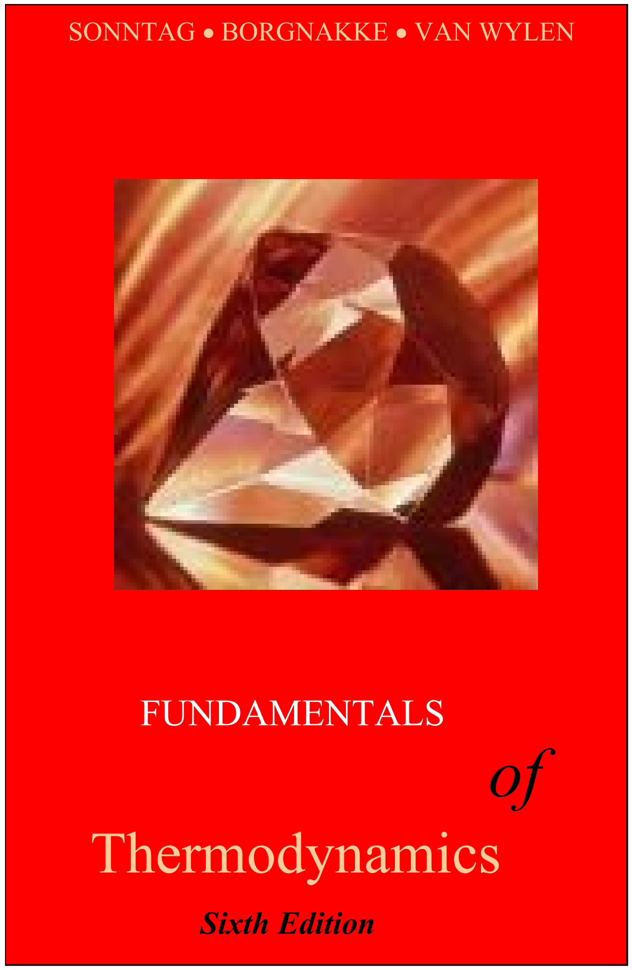
SOLUTION MANUAL
SI UNIT PROBLEMS
CHAPTER 5



CONTENT

CHAPTER 5 CORRESPONDENCE TABLE

The correspondence between this problem set and 5th edition chapter 5 problem set.
Study guide problems 5.1-5.19 are all new

New	5th	New	5th	New	5th	New	5th
20	1	50	28	80	new	110	new
21	4	51	new	81	new	111	84
22	2mod	52	17	82	new	112	77
23	3	53	new	83	new	113	30
24	new	54	27	84	new	114	54
25	5	55	51	85	67 mod	115	82
26	new	56	53	86	new	116	new
27	new	57	40	87	68 mod	117	89
28	6 mod	58	37	88	62	118	87
29	new	59	44	89	72 mod	119	new
30	7 mod	60	42	90	63	120	90
31	new	61	new	91	new	121	new
32	8 mod	62	38	92	new	122	86
33	9 mod	63	39	93	79	123	new
34	new	64	20	94	new	124	new
35	10 mod	65	23 mod	95	64	125	new
36	new	66	43	96	new	126	22
37	12	67	24	97	65	127	29
38	14	68	45	98	new	128	57
39	11	69	new	99	new	129	35
40	new	70	new	100	new	130	31
41	13	71	49 mod	101	69	131	32
42	15	72	55	102	new	132	48
43	21	73	36	103	new	133	56
44	new	74	new	104	74	134	18
45	new	75	58	105	76	135	new
46	new	76	60	106	new	136	83
47	26	77	new	107	66	137	new
48	41	78	59	108	new	138	85
49	new	79	61	109	46		

The english unit problem set corresponds to the 5th edition as

New	5th	New	5th	New	5th	New	5th
139	new	151	107	163	124	175	127
140	new	152	108	164	119	176	new
141	new	153	106	165	new	177	131
142	new	154	new	166	120	178	132
143	new	155	112	167	new	179	135
144	new	156	115	168	122	180	new
145	new	157	111	169	121	181	136
146	102	158	110	170	new	182	134
147	103	159	109	171	125		
148	104 mod	160	113	172	130		
149	105 mod	161	114	173	129		
150	104 mod	162	118	174	123		

Concept-Study Guide Problems

5.1

What is 1 cal in SI units and what is the name given to 1 N-m?

Look in the conversion factor table A.1 under energy:

$$1 \text{ cal (Int.)} = 4.1868 \text{ J} = 4.1868 \text{ Nm} = 4.1868 \text{ kg m}^2/\text{s}^2$$

This was historically defined as the heat transfer needed to bring 1 g of liquid water from 14.5$^{\text{o}}$C to 15.5$^{\text{o}}$C, notice the value of the heat capacity of water in Table A.4

1 N-m = 1 J   or   Force times displacement = energy = Joule

5.2

In a complete cycle what is the net change in energy and in volume?

For a complete cycle the substance has no change in energy and therefore no storage, so the net change in energy is zero.

For a complete cycle the substance returns to its beginning state, so it has no change in specific volume and therefore no change in total volume.

5.3

Why do we write ΔE or $E_2 - E_1$ whereas we write ${}_1Q_2$ and ${}_1W_2$?

ΔE or $E_2 - E_1$ is the **change** from state 1 to state 2 and depends only on states 1 and 2 not upon the process between 1 and 2.

${}_1Q_2$ and ${}_1W_2$ are amounts of energy **transferred during the process** between 1 and 2 and depend on the process path.

5.4

When you wind a spring up in a toy or stretch a rubber band what happens in terms of work, energy and heat transfer? Later when they are released, what happens then?

In both processes work is put into the device and the energy is stored as potential energy. If the spring or rubber is inelastic some of the work input goes into internal energy (it becomes warmer) and not its potential energy and being warmer than the ambient air it cools slowly to ambient temperature.

When the spring or rubber band is released the potential energy is transferred back into work given to the system connected to the end of the spring or rubber band. If nothing is connected the energy goes into kinetic energy and the motion is then dampened as the energy is transformed into internal energy.

5.5

Explain in words what happens with the energy terms for the stone in Example 5.2. What would happen if it were a bouncing ball falling to a hard surface?

In the beginning all the energy is potential energy associated with the gravitational force. As the stone falls the potential energy is turned into kinetic energy and in the impact the kinetic energy is turned into internal energy of the stone and the water. Finally the higher temperature of the stone and water causes a heat transfer to the ambient until ambient temperature is reached.

With a hard ball instead of the stone the impact would be close to elastic transforming the kinetic energy into potential energy (the material acts as a spring) that is then turned into kinetic energy again as the ball bounces back up. Then the ball rises up transforming the kinetic energy into potential energy (mgZ) until zero velocity is reached and it starts to fall down again. The collision with the floor is not perfectly elastic so the ball does not rise exactly up to the original height loosing a little energy into internal energy (higher temperature due to internal friction) with every bounce and finally the motion will die out. All the energy eventually is lost by heat transfer to the ambient or sits in lasting deformation (internal energy) of the substance.

5.6

Make a list of at least 5 systems that store energy, explaining which form of energy.

A spring that is compressed. Potential energy $(1/2)kx^2$
A battery that is charged. Electrical potential energy. V Amp h
A raised mass (could be water pumped up higher) Potential energy mgH
A cylinder with compressed air. Potential (internal) energy like a spring.
A tank with hot water. Internal energy mu
A fly-wheel. Kinetic energy (rotation) $(1/2)I\omega^2$
A mass in motion. Kinetic energy $(1/2)m\mathbf{V}^2$

5.7

A 1200 kg car is accelerated from 30 to 50 km/h in 5 s. How much work is that? If you continue from 50 to 70 km/h in 5 s is that the same?

The work input is the increase in kinetic energy.

$$E_2 - E_1 = (1/2)m\left[\mathbf{V}_2^2 - \mathbf{V}_1^2\right] = {}_1W_2$$

$$= 0.5 \times 1200 \text{ kg } [50^2 - 30^2] \left(\frac{\text{km}}{\text{h}}\right)^2$$

$$= 600 \text{ [} 2500 - 900 \text{] kg} \left(\frac{1000 \text{ m}}{3600 \text{ s}}\right)^2 = 74\ 074 \text{ J} = \mathbf{74.1\ kJ}$$

The second set of conditions does not become the same

$$E_2 - E_1 = (1/2)m\left[\mathbf{V}_2^2 - \mathbf{V}_1^2\right] = 600 \text{ [} 70^2 - 50^2 \text{] kg} \left(\frac{1000 \text{ m}}{3600 \text{ s}}\right)^2 = \mathbf{111\ kJ}$$

5.8

A crane use 2 kW to raise a 100 kg box 20 m. How much time does it take?

$$\text{Power} = \dot{W} = F\mathbf{V} = mg\mathbf{V} = mg\frac{L}{t}$$

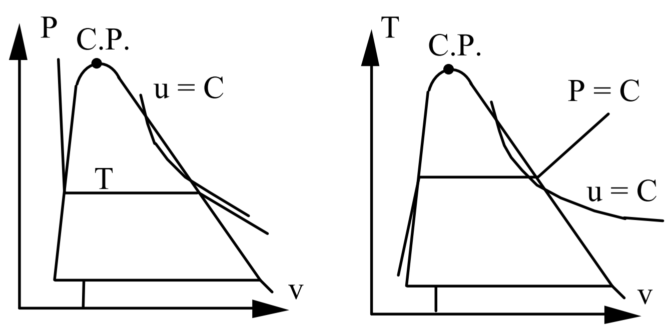
$$t = \frac{mgL}{\dot{W}} = \frac{100 \text{ kg } 9.807 \text{ m/s}^2 \text{ } 20 \text{ m}}{2000 \text{ W}} = \mathbf{9.81 \text{ s}}$$

5.9

Saturated water vapor has a maximum for u and h at around 235°C. Is it similar for other substances?

Look at the various substances listed in appendix B. Everyone has a maximum u and h somewhere along the saturated vapor line at different T for each substance. This means the constant u and h curves are different from the constant T curves and some of them cross over the saturated vapor line twice, see sketch below.

Constant h lines are similar to the constant u line shown.



Notice the constant u(h) line becomes parallel to the constant T lines in the superheated vapor region for low P where it is an ideal gas. In the T-v diagram the constant u (h) line becomes horizontal.

5.10

A pot of water is boiling on a stove supplying 325 W to the water. What is the rate of mass (kg/s) vaporizing assuming a constant pressure process?

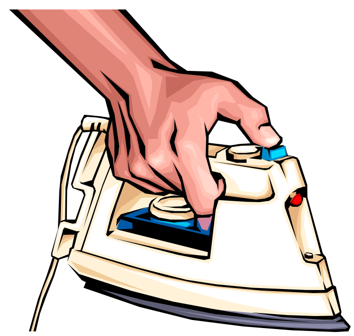
To answer this we must assume all the power goes into the water and that the process takes place at atmospheric pressure 101 kPa, so T = 100°C.

Energy equation

$$dQ = dE + dW = dU + PdV = dH = h_{fg}\, dm$$

$$\frac{dQ}{dt} = h_{fg} \frac{dm}{dt}$$

$$\frac{dm}{dt} = \frac{\dot{Q}}{h_{fg}} = \frac{325 \text{ W}}{2257 \text{ kJ/kg}} = \mathbf{0.144\ g/s}$$



The volume rate of increase is

$$\frac{dV}{dt} = \frac{dm}{dt} v_{fg} = 0.144 \text{ g/s} \times 1.67185 \text{ m}^3\text{/kg}$$

$$= 0.24 \times 10^{-3} \text{ m}^3\text{/s} = 0.24 \text{ L/s}$$

5.11

A constant mass goes through a process where 100 W of heat transfer comes in and 100 W of work leaves. Does the mass change state?

Yes it does.

As work leaves a control mass its volume must go up, v increases

As heat transfer comes in at a rate equal to the work out means u is constant if there are no changes in kinetic or potential energy.

5.12

I have 2 kg of liquid water at 20^oC, 100 kPa. I now add 20 kJ of energy at a constant pressure. How hot does it get if it is heated? How fast does it move if it is pushed by a constant horizontal force? How high does it go if it is raised straight up?

a) Heat at 100 kPa.

Energy equation:

$$E_2 - E_1 = {}_1Q_2 - {}_1W_2 = {}_1Q_2 - P(V_2 - V_1) = H_2 - H_1 = m(h_2 - h_1)$$

$$h_2 = h_1 + {}_1Q_2/m = 83.94 + 20/2 = 94.04 \text{ kJ/kg}$$

Back interpolate in Table B.1.1: $T_2 = \mathbf{22.5^oC}$

(We could also have used $\Delta T = {}_1Q_2/mC = 20 / (2*4.18) = 2.4^oC$)

b) Push at constant P. It gains kinetic energy.

$$0.5 \text{ m } \mathbf{V}_2^2 = {}_1W_2$$

$$\mathbf{V}_2 = \sqrt{2\ {}_1W_2/m} = \sqrt{2 \times 20 \times 1000 \text{ J}/2 \text{ kg}} = \mathbf{141.4 \text{ m/s}}$$

c) Raised in gravitational field

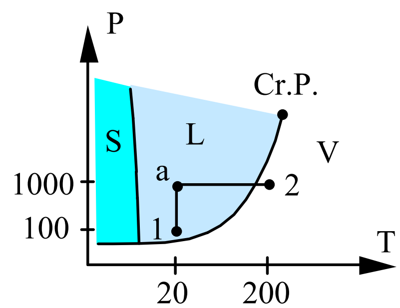
$$m\ g\ Z_2 = {}_1W_2$$

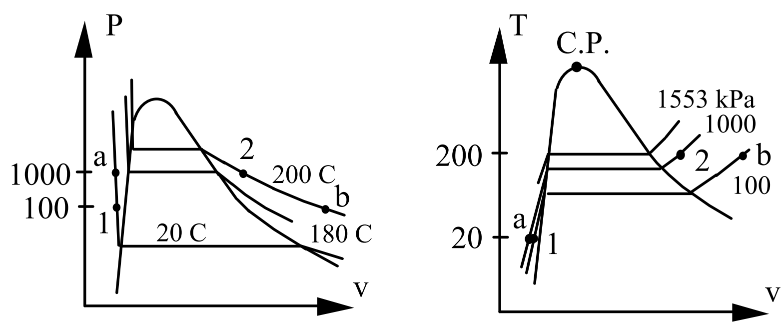
$$Z_2 = {}_1W_2/m\ g = \frac{20\ 000 \text{ J}}{2 \text{ kg} \times 9.807 \text{ m/s}^2} = \mathbf{1019 \text{ m}}$$

5.13

Water is heated from 100 kPa, 20°C to 1000 kPa, 200°C. In one case pressure is raised at T = C, then T is raised at P = C. In a second case the opposite order is done. Does that make a difference for $_1Q_2$ and $_1W_2$?

Yes it does. Both $_1Q_2$ and $_1W_2$ are process dependent. We can illustrate the work term in a P-v diagram.





In one case the process proceeds from 1 to state "a" along constant T then from "a" to state 2 along constant P.

The other case proceeds from 1 to state "b" along constant P and then from "b" to state 2 along constant T.

5.14

Two kg water at 120°C with a quality of 25% has its temperature raised 20°C in a constant volume process. What are the new quality and specific internal energy?

Solution:

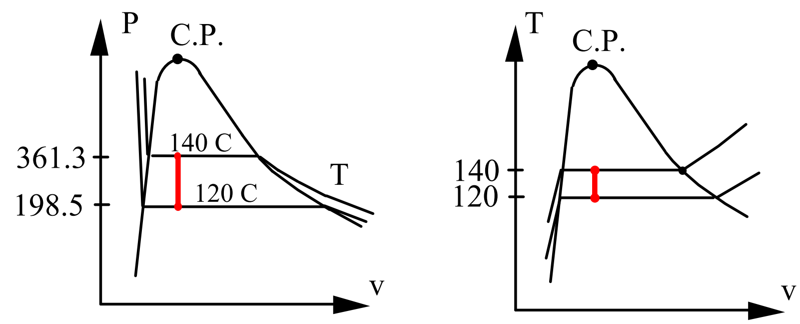
State 1 from Table B.1.1 at 120°C

$$v = v_f + x\ v_{fg} = 0.001060 + 0.25 \times 0.8908 = 0.22376\ m^3/kg$$

State 2 has same v at 140°C also from Table B.1.1

$$x = \frac{v - v_f}{v_{fg}} = \frac{0.22376 - 0.00108}{0.50777} = \mathbf{0.4385}$$

$$u = u_f + x\ u_{fg} = 588.72 + 0.4385 \times 1961.3 = \mathbf{1448.8\ kJ/kg}$$



5.15

Two kg water at 200 kPa with a quality of 25% has its temperature raised 20°C in a constant pressure process. What is the change in enthalpy?

Solution:

State 1 from Table B.1.2 at 200 kPa

$h = h_f + x\, h_{fg} = 504.68 + 0.25 \times 2201.96 = 1055.2$ kJ/kg

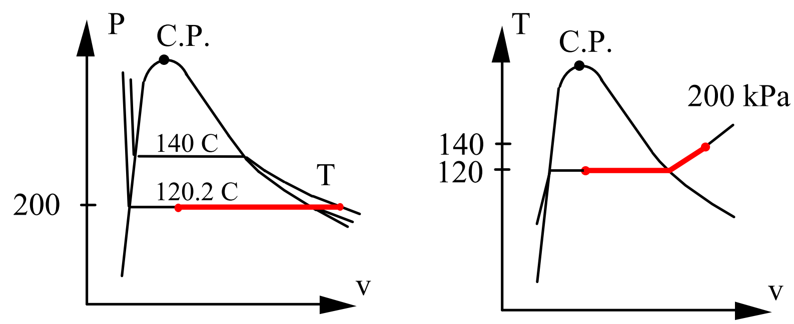
State 2 has same P from Table B.1.2 at 200 kPa

$T_2 = T_{sat} + 20 = 120.23 + 20 = 140.23^{o}C$

so state 2 is superheated vapor (x = undefined) from Table B.1.3

$$h_2 = 2706.63 + (2768.8 - 2706.63)\frac{20}{150 - 120.23} = 2748.4 \text{ kJ/kg}$$

$h_2 - h_1 = 2748.4 - 1055.2 =$ **1693.2 kJ/kg**



5.16

You heat a gas 10 K at P = C. Which one in table A.5 requires most energy? Why?

A constant pressure process in a control mass gives (recall Eq.5.29)

$$_1q_2 = u_2 - u_1 + {}_1w_2 = h_2 - h_1 \approx C_p\, \Delta T$$

The one with the highest specific heat is hydrogen, H_2. The hydrogen has the smallest mass but the same kinetic energy per mol as other molecules and thus the most energy per unit mass is needed to increase the temperature.

5.17

Air is heated from 300 to 350 K at V = C. Find ${}_1q_2$? What if from 1300 to 1350 K?

Process: V = C → ${}_1W_2 = Ø$

Energy Eq.: $u_2 - u_1 = {}_1q_2 - 0 \rightarrow \quad {}_1q_2 = u_2 - u_1$

Read the u-values from Table A.7.1

a) ${}_1q_2 = u_2 - u_1 = 250.32 - 214.36 =$ **36.0 kJ/kg**

b) ${}_1q_2 = u_2 - u_1 = 1067.94 - 1022.75 =$ **45.2 kJ/kg**

case a) $C_v \approx 36/50 = 0.72$ kJ/kg K , see A.5

case b) $C_v \approx 45.2/50 = 0.904$ kJ/kg K (25 % higher)

5.18

A mass of 3 kg nitrogen gas at 2000 K, V = C, cools with 500 W. What is dT/dt?

Process: V = C → ${}_1W_2 = 0$

$$\frac{dE}{dt} = \frac{dU}{dt} = m\frac{dU}{dt} = mC_v\frac{dT}{dt} = \dot{Q} - W = \dot{Q} = -500\text{ W}$$

$$C_{v\,2000} = \frac{du}{dT} = \frac{\Delta u}{\Delta T} = \frac{u_{2100} - u_{1900}}{2100\text{-}1900} = \frac{1819.08 - 1621.66}{200} = 0.987\text{ kJ/kg K}$$

$$\frac{dT}{dt} = \frac{\dot{Q}}{mC_v} = \frac{-500\text{ W}}{3 \times 0.987\text{ kJ/K}} = \mathbf{-0.17\ \frac{K}{s}}$$

Remark: Specific heat from Table A.5 has $C_{v\,300} = 0.745$ kJ/kg K which is nearly 25% lower and thus would over-estimate the rate with 25%.

5.19

A drag force on a car, with frontal area A = 2 m^2, driving at 80 km/h in air at 20^{o}C is $F_d = 0.225\ A\ \rho_{air}\mathbf{V}^2$. How much power is needed and what is the traction force?

$$\dot{W} = F\mathbf{V}$$

$$\mathbf{V} = 80\ \frac{km}{h} = 80 \times \frac{1000}{3600}\ ms^{-1} = 22.22\ ms^{-1}$$

$$\rho_{AIR} = \frac{P}{RT} = \frac{101}{0.287 \times 293} = 1.20\ kg/m^3$$

$$F_d = 0.225\ A\rho\mathbf{V}^2 = 0.225 \times 2 \times 1.2 \times 22.22^2 = \mathbf{266.61\ N}$$

$$\dot{W} = F\mathbf{V} = 266.61\ N \times 22.22\ m/s = 5924\ W = \mathbf{5.92\ kW}$$

Kinetic and Potential Energy

5.20

A hydraulic hoist raises a 1750 kg car 1.8 m in an auto repair shop. The hydraulic pump has a constant pressure of 800 kPa on its piston. What is the increase in potential energy of the car and how much volume should the pump displace to deliver that amount of work?

Solution: C.V. Car.

No change in kinetic or internal energy of the car, neglect hoist mass.

$$E_2 - E_1 = PE_2 - PE_1 = mg\,(Z_2 - Z_1)$$

$$= 1750 \times 9.80665 \times 1.8 = \mathbf{30\ 891\ \ J}$$

The increase in potential energy is work into car from pump at constant P.

$$W = E_2 - E_1 = \int P\,dV = P\,\Delta V \qquad \Rightarrow$$

$$\Delta V = \frac{E_2 - E_1}{P} = \frac{30891}{800 \times 1000} = \mathbf{0.0386\ m^3}$$

5.21

A piston motion moves a 25 kg hammerhead vertically down 1 m from rest to a velocity of 50 m/s in a stamping machine. What is the change in total energy of the hammerhead?

Solution: C.V. Hammerhead

The hammerhead does not change internal energy (i.e. same P, T), but it does have a change in kinetic and potential energy.

$$E_2 - E_1 = m(u_2 - u_1) + m[(1/2)\mathbf{V}_2{}^2 - 0] + mg\,(h_2 \;- 0)$$

$$= 0 + 25 \times (1/2) \times 50^2 + 25 \times 9.80665 \times (-1)$$

$$= 31250 - 245.17 = 31005 \text{ J} = \mathbf{31\ kJ}$$

5.22

Airplane takeoff from an aircraft carrier is assisted by a steam driven piston/cylinder device with an average pressure of 1250 kPa. A 17500 kg airplane should be accelerated from zero to a speed of 30 m/s with 30% of the energy coming from the steam piston. Find the needed piston displacement volume.

Solution: C.V. Airplane.

No change in internal or potential energy; only kinetic energy is changed.

$$E_2 - E_1 = m\,(1/2)\,(\mathbf{V}_2^2 - 0) = 17500 \times (1/2) \times 30^2 = 7875\,000 \text{ J} = 7875 \text{ kJ}$$

The work supplied by the piston is 30% of the energy increase.

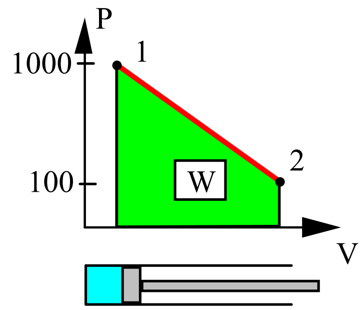
$$W = \int P\,dV = P_{avg}\ \Delta V = 0.30\,(E_2 - E_1)$$
$$= 0.30 \times 7875 = 2362.5 \text{ kJ}$$

$$\Delta V = \frac{W}{P_{avg}} = \frac{2362.5}{1250} = \mathbf{1.89\ m^3}$$

5.23

Solve Problem 5.22, but assume the steam pressure in the cylinder starts at 1000 kPa, dropping linearly with volume to reach 100 kPa at the end of the process.

Solution: C.V. Airplane.



$$E_2 - E_1 = m\,(1/2)\,(\mathbf{V}_2^2 - 0)$$
$$= 3500 \times (1/2) \times 30^2$$
$$= 1575000 \text{ J} = 1575 \text{ kJ}$$
$$W = 0.25(E_2 - E_1) = 0.25 \times 1575 = 393.75 \text{ kJ}$$
$$W = \int P\, dV = (1/2)(P_{beg} + P_{end})\, \Delta V$$

$$\Delta V = \frac{W}{P_{avg}} = \frac{2362.5}{1/2(1000 + 100)} = \mathbf{4.29\ m^3}$$

5.24

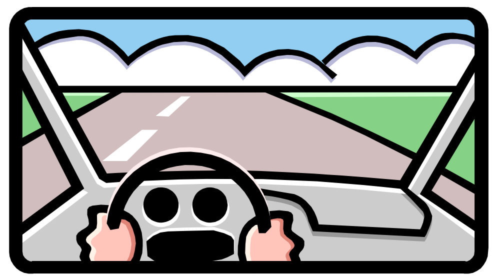
A 1200 kg car accelerates from zero to 100 km/h over a distance of 400 m. The road at the end of the 400 m is at 10 m higher elevation. What is the total increase in the car kinetic and potential energy?

Solution:

$$\Delta KE = \frac{1}{2} m (\mathbf{V}_2^2 - \mathbf{V}_1^2)$$

$$\mathbf{V}_2 = 100 \text{ km/h} = \frac{100 \times 1000}{3600} \text{ m/s}$$

$$= 27.78 \text{ m/s}$$



$\Delta KE = ½ \times 1200 \text{ kg} \times (27.78^2 – 0^2) \text{ (m/s)}^2 = 463\ 037 \text{ J} =$ **463 kJ**

$\Delta PE = mg(Z_2 – Z_1) = 1200 \text{ kg} \times 9.807 \text{ m/s}^2 \text{ (10 - 0) m} = 117684 \text{ J}$ **= 117.7 kJ**

5.25

A 25 kg piston is above a gas in a long vertical cylinder. Now the piston is released from rest and accelerates up in the cylinder reaching the end 5 m higher at a velocity of 25 m/s. The gas pressure drops during the process so the average is 600 kPa with an outside atmosphere at 100 kPa. Neglect the change in gas kinetic and potential energy, and find the needed change in the gas volume.

Solution:

C.V. Piston

$$(E_2 - E_1)_{PIST.} = m(u_2 - u_1) + m[(1/2)V_2^{\ 2} - 0] + mg\ (h_2\ - 0)$$

$$= 0 + 25 \times (1/2) \times 25^2 + 25 \times 9.80665 \times 5$$

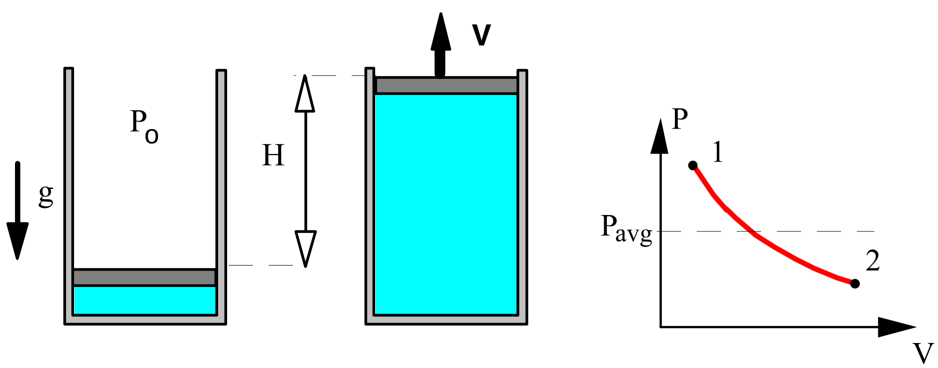
$$= 7812.5 + 1225.8 = 9038.3 \text{ J} = 9.038 \text{ kJ}$$

Energy equation for the piston is:

$$E_2 - E_1\ = W_{gas} - W_{atm} = P_{avg}\ \Delta V_{gas} - P_o\ \Delta V_{gas}$$

(remark $\Delta V_{atm} = -\Delta V_{gas}$ so the two work terms are of opposite sign)

$$\Delta V_{gas} = 9.038/(600 - 100) = \mathbf{0.018\ m^3}$$



5.26

The rolling resistance of a car depends on its weight as: F = 0.006 mg. How far will a car of 1200 kg roll if the gear is put in neutral when it drives at 90 km/h on a level road without air resistance?

Solution:

The car decreases its kinetic energy to zero due to the force (constant) acting over the distance.

$$m\,(1/2\mathbf{V}_2^2 - 1/2\mathbf{V}_1^2) = -{}_1W_2 = -\int F\,dx = -FL$$

$$\mathbf{V}_2 = 0, \quad \mathbf{V}_1 = 90\,\frac{\text{km}}{\text{h}} = \frac{90\times1000}{3600}\,\text{ms}^{-1} = 25\ \text{ms}^{-1}$$

$$-1/2\,m\mathbf{V}_1^2 = -FL = -\,0.006\,mgL$$

$$\rightarrow \qquad L = \frac{0.5\,\mathbf{V}_1^2}{0.0006g} = \frac{0.5\times25^2}{0.006\times9.807}\,\frac{\text{m}^2/\text{s}^2}{\text{m/s}^2} = 5311\ \text{m}$$

Remark: Over 5 km! The air resistance is much higher than the rolling resistance so this is not a realistic number by itself.

5.27

A mass of 5 kg is tied to an elastic cord, 5 m long, and dropped from a tall bridge. Assume the cord, once straight, acts as a spring with k = 100 N/m. Find the velocity of the mass when the cord is straight (5 m down). At what level does the mass come to rest after bouncing up and down?

