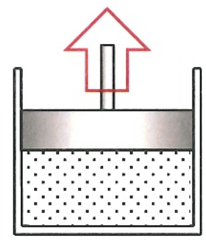
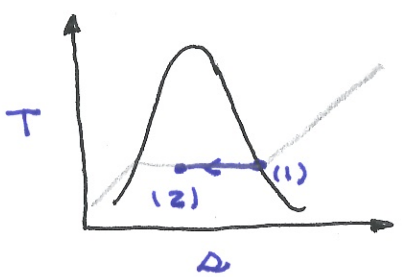
ROSE-HULMAN Institute of Technology
Department of Mechanical Engineering

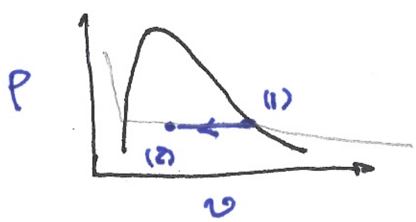
Example

Two kg of saturated steam vapor is contained in a piston cylinder at 200 kPa. It undergoes a constant pressure process until the quality is 0.5. The surroundings are at 101 kPa and 300 K.



(a) Find the work *out* of the steam for this process.
(b) Find the *useful* work out of the steam for this process.
(c) What is the *maximum* amount of useful work that can be extracted from the steam
  1. at its initial state?
  2. at its final state?
  3. between the two states?
(d) How do your answers to (b) and (c) compare? What does that mean?
(e) Calculate the heat transfer in or out of the system and the entropy generation using a good ole ConApps approach. How does $T_0 S_{gen}$ compare to part (d)?





(a) $$W_{OUT,12} = \int_1^2 p\,d\forall = m\int_1^2 p\,dv$$

$$= m p_1 \int_1^2 dv = m p_1 (v_2 - v_1)$$

$$v_1 = v(P_1, x = 1) =$$

$$v_2 = v(P_2 = P_1, x = 0.5) =$$

$$W_{OUT\,12} = \ldots = \boxed{-177\ \text{kJ}} \quad \text{OR} \quad W_{IN,12} = 177\ \text{kJ}$$

(b) $$W_{USE,OUT\,12} = W_{OUT\,12} - p_0(\forall_2 - \forall_1)$$

$$= W_{OUT\,12} - \underbrace{m p_0 (v_2 - v_1)}$$

$$= \text{''} \quad -89.4\ \text{kJ}$$ ATMOSPHERE DOES WORK ON SYSTEM

$$= \boxed{-87.7\ \text{kJ}}$$

(c) MAX USE WORK OUT IS THE EXERGY.

IN K!!

(1) $W_{MAX,USE,OUT,1\to 0} = A_1$

$$= ma_1 = m\left[(u_1 - u_0) + P_0(v_1 - v_0) - T_0(s_1 - s_0)\right]$$

u @ STATE (1)

u of STUFF IF IT WERE @ T_0, P_0 (NOT u of ENVIRONMENT)

$u_1 = u(P = P_1, x = 1)$

$= 2529$ kJ/kg

$u_0 = u(P = P_0 = 101\text{ kPa}, T = T_0 = 300\text{ K})$

$= 112.5$ kJ/kg

v_1, v_0, s_1, s_0 FOUND IN SIMILAR MANNER

$\therefore A_1 = \ldots = \boxed{971.5\text{ kJ}}$

(2) $W_{MAX,USE,2\to 0} = A_2$

$$= ma_2 = m\left[(u_2 - u_0) + P_0(v_2 - v_0) - T_0(s_2 - s_1)\right]$$

$= \ldots = \boxed{537\text{ kJ}}$

(3) $\dot{W}_{MAX,OUT,USE,1-2} = A_1 - A_2 = \ldots$

DECREASE IN A

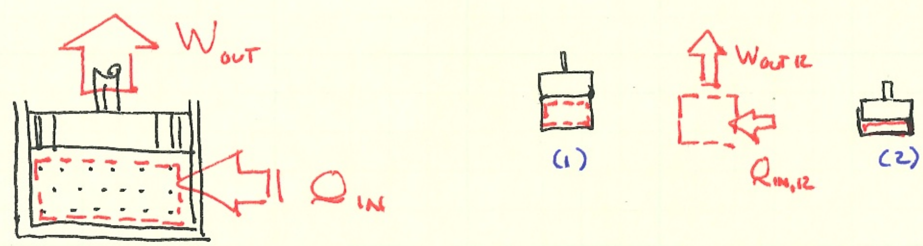
$= (971.5 - 537)\text{ kJ} = \boxed{435\text{ kJ}}$

