Thermodynamics (ES 340) Quiz 2 June 7, 2004

Name: (1 Hour)

Problem 1: A 4 kg/s steady flow of ammonia runs through a device where it goes through a Polytropic process. The inlet state is 150 kPa, -20°C and the exit state is 400 kPa, 80°C, where all kinetic and potential energies can be neglected. The specific work input has been found to be given as **[n/(n-1)]** Δ**(Pv)**.

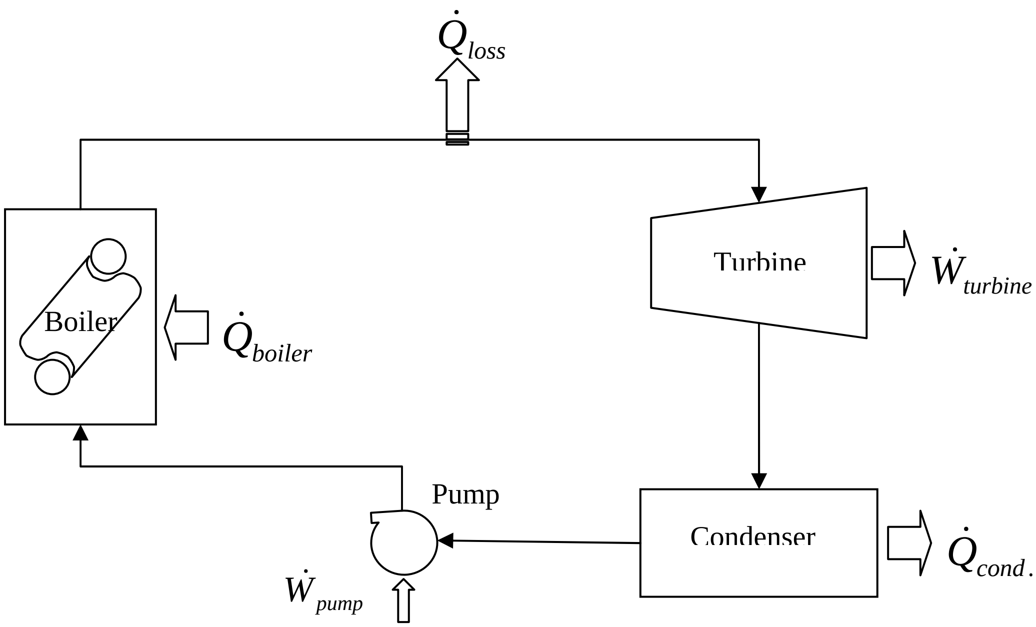
a) Find the Polytropic exponent **n**

b) Find the specific work and the specific heat transfer. (5 points)

Hints:

1. Polytropic process: Pv^n=constant
2. $\ln(x^y) = y\ln(x), \quad \ln\left(\frac{x}{y}\right) = \ln(x) - \ln(y)$

Problem 2: Consider a simple steam power plant, as shown in Figure 1. The following data are for such a power plant.



Location	Pressure	Temperature/Quality
Leaving boiler	2.0 MPa	300°C
Entering turbine	1.9 MPa	290°C
Leaving turbine, entering condenser	15 KPa	90%
Leaving condenser, entering pump	14 KPa	45°C

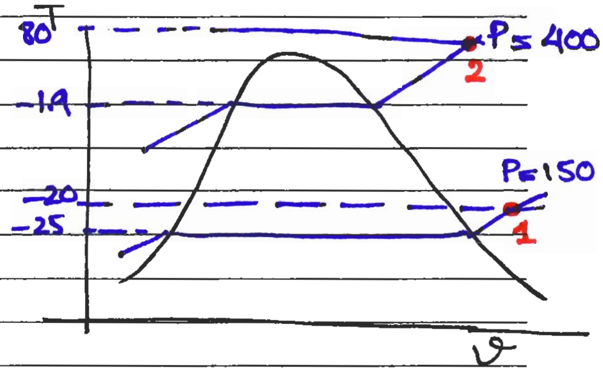
For pump work = 4 KJ/Kg and negligible potential and kinetic energies, determine the following quantities per kilogram flowing through the unit:

1. Show the states at each connection in a T-v diagram and explains your assumptions.
2. Heat Transfer in line between boiler and turbine.
3. Turbine work.
4. Heat transfer in condenser.
5. Heat transfer in boiler. (10 points)

Hints: Use control volume balances of mass and energy for each device in the unit

PROBLEM 1.

