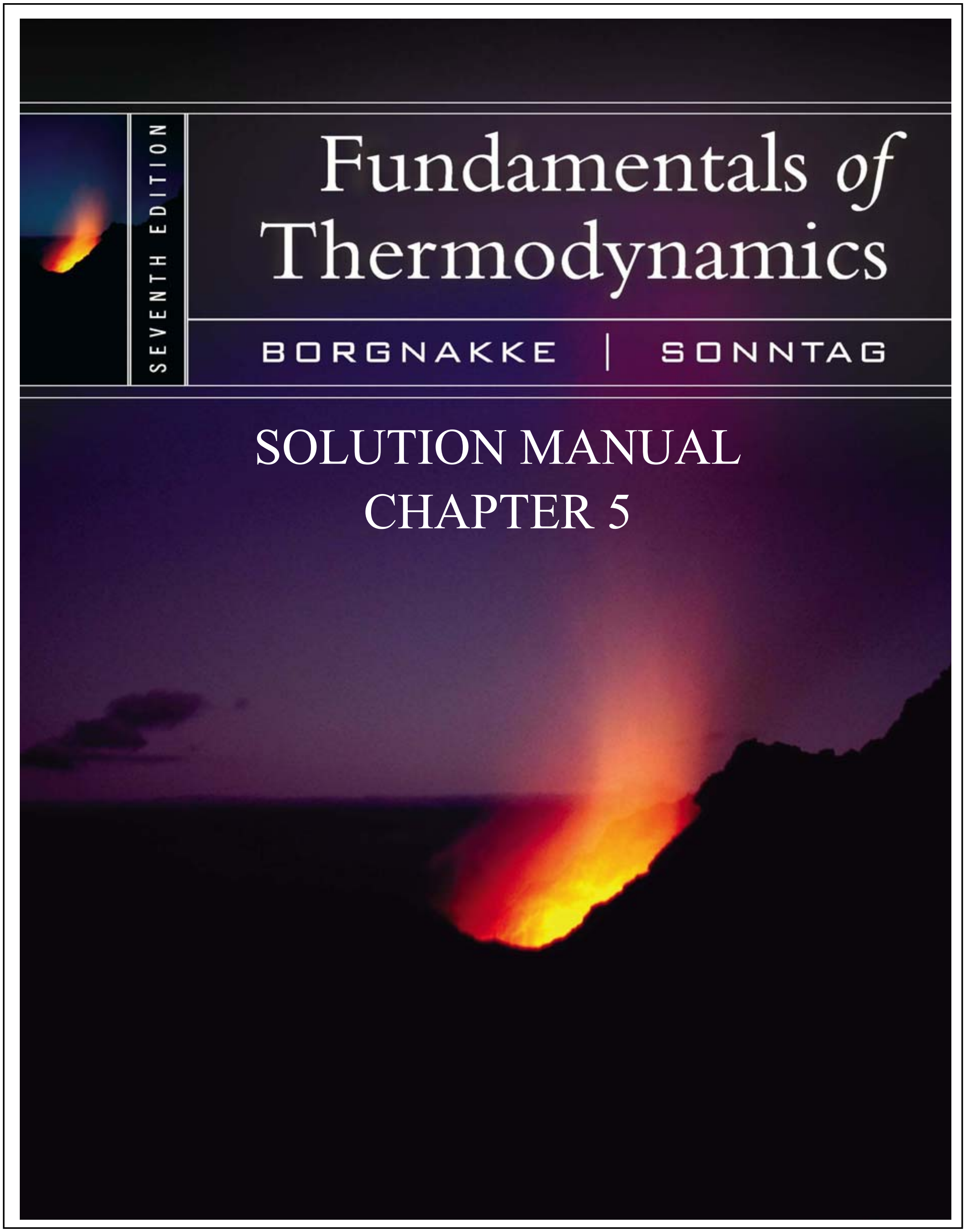

Fundamentals of
Thermodynamics
SEVENTH EDITION
BORGNAKKE | SONNTAG
SOLUTION MANUAL
CHAPTER 5

CONTENT

SUBSECTION	PROB NO.
Concept Problems	1-14
Kinetic and potential energy	15-24
Properties (u,h) from general tables	25-34
Energy equation: simple process	35-67
Energy eqaution: multistep process	68-77
Energy equation: solids and liquids	78-89
Properties (u, h, Cv, Cp), ideal gas	90-101
Energy equation: ideal gas	102-120
Energy equation: polytropic process	121-135
Energy equation in rate form	136-156
Review Problems	157-172

In-Text Concept Questions

5.a

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.b

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 losing 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.c

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.d

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

Yes it does.