Solution:

Let us assume we can neglect the cord mass and motion.

$$1: \mathbf{V}_1 = 0, \quad Z_1 = 0 \qquad\qquad 2: \mathbf{V}_2, \; Z_2 = -5\text{m}$$

$$3: \mathbf{V}_3 = 0, \quad Z_3 = -L, \; F_{up} = mg = k_s \; \Delta L$$

$$1 \rightarrow 2: \qquad \tfrac{1}{2} m\mathbf{V}_1^2 + mg\,Z_1 = \tfrac{1}{2}\mathbf{V}_2^2 + mgZ_2$$

Divide by mass and left hand side is zero so

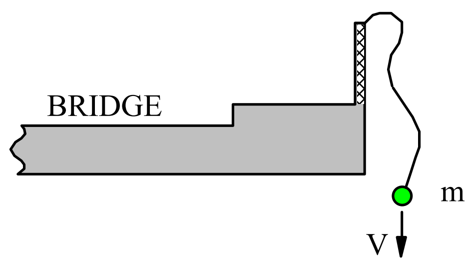
$$\tfrac{1}{2}\mathbf{V}_2^2 + g\,Z_2 = 0$$

$$\mathbf{V}_2 = (-2g\,Z_2)^{1/2} = (\,-2 \times 9.807 \times (-5))^{\,1/2} = \mathbf{9.9\ m/s}$$

State 3: m is at rest so $F_{up} = F_{down}$

$$k_s \;\Delta L \;= mg \rightarrow$$

$$\Delta L = \frac{mg}{k_s} = \frac{5 \times 9.807}{100} \; \frac{\text{kg ms}^{-2}}{\text{Nm}^{-1}} = 0.49 \text{ m}$$



$$L = L_o + \Delta L = 5 + 0.49 = 5.49 \text{ m}$$

So: $\quad Z_2 = -L = \mathbf{-\ 5.49\ m}$

Properties (u, h) from General Tables

5.28

Find the missing properties.

a.	H_2O	$T = 250°C$, $v = 0.02\ m^3/kg$	$P = ?$ $u = ?$
b.	N_2	$T = 120\ K$, $P = 0.8\ MPa$	$x = ?$ $h = ?$
c.	H_2O	$T = -2°C$, $P = 100\ kPa$	$u = ?$ $v = ?$
d.	R-134a	$P = 200\ kPa$, $v = 0.12\ m^3/kg$	$u = ?$ $T = ?$

Solution:

a) Table B.1.1 at 250°C: $v_f < v < v_g$ ⇒ P = Psat = **3973 kPa**

$x = (v - v_f)/ v_{fg} = (0.02 – 0.001251)/0.04887 = 0.38365$

$u = u_f + x\ u_{fg} = 1080.37 + 0.38365 \times 1522.0 =$ **1664.28 kJ/kg**

b) Table B.6.1 P is lower than P_{sat} so it is super heated vapor

=> x = **undefined** and we find the state in Table B.6.2

Table B.6.2: h = **114.02 kJ/kg**

c) Table B.1.1 : $T < T_{triple\ point}$ => B.1.5: $P > P_{sat}$ so compressed solid

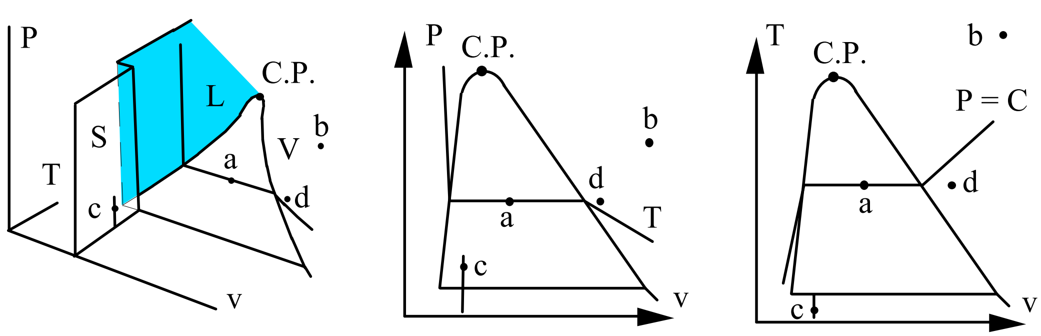
$u \cong u_i =$ **-337.62 kJ/kg** $v \cong v_i =$ **$1.09\times10^{-3}\ m^3/kg$**

approximate compressed solid with saturated solid properties at same T.

d) Table B.5.1 $v > v_g$ superheated vapor => Table B.5.2.

T ~ **32.5°C** = 30 + (40 – 30) × (0.12 – 0.11889)/(0.12335 - 0.11889)

u = 403.1 + (411.04 – 403.1) × 0.24888 = **405.07 kJ/kg**



5.29

Find the missing properties of T, P, v, u, h and x if applicable and plot the location of the three states as points in the T-v and the P-v diagrams

a. Water at 5000 kPa, u = 800 kJ/kg

b. Water at 5000 kPa, v = 0.06 m^3/kg

c. R-134a at 35^{o}C, v = 0.01 m^3/kg

Solution:

a) Look in Table B.1.2 at 5000 kPa

$u < u_f = 1147.78$ => compressed liquid

Table B.1.4: between 180 ^{o}C and 200 ^{o}C

$$T = 180 + (200 - 180) \frac{800 - 759.62}{848.08 - 759.62} = 180 + 20*0.4567 = 189.1 \text{ C}$$

$v = 0.001124 + 0.4567 (0.001153 - 0.001124) = 0.001137$

b) Look in Table B.1.2 at 5000 kPa

$v > v_g = 0.03944$ => superheated vapor

Table B.1.3: between 400 ^{o}C and 450 ^{o}C.

$T = 400 + 50*(0.06 - 0.05781)/(0.0633 - 0.05781)$

$= 400 + 50*0.3989 = 419.95$ ^{o}C

$h = 3195.64 + 0.3989 *(3316.15 - 3195.64) = 3243.71$

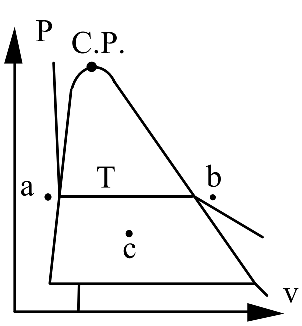
c) B.5.1: $v_f < v < v_g$

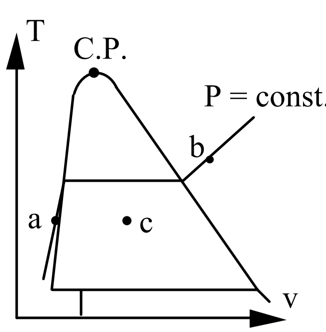
=> 2-phase, $P = P_{sat} =$ 887.6 kPa,

$x = (v - v_f) / v_{fg} = (0.01 - 0.000857)/0.02224 = 0.4111$

$u = u_f + x\, u_{fg} = 248.34 + 0.4111*148.68 = 309.46$ kJ/kg

States shown are placed relative to the two-phase region, not to each other.





5.30

Find the missing properties and give the phase of the ammonia, NH_3.

a. T = 65^{o}C, P = 600 kPa   u = ?   v = ?

b. T = 20^{o}C, P = 100 kPa   u = ?   v = ?   x = ?

c. T = 50^{o}C, v = 0.1185 m^3/kg   u = ?   P = ?   x = ?

Solution:

a) Table B.2.1   P < Psat   => superheated vapor Table B.2.2:

$v = 0.5 \times 0.25981 + 0.5 \times 0.26888 = \mathbf{0.2645\ m^3/kg}$

$u = 0.5 \times 1425.7 + 0.5 \times 1444.3 = \mathbf{1435\ kJ/kg}$

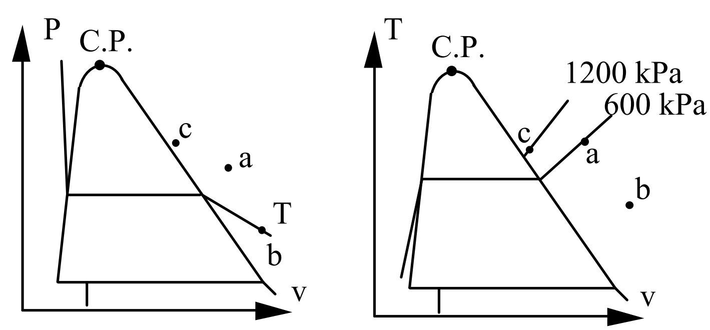
b) Table B.2.1: P < Psat => x = **undefined**, **superheated vapor**, from B.2.2:

$v = \mathbf{1.4153\ m^3/kg}$; $u = \mathbf{1374.5\ kJ/kg}$

c) Sup. vap. ($v > v_g$) Table B.2.2.   P = **1200 kPa**, x = **undefined**

u = **1383 kJ/kg**

States shown are placed relative to the two-phase region, not to each other.



5.31

Find the phase and missing properties of P, T, v, u, and x.

a. Water at 5000 kPa, u = 1000 kJ/kg (Table B.1 reference)

b. R-134a at 20^oC, u = 300 kJ/kg

c. Nitrogen at 250 K, 200 kPa

Show also the three states as labeled dots in a T-v diagram with correct position relative to the two-phase region.

Solution:

a) Compressed liquid: B.1.4 interpolate between 220^oC and 240^oC.

T = **233.3^oC**, v = **0.001213 m^3/kg**, x = **undefined**

b) Table B.5.1: $u < u_g$ => two-phase liquid and vapor

$x = (u - u_f)/u_{fg} = (300 - 227.03)/162.16 = 0.449988 =$ **0.45**

$v = 0.000817 + 0.45*0.03524 =$ **0.01667 m^3/kg**

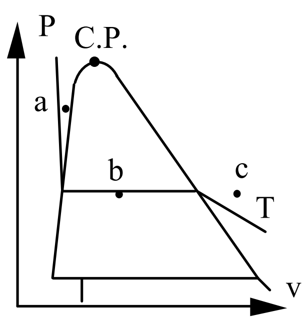
c) Table B.6.1: $T > T_{sat}$ (200 kPa) so superheated vapor in Table B.6.2

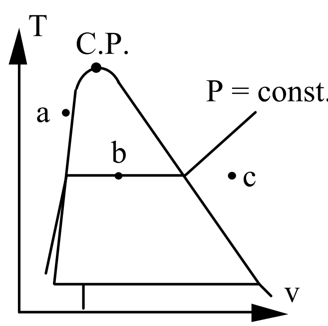
x = **undefined**

v = 0.5(0.35546 + 0.38535) = **0.3704 m^3/kg**,

u = 0.5(177.23 + 192.14) = **184.7 kJ/kg**

States shown are placed relative to the two-phase region, not to each other.





5.32

Find the missing properties and give the phase of the substance

a.	H_2O	$T = 120°C$, $v = 0.5\ m^3/kg$	$u = ?$ $P = ?$ $x = ?$
b.	H_2O	$T = 100°C$, $P = 10$ MPa	$u = ?$ $x = ?$ $v = ?$
c.	N_2	$T = 200$ K, $P = 200$ kPa	$v = ?$ $u = ?$
d.	NH_3	$T = 100°C$, $v = 0.1\ m^3/kg$	$P = ?$ $x = ?$
e.	N_2	$T = 100$ K, $x = 0.75$	$v = ?$ $u = ?$

Solution:

a) Table B.1.1: $v_f < v < v_g$ => L+V mixture, P = **198.5 kPa**,

$x = (0.5 - 0.00106)/0.8908 =$ **0.56**,

$u = 503.48 + 0.56 \times 2025.76 =$ **1637.9 kJ/kg**

b) Table B.1.4: compressed liquid, v = 0**.001039 m^3/kg**, u = **416.1 kJ/kg**

c) Table B.6.2: 200 K, 200 kPa

v = **0.29551 m^3/kg** ; u = **147.37 kJ/kg**

d) Table B.2.1: $v > v_g$ => superheated vapor, x = **undefined**

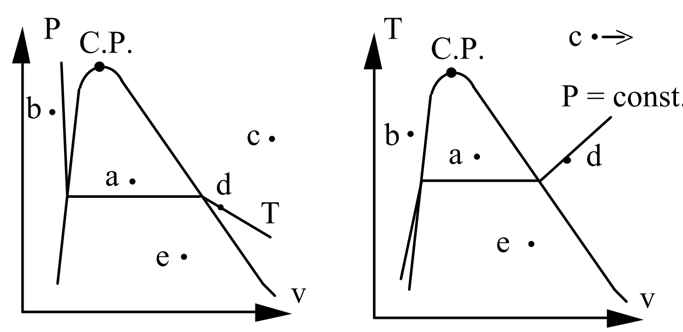
B.2.2: $P = 1600 + 400 \times \dfrac{0.1 - 0.10539}{0.08248 - 0.10539} =$ **1694 kPa**

e) Table B.6.1: 100 K, x = 0.75

$v = 0.001452 + 0.75 \times 0.02975 =$ **0.023765 m^3/kg**

$u = -74.33 + 0.75 \times 137.5 =$ **28.8 kJ/kg**

States shown are placed relative to the two-phase region, not to each other.



5.33

Find the missing properties among (T, P, v, u, h and x if applicable) and give the phase of the substance and indicate the states relative to the two-phase region in both a T-v and a P-v diagram.

a.	R-12	P = 500 kPa, h = 230 kJ/kg
b.	R-22	T = 10°C, u = 200 kJ/kg
c.	R-134a	T = 40°C, h = 400 kJ/kg

Solution:

a) Table B.3.2: $h > h_g$ => **superheated vapor**, look in section 500 kPa and interpolate

T = **68.06°C**, v = **0.04387 m^3/kg**, u = **208.07 kJ/kg**

b) Table B.4.1: $u < u_g$ => L+V mixture, P = **680.7 kPa**

$$x = \frac{u - u_f}{u_{fg}} = \frac{200 - 55.92}{173.87} = \mathbf{0.8287},$$

v = 0.0008 + 0.8287 × 0.03391 = **0.0289 m^3/kg**,

h = 56.46 + 0.8287 × 196.96 = **219.7 kJ/kg**

c) Table B.5.1: $h < h_g$ => **two-phase L + V,** look in B.5.1 at 40°C:

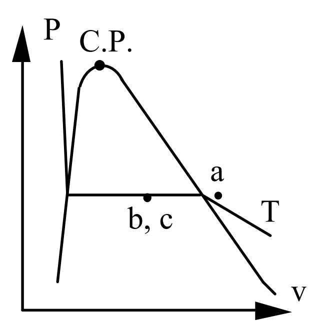
$$x = \frac{h - h_f}{h_{fg}} = \frac{400 - 256.5}{163.3} = 0.87875$$

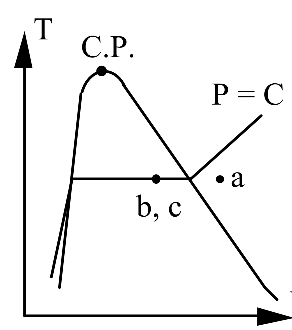
$P = P_{sat} =$ **1017 kPa**,

v = 0.000 873 + 0.87875 × 0.01915 = **0.0177 m^3/kg**

u = 255.7 + 0.87875 × 143.8 = **382.1 kJ/kg**

States shown are placed relative to the two-phase region, not to each other.





5.34

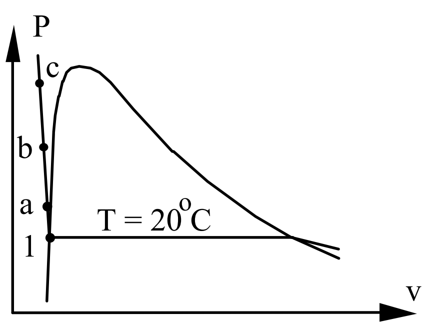
Saturated liquid water at 20°C is compressed to a higher pressure with constant temperature. Find the changes in u and h from the initial state when the final pressure is a) 500 kPa, b) 2000 kPa, c) 20 000 kPa

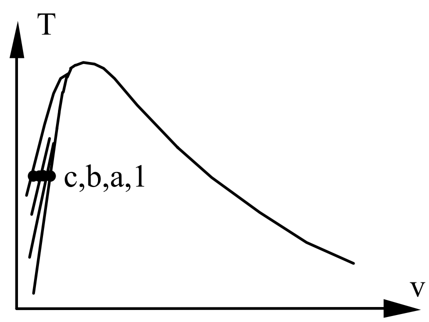
Solution:

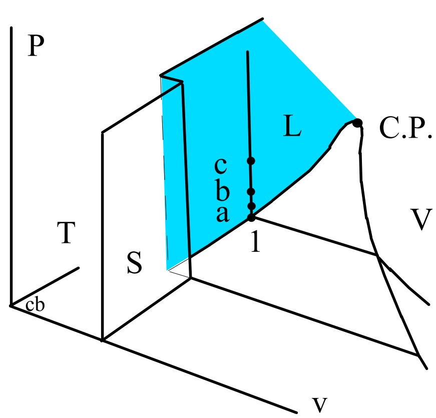
State 1 is located in Table B.1.1 and the states a-c are from Table B.1.4

State	u [kJ/kg]	h [kJ/kg]	$\Delta u = u - u_1$	$\Delta h = h - h_1$	$\Delta(Pv)$
1	83.94	83.94			
a	83.91	84.41	-0.03	0.47	0.5
b	83.82	85.82	-0.12	1.88	2
c	82.75	102.61	-1.19	18.67	20

For these states u stays nearly constant, dropping slightly as P goes up.
h varies with Pv changes.







Energy Equation: Simple Process

5.35

A 100-L rigid tank contains nitrogen (N_2) at 900 K, 3 MPa. The tank is now cooled to 100 K. What are the work and heat transfer for this process?

Solution:

C.V.: Nitrogen in tank. $m_2 = m_1$;

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: V = constant, $v_2 = v_1 = V/m$ => $\mathbf{{}_1W_2 = 0}$

Table B.6.2: State 1: $v_1 = 0.0900\ m^3/kg$ => $m = V/v_1 = 1.111$ kg

$u_1 = 691.7$ kJ/kg

State 2: 100 K, $v_2 = v_1 = V/m$, look in Table B.6.2 at 100 K

200 kPa: $v = 0.1425\ m^3/kg$; $u = 71.7$ kJ/kg

400 kPa: $v = 0.0681\ m^3/kg$; $u = 69.3$ kJ/kg

so a linear interpolation gives:

$$P_2 = 200 + 200\ (0.09 - 0.1425)/(0.0681 - 0.1425) = 341\text{ kPa}$$

$$u_2 = 71.7 + (69.3 - 71.7)\frac{0.09 - 0.1425}{0.0681 - 0.1425} = 70.0\text{ kJ/kg},$$

$${}_1Q_2 = m(u_2 - u_1) = 1.111\ (70.0 - 691.7) = \mathbf{-690.7\ kJ}$$

5.36

A rigid container has 0.75 kg water at 300°C, 1200 kPa. The water is now cooled to a final pressure of 300 kPa. Find the final temperature, the work and the heat transfer in the process.

Solution:

C.V. Water. Constant mass so this is a control mass

Energy Eq.: $U_2 - U_1 = {}_1Q_2 - {}_1W_2$

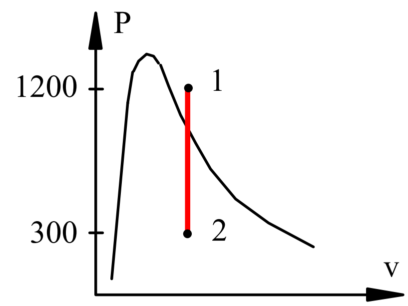
Process eq.: V = constant. (rigid)

=> ${}_1W_2 = \int P\, dV = \mathbf{0}$

State 1: 300°C, 1200 kPa

=> superheated vapor Table B.1.3

$v = 0.21382\ m^3/kg$, $u = 2789.22\ kJ/kg$



State 2: 300 kPa and $v_2 = v_1$ from Table B.1.2 $v_2 < v_g$ two-phase

$T_2 = T_{sat} = \mathbf{133.55^oC}$

$$x_2 = \frac{v_2 - v_f}{v_{fg}} = \frac{0.21382 - 0.001073}{0.60475} = 0.35179$$

$u_2 = u_f + x_2\, u_{fg} = 561.13 + x_2\, 1982.43 = 1258.5$ kJ/kg

${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = m(u_2 - u_1)$

$= 0.75\ (1258.5 - 2789.22) = \mathbf{-1148\ kJ}$

5.37

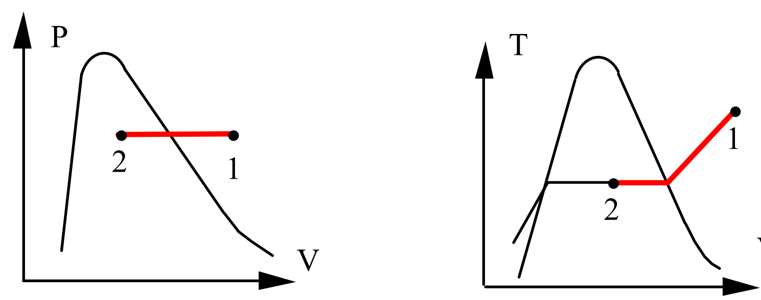
A cylinder fitted with a frictionless piston contains 2 kg of superheated refrigerant R-134a vapor at 350 kPa, 100°C. The cylinder is now cooled so the R-134a remains at constant pressure until it reaches a quality of 75%. Calculate the heat transfer in the process.

Solution:

C.V.: R-134a $\quad m_2 = m_1 = m;$

Energy Eq.5.11 $\quad m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: P = const. $\Rightarrow {}_1W_2 = \int PdV = P\Delta V = P(V_2 - V_1) = Pm(v_2 - v_1)$



State 1: Table B.5.2 $\quad h_1 = (490.48 + 489.52)/2 = 490$ kJ/kg

State 2: Table B.5.1 $\quad h_2 = 206.75 + 0.75 \times 194.57 = 352.7$ kJ/kg (350.9 kPa)

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = m(u_2 - u_1) + Pm(v_2 - v_1) = m(h_2 - h_1)$$

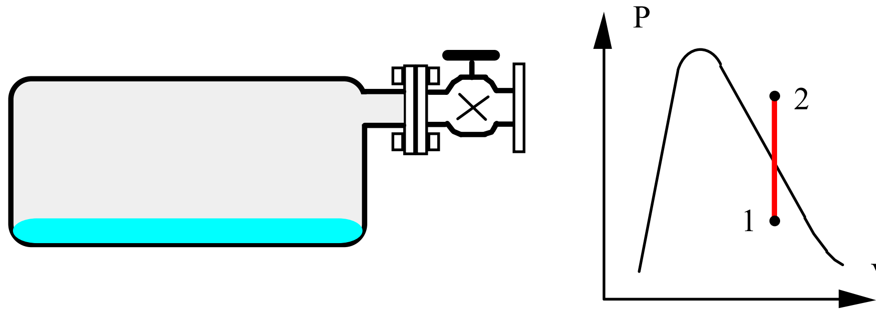
$${}_1Q_2 = 2 \times (352.7 - 490) = \mathbf{-274.6\ kJ}$$

5.38

Ammonia at 0°C, quality 60% is contained in a rigid 200-L tank. The tank and ammonia is now heated to a final pressure of 1 MPa. Determine the heat transfer for the process.

Solution:

C.V.: NH_3



Continuity Eq.: $m_2 = m_1 = m$;

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: Constant volume $\Rightarrow$ $v_2 = v_1$ & ${}_1W_2 = 0$

State 1: Table B.2.1 two-phase state.

$v_1 = 0.001566 + x_1 \times 0.28783 = 0.17426 \text{ m}^3\text{/kg}$

$u_1 = 179.69 + 0.6 \times 1138.3 = 862.67 \text{ kJ/kg}$

$m = V/v_1 = 0.2/0.17426 = 1.148 \text{ kg}$

State 2: P_2 , $v_2 = v_1$ superheated vapor Table B.2.2

$\Rightarrow T_2 \cong 100°C$, $u_2 \cong 1490.5$ kJ/kg

So solve for heat transfer in the energy equation

${}_1Q_2 = m(u_2 - u_1) = 1.148(1490.5 - 862.67) =$ **720.75 kJ**

5.39

Water in a 150-L closed, rigid tank is at 100°C, 90% quality. The tank is then cooled to −10°C. Calculate the heat transfer during the process.

Solution:

C.V.: Water in tank. $m_2 = m_1$;

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: V = constant, $v_2 = v_1$, ${}_1W_2 = 0$

State 1: Two-phase L + V look in Table B.1.1

$v_1 = 0.001044 + 0.9 \times 1.6719 = 1.5057 \text{ m}^3\text{/kg}$

$u_1 = 418.94 + 0.9 \times 2087.6 = 2297.8 \text{ kJ/kg}$

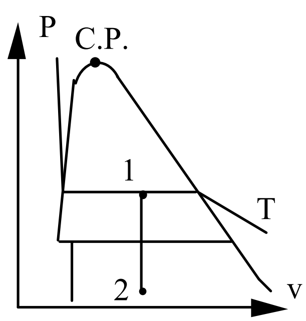
State 2: T_2, $v_2 = v_1$ ⇒ mix of saturated solid + vapor Table B.1.5

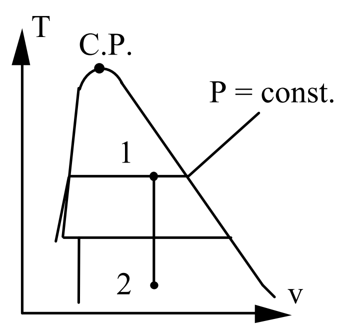
$v_2 = 1.5057 = 0.0010891 + x_2 \times 466.7$ => $x_2 = 0.003224$

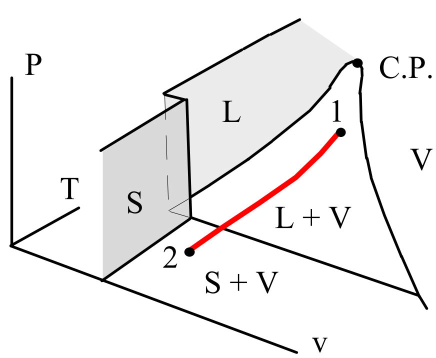
$u_2 = -354.09 + 0.003224 \times 2715.5 = -345.34 \text{ kJ/kg}$

$m = V/v_1 = 0.15/1.5057 = 0.09962 \text{ kg}$

${}_1Q_2 = m(u_2 - u_1) = 0.09962(-345.34 - 2297.8) =$ **-263.3 kJ**







5.40

A piston/cylinder contains 1 kg water at 20°C with volume 0.1 m^3. By mistake someone locks the piston preventing it from moving while we heat the water to saturated vapor. Find the final temperature and the amount of heat transfer in the process.

Solution:

C.V. Water. This is a control mass

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

Process : V = constant → ${}_1W_2 = 0$

State 1: T, $v_1 = V_1/m = 0.1\ m^3/kg > v_f$ so two-phase

$$x_1 = \frac{v_1 - v_f}{v_{fg}} = \frac{0.1\text{-}0.001002}{57.7887} = 0.0017131$$

$$u_1 = u_f + x_1\, u_{fg} = 83.94 + x_1 \times 2318.98 = 87.913 \text{ kJ/kg}$$

State 2: $v_2 = v_1 = 0.1$ & $x_2 = 1$

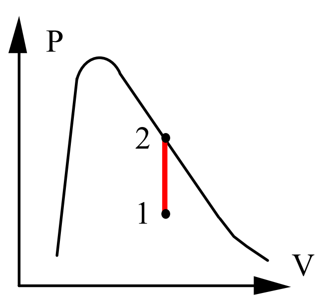
→ found in Table B.1.1 between 210°C and 215° C

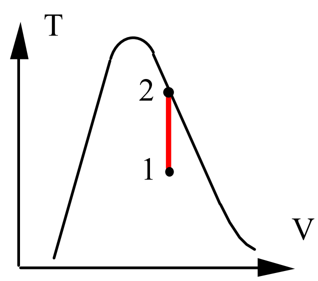
$$T_2 = 210 + 5 \times \frac{0.1\text{-}0.10441}{0.09479\text{-}0.10441} = 210 + 5 \times 0.4584 = 212.3°C$$

$$u_2 = 2599.44 + 0.4584\,(2601.06 - 2599.44) = 2600.2 \text{ kJ/kg}$$

From the energy equation

$${}_1Q_2 = m(u_2 - u_1) = 1(\,2600.2 - 87.913) = \mathbf{2512.3\ kJ}$$





5.41

A test cylinder with constant volume of 0.1 L contains water at the critical point. It now cools down to room temperature of 20°C. Calculate the heat transfer from the water.

Solution:

C.V.: Water

$m_2 = m_1 = m$;

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

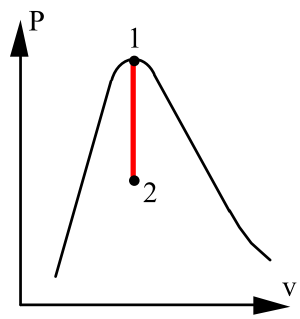
Process: Constant volume $\Rightarrow v_2 = v_1$

Properties from Table B.1.1

State 1: $v_1 = v_c = 0.003155\ m^3/kg$,

$u_1 = 2029.6$ kJ/kg

$m = V/v_1 = 0.0317$ kg



State 2: T_2, $v_2 = v_1 = 0.001002 + x_2 \times 57.79$

$x_2 = 3.7\times10^{-5}$, $u_2 = 83.95 + x_2 \times 2319 = 84.04$ kJ/kg

Constant volume => ${}_1W_2 = \emptyset$

${}_1Q_2 = m(u_2 - u_1) = 0.0317(84.04 - 2029.6) =$ **-61.7 kJ**

5.42

A 10-L rigid tank contains R-22 at −10°C, 80% quality. A 10-A electric current (from a 6-V battery) is passed through a resistor inside the tank for 10 min, after which the R-22 temperature is 40°C. What was the heat transfer to or from the tank during this process?

