ROSE-HULMAN Institute of Technology
Department of Mechanical Engineering

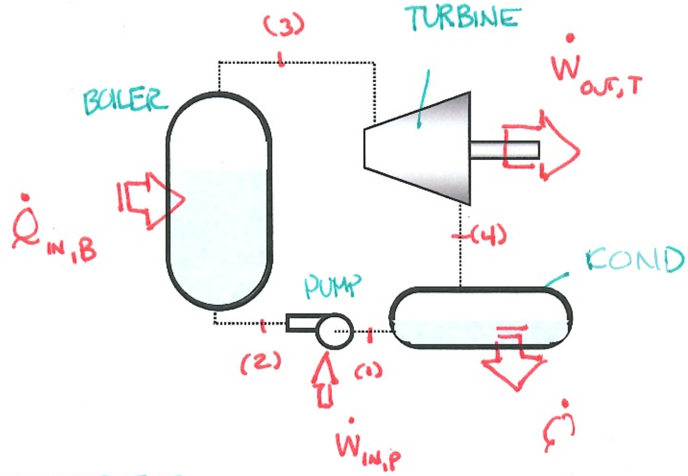
ME 301 | Thermodynamics II

NOT, (IDEAL IMPLIES $x_3 = 1$ too!)

Example

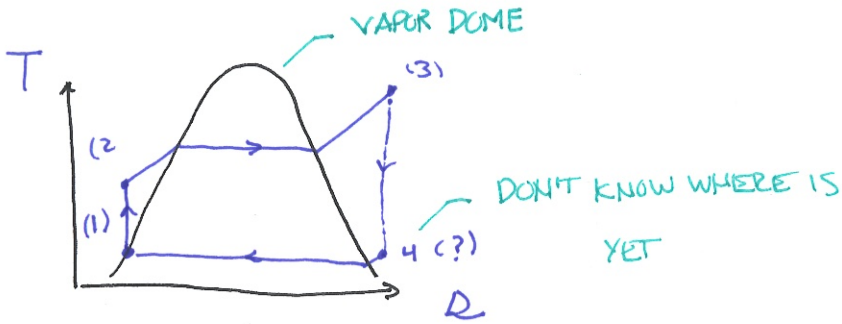
SO IT'S ALMOST IDEAL!

An ~~ideal~~ Rankine cycle operates with a boiler pressure of 8 MPa and a condenser pressure of 10 kPa. The liquid entering the pump is saturated, and the vapor entering the turbine has a temperature of 700°C. The mass flow rate of steam through the cycle is 1 kg/s.



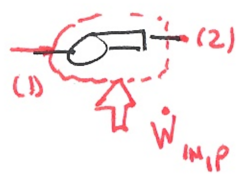
a) Sketch the cycle on a *T-s* diagram.
b) Calculate:
   1) the power into the pump,
   2) the heat transfer into the boiler,
   3) the power out of the turbine, and
   4) the heat transfer rejected by the condenser.
c) Find the efficiency of the cycle.

a)



b) PUMP:

1)



$$\cancel{\frac{dE}{dt}}^{\,0} = \cancel{\dot Q_{IN}}^{\,0} + \dot W_{IN,P} + \dot m(h_1 + \dots) - \dot m(h_2 + \dots)$$

$$\dot W_{IN,P} = \dot m (h_2 - h_1)$$

$$h_1 = h(10\text{ kPa}, x=0) = \underline{191.7\text{ kJ/kg}}$$

$$s_1 = s(\text{ " \quad " }) = \underline{0.6489\text{ kJ/kg}}$$

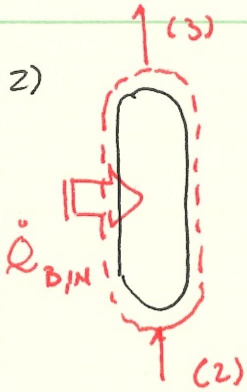
$$h_2 = h(8\text{ MPa}, s_2 = s_1) = \underline{199.8\text{ kJ/kg}}$$

$$\dot W_{IN,P} = (1\text{ kg/s})\left(199.8\frac{\text{kJ}}{\text{kg}} - 191.7\text{ kJ/kg}\right)$$

$$= 8.058\text{ kW}$$

$$w_{IN,P} = \frac{\dot W_P}{\dot m} = 8.058\text{ kJ/kg}$$

2)



$$\cancel{\frac{dE_{sys}}{dt}}^{\to 0} = \dot{Q}_{IN} + \cancelto{0}{} + \dot{m}(h_2 + \ldots) - \dot{m}(h_3 + \ldots)$$