Ammonia, Steady State
Polytropic
$\Delta PE = \Delta KE = 0$



① $P_1 = 150$ Kpa $\xrightarrow[A14]{Table}$ $T_{sat1} = -25°C$
$T_1 = -20°C$

② $P_2 = 400$ Kpa $\xrightarrow[A14]{Table}$ $T_{sat2} = -1.9°C$
$T_2 = 80°C$

So both states ① & ② are superheated vapors.

Using table A15, ①: $\upsilon_1 = 0.7978\ m^3/kg$, $h_1 = 1422.67$ KJ/kg
②: $\upsilon_2 = 0.4216$, $h_2 = 1636.41$ KJ/kg

Mass Balance:

$$\frac{dm_{cv}}{dt} = \sum \dot{m}_i - \sum \dot{m}_e \longrightarrow \boxed{\dot{m}_1 = \dot{m}_2 = \dot{m}} \quad (I)$$

($\frac{dm_{cv}}{dt} = 0$, s.s.)

Energy Balance:

$$\frac{dE_{cv}}{dt} = \sum \dot{Q}_{cv} - \sum \dot{W}_{cv} + \sum \dot{m}_i \left(h_i + \frac{V_i^2}{2} + gz_i\right) - \sum \dot{m}_e \left(h_e + \frac{V_e^2}{2} + gz_e\right)$$

($\frac{dE_{cv}}{dt} = 0$ s.s.; $\frac{V_i^2}{2} = 0$, $gz_i = 0$ (Prob. St.); $\frac{V_e^2}{2} = 0$, $gz_e = 0$ (Prob. St.))

using (I): $0 = \dot{Q} - \dot{W} + \dot{m}(h_1 - h_2) \xrightarrow[\dot{m}]{\text{divide by}} \boxed{q = w + h_2 - h_1}$

Polytropic process:

$P\upsilon^n = \text{constant}$ or $P_1\upsilon_1^n = P_2\upsilon_2^n \longrightarrow \frac{P_1}{P_2} = \left(\frac{\upsilon_2}{\upsilon_1}\right)^n$

· taking Natural log ; $\ln\left(\frac{P_1}{P_2}\right) = n \ln\left(\frac{\upsilon_2}{\upsilon_1}\right)$

Prob. 1 (cont'd)

pluging for P_1, P_2, v_1, v_2 gives:

$$n = \frac{\ln\left(\frac{P_1}{P_2}\right)}{\ln\left(\frac{v_2}{v_1}\right)} = \frac{\ln\left(\frac{150}{400}\right)}{\ln\left(\frac{0.4216}{0.7978}\right)} = 1.538 \quad \text{Ans. (a)}$$

$$w = \frac{n}{n-1}\Delta(Pv) = \frac{n}{n-1}\left(P_2v_2 - P_1v_1\right)$$

$$= \frac{1.538}{1.538-1}\left(-150 \times 0.7978 + 400 \times 0.4216\right)$$

$\rightarrow w = 140.02$ KJ/kg Ans. (b)

$\rightarrow w_{input} = -140.02$ KJ/kg , $\dot{W}_{input} = -560.08$ Kg

$$q = w + h_2 - h_1 = -140.02 + (1636.41 - 1422.67)$$

$\rightarrow q = 73.72$ KJ/kg , $\dot{Q} = 294.88$ Kg

point:

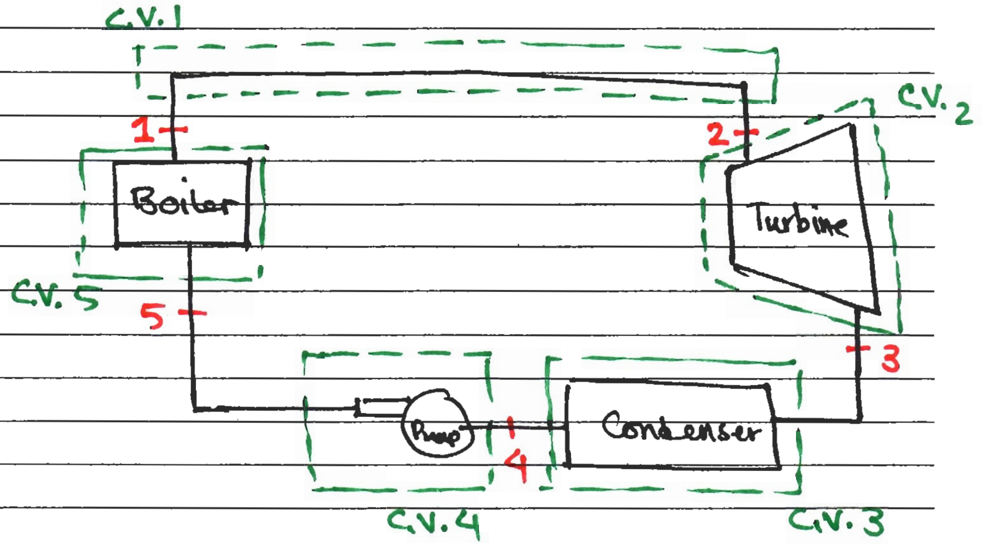
$$W = \int p\,dv \text{ or } \int v\,dp$$
(1) (2)

if you use (1) $\rightarrow W = \frac{\Delta(Pv)}{1-n}$ Work done by Comp./Exp.

" " " (2) $\rightarrow W = \frac{n}{n-1}\Delta(Pv)$ Work done by a pump

PROBLEM 2.

Steam
Steady State
$\Delta PE = 0, \Delta KE = 0$
$\dot{Q}_T = \dot{Q}_P = 0$

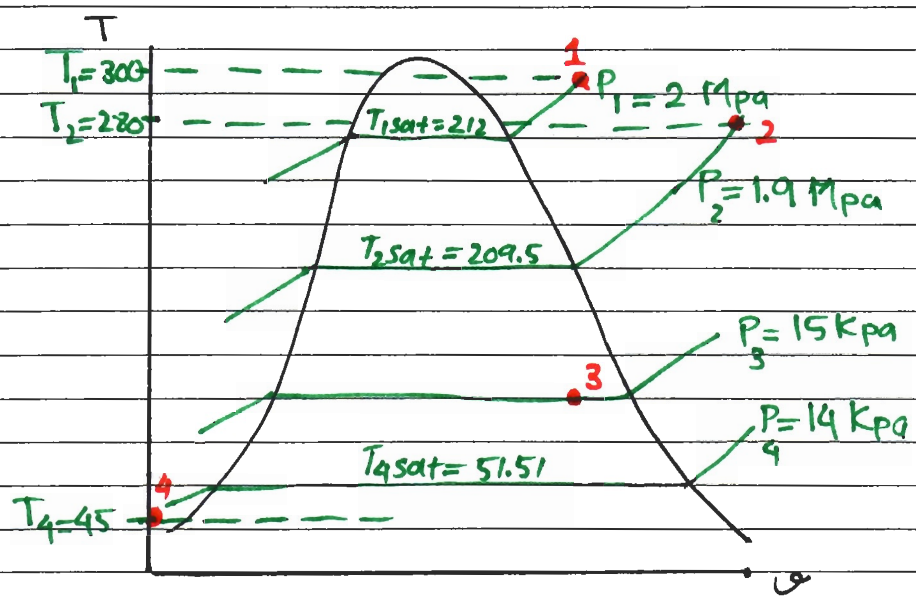


$\begin{cases} P_1 = 2\ \text{Mpa} = 20\,\text{bar} \\ T_1 = 300°\text{C} \end{cases} \xrightarrow[A3]{\text{Table}} T_{1sat} = 212.4°\text{C}$