Solution:

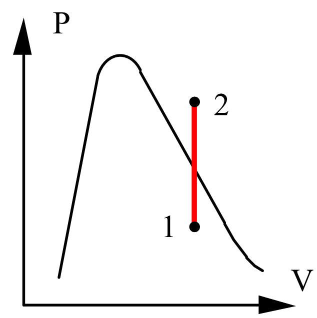
C.V. R-22 in tank. Control mass at constant V.

Continuity Eq.: $m_2 = m_1 = m$;

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

Process: Constant V $\Rightarrow$ $v_2 = v_1$

=> no boundary work, but electrical work



State 1 from table B.4.1

$v_1 = 0.000759 + 0.8 \times 0.06458 = 0.05242 \text{ m}^3/\text{kg}$

$u_1 = 32.74 + 0.8 \times 190.25 = 184.9 \text{ kJ/kg}$

$m = V/v = 0.010/0.05242 = 0.1908 \text{ kg}$

State 2: Table B.4.2 at 40°C and $v_2 = v_1 = 0.05242 \text{ m}^3/\text{kg}$

=> sup.vapor, so use linear interpolation to get

$P_2 = 500 + 100 \times (0.05242 - 0.05636)/(0.04628 - 0.05636) = 535 \text{ kPa}$,

$u_2 = 250.51 + 0.35\times (249.48 - 250.51) = 250.2 \text{ kJ/kg}$

$${}_1W_{2\ elec} = -\text{power} \times \Delta t = -\text{Amp} \times \text{volts} \times \Delta t = -\frac{10 \times 6 \times 10 \times 60}{1000} = -36 \text{ kJ}$$

${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 0.1908\ (250.2 - 184.9) - 36 =$ **−23.5 kJ**

5.43

A piston/cylinder contains 50 kg of water at 200 kPa with a volume of 0.1 m^3. Stops in the cylinder are placed to restrict the enclosed volume to a maximum of 0.5 m^3. The water is now heated until the piston reaches the stops. Find the necessary heat transfer.

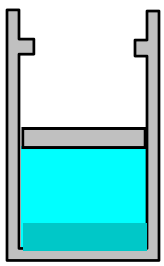
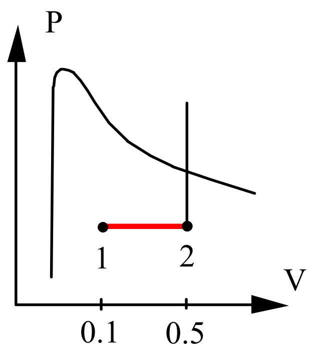
Solution:

C.V. H_2O m = constant

Energy Eq.5.11: $m(e_2 - e_1) = m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process : P = constant (forces on piston constant)

$$\Rightarrow {}_1W_2 = \int P\,dV = P_1 (V_2 - V_1)$$

Properties from Table B.1.1

State 1 : $v_1 = 0.1/50 = 0.002$ m^3/kg => 2-phase as $v_1 < v_g$

$$x = \frac{v_1 - v_f}{v_{fg}} = \frac{0.002 - 0.001061}{0.88467} = 0.001061$$

$$h = 504.68 + 0.001061 \times 2201.96 = 507.02 \text{ kJ/kg}$$

State 2 : $v_2 = 0.5/50 = 0.01$ m^3/kg also 2-phase same P

$$x_2 = \frac{v_2 - v_f}{v_{fg}} = \frac{0.01 - 0.001061}{0.88467} = 0.01010$$

$$h_2 = 504.68 + 0.01010 \times 2201.96 = 526.92 \text{ kJ/kg}$$

Find the heat transfer from the energy equation as

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = m(h_2 - h_1)$$

$${}_1Q_2 = 50 \text{ kg} \times (526.92 - 507.02) \text{ kJ/kg} = \mathbf{995\ kJ}$$

[Notice that $_1W_2 = P_1 (V_2 - V_1) = 200 \times (0.5 - 0.1) = 80$ kJ]

5.44

A constant pressure piston/cylinder assembly contains 0.2 kg water as saturated vapor at 400 kPa. It is now cooled so the water occupies half the original volume. Find the heat transfer in the process.

Solution:

C.V. Water. This is a control mass.

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: P = constant => ${}_1W_2 = Pm(v_2 - v_1)$

So solve for the heat transfer:

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = m(u_2 - u_1) + Pm(v_2 - v_1) = m(h_2 - h_1)$$

State 1: Table B.1.2 $v_1 = 0.46246\ m^3/kg$; $h_1 = 2738.53$ kJ/kg

State 2: $v_2 = v_1 / 2 = 0.23123 = v_f + x\ v_{fg}$ from Table B.1.2

$$x_2 = (v_2 - v_f) / v_{fg} = (0.23123 - 0.001084) / 0.46138 = 0.4988$$

$$h_2 = h_f + x_2\ h_{fg} = 604.73 + 0.4988 \times 2133.81 = 1669.07 \text{ kJ/kg}$$

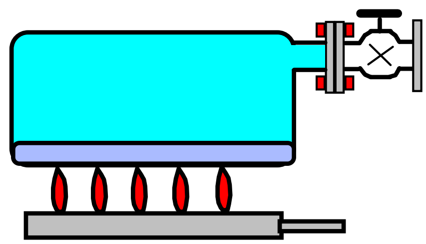
$${}_1Q_2 = 0.2\ (1669.07 - 2738.53) = \mathbf{-213.9\ KJ}$$

5.45

Two kg water at 120°C with a quality of 25% has its temperature raised 20°C in a constant volume process as in Fig. P5.45. What are the heat transfer and work in the process?

Solution:

C.V. Water. This is a control mass



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

Process : V = constant

$\rightarrow \quad {}_1W_2 = \int P\, dV = 0$

State 1: T, x_1 from Table B.1.1

$v_1 = v_f + x_1 v_{fg} = 0.00106 + 0.25 \times 0.8908 = 0.22376 \text{ m}^3\text{/kg}$

$u_1 = u_f + x_1 u_{fg} = 503.48 + 0.25 \times 2025.76 = 1009.92 \text{ kJ/kg}$

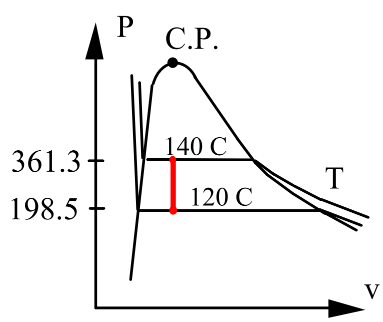
State 2: T_2, $v_2 = v_1 < v_{g2} = 0.50885 \text{ m}^3\text{/kg}$ so two-phase

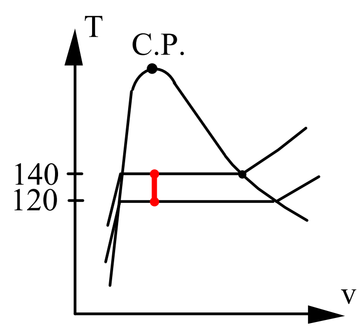
$$x_2 = \frac{v_2 - v_{f2}}{v_{fg2}} = \frac{0.22376 - 0.00108}{0.50777} = 0.43855$$

$u_2 = u_{f2} + x_2 u_{fg2} = 588.72 + x_2 \times 1961.3 = 1448.84 \text{ kJ/kg}$

From the energy equation

${}_1Q_2 = m(u_2 - u_1) = 2 (1448.84 - 1009.92) = \mathbf{877.8 \text{ kJ}}$





5.46

A 25 kg mass moves with 25 m/s. Now a brake system brings the mass to a complete stop with a constant deceleration over a period of 5 seconds. The brake energy is absorbed by 0.5 kg water initially at 20^{o}C, 100 kPa. Assume the mass is at constant P and T. Find the energy the brake removes from the mass and the temperature increase of the water, assuming P = C.

Solution:

C.V. The mass in motion.

$$E_2 - E_1 = \Delta E = 0.5\ mV^2 = 0.5 \times 25 \times 25^2/1000 = 7.8125\ kJ$$

C.V. The mass of water.

$m(u_2 - u_1)_{H_2O} = \Delta E = 7.8125$ kJ $\quad => \quad u_2 - u_1 = 7.8125 / 0.5 = 15.63$

$u_2 = u_1 + 15.63 = 83.94 + 15.63 = 99.565$ kJ/kg

Assume $u_2 = u_f$ then from Table B.1.1: $T_2 \cong 23.7^o$C, $\Delta T =$ **3.7^{o}C**

We could have used $u_2 - u_1 = C\Delta T$ with C from Table A.4: C = 4.18 kJ/kg K giving $\Delta T = 15.63/4.18 =$ **3.7^{o}C**.

5.47

An insulated cylinder fitted with a piston contains R-12 at 25°C with a quality of 90% and a volume of 45 L. The piston is allowed to move, and the R-12 expands until it exists as saturated vapor. During this process the R-12 does 7.0 kJ of work against the piston. Determine the final temperature, assuming the process is adiabatic.

Solution:

Take CV as the R-12.

Continuity Eq.: $m_2 = m_1 = m$;

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

State 1: (T, x) Tabel B.3.1 =>

$v_1 = 0.000763 + 0.9 \times 0.02609 = 0.024244 \text{ m}^3/\text{kg}$

$m = V_1/v_1 = 0.045/0.024244 = 1.856 \text{ kg}$

$u_1 = 59.21 + 0.9 \times 121.03 = 168.137 \text{ kJ/kg}$

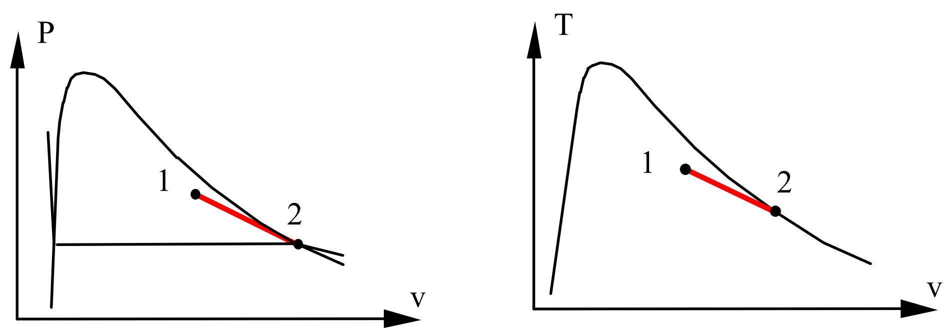
State 2: (x = 1, ?) We need one property information.

Apply now the energy equation with known work and adiabatic so

${}_1Q_2 = \emptyset = m(u_2 - u_1) + {}_1W_2 = 1.856 \times (u_2 - 168.137) + 7.0$

=> $u_2 = 164.365 \text{ kJ/kg} = u_g \text{ at } T_2$

Table B.3.1 gives u_g at different temperatures: $T_2 \cong$ **-15°C**



5.48

A water-filled reactor with volume of 1 m^3 is at 20 MPa, 360°C and placed inside a containment room as shown in Fig. P5.48. The room is well insulated and initially evacuated. Due to a failure, the reactor ruptures and the water fills the containment room. Find the minimum room volume so the final pressure does not exceed 200 kPa.

Solution:

Solution:

C.V.: Containment room and reactor.

Mass: $m_2 = m_1 = V_{reactor}/v_1 = 1/0.001823 = 548.5$ kg

Energy: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2 = 0 - 0 = 0$

State 1: Table B.1.4 $v_1 = 0.001823$ m^3/kg, $u_1 = 1702.8$ kJ/kg

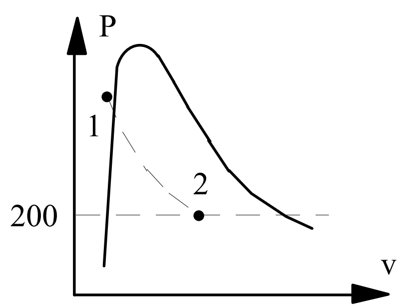
Energy equation then gives $u_2 = u_1 = 1702.8$ kJ/kg

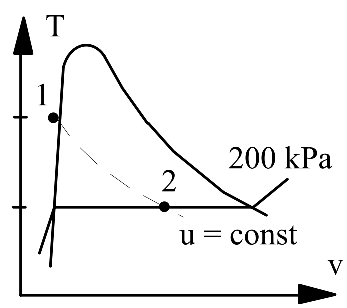
State 2: $P_2 = 200$ kPa, $u_2 < u_g$ => Two-phase Table B.1.2

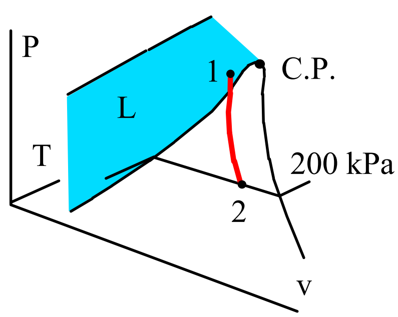
$x_2 = (u_2 - u_f)/ u_{fg} = (1702.8 - 504.47)/2025.02 = 0.59176$

$v_2 = 0.001061 + 0.59176 \times 0.88467 = 0.52457$ m^3/kg

$V_2 = m_2 v_2 = 548.5 \times 0.52457 =$ **287.7 m^3**







5.49

A piston/cylinder arrangement contains water of quality x = 0.7 in the initial volume of 0.1 m^3, where the piston applies a constant pressure of 200 kPa. The system is now heated to a final temperature of 200°C. Determine the work and the heat transfer in the process.

Take CV as the water.

Continuity Eq.: $m_2 = m_1 = m$;

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: P = constant $\Rightarrow$ ${}_1W_2 = \int PdV = Pm(v_2 - v_1)$

State 1: Table B.1.2

$T_1 = T_{sat}$ at 200 kPa = 120.23°C

$v_1 = v_f + xv_{fg} = 0.001061 + 0.7 \times 0.88467 = 0.62033\ m^3$

$h_1 = h_f + xh_{fg} = 504.68 + 0.7 \times 2201.96 = 2046.05$ kJ/kg

Total mass can be determined from the initial condition,

$m = V_1/v_1 = 0.1/0.62033 = 0.1612$ kg

$T_2 = 200°C$, $P_2 = 200$ kPa (Table B.1.3) gives $v_2 = 1.08034\ m^3/kg$

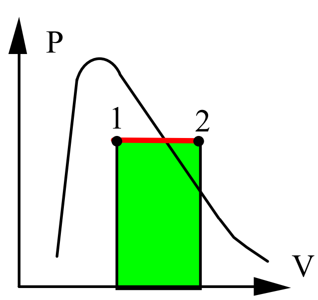
$h_2 = 2870.46$ kJ/kg (Table B.1.3)

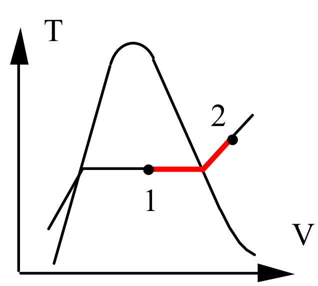
$V_2 = mv_2 = 0.1612\ kg \times 1.08034\ m^3/kg = \mathbf{0.174\ m^3}$

Substitute the work into the energy equation

${}_1Q_2 = U_2 - U_1 + {}_1W_2 = m (u_2 - u_1 + Pv_2 - Pv_1) = m(h_2 - h_1)$

${}_1Q_2 = 0.1612\ kg \times (2870.46 - 2046.05)\ kJ/kg =$ **132.9 kJ** (heat added to system).





5.50

A piston/cylinder arrangement has the piston loaded with outside atmospheric pressure and the piston mass to a pressure of 150 kPa, shown in Fig. P5.50. It contains water at −2°C, which is then heated until the water becomes saturated vapor. Find the final temperature and specific work and heat transfer for the process.

Solution:

C.V. Water in the piston cylinder.

Continuity: $m_2 = m_1$,

Energy Eq. per unit mass: $u_2 - u_1 = {}_1q_2 - {}_1w_2$

Process: P = constant = P_1, => ${}_1w_2 = \int_1^2 P\,dv = P_1(v_2 - v_1)$

State 1: T_1 , P_1 => Table B.1.5 compressed solid, take as saturated solid.

$$v_1 = 1.09\times10^{-3}\ m^3/kg, \quad u_1 = -337.62\ kJ/kg$$

State 2: x = 1, $P_2 = P_1 = 150$ kPa due to process => Table B.1.2

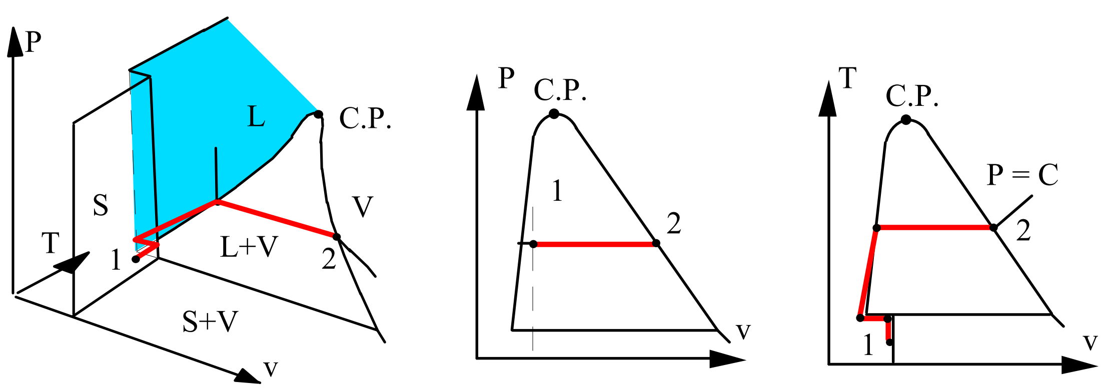
$$v_2 = v_g(P_2) = 1.1593\ m^3/kg, \quad T_2 = \mathbf{111.4°C}\ ; \quad u_2 = 2519.7\ kJ/kg$$

From the process equation

$${}_1w_2 = P_1(v_2 - v_1) = 150(1.1593 - 1.09\times10^{-3}) = \mathbf{173.7\ kJ/kg}$$

From the energy equation

$${}_1q_2 = u_2 - u_1 + {}_1w_2 = 2519.7 - (-337.62) + 173.7 = \mathbf{3031\ kJ/kg}$$



5.51

A piston/cylinder assembly contains 1 kg of liquid water at 20°C and 300 kPa. There is a linear spring mounted on the piston such that when the water is heated the pressure reaches 1 MPa with a volume of 0.1 m^3. Find the final temperature and the heat transfer in the process.

Solution:

Take CV as the water.

$$m_2 = m_1 = m \quad ; \qquad m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$$

State 1: Compressed liquid, take saturated liquid at same temperature.

$$v_1 = v_f(20) = 0.001002\ m^3/kg, \qquad u_1 = u_f = 83.94\ kJ/kg$$

State 2: $v_2 = V_2/m = 0.1/1 = 0.1\ m^3/kg$ and P = 1000 kPa

=> Two phase as $v_2 < v_g$ so $T_2 = T_{sat} =$ **179.9°C**

$$x_2 = (v_2 - v_f)/v_{fg} = (0.1 - 0.001127)/0.19332 = 0.51145$$

$$u_2 = u_f + x_2 u_{fg} = 780.08 + 0.51147 \times 1806.32 = 1703.96\ kJ/kg$$

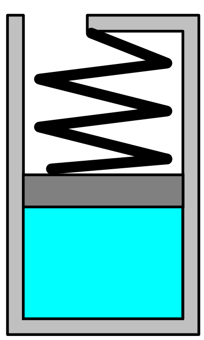
Work is done while piston moves at linearly varying pressure, so we get

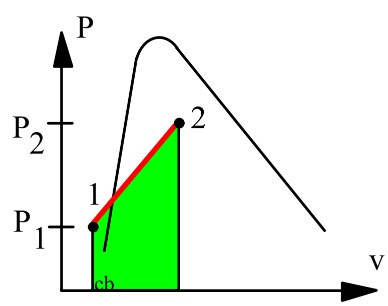
$${}_1W_2 = \int P\,dV = \text{area} = P_{avg}(V_2 - V_1)$$

$$= 0.5 \times (300 + 1000)(0.1 - 0.001) = 64.35\ kJ$$

Heat transfer is found from the energy equation

${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 1 \times (1703.96 - 83.94) + 64.35 =$ **1684 kJ**





5.52

A closed steel bottle contains ammonia at −20°C, x = 20% and the volume is 0.05 m^3. It has a safety valve that opens at a pressure of 1.4 MPa. By accident, the bottle is heated until the safety valve opens. Find the temperature and heat transfer when the valve first opens.

Solution:

C.V.: NH_3 : $m_2 = m_1 = m$;

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

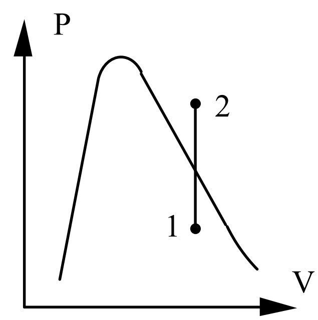
Process: constant volume process $\Rightarrow {}_1W_2 = 0$

State 1: (T, x) Table B.2.1

$v_1 = 0.001504 + 0.2 \times 0.62184 = 0.1259 \text{ m}^3\text{/kg}$

=> $m = V/v_1 = 0.05/0.1259 = 0.397 \text{ kg}$

$u_1 = 88.76 + 0.2 \times 1210.7 = 330.9 \text{ kJ/kg}$



State 2: P_2 , $v_2 = v_1$ => superheated vapor, interpolate in Table B.2.2:

$\mathbf{T \cong 110°C} = 100 + 20(0.1259 - 0.12172)/(0.12986 - 0.12172)$,

$u_2 = 1481 + (1520.7 - 1481) \times 0.51 = 1501.25 \text{ kJ/kg}$

${}_1Q_2 = m(u_2 - u_1) = 0.397(1501.25 - 330.9) = \mathbf{464.6\ kJ}$

5.53

Two kg water at 200 kPa with a quality of 25% has its temperature raised 20°C in a constant pressure process. What are the heat transfer and work in the process?

C.V. Water. This is a control mass

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

Process : P = constant $\rightarrow$ ${}_1W_2 = \int P\, dV = mP (v_2 - v_1)$

State 1: Two-phase given P,x so use Table B.1.2

$$v_1 = 0.001061 + 0.25 \times 0.88467 = 0.22223 \text{ m}^3/\text{kg}$$

$$u_1 = 504047 + 0.25 \times 2025.02 = 1010.725 \text{ kJ/kg}$$

$$T = T + 20 = 120.23 + 20 = 140.23$$

State 2 is superheated vapor

$$v_2 = 0.88573 + \frac{20}{150\text{-}120.23} \times (0.95964 - 0.88573) = 0.9354 \text{ m}^3/\text{kg}$$

$$u_2 = 2529.49 + \frac{20}{150\text{-}120.23} (2576.87\text{- } 2529.49) = 2561.32 \text{ kJ/kg}$$

From the process equation we get

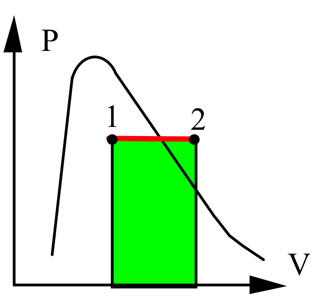
$${}_1W_2 = mP (v_2 - v_1) = 2 \times 200 \text{ (} 0.9354 \text{ - } 0.22223) = \mathbf{285.3 \text{ kJ}}$$

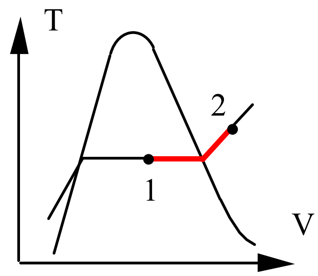
From the energy equation

$${}_1Q_2 = m (u_2 - u_1) + {}_1W_2$$

$$= 2 \text{ (} 2561.32 - 1010.725 \text{) } + 285.3$$

$$= 3101.2 + 285.27 = \mathbf{3386.5 \text{ kJ}}$$





5.54

Two kilograms of nitrogen at 100 K, $x = 0.5$ is heated in a constant pressure process to 300 K in a piston/cylinder arrangement. Find the initial and final volumes and the total heat transfer required.

Solution:

Take CV as the nitrogen.

Continuity Eq.: $m_2 = m_1 = m$;

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: P = constant $\Rightarrow$ ${}_1W_2 = \int P dV = Pm(v_2 - v_1)$

State 1: Table B.6.1

$$v_1 = 0.001452 + 0.5 \times 0.02975 = 0.01633 \text{ m}^3\text{/kg}, \quad V_1 = \mathbf{0.0327\ m^3}$$

$$h_1 = -73.20 + 0.5 \times 160.68 = 7.14 \text{ kJ/kg}$$

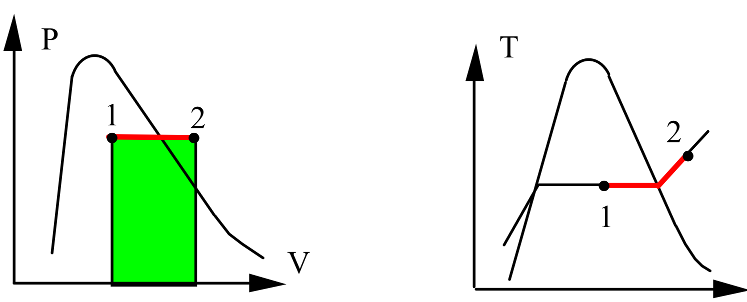
State 2: (P = 779.2 kPa , 300 K) => sup. vapor interpolate in Table B.6.2

$$v_2 = 0.14824 + (0.11115\text{-}0.14824) \times 179.2/200 = 0.115 \text{ m}^3\text{/kg}, \; V_2 = \mathbf{0.23\ m^3}$$

$$h_2 = 310.06 + (309.62\text{-}310.06) \times 179.2/200 = 309.66 \text{ kJ/kg}$$

Now solve for the heat transfer from the energy equation

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = m(h_2 - h_1) = 2 \times (309.66 - 7.14) = \mathbf{605\ kJ}$$



5.55

A 1-L capsule of water at 700 kPa, 150°C is placed in a larger insulated and otherwise evacuated vessel. The capsule breaks and its contents fill the entire volume. If the final pressure should not exceed 125 kPa, what should the vessel volume be?

Solution:

C.V. Larger vessel.

Continuity: $m_2 = m_1 = m = V/v_1 = 0.916$ kg

Process: expansion with ${}_1Q_2 = \emptyset$, ${}_1W_2 = \emptyset$

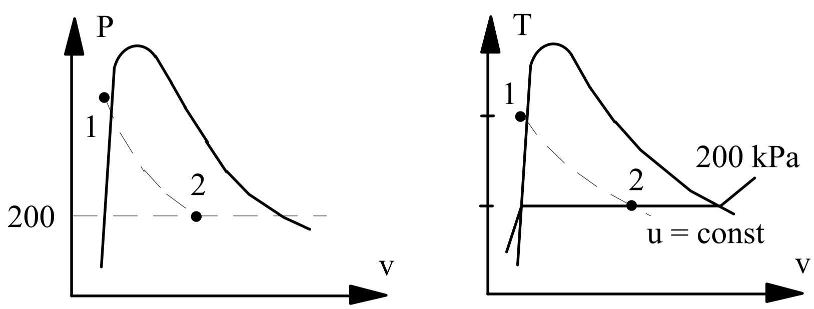
Energy: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2 = \emptyset \;\Rightarrow\; u_2 = u_1$

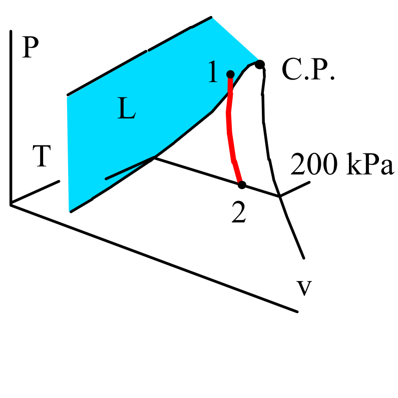
State 1: $v_1 \cong v_f = 0.001091$ m^3/kg; $u_1 \cong u_f = 631.66$ kJ/kg

State 2: P_2 , u_2 $\Rightarrow$ $x_2 = \dfrac{631.66 - 444.16}{2069.3} = 0.09061$

$v_2 = 0.001048 + 0.09061 \times 1.37385 = 0.1255$ m^3/kg

$V_2 = mv_2 = 0.916 \times 0.1255 =$ **0.115 m^3** = **115 L**





5.56

Superheated refrigerant R-134a at 20°C, 0.5 MPa is cooled in a piston/cylinder arrangement at constant temperature to a final two-phase state with quality of 50%. The refrigerant mass is 5 kg, and during this process 500 kJ of heat is removed. Find the initial and final volumes and the necessary work.

Solution:

C.V. R-134a, this is a control mass.

Continuity: $m_2 = m_1 = m$;

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2 = -500 - {}_1W_2$

State 1: T_1 , P_1 Table B.5.2, $v_1 = 0.04226\ m^3/kg$; $u_1 = 390.52\ kJ/kg$

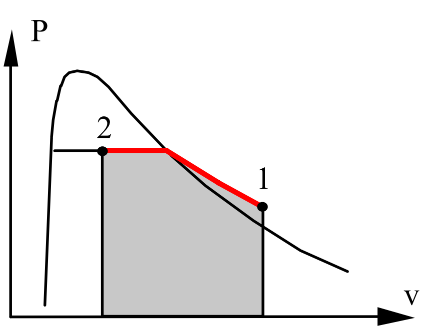
=> $V_1 = mv_1 = \mathbf{0.211\ m^3}$

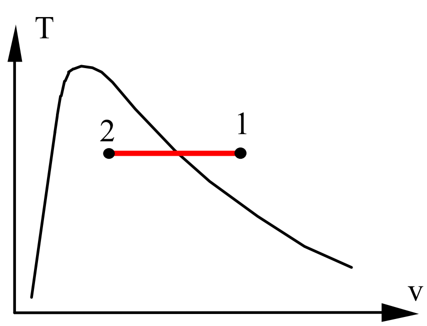
State 2: T_2 , x_2 $\Rightarrow$ Table B.5.1

$u_2 = 227.03 + 0.5 \times 162.16 = 308.11\ kJ/kg,$

$v_2 = 0.000817 + 0.5 \times 0.03524 = 0.018437\ m^3/kg$ => $V_2 = mv_2 = \mathbf{0.0922\ m^3}$

${}_1W_2 = -500 - m(u_2 - u_1) = -500 - 5 \times (308.11 - 390.52) = \mathbf{-87.9\ kJ}$





5.57

A cylinder having a piston restrained by a linear spring (of spring constant 15 kN/m) contains 0.5 kg of saturated vapor water at 120°C, as shown in Fig. P5.57. Heat is transferred to the water, causing the piston to rise. If the piston cross-sectional area is 0.05 m^2, and the pressure varies linearly with volume until a final pressure of 500 kPa is reached. Find the final temperature in the cylinder and the heat transfer for the process.