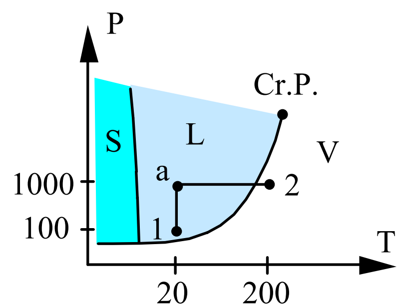
As work leaves a control mass its volume must go up, v increases

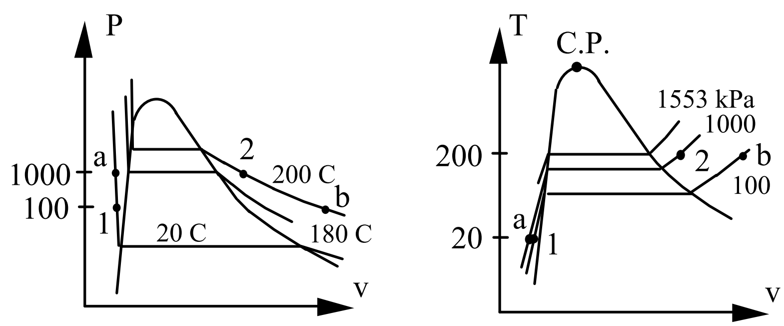
As heat transfer comes in an amount equal to the work out means u is constant if there are no changes in kinetic or potential energy.

5.e

Water is heated from 100 kPa, 20^{o}C to 1000 kPa, 200^{o}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.f

A rigid insulated tank A contains water at 400 kPa, 800C. A pipe and valve connect this to another rigid insulated tank B of equal volume having saturated water vapor at 100 kPa. The valve is opened and stays open while the water in the two tanks comes to a uniform final state. Which two properties determine the final state?

Continuity eq.: $m_2 - m_{1A} - m_{1B} = 0 \;\Rightarrow\; m_2 = m_{1A} + m_{1B}$

Energy eq.: $m_2u_2 - m_{1A}u_{1A} - m_{1B}u_{1B} = 0 - 0$

Process: Insulated: ${}_1Q_2 = 0$,

Rigid: $V_2 = C = V_A + V_B \;\Rightarrow\; {}_1W_2 = 0$

From continuity eq. and process: $v_2 = V_2/m_2 = \frac{m_{1A}}{m_2} v_{1A} + \frac{m_{1B}}{m_2} v_{1B}$

From energy eq.: $u_2 = \frac{m_{1A}}{m_2} u_{1A} + \frac{m_{1B}}{m_2} u_{1B}$

Final state 2: (v_2, u_2) both are the mass weighted average of the initial values.

5.g

To determine v or u for some liquid or solid, is it more important that I know P or T?

T is more important, v and u are nearly independent of P.

5.h

To determine v or u for an ideal gas, is it more important that I know P or T?

For v they are equally important ($v = RT/P$), but for u only T is important. For an ideal gas u is a function of T only (independent of P).

5.i

I heat 1 kg of substance at a constant pressure (200 kPa) 1 degree. How much heat is needed if the substance is water at 10^{o}C, steel at 25^{o}C, air at 325 K, or ice at –10^{o}C.

