8.011\,m^3}$$

c)

$$P_2 = \frac{m R_{mix} T}{V} \qquad R_{mix} = \Sigma mf_i R_i = \frac{7(.2598) + 4(.2968)}{7+4} = .2733$$

$$= \frac{11(.2733)(305.2)}{8.011} \Rightarrow \boxed{P_2 = 114.5\,kPa}$$

d)

$$(S_2 - S_1)_{O_2} = c_p \ln\left(\frac{T_2}{T_1}\right) - R \ln\left(\frac{P_2}{P_1}\right) = .918 \ln\left(\frac{305.2}{313}\right) - .2598 \ln\left(\frac{69.3}{100}\right) = (.07211)(7kg)$$

$$(S_2 - S_1)_{N_2} = 1.039 \ln\left(\frac{305.2}{298}\right) - .2968 \ln\left(\frac{45.3}{150}\right) = (.3982)(4kg)$$

$$(S_2 - S_1) = \longrightarrow .5048 + 1.593 = 2.098$$

$$\frac{{}_1Q_3}{T_0} = \frac{0}{T_0} \Rightarrow S_2 - S_1 = \boxed{S_{Gen} = 2.098\,\frac{kJ}{K}}$$

$$P_{2,N_2} = \left(\frac{.143}{.219 + .143}\right)(114.6) = 69.3$$

$$P_{2,O_2} = \left(\frac{.219}{.219 + .143}\right)(114.6) = 45.3$$

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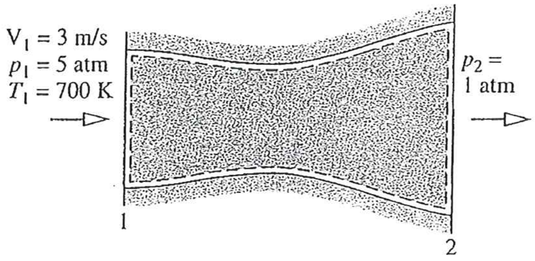
D.29 A gas mixture consisting of CO_2 (mole fraction, $y_{CO2} = 0.8$) and O_2 (mole fraction, $y_{O2} = 0.2$) enters a test section and expands isentropically. The inlet conditions, state 1, have $P_1 = 500$ kPa (5 atm), $T_1 = 700$K and $V_1 = 3$ m/s. At the exit, state 2, the pressure is 100 kPa (1 atm). Assume constant specific heats evaluated at 300 K.



a) Find the mass fraction of each gas
b) Find the final temperature (T_2)
c) Find the exit velocity, V_2 (m/s).

$$MW_{mix} = (.8)(44.01) + (.2)(32.0) = 41.61$$

$$mf_i = \frac{y_i MW_i}{MW_{mix}} = \frac{.8(44.01)}{41.61} = \boxed{\begin{matrix} MW_{CO_2} \\ .846 \end{matrix}} \qquad MW_{O_2} = \frac{.2(32.0)}{41.61} = \boxed{.153}$$

$$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} \qquad k = \frac{c_p}{c_v} \qquad c_{p_{mix}} = \Sigma mf_i c_{pi} = 0.846(.846) + (.153)(.918) = .8561$$

$$c_{v_{mix}} = \Sigma mf_i c_{vi} = .846(.657) + (.153)(.658) = .6565$$

$$k = 1.304$$

$$T_2 = 700\left(\frac{1}{5}\right)^{\frac{.304}{1.304}} = \boxed{481.0 \text{ K}}$$

$$\Delta E = 0 \qquad \left(h_1 + \frac{V_1^2}{2}\right) = \left(h_2 + \frac{V_2^2}{2}\right) \Rightarrow V_2 = \sqrt{2\left[h_1 - h_2 + \frac{V_1^2}{2}\right]}$$

$$h_1 - h_2 = C_p(T_1 - T_2) = .8561(700 - 481) = 187.5 \frac{kJ}{kg}$$

$$\frac{V_1^2}{2} = \frac{(3 m/s)^2}{2} \frac{1 kJ/kg}{1000 (m/s)^2} = .0045 \text{ kJ/kg}$$

$$V_2 = \sqrt{2(187.5 + .0045)\frac{kJ}{kg}\left(\frac{1000 \, m^2/s^2}{kJ/kg}\right)}$$

$$\boxed{V_2 = 612.4 \text{ m/s}}$$

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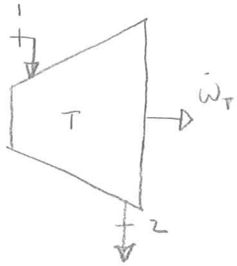
like D 23

D.28 A mixture of 60% helium and 40% nitrogen, by volume, enters a turbine at 1MPa, and 800K. The mass flow rate of the mixture is 2 kg/s. The adiabatic turbine has an exit pressure of 100 kPa. Assume the turbine has an isentropic efficiency of 85%. Find the actual turbine power (kW) and the actual exit temperature (K). Assume constant specific heats.



$\eta_T = .85$

$\cancel{Q_T}^{0} - W_T = \dot{m}(h_2 - h_1) = \dot{m} C_{p,mix}(T_2 - T_1)$

$\dot{W}_T = \dot{m} C_{pmix}(T_1 - T_2)$ $T_{2s} = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$

$\overline{C_{pmix}} = \sum_i y_i = (0.6)(5.193)(4) + 4(1.039)(28) = \boxed{24.1 \text{ kJ/kmol K}}$

$k = \frac{\overline{C_p}}{\overline{C_v}}$ $\bar{C_p} - \bar{C_v} = R_u$ $\frac{\bar{C_p}}{\bar{C_p} - R_u} = k = \frac{24.1}{24.1 - 8.314} = 1.527$ ✓

$mw_{mix} = \sum_i y_i mw_i = (0.6)(4)\ (0.4)(28) = 13.6 \text{ kg/kmol}$

$C_{pmix} = \frac{24.1 \text{ kJ/kmol K}}{13.6 \text{ kg/kmol}} = 1.772 \text{ kJ/kg K}$

$T_{2s} = 800\left(\frac{100}{1000}\right)^{\frac{.527}{1.527}} = 361.4 \text{ K}$

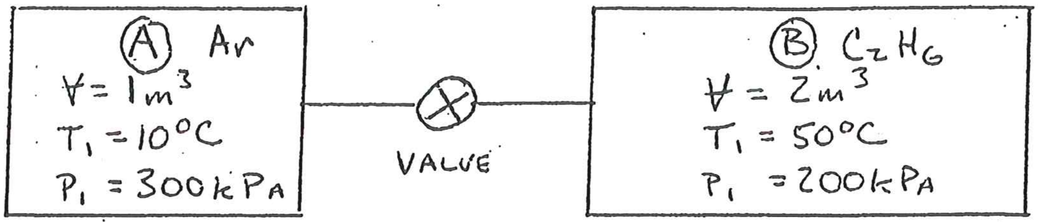
$\dot{W}_{Ts} = 2 \frac{kg}{s}\left(1.772 \frac{kJ}{kg\,K}\right)(800 - 361.4) = 1554 \text{ kW}$

$\dot{W}_{TA} = (.85) W_{Ts} = \boxed{1321 \text{ kW}}$

$\dot{m} C_{pmix}(T_1 - T_{2A}) = 2 \text{ kg/s}\left(1.772 \frac{kJ}{kg\,K}\right)(800 - T_{2A})$ $\boxed{T_{2A} = 427 \text{K}}$

ME 221 Applied Thermodynamics
Fall 2010

D.27 Two insulated tanks A and B are connected by a valve as shown in the sketch below. Tank A has a volume of 1 m^3 and initially contains argon (Ar) at 300 kPa and 10 °C. Tank B has a volume of 2 m^3 and initially contains ethane (C_2H_6) at 200 kPa and 50 °C. The valve is opened and remains open until the resulting gas mixture comes to a uniform state. Assume constant specific heats.



a) Find the final temperature of the gas mixture.
b) Find the final tank pressure.

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a) $0 = U_2 - U_1 = m_{AR}(u_{Ar_2} - u_{Ar_1}) + m_{C_2H_6}(u_{C_2H_6,2} - u_{C_2H_6,1})$

$= m_{''}\, c_{v\,''}(T_{..} - T_{..}) + m_{''}\, c_{v\,''}(T_{''} - T_{''})$

$m_{Ar} = \dfrac{P_{Ar,1} V_{Ar}}{R_{Ar} T_{Ar}} = \dfrac{300(1)}{(.2081)(283)} = 5.094 \text{ kg}$

$m_{C_2H_6} = \dfrac{P_1 V}{R T_1}, C_2H_6 = \dfrac{(200)(2)}{(.2765)(323)} = 4{,}479 \text{ kg}$

$0 = \overset{kg}{(5.094)}(.3122 \tfrac{kJ}{kg\,k})(T_2 - 283k) + (4.479)(1.490)(T_2 - 323k)$

$\Rightarrow \boxed{T_2 = 315.3 \text{ k}}$

b) $P_2 = \dfrac{m_{tot} R_{tot} T_2}{V_2}$ $V_2 = 3m^3$ $R_{tot} = \Sigma mf_i R_i = \left(\dfrac{5.094}{9.573}\right)(.2081) + \dfrac{4.479}{9.575}(.2765)$

$m_{tot} = 5.094 + 4.479 = 9.573 \text{ kg}$

$P_2 = \dfrac{(9.573)(.240)(315.3)}{3m^3} = \boxed{241.6 \text{ kPa}}$

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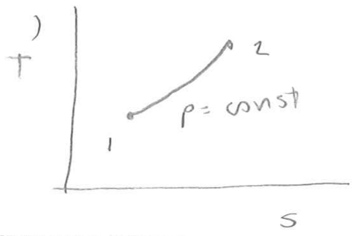
$R_{mix} = \sum_i mf_i R_i = (.3077)(\quad) + .4231(\quad) + .2692(\quad)$

$= .3193$

10



ME 221 Applied Thermodynamics
Fall 2010

D.26 A mixture of ideal gases in a container consists of 50% CH_4, 25% CO_2 and 25% N_2 by volume. The gas mixture has a total mass of 12 kg and is initially at 293 K. The fixed mass mixture is then heated, **at constant pressure**, to 673 K. For this problem assume constant specific heats.

a) Find the molecular weight of the mixture.
b) Find the mass fraction of each species.
c) Find C_p for the mixture (kJ/kgK)
d) Find C_v for the mixture (kJ/kgK)
e) Find the total heat transfer, Q, required to heat the mixture from 293 K to 673 K at constant pressure for the mixture. (kJ)
f) Find the total work, W, during this heating process. (kJ)

$\frac{M_i}{M_{total}} = \frac{Y_i MW_i}{MW_{total}}$

a) $MW = \sum_i y_i MW_i = (.5)(16.043) + (.25)(44.01) + (.25)(28.013)$

$MW = \boxed{26.03 \frac{kg}{kmol}}$ total mols $n = \frac{12 kg}{26.03\ kg/kmol} = .4610\ kmol$

b) $m_{fi} = \frac{M_i}{M_{total}} = \frac{(.5)(16.043)}{26.03} = \boxed{.3079 = mf_{CH_4}}$ $\quad m_{f\,CO_2} = \frac{(.25)(44)}{26} = \boxed{.4231}$

$m_{f\,N_2} = \frac{(.25)(28)}{(26)} = \boxed{.2692}$

c) $C_{p\,mix} = \sum_i m_{fi} C_{pi} = .3077(2.2537 \frac{kJ}{kg}) + .4231(.846 \frac{kJ}{kg}) + .2692(1.039)$

$\boxed{C_{p,mix} = 1.331\ kJ/kg}$

d) $\sum_i m_{fi} C_{vi} = \underbrace{.3077}(1.7354) + .4231(.657) + .2692(.743)$

$\boxed{C_{v,mix} = 1.0123}$

e) ${}_1Q_2 = u_2 - u_1 + {}_1W_2 = h_2 - h_1 = C_p(T_2 - T_1) = 1.331(673 - 293) = 505.8(12 kg) = \boxed{6070 kJ}$

${}_1W_2 = {}_1Q_2 - (u_2 - u_1) \Rightarrow C_v(T_2 - T_1) = .9621(673 - 293) = 365.6$

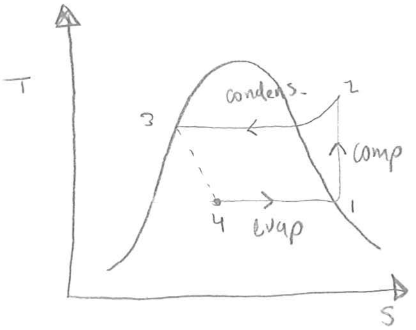
$W = \underline{140.2} \frac{kJ}{kg}(12 kg) = \boxed{1456 kJ}$

David Malawey Thermo HW 10-14-10

10

11.16, 11.19

11.16) 134a ideal refrigeration cycle .12-.7MPa $\dot m = .05\,kg/s$



① sat vapor
P= .12 MPa
T= -22.32°C
S= .9478
h= 236.97

② SHV
P= .7MPa
S=.9478
h=273.7

③ sat liq
P= .7MPa
h= 88.82

④
P= .12MPa
h= 88.82

$$h_2 = \begin{array}{cc} 268.5 & .9313 \\ \bigcirc & .9478 \\ 278.6 & .7641 \end{array} \quad h_2 = 273.7$$

a) $\dot q_L$ & $P_{compressor}$

b) $\dot q_H$ & COP

$${}_1\cancel{q}_2^{\,0} - {}_1w_2 = h_2 - h_1 \qquad {}_1w_2 = h_1 - h_2 = 236.97 - 273.7$$

$${}_1\dot w_2 = \dot m(h_1 - h_2) = \boxed{\cancel{-}1.837\text{ kW}}$$ means work into system

$\boxed{\dot W_c}$

$${}_2q_3 - \cancel{{}_2w_3}^{\,0} = h_3 - h_2 = 88.82 - 273.7 =$$

$$\dot q_L = {}_4\dot q_1 = \dot m(h_1 - h_4) = .05(237.0 - 88.82) = \boxed{7.409\text{ kW}}\,\boxed{\dot Q_L}$$

$$\dot q_H = {}_2\dot q_3 = \dot m(h_3 - h_2) = .05(88.82 - 273.7) = \boxed{\cancel{-}7.44\text{ kW}}$$ heat out of system

$\boxed{\dot Q_H}$

$$COP = \frac{\dot Q_L}{\dot W_{in}} = \frac{7.409}{1.837} = \boxed{4.033}$$

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10

ME 221 Applied Thermodynamics
Fall 2010

Due MON 10-25

D.25 A 100 m^3 storage tank contains fuel gases at 20 °C and a total pressure of 100 kPa. The gases consist of methane (CH_4), propane (C_3H_8), and butane (C_4H_{10}). A test shows that the partial pressure of the methane is 15 kPa and that of the propane is 65 kPa.

a) Find the mole fraction for each of the three species.
b) Find the mass of each of the three species in the tank.
c) Find the mass fraction of each of the three species.
d) Find C_p for the mixture. (kJ/kgK)

a) $P_i = y_i P_T$ $\quad y_i = \frac{P_i}{P_T}$ $\quad P_{C_4H_{10}} = 100 - 15 - 65 = 20\,kPa$

$$\boxed{y_{CH_4} = .15 \quad y_{C_3H_8} = .65 \quad y_{C_4H_{10}} = .20}$$

b) $M_i = n_i (MW_i)$ $\quad n_i = y_i n_{Total}$ $\quad n_{tot} = \frac{PV}{R_u T} = \frac{100kPa(100m^3)}{(8.314)\frac{kJ}{kmol}(293K)} = 4.105\,kmol$

$M_{CH_4} = .15(4.105)(16\,kg/kmol) = \boxed{9.852\,kg}$
(kmol)

$M_{C_3H_8} = .65(4.105)(44) = \boxed{117.4\,kg}$

$M_{C_4H_{10}} = \boxed{47.6\,kg}$

c) $M_{f_i} = M_i / M_{total}$ $\Rightarrow$

$M_{f\,CH_4} = \boxed{.0563}$

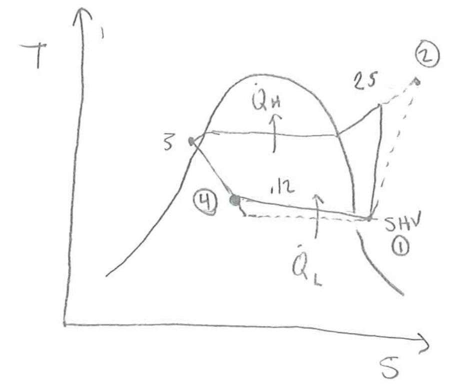
$M_{f\,C_3H_4} = \boxed{.671}$

$M_{f\,C_4H_{10}} = \boxed{.272}$

d) $C_p = \Sigma M_{f_i} C_{p_i} = .0563(2.2537) + .671(1.6794) + .272(1.7164)$

$= \boxed{1.721\,kJ/kg\cdot K}$

11.19 134a



① SHV
P = .14 MPa
T = -10°C
h = 246.4
s = .9724

②
P = .7 MPa
T = 50°C
h = 288.5

③
T = 24°C
P = .65 MPa
h = 85.26

④
P = .15 MPa
h = 85.26

$\dot{m} = .12\,\text{kg/s}$

a) $\dot{q}_L = ?$ $\dot{W}_{comp}$

b) $\eta_{isen,c} = ?$

c) COP = ?

a) $\dot{q}_L = \dot{m}_4 q_1 = .12(246.4 - 85.26) = \boxed{19.34\,\text{kW}}$

$\dot{W}_{comp} = \dot{m}(h_1 - h_2) = (246.4 - 288.5).12 = \boxed{5.052\,\text{kW}}$ work in

b) h_{2s}: $S_{2s} = S_1 = .9724$ h = (interpolate) 281.2 kJ/kg

$$\eta_{isen} = \frac{281.2 - 246.4}{288.5 - 246.4} \quad \boxed{82.66\,\%}$$

c) $$COP = \frac{q_L}{W_{in}} = \frac{19.34}{5.052} \quad \boxed{COP = 3.828}$$

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10

& 13.33

ME 221 Applied Thermodynamics
Fall 2010

D.24 A gas mixture contains 5 kg of O2, 8 kg of N2 and 10 kg of CO2. Find (*a*) the mass fraction of each component, (*b*) the mole fraction of each component, and (*c*) the average molar mass and gas constant of the mixture.