Solution:

C.V. Water in cylinder.

Continuity: $m_2 = m_1 = m$;

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

State 1: (T, x) Table B.1.1 => $v_1 = 0.89186\ m^3/kg$, $u_1 = 2529.2$ kJ/kg

Process: $P_2 = P_1 + \frac{k_s m}{A_p{}^2}(v_2 - v_1) = 198.5 + \frac{15 \times 0.5}{(0.05)^2}(v_2 - 0.89186)$

State 2: $P_2 = 500$ kPa and on the process curve (see above equation).

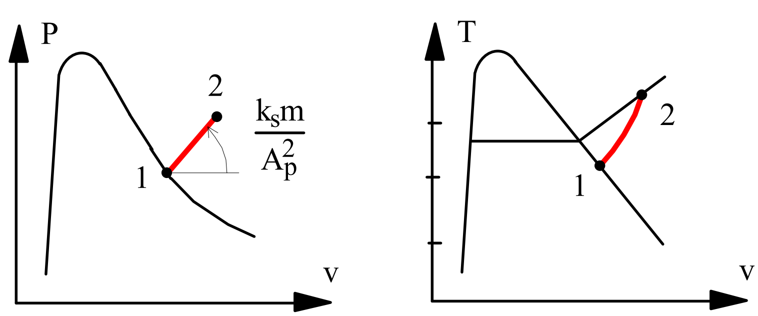
=> $v_2 = 0.89186 + (500 - 198.5) \times (0.05^2/7.5) = 0.9924\ m^3/kg$

(P, v) Table B.1.3 => $T_2 =$ **803°C**; $u_2 = 3668$ kJ/kg

$$W_{12} = \int PdV = \left(\frac{P_1 + P_2}{2}\right) m(v_2 - v_1)$$

$$= \left(\frac{198.5 + 500}{2}\right) \times 0.5 \times (0.9924 - 0.89186) = 17.56 \text{ kJ}$$

${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 0.5 \times (3668 - 2529.2) + 17.56 =$ **587 kJ**

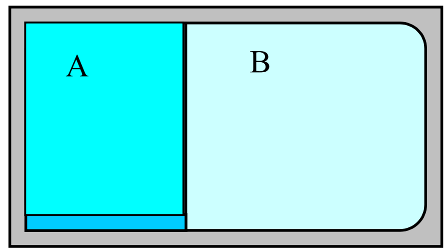


5.58

A rigid tank is divided into two rooms by a membrane, both containing water, shown in Fig. P5.58. Room A is at 200 kPa, $v = 0.5$ m^3/kg, $V_A = 1$ m^3, and room B contains 3.5 kg at 0.5 MPa, 400°C. The membrane now ruptures and heat transfer takes place so the water comes to a uniform state at 100°C. Find the heat transfer during the process.

Solution:

C.V.: Both rooms A and B in tank.



Continuity Eq.: $m_2 = m_{A1} + m_{B1}$;

Energy Eq.: $m_2u_2 - m_{A1}u_{A1} - m_{B1}u_{B1} = {}_1Q_2 - {}_1W_2$

State 1A: (P, v) Table B.1.2, $m_{A1} = V_A/v_{A1} = 1/0.5 = 2$ kg

$$x_{A1} = \frac{v - v_f}{v_{fg}} = \frac{0.5 - 0.001061}{0.88467} = 0.564$$

$$u_{A1} = u_f + x\, u_{fg} = 504.47 + 0.564 \times 2025.02 = 1646.6 \text{ kJ/kg}$$

State 1B: Table B.1.3, $v_{B1} = 0.6173$, $u_{B1} = 2963.2$, $V_B = m_{B1}v_{B1} = 2.16$ m^3

Process constant total volume: $V_{tot} = V_A + V_B = 3.16$ m^3 and ${}_1W_2 = \emptyset$

$$m_2 = m_{A1} + m_{B1} = 5.5 \text{ kg} \quad => \quad v_2 = V_{tot}/m_2 = 0.5746 \text{ m}^3\text{/kg}$$

State 2: T_2 , v_2 $\Rightarrow$ Table B.1.1 two-phase as $v_2 < v_g$

$$x_2 = \frac{v_2 - v_f}{v_{fg}} = \frac{0.5746 - 0.001044}{1.67185} = 0.343 ,$$

$$u_2 = u_f + x\, u_{fg} = 418.91 + 0.343 \times 2087.58 = 1134.95 \text{ kJ/kg}$$

Heat transfer is from the energy equation

$${}_1Q_2 = m_2u_2 - m_{A1}u_{A1} - m_{B1}u_{B1} = \mathbf{-7421\ kJ}$$

5.59

A 10-m high open cylinder, $A_{cyl} = 0.1\ m^2$, contains 20°C water above and 2 kg of 20°C water below a 198.5-kg thin insulated floating piston, shown in Fig. P5.59. Assume standard *g*, *Po*. Now heat is added to the water below the piston so that it expands, pushing the piston up, causing the water on top to spill over the edge. This process continues until the piston reaches the top of the cylinder. Find the final state of the water below the piston (*T*, *P*, *v*) and the heat added during the process.

Solution:

C.V. Water below the piston.

Piston force balance at initial state: $F\uparrow = F\downarrow = P_A A = m_p g + m_B g + P_0 A$

State $1_{A,B}$: Comp. Liq. $\Rightarrow$ $v \cong v_f = 0.001002\ m^3/kg$; $u_{1A} = 83.95$ kJ/kg

$V_{A1} = m_A v_{A1} = 0.002\ m^3$; $m_{tot} = V_{tot}/v = 1/0.001002 = 998$ kg

mass above the piston $m_{B1} = m_{tot} - m_A =$ **996 kg**

$$P_{A1} = P_0 + (m_p + m_B)g/A = 101.325 + \frac{(198.5+996)*9.807}{0.1*1000} = \mathbf{218.5\ kPa}$$

State 2_A: $P_{A2} = P_0 + \frac{m_p g}{A} =$ **120.8 kPa** ; $v_{A2} = V_{tot}/ m_A =$ **0.5 m³/kg**

$x_{A2} = (0.5 - 0.001047)/1.4183 = 0.352$; $T_2 =$ **105°C**

$u_{A2} = 440.0 + 0.352 \times 2072.34 = 1169.5$ kJ/kg

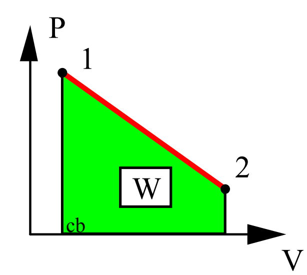
Continuity eq. in A: $m_{A2} = m_{A1}$

Energy: $m_A(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: P linear in V as m_B is linear with V

$${}_1W_2 = \int PdV = \frac{1}{2}(218.5 + 120.82)(1 - 0.002)$$

$= \mathbf{169.32\ kJ}$



${}_1Q_2 = m_A(u_2 - u_1) + {}_1W_2 = 2170.1 + 169.3 =$ **2340.4 kJ**

5.60

Assume the same setup as in Problem 5.48, but the room has a volume of 100 m^3. Show that the final state is two-phase and find the final pressure by trial and error.

C.V.: Containment room and reactor.

Mass: $m_2 = m_1 = V_{reactor}/v_1 = 1/0.001823 = 548.5$ kg

Energy: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2 = 0 - 0 = 0 \Rightarrow \; u_2 = u_1 = 1702.8$ kJ/kg

Total volume and mass => $v_2 = V_{room}/m_2 = 0.1823 \text{ m}^3/\text{kg}$

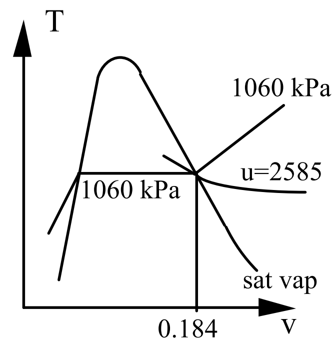
State 2: u_2 , v_2 Table B.1.1 see Figure.

Note that in the vicinity of $v = 0.1823 \text{ m}^3/\text{kg}$ crossing the saturated vapor line the internal energy is about 2585 kJ/kg. However, at the actual state 2, u = 1702.8 kJ/kg. Therefore state 2 must be in the two-phase region.

Trial & error $v = v_f + xv_{fg}$; $u = u_f + xu_{fg}$

$$\Rightarrow u_2 = 1702.8 = u_f + \frac{v_2 - v_f}{v_{fg}} u_{fg}$$

Compute RHS for a guessed pressure P_2:



$$P_2 = 600 \text{ kPa: RHS} = 669.88 + \frac{0.1823\text{-}0.001101}{0.31457} \times 1897.52 = 1762.9 \quad \text{too large}$$

$$P_2 = 550 \text{ kPa: RHS} = 655.30 + \frac{0.1823\text{-}0.001097}{0.34159} \times 1909.17 = 1668.1 \quad \text{too small}$$

Linear interpolation to match u = 1702.8 gives $P_2 \cong$ **568.5 kPa**

Energy Equation: Multistep Solution

5.61

10 kg of water in a piston cylinder arrangement exists as saturated liquid/vapor at 100 kPa, with a quality of 50%. It is now heated so the volume triples. The mass of the piston is such that a cylinder pressure of 200 kPa will float it, as in Fig. 4.68. Find the final temperature and the heat transfer in the process.

Solution:

Take CV as the water.

$$m_2 = m_1 = m \quad ; \qquad m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$$

Process: v = constant until $P = P_{lift}$, then P is constant.

State 1: Two-phase so look in Table B.1.2 at 100 kPa

$$u_1 = 417.33 + 0.5 \times 2088.72 = 1461.7 \text{ kJ/kg},$$

$$v_1 = 0.001043 + 0.5 \times 1.69296 = 0.8475 \text{ m}^3\text{/kg}$$

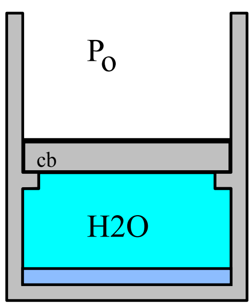
State 2: v_2, $\mathbf{P_2 \le P_{lift}}$ => $v_2 = 3 \times 0.8475 = 2.5425 \text{ m}^3\text{/kg}$;

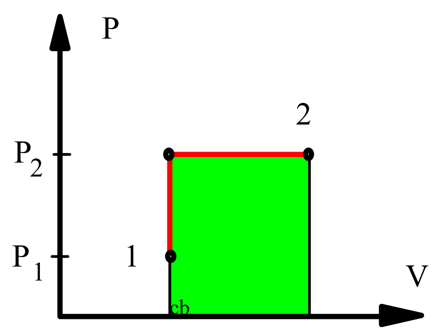
Interpolate: $\mathbf{T_2 = 829°C}$, $u_2 = 3718.76$ kJ/kg

=> $V_2 = mv_2 = 25.425 \text{ m}^3$

$${}_1W_2 = P_{lift}(V_2 - V_1) = 200 \times 10\,(2.5425 - 0.8475) = 3390 \text{ kJ}$$

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 10 \times (3718.76 - 1461.7) + 3390 = \mathbf{25\ 961\ kJ}$$





5.62

Two tanks are connected by a valve and line as shown in Fig. P5.62. The volumes are both 1 m^3 with R-134a at 20°C, quality 15% in A and tank B is evacuated. The valve is opened and saturated vapor flows from A into B until the pressures become equal. The process occurs slowly enough that all temperatures stay at 20°C during the process. Find the total heat transfer to the R-134a during the process.

Solution:

C.V.: A + B

State 1A: $v_{A1} = 0.000817 + 0.15 \times 0.03524 = 0.006103 \text{ m}^3/\text{kg}$

$u_{A1} = 227.03 + 0.15 \times 162.16 = 251.35 \text{ kJ/kg}$

$m_{A1} = V_A/v_{A1} = 163.854 \text{ kg}$

Process: Constant temperature and constant total volume.

$m_2 = m_{A1}$; $V_2 = V_A + V_B = 2 \text{ m}^3$; $v_2 = V_2/m_2 = 0.012206 \text{ m}^3/\text{kg}$

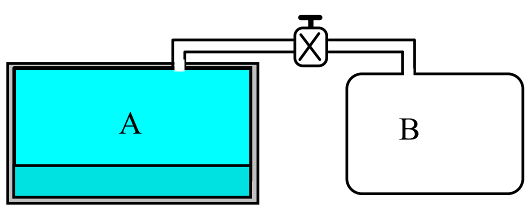
$_1W_2 = \int P\, dV = 0$

State 2: T_2 , v_2 $\Rightarrow$ $x_2 = (0.012206 - 0.000817)/0.03524 = 0.3232$

$u_2 = 227.03 + 0.3232 \times 162.16 = 279.44 \text{ kJ/kg}$

$_1Q_2 = m_2u_2 - m_{A1}u_{A1} - m_{B1}u_{B1} + {_1W_2} = m_2(u_2 - u_{A1})$

$= 163.854 \times (279.44 - 251.35) =$ **4603 kJ**



5.63

Consider the same system as in the previous problem. Let the valve be opened and transfer enough heat to both tanks so all the liquid disappears. Find the necessary heat transfer.

Solution:

C.V. A + B, so this is a control mass.

State 1A: $v_{A1} = 0.000817 + 0.15 \times 0.03524 = 0.006\ 103\ m^3/kg$

$u_{A1} = 227.03 + 0.15 \times 162.16 = 251.35$ kJ/kg

$m_{A1} = V_A/v_{A1} = 163.854$ kg

Process: Constant temperature and total volume.

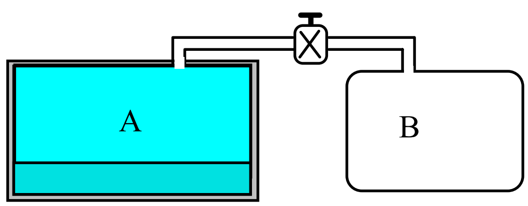
$m_2 = m_{A1}$; $V_2 = V_A + V_B = 2\ m^3$; $v_2 = V_2/m_2 = 0.012\ 206\ m^3/kg$

State 2: $x_2 = 100\%$, $v_2 = 0.012206$

$\Rightarrow$ $T_2 = 55 + 5 \times (0.012206 – 0.01316)/(0.01146 – 0.01316) = 57.8°C$

$u_2 = 406.01 + 0.56 \times (407.85 – 406.01) = 407.04$ kJ/kg

${}_1Q_2 = m_2(u_2 - u_{A1}) = 163.854 \times (407.04 - 251.35) =$ **25 510 kJ**



5.64

A vertical cylinder fitted with a piston contains 5 kg of R-22 at 10°C, shown in Fig. P5.64. Heat is transferred to the system, causing the piston to rise until it reaches a set of stops at which point the volume has doubled. Additional heat is transferred until the temperature inside reaches 50°C, at which point the pressure inside the cylinder is 1.3 MPa.

a. What is the quality at the initial state?

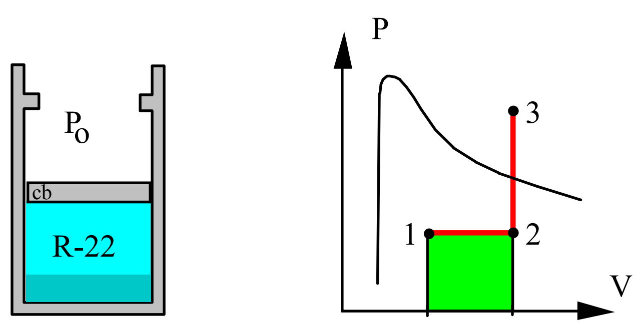
b. Calculate the heat transfer for the overall process.

Solution:

C.V. R-22. Control mass goes through process: 1 -> 2 -> 3

As piston floats pressure is constant (1 -> 2) and the volume is constant for the second part (2 -> 3). So we have: $v_3 = v_2 = 2 \times v_1$

State 3: Table B.4.2 (P,T) $v_3 = 0.02015\ \text{m}^3/\text{kg}$, $u_3 = 248.4$ kJ/kg



So we can then determine state 1 and 2 Table B.4.1:

$v_1 = 0.010075 = 0.0008 + x_1 \times 0.03391 \quad \Rightarrow \quad x_1 = \mathbf{0.2735}$

b) $u_1 = 55.92 + 0.2735 \times 173.87 = 103.5$ kJ/kg

State 2: $v_2 = 0.02015\ \text{m}^3/\text{kg}$, $P_2 = P_1 = 681$ kPa this is still 2-phase.

$${}_1W_3 = {}_1W_2 = \int_1^2 PdV = P_1(V_2 - V_1) = 681 \times 5\,(0.02 - 0.01) = \mathbf{34.1\ kJ}$$

$${}_1Q_3 = m(u_3 - u_1) + {}_1W_3 = 5(248.4 - 103.5) + 34.1 = \mathbf{758.6\ kJ}$$

5.65

Find the heat transfer in Problem 4.67.

A piston/cylinder contains 1 kg of liquid water at 20°C and 300 kPa. Initially the piston floats, similar to the setup in Problem 4.64, with a maximum enclosed volume of 0.002 m^3 if the piston touches the stops. Now heat is added so a final pressure of 600 kPa is reached. Find the final volume and the work in the process.

Solution:

Take CV as the water. Properties from table B.1

$$m_2 = m_1 = m \; ; \quad m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$$

State 1: Compressed liq. $v = v_f(20) = 0.001002 \text{ m}^3/\text{kg}$, $u = u_f = 83.94$ kJ/kg

State 2: Since $P > P_{lift}$ then $v = v_{stop} = 0.002$ and $P = 600$ kPa

For the given P : $v_f < v < v_g$ so 2-phase $T = T_{sat} = 158.85$ °C

$$v = 0.002 = 0.001101 + x \times (0.3157\text{-}0.001101) \;\; \Rightarrow \;\; x = 0.002858$$

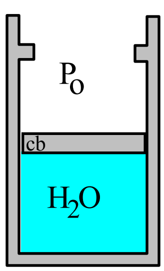
$$u = 669.88 + 0.002858 \times 1897.5 = 675.3 \text{ kJ/kg}$$

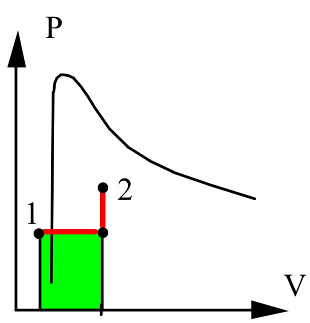
Work is done while piston moves at P_{lift}= constant = 300 kPa so we get

$${}_1W_2 = \int P\, dV = m\, P_{lift}\, (v_2 - v_1) = 1 \times 300(0.002 - 0.001002) = 0.299 \text{ kJ}$$

Heat transfer is found from energy equation

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 1(675.3 - 83.94) + 0.299 = \mathbf{591.66\ kJ}$$

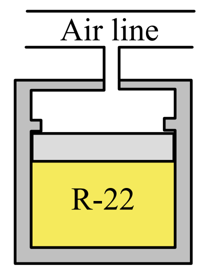




5.66

Refrigerant-12 is contained in a piston/cylinder arrangement at 2 MPa, 150°C with a massless piston against the stops, at which point $V = 0.5\ m^3$. The side above the piston is connected by an open valve to an air line at 10°C, 450 kPa, shown in Fig. P5.66. The whole setup now cools to the surrounding temperature of 10°C. Find the heat transfer and show the process in a *P–v* diagram.

C.V.: R-12. Control mass.



Continuity: m = constant,

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: $F\downarrow = F\uparrow = P\,A = P_{air}A + F_{stop}$

$\text{if } V < V_{stop} \Rightarrow F_{stop} = \emptyset$

This is illustrated in the P-v diagram shown below.

State 1: $v_1 = 0.01265\ m^3/kg$, $u_1 = 252.1\ kJ/kg$

$\Rightarrow$ $m = V/v =$ **39.523 kg**

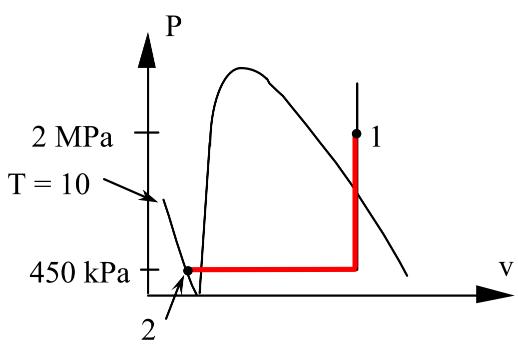
State 2: T_2 and on line $\Rightarrow$ compressed liquid, see figure below.

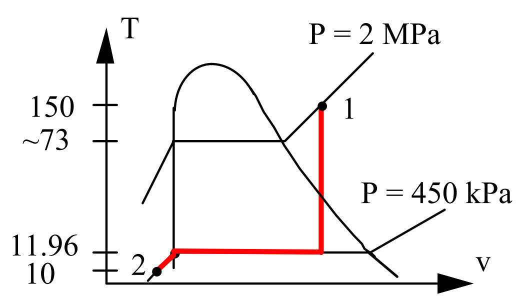
$v_2 \cong v_f = 0.000733\ m^3/kg \Rightarrow V_2 = 0.02897\ m^3$; $u_2 = u_f = 45.06\ kJ/kg$

$${}_1W_2 = \int PdV = P_{lift}(V_2 - V_1) = 450\ (0.02897 - 0.5) = -212.0\ kJ\ ;$$

Energy eq. $\Rightarrow$

$${}_1Q_2 = 39.526\ (45.06 - 252.1) - 212 = \mathbf{-8395\ kJ}$$





5.67

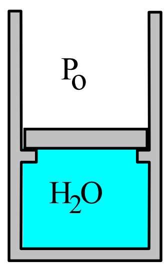
Find the heat transfer in Problem 4.114.

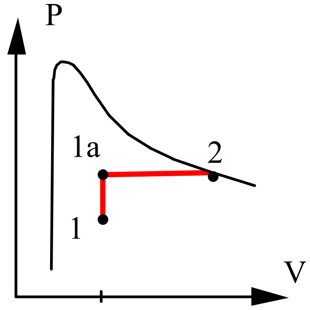
A piston/cylinder (Fig. P4.114) contains 1 kg of water at 20°C with a volume of 0.1 m^3. Initially the piston rests on some stops with the top surface open to the atmosphere, P_o and a mass so a water pressure of 400 kPa will lift it. To what temperature should the water be heated to lift the piston? If it is heated to saturated vapor find the final temperature, volume and the work, ${}_1W_2$.

Solution:

C.V. Water. This is a control mass.

$$m_2 = m_1 = m \ ; \quad m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$$





State 1: 20 C, $v_1 = V/m = 0.1/1 = 0.1\ m^3/kg$

$$x = (0.1 - 0.001002)/57.789 = 0.001713$$

$$u_1 = 83.94 + 0.001713 \times 2318.98 = 87.92\ kJ/kg$$

To find state 2 check on state 1a:

$P = 400\ kPa, \quad v = v_1 = 0.1\ m^3/kg$

Table B.1.2: $\quad v_f < v < v_g = 0.4625\ m^3/kg$

State 2 is saturated vapor at 400 kPa since state 1a is two-phase.

$v_2 = v_g = 0.4625\ m^3/kg\ , \quad V_2 = m\ v_2 = 0.4625\ m^3, \quad u_2 = u_g = 2553.6\ kJ/kg$

Pressure is constant as volume increase beyond initial volume.

$${}_1W_2 = \int P\ dV = P\ (V_2 - V_1) = P_{lift}\ (V_2 - V_1) = 400\ (0.4625 - 0.1) = 145\ kJ$$

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 1\ (2553.6 - 87.92) + 145 = \mathbf{2610.7\ kJ}$$

5.68

A rigid container has two rooms filled with water, each 1 m^3 separated by a wall. Room A has P = 200 kPa with a quality x = 0.80. Room B has P = 2 MPa and T = 400°C. The partition wall is removed and the water comes to a uniform state, which after a while due to heat transfer has a temperature of 200°C. Find the final pressure and the heat transfer in the process.

Solution:

C.V. A + B. Constant total mass and constant total volume.

Continuity: $m_2 - m_{A1} - m_{B1} = 0$; $V_2 = V_A + V_B = 2\ m^3$

Energy Eq.5.11: $U_2 - U_1 = m_2 u_2 - m_{A1} u_{A1} - m_{A1} u_{A1} = {}_1Q_2 - {}_1W_2 = {}_1Q_2$

Process: $V = V_A + V_B = \text{constant}$ => ${}_1W_2 = 0$

State 1A: Table B.1.2 $u_{A1} = 504.47 + 0.8 \times 2025.02 = 2124.47$ kJ/kg,

$v_{A1} = 0.001061 + 0.8 \times 0.88467 = 0.70877\ m^3/kg$

State 1B: Table B.1.3 $u_{B1} = 2945.2$, $v_{B1} = 0.1512$

$m_{A1} = 1/v_{A1} = 1.411$ kg $m_{B1} = 1/v_{B1} = 6.614$ kg

State 2: T_2, $v_2 = V_2/m_2 = 2/(1.411 + 6.614) = 0.24924\ m^3/kg$

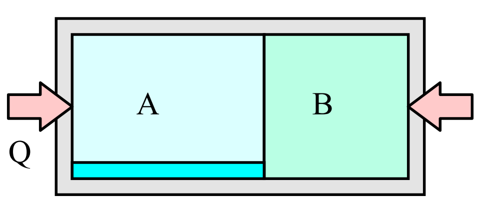
Table B.1.3 superheated vapor. 800 kPa < P_2 < 1 MPa

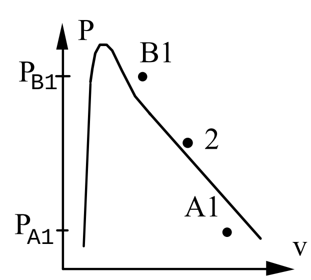
Interpolate to get the proper v_2

$$P_2 \cong 800 + \frac{0.24924-0.2608}{0.20596-0.2608} \times 200 = \mathbf{842\ kPa} \qquad u_2 \cong 2628.8 \text{ kJ/kg}$$

From the energy equation

$${}_1Q_2 = 8.025 \times 2628.8 - 1.411 \times 2124.47 - 6.614 \times 2945.2 = \mathbf{-\ 1381\ kJ}$$





5.69

The cylinder volume below the constant loaded piston has two compartments A and B filled with water. A has 0.5 kg at 200 kPa, 150°C and B has 400 kPa with a quality of 50% and a volume of 0.1 m^3. The valve is opened and heat is transferred so the water comes to a uniform state with a total volume of 1.006 m^3.

a) Find the total mass of water and the total initial volume.

b) Find the work in the process

c) Find the process heat transfer.

Solution:

Take the water in A and B as CV.

Continuity: $m_2 - m_{1A} - m_{1B} = 0$

Energy: $m_2u_2 - m_{1A}u_{1A} - m_{1B}u_{1B} = {}_1Q_2 - {}_1W_2$

Process: $P = \text{constant} = P_{1A}$ if piston floats

(V_A positive) i.e. if $V_2 > V_B = 0.1\ m^3$

State A1: Sup. vap. Table B.1.3 $v = 0.95964\ m^3/kg$, $u = 2576.9\ kJ/kg$

$\Rightarrow V = mv = 0.5 \times 0.95964 = 0.47982$

State B1: Table B.1.2 $v = (1-x) \times 0.001084 + x \times 0.4625 = 0.2318\ m^3/kg$

$\Rightarrow m = V/v = 0.4314\ kg$

$u = 604.29 + 0.5 \times 1949.3 = 1578.9\ kJ/kg$

State 2: 200 kPa, $v_2 = V_2/m = 1.006/0.9314 = 1.0801\ m^3/kg$

Table B.1.3 $\Rightarrow$ close to $T_2 = 200°C$ and $u_2 = 2654.4\ kJ/kg$

So now

$V_1 = 0.47982 + 0.1 = \mathbf{0.5798\ m^3}$, $m_1 = 0.5 + 0.4314 = \mathbf{0.9314\ kg}$

Since volume at state 2 is larger than initial volume piston goes up and the pressure then is constant (200 kPa which floats piston).

$${}_1W_2 = \int P\, dV = P_{lift}(V_2 - V_1) = 200\,(1.006 - 0.57982) = \mathbf{85.24\ kJ}$$

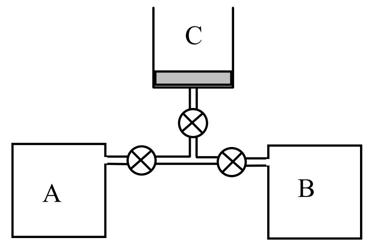
$${}_1Q_2 = m_2u_2 - m_{1A}u_{1A} - m_{1B}u_{1B} + {}_1W_2$$
$$= 0.9314 \times 2654.4 - 0.5 \times 2576.9 - 0.4314 \times 1578.9 + 85.24 = \mathbf{588\ kJ}$$

5.70

A rigid tank A of volume 0.6 m^3 contains 3 kg water at 120^{o}C and the rigid tank B is 0.4 m^3 with water at 600 kPa, 200^{o}C. They are connected to a piston cylinder initially empty with closed valves. The pressure in the cylinder should be 800 kPa to float the piston. Now the valves are slowly opened and heat is transferred so the water reaches a uniform state at 250^{o}C with the valves open. Find the final volume and pressure and the work and heat transfer in the process.

