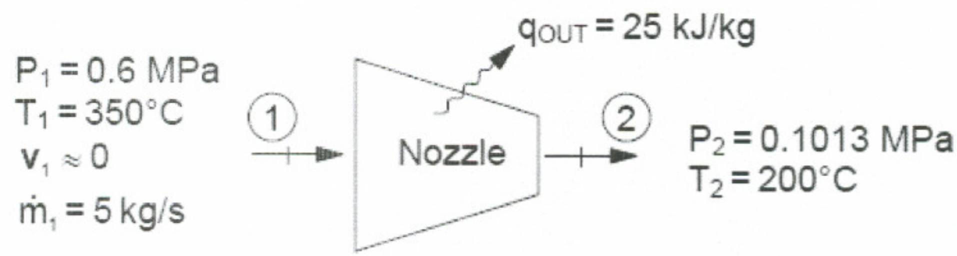
Thermodynamics (ES 340) Quiz 3 June 7, 2005
Name: (1 Hour)

Problem 1 (10 points): A carbon dioxide nozzle is shown below. Assuming carbon dioxide is an ideal gas

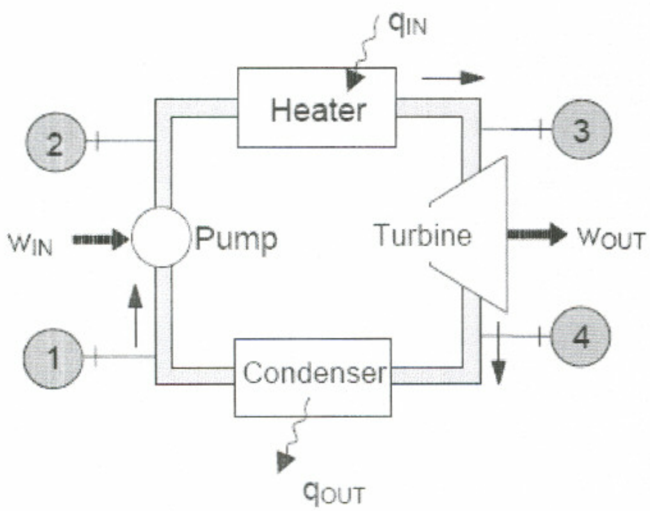
Max 19/20
Min 9/20
Avg. 12.5/20

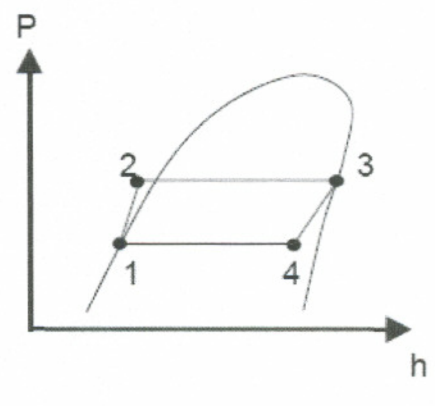


1. Draw the P-h and T-h diagrams. (2 points)
2. Determine the exit velocity. (2 points)
3. Find the area of the nozzle at the exit. (2 points)
4. If process 1-2 is a polytropic process (Pv^n=constant), find power n. (2 points)
5. Add the polytropic process 1-2 to the P-h and T-h diagrams in part 1. (2 points)

Problem 2 (10 points): A power cycle uses refrigerant R-134A as the working fluid. It operates between pressures of 60 and 600 kPa, and the states at the process endpoints are shown on the P-h diagram. The quality (x) at state 4 is 0.98.

1. Construct a state table for this heat engine. (7 points)
2. Find w_{NET}/q_{IN} , explain what is this quantity. (3 points)

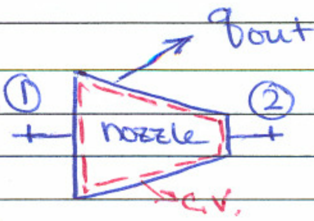




PROBLEM 1

CO_2
ideal gas

$P_1 = 0.6\,\text{Mpa}$
$T_1 = 350^\circ C$
$V_1 = 0$
$\dot{m}_1 = 5\,\text{kg/s}$



$P_2 = 0.1013\,\text{MPa}$
$T_2 = 200^\circ C$

Mass Balance:

$$\frac{d\cancel{m_{cv}}}{dt} = \sum \dot{m}_{in} - \sum \dot{m}_{out} \Rightarrow 0 = \dot{m}_1 - \dot{m}_2 \rightarrow \dot{m}_1 = \dot{m}_2 = 5\,\text{kg/s}$$

0 (S.S.)