$\begin{cases} P_2 = 1.9\ \text{Mpa} = 19\,\text{bar} \\ T_2 = 280°\text{C} \end{cases} \xrightarrow[A3]{\text{Table}} \begin{cases} P_2' = 15\,\text{bar} \rightarrow T_2' = 198.3°\text{C} \\ P_2'' = 20\,\text{bar} \rightarrow T_2'' = 212.4°\text{C} \end{cases} \xrightarrow{\text{interpolating}} T_{2sat} = 209.5$

$\begin{cases} P_3 = 15\ \text{Kpa} \\ x_3 = 90\% = 0.9 \end{cases} \longrightarrow$ Sat. Mixture

$\begin{cases} P_4 = 14\ \text{Kpa} \\ T_4 = 45°\text{C} \end{cases} \xrightarrow[A3]{\text{Table}} \begin{cases} P_4' = 0.1\,\text{bar} \rightarrow T_4' = 45.81°\text{C} \\ P_4'' = 0.2\,\text{bar} \rightarrow T_4'' = 60.06°\text{C} \end{cases} \xrightarrow{\text{interpolating}} T_{4sat} = 51.51°\text{C}$



① & ② are Superheated vapors, ③ is mixture, ④ is Subcooled (Comp. liq.)

PROB 2. (Cont'd)

for ①: Superheated vapor $\xrightarrow[A4]{Table}$ $h_1 = \frac{2976.4 + 3069.5}{2} = 3022.95$ KJ/kg (T = 280°C, T = 320°C)

for ②: " " $\xrightarrow[A4]{Table}$ $\begin{cases} h_2' = 2976.4 \\ h_2'' = 2992.2 \end{cases}$ $\xrightarrow{\text{interpolation}}$ $h_2 = 2979.60$ KJ/kg (P = 0.1 bar, P = 0.2 bar)

for ③: Mixture $\xrightarrow[A3]{Table}$ $h_{f3} = \frac{191.83 + 251.40}{2} = 221.61$ KJ/kg

$h_{fg3} = \frac{2392.8 + 2358.3}{2} = 2374.55$ KJ/kg

$\longrightarrow h_3 = h_{f_3} + x\, h_{fg_3} = 221.61 + (0.9)(2374.55)$

$\longrightarrow h_3 = 2358.71$ KJ/kg

for ④: Subcooled $\longrightarrow h_4 \cong h_f(T = 45°C) \xrightarrow[A3]{Table} h_4 = 188.45$ KJ/kg

Mass Balance: (C.V.1)

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

Energy Balance: (C.V.1)

$0 = \dot{Q}_{12} + \dot{m}_1 h_1 - \dot{m}_2 h_2 \longrightarrow q_{12} = \frac{\dot{Q}}{\dot{m}} = h_2 - h_1$

$\longrightarrow q_{12} = -43.29$ KJ/kg

Now for C.V.2

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

$0 = 0 - \dot{W}_T + \dot{m}_2 h_2 - \dot{m}_3 h_3 \longrightarrow w_T = \frac{\dot{W}_T}{\dot{m}} = h_2 - h_3$

$\longrightarrow w_T = 620.89$ KJ/kg

for C.V. 3

$\dot{m}_3 = \dot{m}_4 = \dot{m}$, $q_{34} = -h_3 + h_4 = -2170.26$ KJ/kg

Prob. 2 (cont'd)

for C.V. 4

$$0 = 0 - \dot{W}_p + \dot{m}(h_4 - h_5) \rightarrow w_p = \frac{\dot{W}_p}{\dot{m}} = h_4 - h_5$$

$$\rightarrow h_5 = h_4 - w_p$$

$$= 188.45 - (-4)$$

$$\rightarrow h_5 = \underline{\underline{192.45}} \text{ KJ/kg}$$

for C.V. 5

$$0 = \dot{Q}_b + \dot{m}(h_5 - h_1) \rightarrow q_b = \frac{\dot{Q}_b}{\dot{m}} = -h_5 + h_1$$

$$\rightarrow q_b = -184.45 + 3022.95$$

$$\rightarrow q_b = \underline{\underline{2838.45}} \text{ KJ/kg}$$