C.V.: A + B + C.

Only work in C, total mass constant.



$m_2 - m_1 = 0 \quad => \quad m_2 = m_{A1} + m_{B1}$

$U_2 - U_1 = {}_1Q_2 - {}_1W_2$;

${}_1W_2 = \int PdV = P_{lift} (V_2 - V_1)$

1A: $v = 0.6/3 = 0.2$ m^3/kg => $x_{A1} = (0.2 - 0.00106)/0.8908 = 0.223327$

$u = 503.48 + 0.223327 \times 2025.76 = 955.89$ kJ/kg

1B: $v = 0.35202$ m^3/kg => $m_{B1} = 0.4/0.35202 = 1.1363$ kg ; $u = 2638.91$ kJ/kg

$m_2 = 3 + 1.1363 = 4.1363$ kg and

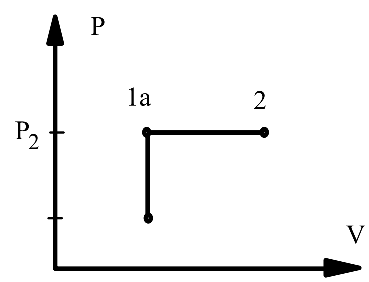
$V_2 = V_A + V_B + V_C = 1 + V_C$

Locate state 2: Must be on P-V lines shown

State 1a: 800 kPa,

$$v_{1a} = \frac{V_A + V_B}{m} = 0.24176 \text{ m}^3\text{/kg}$$

800 kPa, v_{1a} => T = 173°C too low.



Assume 800 kPa: 250°C => $v = 0.29314$ m^3/kg > v_{1a} OK

Final state is : **800 kPa**; 250°C => $u_2 = 2715.46$ kJ/kg

$W = 800(0.29314 - 0.24176) \times 4.1363 = 800 \times (1.2125 - 1) =$ **170 kJ**

$Q = m_2u_2 - m_1u_1 + {}_1W_2 = m_2u_2 - m_{A1}u_{A1} - m_{B1}u_{B1} + {}_1W_2$

$= 4.1363 \times 2715.46 - 3 \times 955.89 - 1.1363 \times 2638.91 + 170$

$= 11\,232 - 2867.7 - 2998.6 + 170 =$ **5536 kJ**

5.71

Calculate the heat transfer for the process described in Problem 4.60.

A cylinder containing 1 kg of ammonia has an externally loaded piston. Initially the ammonia is at 2 MPa, 180°C and is now cooled to saturated vapor at 40°C, and then further cooled to 20°C, at which point the quality is 50%. Find the total work for the process, assuming a piecewise linear variation of *P* versus *V*.

Solution:

C.V. Ammonia going through process 1 - 2 - 3. Control mass.

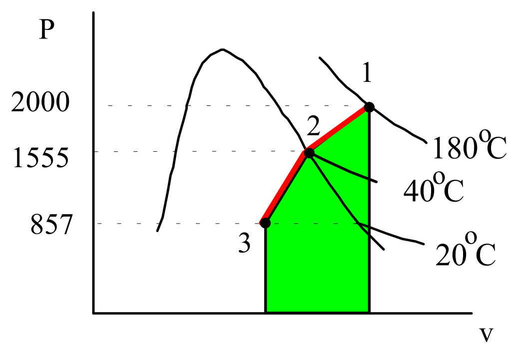
Continuity: m = constant,

Energy Eq.5.11: $m(u_3 - u_1) = {}_1Q_3 - {}_1W_3$

Process: P is piecewise linear in V

State 1: (T, P) Table B.2.2: $v_1 = 0.10571\ m^3/kg$, $u_1 = 1630.7$ kJ/kg

State 2: (T, x) Table B.2.1 sat. vap. $P_2 = 1555$ kPa, $v_2 = 0.08313\ m^3/kg$



State 3: (T, x) $P_3 = 857$ kPa,

$v_3 = (0.001638+0.14922)/2 = 0.07543$ $u_3 = (272.89 + 1332.2)/2 = 802.7$ kJ/kg

Process: piecewise linear P versus V, see diagram. Work is area as:

$$W_{13} = \int_1^3 PdV \approx \left(\frac{P_1 + P_2}{2}\right) m(v_2 - v_1) + \left(\frac{P_2 + P_3}{2}\right) m(v_3 - v_2)$$

$$= \frac{2000 + 1555}{2} 1(0.08313 - 0.10571) + \frac{1555 + 857}{2} 1(0.07543 - 0.08313)$$

$= \mathbf{-49.4\ kJ}$

From the energy equation, we get the heat transfer as:

${}_1Q_3 = m(u_3 - u_1) + {}_1W_3 = 1\times (802.7 - 1630.7) - 49.4 =$ **-877.4 kJ**

5.72

Calculate the heat transfer for the process described in Problem 4.70.

A piston cylinder setup similar to Problem 4.24 contains 0.1 kg saturated liquid and vapor water at 100 kPa with quality 25%. The mass of the piston is such that a pressure of 500 kPa will float it. The water is heated to 300°C. Find the final pressure, volume and the work, ${}_1W_2$.

Solution:

Take CV as the water: $m_2 = m_1 = m$

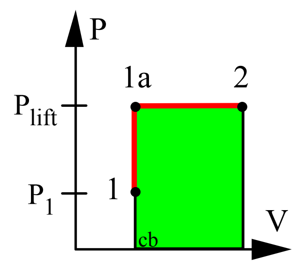
Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: v = constant until $P = P_{lift}$

To locate state 1: Table B.1.2

$v_1 = 0.001043 + 0.25\times1.69296 = 0.42428 \text{ m}^3/\text{kg}$

$u_1 = 417.33 + 0.25\times2088.7 = 939.5 \text{ kJ/kg}$



State 1a: 500 kPa, $v_{1a} = v_1 = 0.42428 > v_g$ at 500 kPa,

so state 1a is superheated vapor Table B.1.3 $T_{1a} = 200°C$

State 2 is 300°C so heating continues after state 1a to 2 at constant P = 500 kPa.

2: T_2, $P_2 = P_{lift}$ => Tbl B.1.3 $v_2 = 0.52256 \text{ m}^3/\text{kg}$; $u_2 = 2802.9$ kJ/kg

From the process, see also area in P-V diagram

$${}_1W_2 = P_{lift}\ m(v_2 - v_1) = 500 \times 0.1\ (0.5226 - 0.4243) = 4.91 \text{ kJ}$$

From the energy equation

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 0.1(2802.9 - 939.5) + 4.91 = \mathbf{191.25\ kJ}$$

5.73

A cylinder/piston arrangement contains 5 kg of water at 100°C with x = 20% and the piston, m_P = 75 kg, resting on some stops, similar to Fig. P5.73. The outside pressure is 100 kPa, and the cylinder area is A = 24.5 cm^2. Heat is now added until the water reaches a saturated vapor state. Find the initial volume, final pressure, work, and heat transfer terms and show the P–v diagram.

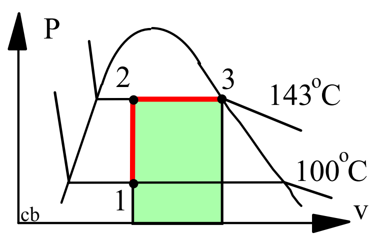
Solution:

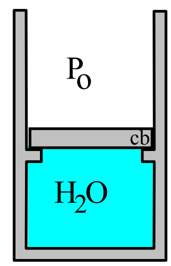
C.V. The 5 kg water.

Continuity: $m_2 = m_1 = m$;   Energy: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: V = constant if $P < P_{lift}$ otherwise $P = P_{lift}$ see P-v diagram.

$$P_3 = P_2 = P_{lift} = P_0 + m_p\, g / A_p = 100 + \frac{75 \times 9.807}{0.00245 \times 1000} = \mathbf{400\ kPa}$$





State 1: (T,x) Table B.1.1

$v_1 = 0.001044 + 0.2 \times 1.6719$, $V_1 = mv_1 = 5 \times 0.3354 = \mathbf{1.677\ m^3}$

$u_1 = 418.91 + 0.2 \times 2087.58 = 836.4$ kJ/kg

State 3: (P, x = 1) Table B.1.2 => $v_3 = 0.4625 > v_1$, $u_3 = 2553.6$ kJ/kg

Work is seen in the P-V diagram (if volume changes then $P = P_{lift}$)

$${}_1W_3 = {}_2W_3 = P_{ext}m(v_3 - v_2) = 400 \times 5(0.46246 - 0.3354) = \mathbf{254.1\ kJ}$$

Heat transfer is from the energy equation

$${}_1Q_3 = 5\,(2553.6 - 836.4) + 254.1 = \mathbf{8840\ kJ}$$

Energy Equation: Solids and Liquids

5.74

Because a hot water supply must also heat some pipe mass as it is turned on so it does not come out hot right away. Assume 80^{o}C liquid water at 100 kPa is cooled to 45^{o}C as it heats 15 kg of copper pipe from 20 to 45^{o}C. How much mass (kg) of water is needed?

Solution:

C.V. Water and copper pipe. No external heat transfer, no work.

Energy Eq.5.11: $U_2 - U_1 = \Delta U_{cu} + \Delta U_{H_2O} = 0 - 0$

From Eq.5.18 and Table A.3:

$$\Delta U_{cu} = mC\ \Delta T = 15\text{ kg} \times 0.42 \frac{\text{kJ}}{\text{kg K}} \times (45 - 20)\text{ K} = 157.5\text{ kJ}$$

From the energy equation

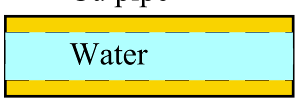
$$m_{H_2O} = -\ \Delta U_{cu} / \Delta u_{H_2O}$$

$$m_{H_2O} = \Delta U_{cu} / C_{H_2O}(-\Delta T_{H_2O}) = \frac{157.5}{4.18 \times 35} = \mathbf{1.076\ kg}$$

or using Table B.1.1 for water

$$m_{H_2O} = \Delta U_{cu} / (\ u_1 - u_2) = \frac{157.5}{334.84 - 188.41} = \mathbf{1.076\ kg}$$

Cu pipe



The real problem involves a flow and is not analyzed by this simple process.

5.75

A house is being designed to use a thick concrete floor mass as thermal storage material for solar energy heating. The concrete is 30 cm thick and the area exposed to the sun during the daytime is 4 m × 6 m. It is expected that this mass will undergo an average temperature rise of about 3°C during the day. How much energy will be available for heating during the nighttime hours?

Solution:

C.V. The mass of concrete.

Concrete is a solid with some properties listed in Table A.3

$V = 4 \times 6 \times 0.3 = 7.2 \text{ m}^3$;

$m = \rho V = 2200 \text{ kg/m}^3 \times 7.2 \text{ m}^3 = 15\,840 \text{ kg}$

From Eq.5.18 and C from table A.3

$$\Delta U = m\, C\, \Delta T = 15840 \text{ kg} \times 0.88 \frac{\text{kJ}}{\text{kg K}} \times 3 \text{ K} = 41818 \text{ kJ} = \mathbf{41.82\ MJ}$$

5.76

A copper block of volume 1 L is heat treated at 500°C and now cooled in a 200-L oil bath initially at 20°C, shown in Fig. P5.76. Assuming no heat transfer with the surroundings, what is the final temperature?

Solution:

C.V. Copper block and the oil bath.

Also assume no change in volume so the work will be zero.

Energy Eq.: $U_2 - U_1 = m_{met}(u_2 - u_1)_{met} + m_{oil}(u_2 - u_1)_{oil} = {}_1Q_2 - {}_1W_2 = 0$

Properties from Table A.3 and A.4

$$m_{met} = V\rho = 0.001 \text{ m}^3 \times 8300 \text{ kg/m}^3 = 8.3 \text{ kg},$$

$$m_{oil} = V\rho = 0.2 \text{ m}^3 \times 910 \text{ kg/m}^3 = 182 \text{ kg}$$

Solid and liquid Eq.5.17: $\Delta u \cong C_V \Delta T$,

Table A.3 and A.4: $C_{V\ met} = 0.42 \frac{kJ}{kg\ K}$, $C_{V\ oil} = 1.8 \frac{kJ}{kg\ K}$

The energy equation for the C.V. becomes

$$m_{met}C_{V\ met}(T_2 - T_{1,met}) + m_{oil}C_{V\ oil}(T_2 - T_{1,oil}) = 0$$

$$8.3 \times 0.42(T_2 - 500) + 182 \times 1.8\ (T_2 - 20) = 0$$

$$331.09\ T_2 - 1743 - 6552 = 0$$

$$\Rightarrow\ T_2 = \mathbf{25\ °C}$$

5.77

A 1 kg steel pot contains 1 kg liquid water both at 15°C. It is now put on the stove where it is heated to the boiling point of the water. Neglect any air being heated and find the total amount of energy needed.

Solution:

Energy Eq.: $U_2 - U_1 = {}_1Q_2 - {}_1W_2$

The steel does not change volume and the change for the liquid is minimal, so ${}_1W_2 \cong 0$.

State 2: $T_2 = T_{sat}$ (1atm) = 100°C

Tbl B.1.1 : u_1 = 62.98 kJ/kg, u_2 = 418.91 kJ/kg

Tbl A.3 : C_{st} = 0.46 kJ/kg K

Solve for the heat transfer from the energy equation

$${}_1Q_2 = U_2 - U_1 = m_{st}(u_2 - u_1)_{st} + m_{H2O}(u_2 - u_1)_{H2O}$$

$$= m_{st}C_{st}\ (T_2 - T_1) + m_{H2O}(u_2 - u_1)_{H2O}$$

$${}_1Q_2 = 1\text{ kg} \times 0.46 \frac{\text{kJ}}{\text{kg K}} \times (100 - 15)\text{ K} + 1\text{ kg} \times (418.91 - 62.98)\text{ kJ/kg}$$

$$= 39.1 + 355.93 = \mathbf{395\ kJ}$$

5.78

A car with mass 1275 kg drives at 60 km/h when the brakes are applied quickly to decrease its speed to 20 km/h. Assume the brake pads are 0.5 kg mass with heat capacity of 1.1 kJ/kg K and the brake discs/drums are 4.0 kg steel. Further assume both masses are heated uniformly. Find the temperature increase in the brake assembly.

Solution:

C.V. Car. Car loses kinetic energy and brake system gains internal u.

No heat transfer (short time) and no work term.

m = constant;

Energy Eq.5.11: $E_2 - E_1 = 0 - 0 = m_{car} \frac{1}{2}(V_2^2 - V_1^2) + m_{brake}(u_2 - u_1)$

The brake system mass is two different kinds so split it, also use C_v from Table A.3 since we do not have a u table for steel or brake pad material.

$$m_{steel}\, C_v\, \Delta T + m_{pad}\, C_v\, \Delta T = m_{car}\, 0.5\, (60^2 - 20^2) \left(\frac{1000}{3600}\right)^2 \, m^2/s^2$$

$$(4 \times 0.46 + 0.5 \times 1.1)\, \frac{kJ}{K}\, \Delta T = 1275 \text{ kg} \times 0.5 \times (3200 \times 0.077\,16)\, m^2/s^2$$

$$= 157\,406 \text{ J} = 157.4 \text{ kJ}$$

$$\Rightarrow \Delta T = \mathbf{65.9\ ^\circ C}$$

5.79

Saturated, x = 1%, water at 25°C is contained in a hollow spherical aluminum vessel with inside diameter of 0.5 m and a 1-cm thick wall. The vessel is heated until the water inside is saturated vapor. Considering the vessel and water together as a control mass, calculate the heat transfer for the process.

Solution:

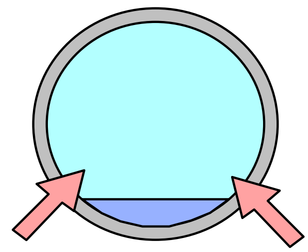
C.V. Vessel and water. This is a control mass of constant volume.

Continuity Eq.: $m_2 = m_1$

Energy Eq.5.11: $U_2 - U_1 = {}_1Q_2 - {}_1W_2 = {}_1Q_2$

Process: V = constant

=> ${}_1W_2 = 0$ used above



State 1: $v_1 = 0.001003 + 0.01 \times 43.359 = 0.4346 \text{ m}^3\text{/kg}$

$u_1 = 104.88 + 0.01 \times 2304.9 = 127.9 \text{ kJ/kg}$

State 2: $x_2 = 1$ and constant volume so $v_2 = v_1 = V/m$

$v_{g\,T2} = v_1 = 0.4346$ => $T_2 = 146.1°C$; $u_2 = u_{G2} = 2555.9$

$$V_{INSIDE} = \frac{\pi}{6}(0.5)^3 = 0.06545 \text{ m}^3 \;;\; m_{H_2O} = \frac{0.06545}{0.4346} = 0.1506 \text{ kg}$$

$$V_{alu} = \frac{\pi}{6}\left((0.52)^3 - (0.5)^3\right) = 0.00817 \text{ m}^3$$

$$m_{alu} = \rho_{alu}V_{alu} = 2700 \times 0.00817 = 22.065 \text{ kg}$$

From the energy equation

$${}_1Q_2 = U_2 - U_1 = m_{H_2O}(u_2 - u_1)_{H_2O} + m_{alu}C_{V\,alu}(T_2 - T_1)$$

$$= 0.1506(2555.9 - 127.9) + 22.065 \times 0.9(146.1 - 25)$$

$$= \mathbf{2770.6\ kJ}$$

5.80

A 25 kg steel tank initially at –10°C is filled up with 100 kg of milk (assume properties as water) at 30°C. The milk and the steel come to a uniform temperature of +5 °C in a storage room. How much heat transfer is needed for this process?

Solution:

C.V. Steel + Milk. This is a control mass.

Energy Eq.5.11: $U_2 - U_1 = {}_1Q_2 - {}_1W_2 = {}_1Q_2$

Process: V = constant, so there is no work ${}_1W_2 = 0$.

Use Eq.5.18 and values from A.3 and A.4 to evaluate changes in u

$${}_1Q_2 = m_{steel}\,(u_2 - u_1)_{steel} + m_{milk}(u_2 - u_1)_{milk}$$

$$= 25 \text{ kg} \times 0.466 \frac{\text{kJ}}{\text{kg K}} \times [5 - (-10)] \text{ K} + 100 \text{ kg} \times 4.18 \frac{\text{kJ}}{\text{kg K}} \times (5 - 30) \text{ K}$$

$$= 172.5 - 10450 = \mathbf{-10277\ kJ}$$

5.81

An engine consists of a 100 kg cast iron block with a 20 kg aluminum head, 20 kg steel parts, 5 kg engine oil and 6 kg glycerine (antifreeze). Everything begins at 5°C and as the engine starts we want to know how hot it becomes if it absorbs a net of 7000 kJ before it reaches a steady uniform temperature.

Energy Eq.: $U_2 - U_1 = {}_1Q_2 - {}_1W_2$

Process: The steel does not change volume and the change for the liquid is minimal, so ${}_1W_2 \cong 0$.

So sum over the various parts of the left hand side in the energy equation

$$m_{Fe}\,(u_2 - u_1) + m_{Al}\,(u_2 - u_1)_{Al} + m_{st}\,(u - u_1)_{st} + m_{oil}\,(u_2 - u_1)_{oil} + m_{gly}\,(u_2 - u_1)_{gly} = {}_1Q_2$$

Tbl A.3 : $C_{Fe} = 0.42$, $C_{Al} = 0.9$, $C_{st} = 0.46$ all units of kJ/kg K

Tbl A.4 : $C_{oil} = 1.9$, $C_{gly} = 2.42$ all units of kJ/kg K

So now we factor out $T_2 - T_1$ as $u_2 - u_1 = C(T_2 - T_1)$ for each term

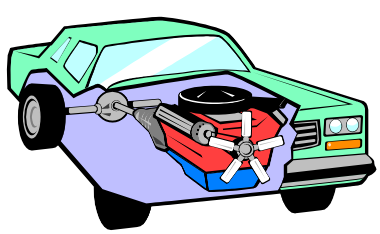
$$[\, m_{Fe}C_{Fe} + m_{Al}C_{Al} + m_{st}C_{st} + m_{oil}C_{oil} + m_{gly}C_{gly} \,]\,(T_2 - T_1) = {}_1Q_2$$

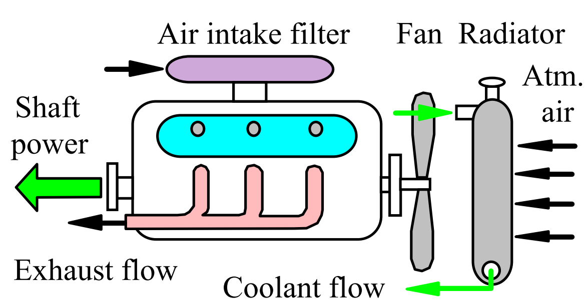
$$T_2 - T_1 = {}_1Q_2 / \Sigma m_i\, C_i$$

$$= \frac{7000}{100\times 0.42 + 20\times 0.9 + 20\times 0.46 + 5\times 1.9 + 6\times 2.42}$$

$$= \frac{7000}{93.22} = 75 \text{ K}$$

$T_2 = T_1 + 75 = 5 + 75 =$ **80°C**





Properties (u, h, C_V and C_p), Ideal Gas

5.82

Use the ideal gas air table A.7 to evaluate the heat capacity C_p at 300 K as a slope of the curve h(T) by Δh/ΔT. How much larger is it at 1000 K and 1500 K.

Solution :

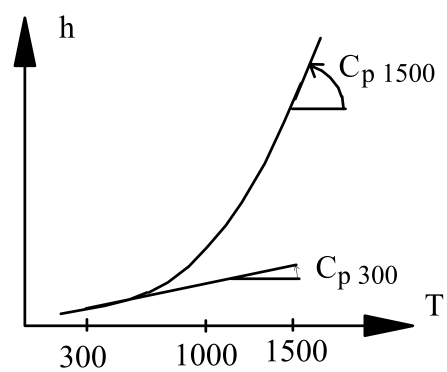
From Eq.5.24:

$$C_p = \frac{dh}{dT} = \frac{\Delta h}{\Delta T} = \frac{h_{320} - h_{290}}{320 - 290} = \mathbf{1.005\ kJ/kg\ K}$$

$$1000\text{K} \quad C_p = \frac{\Delta h}{\Delta T} = \frac{h_{1050} - h_{950}}{1050 - 950} = \frac{1103.48 - 989.44}{100} = \mathbf{1.140\ kJ/kg\ K}$$

$$1500\text{K} \quad C_p = \frac{\Delta h}{\Delta T} = \frac{h_{1550} - h_{1450}}{1550 - 1450} = \frac{1696.45 - 1575.4}{100} = \mathbf{1.21\ kJ/kg\ K}$$

Notice an increase of 14%, 21% respectively.



5.83

We want to find the change in u for carbon dioxide between 600 K and 1200 K.

a) Find it from a constant C_{vo} from table A.5

b) Find it from a C_{vo} evaluated from equation in A.6 at the average T.

c) Find it from the values of u listed in table A.8

Solution :

a) $\Delta u \cong C_{vo}\,\Delta T = 0.653 \times (1200 - 600) =$ **391.8 kJ/kg**

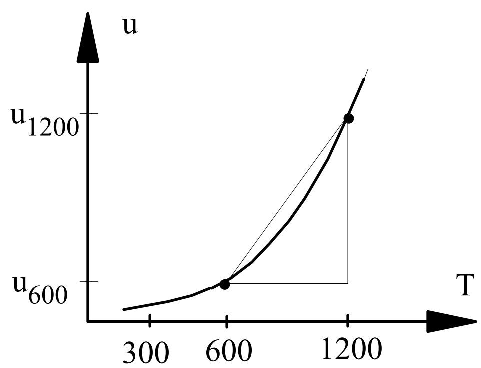
b) $T_{avg} = \frac{1}{2}(1200 + 600) = 900, \qquad \theta = \frac{T}{1000} = \frac{900}{1000} = 0.9$

$C_{po} = 0.45 + 1.67 \times 0.9 - 1.27 \times 0.9^2 + 0.39 \times 0.9^3 = 1.2086$ kJ/kg K

$C_{vo} = C_{po} - R = 1.2086 - 0.1889 = 1.0197$ kJ/kg K

$\Delta u = 1.0197 \times (1200 - 600) =$ **611.8 kJ/kg**

c) $\Delta u = 996.64 - 392.72 =$ **603.92 kJ/kg**



5.84

We want to find the change in u for oxygen gas between 600 K and 1200 K.

a) Find it from a constant C_{vo} from table A.5

b) Find it from a C_{vo} evaluated from equation in A.6 at the average T.

c) Find it from the values of u listed in table A.8

Solution:

a) $\Delta u \cong C_{vo}\,\Delta T = 0.662 \times (1200 - 600) = \mathbf{397.2\ kJ/kg}$

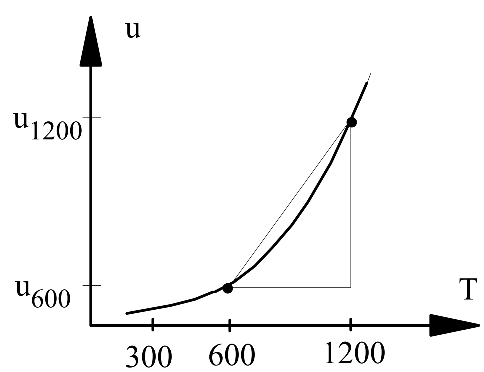
b) $T_{avg} = \frac{1}{2}(1200 + 600) = 900\ K, \qquad \theta = \frac{T}{1000} = \frac{900}{1000} = 0.9$

$C_{po} = 0.88 - 0.0001 \times 0.9 + 0.54 \times 0.9^2 - 0.33 \times 0.9^3 = 1.0767$

$C_{vo} = C_{po} - R = 1.0767 - 0.2598 = 0.8169\ kJ/kg\ K$

$\Delta u = 0.8169 \times (1200 - 600) = \mathbf{490.1\ kJ/kg}$

c) $\Delta u = 889.72 - 404.46 = \mathbf{485.3\ kJ/kg}$



5.85

Water at 20°C, 100 kPa, is brought to 200 kPa, 1500°C. Find the change in the specific internal energy, using the water table and the ideal gas water table in combination.

Solution:

State 1: Table B.1.1 $u_1 \cong u_f = 83.95$ kJ/kg

State 2: Highest T in Table B.1.3 is 1300°C

Using a Δu from the ideal gas tables, A.8, we get

$u_{1500} = 3139$ kJ/kg $\qquad u_{1300} = 2690.72$ kJ/kg

$u_{1500} - u_{1300} = 448.26$ kJ/kg

We now add the ideal gas change at low P to the steam tables, B.1.3, u_x = 4683.23 kJ/kg as the reference.

$$u_2 - u_1 = (u_2 - u_x)_{ID.G.} + (u_x - u_1)$$

$$= 448.28 + 4683.23 - 83.95 = \mathbf{5048\ kJ/kg}$$

5.86

We want to find the increase in temperature of nitrogen gas at 1200 K when the specific internal energy is increased with 40 kJ/kg.

a) Find it from a constant C_{vo} from table A.5

b) Find it from a C_{vo} evaluated from equation in A.6 at 1200 K.

c) Find it from the values of u listed in table A.8

Solution :

$\Delta u = \Delta u_{A.8} \cong C_{v\,avg}\,\Delta T \cong C_{vo}\,\Delta T$

a) $\Delta T = \Delta u / C_{vo} = \frac{40}{0.745}$ **= 53.69°C**

b) $\theta = 1200 / 1000 = 1.2$

$C_{po} = 1.11 - 0.48 \times 1.2 + 0.96 \times 1.2^2 - 0.42 \times 1.2^3 = 1.1906$ kJ/kg K

$C_{vo} = C_{po} - R = 1.1906 - 0.2968 = 0.8938$ kJ/kg K

$\Delta T = \Delta u / C_{vo} = 40 / 0.8938 =$ **44.75°C**

c) $u = u_1 + \Delta u = 957 + 40 = 997$ kJ/kg

less than 1300 K so linear interpolation.

$\Delta T = \frac{1300 - 1200}{1048.46 - 957} \times 40 =$ **43.73°C**

$C_{vo} \cong (1048.46 - 957) / 100 = 0.915$ kJ/kg K

So the formula in A.6 is accurate within 2.3%.

5.87

For an application the change in enthalpy of carbon dioxide from 30 to 1500°C at 100 kPa is needed. Consider the following methods and indicate the most accurate one.

a. Constant specific heat, value from Table A.5.

b. Constant specific heat, value at average temperature from the equation in Table A.6.

c. Variable specific heat, integrating the equation in Table A.6.

d. Enthalpy from ideal gas tables in Table A.8.

Solution:

a) $\Delta h = C_{po}\Delta T = 0.842\ (1500 - 30) = \mathbf{1237.7\ kJ/kg}$

b) $T_{ave} = \frac{1}{2}(30 + 1500) + 273.15 = 1038.15\ K;\quad \theta = T/1000 = 1.0382$

Table A.6 $\Rightarrow$ $C_{po} = 1.2513$

$\Delta h = C_{po,ave}\ \Delta T = 1.2513 \times 1470 = \mathbf{1839\ kJ/kg}$

c) For the entry to Table A.6: $\theta_2 = 1.77315$; $\theta_1 = 0.30315$

$$\Delta h = h_2 - h_1 = \int C_{po}\ dT$$

$$= [0.45\ (\theta_2 - \theta_1) + 1.67 \times \frac{1}{2}(\theta_2^2 - \theta_1^2)$$

$$-1.27 \times \frac{1}{3}(\theta_2^3 - \theta_1^3) + 0.39 \times \frac{1}{4}(\theta_2^4 - \theta_1^4)] = \mathbf{1762.76\ kJ/kg}$$

d) $\Delta h = 1981.35 - 217.12 = \mathbf{1764.2\ kJ/kg}$

The result in d) is best, very similar to c). For large ΔT or small ΔT at high T_{avg}, a) is very poor.