Heating at constant pressure gives (recall the analysis in Section 5.5, page 141)

$$_1Q_2 = H_2 - H_1 = m(h_2 - h_1) \approx m\, C_p\, (T_2 - T_1)$$

For all cases: $_1Q_2 = 1 \text{ kg} \times C \times 1 \text{ K}$

Water 10^{o}C, 200 kPa (liquid)	so A.4:	C = 4.18 kJ/kg-K,	$_1Q_2$ = 4.18 kJ
Steel 25^{o}C, 200 kPa (solid)	so A.3:	C = 0.46 kJ/kg-K	$_1Q_2$ = 0.46 kJ
Air 325 K, 200 kPa (gas)	so A.5:	C_p = 1.004 kJ/kg-K	$_1Q_2$ = 1.004 kJ
Ice –10^{o}C, 200 kPa (solid)	so A.3:	C = 2.04 kJ/kg-K	$_1Q_2$ = 2.04 kJ

Comment: For liquid water we could have interpolated $h_2 - h_1$ from Table B.1.1 and for ice we could have used Table B.1.5. For air we could have used Table A.7.

Concept 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^{o}C to 15.5^{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

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** in the stored energy 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. The quantities are associated with the process and they are not state properties.

5.3

If a process in a control mass increases energy $E_2 - E_1 > 0$ can you say anything about the sign for ${}_1Q_2$ and ${}_1W_2$?

No.

The net balance of the heat transfer and work terms from the energy equation is

$$E_2 - E_1 = {}_1Q_2 - {}_1W_2 > 0$$

but that does not separate the effect of the two terms.

5.4

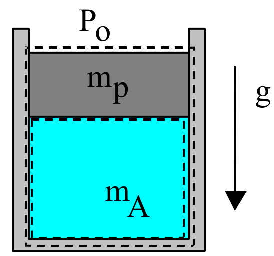
When you windup a spring in a toy or stretch a rubber band what happens in terms of work, energy, and heat transfer? Later, when they are released, what happens then?

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 or permanently deformed) and not into its potential energy. 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

CV A is the mass inside a piston-cylinder, CV B is that plus the piston outside, which is the standard atmosphere. Write the energy equation and work term for the two CVs assuming we have a non-zero Q between state 1 and state 2.



CV A: $E_2 - E_1 = m_A(e_2 - e_1) = m_A(u_2 - u_1) = {}_1Q_2 - {}_1WA_2$

$${}_1WA_2 = \int P\,dV = P(V_2 - V_1)$$

CV B: $E_2 - E_1 = m_A(e_2 - e_1) + m_{pist}(e_2 - e_1) = m_A(u_2 - u_1) + m_{pist}(gZ_2 - gZ_1)$

$$= {}_1Q_2 - {}_1WB_2$$

$${}_1WB_2 = \int P_o\,dV = P_o(V_2 - V_1)$$

Notice how the P inside CV A is $P = P_o + m_{pist}g / A_{cyl}$ i.e. the first work term is larger than the second. The difference between the work terms is exactly equal to the potential energy of the piston sitting on the left hand side in the CV B energy Eq. The two equations are mathematically identical.

$${}_1WA_2 = P(V_2 - V_1) = [P_o + m_{pist}g / A_{cyl}]\,(V_2 - V_1) = {}_1WB_2 + m_{pist}g(V_2 - V_1)/A_{cyl}$$

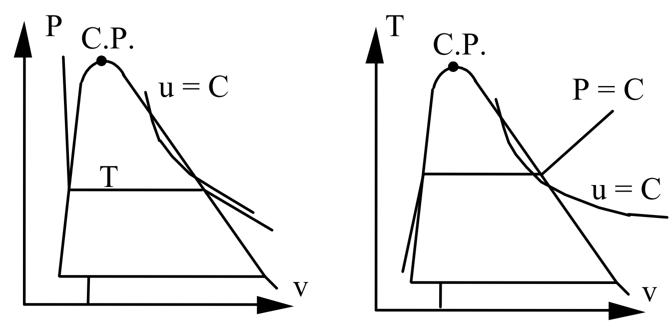
$$= {}_1WB_2 + m_{pist}g(Z_2 - Z_1)$$

5.6

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 (or 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 (or h) line becomes horizontal in the ideal gas region.

5.7

Some liquid water is heated so it becomes superheated vapor. Do I use u or h in the energy equation? Explain.

