HW5 (Thermodynamics I)

Due: 2015/06/04, 1 PM

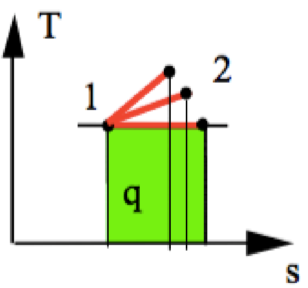
1. Water at 100 kPa, 150^{O}C receives 75 kJ/kg in a reversible process by heat transfer. Which process changes s the most: constant T, constant v or constant P?

$$ds = \frac{dq}{T}$$

Look at the constant property lines in a T-s diagram, Fig. 6.5. The constant v line has a higher slope than the constant P line also at positive slope. Thus both the constant P and v processes have an increase in T. As T goes up the change in s is smaller for the same area (heat transfer) under the process curve in the T-s diagram as compared with the constant T process.

The constant T (isothermal) process therefore changes s the most.

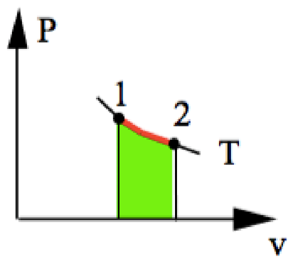
In a reversible process the area below the process curve in the T-s diagram is the heat transfer.

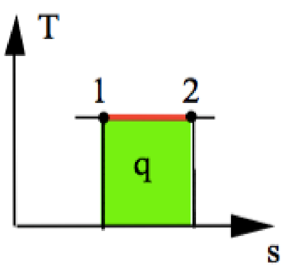


2. An ideal gas goes through a constant T reversible heat addition process. How do the properties (v, u, h, s, P) change (up, down or constant)?

Ideal gas: u(T), h(T) so they are both constant

Eq. 6.2 gives:	$ds = dq/T > 0$	so s goes up by q/T
Eq. 6.12 gives:	$ds = (R/v)\ dv$	so v increases
Eq. 6.14 gives:	$ds = -(R/P)\ dP$	so P decreases

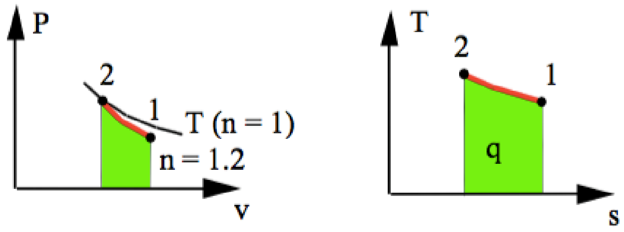




3. Carbon dioxide is compressed to a smaller volume in a polytropic process with n = 1.2. How do the properties (u, h, s, P, T) change (up, down or constant)?

For carbon dioxide Table A.5 $k = 1.289$ so we have $n < k$ and the process curve can be recognized in Figure 8.13. From this we see a smaller volume means moving to the left in the P-v diagram and thus also up.

From P-v diagram: P up, T up
From T-s diagram Since T is up then s down.
As T is up so is h and u.



4. A reversible process in a piston/cylinder is shown in Fig. P6.8. Indicate the storage change $u_2 - u_1$ and transfers ${}_1w_2$ and ${}_1q_2$ as positive, zero, or negative.