5.88

An ideal gas is heated from 500 to 1500 K. Find the change in enthalpy using constant specific heat from Table A.5 (room temperature value) and discuss the accuracy of the result if the gas is

a. Argon b. Oxygen c. Carbon dioxide

Solution:

$T_1 = 500$ K, $T_2 = 1500$ K, $\Delta h = C_{P0}(T_2 - T_1)$

a) Ar : $\Delta h = 0.520(1500-500) = 520$ kJ/kg

Monatomic inert gas very good approximation.

b) O_2 : $\Delta h = 0.922(1500-500) = 922$ kJ/kg

Diatomic gas approximation is OK with some error.

c) CO_2: $\Delta h = 0.842(1500-500) = 842$ kJ/kg

Polyatomic gas heat capacity changes, see figure 5.11

See also appendix C for more explanation.

Energy Equation: Ideal Gas

5.89

A 250 L rigid tank contains methane at 500 K, 1500 kPa. It is now cooled down to 300 K. Find the mass of methane and the heat transfer using a) ideal gas and b) the methane tables.

Solution:

a) Assume ideal gas, $P_2 = P_1 \times (T_2 / T_1) = 1500 \times 300 / 500 = 900$ kPa

$$m = P_1V/RT_1 = \frac{1500 \times 0.25}{0.5183 \times 500} = 1.447 \text{ kg}$$

Use specific heat from Table A.5

$$u_2 - u_1 = C_v (T_2 – T_1) = 1.736 (300 – 500) = –347.2 \text{ kJ/kg}$$

$${}_1Q_2 = m(u_2 - u_1) = 1.447(-347.2) = \mathbf{–502.4 \text{ kJ}}$$

b) Using the methane Table B.7,

$$v_1 = 0.17273 \text{ m}^3\text{/kg}, \quad u_1 = 872.37 \text{ kJ/kg}$$

$$m = V/v_1 = 0.25/0.17273 = 1.4473 \text{ kg}$$

State 2: $v_2 = v_1$ and 300 K is found between 800 and 1000 kPa

$$u_2 = 467.36 + (465.91 – 467.36) \frac{0.17273 – 0.19172}{0.15285 – 0.19172} = 466.65 \text{ kJ/kg}$$

$${}_1Q_2 = 1.4473 (466.65 – 872.37) = \mathbf{–587.2 \text{ kJ}}$$

5.90

A rigid insulated tank is separated into two rooms by a stiff plate. Room A of 0.5 m^3 contains air at 250 kPa, 300 K and room B of 1 m^3 has air at 150 kPa, 1000 K. The plate is removed and the air comes to a uniform state without any heat transfer. Find the final pressure and temperature.

Solution:

C.V. Total tank. Control mass of constant volume.

Mass and volume: $m_2 = m_A + m_B$; $V = V_A + V_B = 1.5\ m^3$

Energy Eq.: $U_2 - U_1 = m_2 u_2 - m_A u_{A1} - m_B u_{B1} = Q - W = 0$

Process Eq.: $V = \text{constant} \Rightarrow W = 0$; Insulated $\Rightarrow Q = 0$

Ideal gas at 1: $m_A = P_{A1}V_A/RT_{A1} = 250 \times 0.5/(0.287 \times 300) = 1.452$ kg

$u_{A1} = 214.364$ kJ/kg from Table A.7

Ideal gas at 2: $m_B = P_{B1}V_B/RT_{B1} = 150 \times 1/(0.287 \times 1000) = 0.523$ kg

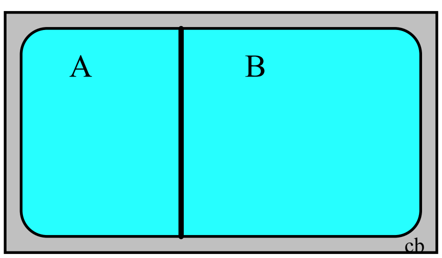
$u_{B1} = 759.189$ kJ/kg from Table A.7

$m_2 = m_A + m_B = 1.975$ kg

$$u_2 = \frac{m_A u_{A1} + m_B u_{B1}}{m_2} = \frac{1.452 \times 214.364 + 0.523 \times 759.189}{1.975} = 358.64 \text{ kJ/kg}$$

=> Table A.7.1: $\mathbf{T_2 = 498.4\ K}$

$P_2 = m_2 RT_2 /V = 1.975 \times 0.287 \times 498.4/1.5 =$ **188.3 kPa**



5.91

A rigid container has 2 kg of carbon dioxide gas at 100 kPa, 1200 K that is heated to 1400 K. Solve for the heat transfer using a. the heat capacity from Table A.5 and b. properties from Table A.8

Solution:

C.V. Carbon dioxide, which is a control mass.

Energy Eq.5.11: $U_2 – U_1 = m (u_2 - u_1) = {}_1Q_2 - {}_1W_2$

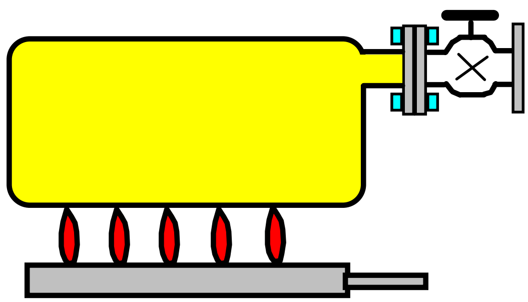
Process: $\Delta V = 0 \Rightarrow {}_1W_2 = 0$

a) For constant heat capacity we have: $u_2 - u_1 = C_{vo} (T_2 - T_1)$ so

$${}_1Q_2 \cong mC_{vo} (T_2 - T_1) = 2 \times 0.653 \times (1400 – 1200) = \mathbf{261.2\ kJ}$$

b) Taking the u values from Table A.8 we get

$${}_1Q_2 = m (u_2 - u_1) = 2 \times (1218.38 – 996.64) = \mathbf{443.5\ kJ}$$



5.92

Do the previous problem for nitrogen, N_2, gas.

A rigid container has 2 kg of carbon dioxide gas at 100 kPa, 1200 K that is heated to 1400 K. Solve for the heat transfer using a. the heat capacity from Table A.5 and b. properties from Table A.8

Solution:

C.V. Nitrogen gas, which is a control mass.

Energy Eq.5.11: $U_2 - U_1 = m (u_2 - u_1) = {}_1Q_2 - {}_1W_2$

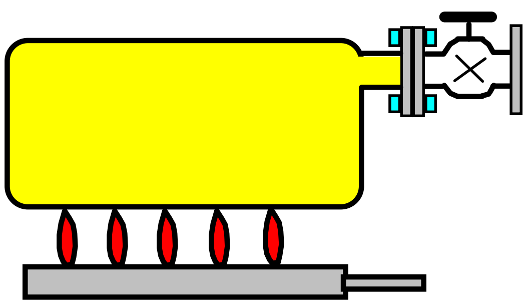
Process: $\Delta V = 0 \;\Rightarrow {}_1W_2 = 0$

a) For constant heat capacity we have: $u_2 - u_1 = C_{vo} (T_2 - T_1)$ so

$${}_1Q_2 \cong mC_{vo} (T_2 - T_1) = 2 \times 0.745 \times (1400 - 1200) = \mathbf{298\ kJ}$$

b) Taking the u values from Table A.8, we get

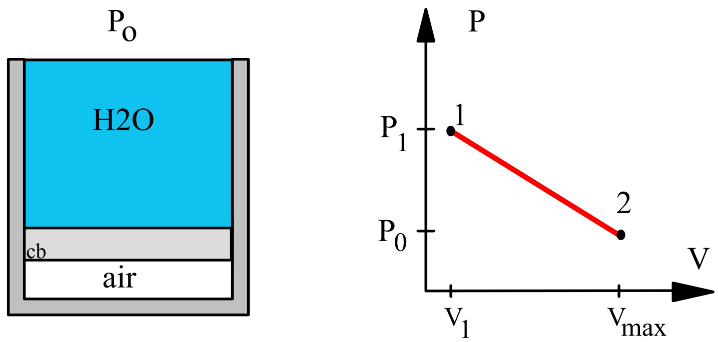
$${}_1Q_2 = m (u_2 - u_1) = 2 \times (1141.35 - 957) = \mathbf{368.7\ kJ}$$



5.93

A 10-m high cylinder, cross-sectional area 0.1 m^2, has a massless piston at the bottom with water at 20°C on top of it, shown in Fig. P5.93. Air at 300 K, volume 0.3 m^3, under the piston is heated so that the piston moves up, spilling the water out over the side. Find the total heat transfer to the air when all the water has been pushed out.

Solution:



The water on top is compressed liquid and has volume and mass

$$V_{H_2O} = V_{tot} - V_{air} = 10 \times 0.1 - 0.3 = 0.7 \text{ m}^3$$

$$m_{H_2O} = V_{H_2O}/v_f = 0.7 / 0.001002 = 698.6 \text{ kg}$$

The initial air pressure is then

$$P_1 = P_0 + m_{H_2O}g/A = 101.325 + \frac{698.6 \times 9.807}{0.1 \times 1000} = \mathbf{169.84\ kPa}$$

and then $m_{air} = PV/RT = \frac{169.84 \times 0.3}{0.287 \times 300} = 0.592$ kg

State 2: No liquid water over the piston so

$$P_2 = P_0 + \emptyset = 101.325 \text{ kPa}, \quad V_2 = 10{\times}0.1 = 1 \text{ m}^3$$

State 2: P_2, V_2 $\Rightarrow$ $T_2 = \frac{T_1P_2V_2}{P_1V_1} = \frac{300{\times}101.325{\times}1}{169.84{\times}0.3} = 596.59$ K

The process line shows the work as an area

$${}_1W_2 = \int PdV = \frac{1}{2}(P_1 + P_2)(V_2 - V_1) = \frac{1}{2}(169.84 + 101.325)(1 - 0.3) = 94.91 \text{ kJ}$$

The energy equation solved for the heat transfer becomes

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 \cong mC_v(T_2 - T_1) + {}_1W_2$$

$$= 0.592 \times 0.717 \times (596.59 - 300) + 94.91 = \mathbf{220.7\ kJ}$$

Remark: we could have used u values from Table A.7:

$u_2 - u_1 = 432.5 - 214.36 = 218.14$ kJ/kg versus 212.5 kJ/kg with C_v.

5.94

Find the heat transfer in Problem 4.43.

A piston cylinder contains 3 kg of air at 20^{o}C and 300 kPa. It is now heated up in a constant pressure process to 600 K.

Solution:

Ideal gas $PV = mRT$

State 1: T_1, P_1

State 2: $T_2, P_2 = P_1$

$P_2V_2 = mRT_2$ $\quad V_2 = mR\,T_2 / P_2 = 3\times0.287\times600 / 300 = 1.722\ m^3$

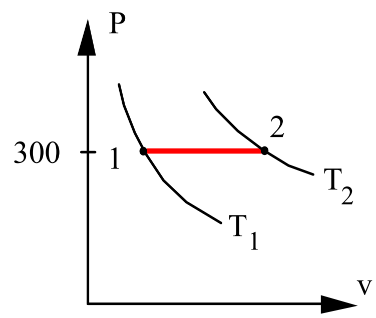
Process: $P = $ constant,

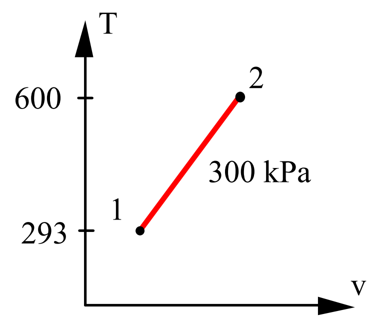
$${}_1W_2 = \int PdV = P\,(V_2 - V_1) = 300\,(1.722 - 0.8413) = 264.2\ kJ$$

Energy equation becomes

$$U_2 - U_1 = {}_1Q_2 - {}_1W_2 = m(u_2 - u_1)$$

$${}_1Q_2 = U_2 - U_1 + {}_1W_2 = 3(435.097 - 209.45) + 264.2 = \mathbf{941\ kJ}$$





5.95

An insulated cylinder is divided into two parts of 1 m^3 each by an initially locked piston, as shown in Fig. P5.95. Side A has air at 200 kPa, 300 K, and side B has air at 1.0 MPa, 1000 K. The piston is now unlocked so it is free to move, and it conducts heat so the air comes to a uniform temperature $T_A = T_B$. Find the mass in both A and B, and the final *T* and *P*.

C.V. A + B   Force balance on piston: $P_A A = P_B A$

So the final state in A and B is the same.

State 1A: Table A.7 $u_{A1} = 214.364$ kJ/kg,

$m_A = P_{A1}V_{A1}/RT_{A1} = 200 \times 1/(0.287 \times 300) = \mathbf{2.323\ kg}$

State 1B: Table A.7 $u_{B1} = 759.189$ kJ/kg,

$m_B = P_{B1}V_{B1}/RT_{B1} = 1000 \times 1/(0.287 \times 1000) = \mathbf{3.484\ kg}$

For chosen C.V. ${}_1Q_2 = 0$, ${}_1W_2 = 0$ so the energy equation becomes

$$m_A(u_2 - u_1)_A + m_B(u_2 - u_1)_B = 0$$

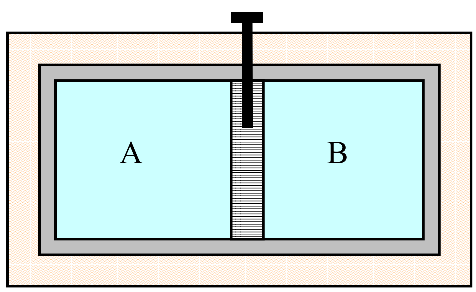
$$(m_A + m_B)u_2 = m_A u_{A1} + m_B u_{B1}$$

$$= 2.323 \times 214.364 + 3.484 \times 759.189 = 3143 \text{ kJ}$$

$$u_2 = 3143/(3.484 + 2.323) = 541.24 \text{ kJ/kg}$$

From interpolation in Table A.7: $\Rightarrow$ $\mathbf{T_2 = 736\ K}$

$$P = (m_A + m_B)RT_2/V_{tot} = 5.807 \text{ kg} \times 0.287 \frac{\text{kJ}}{\text{kg K}} \times 736 \text{ K}/ 2 \text{ m}^3 = \mathbf{613\ kPa}$$



5.96

A piston cylinder contains air at 600 kPa, 290 K and a volume of $0.01\ m^3$. A constant pressure process gives 54 kJ of work out. Find the final temperature of the air and the heat transfer input.

Solution:

C.V AIR control mass

Continuity Eq.: $m_2 – m_1 = 0$

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

Process: $P = C$ so ${}_1W_2 = \int P\, dV = P(V_2 – V_1)$

1 : P_1 , T_1,V_1 2 : $P_1 = P_2$, ?

$$m_1 = P_1V_1/RT_1 = 600 \times 0.01 / 0.287 \times 290 = 0.0721 \text{ kg}$$

$$ {}_1W_2 = P(V_2 – V_1) = 54 \text{ kJ} \rightarrow$$

$$V_2 – V_1 = {}_1W_2 / P = 54 \text{ kJ} / 600 \text{ kPa} = 0.09 \text{ m}^3$$

$$V_2 = V_1 + {}_1W_2 / P = 0.01 + 0.09 = 0.10 \text{ m}^3$$

Ideal gas law : $P_2V_2 = mRT_2$

$$T_2 = P_2V_2 / mR = \frac{P_2V_2}{P_1V_1} T_1 = \frac{0.10}{0.01} \times 290 = \mathbf{2900\ K}$$

Energy equation with u's from table A.7.1

$$ {}_1Q_2 = m (u_2 – u_1) + {}_1W_2$$

$$= 0.0721 (2563.8 – 207.2) + 54$$

$$= \mathbf{223.9\ kJ}$$

5.97

A cylinder with a piston restrained by a linear spring contains 2 kg of carbon dioxide at 500 kPa, 400°C. It is cooled to 40°C, at which point the pressure is 300 kPa. Calculate the heat transfer for the process.

Solution:

C.V. The carbon dioxide, which is a control mass.

Continuity Eq.: $m_2 - m_1 = 0$

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

Process Eq.: $P = A + BV$ (linear spring)

$${}_1W_2 = \int PdV = \frac{1}{2}(P_1 + P_2)(V_2 - V_1)$$

Equation of state: $PV = mRT$ (ideal gas)

State 1: $V_1 = mRT_1/P_1 = 2 \times 0.18892 \times 673.15 /500 = 0.5087 \text{ m}^3$

State 2: $V_2 = mRT_2/P_2 = 2 \times 0.18892 \times 313.15 /300 = 0.3944 \text{ m}^3$

$${}_1W_2 = \frac{1}{2}(500 + 300)(0.3944 - 0.5087) = -45.72 \text{ kJ}$$

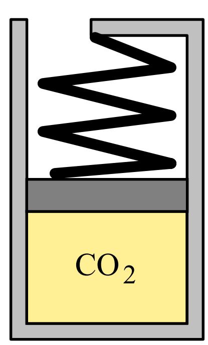
To evaluate $u_2 - u_1$ we will use the specific heat at the average temperature.

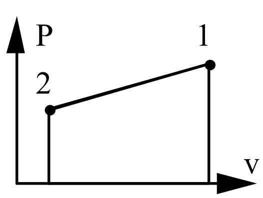
From Figure 5.11: $C_{po}(T_{avg}) = 45/44 = 1.023 \Rightarrow C_{vo} = 0.83 = C_{po} - R$

For comparison the value from Table A.5 at 300 K is $C_{vo} = 0.653$ kJ/kg K

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = mC_{vo}(T_2 - T_1) + {}_1W_2$$

$$= 2 \times 0.83(40 - 400) - 45.72 = \mathbf{-643.3\ kJ}$$





Remark: We could also have used the ideal gas table in A.8 to get $u_2 - u_1$.

5.98

Water at 100 kPa, 400 K is heated electrically adding 700 kJ/kg in a constant pressure process. Find the final temperature using

a) The water tables B.1 b) The ideal gas tables A.8

c) Constant specific heat from A.5

Solution :

Energy Eq.5.11: $u_2 - u_1 = {}_1q_2 - {}_1w_2$

Process: P = constant => ${}_1w_2 = P (v_2 - v_1)$

Substitute this into the energy equation to get

$${}_1q_2 = h_2 - h_1$$

Table B.1:

$$h_1 \cong 2675.46 + \frac{126.85 - 99.62}{150 - 99.62} \times (2776.38 - 2675.46) = 2730.0 \text{ kJ/kg}$$

$$h_2 = h_1 + {}_1q_2 = 2730 + 700 = 3430 \text{ kJ/kg}$$

$$T_2 = 400 + (500 - 400) \times \frac{3430 - 3278.11}{3488.09 - 3278.11} = \mathbf{472.3°C}$$

Table A.8:

$$h_2 = h_1 + {}_1q_2 = 742.4 + 700 = 1442.4 \text{ kJ/kg}$$

$$T_2 = 700 + (750 - 700) \times \frac{1442.4 - 1338.56}{1443.43 - 1338.56} = 749.5 \text{ K} = \mathbf{476.3°C}$$

Table A.5

$$h_2 - h_1 \cong C_{po} (T_2 - T_1)$$

$$T_2 = T_1 + {}_1q_2 / C_{po} = 400 + 700 / 1.872 = 773.9\text{K} = \mathbf{500.8°C}$$

5.99

A piston/cylinder has 0.5 kg air at 2000 kPa, 1000 K as shown. The cylinder has stops so $V_{min} = 0.03\ m^3$. The air now cools to 400 K by heat transfer to the ambient. Find the final volume and pressure of the air (does it hit the stops?) and the work and heat transfer in the process.

Solution:

We recognize this is a possible two-step process, one of constant P and one of constant V. This behavior is dictated by the construction of the device.

Continuity Eq.: $m_2 - m_1 = 0$

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: $P = \text{constant} = F/A = P_1$ if $V > V_{min}$

$V = \text{constant} = V_{1a} = V_{min}$ if $P < P_1$

State 1: (P, T) $V_1 = mRT_1/P_1 = 0.5 \times 0.287 \times 1000/2000 = 0.07175\ m^3$

The only possible P-V combinations for this system is shown in the diagram so both state 1 and 2 must be on the two lines. For state 2 we need to know if it is on the horizontal P line segment or the vertical V segment. Let us check state 1a:

State 1a: $P_{1a} = P_1,\ V_{1a} = V_{min}$

$$\text{Ideal gas so } T_{1a} = T_1 \frac{V_{1a}}{V_1} = 1000 \times \frac{0.03}{0.07175} = 418\ K$$

We see that $T_2 < T_{1a}$ and state 2 must have $V_2 = V_{1a} = V_{min} = 0.03\ m^3$.

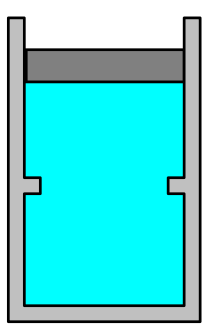
$$P_2 = P_1 \times \frac{T_2}{T_1} \times \frac{V_1}{V_2} = 2000 \times \frac{400}{1000} \times \frac{0.07175}{0.03} = 1913.3\ kPa$$

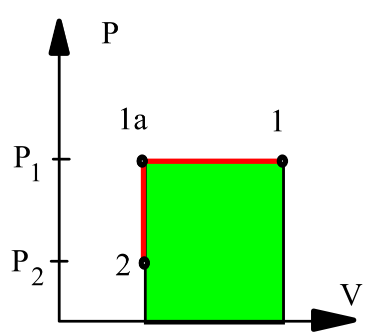
The work is the area under the process curve in the P-V diagram

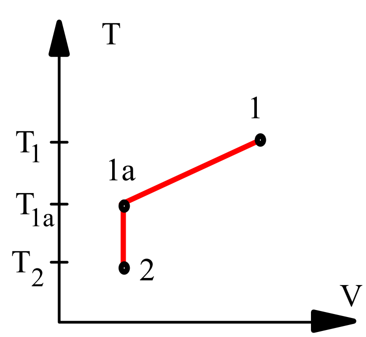
$${}_1W_2 = \int_1^2 P\,dV = P_1 (V_{1a} - V_1) = 2000\ kPa\ (0.03 - 0.07175)\ m^3 = \mathbf{-83.5\ kJ}$$

Now the heat transfer is found from the energy equation, u's from Table A.7.1,

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 0.5\ (286.49 - 759.19) - 83.5 = \mathbf{-319.85\ kJ}$$







5.100

A spring loaded piston/cylinder contains 1.5 kg of air at 27C and 160 kPa. It is now heated to 900 K in a process where the pressure is linear in volume to a final volume of twice the initial volume. Plot the process in a P-v diagram and find the work and heat transfer.

Take CV as the air.

$m_2 = m_1 = m$; $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: $P = A + BV$ => ${}_1W_2 = \int P\, dV = \text{area} = 0.5(P_1 + P_2)(V_2 - V_1)$

State 1: Ideal gas. $V_1 = mRT_1/P_1 = 1.5\times 0.287 \times 300/160 = 0.8072\ m^3$

Table A.7 $u_1 = u(300) = 214.36$ kJ/kg

State 2: $P_2V_2 = mRT_2$ so ratio it to the initial state properties

$P_2V_2 / P_1V_1 = P_2 2 / P_1 = mRT_2 / mRT_1 = T_2 / T_1$ =>

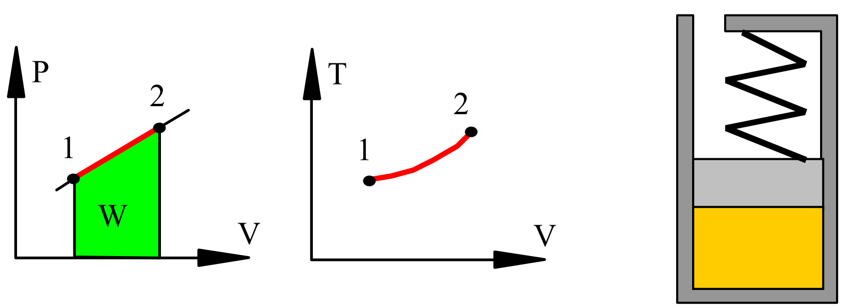
$P_2 = P_1 (T_2 / T_1)(1/2) = 160 \times (900/300) \times (1/2) =$ **240 kPa**

Work is done while piston moves at linearly varying pressure, so we get

${}_1W_2 = 0.5(P_1 + P_2)(V_2 - V_1) = 0.5\times(160 + 240)\ \text{kPa} \times 0.8072\ m^3 =$ **161.4 kJ**

Heat transfer is found from energy equation

${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 1.5\times(674.824 - 214.36) + 161.4 =$ **852.1 kJ**



5.101

Air in a piston/cylinder at 200 kPa, 600 K, is expanded in a constant-pressure process to twice the initial volume (state 2), shown in Fig. P5.101. The piston is then locked with a pin and heat is transferred to a final temperature of 600 K. Find *P*, *T*, and *h* for states 2 and 3, and find the work and heat transfer in both processes.

Solution:

C.V. Air. Control mass $m_2 = m_3 = m_1$

Energy Eq.5.11: $u_2 - u_1 = {}_1q_2 - {}_1w_2$;

Process 1 to 2: P = constant => ${}_1w_2 = \int P\,dv = P_1(v_2 - v_1) = R(T_2 - T_1)$

Ideal gas $Pv = RT \Rightarrow T_2 = T_1 v_2/v_1 = 2T_1 =$ **1200 K**

$P_2 = P_1 = 200$ kPa, ${}_1w_2 = RT_1 =$ **172.2 kJ/kg**

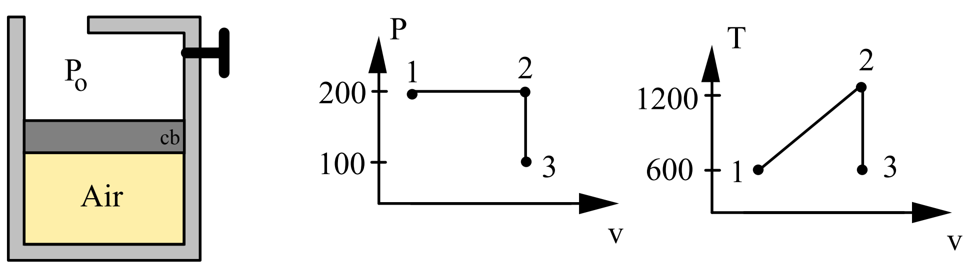
Table A.7 **h_2 = 1277.8 kJ/kg, $h_3 = h_1$ = 607.3 kJ/kg**

${}_1q_2 = u_2 - u_1 + {}_1w_2 = h_2 - h_1 = 1277.8 - 607.3 =$ **670.5 kJ/kg**

Process 2→3: $v_3 = v_2 = 2v_1 \Rightarrow$ **${}_2w_3 = 0$,**

$P_3 = P_2T_3/T_2 = P_1T_1/2T_1 = P_1/2 =$ **100 kPa**

${}_2q_3 = u_3 - u_2 = 435.1 - 933.4 =$ **-498.3 kJ/kg**



5.102

A vertical piston/cylinder has a linear spring mounted as shown so at zero cylinder volume a balancing pressure inside is zero. The cylinder contains 0.25 kg air at 500 kPa, 27^{o}C. Heat is now added so the volume doubles.

a) Show the process path in a P-V diagram

b) Find the final pressure and temperature.

c) Find the work and heat transfer.

Solution:

Take CV around the air. This is a control mass.

Continuity: $m_2 = m_1 = m$;

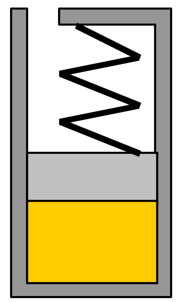
Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: P linear in V so, $P = A + BV$,

since $V = 0$ => $P = 0$ => $A = 0$

now: $P = BV$; $B = P_1/V_1$

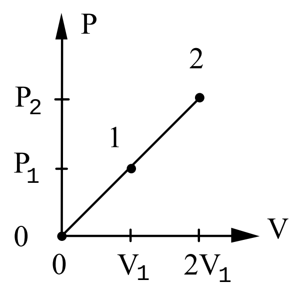
State 1: P, T Ideal gas :



$$V = \frac{mRT}{P} = \frac{0.25 \times 0.287 \times 300}{500}$$

$= 0.04305 \text{ m}^3$

a)



b) State 2: $V_2 = 2\,V_1$; ?

must be on line in P-V diagram, this substitutes for the question mark only one state is on the line with that value of V_2

$$P_2 = BV_2 = (P_1/V_1)V_2 = 2P_1 = \mathbf{1000\ kPa}.$$

$$T_2 = \frac{PV}{mR} = \frac{2P_1 2V_1}{mR} = \frac{4P_1V_1}{mR} = 4\,T_1 = \mathbf{1200\ K}$$

c) The work is boundary work and thus seen as area in the P-V diagram:

$${}_1W_2 = \int P\,dV = 0.5(P_1 + P_2)(2V_1 - V_1) = 0.5(500 + 1000)\,0.04305 = \mathbf{32.3\ kJ}$$

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 0.25(933.4 - 214.4) + 32.3 = \mathbf{212\ kJ}$$

Internal energy u was taken from air table A.7. If constant Cv were used then

$(u_2 - u_1) = 0.717\,(1200 - 300) = 645.3$ kJ/kg (versus 719 above)

Energy Equation: Polytropic Process

5.103

A piston cylinder contains 0.1 kg air at 300 K and 100 kPa. The air is now slowly compressed in an isothermal (T = C) process to a final pressure of 250 kPa. Show the process in a P-V diagram and find both the work and heat transfer in the process.