a) $\boxed{m_{f,O_2} = .2174 \quad m_{f,N_2} = .3478 \quad m_{f,CO_2} = .4348}$

$y_{O_2} = \frac{n_{O_2}}{n}$

O_2: 32.00 kg/kmol — 5kg/32 = .1563 kmol — n_{total} = .6691 kmol

N_2: 28.01 kg/kmol — 8kg/28.01 = .2856 kmol

CO_2: 44.01 kg/kmol — 10/44.01 = .2272 kmol

b) $y_{O_2} = .1563/.6691$

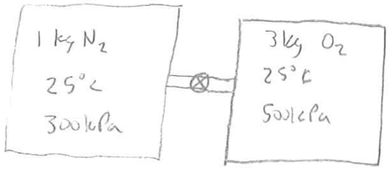
$$\boxed{\begin{aligned} y_{O_2} &= .2336 \\ y_{N_2} &= .4268 \\ y_{CO_2} &= .3396 \end{aligned}}$$

c) $\boxed{MW_{avg} = 34.38 \frac{kg}{kmol}}$

$$R = \frac{R_u}{MW} = \frac{8.314}{34.38} = \boxed{.242 \frac{kJ}{kg \cdot K}}$$

13- 33)

rigid tank



$T_{final} = 25°C$

$\forall_{final} = ?$ $\quad P_{final} = ?$

$N_2 : M = 28.013 \frac{kg}{kmol}$

$O_2 : m = 32.00$ kg/kmol

$R_{N_2} = .2968$

$R_{O_2} = .2598$

$300 \forall = 1kg(.2968)(25+273) \Rightarrow \forall = \boxed{.2948 \text{ m}^3}$

$500 \forall = 3kg(.2598)(298) \Rightarrow \forall = \boxed{.4645 \text{ m}^3}$

$V_{tot} = .7593$

$R_{final} = \frac{R_u}{MW} \quad MW = \sum_i y_i MW_i =$

$y_{N_2} = \overset{(n_i)}{\frac{1}{28.01}} \Big/ \overset{(n)}{\left(\frac{1}{28.01} + \frac{3}{32.00}\right)} = .2758$ $\quad MW_{N_2}$

MW_{O_2}

$y_{O_2} = \frac{3}{32.00} \Big/ .1295 = .7242$

$N_{N_2} = \frac{1 kg}{28.01 \text{ kg/kmol}} = .03571 \text{ kmol}$

$N_{O_2} = \frac{3 kg}{32.00 \text{ kg/kmol}} = .09375 \text{ kmol}$

$\Big\} N_m = .1295 \text{ kmol}$

$P_{final} = \frac{N R_u T}{\forall} = \frac{.1295(8.314)(298)}{.7593}$

$\boxed{P_{final} = 422.2 \text{ kPa}}$

$\boxed{10}$ (book)

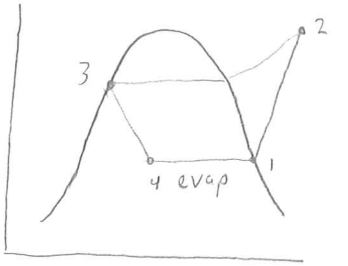
ME 221 Applied Thermodynamics
Fall 2010

D.23 The air conditioner in your car is modeled with a vapor compression refrigeration cycle using R-134a. Refrigerant enters the compressor at 200 kPa and is compressed to 1200 kPa, 60°C. Note that the compressor can be considered adiabatic but not reversible. The required compressor input is 1.5 kW. Assume saturated vapor entering the compressor and a saturated liquid leaving the condenser.

a) Sketch the T-S diagram for this cycle, labeling the states and assumptions for each of the four processes.

b) Find the mass flow rate of the refrigerant. (kJ/kg)

c) Find the capacity of the system (i.e. the heat transfer rate through the evaporator). (kW)



(1-2) adiabatic, not rev.

(2-3) constant P heat rejection

(3-4) constant h throttling

(4-1) $\dot{W}=0$, const P, T heat addition

① Sat. Vap.	②	③ sat. liquid	④
P = 200 kPa	P = 1.2 MPa	P = 1.2 MPa	$h = h_3 = 117.8$
h = 244.5	T = 60°C	T =	
	h = 289.6	h = 117.8	

b) $_1W_2 = (h_1 - h_2) = -45.1$ kJ/kg $\qquad \dot{m}\,{}_1w_2 = \dot{W} = 1.5$ kW $\qquad \boxed{\dot{m} = .0333}$

c) $_1q_4 = (h_1 - h_4) = 2445 - 117.8 = 126.7$ kJ/kg

$_1\dot{q}_4 = \dot{m}\,{}_1q_4 = \boxed{4.219 \text{ kW}}$

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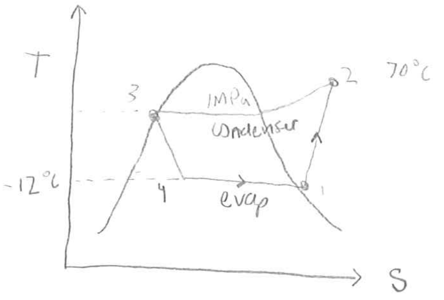
ME 221 Applied Thermodynamics
Fall 2010

D22. A refrigerator using R-134a as the working fluid has a minimum temperature of -12°C and a maximum pressure of 1 MPa. The actual adiabatic (non-isentropic) compressor exit temperature is 70 °C. Assume no pressure loss in the heat exchangers and a cycle with saturated vapor entering the compressor and a saturated liquid leaving the condenser.

a) Sketch the T-S diagram for this refrigeration cycle, labeling the states.
b) Find the specific heat transfer from the cold space. (kJ/kg)
c) Find the specific heat transfer from the hot space. (kJ/kg)
d) Find the required refrigerant mass flow rate for 1 ton of cooling. (kg/s)



① Sat. Vapor
P = 185.37
T = -12°C
S = .9341
h = 243.3

②
P = 1MPa
T = 70°C
h = 303.9

③ Sat. liquid
P = 1MPa
T =
h = 107.3

④
P =
T = -12°C
h = 107.3

b) $q_L = {}_4q_1 = h_1 - h_4 = (243.3 - 107.3) = \boxed{136.1\ kJ/kg}$

c) $q_H = {}_2q_3 = h_3 - h_2 = (107.3 - 303.9) = \boxed{-196.6\ kJ/kg}$

d) 1 ton = 3.52 kW

$\dot{m}\left(136.1\ \frac{kJ}{kg}\right) = 3.52\ kW$

$\boxed{\dot{m} = .0259\ kg/s}$

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10

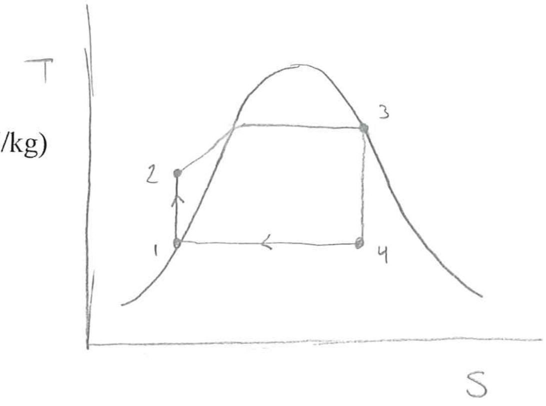
ME 221 Applied Thermodynamics
Fall 2010

D.21 A steam power generation system operates using a Rankine cycle. The water leaves the boiler as a saturated vapor at 3.5 MPa. The working fluid leaves the turbine and enters the condenser at 10 kPa. The pump has an isentropic efficiency of 80% and the turbine has an isentropic efficiency of 85%. Both can be considered adiabatic. You may assume a constant pressure boiler and condenser.

a) Find the **actual** specific pump work. (kJ/kg)

b) Find the **actual** specific turbine work (kJ/kg)

c) Find the **actual** specific heat rejected from the condenser (kJ/kg)



sat liq
①
$P=10\,kPa$
$x=0$

②
$P=3.5\,MPa$

sat vapor
③
$P=3.5\,MPa$
$h=2803$
$s=6.124$

④
$P=10\,kPa$
$S_s=6.124$

$$\cancel{{}_1q_2}^{0} - {}_1w_2 = h_2-h_1 = v\,dP$$

a) $${}_1w_2 = \frac{1}{\eta_{isen}}(.001014)(10-3500) = \boxed{-4.424\ kJ/kg}$$

$$\cancel{{}_3q_4} - {}_3w_4 = h_4-h_3$$

b) $$6.124 = .6492 + x_{4s}(7.4996) = x_{4s} = .7300 \quad \Rightarrow h_4 = 191.8 + (.73)(2392) = 1938$$

$${}_3W_4 = \eta_s(h_3-h_4) = (2803-1938).85 = \boxed{735.3\ kJ/kg}$$

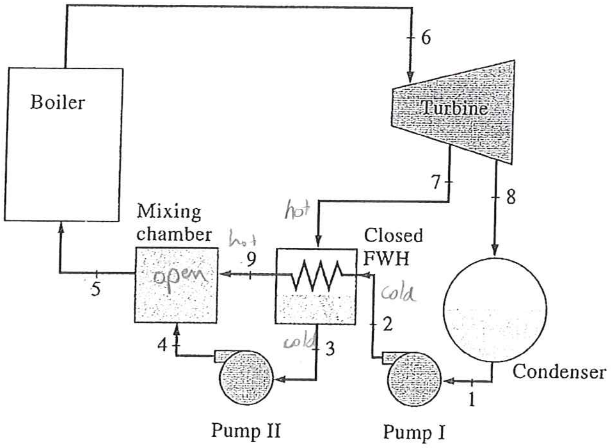
c) $${}_4q_1 - \cancel{{}_4w_1}^{0} = h_1-h_4 = 191.81-2068 = \boxed{-1876\ kJ/kg}$$

$$h_4\ \text{actual} = h_3 - {}_3W_4 = 2803-735.3 = 2068$$

David Makowy 10-11-10 (9)

ME 221 Applied Thermodynamics
Fall 2010

D.20 A steam power system operates using a Rankine cycle with one closed feed water heater. The steam leaves the boiler at 5 MPa, 900 °C and expands isentropically to the condenser temperature of 45 °C. Steam is extracted at 1 MPa for the feed water heater (state 7). Assume isentropic pumps and turbine and saturated liquid entering the pumps (state 1 and 3). Also assume state 4, 5 and 9 are the same and at a temperature of 200 °C. You may also assume a constant pressure boiler and condenser and an adiabatic FWH. Do not interpolate in the steam tables, simple chose the state with the closest values.



✓ a) Sketch the T-S diagram, labeling the states.

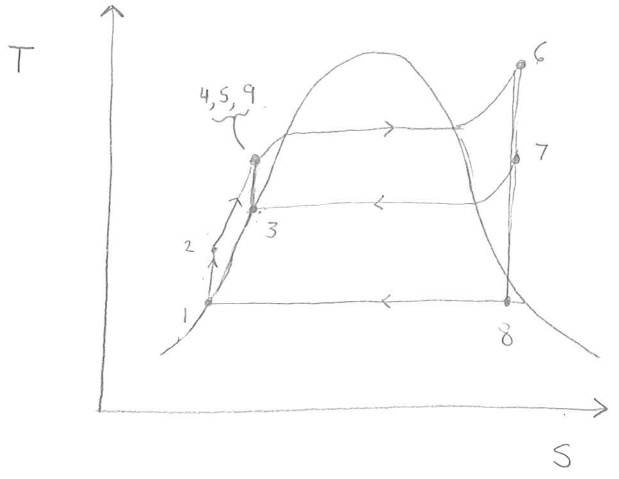
✓ b) Find the quality entering the condenser (i.e. x_8).

✓ c) Find the specific pump work for pump 1 (kJ/kg)

✓ d) Find the specific pump work for pump 2 (kJ/kg)

e) Find an **expression** (not a value) for the turbine work per kg of steam through the boiler (i.e. $\frac{\dot{W}_T}{\dot{m}_6}$). Your answer should be in terms of enthalpies and the fraction y, where y=$\frac{\dot{m}_7}{\dot{m}_6}$.

— f) Find the fraction of steam, y, extracted for the FWH relative to the steam in the boiler (i.e. $\frac{\dot{m}_7}{\dot{m}_6}$).



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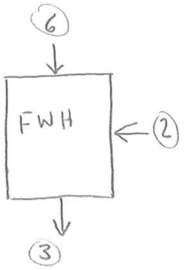
D.19

① Sat. liquid	②	③ Sat. liq.	④ Sat. liquid	⑤	⑥	⑦
$P=10kPa$	$P=.5MPa$	$P=.5MPa$	$P=8MPa$	$P=8MPa$	$P=.5MPa$	$P=10kPa$
$h=191.8$	$h=192.3$	$S=$	$S=$	$T=500°C$	$S=6.727$	
		$X=0$		$S=6.727$	$X=.9813$	
		$h=640.1$		$h=3400$	$h=2717$	

b) find ${}_1W_2 = v(P_1-P_2) = .001010(10-500) = \boxed{-.4949}$

c) find X_6: $S_5 = S_6$ $\quad 6.727 = 1.560 + x(4.960)$ $\quad \boxed{X_6 = .9813}$

d) find $\frac{\dot{m}_6}{\dot{m}_5}$



$\dot{m}_6 h_6 + \dot{m}_2 h_2 = \dot{m}_3 h_3$ $\qquad \dot{m}_5 = \dot{m}_3$

$h_6 = 670.4 + .9813(2086) = 2717$

$h_2 = h_1 - {}_1w_2 = 191.8 + .4949 = 192.3$

$h_3 : h_f <.5MPa> = 640.1$

$$\left.\begin{aligned}\dot{m}_6 &= \dot{m}_2 \frac{(640.1-192.3)}{(2717-640.1)} = .2156\,\dot{m}_2 \\ \dot{m}_3 &= 1.2156\,\dot{m}_2\end{aligned}\right\} \quad \frac{\dot{m}_6}{\dot{m}_3} = \frac{.2156\,\cancel{\dot{m}_2}}{1.2156\,\cancel{\dot{m}_2}}$$

$\frac{\dot{m}_6}{\dot{m}_5} = \boxed{.1773}$ part of total steam in boiler goes to FWH

— T/S on first page ——

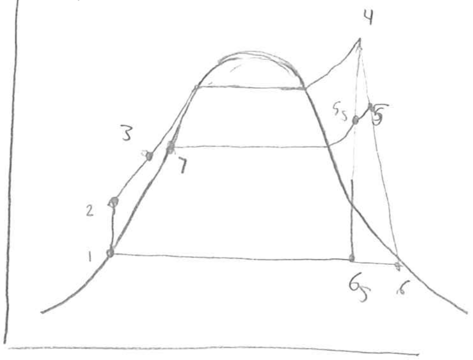
David Malawey

10.58)

$\eta_{s,turbine} = 90\%$ before & after steam extraction pt.

$W_T = ?$ $\dot{q}_{in} = ?$

$W_p = ?$



Sat liq

①

$P = 20$ kPa

$h = 251.4$

②

$P = 3000$ kPa

$h = 254.5$

③

$P = 3000$ kPa

$T = 179.9$ °C

$h = 763.5$

④

$P = 3000$ kPa

$T = 350$ °C

$h = 3116$

$s = 6.745$

⑤

$P = 1000$ kPa

$h = 2852$

$S_s = 6.745$

⑥

$P = 20$ kPa

$S_s = 6.745$

$X =$

$h = 2222$

⑦

$P = 1000$ kPa $T = 179.9$ °C

$X = 0$

$h = 762.5$

W_{pump}

$${}_1W_2 = v(P_1 - P_2) = .001017(20 - 3000) = \underline{-3.030 \text{ kJ/kg}}$$

$$h_2 = h_1 + 3.030 = 254.5$$

$$h_{5s} = \begin{matrix} h & s \\ 2828 & 6.696 \\ 2943 & 6.927 \end{matrix} \quad 6.745 \text{ interpolate} \quad h_{5s} = 2852$$

State 6 – $6.745 = .8320 + X(.7075) \Rightarrow X = .8357$

$$h_6 = 251.4 + (.8357)2358 = 2222$$

$$\eta_T = \frac{h_4 - h_5}{h_4 - h_{5s}} \therefore h_5 = h_4 - \eta_T(h_4 - h_{5s}) = 3116 - (.9)(3116 - 2852) = 2878 \text{ kJ/kg}$$

$$\eta_T = \frac{h_4 - h_6}{h_4 - h_{6s}} \ldots h_6 = 3116 - (.9)(3116 - 2222) = 2311 \text{ kJ/kg}$$

fraction extracted $= \dfrac{\dot{m}_5}{\dot{m}_3} = Y$

$h_3 \approx h_7$ $\dot{m}_5 h_5 + \dot{m}_2 h_2 = \dot{m}_7 h_7 + \dot{m}_3 h_3$

divide by $\dot{m}_3$

$\dot{m}_5 = \dot{m}_7$

$m_2 = \dot{m}_3$

$$\dot{m}_5(h_5 - h_7) = \dot{m}_3(h_3 - h_2)$$

$$Y = \left(\frac{h_3 - h_2}{h_5 - h_7}\right) = .2406$$

$$W_T = h_4 - h_5 + 1 - y(h_5 - h_6) = \underline{668.5 \text{ kJ/kg}} \quad W_T$$

$$q_{in} = h_4 - h_3 = \underline{2353 \text{ kJ/kg}}$$

$$\eta_{th} = \frac{W_{net}}{q_{in}} = \frac{668.5 - 3.03}{2353} = \boxed{.2829}$$