The energy equation for a control mass is: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

The storage of energy is a change in u (when we neglect kinetic and potential energy changes) and that is always so. To solve for the heat transfer we must know the work in the process and it is for a certain process (P = C) that the work term combines with the change in u to give a change in h. To avoid confusion you should always write the energy equation as shown above and substitute the appropriate expression for the work term when you know the process equation that allows you to evaluate work.

5.8

Some liquid water is heated so it becomes superheated vapor. Can I use specific heat to find the heat transfer? Explain.

NO.

The specific heat can not give any information about the energy required to do the phase change. The specific heat is useful for single phase state changes only.

5.9

Look at the R-410a value for u_f at -50^{o}C. Can the energy really be negative? Explain.

The absolute value of u and h are arbitrary. A constant can be added to all u and h values and the table is still valid. It is customary to select the reference such that u for saturated liquid water at the triple point is zero. The standard for refrigerants like R-410a is that h is set to zero as saturated liquid at -40^{o}C, other substances like cryogenic substances like nitrogen, methane etc. may have different states at which h is set to zero. The ideal gas tables use a zero point for h as 25^{o}C or at absolute zero, 0 K.

5.10

A rigid tank with pressurized air is used to a) increase the volume of a linear spring loaded piston cylinder (cylindrical geometry) arrangement and b) to blow up a spherical balloon. Assume that in both cases P = A + BV with the same A and B. What is the expression for the work term in each situation?

The expression is exactly the same; the geometry does not matter as long as we have the same relation between P and V then

$$
\begin{aligned}
{}_1W_2 &= \int P\, dV = \int (A + BV)\, dV \\
&= A(V_2 - V_1) + 0.5\, B\, (V_2^2 - V_1^2) \\
&= A(V_2 - V_1) + 0.5\, B\, (V_2 + V_1)\, (V_2 - V_1) \\
&= 0.5\, [\, A + B\, V_2 + A + B\, V_1]\, (V_2 - V_1) \\
&= 0.5\, (P_1 + P_2)\, (V_2 - V_1)
\end{aligned}
$$

Notice the last expression directly gives the area below the curve in the P-V diagram.

5.11

An ideal gas in a piston-cylinder is heated with 2 kJ during an isothermal process. How much work is involved?

Energy Eq.: $u_2 - u_1 = {}_1q_2 - {}_1w_2 = 0$ since $u_2 = u_1$ (isothermal)

Then

$${}_1W_2 = m\ {}_1w_2 = {}_1Q_2 = m\ {}_1Q_2 = \mathbf{2\ kJ}$$

5.12

An ideal gas in a piston-cylinder is heated with 2 kJ during an isobaric process. Is the work pos., neg., or zero?

As the gas is heated u and T increase and since PV = mRT it follows that the volume increase and thus work goes out.

$$\mathbf{w > 0}$$

5.13

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.

5.14

A 500 W electric space heater with a small fan inside heats air by blowing it over a hot electrical wire. For each control volume: a) wire only b) all the room air and c) total room plus the heater, specify the storage, work and heat transfer terms as + 500W or -500W or 0 W, neglect any $\dot{Q}$ through the room walls or windows.

	Storage	Work	Heat transfer
Wire	0 W	-500 W	-500 W
Room air	500 W	0 W	500 W
Tot room	500 W	-500 W	0 W

Kinetic and Potential Energy

5.15

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.

$$E_2 - E_1 = m(u_2 - u_1) + m[(1/2)\mathbf{V}_2^{\ 2} - 0] + mg\ (Z_2\ - 0)$$

$$= 0 + 25\ \text{kg} \times (1/2) \times (50\ \text{m/s})^2\ + 25\ \text{kg} \times 9.80665\ \text{m/s}^2 \times (-1)\ \text{m}$$

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

5.16

A steel ball weighing 5 kg rolls horizontal with 10 m/s. If it rolls up an incline how high up will it be when it comes to rest assuming standard gravitation.

C.V. Steel ball.