$$\dot{Q}_{IN,B} = \dot{m}(h_3 - h_2)$$

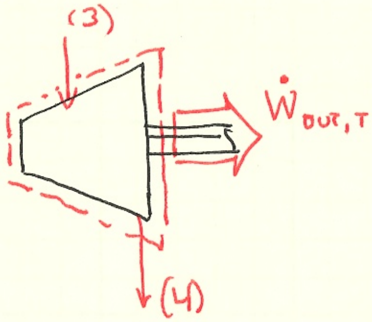
$$q_{IN,B} = \frac{\dot{Q}_{IN,B}}{\dot{m}} (h_3 - h_2)$$

$$h_3 = h(700°C,\ 8\ MPa)$$

$$= \underline{3881\ kJ/kg}$$

$q_B = \ldots = 3682\ kJ/kg$

3)



$$\cancelto{0}{} = \cancelto{0}{} - \dot{W}_{OUT,T} + \dot{m}(h_3 + \ldots) - \dot{m}(h_4 + \ldots)$$

$$\dot{W}_{OUT,T} = \dot{m}(h_3 - h_4)$$

$$w_{OUT,T} = (h_3 - h_4)$$

$$s_3 = s(700°C,\ 8MPa) = \underline{7.28\ kJ/kg \cdot K}$$

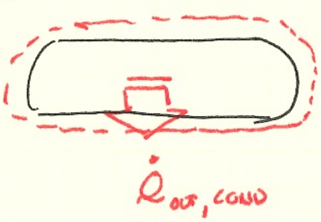
$$h_4 = h(10\ kPa,\ s_4 = s_3)$$

$$= \underline{2307.\ kJ/kg}$$

$< h_g(10kPa)$ IT IS A MIXTURE!!

$w_{OUT,T} = 1575\ kJ/kg$

4)



$$\cancelto{0}{} = -\dot{Q}_{OUT,C} + \cancelto{0}{} + \dot{m}(h_4 + \ldots) - \dot{m}(h_1 + \ldots)$$

$$q_{OUT,COND} = \frac{\dot{Q}_{OUT}}{\dot{m}} = (h_4 - h_1)$$

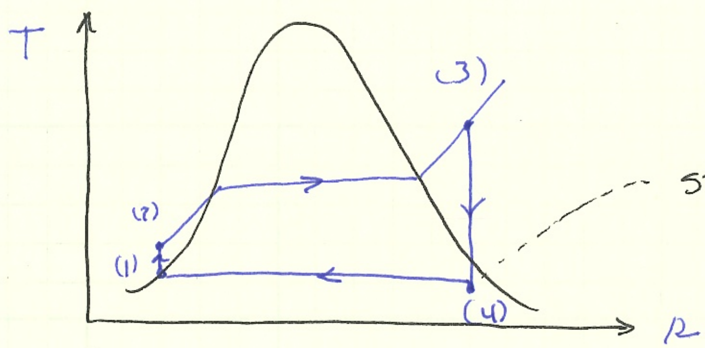
$$= \ldots = 2115\ kJ/kg$$

$\dot{q}_{OUT,COND}$ SHOULD ALSO BE $q_{IN,B} - (w_{OUT,T} - w_{IN,P})$. WHY?

c) $\eta_{TH} \equiv \dfrac{\dot{W}_{NET,OUT}}{\dot{Q}_{IN}} = \dfrac{w_{NET,OUT}}{q_{IN}} = \dfrac{w_{T,OUT} - w_{P,IN}}{q_{IN,B}} = \ldots$

$= 0.426 = 42.6\%$

CORRECTED T-s DIAGRAM



STATE (4) IS A MIXTURE SINCE $h_4 < h_g(10\ kPa)$

Example

Repeat the last problem, but increase the boiler pressure to 10 MPa.