Cale madsen

① sat liq	② comp liq	③ sat liq	④ comp liq	⑤	⑥	⑦	⑧	⑨ comp liq
$P = 9.595\,kPa$	$P = 5\,MPa$	$P = 1\,MPa$	$T = 200°C$	$T = 200°C$	$P = 5\,MPa$	$P = 1\,MPa$	$T = 45°C$	$T = 200°C$
$T = 45°C$	$T =$	$T = 179.9°C$	$P = 5\,MPa$	$P = 5\,MPa$	$T = 900°C$	$T \approx 600°C$	$P = 9.595$	$P =$
$S = .6386$	$S = .6386$	$S = 2.138$	$S = 2.138$	$S = 2.138$	$S = 7.962$	$S = 7.962$	$S = 7.962$	$S = 2.138$
$h = 188.4$	$h = 183.4$	$h = 762.5$				$h \approx 3699$	$x = .9732$	$h = 852.3$

b) $S_8 = S_f + x(S_{fg})$ $\quad 7.962 = .6386 + x(7.5247) \Rightarrow \boxed{x = .9732}$

c) $\cancel{{}_1q_2}^{\,0} - {}_1w_2 = h_2 - h_1 = v\,dP = .001010\,(5000 - 9.595) \Rightarrow \boxed{{}_1W_2 = -5.040\ kJ/kg}$

d) $\cancel{{}_3q_4}^{\,0} - {}_3w_4 = v\,dP = .001127(5000 - 1000)$ $\quad \boxed{{}_3W_4 = -4.508\ kJ/kg}$

e)
$$\frac{\dot{W}_T}{\dot{m}_6} = \frac{{}_6\dot{W}_7 + {}_6\dot{W}_8}{\dot{m}_6} = \frac{\dot{m}_7(h_6 - h_7) + \dot{m}_8(h_8 - h_7)}{\dot{m}_6} = y(h_6 - h_7) + (1-y)(h_6 - h_8) = \cancel{yh_6} - yh_7 \cancel{-yh_6} + yh_8 + h_6 - h_8$$
$$= \boxed{y(h_8 - h_7) + h_6 - h_8}$$

f) $\dfrac{\dot{m}_7}{\dot{m}_6}$

$$\dot{m}_2(h_9 - h_2) = \dot{m}_7(h_3 - h_7)$$
$$(\dot{m}_6 - \dot{m}_7)(h_9 - h_2) = \dot{m}_7(h_3 - h_7)$$
$$\dot{m}_6(h_9 - h_2) = \dot{m}_7\left[(h_3 - h_7) + (h_9 - h_2)\right] \Rightarrow \frac{\dot{m}_7}{\dot{m}_6} = \frac{(h_9 - h_2)}{h_3 - h_7 + h_9 - h_2} = \frac{(852.3 - 193.5)}{762.5 - 3699 + (\quad " \quad)}$$

$h_2 - h_1 = +5.040$

$h_2 = h_1 + 5.040 = 193.48$

$$\boxed{\frac{\dot{m}_7}{\dot{m}_6} = .2892}$$

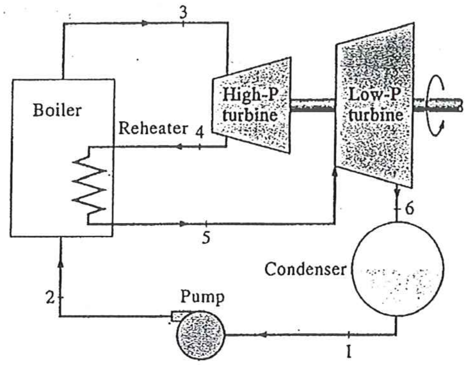
ask about h_3 & ${}_2W_3$

David Malawey

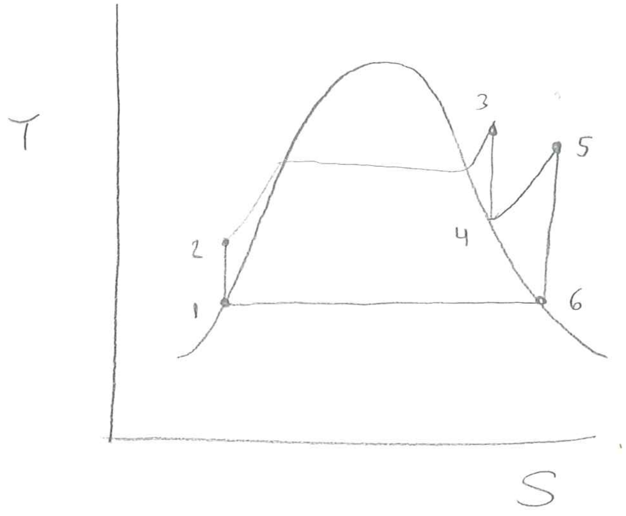
B

ME 221 Applied Thermodynamics
Fall 2010

D.18 A steam power system operates using a Rankine cycle with reheat. The steam leaves the boiler at 6 MPa, 450 °C and expands isentropically to $\overset{4,5}{\text{0.6 MPa}}$ where it is reheated at constant pressure to 400 °C. The steam is further expanded to 15 kPa at which point it enters the condenser. Assume a isentropic pump and turbine and saturated liquid entering the pump. You may also assume a constant pressure boiler and condenser.

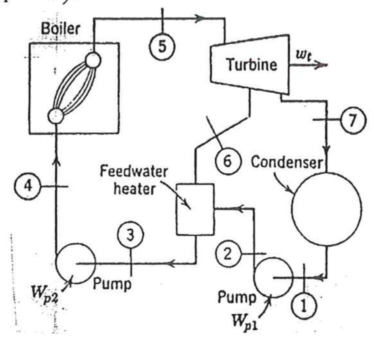


a) Find the quality after the high pressure turbine (i.e. x_4).
b) Find the quality after the low pressure turbine (i.e. x_6).
c) Find the specific pump work (kJ/kg)
d) Find the **total** specific turbine work (kJ/kg)
e) Find the **total** specific heat into the boiler (kJ/kg)

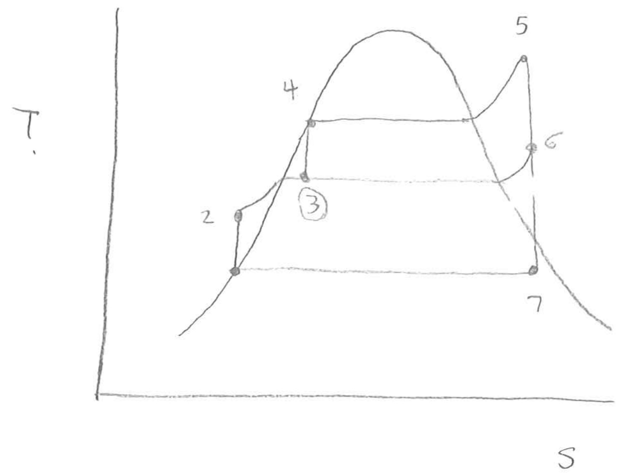


ME 221 Applied Thermodynamics
Fall 2010

D.19 An ideal (i.e. isentropic pumps and turbine) steam power system operates on a Rankine cycle with regeneration using an open feedwater heater. Steam enters the turbine at 8 MPa and 500 °C and enters the condenser at 10 kPa. A portion of the steam is extracted from the turbine at 0.5 MPa for use in the open feedwater heater. Assume an adiabatic feedwater heater and that the feedwater leaving to pump 2 is a saturated liquid (i.e. $x_3 = 0$). Also assume a saturated liquid leaving the condenser (i.e. $x_1 = 0$).



a) Sketch the T-S diagram, labeling the states.
b) Find the specific work of pump 1. (kJ/kg)
c) Find the quality of the bleed steam into the FWH (i.e. x_6)
d) Find the fraction of steam extracted for the FWH relative to the steam in the boiler (i.e. $\frac{\dot{m}_6}{\dot{m}_5}$).



$$\dot{m}_6 h_6 + \dot{m}_2 h_2 = (\dot{m}_2 + \dot{m}_6) h_3$$

$$\dot{m}_6 h_6 - \dot{m}_6 h_3 = \dot{m}_2 h_3 - \dot{m}_2 h_2$$

$$\dot{m}_6 (h_6 - h_3) = \dot{m}_2 (h_3 - h_2)$$

$$\dot{m}_6 = \frac{\dot{m}_2 (h_3 - h_2)}{(h_6 - h_3)}$$

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D18.

① Sat. liq	②	③	④	⑤	⑥
$P = 15\,kPa$	$P = 6\,MPa$	$P = 6\,MPa$	$P = 0.6\,MPa$	$P = 0.6\,MPa$	$P = 15\,kPa$
$h = 225.9$	$h = 232.1$	$T = 450°C$	$S = 6.722$	$T = 400°C$	$S = 7.710$
		$S = 6.722$	$X = .9923$	$S = 7.710$	$h = 2501$
		$h = 3303$	$h = 3024$	$h = 3271$	$X = .9590$

a) find X_4:

$$s = s_f + x\, s_{fg}$$

$$6.722 = 1.9308 + x(4.8285) \Rightarrow \boxed{X_4 = .9923}$$

b) find X_6: $7.710 = .7549 + x\,7.2522 \Rightarrow \boxed{X_6 = .9590}$

c) find w_{pump}: ${}_1w_2 = v(P_1 - P_2) = v_{sat}\langle 15\,kPa\rangle(\quad)$

$$= .001014(15 - 6000) \quad \boxed{{}_1w_2 = -6.224\ kJ/kg}$$

d) find $W_{T,\,Total}$ isentropic ${}_3q_4 - {}_3w_4 = h_4 - h_3$

$$h_4 = h_f + x\,h_{fg} = 670.38 + .9923(2086) = 3024$$

$$h_6 = h_f + x\,h_{fg} = 225.9 + .9590(2372) = 2501$$

$${}_3w_4 + {}_5w_6 = h_3 - h_4 + h_5 - h_6 = \boxed{1049\ kJ/kg}$$

-1

$$q_{total,\,boiler} = h_2 - h_3 + h_4 - h_5$$

$$h_2 = h_1 - {}_1w_2 = 225.9 + 6.224 = 232.1$$

$$\boxed{q_{total\ into\ boiler} = 2548\ kJ/kg}$$

-1

10.105

$\dot{m}_8 = ?$

$\eta_{th} = ?$

①	②	③	④	⑤	⑥	⑦	⑧	⑨
P=15kPa	P=600kPa	sat liq. P= 600kPa T= h=670.4	P=10MPa T= h = 680.73	P=10MPa T= 500°C h=3375 s = 6.5995	P= 1MPa S= 6.600 h=2784	P= 1MPa T= 500°C S=7.764 h= 3479	P=0.6MPa S =7.764	P=15kPa S = 7.764 T= X = .9665

$$ {}_1W_2 = vdp = (.001014)(600-15) = .59\ kJ/kg $$

$$ {}_3W_4 = vdp = (.001101)(10{,}000-600) = 10.35\ kJ/kg $$

$$ h_4 = h_3 + {}_3W_4 = 680.73 $$

$$ S_9 = S_f + X S_{fg} \Rightarrow X_9 = \frac{7.764 - .7549}{7.252} = .9665 $$

$$ \left\{ \begin{array}{l} \dot{m}_8 h_8 + \dot{m}_2 h_2 = \dot{m}_3 h_3 \\ y(h_8) + (1-y) h_2 = h_3 \end{array} \right. $$

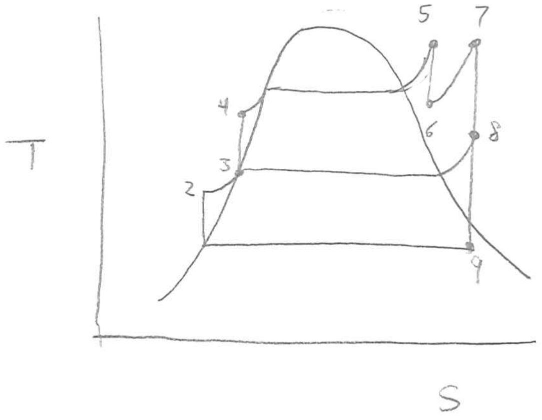
$$ y = \frac{\dot{m}_8}{\dot{m}_3} \Rightarrow $$

$$ y = \frac{h_3 - h_2}{h_8 - h_2} = \frac{670.38 - 226.5}{3310 - 226.5} \quad \boxed{y = .144} $$

$$ q_{in,net} = h_5 - h_4 + h_7 - h_6 = 3390\ kJ/kg $$

$$ q_{out} = (1-y)(h_9 - h_1) = 1963\ kJ/kg $$

$$ \eta_{th} = 1 - \frac{q_{out}}{q_{in}} = 1 - \frac{1963}{3390} = \boxed{42.1\%} $$



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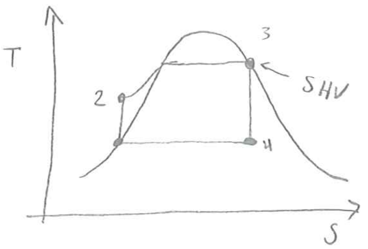
REGRADE

⑦

+ 10.25



ME 221 Applied Thermodynamics
Fall 2010

D.17 Consider a steam power plant operating on the ideal Rankine cycle. The steam enters the turbine at 3 MPa and 350 °C and is condensed in the condenser at a pressure of 10 kPa. Assume isentropic pump and turbine. Determine:

a) The thermal efficiency of the plant at the given conditions.
b) The thermal efficiency if the steam is superheated to 600 °C instead of 350 °C.
c) The thermal efficiency if the boiler pressure is raised to 15 MPa while the turbine inlet is maintained at 600°C.

?? Be sure to comment on the impact of the change in b) and c) on the turbine inlet and/or outlet conditions.

① $P = 10kPa$ ② $P = 3MPa$ ③ $P = 3MPa$, $T = 350°C$, $S = 6.7450$ ④ $P = 10kPa$

$\eta_{th} = \frac{w_{net}}{q_{in}} = \frac{w_P + w_T}{{}_2q_3}$ (1-2) $\cancel{{}_1q_2}^{0} - {}_1w_2 = h_2 - h_1$ ${}_1w_2 = h_1 - h_2 = -\int v\,dP$

$v_1 (P_2 - P_1)$ $v = v_{sat}(10kPa) = .001010\ m^3/kg\ (3000 - 10)$ ${}_1w_2 = -3.020\ kJ/kg$

w_T: ${}_3w_4 = h_3 - h_4 = \overset{SHV}{3116.1} - 2136.02$ ${}_3w_4 = 980.1\ kJ/kg$

$S_4 = 6.7450 = .6492 + x(7.4996) \Rightarrow x = .8128$ $\Rightarrow h_4 = 191.81 + (.8128)\,2392.1$

${}_2q_3$: Const. p no shaft work ${}_2q_3 = h_3 - h_2$

$h_2 = h_1 - w_p = \underset{h_f(10kPa)}{191.81} + 3.02$ $h_2 = 194.83$ $\rightarrow$ ${}_2q_3 = 2921$

$\boxed{\eta_{th} = 33.45\%}$

b) $T_3 = 600°C$
$S_3 = 7.5103$
$h_3 = 3683$

${}_1w_2 = -3.020$
$h_4 = 2380 \rightarrow$ ${}_3w_4 = 1303\ kJ/kg$
$x_4 = .9149$

${}_2q_3 = h_3 - h_2 = 3683 - 194.83$
${}_2q_3 = 3488$

$\boxed{\eta_{th} = 37.27\%}$

$h_3 = 3582.3$ $S_3 = 6.6775$ $\Rightarrow h_4 = 2115.7$

c) $P_2 = P_3 = 15MPa$ (barely SHV)
$S_3 = 5.444$
$h_3 = \cancel{2693}$
$x_4 = .6393$
$h_4 = 1721$
$h_1 = 191.81$

${}_1w_2 = .001010\ m^3/kg\ (15000 - 10) = -15.14$

${}_3w_4 = h_3 - h_4 = 972\ kJ/kg$

${}_2q_3 = h_3 - h_2 = h_3 - (h_1 - w_p)$

? -3

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$\eta_{th} = ?$ $\dot{m}_{steam} = ?$ $\Delta T_{cooling\ water} = ?$

10.25/ Rankine cycle

cooling water 4-1 2000kg/s

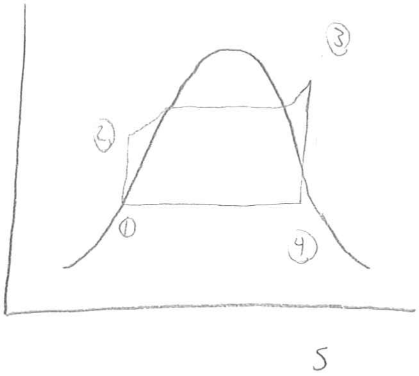
net $\dot{w}_{out} = 45MW$

① $P = 10kPa$
$T =$
$h = 191.81$

② $P = 7MPa$
$h = 198.9$

③ SHV
$P = 7MPa$
$T = 500°C$
$S = 6.800$
$h = 3411$

④ $P = 10kPa$
$h = 2154$
$x =$
$S = 6.800$



4) $\overset{S}{6.800} = .6492 + x\,7.4996 \Rightarrow x = .8202$

$h_4 = 191.81 + .8202(2392.1)$ $h_4 = 2154\ kJ/kg$

$\eta_{th} = \frac{W_{net}}{{}_2q_3} = \frac{{}_1W_2 + {}_3W_4}{{}_2q_3}$

${}_1W_2 = h_1 - h_2 = v(P_1 - P_2) = .00101(10 - 7000)$

${}_1W_2 = -7.060\ kJ/kg$

${}_3W_4 = h_3 - h_4 = 1257$

${}_2q_3 = h_3 - h_2$ $h_2 = h_1 - {}_1W_2 = 198.9$

${}_2q_3 = 3212\ kJ/kg$

$\boxed{\eta_{th} = 38.92\ \%}$

$\dot{W}_{net} = \dot{m}_{steam}({}_1W_2 + {}_3W_4)$ $45,000 = \dot{m}(1250)$ $\boxed{\dot{m} = 36\ kg/s}$

${}_4q_1 = h_1 - h_4 = -1962\ kJ/kg$

$\dot{m}\Delta h = \dot{q} = 70640\ kJ/s$

$\frac{70640\ kJ/s}{2000\ kg/s} = 35.32\ kJ/kg$ $\frac{35.32\ kJ/kg}{C_p\ water\ 4.18\ kJ/kg} = \boxed{8.450°C}$

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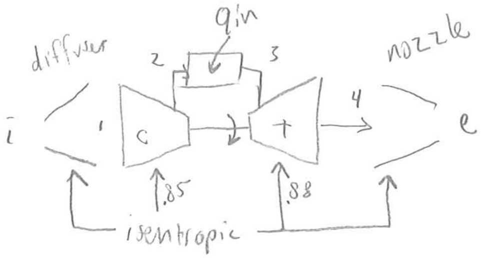
10



ME 221 Applied Thermodynamics
Fall 2010

D.16 Air at 22 kPa, 220 K, and 250 m/s enters a turbojet engine in flight at an altitude of 10,000 m. The pressure ratio across the compressor is $\boxed{12.}$ The turbine inlet temperature is $\boxed{1240\text{ K}}$ and the pressure at the nozzle exit is 22 kPa. The diffuser and nozzle processes are isentropic, the compressor and turbine have isentropic efficiencies of 85 and 88 %, respectively. There is negligible pressure drop through the combustor. Assuming constant specific heats and $P_{4s} = P_4$ (at the turbine exit), determine

a) The pressures and temperatures at states 1 through 4.

b) The velocity at the exit of the nozzle, V_e.