Energy Balance:

$$\underbrace{\frac{d\cancel{E_{cv}}}{dt}}_{0\ \text{S.S.}} = \sum \dot{Q} - \underbrace{\cancel{\sum \dot{W}}}_{0} + \sum \dot{m}_i \Big(h_i + \underbrace{\cancel{\frac{V_i^2}{2}}}_{0} + \underbrace{\cancel{g z_i}}_{0}\Big) - \sum \dot{m}_e \Big(h_e + \frac{V_e^2}{2} + \underbrace{\cancel{g z_e}}_{0}\Big)$$

$$\xrightarrow{\div \dot{m}} 0 = q + h_1 - h_2 - \frac{V_2^2}{2} \rightarrow V_2 = \sqrt{2(q + h_1 - h_2)}$$

Table A23

$T = 620\,K \quad \bar{h} = 23231\ \text{KJ/Kmol}$

$T = 630\,K \quad \bar{h} = 23709\ \text{KJ/Kmol}$

$T_1 = 350 + 273 = 623\,K \xrightarrow{\text{interpolate}} \bar{h}_1 = 23386\ \text{KJ/Kmol} = \dfrac{23386}{44} = 531.50\ \text{KJ/kg}$

M_{CO_2}

Table A23

$T = 470\,K \quad \bar{h} = 16351\ \text{KJ/Kmol}$

$T = 480\,K \quad \bar{h} = 16791\ \text{KJ/Kmol}$

$T_2 = 473\,K \rightarrow \bar{h}_2 = 16492.1\ \dfrac{\text{KJ}}{\text{Kmol}} = 374.82\ \dfrac{\text{KJ}}{\text{Kg}}$

the relation with temperature for an ideal gas

$$\left(\frac{P_1}{P_2}\right)^{\frac{n-1}{n}} = \frac{T_1}{T_2} \xrightarrow[\ln]{\text{take}} \left(\frac{n-1}{n}\right)\ln\left(\frac{P_1}{P_2}\right) = \ln\left(\frac{T_1}{T_2}\right)$$

$$\rightarrow \left(\frac{n-1}{n}\right)\left(\ln\left(\frac{0.6}{0.1013}\right)\right) = \ln\left(\frac{350+273}{200+273}\right)$$

$$\rightarrow n = 1.1832 \text{ Ans.}$$

To add the polytropic process to the P–h and T–h diagrams we need to find another value of h in each case.

if assuming c_p = constant (is valid for grapling purposes)

the $h = C_p T \rightarrow$

$$\left(\frac{P_1}{P_2}\right)^{\frac{n-1}{n}} = \frac{h_1/\cancel{c_p}}{h_2/\cancel{c_p}} = \frac{h_1}{h_2}$$

$$\rightarrow \frac{h_1}{h_2} = \left(\frac{P_1}{P_2}\right)^{0.154} \rightarrow$$ at an arbitrary point with $P_3 = 0.4^{\text{MPa}}$ for example

$$\rightarrow \frac{h_1}{h_3} = \left(\frac{P_1}{P_3}\right)^{0.154} \rightarrow \frac{531.50}{h_3} = \left(\frac{0.6}{0.4}\right)^{0.154}$$

$$\rightarrow h_3 = 499.15 \text{ KJ/kg}$$

and $\frac{T_1}{T_3} = \left(\frac{P_1}{P_3}\right)^{0.154} = h_1/h_3 \rightarrow T_3 = 585.09\text{ K}$

$= 312\ ^\circ C$

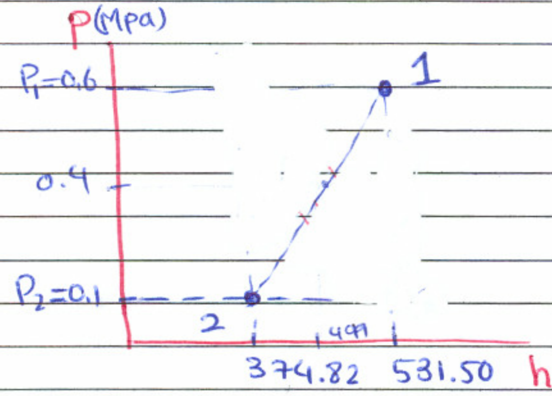
Prob 1 (cont'd)

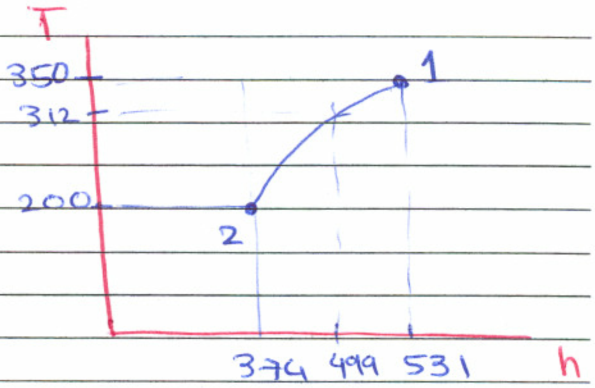
pluging for h_1 and h_2

$$V_2 = \sqrt{2(25 + 531.50 - 374.82) \times 1000}$$

Kilo

$$\rightarrow V_2 = 513.2 \text{ m/s} \quad \text{Ans.}$$





$$\dot m = \rho A V \rightarrow \dot m_2 = \rho_2 A_2 V_2 \rightarrow \dot m_2 = \frac{A_2 V_2}{v_2} \quad (1)$$