ANALYSIS AS BEFORE. THESE PROPERTIES CHANGE:

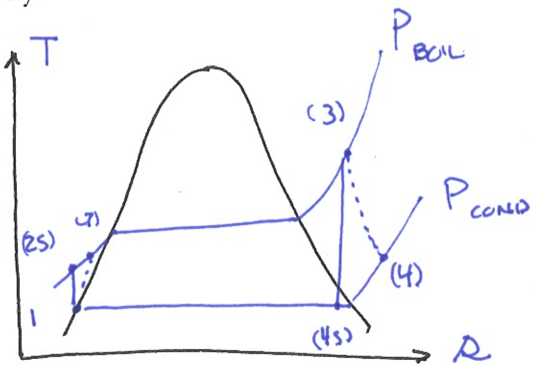
	WAS	IS NOW
h_2 =	$199.8 \frac{kJ}{kg}$	$201.8 \frac{kJ}{kg}$
h_3 =	$3881 \frac{kJ}{kg}$	$3869 \frac{kJ}{kg}$
s_3 =	$7.28 \frac{kJ}{kg \cdot K}$	$7.167 \frac{kJ}{kg \cdot K}$
h_4 =	$2307 \frac{kJ}{kg}$	$2271 \frac{kJ}{kg}$
$w_{P,IN}$ =	$8.058 \frac{kJ}{kg}$	$10.07 \frac{kJ}{kg}$
$q_{B,IN}$ =	$3682 \frac{kJ}{kg}$	$3667 \frac{kJ}{kg}$
$w_{T,OUT}$ =	$1575 \frac{kJ}{kg}$	$1598 \frac{kJ}{kg}$
$q_{C,OUT}$ =	$2115 \frac{kJ}{kg}$	$2079 \frac{kJ}{kg}$
η_T =	42.6%	43.3%
P_2 =	8 MPa	10 MPa

Example

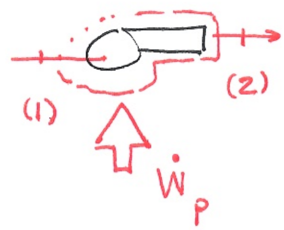
Repeat the problem again, but this time let the adiabatic efficiencies of the pump and the turbine be 70% and 90%, respectively.

(USE $P_B = 10$ MPa)

a)



PUMP



CONS. of ENERGY LOOKS THE SAME, BUT...

$$\dot{W}_p = \dot{m}(h_2 - h_1)$$

$$w_p = h_2 - h_1 \quad (1)$$

$$h_1 = h(10\text{ kPa}, x=0) = \checkmark$$

$$h_2 = h(10\text{ MPa}, \underline{\ ?\ }) = ?$$

USE ISENTROPIC EFFICIENCY

$$\eta_p = \frac{\dot{W}_{IN,s}}{\dot{W}_{IN}} = \frac{w_{IN,s}}{w_{IN}} = \frac{h_{2s} - h_1}{h_2 - h_1}$$

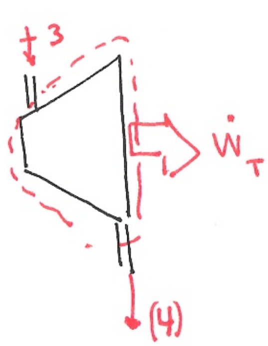
?

$$\therefore \quad w_p = \frac{w_{IN,s}}{\eta_p} = \frac{h_{2s} - h_1}{\eta_p} = \frac{(201.8 - 191.7)\text{ kJ/kg}}{0.7} = 14.39\text{ kJ/kg}$$

USE (1) (CONS of ENERGY) TO FIND h_2...

$$h_2 = w_p + h_1 = \ldots = 206.1\text{ kJ/kg}$$

TURBINE IS SIMILAR



$$\ldots \quad \dot{W}_T = h_3 - h_4$$

$$w_T = h_3 - h_4$$

$$h_3 = h(10\text{ MPa}, T = 700°\text{C})$$

$$h_4 = h(10\text{ kPa}, \underline{\ ?\ })$$

ISENTROPIC TURBINE EFF.

$$\eta_T = \frac{w_T}{w_{T,s}} = \frac{h_3 - h_4}{h_3 - h_{4s}}$$

$$w_T = w_{T,R}\,\eta_T = (h_3 - h_{4R})\,\eta_T$$

$$= \left(3689\ \frac{kJ}{kg} - 2271\ \frac{kJ}{kg}\right)(0.9) = 1439\ kJ/kg$$

ANALYSIS of BOILER & COND SAME AS BEFORE. NEW VALUES

$$q_{COND} = 2239\ kJ/kg \qquad q_{BOIL} = 3663\ kJ/kg$$

$$\eta_{TH} = \frac{w_T - w_P}{q_{BOIL}} = \frac{(1439 - 14.39)\ \cancel{kJ/kg}}{3663\ \cancel{kJ/kg}} = \boxed{0.389}$$

NOTE IT HAS GONE DOWN *SIGNIFICANTLY*.

FOR POWER PLANTS TO OPERATE WELL, ADIABATIC EFFICIENCIES of TURBINES & PUMPS MUST BE HIGH.