①	②	③	④	ⓘ	ⓔ
$T = 251.1$	$T = 556.5$ k	$T = 1240$k	$T = 971.2$ k	$P = 22$ kPa	$P = 22$ kPa
$P = 34.41$ kPa	$P = P_3 = 412.9$ kPa	$P = 412.9$ kPa	$P = 130.7$	$T = 220$k	
				$V = 250$m/s	
				S	

$h_1 = h_i$

$$T_1 c_p = T_i c_p + \frac{V^2}{2} \Rightarrow T_1 = T_i + \frac{V^2}{2c_p} = 220\text{k} + \frac{250^2 \ \text{m/s}}{1.005(2)\ \frac{\text{kJ}}{\text{kg·k}}} \quad T_1 = \boxed{251.1\text{ k}}$$

$$P_1 = P_i \left(\frac{T_1}{T_i}\right)^{\frac{k}{k-1}} = 22\text{kPa}\left(\frac{251.1}{220\text{k}}\right)^{\frac{1.4}{.4}} = \boxed{34.41\text{kPa}}$$

$$(1\text{-}2) \text{ isentropic: } \cancel{{}_1q_2}^{0} - {}_1w_2 = h_2 - h_1 \qquad {}_1w_2 = c_p(T_1 - T_2) \qquad \eta_T = \frac{w_{isen}}{w_{act}} = \frac{(251.1 - 510.7)}{(251.1 - T_2)} = .85$$

$$T_{2s} = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} = 251.1(12)^{\frac{.4}{1.4}} = 510.72 \qquad \boxed{T_2 = 556.5\text{ k}}$$

$$P_2 = 12 P_1 = 412.9\text{ kPa}$$

$$(3\text{-}4) \text{ for isentropic case: } -w_c = w_T \quad \cancel{{}_3q_4}^{0} - {}_3w_4 = h_4 - h_3 \qquad {}_3w_4 = c_p(T_3 - T_4) \qquad \eta_T\, {}_3w_4 = |-{}_1w_2|$$

$$\eta_T(-{}_1w_2) = \cancel{c_p}(T_3 - T_4) = \cancel{c_p}\frac{(T_2 - T_1)}{.88} \qquad \boxed{T_4 = 892.7}$$

$$P_4 = P_3 \left(\frac{T_4}{T_3}\right)^{\frac{k}{k-1}} = 412.9\left(\frac{892.7}{1240}\right)^{\frac{1.4}{.4}} = \boxed{130.7\text{ kPa}}$$

$$T_4 = T_e + \frac{V_e^2}{2c_p} \qquad V_e = \sqrt{(T_4 - T_e)\,2c_p} \qquad T_e = T_4\left(\frac{P_e}{P_4}\right)^{\frac{k-1}{k}} = 934.4\left(\frac{22}{133}\right)^{\frac{.4}{1.4}} = 559\text{K}$$

$$= \sqrt{(892.7 - 559)(2 \cdot 1.0035)(1000)}$$

$$\boxed{V_e = 868\text{m/s}}$$

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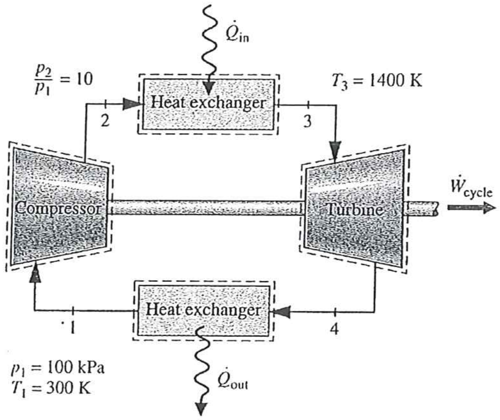
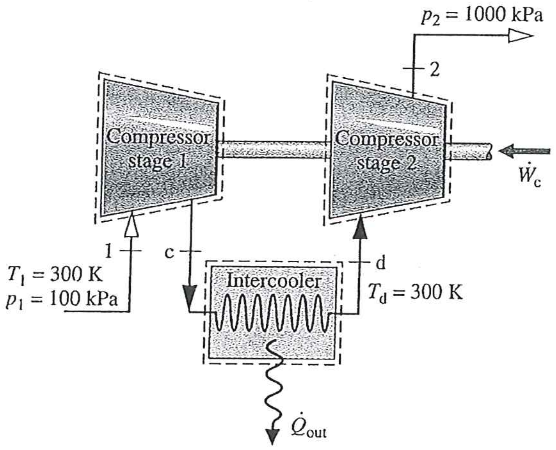
10

ME 221 Applied Thermodynamics
Fall 2010

D.13 Air enters the compressor of an ideal air-standard Brayton cycle at 100 kPa and 300K. The compressor pressure ratio is 10. The turbine inlet temperature is 1400 K. Assume isentropic compressor and turbine. Assume constant specific heats (i.e. $C_v = 0.717$ kJ/kgK, $C_p = 1.004$ kJ/kgK, $k = 1.4$).



a) Find the temperature after the compressor. (K).
b) Find the temperature after the turbine. (K)
c) Find the specific compressor work (kJ/kg)
d) Find the cycle thermal efficiency.
e) A two-stage compressor is now used with an intercooler between the two stages of compression. Stage 1 compresses the air to 300 kPa (i.e. $P_c = 300$ kPa) and stage 2 compresses the air to the final pressure of 1000 kPa ($P_2 = 1000$kPa):



The intercooler, which is a simple heat exchanger, can be assumed to be a constant pressure device which cools the compressed air to $T_d = 300$K. Find the **total** required work for this two stage compressor (kJ/kg).

D.13

a) $T_2 = T_1 \left(\frac{P_2}{P_1} \right)^{\frac{k-1}{k}} = 300k\,(10)^{0.4/1.4} = \boxed{579.2k}\ T_2$

b) $T_4 = T_3 \left(\frac{P_4}{P_3} \right)^{\frac{k-1}{k}} = 1400k\,(\frac{1}{10})^{.4/1.4} = \boxed{725.1k}\ T_4$

c) $W_c = h_1 - h_2 = C_p(T_1 - T_2) = 1.004(300 - 579.2) = \boxed{-280.3\ kJ/kg}$

d) $\eta_{th} = \frac{W_{net}}{q_{in}}$ $h_3 - h_4 = C_p(T_3 - T_4)$ $W_T = 1.004(1400 - 725.1) = 677.6\ kJ/kg$

$q_{in} = h_3 - h_2 = 1.064(1400 - 579.2) = 824.1\ kJ/kg$

$= \frac{677.6 - 280.3}{824.1} = .482 \quad \boxed{\eta_{th} = 48.2\%}$

e) 2-stage compression

$W_c = W_{c1} + W_{c2} = c_p\left[(T_1 - T_c) + (T_d - T_c)\right]$

$T_c = T_1 \left(\frac{P_c}{P_1} \right)^{\frac{k-1}{k}} = 300\left(\frac{300}{100}\right)^{0.4/1.4} = 410.6\,k$

$T_2 = T_d \left(\frac{P_2}{P_d} \right)^{\frac{k-1}{k}} = 300\left(\frac{1000}{300}\right)^{\frac{0.4}{1.4}} = 423.2\,k$

$W_{c,TOT} = 1.004\ kJ/kg\ (300 - 410 + 300 - 423.2)$

$\boxed{W_{c,TOT} = -234.7\ kJ/kg}$

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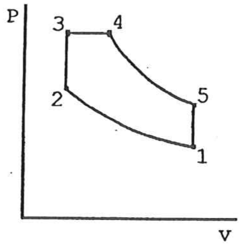
AND 9.98

ME 221 Applied Thermodynamics
Fall 2010

D.12 An engine is to be modeled with an ideal "dual" cycle using air as the working fluid. The dual cycle is one where the first part of the energy addition is modeled as constant volume and the second part as constant pressure. Assume that 2/3 of the energy is input as constant volume ($q_{23} = 2/3\ q_{in}$) and 1/3 of the energy at constant pressure ($q_{34} = 1/3\ q_{in}$). The conditions at the beginning of the compression process (state 1) are 90 kPa and 293 K. The engine has a compression ratio of 7 and the temperature at state 3 is 2900 K. Assume ideal gas behavior and **constant specific heats** evaluated at 300K.



a) Find the temperature and pressure at the end of compression (K)
b) Find the temperature after the constant pressure heat addition, T_4 (K)
c) Find the temperature after expansion, T_5 (K)
d) Find the thermal efficiency

David Malaway D12

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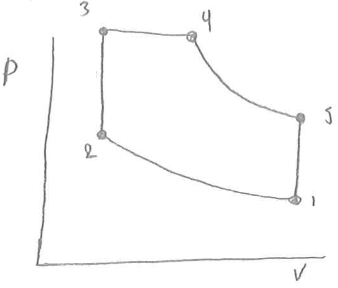


(1-2) isentropic

(2-3) const $\forall$ q_{in} $\quad {}_2q_3 = \frac{2}{3} q_{in}$

(3-4) const P q_{in} $\quad {}_3q_4 = {}^1\!/_3\, q_{in}$

(4-5) isentropic exp.

$k = 1.4$

$r = 7 = \frac{V_2}{V_1}$

$C_p = 1.005$

$C_v = .718 \ kJ/kg\cdot k$

① $P = 90 \text{ kPa}$
$T = 293 k$

② $\boxed{P = 1372 \text{kPa}}$
$\boxed{T = 638.1 \ k}$

③ $P = 6235 \text{ kPa}$
$T = 2900 k$

④ $P =$
$\boxed{T = 3708 \ k}$

⑤ $P =$
$\boxed{T = 1878 \ k}$

(1-2) $\quad \frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^k \qquad \frac{90}{P_2} = \left(\frac{1}{7}\right)^{1.4} \qquad \underline{P_2 = 1372.08 \text{ kPa}}$

$\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{k-1} \qquad \frac{293}{T_2} = \left(\frac{1}{7}\right)^{0.4} \qquad \underline{T_2 = 638.1 \ k}$

(2-3) $\quad {}_2Q_3 - \cancel{{}_2W_3}^{\,0} = U_3 - U_2 = C_v(T_3 - T_2) = .718(2900 - 638.1)$

$\underline{{}_2q_3 = 1624 \ kJ/kg}$

$P_3 = \frac{mRT_3}{V_3} = \frac{P_2 T_3}{T_2} = \frac{(1372)(2900)}{(638.1)} = \underline{P_3 = 6235 \text{ kPa}}$

${}_3q_4 = \frac{1}{2}\, {}_2q_3 = 812.0 \ kJ/kg$

(3-4) $\quad {}_3Q_4 - {}_3W_4 = (U_4 - U_3) \qquad {}_3q_4 - \int P\,d\forall = u_4 - u_3 \qquad {}_3q_4 = h_4 - h_3$

${}_3q_4 = c_p(T_4 - T_3) \qquad 812.0 = 1.005(T_4 - 2900) \qquad \Rightarrow \quad \underline{T_4 = 3708 K}$

(4-5) $\quad \frac{V_4}{V_5} = \frac{V_4}{\cancel{V_3}} \cdot \frac{\cancel{V_3}}{V_5} \quad \Rightarrow \quad T_5 = T_4\left(\frac{T_4}{T_3} \cdot \frac{1}{r}\right)^{k-1}$

$T_5 = 3708\left(\frac{3708}{2900} \cdot \frac{1}{7}\right)^{0.4} \quad \Rightarrow \quad \underline{T_5 = 1878 \ k}$

$\eta_{th} = \frac{W_{net}}{q_{in}} = \frac{{}_1W_2 + {}_3W_4 + {}_4W_5}{q_{in}} = {}_2q_3 + {}_3q_4 + {}_5q_1 = \frac{1624 + 812.0 - 1138 \ kJ/kg}{1624 + 812.0}$

${}_5q_1 = c_v(T_1 - T_5) = .718(293 - 1878) = -1138 \ kJ/kg$

$\boxed{\eta_{th} = 53.3\%}$

D10 ✓

D9 ✓

D8

D7 ✓

D6 ✓ otto, var specific heats

D5 ✓

D4 ✓

D3 ✓

D2

D1

Stirling:

- const T compression (1-2)

$${}_1w_2 = {}_1q_2 = \int P dv$$

$$= R T_1 \ln\left(\frac{v_2}{v_1}\right)$$

ME221
Drallmeier
Fall 2010

Test Notes—Hour Exam I

D-problems 1-12 ?

Definitions:

$$h = u + Pv$$

$$c_p = (\partial h / \partial T)_p \ , \quad c_v = (\partial u / \partial T)_v \ , \ k = c_p / c_v$$

$$Tds = du + Pdv = dh - vdP$$

Ideal Gas Relations:

$$Pv = RT \ , \ R = \bar{R}/MW \ \ (\bar{R} = 8.314 \quad kJ/kmol-K, \ MW = \text{molecular weight})$$

$$h \ , u \ , \ c_p \ , \ c_v = \text{functions of temperature only}$$

$$du = \ c_v \, dT \ , \ dh = \ c_p \, dT \quad (\text{any process})$$

$$s_2 - s_1 = s^o_{T2} - s^o_{T1} - R\ln\left(\frac{P_2}{P_1}\right) \quad ; \quad \frac{v_2}{v_1} = \left(\frac{v_{r,T2}}{v_{r,T1}}\right)_{s=\text{constant}}$$

$$s_2 - s_1 = c_p \ln\left(\frac{T_2}{T_1}\right) - R\ln\left(\frac{P_2}{P_1}\right) \quad (\text{constant specific heats})$$

$$s_2 - s_1 = c_v \ln\left(\frac{T_2}{T_1}\right) + R\ln\left(\frac{V_2}{V_1}\right) \quad (\text{constant specific heats})$$

Isentropic Processes (constant specific heats):

$$Pv^k = \text{Constant}$$

$$\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^k = \left(\frac{T_1}{T_2}\right)^{\frac{k}{k-1}}, \quad \frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{k-1} = \left(\frac{P_1}{P_2}\right)^{\frac{k-1}{k}}, \quad \frac{V_1}{V_2} = \left(\frac{T_2}{T_1}\right)^{\frac{1}{k-1}} = \left(\frac{P_2}{P_1}\right)^{\frac{1}{k}}$$

Polytropic Processes

$$Pv^n = \text{Constant} \qquad {}_1w_2 = \left(\frac{R}{1-n}\right)(T_2 - T_1)$$

Fixed Mass Systems:

$$\delta Q - \delta W = dE \qquad {}_1Q_2 - {}_1W_2 = E_2 - E_1$$

$$E = 1/2m\,v^2 + mg\,z + U \qquad W = \int P dV$$

$$S_2 - S_1 = \int_1^2 \frac{\delta Q}{T} + S_{gen}$$

$$x = (u - u_o) + P_o(v - v_o) - T_o(s - s_o)$$

$$W_{REV} = m(x_1 - x_2)$$

Open Systems:

$$\frac{dE_{cv}}{dt} = \dot{Q}_{cv} - \dot{W}_{cv} + \dot{m}_{in}\left(h + \frac{V^2}{2} + gz\right)_{in} - \dot{m}_{out}\left(h + \frac{V^2}{2} + gz\right)_{out}$$

If isentropic: $w = \int_o^i v dP$

Memorize

$$\frac{dScv}{dt} = \sum_{in} \dot{m}_{in}\, s_{in} - \sum_{out} m_{out}s_{out} + \sum \frac{Q_i}{T_i} + \dot{S}_{GEN}$$

Max power/work = ΔX

Actual power = $\dot{m}\,\Delta h$

$$\psi = (h - h_o) - T_o(s - s_o) + 1/2V^2$$

$${}_2q_3 = h_3 - h_2 \text{ (const P. work)}$$

$$\dot{W}_{REV} = \sum \dot{m}_i \psi_i - \sum \dot{m}_e \psi_e$$

Efficiencies:

$$\eta_{MAX} = 1 - \frac{T_L}{T_H}$$

$$\eta_{th} = \frac{W_{ACT}}{Energy_{IN}} \text{ (1st Law Efficiency)}; \quad \eta_{II} = \frac{W_{ACT}}{W_{REV}} \text{ (2nd Law Efficiency)}$$

$$\eta_{isen,t} = \frac{W_{ACT}}{W_{ISEN}} = \frac{(h_1 - h_2)_{ACT}}{(h_1 - h_2)_{ISEN}}$$

$$\eta_{isen,p} = \eta_{isen,c} = \frac{W_{ISEN}}{W_{ACT}} = \frac{(h_1 - h_2)_{ISEN}}{(h_1 - h_2)_{ACT}}$$

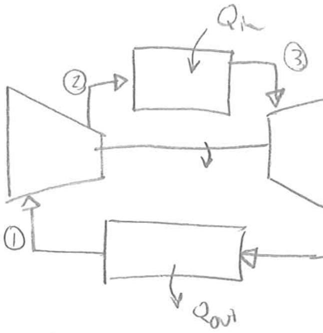
memorize:

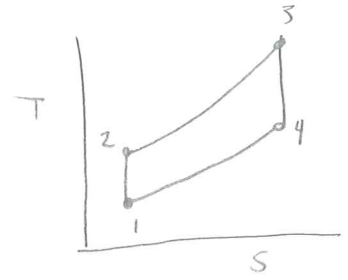
otto,

const $c_{v,p}$ → $\eta_{th} = 1 - \frac{1}{r^{k-1}}$; $MEP = \frac{W_{NET}}{V_1 - V_2}$

David Malawey

$\boxed{9.98}$



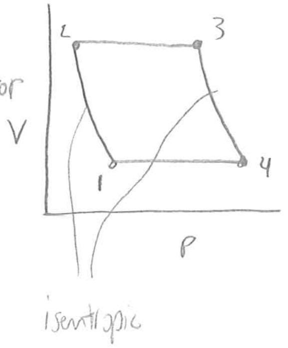


Brayton Cycle, $r = 12$

total Q_{in} needed = ?