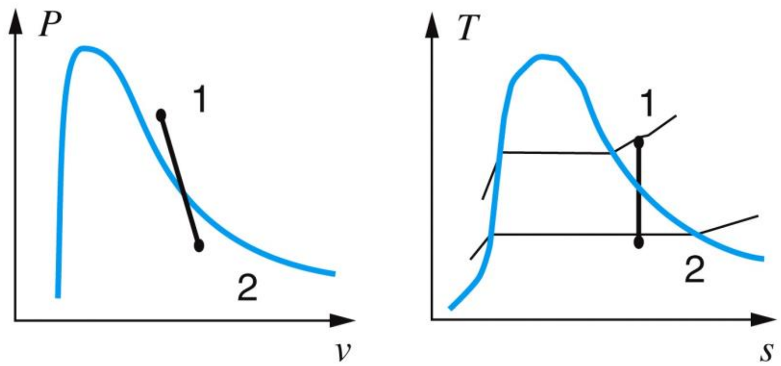


Figure P6.8

$${}_1w_2 = \int P\, dv > 0 ; \qquad {}_1q_2 = \int T\, ds = 0$$

$$u_2 - u_1 = {}_1q_2 - {}_1w_2 < 0$$

5. A heat engine receives 6 kW from a 250°C source and rejects heat at 30°C. Examine each of three cases with respect to the inequality of Clausius.

a. $\dot{W} = 6$ kW

b. $\dot{W} = 0$ kW

c. Carnot cycle

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Solution:

$T_H = 250 + 273 = 523$ K ; $T_L = 30 + 273 = 303$ K

Case a) $\displaystyle\int \frac{d\dot{Q}}{T} = \frac{6000}{523} - \frac{0}{303} = 11.47 \text{ kW/K} > 0$ **Impossible**

b) $\displaystyle\int \frac{d\dot{Q}}{T} = \frac{6000}{523} - \frac{6000}{303} = -8.33 \text{ kW/K} < 0$ **OK**

c) $\displaystyle\int \frac{d\dot{Q}}{T} = 0 = \frac{6000}{523} - \frac{\dot{Q}_L}{303} \Rightarrow$

$$\dot{Q}_L = \frac{303}{523} \times 6 \text{ kW} = 3.476 \text{ kW}$$

$$\dot{W} = \dot{Q}_H - \dot{Q}_L = 2.529 \text{ kW}$$

6. Find the missing properties of P, v, s and x for ammonia (NH_3) at

a. T = 65°C, P = 600 kPa

b. T = 20°C, u = 800 kJ/kg

c. T = 50°C, v = 0.1185 m^3/kg

a) B.2.2 average between 60°C and 70°C

$v = (0.25981 + 0.26999)/2 = 0.26435\ m^3/kg$

$s = (5.6383 + 5.7094)/2 = 5.6739\ kJ/kgK$

b) B.2.1: $u < u_g = 1332.2\ kJ/kg \Rightarrow P = P_{sat} = 857.5\ kPa$

$$x = (u - u_f)/u_{fg} = \frac{800 - 272.89}{1059.3} = 0.49666$$

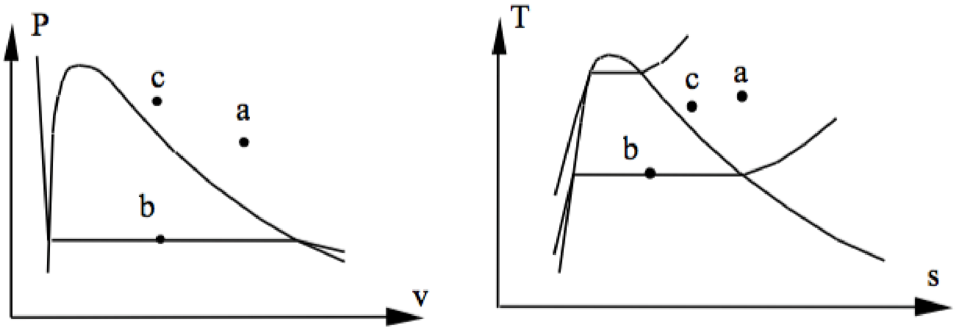
$v = 0.001638 + x \times 0.14758 = 0.07494\ m^3/kg$,

$s = 1.0408 + x \times 4.0452 = 3.04989\ kJ/kg\text{-}K$

c) B.2.1: $v > v_g = 0.06337\ m^3/kg \Rightarrow$

B.2.2 superheated vapor so x is undefined

very close to 1200 kPa, $s = 5.1497\ kJ/kgK$



7. Two kg water at 400 kPa with a quality of 25% has its temperature raised 20°C in a constant pressure process. What is the change in entropy?