Energy Eq.: $E_2 - E_1 = {}_1Q_2 - {}_1W_2 = 0 - 0 = 0$

$$E_1 = mu_1 + mgZ_1 + 0.5\ mV^2$$

$$E_2 = mu_2 + mgZ_2 + 0$$

We assume the steel ball does not change temperature ($u_2 = u_1$) so then the energy equation gives

$$mu_2 + mgZ_2 - mu_1 - mgZ_1 - 0.5\ mV^2 = 0$$

$$mg\ (Z_2 - Z_1) = 0.5\ mV^2$$

$$Z_2 - Z_1 = 0.5\ V^2/g = 0.5 \times 10^2\ (m^2/s^2) / (9.81\ m/s^2) = \mathbf{5.1\ m}$$

5.17

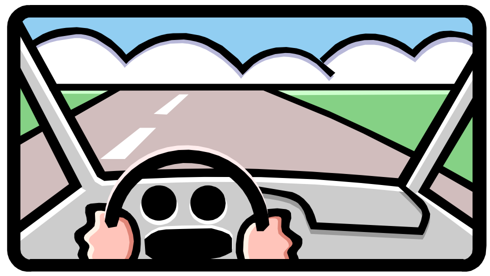
A 1200 kg car accelerates from zero to 100 km/h over a distance of 400 m. The road at the end of the 400 m is at 10 m higher elevation. What is the total increase in the car kinetic and potential energy?

Solution:

$$\Delta KE = ½ \, m \, (\mathbf{V}_2^2 - \mathbf{V}_1^2)$$

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

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



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

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

5.18

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.

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

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

5.19

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.

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

$$\mathbf{V}_2 = 0, \quad \mathbf{V}_1 = 90\,\frac{\text{km}}{\text{h}} = \frac{90 \times 1000}{3600}\ \text{ms}^{-1} = 25\ \text{ms}^{-1}$$

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

$$\rightarrow \qquad L = \frac{0.5\,\mathbf{V}_1^2}{0.0006g} = \frac{0.5 \times 25^2}{0.006 \times 9.807}\ \frac{\text{m}^2/\text{s}^2}{\text{m/s}^2} = 5311\ \text{m}$$

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

5.20

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.

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

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

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

The second set of conditions does not become the same

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

5.21

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.

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

$$= 7875\,000 \text{ J} = 7875 \text{ kJ}$$

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

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

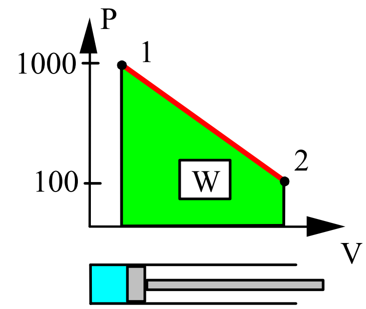
$$= 0.30 \times 7875 = 2362.5 \text{ kJ}$$

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

5.22

Solve Problem 5.21, 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.



$$E_2 - E_1 = m\,(1/2)\,(\mathbf{V}_2^2 - 0)$$
$$= 17\,500 \text{ kg} \times (1/2) \times 30^2 \text{ (m/s)}^2$$
$$= 7875\,000 \text{ J} = 7875 \text{ kJ}$$
$$W = 0.30(E_2 - E_1) = 0.30 \times 7875 = 2362.5 \text{ kJ}$$
$$W = \int P\, dV = (1/2)(P_{beg} + P_{end})\, \Delta V$$

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

5.23

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

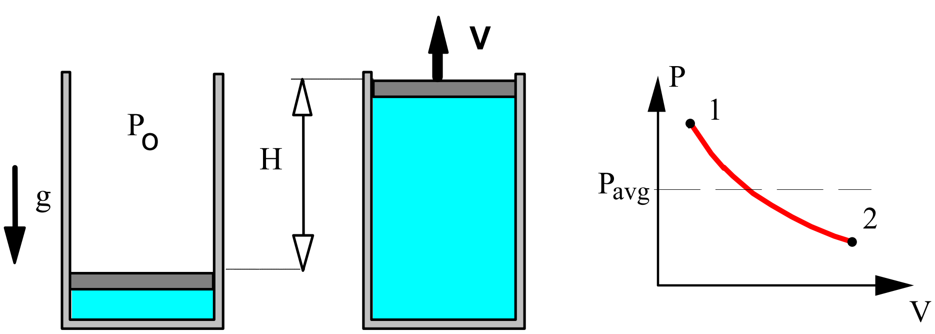
$$(E_2 - E_1)_{PIST.} = m(u_2 - u_1) + m[(1/2)V_2^2 - 0] + mg\,(H_2 - 0)$$
$$= 0 + 25 \times (1/2) \times 25^2 + 25 \times 9.80665 \times 5$$
$$= 7812.5 + 1225.8 = 9038.3 \text{ J} = 9.038 \text{ kJ}$$