① $T = 300k$ ② $T =$ ③ $T = 1000k$

$\dot{W}_{out} = 70\ MW$



$C_p = 1.005$

$C_v = .718$

a) 100% efficiency turbine/compressor

b) 85% efficiency

${}_1W_2 - \cancel{{}_1h_2}^{0} = c_p$

$$T_{2s} = T_1\left(\frac{P_2}{P_1}\right)^{(k-1)/k} = 300(12)^{.4/1.4} = 610.2K$$

$$T_{4s} = T_3\left(\frac{P_4}{P_3}\right)^{(k-1)/k} = 1000\left(\frac{1}{12}\right)^{0.4/1.4} = 491.7k$$

$$W_{s,C\,in} = h_{2s} - h_1 = C_p(T_{2s} - T_1) = (1.005)(610.2 - 300k) = 311.75\ kJ/kg$$

$$w_{s,T\,out} = h_3 - h_{4s} = 1.005(1000 - 491.7) = 510.84\ kJ/kg$$

$$W_{s,net\ out} = 510.84 - 311.75 = 199.1\ kJ/kg$$

$$\dot{m}_s = \frac{\dot{W}_{net\,out}}{W_{s\,net\,out}} = \frac{70{,}000\ kJ/kg}{199.1\ kJ/kg} = \boxed{352.0\ kg/s}$$

$$W_{a,net\,out} = W_{a,T,out} = -W_{a,C,in} = \eta_T W_{s,T,out} - W_{s,C,in}/\eta_c$$

$$= .85(510.84) - 311.75/0.85 = 67.5\ kJ/kg$$

$$\dot{m}_T = \frac{\dot{W}_{net\,out}}{W_{a,net,out}} = \frac{70{,}000\ kJ/s}{67.5\ kJ/kg} = \boxed{1037\ kg/s}$$

David Malawey due 9-15-10

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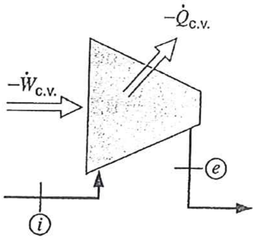
ME 221 Applied Thermodynamics
Fall 2010

D.4 Air enters a compressor at 100 kPa and 25 °C. ① The air is compressed to 1MPa ② where it exits the compressor at 540 K. ② The compressor is hotter than the ambient surroundings due to the compression process. Hence 50 kJ of heat per kg of air is transferred to the ambient which is at a temperature of 25 °C. Assume ideal gas behavior and **constant specific heats** evaluated at 300K.



a) Find the **actual** compressor work given the measured states
b) Find the **minimum** required work into the compressor given the measured states
c) Find the 2nd Law efficiency (i.e. exergy based efficiency) of the compressor.
d) Another method to define the performance of this compressor would be relative to an isentropic device. Find the isentropic exit temperature of the compressor given the same inlet conditions.
e) Find the isentropic efficiency

a) $${}_1\dot{Q}_2 - {}_1\dot{W}_2 = \Delta U$$

$$-50\frac{kJ}{kg} - {}_1W_2 = C_v(T_2 - T_1) = 1.005\ \frac{kJ}{kg\cdot K}\left(540 - (25+273)\right)^\circ K$$

$$\boxed{W = -293.21\ \frac{kJ}{kg}}$$

b) Minimum work $= \Delta\psi = \psi_2 - \psi_1 = h - h_0 - T_0(s - s_0)$

$$h_2 - h_1 - T_0\left(c_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1}\right) =$$

$$= 243.21 - 298\left[1.005\ln\left(\frac{540}{298}\right) - .2870\ln\left(\frac{1000}{100}\right)\right] = 243.21 + (18.89) = \boxed{-262.1\ kJ/kg}$$

placed here to show work will be in.

c) $$\frac{W_{act}}{W_{min}} = \boxed{\eta_{II} = 89.4\%}$$

d) $$\frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} \quad T_2 = 298(10)^{\frac{1.4-1}{1.4}} \quad \boxed{T_2 = 575.35\ k}$$

e) $$W_{isentropic} = 1.005\ (575.4 - 298) = 278.8\ kJ/kg$$

$$\eta_s = \frac{278.8}{293.21} = \boxed{95.08\%}$$

ME 221 Applied Thermodynamics
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D.5 A mixture of gasoline and air has an energy release upon combustion of approximately 2800 kJ/kg of the mixture. To approximate an actual spark ignition engine using such a mixture, consider an Otto cycle that has a heat addition of 2800 kJ/kg of air, a compression ratio of 7 and a pressure and temperature at the beginning of the compression process of 90 kPa and 10°C. Assume ideal gas behavior and **constant specific heats** evaluated at 300K. ①

a) Find the maximum pressure and temperature in the cycle (kPa, K).
b) Find the thermal efficiency of the cycle.
c) Find the net specific work from the cycle (kJ/kg)
d) Find the mean effective pressure for the cycle (kPa)

① 90 kPa, 283°K
② P = 1372 kPa, T = 616 K
③ P = 10.058, T = 4516
④ T = 2074 K

isentropic compression $r = 7 = \frac{\forall_1}{\forall_2}$ $T_2 = T_1 (7)^{k-1}$ $T_2 = 283(7)^{1.4-1}$

$P_2 = P_1 \left(\frac{V_1}{V_2}\right)^k = 90(7)^{1.4} =$

heat addt. const. ∀. ${}_2Q_3 = 2800$ kJ/kg No work $\Delta h = 2800$ kJ/kg $= C_v(T_3 - T_2)$

$2800 = .718(T_3 - 616)$

a) $\boxed{T_3 = 4516\text{ K}}$ $PV = mRT$ $\frac{P_2}{T_2} = \frac{P_3}{T_3}$ $\boxed{P_3 = 10.058\text{ MPa}}$

b) $\eta_{th} = \frac{w_{net}}{q_{in}}$ $w_{net} = {}_1w_2 + {}_3w_4$ isentropic expansion $\frac{T_3}{T_4} = \left(\frac{\forall_4}{\forall_3}\right)^{k-1}$ $T_4 = 4516 \div (7)^{1.4-1}$

$= C_v(T_1 - T_2 + T_3 - T_4) = .718(\quad) = \boxed{1514.26\text{ kJ/kg}}$

$\eta_{th} = \frac{1514}{2800} = \boxed{54.08\%}$

c) $\boxed{w_{net} = 1514.26\text{ kJ/kg}}$

d) $MEP = \frac{w_{net}}{\forall_1 - \forall_2} = \frac{1514.26\text{ kJ/kg}}{.9025 - .1289\text{ kJ/kg}}$

$Pv_1 = RT_1$

$v_1 = .2869(283)$ $\frac{\text{kJ}}{\text{kg}\cdot\text{K}}$(K)

$v_2 = .2869(616)$

~~81.1427~~ kJ/kg
~~-176.73~~ kJ/kg
95.54

$\boxed{MEP = 1957}$

.9025 - .1289

D10

① $T = 283\text{k}$
$P = 90\text{kPa}$

② a) $\boxed{T = 616.34\text{k}}$
$P = 1372\text{ kPa}$

③ b) $\boxed{T = 3123\text{k}}$
$P_3 =$
$V_3 =$

④ c) $\boxed{T = 1219\text{k}}$

⑤ $T = 424.4$
$P = 90\text{kPa}$

$r = 7 \quad \frac{V_1}{V_2}$

$\frac{V_4}{V_3} = 1.5 \quad \frac{V_1}{V_2}$

(1-2) isentropic compression

$$T_2 = T_1\left(\frac{V_1}{V_2}\right)^{k-1} = 283(7)^{0.4} = 616.34\text{ K}$$

$$P_2 = P_1\left(\frac{V_1}{V_2}\right)^{k} = 90(7)^{1.4} = 1372\text{ kPa}$$

$\cancel{{}_1q_2}^{0} - {}_1W_2 = U_2 - U_1$

${}_1W_2 = U_1 - U_2 = C_v(T_1 - T_2)$

${}_1W_2 = .718(-616.34 + 283)$

$\boxed{{}_1W_2 = -239.34\text{ kJ/kg}}$

(2-3) const V q_{in} $\cancel{w}^{0}$ $\quad q_{in} = u_3 - u_2 \quad c_v(T_3 - T_2) = .718(T_3 - 616) \Rightarrow T_3 = 3123\text{ K}$

(1800kJ/kg)

(3-4) isent. expansion $\quad \frac{T_3}{T_4} = \left(\frac{V_4}{V_3}\right)^{k-1} \quad T_4 = \frac{3123}{[1.5(7)]^{0.4}} \quad T_4 = 1219\text{K}$

d) expansion work (3-4) isentropic

$\cancel{{}_3q_4}^{0} - {}_3W_4 = h_4 - h_3 \quad {}_3W_4 = h_4 - h_3 = c_v(T_4 - T_3) = .718(1219 - 3123)$

$\boxed{\cancel{-}{}_3W_4 = \cancel{+}1367\text{ kJ/kg}}$

e) $P_4 = \frac{P_3}{\left(\frac{V_4}{V_3}\right)^k}$

$= 6953\left(1.5(7)\right)^{(-1)(-k)}$

$\boxed{P_4 = 258.5\text{ kPa}}$

$\frac{V_4}{V_3} = 1.5(7)$

$Pv = RT$

$v_2 = v_3 = \frac{RT_2}{P_2} = \frac{.2870(616.34)}{1372} = .1289$

$P_3 = \frac{.2870(3123)}{.1289} = 6953\text{kPa}$

f) $T_5 = ?$ Const volume heat rejection (4-5)

${}_4q_5 = c_v(T_5 - T_4)$

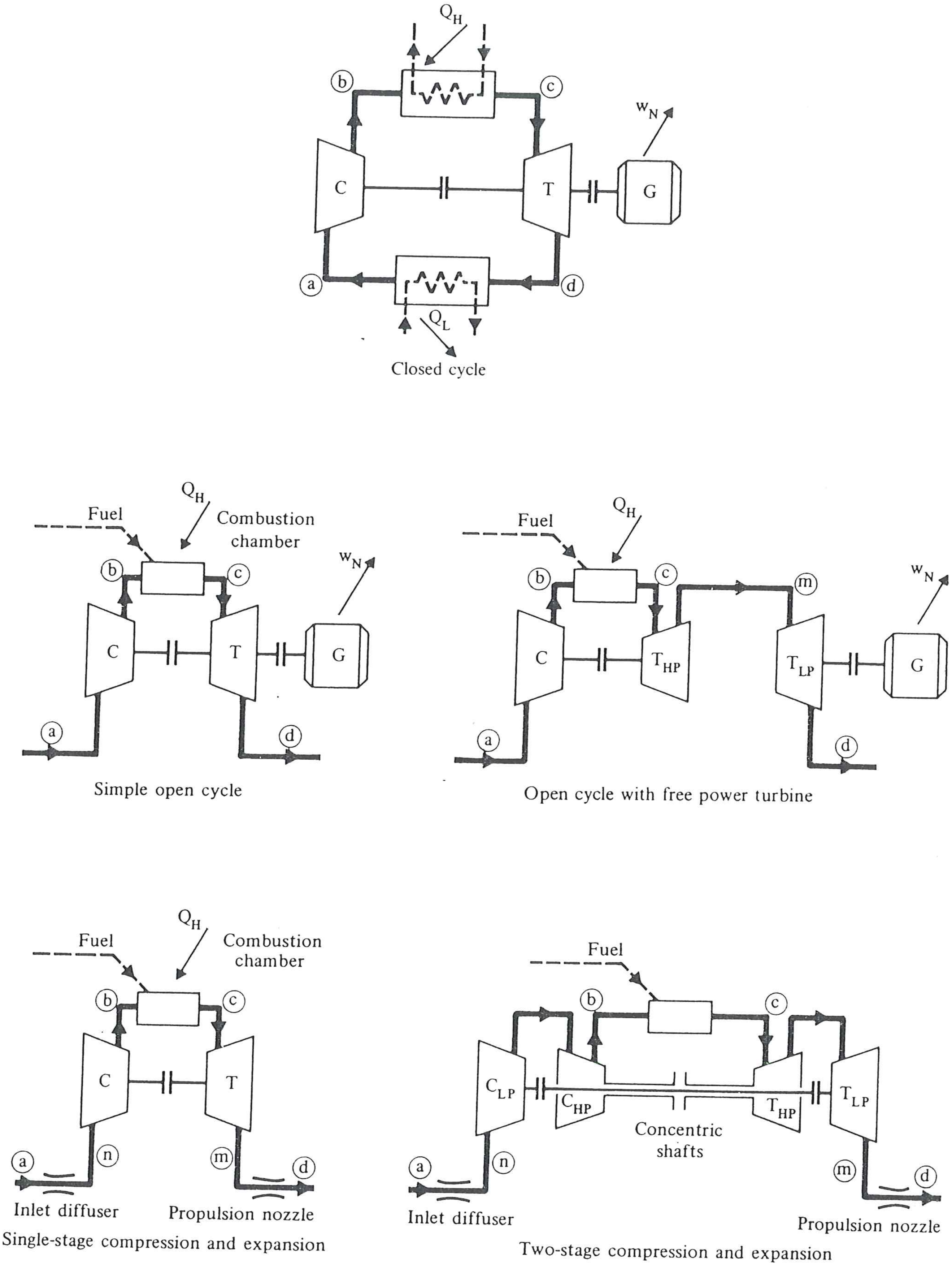
$Pv = RT$

$T_5 = \frac{P_1 v_4}{R} = \frac{P_1 \cancel{R} T_4}{\cancel{R} P_4} = \frac{90(1219)}{258.5}$ $\quad \boxed{T_5 = 424.4\text{K}}$

$V_4 = \frac{R T_4}{P_4} \nearrow$

g) find work during const pressure process $\quad w = \int p\,dV \quad {}_5w_1 = \int_5^1 P\,dv$

${}_5w_1 = 90(v_1 - v_5) = 90(.9025 - 1.353)$ $\quad \boxed{{}_5W_1 = -40.55}$



Closed cycle

Simple open cycle

Open cycle with free power turbine

Single-stage compression and expansion

Two-stage compression and expansion

Turbo-jet propulsion cycles

FIG. 1.36 Variations of the Brayton cycle.

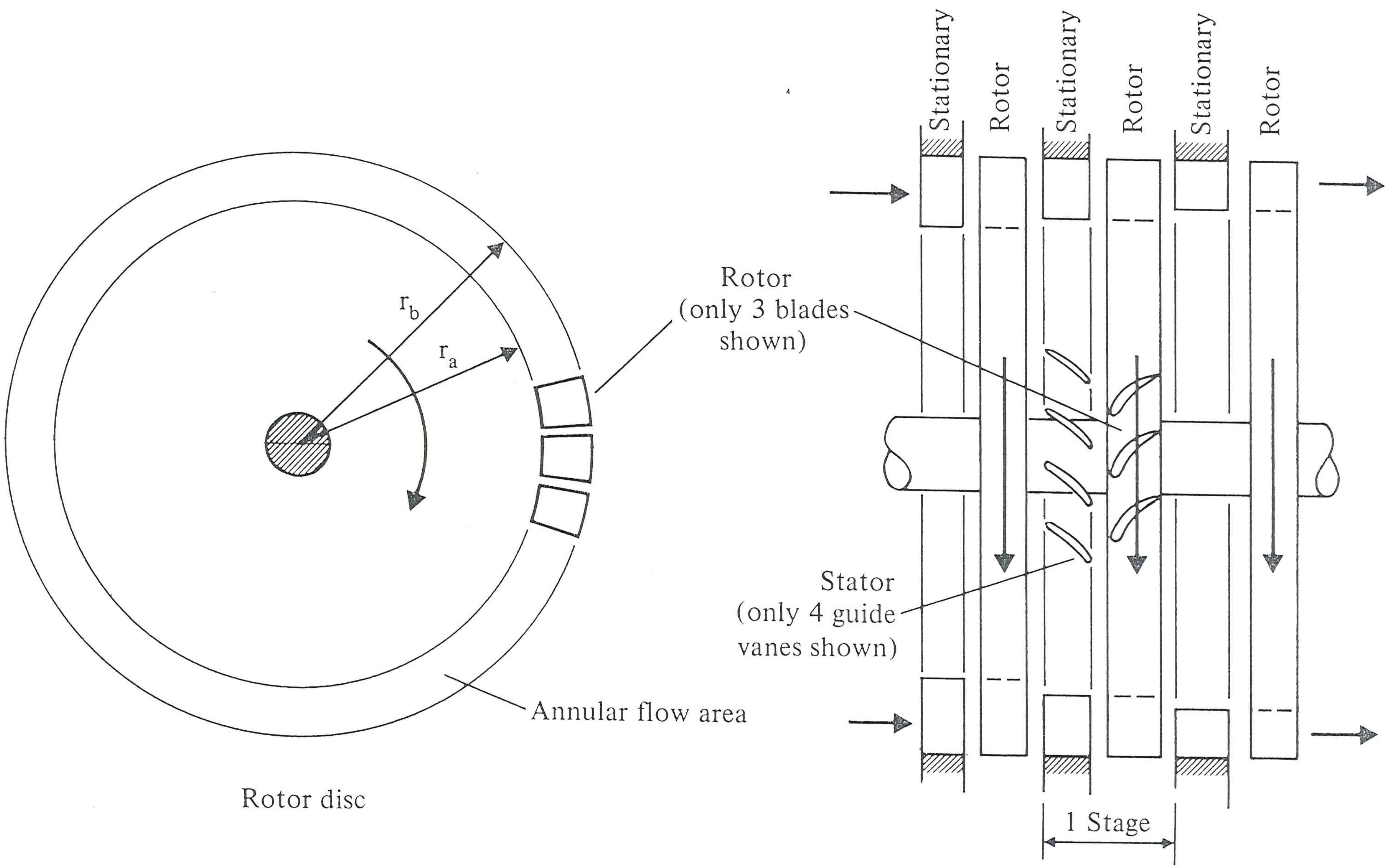


FIG. 3.37 An axial-flow compressor (schematic).