Solution:

State 1 from Table B.1.2 at 400 kPa

$$s = s_f + x\, s_{fg} = 1.7766 + 0.25 \times 5.1193 = 3.0564 \text{ kJ/kg}$$

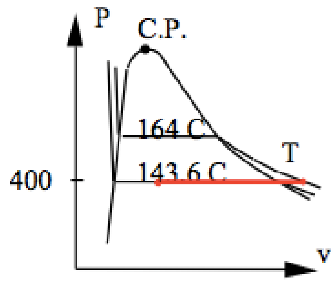
State 2 has same P from Table B.1.2 at 400 kPa

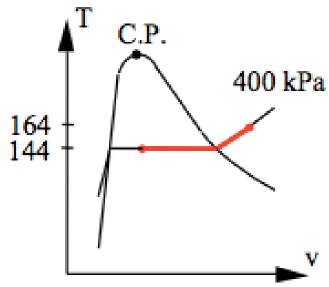
$$T_2 = T_{sat} + 20 = 143.63 + 20 = 163.63^{o}\text{C}$$

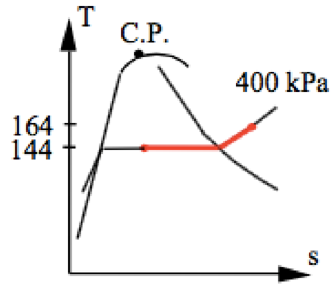
so state is superheated vapor look in B.1.3 and interpolate between 150 and 200 C in the 400 kPa superheated vapor table.

$$s_2 = 6.9299 + (7.1706 - 6.9299)\,\frac{163.63 - 150}{200 - 150} = 6.9955 \text{ kJ/kgK}$$

$$s_2 - s_1 = 6.9955 - 3.0564 = \mathbf{3.9391\ kJ/kgK}$$







8. Water is used as the working fluid in a Carnot cycle heat engine, where it changes from saturated liquid to saturated vapor at 200°C as heat is added. Heat is rejected in a constant pressure process (also constant T) at 20 kPa. The heat engine powers a Carnot cycle refrigerator that operates between –15°C and +20°C. Find the heat added to the water per kg water. How much heat should be added to the water in the heat engine so the refrigerator can remove 1 kJ from the cold space?

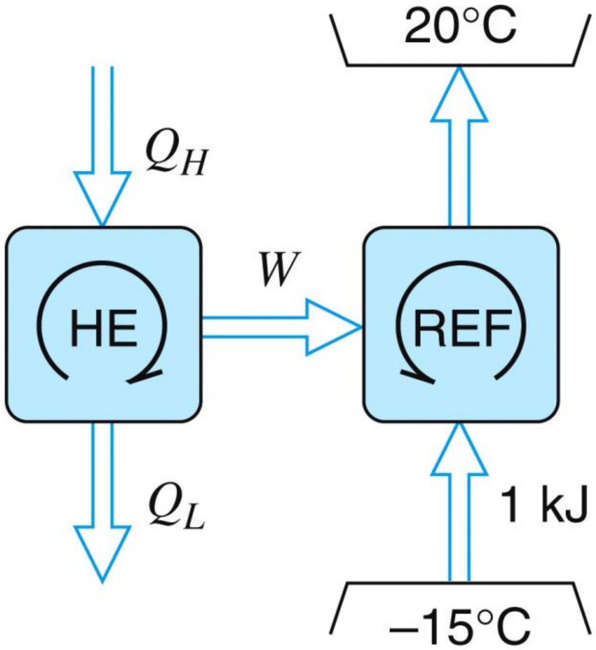
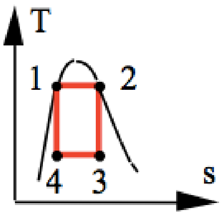