CO2 ideal gas $\rightarrow$ Table A20, $T = 200°C \rightarrow R_{CO_2} = ?$

$T = 400 \rightarrow R_{CO_2} = C_p - C_v = 0.189$ KJ/kgK

and R stays almost constant.

for an ideal gas we have $Pv = RT$

$$\rightarrow v_2 = \frac{R_{CO_2} T_2}{P_2} = \frac{0.189 \times (200+273)}{101.3 \text{ Kpa}} = 0.8825 \text{ m}^3/\text{kg}$$

now pluging into (1) $\quad A_2 = \dot m_2 v_2 / V_2$

$$\rightarrow A_2 = 5 \times 0.8825 / 513.2$$

$$= 85.98 \text{ cm}^2 \quad \text{Ans.}$$

Polytropic then $Pv^n = \text{const} \rightarrow P_1 v_1^n = P_2 v_2^n$ or use

Problem 2

$P_1 = P_4 = 60$ Kpa

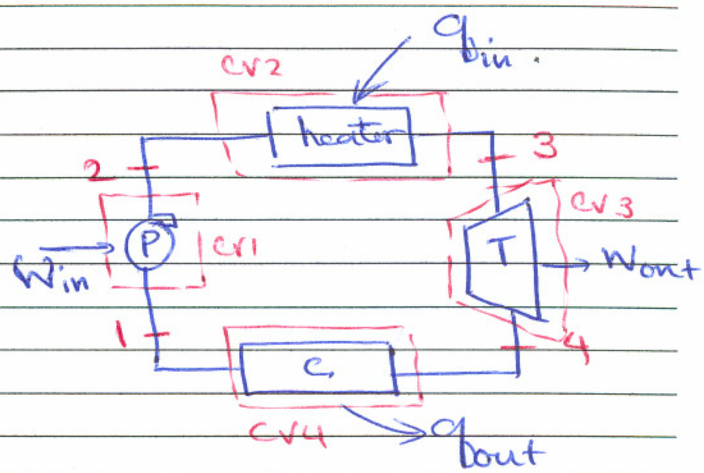
$P_2 = P_3 = 600$ Kpa

$x_4 = 0.98$

$x_1 = 0$

$x_3 = 1$

R-134A , Steady state



C.V. 1

mass balance: $\dot{m}_1 = \dot{m}_2$

energy balance: $0 = -\dot{W}_{in} + \dot{m}(h_1 - h_2)$

or $w_{in} = (h_1 - h_2)$

C.V. 2

M.B. : $\dot{m}_2 = \dot{m}_3$

E.B. : $0 = q_{in} + (h_2 - h_3)$

CV. 3

MB : $\dot{m}_3 = \dot{m}_4$

E.B. : $0 = -\dot{W}_{out} + (\dot{m})(h_3 - h_4)$

or $\dot{w}_{out} = h_3 - h_4$

CV. 4

MB: $\dot{m}_4 = \dot{m}_1$

E.B.: $0 = q_{out} + (h_4 - h_1)$

Finding the properties

point 1: Saturated liquid $\xrightarrow[P=60\,Kpa = 0.6\,bar]{x=0}$ Table A11 $\rightarrow \begin{cases} h_1 = h_f = 3.46 \ KJ/kg \\ v_1 = v_f = 7097 \times 10^{-3} \end{cases}$

Point 3: Saturated Vapor $\xrightarrow[P=600\,Kpa = 6\,bar]{x=1}$ Table A11 $\rightarrow \begin{cases} h_3 = h_g = 259.19 \\ v_3 = v_g = 0.0341 \end{cases}$

Point 4: mixture $x = 0.98$, $P = 60\,Kpa = 0.6\,bar$

$\xrightarrow{TA13}$ $h_f = 3.46$, $h_g = 224.72 \rightarrow h = (1-x)h_f + xh_g$

$\rightarrow h_4 = (1-0.98)(3.46) + 0.98(224.72)$

$\rightarrow h_4 = 220.295\ KJ/kg$

for the pump we have (C.V. 1)

$$\dot{W}_{in} = (h_1 - h_2)$$

to find h_2 we also know work done by a Pump is

$$W_p = -W_{in} = \int v\,dp = v_1(P_2 - P_1)$$

then

$$-(h_1 - h_2) = v_1(P_2 - P_1) \rightarrow h_2 = h_1 + v_1(P_2 - P_1)$$

$$= 3.46 + 0.7097 \times 10^{-3} \times (60 - 600))$$

$$h_2 = 3.84\ KJ/kg$$

Then $W_{IN} = h_1 - h_2 = -0.38\ KJ/kg$

$q_{IN} = h_3 - h_2 = 255.35\ KJ/kg$

$W_{out} = h_3 - h_4 = 38.89 \text{ KJ/Kg}$

$q_{out} = h_1 - h_4 = -216.84 \text{ KJ/Kg}$

then $\dfrac{W_{net}}{q_{in}} = \dfrac{W_{out} - W_{in}}{q_{in}} = \dfrac{38.89 - 0.38}{255.35} = 0.1508$

$= 15.1\%$

This the efficiency of the cycle,