(d) WE COULD HAVE GOTTEN WORK <u>OUT</u> of SYSTEM,

INSTEAD WE PUT WORK <u>IN</u>. I REALLY SHOULD HAVE DONE THINGS REVERSIBLY.

BUT WAIT! THE STEAM WAS <u>COMPRESSED</u>. HOW COULD I HAVE GOTTEN WORK <u>OUT</u>, THEN?

(e)



Cons. of energy, closed system, finite time

$$E_2 - E_1 = Q_{IN\,12} - W_{OUT\,12}$$

NO KE, PE

$$U_2 - U_1 = Q_{IN\,12} - W_{OUT\,12}$$

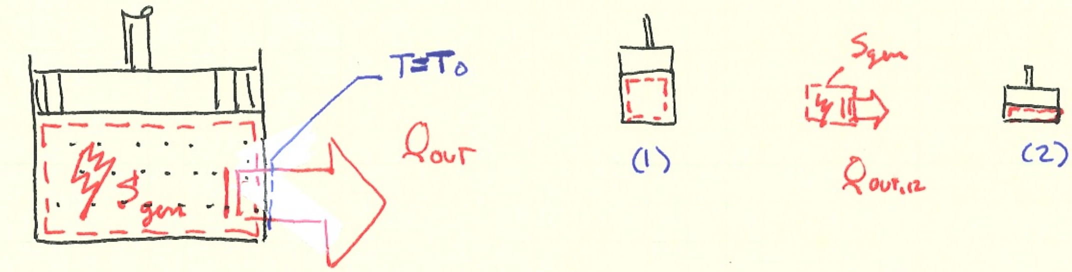
$$Q_{IN,12} = U_2 - U_1 + W_{OUT\,12} = m(u_2 - u_1) + W_{OUT,12}$$

$$u_1 = u(P = P_1,\ x = 1) = 2529\ \text{kJ/kg}$$

$$u_2 = u(P = P_2 = P_1,\ x = 0.5) = 1517\ \text{"}$$

$$\ldots\ Q_{IN\,12} = \ldots = -2202\ \text{kJ} \Rightarrow \boxed{Q_{OUT,12} = 2202\ \text{kJ}}$$

THIS HEAT TRANSFER OUT COULD HAVE BEEN USED TO PRODUCE WORK OUT.



Acct. of S, closed sys, finite time

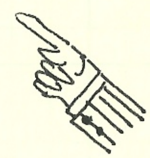
$$(S_2 - S_1)_{SYS} = \frac{Q_{IN\,12}}{T_0} + S_{gen}$$

$$m(s_2 - s_1) = -\frac{Q_{OUT\,12}}{T_0} + S_{gen}$$

$$S_{gen} = m(s_2 - s_1) + \frac{Q_{OUT\,12}}{T_0}$$

$$= (2\,kg)\left(4.329\,\frac{kJ}{kg\cdot K} - 7.127\,\frac{kJ}{kg\cdot K}\right) + \frac{2202\,kJ}{300\,K}$$

$$= 1.74\,kJ/K$$



$$I_{12} = T_0 S_{gen} = (300\,K)(1.74\,kJ/K)$$

$$= \boxed{523\,kJ}$$

COMPARE TO

$$W_{OUT\,12,\,MAX,USE} - W_{OUT\,12,\,USE} = 435\,kJ - (-87.7\,kJ)$$

$$= 523\,kJ$$ ☑

FROM PARTS (b) & (c)