Figure P6.38

Solution:

Carnot cycle heat engine:



Constant T $\Rightarrow$ constant P from 1 to 2, Table B.2.1

$$q_H = \int T ds = T\,(s_2 - s_1) = T\,s_{fg} = h_{fg}$$

$$= 473.15\ (4.1014) = \mathbf{1940\ kJ/kg}$$

States 3 & 4 are two-phase, Table B.2.1

$$\Rightarrow\ T_L = T_3 = T_4 = T_{sat}(P) = 60.06^{o}C$$

Carnot cycle refrigerator (T_L and T_H are different from above):

$$\beta_{ref} = \frac{Q_L}{W} = \frac{T_L}{T_H - T_L} = \frac{273 - 15}{20 - (-15)} = \frac{258}{35} = 7.37$$

$$W = \frac{Q_L}{\beta} = \frac{1}{7.37} = 0.136\ \text{kJ}$$

The needed work comes from the heat engine

$$W = \eta_{HE}\, Q_{H\ H2O}\ ; \qquad \eta_{HE} = 1 - \frac{T_L}{T_H} = 1 - \frac{333}{473} = 0.296$$

$$Q_{H\ H2O} = \frac{W}{\eta_{HE}} = \frac{0.136}{0.296} = \mathbf{0.46\ kJ}$$

9. A piston/cylinder contains 0.5 kg of water at 200 kPa, 300°C, and it now cools to 150°C in an isobaric process. The heat goes into a heat engine that rejects heat to the ambient at 25°C (shown below), and the whole process is assumed to be reversible. Find the heat transfer out of the water and the work given out by the heat engine.

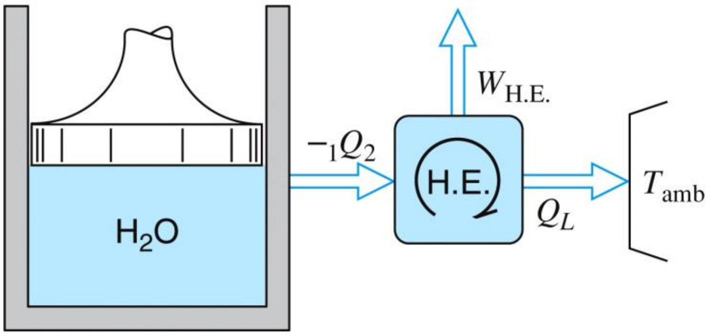


Figure P6.46

C.V. H_2O

Energy Eq.3.5: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Entropy Eq.6.3: $m(s_2 - s_1) = \int dQ/T + 0$

Process: $P = C \Rightarrow W = \int P\, dV = P(V_2 - V_1) = m\, P\, (v_2 - v_1)$

State 1: B.1.3 $s_1 = 7.8926$ kJ/kg-K, $h_1 = 3071.79$ kJ/kg

State 2: B.1.3 $s_2 = 7.2795$ kJ/kg K, $h_2 = 2768.8$ kJ/kg

From the process equation and the energy equation

$$ {}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = m(h_2 - h_1) = 0.5(2768.8 - 3071.79) $$
$$ = \mathbf{-151.495\ kJ} $$

CV Total

Energy Eq.3.5: $m(u_2 - u_1) = -Q_L - {}_1W_2 - W_{HE}$

Entropy Eq.6.3: $m(s_2 - s_1) = -Q_L/T_{amb} + 0$

$$ Q_L = mT_{amb}(s_1 - s_2) = 0.5 \text{ kg } 298.15 \text{ K } (7.8926 - 7.2795) \text{ kJ/kgK} $$
$$ = 91.398 \text{ kJ} $$

Now the energy equation for the heat engine gives

$$ W_{HE} = -{}_1Q_2 - Q_L = 151.495 - 91.398 = \mathbf{60.1\ kJ} $$