Solution :

Process: T = C & ideal gas $\Rightarrow$ PV = mRT = constant

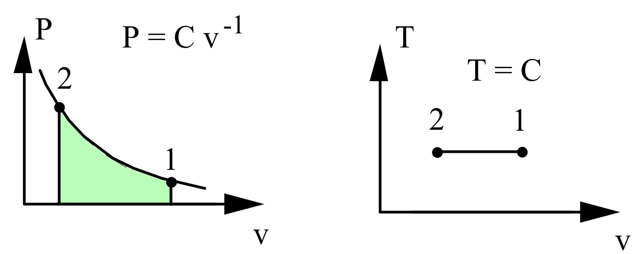
$$ {}_1W_2 = \int P dV = \int \frac{mRT}{V} dV = mRT \ln \frac{V_2}{V_1} = mRT \ln \frac{P_1}{P_2} $$

$$ = 0.1 \times 0.287 \times 300 \ln (100 / 250) = \mathbf{-7.89\ kJ} $$

since $T_1 = T_2 \Rightarrow u_2 = u_1$

The energy equation thus becomes

$$ {}_1Q_2 = m \times (u_2 - u_1) + {}_1W_2 = {}_1W_2 = \mathbf{-7.89\ kJ} $$



5.104

Oxygen at 300 kPa, 100°C is in a piston/cylinder arrangement with a volume of 0.1 m^3. It is now compressed in a polytropic process with exponent, *n* = 1.2, to a final temperature of 200°C. Calculate the heat transfer for the process.

Solution:

Continuty: $m_2 = m_1$

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

State 1: T_1 , P_1 & ideal gas, small change in T, so use Table A.5

$$\Rightarrow m = \frac{P_1V_1}{RT_1} = \frac{300 \times 0.1 \text{ m}^3}{0.25983 \times 373.15} = 0.309 \text{ kg}$$

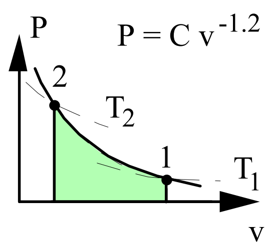
Process: PV^n = constant

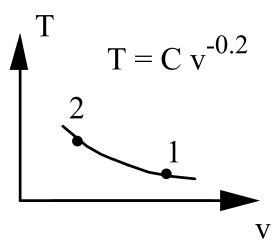
$${}_1W_2 = \frac{1}{1\text{-n}} (P_2V_2 - P_1V_1) = \frac{mR}{1\text{-n}} (T_2 - T_1) = \frac{0.309 \times 0.25983}{1 - 1.2} (200 - 100)$$

$$= -40.2 \text{ kJ}$$

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 \cong mC_v(T_2 - T_1) + {}_1W_2$$

$$= 0.3094 \times 0.662 (200 - 100) - 40.2 = \mathbf{-19.7\ kJ}$$





5.105

A piston/cylinder contains 0.001 m^3 air at 300 K, 150 kPa. The air is now compressed in a process in which $P\,V^{1.25} = C$ to a final pressure of 600 kPa. Find the work performed by the air and the heat transfer.

Solution:

C.V. Air. This is a control mass, values from Table A.5 are used.

Continuty: $m_2 = m_1$

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process : $PV^{1.25} = \text{const.}$

State 2: $V_2 = V_1 (P_1/P_2)^{1.25} = 0.00033\ m^3$

$$T_2 = T_1\, P_2V_2/(P_1V_1) = 300\,\frac{600 \times 0.00033}{150 \times 0.001} = 395.85\text{ K}$$

$${}_1W_2 = \frac{1}{n-1}(P_2\,V_2 - P_1V_1) = \frac{1}{n-1}\,(600 \times 0.00033 - 150 \times 0.001) = -\,0.192\text{ kJ}$$

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = \frac{P_1V_1}{RT_1}\,C_v\,(T_2 - T_1) + {}_1W_2$$

$$= 0.001742 \times 0.717 \times 95.85 - 0.192 = \mathbf{-\,0.072\ kJ}$$

5.106

Helium gas expands from 125 kPa, 350 K and 0.25 m^3 to 100 kPa in a polytropic process with n = 1.667. How much heat transfer is involved?

Solution:

C.V. Helium gas, this is a control mass.

Energy equation: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process equation: $PV^n = \text{constant} = P_1V_1^n = P_2V_2^n$

Ideal gas (A.5): $m = PV/RT = \frac{125 \times 0.25}{2.0771 \times 350} = 0.043 \text{ kg}$

Solve for the volume at state 2

$$V_2 = V_1 (P_1/P_2)^{1/n} = 0.25 \times \left(\frac{125}{100}\right)^{0.6} = 0.2852 \text{ m}^3$$

$$T_2 = T_1 P_2V_2/(P_1V_1) = 350 \frac{100 \times 0.2852}{125 \times 0.25} = 319.4 \text{ K}$$

Work from Eq.4.4

$${}_1W_2 = \frac{P_2V_2 - P_1V_1}{1-n} = \frac{100\times 0.2852 - 125\times 0.25}{1 - 1.667} \text{ kPa m}^3 = 4.09 \text{ kJ}$$

Use specific heat from Table A.5 to evaluate $u_2 - u_1$**,** $C_v = 3.116$ kJ/kg K

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = m\, C_v\, (T_2 - T_1) + {}_1W_2$$

$$= 0.043 \times 3.116 \times (319.4 - 350) + 4.09 = \mathbf{-0.01\ kJ}$$

5.107

A piston/cylinder in a car contains 0.2 L of air at 90 kPa, 20°C, shown in Fig. P5.107. The air is compressed in a quasi-equilibrium polytropic process with polytropic exponent *n* = 1.25 to a final volume six times smaller. Determine the final pressure, temperature, and the heat transfer for the process.

Solution:

C.V. Air. This is a control mass going through a polytropic process.

Continuty: $m_2 = m_1$

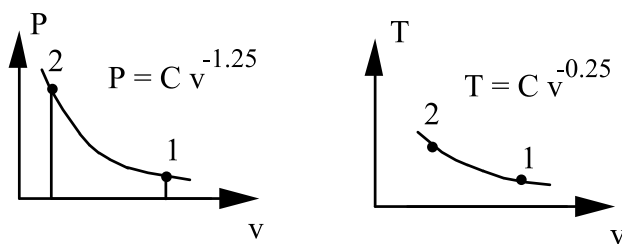
Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: $Pv^n = \text{const.}$

$P_1v_1^n = P_2v_2^n \Rightarrow P_2 = P_1(v_1/v_2)^n = 90 \times 6^{1.25} = \mathbf{845.15\ kPa}$

Substance ideal gas: $Pv = RT$

$T_2 = T_1(P_2v_2/P_1v_1) = 293.15(845.15/90 \times 6) = \mathbf{458.8\ K}$



$$m = \frac{PV}{RT} = \frac{90 \times 0.2\times10^{-3}}{0.287 \times 293.15} = 2.14\times10^{-4}\ \text{kg}$$

The work is integrated as in Eq.4.4

$${}_1w_2 = \int P dv = \frac{1}{1 - n}(P_2v_2 - P_1v_1) = \frac{R}{1 - n}(T_2 - T_1)$$

$$= \frac{0.287}{1 - 1.25}(458.8 - 293.15) = -190.17\ \text{kJ/kg}$$

The energy equation with values of u from Table A.7 is

$${}_1q_2 = u_2 - u_1 + {}_1w_2 = 329.4 - 208.03 - 190.17 = -68.8\ \text{kJ/kg}$$

${}_1Q_2 = m\ {}_1q_2 = \mathbf{-0.0147\ kJ}$ (i.e a heat loss)

5.108

A piston/cylinder has nitrogen gas at 750 K and 1500 kPa. Now it is expanded in a polytropic process with n = 1.2 to P = 750 kPa. Find the final temperature, the specific work and specific heat transfer in the process.

C.V. Nitrogen. This is a control mass going through a polytropic process.

Continuty: $m_2 = m_1$

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: $Pv^n = \text{constant}$

Substance ideal gas: $Pv = RT$

$$T_2 = T_1 \, (P_2/P_1)^{\frac{n-1}{n}} = 750 \left(\frac{750}{1500}\right)^{\frac{0.2}{1.2}} = 750 \times 0.8909 = \mathbf{668\ K}$$

The work is integrated as in Eq.4.4

$${}_1w_2 = \int Pdv = \frac{1}{1 - n}\,(P_2v_2 - P_1v_1) = \frac{R}{1 - n}\,(T_2 - T_1)$$

$$= \frac{0.2968}{1 - 1.2}(668 - 750) = \mathbf{121.7\ kJ/kg}$$

The energy equation with values of u from Table A.8 is

$${}_1q_2 = u_2 - u_1 + {}_1w_2 = 502.8 - 568.45 + 121.7 = \mathbf{56.0\ kJ/kg}$$

If constant specific heat is used from Table A.5

$${}_1q_2 = C(T_2 - T_1) + {}_1w_2 = 0.745(668 - 750) + 121.7 = \mathbf{60.6\ kJ/kg}$$

5.109

A piston/cylinder arrangement of initial volume 0.025 m^3 contains saturated water vapor at 180°C. The steam now expands in a polytropic process with exponent *n* = 1 to a final pressure of 200 kPa, while it does work against the piston. Determine the heat transfer in this process.

Solution:

C.V. Water. This is a control mass.

State 1: Table B.1.1 P = 1002.2 kPa, $v_1 = 0.19405\ m^3/kg$, $u_1 = 2583.7$ kJ/kg ,

$$m = V/v_1 = 0.025/0.19405 = 0.129 \text{ kg}$$

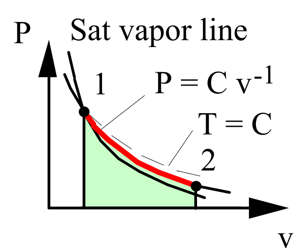
Process: $Pv = \text{const.} = P_1v_1 = P_2v_2$; polytropic process n = 1.

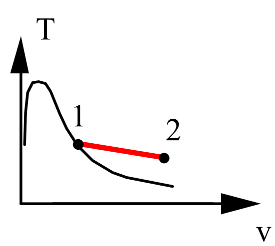
$$\Rightarrow v_2 = v_1P_1/P_2 = 0.19405 \times 1002.1/200 = 0.9723\ m^3/kg$$

State 2: $P_2, v_2 \Rightarrow$ Table B.1.3 $T_2 \cong 155°C$, $u_2 = 2585$ kJ/kg

$$_1W_2 = \int PdV = P_1V_1 \ln\frac{v_2}{v_1} = 1002.2 \times 0.025 \ln\frac{0.9723}{0.19405} = 40.37 \text{ kJ}$$

$$_1Q_2 = m(u_2 - u_1) + {_1W_2} = 0.129(2585 - 2583.7) + 40.37 = \mathbf{40.54\ kJ}$$





Notice T drops, it is not an ideal gas.

5.110

Air is expanded from 400 kPa, 600 K in a polytropic process to 150 kPa, 400 K in a piston cylinder arrangement. Find the polytropic exponent *n* and the work and heat transfer per kg air using constant heat capacity from A.5.

Solution:

Process: $P_1V_1^n = P_2V_2^n$

Ideal gas: $PV = RT \quad \Rightarrow \quad V = RT/ P$

$$\ln \frac{P_1}{P_2} = \ln (V_2 / V_1)^n = n \ln (V_2 / V_1) = n \ln \left[\frac{T_2}{P_2} \times \frac{P_1}{T_1} \right]$$

$$n = \ln \frac{P_1}{P_2} / \ln \left[\frac{P_1}{P_2} \times \frac{T_2}{T_1} \right] = \ln \frac{400}{150} / \ln \left[\frac{400}{600} \times \frac{400}{150} \right] = 1.7047$$

The work integral is from Eq.4.4

$${}_1W_2 = \int PdV = \frac{R}{1 - n} (T_2 - T_1) = \frac{0.287}{-0.7047} (400 - 600) = 81.45 \text{ kJ/kg}$$

Energy equation from Eq.5.11

$${}_1q_2 = u_2 - u_1 + {}_1w_2 = C_V(T_2 - T_1) + {}_1w_2 = 0.717 (400\text{-}600) + 81.45$$

$$= \mathbf{-61.95 \text{ kJ/kg}}$$

5.111

A piston/cylinder has 1 kg propane gas at 700 kPa, 40°C. The piston cross-sectional area is 0.5 m^2, and the total external force restraining the piston is directly proportional to the cylinder volume squared. Heat is transferred to the propane until its temperature reaches 700°C. Determine the final pressure inside the cylinder, the work done by the propane, and the heat transfer during the process.

Solution:

C.V. The 1 kg of propane.

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: $P = P_{ext} = CV^2 \Rightarrow PV^{-2} = \text{constant}$, polytropic $n = -2$

Ideal gas: PV = mRT, and process yields

$$P_2 = P_1(T_2/T_1)^{\frac{n}{n-1}} = 700\left(\frac{700+273.15}{40+273.15}\right)^{2/3} = \mathbf{1490.7\ kPa}$$

The work is integrated as Eq.4.4

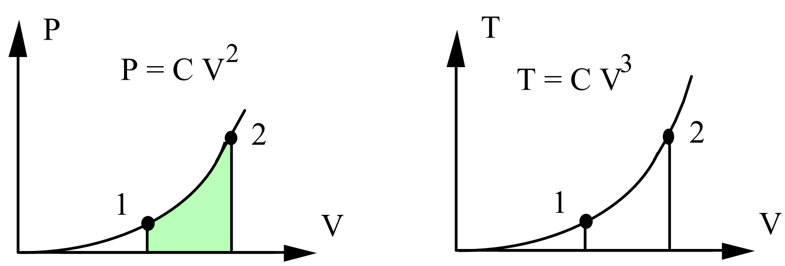
$${}_1W_2 = \int_1^2 PdV = \frac{P_2V_2 - P_1V_1}{1-n} = \frac{mR(T_2 - T_1)}{1-n}$$

$$= \frac{1\times 0.18855\times (700-40)}{1-(-2)} = \mathbf{41.48\ kJ}$$

The energy equation with specific heat from Table A.5 becomes

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = mC_v(T_2 - T_1) + {}_1W_2$$

$$= 1 \times 1.490 \times (700 - 40) + 41.48 = \mathbf{1024.9\ kJ}$$



5.112

An air pistol contains compressed air in a small cylinder, shown in Fig. P5.112. Assume that the volume is 1 cm^3, pressure is 1 MPa, and the temperature is 27°C when armed. A bullet, *m* = 15 g, acts as a piston initially held by a pin (trigger); when released, the air expands in an isothermal process (*T* = constant). If the air pressure is 0.1 MPa in the cylinder as the bullet leaves the gun, find

a. The final volume and the mass of air.

b. The work done by the air and work done on the atmosphere.

c. The work to the bullet and the bullet exit velocity.

Solution:

C.V. Air.

Air ideal gas: $m_{air} = P_1V_1/RT_1 = 1000 \times 10^{-6}/(0.287 \times 300) = \mathbf{1.17{\times}10^{-5}\ kg}$

Process: $PV = \text{const} = P_1V_1 = P_2V_2 \Rightarrow V_2 = V_1P_1/P_2 = \mathbf{10\ cm^3}$

$$_1W_2 = \int PdV = \int \frac{P_1V_1}{V}\, dV = P_1V_1 \ln (V_2/V_1) = \mathbf{2.303\ J}$$

$$_1W_{2,ATM} = P_0(V_2 - V_1) = 101 \times (10 - 1) \times 10^{-6}\text{ kJ} = \mathbf{0.909\ J}$$

$$W_{bullet} = {}_1W_2 - {}_1W_{2,ATM} = 1.394\text{ J} = \frac{1}{2}\, m_{bullet}(V_{exit})^2$$

$$V_{exit} = (2W_{bullet}/m_B)^{1/2} = (2 \times 1.394/0.015)^{1/2} = \mathbf{13.63\ m/s}$$

5.113

A spherical balloon contains 2 kg of R-22 at 0°C, 30% quality. This system is heated until the pressure in the balloon reaches 600 kPa. For this process, it can be assumed that the pressure in the balloon is directly proportional to the balloon diameter. How does pressure vary with volume and what is the heat transfer for the process?

Solution:

C.V. R-22 which is a control mass.

$$m_2 = m_1 = m \;;$$

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

State 1: 0°C, x = 0.3. Table B.4.1 gives $P_1 = 497.6$ kPa

$$v_1 = 0.000778 + 0.3 \times 0.04636 = 0.014686 \text{ m}^3/\text{kg}$$

$$u_1 = 44.2 + 0.3 \times 182.3 = 98.9 \text{ kJ/kg}$$

Process: $P \propto D$, $V \propto D^3$ => $PV^{-1/3}$ = constant, polytropic n = -1/3.

$$\Rightarrow \; V_2 = mv_2 = V_1 (P_2 /P_1)^3 = mv_1 (P_2 /P_1)^3$$

$$v_2 = v_1 (P_2 /P_1)^3 = 0.014686 \times (600 / 497.6)^3 = 0.02575 \text{ m}^3/\text{kg}$$

State 2: $P_2 = 600$ kPa, process : $v_2 = 0.02575$ → Table B.4.1

$$x_2 = 0.647, \quad u_2 = 165.8 \text{ kJ/kg}$$

$${}_1W_2 = \int P\, dV = \frac{P_2V_2 - P_1V_1}{1 - n} = \frac{600 \times 0.05137 - 498 \times 0.02937}{1 - (-1/3)} = 12.1 \text{ kJ}$$

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 2(165.8 - 98.9) + 12.1 = \mathbf{145.9\ kJ}$$

5.114

Calculate the heat transfer for the process described in Problem 4.55.

Consider a piston cylinder with 0.5 kg of R-134a as saturated vapor at -10°C. It is now compressed to a pressure of 500 kPa in a polytropic process with n = 1.5. Find the final volume and temperature, and determine the work done during the process.

Solution:

Take CV as the R-134a which is a control mass

Continuity: $m_2 = m_1 = m$; Energy: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: $Pv^{1.5}$ = constant. Polytropic process with n = 1.5

1: (T, x) P = Psat = 201.7 kPa from Table B.5.1

$v_1 = 0.09921\ m^3/kg$, $u_1 = 372.27$ kJ/kg

2: (P, process) $v_2 = v_1 (P_1/P_2)^{(1/1.5)} = 0.09921\times (201.7/500)^{0.667} = 0.05416$

=> Table B.5.2 superheated vapor, T_2 = 79°C,

u_2 = 440.9 kJ/kg

Process gives $P = C\ v^{(-1.5)}$, which is integrated for the work term, Eq.4.4

$${}_1W_2 = \int P\ dV = m(P_2v_2 - P_1v_1)/(1-1.5)$$

$$= -2\times 0.5\times (500\times 0.05416 - 201.7\times 0.09921) = \mathbf{-7.07\ kJ}$$

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 0.5(440.9 - 372.27) + (-7.07) = \mathbf{27.25\ kJ}$$

5.115

A piston/cylinder setup contains argon gas at 140 kPa, 10°C, and the volume is 100 L. The gas is compressed in a polytropic process to 700 kPa, 280°C. Calculate the heat transfer during the process.

Solution:

Find the final volume, then knowing P_1, V_1, P_2, V_2 the polytropic exponent can be determined. Argon is an ideal monatomic gas (Cv is constant).

$$V_2 = V_1 \times \frac{P_1}{P_2}\frac{T_2}{T_1} = 0.1 \times \frac{140}{700}\frac{553.15}{283.15} = \mathbf{0.0391\ m^3}$$

$$P_1V_1^n = P_2V_2^n \quad \Rightarrow \quad n = \ln\left(\frac{P_2}{P_1}\right) / \ln\left(\frac{V_1}{V_2}\right) = \frac{1.6094}{0.939} = 1.714$$

$${}_1W_2 = \int PdV = \frac{P_2V_2 - P_1V_1}{1 - n} = \frac{700 \times 0.0391 - 140 \times 0.1}{1 - 1.714} = \mathbf{-18.73\ kJ}$$

$$m = P_1V_1/RT_1 = 140 \times 0.1/(0.20813 \times 283.15) = \mathbf{0.2376\ kg}$$

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = mC_v(T_2 - T_1) + {}_1W_2$$

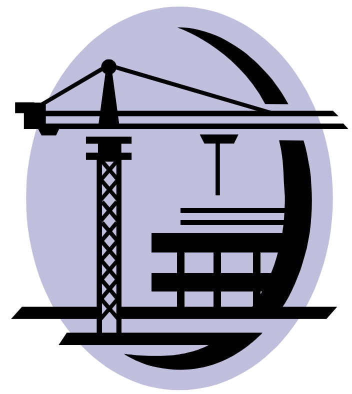
$$= 0.2376 \times 0.3122\ (280 - 10) - 18.73 = \mathbf{1.3\ kJ}$$

Energy Equation in Rate Form

5.116

A crane lifts a load of 450 kg vertically up with a power input of 1 kW. How fast can the crane lift the load?

Solution :



Power is force times rate of displacement

$$\dot{W} = F \cdot \mathbf{V} = mg \cdot \mathbf{V}$$

$$\mathbf{V} = \frac{\dot{W}}{mg} = \frac{1000}{450 \times 9.806} \frac{W}{N} = \mathbf{0.227\ m/s}$$

5.117

A computer in a closed room of volume 200 m^3 dissipates energy at a rate of 10 kW. The room has 50 kg wood, 25 kg steel and air, with all material at 300 K, 100 kPa. Assuming all the mass heats up uniformly, how long will it take to increase the temperature 10°C?

Solution:

C.V. Air, wood and steel. $m_2 = m_1$; no work

Energy Eq.5.11: $U_2 - U_1 = {}_1Q_2 = \dot{Q}\Delta t$

The total volume is nearly all air, but we can find volume of the solids.

$V_{wood} = m/\rho = 50/510 = 0.098\ m^3$; $V_{steel} = 25/7820 = 0.003\ m^3$

$V_{air} = 200 - 0.098 - 0.003 = 199.899\ m^3$

$m_{air} = PV/RT = 101.325 \times 199.899/(0.287 \times 300) = 235.25$ kg

We do not have a u table for steel or wood so use heat capacity from A.3.

$\Delta U = [m_{air}\, C_v + m_{wood}\, C_v + m_{steel}\, C_v\,]\Delta T$

$= (235.25 \times 0.717 + 50 \times 1.38 + 25 \times 0.46)\ 10$

$= 1686.7 + 690 + 115 = 2492\ \text{kJ} = \dot{Q} \times \Delta t = 10\ \text{kW} \times \Delta t$

=> $\Delta t = 2492/10 =$ **249.2 sec = 4.2 minutes**

5.118

The rate of heat transfer to the surroundings from a person at rest is about 400 kJ/h. Suppose that the ventilation system fails in an auditorium containing 100 people. Assume the energy goes into the air of volume 1500 m^3 initially at 300 K and 101 kPa. Find the rate (degrees per minute) of the air temperature change.

Solution:

$\dot{Q} = n\,\dot{q} = 100 \times 400 =$ **40000 kJ/h** = **666.7 kJ/min**

$$\frac{dE_{air}}{dt} = \dot{Q} = m_{air} C_v \frac{dT_{air}}{dt}$$

$m_{air} = PV/RT = 101 \times 1500 / 0.287 \times 300 = 1759.6$ kg

$$\frac{dT_{air}}{dt} = \dot{Q} / mC_v = 666.7 / (1759.6 \times 0.717) = \mathbf{0.53°C/min}$$

5.119

A piston/cylinder of cross sectional area 0.01 m^2 maintains constant pressure. It contains 1 kg water with a quality of 5% at 150^{o}C. If we heat so 1 g/s liquid turns into vapor what is the rate of heat transfer needed?

Solution:

Control volume the water.

Continuity Eq.: m_{tot} = constant = $m_{vapor} + m_{liq}$

on a rate form: $\dot{m}_{tot} = 0 = \dot{m}_{vapor} + \dot{m}_{liq} \quad \Rightarrow \quad \dot{m}_{liq} = -\dot{m}_{vapor}$

$V_{vapor} = m_{vapor}\, v_g\,, \quad V_{liq} = m_{liq}\, v_f$

$V_{tot} = V_{vapor} + V_{liq}$

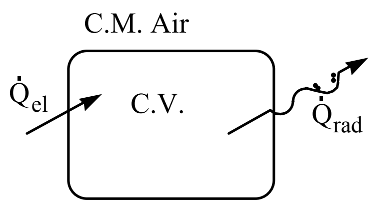
$$\dot{V}_{tot} = \dot{V}_{vapor} + \dot{V}_{liq} = \dot{m}_{vapor} v_g + \dot{m}_{liq} v_f$$
$$= \dot{m}_{vapor}\,(v_g - v_f) = \dot{m}_{vapor}\, v_{fg}$$

$$\dot{W} = P\dot{V} = P\,\dot{m}_{vapor}\, v_{fg}$$
$= 475.9 \times 0.001 \times 0.39169$ = **0.1864 kW = 186 W**

5.120

The heaters in a spacecraft suddenly fail. Heat is lost by radiation at the rate of 100 kJ/h, and the electric instruments generate 75 kJ/h. Initially, the air is at 100 kPa, 25°C with a volume of 10 m^3. How long will it take to reach an air temperature of −20°C?

Solution:



Continuity Eq: $\frac{dM}{dt} = 0$

Energy Eq: $\frac{dE}{dt} = \dot{Q}_{el} - \dot{Q}_{rad}$

$\dot{W} = 0$, $\dot{KE} = 0$, $\dot{PE} = 0$

$$\dot{E} = \dot{U} = \dot{Q}_{el} - \dot{Q}_{rad} = \dot{Q}_{net} \;\Rightarrow\; U_2 - U_1 = m(u_2 - u_1) = \dot{Q}_{net}(t_2 - t_1)$$

$$\text{Ideal gas: } m = \frac{P_1V_1}{RT_1} = \frac{100 \times 10}{0.287 \times 298.15} = 11.688 \text{ kg}$$

$$u_2 - u_1 = C_{v0}(T_2 - T_1) = 0.717\ (-20 - 25) = -32.26 \text{ kJ/kg}$$

$$t_2 - t_1 = mC_{v0}(T_2 - T_1)/\dot{Q}_{net} = 11.688 \times (-32.26)/(-25) = \mathbf{15.08\ h}$$

5.121

A steam generating unit heats saturated liquid water at constant pressure of 200 kPa in a piston cylinder. If 1.5 kW of power is added by heat transfer find the rate (kg/s) of saturated vapor that is made.

Solution:

Energy equation on a rate form making saturated vapor from saturated liquid

$\dot{U} = (\dot{m}u) = \dot{m}\Delta u = \dot{Q} - \dot{W} = \dot{Q} - P\dot{V} = \dot{Q} - P\dot{m}\Delta v$

$\dot{m}(\Delta u + \Delta vP) = \dot{Q} = \dot{m}\Delta h = \dot{m}h_{fg}$

$\dot{m} = \dot{Q}/h_{fg} = 1500 / 2201.96 =$ **0.681 kg/s**

5.122

A small elevator is being designed for a construction site. It is expected to carry four 75-kg workers to the top of a 100-m tall building in less than 2 min. The elevator cage will have a counterweight to balance its mass. What is the smallest size (power) electric motor that can drive this unit?

Solution:

$$m = 4 \times 75 = 300 \text{ kg} ; \quad \Delta Z = 100 \text{ m} ; \quad \Delta t = 2 \text{ minutes}$$

$$-\dot{W} = \Delta\dot{PE} = mg \frac{\Delta Z}{\Delta t} = \frac{300 \times 9.807 \times 100}{1000 \times 2 \times 60} = \mathbf{2.45 \ kW}$$

5.123

As fresh poured concrete hardens, the chemical transformation releases energy at a rate of 2 W/kg. Assume the center of a poured layer does not have any heat loss and that it has an average heat capacity of 0.9 kJ/kg K. Find the temperature rise during 1 hour of the hardening (curing) process.

Solution:

$\dot{U} = (m\dot{u}) = mC_V\dot{T} = \dot{Q} = m\dot{q}$

$\dot{T} = \dot{q}/C_V = 2\times10^{-3} / 0.9$

$= 2.222 \times 10^{-3}$ °C/sec

$\Delta T = \dot{T}\Delta t = 2.222 \times 10^{-3} \times 3600 =$ **8 °C**

5.124

A 100 Watt heater is used to melt 2 kg of solid ice at $-10^{o}C$ to liquid at $+5^{o}C$ at a constant pressure of 150 kPa.

a) Find the change in the total volume of the water.

b) Find the energy the heater must provide to the water.

c) Find the time the process will take assuming uniform T in the water.

Solution:

Take CV as the 2 kg of water. $m_2 = m_1 = m$;

Energy Eq.5.11 $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

State 1: Compressed solid, take sat. solid at same temperature.

$v = v_i(-10) = 0.0010891\ m^3/kg$, $h = h_i = -354.09$ kJ/kg

State 2: Compressed liquid, take sat. liquid at same temperature

$v = v_f = 0.001$, $h = h_f = 20.98$ kJ/kg

Change in volume:

$$V_2 - V_1 = m(v_2 - v_1) = 2(0.001 - 0.0010891) = \mathbf{0.000178\ m^3}$$

Work is done while piston moves at constant pressure, so we get

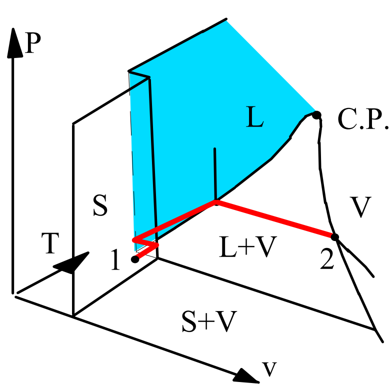
$${}_1W_2 = \int P\,dV = \text{area} = P(V_2 - V_1) = -150 \times 0.000178 = -0.027 \text{ kJ} = -27 \text{ J}$$

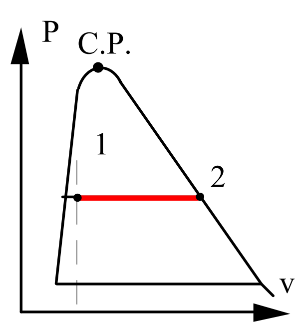
Heat transfer is found from energy equation

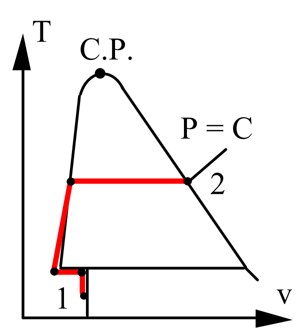
$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = m(h_2 - h_1) = 2 \times [20.98 - (-354.09)] = \mathbf{750\ kJ}$$

The elapsed time is found from the heat transfer and the rate of heat transfer

$$t = {}_1Q_2/\dot{Q} = (750/100)\ 1000 = 7500 \text{ s} = \mathbf{125\ min = 2\ h\ 5\ min}$$







5.125

Water is in a piston cylinder maintaining constant P at 700 kPa, quality 90% with a volume of 0.1 m^3. A heater is turned on heating the water with 2.5 kW. What is the rate of mass (kg/s) vaporizing?