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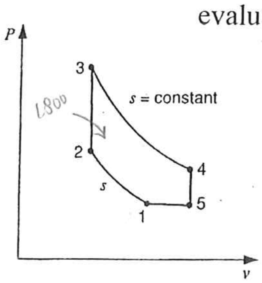
ME 221 Applied Thermodynamics
Fall 2010

D.10 A Miller cycle can be used to model an engine that has a longer expansion process than the compression process, as shown in the pressure-volume diagram below. This difference in compression and expansion ratios can be achieved using variable valve timing such as in the Toyota hybrid system. For the problem below using air, the inlet temperature and pressure at state 1 are $\boxed{283\text{ K}}$ and $\boxed{90\text{ kPa,}}$ respectively. The constant volume heat input is $\boxed{1800\text{ kJ/kg.}}$ The compression ratio (i.e. V_1/V_2) is 7 whereas the expansion ratio (i.e. V_4/V_3) is 1.5 times larger, i.e. $V_4/V_3 = 1.5(V_1/V_2)$. Assume ideal gas behavior and **constant specific heats** evaluated at 300K.



Process 1-2 and 3-4 are isentropic

Process 5-1 is constant pressure

a) Find the temperature at the end of compression **and** the compression work, $_1w_2$
b) Find the temperature after the constant volume heat addition, T_3
c) Find the temperature after expansion, T_4
d) Find the expansion work, $_3w_4$
e) Find the pressure after expansion, i.e. P_4
f) Find the temperature after the constant volume heat rejection process, i.e. T_5
g) Find the work during the constant pressure process, state 5 to state 1. (kJ/kg)

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D.11 An ideal Stirling cycle uses 0.12 kg of air as the working fluid. The lower temperature at which energy is exchanged is 300 K while the upper temperature is 2000 K. Air is at 150 kPa at the beginning of compression and the peak pressure is 3 MPa. Assume that an ideal regenerator is used. Determine a) the energy captured and supplied by the regenerator, b) the net work from the cycle, c) the thermal efficiency of the cycle. Assume constant specific heats.

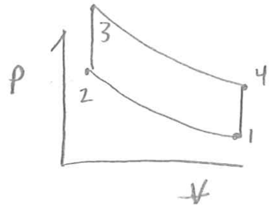
① $T = 300K$
$P = 150 kPa$

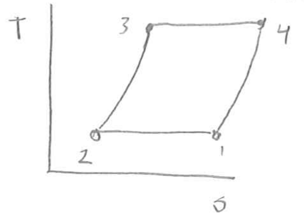
② $T = 300k$

③ $T = 2000k$
$P = 3 MPa$

④ $T =$

$m = 0.12g$
$q_{reg} = {}_2q_3$





$R_{air} = .2870$
$c_v = .718$
$c_p = 1.005$

(1-2) isothermal compression $\quad {}_1q_2 - {}_1w_2 = u_2 - u_1 = 0 \quad (T_2 = T_1)$

$${}_1q_2 = {}_1w_2 = \int P\,dV \qquad P = \frac{RT}{v} \qquad {}_1q_2 = RT\int\frac{dv}{v} = RT\ln\left(\frac{v_2}{v_1}\right) = RT\ln\left(\frac{P_1T_3}{\cancel{P_1}P_3}\right)$$

$$= (.287)(300)\ln\left(\frac{150 \cdot 200}{300 \cdot 3000}\right) = -94.59\ kJ/kg$$

(2-3) ${}_2w_3 = 0$ Const. V heat add'n $\quad {}_2q_3 = u_3 - u_2 = c_v(T_3 - T_2) = .718(2000 - 300)$

$${}_2q_3 = 1221\ kJ/kg \leftarrow x(.12kg) \qquad \boxed{{}_2Q_3 = 146.5\ kJ}$$

isothermal expansion
(3-4) $${}_3q_4 = {}_3w_4 = RT_3\ln\left(\frac{v_4}{v_3}\right) = RT_3\ln\left(\frac{T_1P_3}{P_1T_3}\right) = .287(2000)\ln\left(\frac{300 \cdot 3000}{150 \cdot 2000}\right) = 630.6\ kJ/kg$$

(4-1) const. V heat rejection

$${}_4q_1 = c_v(T_1 - T_4) = .718(300 - 2000) = -1221\ kJ/kg$$

$$W_{net} = m({}_1w_2 + {}_3w_4) = .12kg(-94.59 + 630.6) = \boxed{64.32kJ}$$

$$\eta_{th} = \frac{W_{net}}{q_{in}} = \frac{64.32\ kJ}{(630.6)(.12kg)} = \boxed{85\%}$$

Hw #9

$\textcircled{9}$

David Malawey 9-16-16

ME 221 Applied Thermodynamics
Fall 2010

D.6 A spark ignition engine is to be modeled using an ideal Otto cycle. The working fluid, air, is at 95 kPa and 290 K before compression. The compression ratio is 9 and the maximum temperature is 2000 K. For the calculations below **use variable specific heats** (Do not interpolate, enter the table by choosing the value in the table closest to your calculated value).

a) Find the pressure and temperature at the end of compression.
b) Find the required heat input into the cycle on a specific basis.
c) Find the net specific work from the cycle.
d) Find the cycle thermal efficiency
e) Find the maximum pressure in the cycle as predicted by the model.

①	②	③	④	
$P = 95\,kPa$	$P = 1995$	$P =$		$r = 9 = \frac{V_1}{V_2}$
$T = 290\,K$	$T = 620\,K$	$T = 2000\,K$	$T = 1100\,K$	

a) isentropic compression $\frac{V_2}{V_1} = \frac{1}{7} = \left(\frac{V_{R,T_2}}{V_{R,T_1}}\right)$ $\frac{V_{R,T_2} = 96.59}{676.1}$ $\Rightarrow \boxed{T_2 = 620\,K}$

$0 = S^0_{T_2} - S^0_{T_1} - R\ln\left(\frac{P_2}{P_1}\right) \Rightarrow e^{\left(\frac{2.54175 - 1.66802}{.2870}\right)} = \frac{P_2}{P_1} \Rightarrow \boxed{P_2 = 1995\,kPa}$

b) V const heat addition

${}_2Q_3 = u_3 - u_2$ $(1678.7 - 450.09)\frac{kJ}{kg}$ $\boxed{{}_2q_3 = 1229\,kJ/kg}$

c) isentropic expansion $w_{net} = {}_2q_3 + {}_4q_1 \Rightarrow v_{r_3} = f(T_3) = 2.776$

$v_{r_4} = 7(2.776) = 19.432 \Rightarrow T_4 = 1100\,k$ $u_4 = 845.33$

$w_{net} = 1229\frac{kJ}{kg} + (206.91 - 845.33)\frac{kJ}{kg} = \boxed{590.58\,\frac{kJ}{kg}}$ low

d) $\eta_{th} = \frac{w_{net}}{q_{in}} = \frac{590.58}{1229} = \boxed{48.05\%}$ ok

e) $P_{max} = P_3$ $\frac{P_2 \cancel{V_2}}{\cancel{R}T_2} = \frac{P_3\cancel{V_3}}{\cancel{R}T_3}$ $P_3 = \frac{1995}{620}(2000)$ $\boxed{P_3 = 6435\,kPa}$ high

-1

David Malawey

ME 221 Applied Thermodynamics
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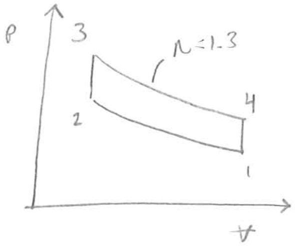
D.7 An Otto cycle is to be used to model an engine cycle. All assumptions of the ideal Otto cycle are to be applied except a **polytropic process** with n = 1.3 will be used for the **expansion process**. The conditions at the beginning of compression are $T_1 = 333$ K, $P_1 = 90$ kPa and the compression ratio is 8. The energy input into the cycle during the constant volume process is 2000 kJ/kg. **Assume constant specific heats.**

$_1q_2$

a) Find the temperature (K) and pressure (kPa) after compression
b) Find the peak temperature of the cycle. (K)
c) Find the temperature at the end of the expansion process. (K)
d) Find the expansion work (kJ/kg)
e) Find the **net** heat transfer for the cycle (kJ/kg)



① P = 90kPa, T = 333K

② P = 1654 kPa, T = 765 K

③ T = 3554 K

④

r = 8

a) isentropic compression $T_2 = T_1\left(\frac{v_1}{v_2}\right)^{k-1} = 333\text{ K}\,(8)^{0.4} = \boxed{765\text{ K}}$

$P_2 = P_1\left(\frac{v_1}{v_2}\right)^{k} = 90\text{ kPa}\,(8)^{1.4} = \boxed{1654\text{ kPa}}$

b) v const q in $_2q_3 = u_3 - u_2 = C_v(T_3 - T_2)$ $T_3 = \frac{_2q_3}{C_v} + T_2 = \frac{2000}{.717} + 765 = \boxed{3554\text{ K}}$

c) polytropic expansion

$P_3 V_3^{\,n} = P_4 V_4^{\,n}$ $\frac{P_4}{P_3} = \left(\frac{V_3}{V_4}\right)^n = \left(\frac{1}{r}\right)^n$ $P_3 = \frac{RT_3}{V_3}$ $P_4 = \frac{RT_4}{V_4}$

$\frac{T_4}{T_3} = \left(\frac{V_3}{V_4}\right)^{n-1} = \left(\frac{1}{r}\right)^{n-1}$ $T_4 = 3554\text{ K}\left(\frac{1}{8}\right)^{0.3} = \boxed{1905\text{ K}}$

d)

e) $q_{net} = w_{net} = {}_1w_2 + {}_3w_4$ $\cancel{{}_1q_2}^{\,0} - {}_1w_2 = u_2 - u_1 = C_v(T_2 - T_1) \Rightarrow {}_1w_2 = .717\,\frac{\text{kJ}}{\text{kg}\cdot\text{K}}(333 - 765)$

${}_1w_2 = -309.7\ \frac{\text{kJ}}{\text{kg}}$ $q_{net} = 1578 - 309.7 = \boxed{1268\ \text{kJ/kg}}$

d) Polytropic expansion ${}_3w_4 = \left(\frac{R}{1-n}\right)(T_4 - T_3) = \frac{.287\ \text{kJ/kg K}}{(1-1.3)}(1905 - 3554\text{ K}) = \boxed{1578\ \text{kJ/kg}}$

David Malawey

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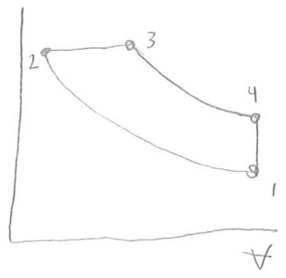

ME 221 Applied Thermodynamics
Fall 2010

D.8 The processes within an engine are to be modeled using an ideal Diesel cycle with a compression ratio of 14.84. The cylinder has a volume of 0.0005 m^3 before compression (state 1). At this state (state 1) the temperature is 300 K and the mass of air is 0.001 kg. Energy, equivalent to 1.386 kJ, is added to this ideal Diesel cycle as heat addition. For the calculations below **use variable specific heats** (Do not interpolate, enter the table by choosing the value in the table closest to your calculated value).

a) Find the temperature and pressure at the end of compression (K, kPa)
b) Find the temperature after the heat addition (K)
c) Find the temperature after expansion (K)
d) Find the total heat rejected from the cycle (kJ)
e) Find the thermal efficiency of the cycle

① $\forall$ .0005 m^3
$T = 300$k
$P = 172$ kPa

② $\forall = 3.37E-5$
$\boxed{T_2 = 840\text{K} \quad P_2 = 7154 \text{ kPa}}$

③ $\boxed{T = 2000\text{ K}}$

④ $\boxed{T = 1140\text{K}}$
$U = 880.35$

a) $P_1 = \frac{mRT_1}{\forall_1} = \frac{.001\text{kg}(.287 \frac{kJ}{kg \cdot K})(300k)}{.0005 \text{ m}^3} = 172.2 \text{ kPa}$

(1-2) isentropic compression

$\frac{1}{14.84} = \frac{V_{R,T_2}}{V_{R,T_1} \underline{621.2}}$ $P_2 = \frac{.001\text{kg}(.287)(840)}{3.37E-5}$

b) (2-3) const p heat addition ${}_2q_3 = h_3 - h_2$ $h_3 = 866.08 \text{kJ/kg} (.001 \text{kg}) + 1.386 = 2252 \text{kJ/kg}$
$T_3 = 2000$k

c) isentropic expansion $V_{r_4} = V_{r_3}(r)\left(\frac{T_2}{T_3}\right)$ $T_4 = 1140$K

d) ${}_4q_1 = u_1 - u_4 = 214.07 - 880.35 = -511 \text{ kJ/kg} (.001 \text{kg}) = \boxed{.667 \text{ kJ}}$ heat rejected

e) $\eta_{th} = \frac{h_3 - h_2 - (u_4 - u_1)}{(h_3 - h_2)} = \frac{1386 \text{ kJ/kg} - (880 - 214))}{1386}$

$\boxed{\eta_{th} = 51.9\%}$

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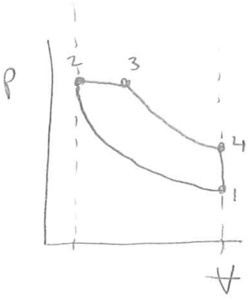
D.9 At the beginning of compression in an ideal diesel cycle, T = 300 K, P = 100 kPa. After combustion (heat addition) is complete, T = 1800 K. The cycle has a compression ratio of 18.11 Assume ideal gas behavior but **do not assume constant specific heats** (i.e. use variable specific heats).

a) Find the temperature after compression
b) Find the energy into the cycle
c) Find the temperature at the end of the expansion process.
d) Find the thermal efficiency.



$r = 18.11$

① $T = 300\,k$
$P = 100\,kPa$
$h = 300.19$
$u = 214.07$

② $T = 900\,k$
$P =$
$h = 932.93$
$u = 674.58$

③ $T = 1800\,k$
P
$h\ 2003.3$
u

④ $T = 876\,k$
$u = 661.13$

(1-2) isentropic compression

$$\frac{V_2}{V_1} = \frac{V_{r_1}, T_2}{V_{R_1} T_1} = \frac{1}{18.11} \quad \frac{\quad}{621.2}$$

$$\boxed{T_2 = 900\,K}$$

(2-3) const. P $q_{in} = h_3 - h_2 = 2003.3 - 932.93$ $\boxed{{}_2q_3 = 1070.4\ \frac{kJ}{kg}}$

(3-4) isentropic expansion

$$r\left(\frac{T_2}{T_3}\right) = \frac{V_{r_4}}{V_{r_3}} = \quad = V_{r_4} = 3.994\,(18.11)\left(\frac{1}{2}\right)$$

$$\boxed{T_4 = 876\,k}$$

$$\eta_{th} = \frac{w_{net}}{{}_2q_3} = \frac{h_3 - h_2 - u_4 - u_1}{h_3 - h_2}$$

$h_3 - h_2 = 2003.3 - 932.9 = 1070.4\ kJ/kg$

$u_4 - u_1 = 661.13 - 214.07 = 447.06\ kJ/kg$

$$\boxed{\eta_{th} = 58.2\ \%}$$

David Malaney

10

ME 221 Applied Thermodynamics
Fall 2010

D.3 An adiabatic turbine operates using air at a flow rate of 5 kg/s. Air enters the turbine at 550 kPa and 425 K. The measured conditions of the air leaving the turbine are 100 kPa and 325K. Take ambient temperature to be 298K and pressure to be 100 kPa. Assume constant specific heats for air at 300K.

a) Find the exergy flow of the state entering the turbine.
b) Find the actual power from the turbine.
c) Find the maximum power that could be extracted from the turbine given the measured inlet and exit states.
d) Find the first law (thermal) and second law efficiencies.
e) Find the exit temperature if the turbine was isentropic, assuming the same exit pressure.

a) $\psi = (h-h_0) - T_0(s-s_0) + \cancel{\frac{V^2}{2}}^{0} + \cancel{gz}^{0}$

$= \cancel{(426.35 - 298.18)} -$

$C_p(\Delta T) \quad T_0\left[c_p \ln\frac{T_1}{T_0} - R\ln\frac{P_1}{P_0}\right] = 1.005(127) - 298\left[1.005\ln\left(\frac{425}{298}\right) - .287\ln\left(\frac{550}{100}\right)\right]$

$\psi_1 = 167.117\ \frac{kJ}{kg}\,(5\ kg/s) = \boxed{835.58\ kW}$

b) $\dot{W}_{actual}$. $\quad \cancel{\dot{Q}}^{0} - \dot{W} = \dot{m}\Delta h \qquad -\dot{W} = \dot{m}\ \overset{c_p\Delta T}{1.005(425-325)}$

$\boxed{\dot{W} = 502.5\ \cancel{\frac{kJ}{s}}\ kW}$ OK

c) $\delta\psi = C_p(T_1 - T_2) + T_0\left(c_p\ln\frac{T_1}{T_2} - R\ln\frac{P_1}{P_2}\right)$

$= 1005(425-325) - 298\left[1.005\ln\left(\frac{425}{325}\right) - .287\ln\left(\frac{550}{100}\right)\right]$

$= (100.5 + 65.458)\,\dot{m}$

$= \boxed{829.79\ kW}$ maximum power that could be ext. (W_{rev})

d) $\eta_I = \frac{\dot{W}_{out}}{\dot{Q}_{in}} = \frac{502.5}{2135.6} \qquad \dot{Q}_{in} = \dot{m}\,C_p(T_{in}) = 5\ kg/s\ 1.005\ \frac{kJ}{kg\cdot K}\,(425\ K)$

$\boxed{\eta_I = .2353}$

$\eta_{II} = \frac{502.5}{829.79} = \boxed{\eta_{II} = .606}$

e) $s_1 - s_2 = 0 \qquad c_p\ln\frac{T_1}{T_2} = R\ln\frac{P_1}{P_2} \qquad 1.005\ln\left(\frac{425}{T_2}\right) = .287\ln\left(\frac{550}{100}\right)$

$\ln(\ ) = .4868$

$\frac{425}{T_2} = 1.627$

$\boxed{T_2 = 261\ K}$

HW#

ME 221 Applied Thermodynamics
Fall 2010

D2. Air enters a steady flow turbine at 1600 K, 3000 kPa and the measured conditions at the exit are 1000 K and 100 kPa. The ambient temperature is 298 K. a) What is the maximum work that could be extracted out of this turbine? (kJ/kg). b) What would be the work output if the turbine was assumed adiabatic? For both parts, assume ideal gas behavior but **do not assume constant specific heats** (i.e. use variable specific heats). $W_{max} = \Delta X$

$\psi_1 = (h - h_0) - T_0(s - s_0)$

$h\langle 1600\rangle - h\langle 298\rangle$

$\psi_1 = (1757.57 - 298.18) - 298(\qquad) = 913.97$

1000k $\psi_2 = (1046.04 - 298.18) - 298(\qquad) =$

$s_1 - s_2 = s_1^{\circ} - s_2^{\circ} - R \ln \frac{P_1}{P_2} = 3.52364 - 2.96720 - .287 \ln\left(\frac{3000}{100}\right)$

$s_1 - s_2 = -.4207 \ \frac{kJ}{kg\,k}$

$\overset{\Delta h}{711.53} - (\overset{T_0\,ds}{298 \cdot -.4207})$

a) $\boxed{W_{max} = 836.90 \ kJ/kg}$ ✓

b) $\cancel{Q}^{0} - {}_1W_2 = \Delta E_{internal}$

$-W = h_2 - h_1 = \quad -$

$\boxed{W = 711.53 \ kJ/kg}$

David Malaway

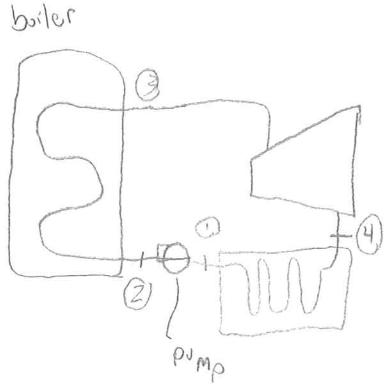
10.17) Rankine Cycle $\dot{m} = 50 kg/s$

$\dot{W}_{turbine}$?

$\dot{W}_{pump} = ?$

shv

① P= 30kPa	② P= 3MPa	③ P=3MPa	④ P= 30kPa
T=	T=	T= 700C	T= 69.09
h=251.42		h= 3912.2	h= 2621.8
v= .001017		S= 7.7590	S= 7.7590



$$\cancel{{}_3q_4}^{0} - {}_3w_4 = h_4 - h_3 \qquad {}_3w_4 = h_3 - h_4$$

$$S_3 = S_4 \qquad S_4 = S_f\langle 30kPa\rangle + x\,S_{fg}\langle 30kPa\rangle$$

$$7.759 = .9441 + x(6.8234)$$

$$x_4 = .9988 \qquad h_4 = 289.27 + .9988(2335.3) = 2621.8$$

$$\dot{W}_{turbine} = \dot{m}(h_3 - h_4) = \boxed{64{,}520\ kJ/s}$$

$$\dot{W}_{pump} = (v\,dP)\,\dot{m}$$

$$= .00107(3{,}000 - 30)(50 kg/s)$$

$$\boxed{\dot{W}_{pump} = 158.90 kW}$$

David Malawey

⑩

ME 221 Applied Thermodynamics
Fall 2010

Due friday 10-1-10

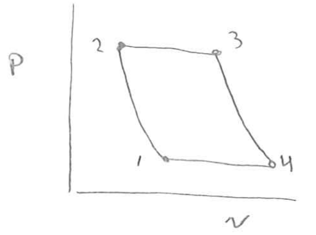
D.14 A simple gas turbine system is to be modeled using a Brayton cycle. Air enters the compressor at 100 kPa and 300K. The compressor has a pressure ratio of 10 and an isentropic efficiency of 85% (i.e. $\eta_C = 0.85$). Due to flow losses in the combustor the air enters the turbine at 950 kPa and 1400 K. The turbine has an exit pressure of 100 kPa and an isentropic efficiency of 88% (i.e. $\eta_T = 0.88$). Assume constant specific heats. (i.e. $C_v = 0.717$ kJ/kgK, $C_p = 1.004$ kJ/kgK).

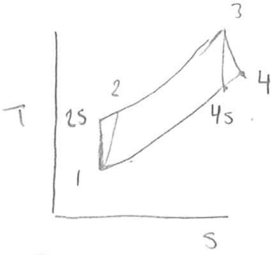
a) Sketch the T-s diagram for the entire system including both the isentropic and actual states for the compressor and turbine. Label the states.

b) Find the actual compressor work (kJ/kg).

c) Find the actual turbine work (kJ/kg)

c) Find the heat transfer into the combustor (kJ/kg)





isentropic

(1-2) isent. comp. $\cancel{\dot{Q}}_{2} - {}_1\dot{W}_2 = \dot{m}(h_2 - h_1)$

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{k-1/k} = 300(10)^{\frac{.4}{1.4}} = 579.2\ \text{K}$$

$$\eta_c = .85 = \frac{W_{cs}}{W_c} = \frac{\cancel{\dot{m}}(h_1 - h_2)_s}{\cancel{\dot{m}}(h_1 - h_2)_{actual}}$$

① 100kPa
300 K

② 1000kPa
$\boxed{579.2K}$ isent.

③ 950kPa
1400K

④ 100kPa

h =

$$.85 = \frac{C_p(T_1 - T_2)_{isen}}{\dot{W}_{actual}} =$$

$$\dot{w}\ actual = \frac{(-280.3)(1.004)}{.85}$$

$$\boxed{W_{compressor} = 388.0\ \frac{kJ}{kg}}$$

$$T_4 = T_3\left(\frac{P_4}{P_3}\right)^{\frac{k-1}{k}} \qquad T_4 = 1400\left(\frac{100}{950}\right)^{\frac{.4}{1.4}} \qquad 735.8\ k$$

$$\Rightarrow W_{TS} = C_p(T_3 - T_{4s}) = 666.8\ kJ/kg \qquad W_{t,act} = \eta_T W_{Ts} = .88(666.8) = \boxed{W_T = 586.8\ kJ/kg}$$

$$q_{in} = h_3 - h_2 = C_p(T_3 - T_2) \qquad W_{c,act} = C_p(T_1 - T_2)$$

$$T_2 = T_1 - \frac{W_{c,act}}{C_p} = 300 - \frac{-329.8}{1.004} = 628.5k$$

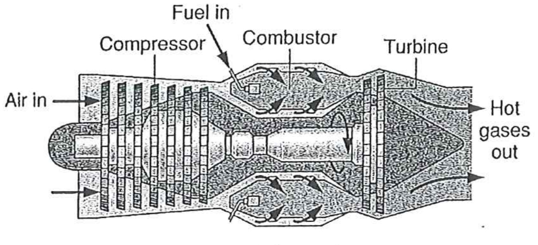
$$q_{in} = 1.004(1400 - 628.5)$$

$$\boxed{q_{in} = 774.6\ kJ/kg}$$

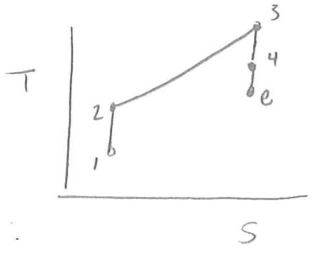
David Malawey

ME 221 Applied Thermodynamics
Fall 2010

D.15 Air enters the compressor of turbo-jet engine, modeled as an ideal air-standard Brayton cycle, at 85 kPa and 270 K. The turbine inlet temperature is 1200 K and the turbine inlet pressure is 800 kPa. Assume an isentropic compressor, turbine and exit nozzle. The ambient pressure is 80 kPa. Assume constant specific heats (i.e. $C_v = 0.717$ kJ/kgK, $C_p = 1.004$ kJ/kgK, $k = 1.4$).



Turbojet engine



a) Find the temperature after the compressor. (K)
b) Find the specific compressor work (kJ/kg)
c) Find the temperature of the flow exiting the turbine (**before** the nozzle) (K)
d) Find the pressure of the flow exiting the turbine (**before** the nozzle) (kPa)
e) Find the temperature of the flow **after** the nozzle assuming it exits at ambient pressure. (K)
e) Find the exit velocity. (m/s)

a) T_2: $T_1 = 270\,k$ $P_1 = 85\,kPa$ $P_2 = P_3 = 800\,kPa$ $T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} = 270\left(\frac{800}{85}\right)^{.4/1.4}$

$\boxed{T_2 = 512.3\,k}$

b) $W_c = C_p(T_1 - T_2)$ $w_c = 1.004(270 - 512.3) = \boxed{-243.3\,kJ/kg}$ W_c

c) T_4 : $W_c = -W_T = 243.3\,kJ/kg = C_p(T_3 - T_4) = 1.004(1200 - T_4)$

$\boxed{T_4 = 957.7\,k}$

d) Find P_4: $P_4 = P_3\left(\frac{T_4}{T_3}\right)^{k/k-1} = 800\left(\frac{957.7}{1200}\right)^{1.4/.4} = \boxed{363.2\ kPa = P_4}$

e) T_e: $T_e = T_4\left(\frac{P_e}{P_4}\right) = 957.7\left(\frac{80}{363.2}\right)^{.4/1.4} = \boxed{621.6\,k}$ isentsopic nozzle

f) V_e: $h_4 = h_e + \frac{V_e^2}{2}$ $C_p(T_4 - T_e) = \frac{V_e^2}{2} = 1004(957.7 - 621.6)$

$\boxed{V_e = 821.5\ m/s}$

David Malawey

(9)

ME 221 Applied Thermodynamics
Fall 2010

D1. Air in a piston/cylinder arrangement undergoes a **polytropic expansion process** (i.e. Pv^n = constant) with n = 1.5. Initially the air is at 3 MPa and 3000 K (i.e. state 1) and the gas expands to 1 MPa (state 2). Assume ideal gas behavior and **constant specific heats** evaluated at 300K. Assume ambient (or dead state) conditions of 298 K and 100 kPa.

a) Find the temperature at state 2. (K)
b) Find the expansion **work** given the polytropic expansion from state 1 to state 2. (kJ/kg)
c) Find the **heat transfer** given the work and states 1 and 2 (kJ/kg).
d) Find the **maximum work** that could be extracted out of this process between states 1 and 2. (kJ/kg)
e) If the air was expanded **isentropically** from the given T and P at state 1 to the pressure at state 2 (i.e. 1 MPa), find the expansion work. (kJ/kg)

David Malawey

D1

$Pv^{1.5} = \text{const.}$ Ideal gas behavior, constant C_p, C_v, < 300k >

① $P = 3MPa$
$T = 3000k$

② $P = 1MPa$

Surr $T = 298k$
$P = 100kPa$

Air $k = 1.4$
$R = .287$
$C_v = .718$ < 300k >

a) $T_2 = ?$ $\quad \frac{T_2}{T_1} = \left(\frac{P_2}{P_1}\right)^{n-1/n}$ $\quad T_2 = 3000\left(\frac{1}{3}\right)^{\frac{(1.5-1)}{(1.5)}}$
$= \boxed{2080K}$

b) $W_{expansion}$ given polytropic exp. from state 1 to 2

$W_b = \frac{P_2V_2 - P_1V_1}{1-n} = \frac{.287(2080-3000)}{1-1.5} = \boxed{528.08\ kJ/kg}$ W_b work done by system

$Pv = RT$

$v_1 = \frac{.287(3000)}{3000} = .287\ m^3/kg$ $\quad v_2 = \frac{.287(2080)}{1000} = .5970\ m^3/kg$ $\quad v_0 =$

c) ${}_1q_2 - {}_1W_2 = (u_2 - u_1) = c_v(T_2 - T_1)$

${}_1q_2 = 528.08\ kJ/kg + .718(2080-3000)$

$\boxed{{}_1q_2 = -132.48\ kJ/kg}$ heat into system

d) $W_{max\ available} = X_1 - X_2 = u - u_0 + P_0(V - V_0) - T_0(S - S_0)$

$u - u_0 = C_v(T - T_0) = .718(2080-3000) = -660.56$

$P_0(v - v_0) = 100(.5970 - .287) = 31.0$

$T_0(s - s_0) = 298(-.054) = -16.09$

$s_1 - s_0 = C_p \ln\frac{T}{T_0} - R\ln\frac{P_1}{P_0} = 1.005\ln\left(\frac{3000}{298}\right) - .287\ln\left(\frac{3000}{100}\right) = 1.345\ \frac{kJ}{kg}\cdot K$

$s_2 - s_0 = C_p \ln\frac{T_2}{T_0} - R\ln\frac{P_2}{P_0} = 1.005\ln\left(\frac{2080}{298}\right) - .287\ln\left(\frac{2080}{100}\right) = 1.291$

$s_2 - s_1 = -0.054$

$X_1 - X_2 = +660 \overset{(-)}{*} 31.0 \overset{(-)}{\times} 30.99 = \boxed{614.2\ kJ/kg}$ $W_{available}$ State1 → state 2 e)

Isentropic expansion $\quad {}_1W_2 = ?$

K = . ~~2870~~ 1.400

T_1 3000 K

P_1 3000 Pa $\quad P_2 = 1000$ K

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

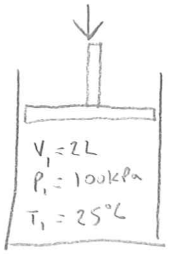
~~$$T_2 = 3000\left(\frac{1}{3}\right)^{.4/1.4} = 2191.8$$~~

$$Q_{in} - W_{out} = \Delta u$$

$$W = \frac{kRT_1}{k-1}\left(\left|\frac{P_2}{P_1}\right|^{\frac{k-1}{k}} - 1\right) = \frac{1.4(.278)(3000)}{0.4}\left(\left|\frac{1}{3}\right|^{\frac{.4}{1.4}} - 1\right) = \boxed{\cancel{-786.38\ \frac{kJ}{kg}}}$$

David Malawey

8.33)



100kPa, 25°C

② $P = 600kPa$
$T = 150°C$
$W_{useful,in} = 1.2kJ$

① <u>dead State</u>
ϕ air initial & final

$X_{initial} =$

$R = .287\ kPa\, m^3 / kg \cdot K$

$C_{p,avg} = 1.009$

$C_{v,avg} = .722\ kJ/kg \cdot K$

$$m = \frac{P_1 \forall_1}{RT_1} = \frac{600(2L)}{.287(25+273)} = 0.00234\,kg$$

$$\frac{P_2 \forall_2}{T_2} = \frac{P_1 \forall_1}{T_1} \quad \forall_2 = \frac{T_2}{T_1}\left(\frac{P_1}{P_2}\right)\forall_1 = \frac{423K \cdot 100kPa}{298K \cdot 600kPa}(2L) = .473L \qquad V_2 \cdot .473L$$

$$S_2 - S_0 = C_{p,avg} \ln \frac{T_2}{T_0} - R \ln \frac{P_2}{P_0} = 1.009 \ln \frac{423K}{298K} - .287 \ln \frac{600}{100\,kpa} = -.1608\ kJ/kg \cdot K$$

$$X_2 = \Phi_2 = m\left[C_{v,avg}(T_2 - T_0) - T_0(S_2 - S_0)\right] + P_0(\forall_2 - \forall_0)$$

$$= .00234\left[.722(423-298) - 298(-.1608)\right] + 100(.000473 - .002)$$

$$= \boxed{0.171\ kJ}$$

b) min work input $\quad X_{dest} = 0 \qquad X_{in} - X_{out} = \Delta X_{system}$

$$W_{rev,in} = X_2 - X_1 = 0.171 - 0 = \boxed{0.171\ kJ}$$

c) 2nd law efficiency $\eta_{II} = \dfrac{W_{rev,in}}{W_{u,in}} = \dfrac{.171\ kJ}{1.2\ kJ} = \boxed{14.3\%}$

ME 221 Applied Thermodynamics
Fall 2010

D1. Air in a piston/cylinder arrangement undergoes a **polytropic expansion process** (i.e. Pv^n = constant) with n = 1.5. Initially the air is at 3 MPa and 3000 K (i.e. state 1) and the gas expands to 1 MPa (state 2). Assume ideal gas behavior and **constant specific heats** evaluated at 300K. Assume ambient (or dead state) conditions of 298 K and 100 kPa.