Solution:

Control volume water.

Continuity Eq.: $m_{tot} = \text{constant} = m_{vapor} + m_{liq}$

on a rate form: $\dot{m}_{tot} = 0 = \dot{m}_{vapor} + \dot{m}_{liq} \quad \Rightarrow \quad \dot{m}_{liq} = -\dot{m}_{vapor}$

Energy equation: $\dot{U} = \dot{Q} - \dot{W} = \dot{m}_{vapor}\, u_{fg} = \dot{Q} - P\, \dot{m}_{vapor}\, v_{fg}$

Rearrange to solve for $\dot{m}_{vapor}$

$$\dot{m}_{vapor}\,(u_{fg} + Pv_{fg}) = \dot{m}_{vapor}\, h_{fg} = \dot{Q}$$

$$\dot{m}_{vapor} = \dot{Q}/h_{fg} = \frac{2.5}{2066.3}\,\frac{\text{kW}}{\text{kJ/kg}} = \mathbf{0.0012\ kg/s}$$

Review Problems

5.126

Ten kilograms of water in a piston/cylinder setup with constant pressure is at 450°C and a volume of 0.633 m^3. It is now cooled to 20°C. Show the *P–v* diagram and find the work and heat transfer for the process.

Solution:

C.V. The 10 kg water.

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

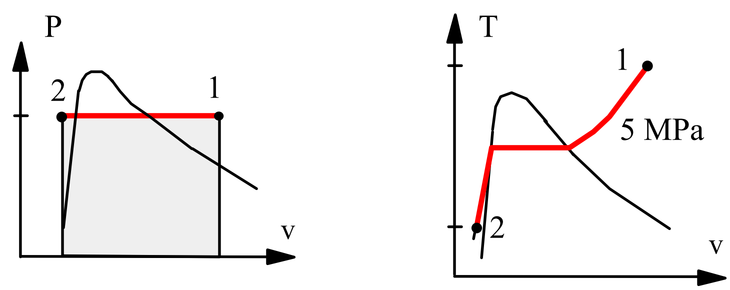
Process: $P = C \quad \Rightarrow \quad {}_1W_2 = mP(v_2 - v_1)$

State 1: $(T, v_1 = 0.633/10 = 0.0633\ m^3/kg)$ Table B.1.3

$P_1 = 5$ MPa, $h_1 = 3316.2$ kJ/kg

State 2: $(P = P = 5$ MPa, 20°C$)$ $\Rightarrow$ Table B.1.4

$v_2 = 0.000\ 999\ 5\ m^3/kg$; $h_2 = 88.65$ kJ/kg



The work from the process equation is found as

$${}_1W_2 = 10 \times 5000 \times (0.0009995 - 0.0633) = \mathbf{-3115\ kJ}$$

The heat transfer from the energy equation is

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = m(h_2 - h_1)$$

$${}_1Q_2 = 10 \times (88.65 - 3316.2) = \mathbf{-32276\ kJ}$$

5.127

Consider the system shown in Fig. P5.127. Tank A has a volume of 100 L and contains saturated vapor R-134a at 30°C. When the valve is cracked open, R-134a flows slowly into cylinder B. The piston mass requires a pressure of 200 kPa in cylinder B to raise the piston. The process ends when the pressure in tank A has fallen to 200 kPa. During this process heat is exchanged with the surroundings such that the R-134a always remains at 30°C. Calculate the heat transfer for the process.

Solution:

C.V. The R-134a. This is a control mass.

Continuity Eq.: $m_2 = m_1 = m$;

Energy Eq.5.11: $m(u_2 – u_1) = {}_1Q_2 - {}_1W_2$

Process in B: If $V_B > 0$ then $P = P_{float}$ (piston must move)

$$\Rightarrow \quad {}_1W_2 = \int P_{float}\, dV = P_{float} m(v_2 - v_1)$$

Work done in B against constant external force (equilibrium P in cyl. B)

State 1: 30°C, x = 1. Table B.5.1: $v_1 = 0.02671\ m^3/kg$, $u_1 = 394.48\ kJ/kg$

$$m = V/v_1 = 0.1 / 0.02671 = 3.744\ kg$$

State 2: 30°C, 200 kPa superheated vapor Table B.5.2

$$v_2 = 0.11889\ m^3/kg, \quad u_2 = 403.1\ kJ/kg$$

From the process equation

${}_1W_2 = P_{float} m(v_2 - v_1) = 200×3.744×(0.11889 - 0.02671) = 69.02\ kJ$

From the energy equation

${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 3.744 ×(403.1 - 394.48) + 69.02 =$ **101.3 kJ**

5.128

Ammonia, NH_3, is contained in a sealed rigid tank at 0°C, x = 50% and is then heated to 100°C. Find the final state P_2, u_2 and the specific work and heat transfer.

Solution:

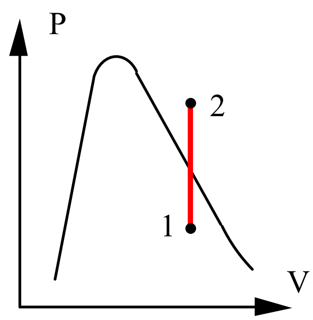
Continuity Eq.: $m_2 = m_1$;

Energy Eq.5.11: $E_2 - E_1 = {}_1Q_2$; $({}_1W_2 = \emptyset)$

Process: $V_2 = V_1 \Rightarrow v_2 = v_1 = 0.001566 + 0.5 \times 0.28783 = 0.14538 \text{ m}^3\text{/kg}$

Table B.2.2: v_2 & $T_2 \Rightarrow$ between 1000 kPa and 1200 kPa

$$P_2 = 1000 + 200 \frac{0.14538 - 0.17389}{0.14347 - 0.17389} = \textbf{1187 kPa}$$



$u_2 = 1490.5 + (1485.8 - 1490.5) \times 0.935$

$= 1485.83$ kJ/kg

$u_1 = 179.69 + 0.5 \times 1138.3 = 748.84$ kJ/kg

Process equation gives no displacement: ${}_1w_2 = \mathbf{0}$;

The energy equation then gives the heat transfer as

$${}_1q_2 = u_2 - u_1 = 1485.83 - 748.84 = \textbf{737 kJ/kg}$$

5.129

A piston/cylinder contains 1 kg of ammonia at 20°C with a volume of 0.1 m^3, shown in Fig. P5.129. Initially the piston rests on some stops with the top surface open to the atmosphere, *P*o, so a pressure of 1400 kPa is required to lift it. To what temperature should the ammonia be heated to lift the piston? If it is heated to saturated vapor find the final temperature, volume, and the heat transfer.

Solution:

C.V. Ammonia which is a control mass.

$$m_2 = m_1 = m \; ; \qquad m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$$

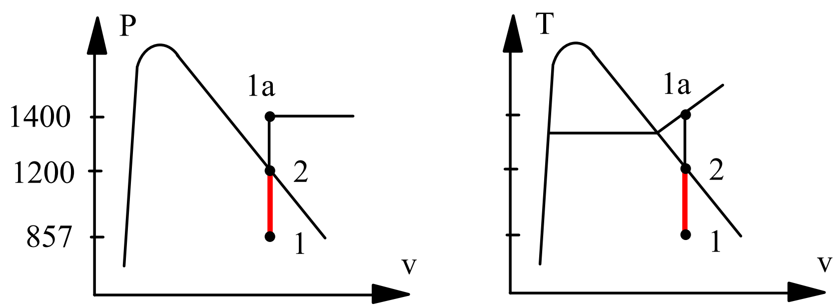
State 1: 20°C; $v_1 = 0.10 < v_g \;\Rightarrow\; x_1 = (0.1 - 0.001638)/0.14758 = 0.6665$

$$u_1 = u_f + x_1\, u_{fg} = 272.89 + 0.6665 \times 1059.3 = 978.9 \text{ kJ/kg}$$

Process: Piston starts to lift at state 1a (P_{lift}, v_1)

State 1a: 1400 kPa, v_1 Table B.2.2 (superheated vapor)

$$T_a = 50 + (60 - 50)\,\frac{0.1 - 0.09942}{0.10423 - 0.09942} = 51.2\ °C$$



State 2: x = 1.0, $v_2 = v_1$ => $V_2 = mv_2 =$ **0.1 m^3**

$T_2 = 30 + (0.1 - 0.11049) \times 5/(0.09397 - 0.11049) =$ **33.2 °C**

$u_2 = 1338.7$ kJ/kg; ${}_1W_2 = 0$;

${}_1Q_2 = m_1q_2 = m(u_2 - u_1) = 1\,(1338.7 - 978.9) =$ **359.8 kJ/kg**

5.130

A piston held by a pin in an insulated cylinder, shown in Fig. P5.130, contains 2 kg water at 100°C, quality 98%. The piston has a mass of 102 kg, with cross-sectional area of 100 cm^2, and the ambient pressure is 100 kPa. The pin is released, which allows the piston to move. Determine the final state of the water, assuming the process to be adiabatic.

Solution:

C.V. The water. This is a control mass.

Continuity Eq.: $m_2 = m_1 = m$;

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process in cylinder: $P = P_{float}$ (if piston not supported by pin)

$$P_2 = P_{float} = P_0 + m_p g/A = 100 + \frac{102 \times 9.807}{100 \times 10^{-4} \times 10^3} = 200 \text{ kPa}$$

We thus need one more property for state 2 and we have one equation namely the energy equation. From the equilibrium pressure the work becomes

$${}_1W_2 = \int P_{float}\, dV = P_2\, m(v_2 - v_1)$$

With this work the energy equation gives per unit mass

$$u_2 - u_1 = {}_1q_2 - {}_1w_2 = 0 - P_2(v_2 - v_1)$$

or with rearrangement to have the unknowns on the left hand side

$$u_2 + P_2 v_2 = h_2 = u_1 + P_2 v_1$$

$$h_2 = u_1 + P_2 v_1 = 2464.8 + 200 \times 1.6395 = 2792.7 \text{ kJ/kg}$$

State 2: (P_2 , h_2) Table B.1.3 => $T_2 \cong$ **161.75°C**

5.131

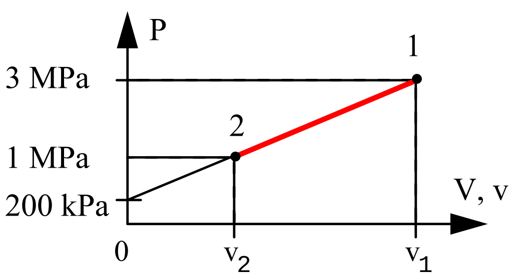
A piston/cylinder arrangement has a linear spring and the outside atmosphere acting on the piston, shown in Fig. P5.131. It contains water at 3 MPa, 400°C with the volume being 0.1 m^3. If the piston is at the bottom, the spring exerts a force such that a pressure of 200 kPa inside is required to balance the forces. The system now cools until the pressure reaches 1 MPa. Find the heat transfer for the process.

Solution:

C.V. Water.

Continuity Eq.: $m_2 = m_1 = m$;

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$



State 1: Table B.1.3

$v_1 = 0.09936\ m^3/kg,\ \ u_1 = 2932.8\ kJ/kg$

$m = V/v_1 = 0.1/0.09936 = 1.006\ kg$

Process: Linear spring so P linear in v.

$P = P_0 + (P_1 - P_0)v/v_1$

$$v_2 = \frac{(P_2 - P_0)v_1}{P_1 - P_0} = \frac{(1000 - 200)0.09936}{3000 - 200} = 0.02839\ m^3/kg$$

State 2: P_2 , v_2 $\Rightarrow$ $x_2 = (v_2 - 0.001127)/0.19332 = 0.141$, $T_2 = 179.91°C$,

$u_2 = 761.62 + x_2 \times 1821.97 = 1018.58\ kJ/kg$

Process => $_1W_2 = \int PdV = \frac{1}{2} m(P_1 + P_2)(v_2 - v_1)$

$= \frac{1}{2} 1.006\ (3000 + 1000)(0.02839 - 0.09936) = -142.79\ kJ$

Heat transfer from the energy equation

$_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 1.006(1018.58 - 2932.8) - 142.79 =$ **-2068.5 kJ**

5.132

Consider the piston/cylinder arrangement shown in Fig. P5.132. A frictionless piston is free to move between two sets of stops. When the piston rests on the lower stops, the enclosed volume is 400 L. When the piston reaches the upper stops, the volume is 600 L. The cylinder initially contains water at 100 kPa, 20% quality. It is heated until the water eventually exists as saturated vapor. The mass of the piston requires 300 kPa pressure to move it against the outside ambient pressure. Determine the final pressure in the cylinder, the heat transfer and the work for the overall process.

Solution:

C.V. Water. Check to see if piston reaches upper stops.

Energy Eq.5.11: $m(u_4 - u_1) = {}_1Q_4 - {}_1W_4$

Process: If $P < 300$ kPa then $V = 400$ L, line 2-1 and below

If $P > 300$ kPa then $V = 600$ L, line 3-4 and above

If $P = 300$ kPa then $400 \text{ L} < V < 600 \text{ L}$ line 2-3

These three lines are shown in the P-V diagram below and is dictated by the motion of the piston (force balance).

State 1: $v_1 = 0.001043 + 0.2\times1.693 = 0.33964$; $m = V_1/v_1 = \frac{0.4}{0.33964} = 1.178$ kg

$u_1 = 417.36 + 0.2 \times 2088.7 = 835.1$ kJ/kg

State 3: $v_3 = \frac{0.6}{1.178} = 0.5095 < v_G = 0.6058$ at $P_3 = 300$ kPa

$\Rightarrow$ Piston does reach upper stops to reach sat. vapor.

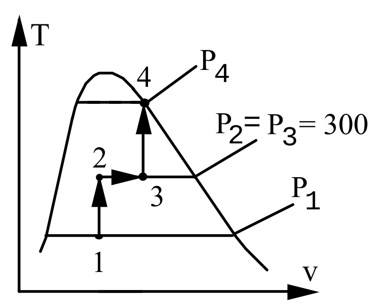
State 4: $v_4 = v_3 = 0.5095 \text{ m}^3\text{/kg} = v_G$ at P_4 From Table B.1.2

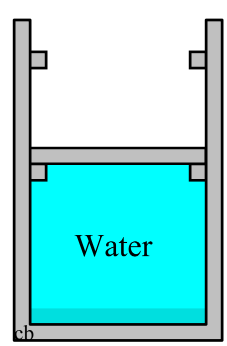
=> $P_4 =$ **361 kPa,** $u_4 = 2550.0$ kJ/kg

${}_1W_4 = {}_1W_2 + {}_2W_3 + {}_3W_4 = 0 + {}_2W_3 + 0$

${}_1W_4 = P_2(V_3 - V_2) = 300 \times (0.6 - 0.4)$ = **60 kJ**

${}_1Q_4 = m(u_4 - u_1) + {}_1W_4 = 1.178(2550.0 - 835.1) + 60 =$ **2080 kJ**





5.133

A piston/cylinder, shown in Fig. P5.133, contains R-12 at − 30°C, x = 20%. The volume is 0.2 m^3. It is known that V_{stop} = 0.4 m^3, and if the piston sits at the bottom, the spring force balances the other loads on the piston. It is now heated up to 20°C. Find the mass of the fluid and show the *P–v* diagram. Find the work and heat transfer.

Solution:

C.V. R-12, this is a control mass. Properties in Table B.3

Continuity Eq.: $m_2 = m_1$

Energy Eq.5.11: $E_2 - E_1 = m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: $P = A + BV$, $V < 0.4\ m^3$, $A = 0$ (at $V = 0$, $P = 0$)

State 1: $v_1 = 0.000672 + 0.2 \times 0.1587 = 0.0324\ m^3/kg$

$u_1 = 8.79 + 0.2 \times 149.4 = 38.67\ kJ/kg$

$m = m_1 = = V_1/v_1$ = **6.17 kg**

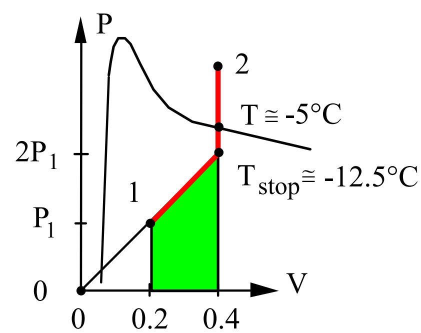
System: on line

$V \le V_{stop}$;

$P_{stop} = 2P_1$ =200 kPa

State stop: (P,v) $\Rightarrow T_{stop} \cong$ -12°C

TWO-PHASE STATE



Since $T_2 > T_{stop}$ $\Rightarrow$ $v_2 = v_{stop} = 0.0648\ m^3/kg$

2: (T_2, v_2) Table B.3.2: Interpolate between 200 and 400 kPa

$P_2 = 292.3$ kPa ; $u_2 = 181.9$ kJ/kg

From the process curve, see also area in P-V diagram, the work is

$${}_1W_2 = \int PdV = \frac{1}{2}(P_1 + P_{stop})(V_{stop} - V_1) = \frac{1}{2}(100 + 200)0.2 = \mathbf{30\ kJ}$$

From the energy equation

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = \mathbf{913.5\ kJ}$$

5.134

A piston/cylinder arrangement B is connected to a 1-m^3 tank A by a line and valve, shown in Fig. P5.134. Initially both contain water, with A at 100 kPa, saturated vapor and B at 400°C, 300 kPa, 1 m^3. The valve is now opened and, the water in both A and B comes to a uniform state.

a. Find the initial mass in A and B.

b. If the process results in T_2 = 200°C, find the heat transfer and work.

Solution:

C.V.: A + B. This is a control mass.

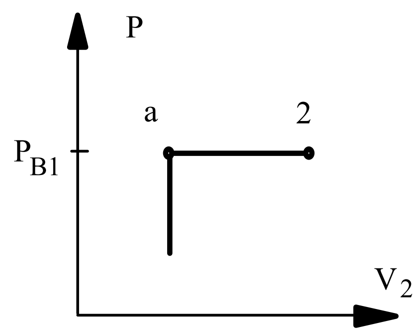
Continuity equation: $m_2 - (m_{A1} + m_{B1}) = 0$;

Energy: $m_2u_2 - m_{A1}u_{A1} - m_{B1}u_{B1} = {}_1Q_2 - {}_1W_2$

System: if $V_B \geq 0$ piston floats $\Rightarrow$ $P_B = P_{B1}$ = const.

if $V_B = 0$ then $P_2 < P_{B1}$ and $v = V_A/m_{tot}$ see P-V diagram

$${}_1W_2 = \int P_B dV_B = P_{B1}(V_2 - V_1)_B = P_{B1}(V_2 - V_1)_{tot}$$



State A1: Table B.1.1, x = 1

$v_{A1} = 1.694$ m^3/kg, $u_{A1} = 2506.1$ kJ/kg

$m_{A1} = V_A/v_{A1} =$ **0.5903 kg**

State B1: Table B.1.2 sup. vapor

$v_{B1} = 1.0315$ m^3/kg, $u_{B1} = 2965.5$ kJ/kg

$m_{B1} = V_{B1}/v_{B1} =$ **0.9695 kg**

$m_2 = m_{TOT} = 1.56$ kg

* At (T_2, P_{B1}) $v_2 = 0.7163 > v_a = V_A/m_{tot} = 0.641$ so $V_{B2} > 0$

so now state 2: $P_2 = P_{B1} = 300$ kPa, $T_2 = 200$ °C

=> $u_2 = 2650.7$ kJ/kg and $V_2 = m_2 v_2 = 1.56 \times 0.7163 = 1.117$ m^3

(we could also have checked T_a at: 300 kPa, 0.641 m^3/kg => T = 155 °C)

${}_1W_2 = P_{B1}(V_2 - V_1) =$ **-264.82 kJ**

${}_1Q_2 = m_2u_2 - m_{A1}u_{A1} - m_{B1}u_{B1} + {}_1W_2 =$ **-484.7 kJ**

5.135

A small flexible bag contains 0.1 kg ammonia at -10^{o}C and 300 kPa. The bag material is such that the pressure inside varies linear with volume. The bag is left in the sun with with an incident radiation of 75 W, loosing energy with an average 25 W to the ambient ground and air. After a while the bag is heated to 30^{o}C at which time the pressure is 1000 kPa. Find the work and heat transfer in the process and the elapsed time.

Solution:

Take CV as the Ammonia, constant mass.

Continuity Eq.: $m_2 = m_1 = m$;

Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

Process: $P = A + BV$ (linear in V)

State 1: Compressed liquid $P > P_{sat}$, take saturated liquid at same temperature.

$$v_1 = v_f(20) = 0.001002 \text{ m}^3\text{/kg}, \qquad u_1 = u_f = 133.96 \text{ kJ/kg}$$

State 2: Table B.2.1 at 30^{o}C : $P < P_{sat}$ so superheated vapor

$$v_2 = 0.13206 \text{ m}^3\text{/kg}, \; u_2 = 1347.1 \text{ kJ/kg}, \qquad V_2 = mv_2 = \mathbf{0.0132 \text{ m}^3}$$

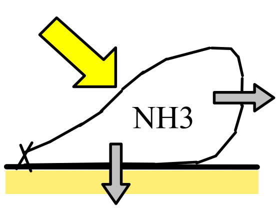
Work is done while piston moves at increacing pressure, so we get

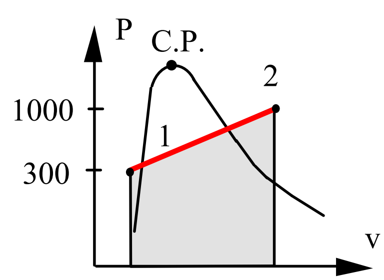
$${}_1W_2 = ½(300 + 1000)*0.1(0.13206 - 0.001534) = \mathbf{8.484 \text{ kJ}}$$

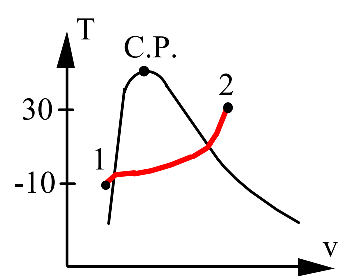
Heat transfer is found from the energy equation

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 0.1\ (1347.1 - 133.96) + 8.484$$

$$= 121.314 + 8.484 = \mathbf{129.8 \text{ kJ}}$$







$$\dot{Q}_{net} = 75 - 25 = 50 \text{ Watts}$$

$$t = {}_1Q_2 / \dot{Q}_{net} = \frac{129800}{50} = \mathbf{2596 \text{ s} = 43.3 \text{ min}}$$

5.136

Water at 150°C, quality 50% is contained in a cylinder/piston arrangement with initial volume 0.05 m^3. The loading of the piston is such that the inside pressure is linear with the square root of volume as $P = 100 + CV^{0.5}$ kPa. Now heat is transferred to the cylinder to a final pressure of 600 kPa. Find the heat transfer in the process.

Continuty: $m_2 = m_1$ Energy: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

State 1: $v_1 = 0.1969$, $u_1 = 1595.6$ kJ/kg $\Rightarrow$ $m = V/v_1 = 0.254$ kg

Process equation $\Rightarrow$ $P_1 - 100 = CV_1^{1/2}$ so

$$(V_2/V_1)^{1/2} = (P_2 - 100)/(P_1 - 100)$$

$$V_2 = V_1 \times \left[\frac{P_2 - 100}{P_1 - 100}\right]^2 = 0.05 \times \left[\frac{500}{475.8 - 100}\right]^2 = 0.0885$$

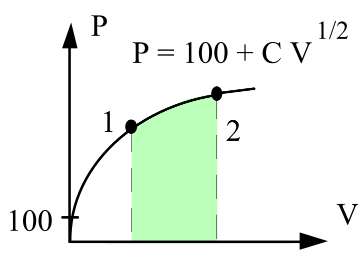
$${}_1W_2 = \int PdV = \int (100 + CV^{1/2})dV = 100\times(V_2 - V_1) + \frac{2}{3}C(V_2^{1.5} - V_1^{1.5})$$

$$= 100(V_2 - V_1)(1 - 2/3) + (2/3)(P_2V_2 - P_1V_1)$$

$${}_1W_2 = 100\ (0.0885\text{-}0.05)/3 + 2\ (600 \times 0.0885\text{-}475.8 \times 0.05)/3 = 20.82 \text{ kJ}$$

State 2: P_2, $v_2 = V_2/m = 0.3484$ $\Rightarrow$ $u_2 = 2631.9$ kJ/kg, $T_2 \cong 196°C$

${}_1Q_2 = 0.254 \times (2631.9 - 1595.6) + 20.82 =$ **284 kJ**



5.137

A 1 m^3 tank containing air at 25^{o}C and 500 kPa is connected through a valve to another tank containing 4 kg of air at 60^{o}C and 200 kPa. Now the valve is opened and the entire system reaches thermal equilibrium with the surroundings at 20^{o}C. Assume constant specific heat at 25^{o}C and determine the final pressure and the heat transfer.

Control volume all the air. Assume air is an ideal gas.

Continuity Eq.: $m_2 - m_{A1} - m_{B1} = 0$

Energy Eq.: $U_2 - U_1 = m_2u_2 - m_{A1}u_{A1} - m_{B1}u_{B1} = {}_1Q_2 - {}_1W_2$

Process Eq.: $V = \text{constant} \quad \Rightarrow \quad {}_1W_2 = 0$

State 1:

$$m_{A1} = \frac{P_{A1}V_{A1}}{RT_{A1}} = \frac{(500\text{ kPa})(1\text{m}^3)}{(0.287\text{ kJ/kgK})(298.2\text{ K})} = 5.84\text{ kg}$$

$$V_{B1} = \frac{m_{B1}RT_{B1}}{P_{B1}} = \frac{(4\text{ kg})(0.287\text{ kJ/kgK})(333.2\text{ K})}{(200\text{ kN/m}^2)} = 1.91\text{ m}^3$$

State 2: $T_2 = 20°C$, $v_2 = V_2/m_2$

$$m_2 = m_{A1} + m_{B1} = 4 + 5.84 = 9.84\text{ kg}$$

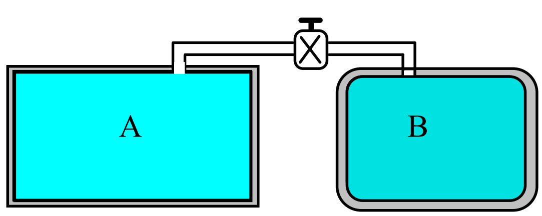
$$V_2 = V_{A1} + V_{B1} = 1 + 1.91 = 2.91\text{ m}^3$$

$$P_2 = \frac{m_2RT_2}{V_2} = \frac{(9.84\text{ kg})(0.287\text{ kJ/kgK})(293.2\text{ K})}{2.91\text{ m}^3} = \mathbf{284.5\text{ kPa}}$$

Energy Eq.5.5 or 5.11:

$$\begin{aligned} {}_1Q_2 &= U_2 - U_1 = m_2u_2 - m_{A1}u_{A1} - m_{B1}u_{B1} \\ &= m_{A1}(u_2 - u_{A1}) + m_{B1}(u_2 - u_{B1}) \\ &= m_{A1}C_{v0}(T_2 - T_{A1}) + m_{B1}C_{v0}(T_2 - T_{B1}) \\ &= 5.84 \times 0.717\,(20 - 25) + 4 \times 0.717\,(20 - 60) = \mathbf{-135.6\text{ kJ}} \end{aligned}$$

The air gave energy out.



5.138

A closed cylinder is divided into two rooms by a frictionless piston held in place by a pin, as shown in Fig. P5.138. Room A has 10 L air at 100 kPa, 30°C, and room B has 300 L saturated water vapor at 30°C. The pin is pulled, releasing the piston, and both rooms come to equilibrium at 30°C and as the water is compressed it becomes two-phase. Considering a control mass of the air and water, determine the work done by the system and the heat transfer to the cylinder.

Solution:

C.V. A + B, control mass of constant total volume.

Energy equation: $m_A(u_2 - u_1)_A + m_B(u_{B2} - u_{B1}) = {}_1Q_2 - {}_1W_2$

Process equation: $V = C \;\Rightarrow\; {}_1W_2 = 0$

$T = C \;\Rightarrow\; (u_2 - u_1)_A = 0$ (ideal gas)

The pressure on both sides of the piston must be the same at state 2.

Since two-phase: $P_2 = P_{g\ H_2O\ at\ 30°C} = P_{A2} = P_{B2} = 4.246$ kPa

Air, I.G.: $P_{A1}V_{A1} = m_A R_A T = P_{A2}V_{A2} = P_{g\ H_2O\ at\ 30°C}\ V_{A2}$

$$\rightarrow V_{A2} = \frac{100 \times 0.01}{4.246}\ \text{m}^3 = 0.2355\ \text{m}^3$$

Now the water volume is the rest of the total volume

$$V_{B2} = V_{A1} + V_{B1} - V_{A2} = 0.30 + 0.01 - 0.2355 = 0.0745\ \text{m}^3$$

$$m_B = \frac{V_{B1}}{v_{B1}} = \frac{0.3}{32.89} = 9.121\times10^{-3}\ \text{kg} \;\Rightarrow\; v_{B2} = 8.166\ \text{m}^3/\text{kg}$$

$$8.166 = 0.001004 + x_{B2} \times (32.89 - 0.001) \;\Rightarrow\; x_{B2} = 0.2483$$

$$u_{B2} = 125.78 + 0.2483 \times 2290.8 = 694.5\ \text{kJ/kg},\quad u_{B1} = 2416.6\ \text{kJ/kg}$$

$${}_1Q_2 = m_B(u_{B2} - u_{B1}) = 9.121\times10^{-3}(694.5 - 2416.6) = \mathbf{-15.7\ kJ}$$