a) Find the temperature at state 2. (K)
b) Find the expansion **work** given the polytropic expansion from state 1 to state 2. (kJ/kg)
c) Find the **heat transfer** given the work and states 1 and 2 (kJ/kg).
d) Find the **maximum work** that could be extracted out of this process between states 1 and 2. (kJ/kg)
e) If the air was expanded **isentropically** from the given T and P at state 1 to the pressure at state 2 (i.e. 1 MPa), find the expansion work. (kJ/kg)

David Malawey

Thermo II

10

7.93, 7.128, 8.22

7.93)

reversible
adiabatic
(isentropic)

$R = .287 \ kJ/kg \cdot k$

$k = 1.4$

$T_1 = 290K$

Const. specific heats

a) $T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{(k-1)/k} = 290k \left[\frac{800kPa}{100kPa}\right] = \boxed{525.3 \ k}$

$T_{avg} = \frac{290 + 525.3}{2} = 407.7 \quad C_{v, avg} = .727 \ kJ/kg \cdot k$

$E_{in} - E_{out} = \Delta E_{sys} \qquad W = \Delta U = m(u_2 - u_1) \equiv mC_v(T_2 - T_1)$

$W_{in} = C_{avg}(T_2 - T_1) = (.727)(525.3 - 290)K = \boxed{W = 171.1 \ kJ/kg \quad \text{into system}}$

Variable specific heats

b) $T_f =$ $\qquad T_1 = 290k \rightarrow P_{r_1} = 1.2311$

$u_1 = 206.41 \ kJ/kg$

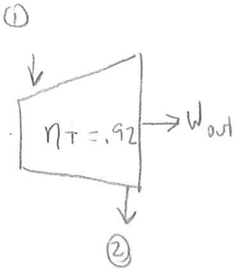
$P_{r_2} = \frac{P_2}{P_1} P_{r_1} = \frac{800 kPa}{100kPa}(1.2311) = 9.849 \qquad \boxed{T_2 = 522.4 \ k}$

$u_2 = 376.16 \ kJ/kg$

$W = u_2 - u_1 = 376.16 - 206.91 \ kJ/kg = \boxed{169.25 kJ/kg}$ Work in

7.128)

$\dot{E}_{in} = \dot{E}_{out}$ (steady)



① $P = 3MPa$

$T = 400°C$

$h = 3231.7$

$S = 69235$

② $P = 30kPa$ adiabatic

$S = 69235$

$x_2 = \frac{S_{2s} - S_f}{S_{fg}} = \frac{6.9235 - .9441}{6.8234} = .8763$

$h_2 = 289.27 + (.8763)(2335.3) = 2335.7$

$\dot{W}_{out} = \eta_T \dot{W}_{s, out} = \eta_T \dot{m}(h_1 - h_{2s}) = .92(2 \ kg/s)(3231.7 - 2335.7) \ kJ/kg$

$\boxed{\dot{W}_{out} = 1649. \ kW}$

David Malawey

HW #

8.22

$E = 100\,kJ$ thermal energy

$T = 800\,K$

$T_{environment} = 25°C = 298\,K$

$W_{rev} = \eta_{th,rev}\, Q_{in}$

$\eta_{th,rev} = 1 - \frac{T_0}{T_H} = 1 - \frac{298}{800} = .6275$

$W_{rev} = (\underline{.6275})(100\,kJ)$

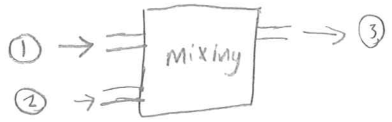
$= \boxed{62.75\ kJ}$

David Malawey 9-2-10

Thermo II h/w

10

5.78



① hot H_2O 80°C
$\dot{m} = .5\,kg/s$
$P = 250\,kPa$

② cold H_2O
20°C
$P = 250\,kPa$

③ 42°C
$P = 250\,kPa$

$h_1 = 335.02$ (h_f <80°>)

$h_2 = 83.915$ kJ/kg

$h_3 = 175.72$ kJ/kg

↑
interpolated 40°, 45°

$\underset{0}{\cancel{\dot{Q}}} - \underset{0}{\cancel{\dot{W}}} = \dot{m}(h)_{in} - \dot{m}(h)_{out}$ (Neglect P.E. & K.E.)

$\dot{m}_1 h_1 + \dot{m}_2 h_2 = \dot{m}_3 h_3 = (\dot{m}_1 + \dot{m}_2) h_3$

$m_1 h_1 + m_2 h_2 = m_1 h_3 + m_2 h_3$

$m_2 \cancel{(h_2 - h_3)} = \dfrac{m_1 h_3 - m_1 h_1}{(h_2 - h_3)} = \dfrac{.5\,kg/s\,(175.72 - 335.02)}{(83.915 - 175.72)} = \boxed{.865\,kg/s = \dot{m}_2}$

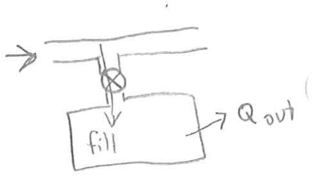
5.124

$\forall = 2\,m^3$
$P_1 = 100\,kPa$
$T_1 = 22\,°C$

$P_2 = 600\,kPa$
$T_2 = 77\,°C$

m & Q = ?
$R = .287\,kPa\,m^3/kg\,K$

$P_i = 600\,kPa$
$T_i = 22°C$



$\underset{0}{Q - \cancel{W}} = \Delta E_{system}$ $Q_{in} + m_i h_i = m_2 u_2 - m_1 u_1$

$m_1 = \dfrac{P_1 \forall}{R T_1} = \dfrac{100\,kPa\ 2\,m^3}{.287\,\frac{kPa\,m^3}{kg}\,295\,K} = 2.362\,kg$

$m_2 = \dfrac{P_2 \forall}{R T_2} = \dfrac{600\,(2)}{.287\,(350)} = 11.946\,kg$

$\Rightarrow m_i = 9.584\,kg$

$Q_{in} = -m_i h_i + m_2 u_2 - m_1 u_1 = -9584(295.17) + (11.946)(250.02) - (2.362)(210.49)$

$\boxed{Q = -339\,kJ}$ heat leaves system

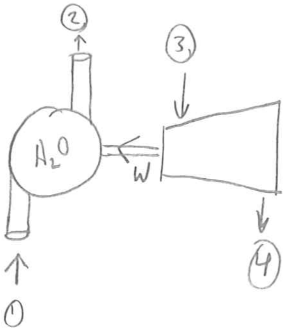
7.116)

sat. liquid
10 MPa

sat. vapor
20 kPa

work delivered by turbine ?
Work consumed by pump =

$\Delta E_{cv} = 0$ $E_{in} = E_{out}$ $W_{in} - Q_{in}$



$s_1 = s_2$ $s_3 = s_4$ (isentropic)

④
$P = 20 kPa$
$h = 2608.9 kJ/kg$
$S = 7.9073$

③ $P = 10 MPa$
$h = 4707.2 kJ/kg$

① $V = .001017 m^3/kg$ $\dot{E}_{in} - \dot{E}_{out} = \cancel{\Delta E}_{sys}$ 0

$\dot{m}h_3 = \dot{m}h_4 + W_{out}$

$W_{out} = \dot{m}(h_3 - h_4)$ $w_{turbine} = h_3 - h_4 = 4707.2 - 2608.9 = \boxed{2098.3 kJ/kg}$ out of sys

$W_{pump,in} = \oint_1^2 V dP = V_1(P_2 - P_1) = .001017 m^3/kg \ (10,000 - 20) kPa \left(\frac{1 kJ}{1 kPa \cdot m^3}\right)$

$= 10.15 kJ/kg$

$$\frac{W_{turb,out}}{W_{pump,in}} = \frac{2098.3}{10.15} = \boxed{206.7}$$

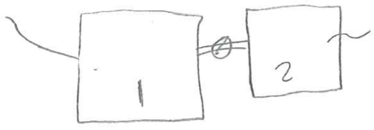
David Malawey

Thermo II 221 3.80, 3.84, 3.90

10

3.80)

$1 m^3$, air
25°C
500kPa



5kg air 35°C
200kPa

$V_{tank 2} = ?$
$P_2 = ?$

surroundings 20°C

Air = .2870 KJ/kg °K

$P\forall = mRT$

$200 v = 5(.2870)(35+273)$

$\boxed{\forall = 2.21 m^3}$

$m_1 = \frac{P_1\forall_1}{R_1T_1} = \frac{500(1)}{.2870(298)} = 5.846 kg$

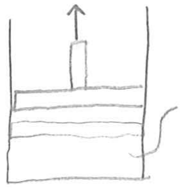
$\forall_{total} = 3.21 m^3$ $M_2 = 5.846 kg + 5kg$

$T_2 = 20°C$

$P_2 =$

$P_2 = \frac{mRT_2}{V_2} = \frac{10.846(.287)(293)}{3.21 m^3} = \boxed{284.1 kPa}$

3.84



① 2kg
Argon
$.05 m^3$
400kPa

② 2kg
$.10 m^3$
$P_2 = ?$

$T_2 = T_1$

$PV = mRT$

$P_1V_1 = P_2V_2$

$400(.05) = P_2(.10) \Rightarrow \boxed{P_2 = 200 kPa}$

3.90

134a

a) vapor,
$P = 9 MPa$
$T = 70°C$
$R = .08149$

$PV = mRT$

$\frac{\forall}{m} = \frac{RT}{P} = \frac{.08149(343k)}{900 kPa} = \boxed{.03105 m^3/kg}$

13.26% ellor

b) $T_{cr} = 374.2 k$
$P_{cr} = 4.059$

$P_r = \frac{P}{P_{cr}} = \frac{.9}{4.059} = .222$

$T_r = \frac{T}{T_{cr}} = \frac{343}{374.2} = .917$

$Z = .895$

$v = Z v_{ideal}$
$= .895(.03105)$
$= \boxed{.0278 m^3/kg}$

1.4% error

C) superheated table $\Rightarrow$ $\boxed{.027413 m^3/kg}$

David Malawey (Poo head)

15

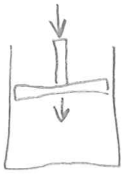
Thermo 2 8-31-10

4.81, 5.51, 5.54

4.81) ① 0.8kg N_2

100 kPa

27°C



Polytropic $PV^{1.3}$ = constant

$P_1V_1^{1.3} = P_2V_2^{1.3}$ $\frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^{1.3}$ $\frac{P_1}{P_2} = (.5)^{1.3}$

$P_1 = .4061\, P_2$ $\underline{P_2 = 246.2 \text{ kPa}}$

② $V_2 = .5V_1$

Q = ?

W = ?

$P_1V_1 = mRT_1$ $\frac{P_1V_1}{T_1} = \cancel{mR} = \frac{P_2V_2}{T_2}$ $T_2 = \frac{P_2V_2}{P_1V_1}T_1 = \frac{246.2}{100}(.5)(27+273)$

$\underline{T_2 = 369.3 \text{ K}}$

boundary work ${}_1W_2 = \int_1^2 P\,d\forall$ $\frac{P_2\forall_2 - P_1\forall_1}{1-n} = \frac{mR(T_2-T_1)}{1-n} = \frac{.8\text{kg}\,(.2968\,\frac{\text{kJ}}{\text{kg}\cdot\text{K}})(369.3-300)}{1-1.3}$

$\boxed{W_b = -54.85 \text{ means work goes } \underline{\text{into}} \text{ system}}$

${}_1Q_2 - {}_1W_2 = dU = mC_v(T_2-T_1) = .8\text{kg}\,(.744\,\frac{\text{kJ}}{\text{kg}\cdot\text{K}})(69.3\text{K})$

$C_{v,avg} = .744$

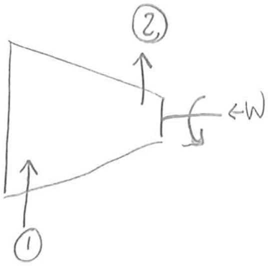
$= 41.25 \text{ kJ}$

${}_1Q_2 = -54.85 \text{ kJ} + 41.25 \text{ kJ}$

$\boxed{{}_1Q_2 = -13.60 \text{ kJ}}$ means heat goes $\underline{\text{out}}$ of system

David Malaney
H/W continued...

Compressor



5.51) adiabatic compressor

① $\dot{V} = 10\,L/s$
120 kPa
20°C
Air

② 1000 kPa
300°C
w required = ?
power req'd = ?

$\dot{Q} - \dot{W} = \dot{m}\,\Delta h$

$\dot{Q} - \dot{W} = .01427\,\frac{kg}{s}\;285.0\,\frac{kJ}{kg}$

$\cancel{\dot{Q}} - \dot{W} = 4.067\,kJ/s$

0, adiabatic

$\boxed{\dot{W}_b = 4.067\,kW \text{ work into system}}$

$h_2 - h_1 = C_p(T_2 - T_1) = 1.018(280) = 285.0\,\frac{kJ}{kg}$

$C_{p,avg} = C_p,\ 160°C = 1.018\,kJ/kg\cdot K$

control volume $\dot{Q} - \dot{W} = \dot{m}(\Delta h + \cancel{ke} + \cancel{pe})$

$\dot{m}:\quad P_1\dot{V}_1 = \dot{m}RT_1$

$$\dot{m} = \frac{P_1\dot{V}_1}{RT_1} = \frac{120\,kPa\,(.01\,m^3/s)}{.287\,\frac{kPa\cdot m^3}{kg\cdot K}\,(293\,K)}$$

$= .01427\,kg/s$

$\boxed{w = 285.0\,\frac{kJ}{kg} \text{ into sys.}}$

5.54) turbine

① 10 MPa
500°C

② 10 kPa
x = .9

$\dot{m} = ?$
$P = 5\,MW = 5000\,kJ/s$

Tables: $h_1 = 3375.1\,kJ/kg$

$h_2 = h_f + .9\,h_{fg}\,(10\,kPa) = 2344.7\,kJ/kg$

$E_{in} - E_{out} = \cancel{\Delta E}^{\,0}$ $\quad \cancel{\dot{Q}}^{0} - \dot{W} = \dot{m}(\Delta h)$

$-5000\,\frac{kJ}{s} = \dot{m}(h_2 - h_1)$

$\boxed{\dot{m} = 4.852\,kg/s}$

10

David Malawey

ME 221 HW due 9-31-10

(Valid temperature range?)

a) A-2c table $\Delta\bar{u} = \int_1^2 c_v(T)$

4.63) $\Delta u = ?$ hydrogen, $\Delta\bar{u} = \int_1^2 \left[(29.11 - R_u) - .1916\times10^{-2}(T) + .4003\times10^{-5}(T^2) - .8704\times10^{-9}\,T^3\right]dt$

$T_1 = 200\,K$ $= 12{,}487\ kJ/kmol \left(\frac{1}{2.016\ kg/mol}\right)$

$T_2 = 800\,K$

$= \boxed{6194\ kJ/kg}$

b) $c_{v,avg} = c_v(500K) = 10.389\ \frac{kJ}{kg\cdot K}$

$\Delta u = 10.389\ \frac{kJ}{kg\cdot K}(800K - 200K) = \boxed{6233\ kJ/kg}$

c) $c_{v,} = 10.183\ kJ/kg\ K$

$\Delta u = c_{v_{RT}}(T_2 - T_1) = 10.183\ \frac{kJ}{kg\cdot K}(600K) = \boxed{6110\ \frac{kJ}{kg}}$

4.29) ① H_2O sat. vapor 200°C $P = 1554.9\ kPa$

② sat liquid, 200°C $Q = ?$ ${}_1W_2 = ?$

$U_1 = 2594.2\ kJ/kg$ $U_2 = 850.46$ $\Delta U = 1743.7$

$v_1 = .12721$ $v_2 = .001157$

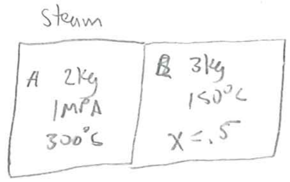
$${}_1W_2 = \int P\,dv = \underset{kPa}{1554.9}(\underset{m^3/kg}{.001157 - .12721}) = -196.0\ \frac{kPa\cdot m^3}{kg} = \boxed{{}_1W_2\ \ 196.0\ \frac{kJ}{kg}}$$

On ~~into~~ system

${}_1Q_2 - {}_1W_2 = E_2 - E_1$ ${}_1Q_2 - 196.0\ \frac{kJ}{kg} = 1743.7\ kJ/kg$

$\boxed{{}_1Q_2 = 1940\ kJ/kg}$ heat is transferred out of system

4.42



①

② P = 300 kPa 5Kg

$V_A = .25799 \, m^3/kg \Rightarrow .51598 \, m^3$

$V_B = .5(.001091) + .5(.39248) = .196786 \, m^3/kg \, (3kg) = .59036 \, m^3$

$V_{total} = 1.106 \, m^3 \quad v_{total} = .2212 \, m^3/kg$

$v_f < .2212 < v_g \therefore$ sat. mixture

$$x(\overset{v_g}{.60582}) + (1-x)(\overset{v_f}{.001073}) = .2212$$

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

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

$$\frac{.2212 - .001073}{(.60582 - .001073)} = \boxed{x = .3640}$$

$\boxed{T_{final} = 133.52 °C}$

$$\left.\begin{array}{l} U_A = m(u) = 2kg\,(2793.7 \, \frac{kJ}{kg}) = 5587.4 \, kJ \\ U_B = m(.5u_f + .5u_g) = 3[.5(631.66) + .5(2559.1)] \\ \quad = 4786.14 \, kJ \end{array}\right\} = 10373.5 \, kJ$$

$$U_{final} = m(u_f + x u_{fg}) = 5kg\,(561.11 + (.364)\,1982.1) = 6412.97 \, kJ$$

$$\Delta U = U_2 - U_1 = -3961 \, kJ$$

$${}_1Q_2 - \underbrace{\cancel{{}_1W_2}^{\,0}}_{\text{no work}} = \Delta U$$

$$\boxed{{}_1Q_2 = 3961 \, kJ \text{ out of system}}$$