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)

$$\Delta V_{gas} = \frac{9.038}{600 - 100}\ \frac{\text{kJ}}{\text{kPa}} = \mathbf{0.018\ m^3}$$



5.24

A piston of 2 kg is accelerated to 20 m/s from rest. What constant gas pressure is required if the area is 10 cm^2, the travel 10 cm and the outside pressure is 100 kPa?

C.V. Piston

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

$$= (1/2)\,m\,V_2^2 = 0.5 \times 2\text{ kg} \times 20^2\,(\text{m/s})^2 = 400\text{ J}$$

Energy equation for the piston is:

$$(E_2 - E_1)_{PIST.} = W_{gas} - W_{atm} = P_{avg}\;\Delta V_{gas} - P_o\;\Delta V_{gas}$$

$$\Delta V_{gas} = A\,L = 10\text{ cm}^2 \times 10\text{ cm} = 0.0001\text{ m}^3$$

$$P_{avg}\;\Delta V_{gas} = (E_2 - E_1)_{PIST.} + P_o\;\Delta V_{gas}$$

$$P_{avg} = (E_2 - E_1)_{PIST.} / \Delta V_{gas} + P_o$$

$$= 400\text{ J} / 0.0001\text{ m}^3 + 100\text{ kPa}$$

$$= 4000\text{ kPa} + 100\text{ kPa} = \mathbf{4100\ kPa}$$

Properties (u, h) from General Tables

5.25

Find the phase and the missing properties of T, P, v, u and x for water at:

a. 500 kPa, 100°C   b. 5000 kPa, u = 800 kJ/kg

c. 5000 kPa, v = 0.06 m^3/kg   d. -6°C, v = 1 m^3/kg

Solution:

a) Look in Table B.1.2 at 500 kPa

$T < T_{sat} = 151^oC$ => compressed liquid

Table B.1.4: v = 0.001043 m^3/kg, u = 418.8 kJ/kg

b) Look in Table B.1.2 at 5000 kPa

$u < u_f = 1147.78$ kJ/kg => compressed liquid

Table B.1.4: between 180°C and 200°C

$$T = 180 + (200 - 180)\frac{800 - 759.62}{848.08 - 759.62} = 180 + 20\times0.4567 = 189.1^oC$$

$$v = 0.001124 + 0.4567\ (0.001153 - 0.001124) = 0.001137\ m^3/kg$$

c) Look in Table B.1.2 at 5000 kPa

$v > v_g = 0.03944\ m^3/kg$ => superheated vapor

Table B.1.3: between 400°C and 450°C.

$$T = 400 + 50\times\frac{0.06 - 0.05781}{0.0633 - 0.05781} = 400 + 50\times0.3989 = 419.95^oC$$

$$u = 2906.58 + 0.3989 \times (2999.64 - 2906.58) = 2943.7\ kJ/kg$$

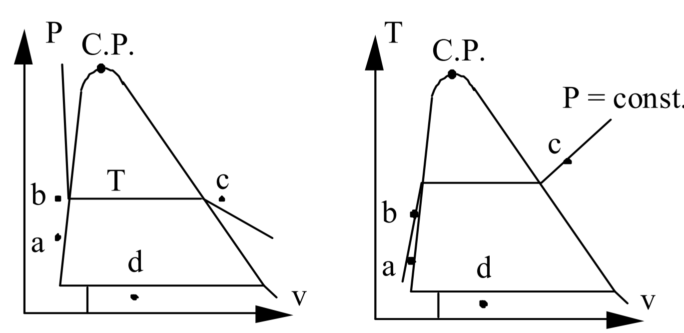
d) B.1.5: $v_i < v < v_g = 334.14\ m^3/kg$ => 2-phase, $P = P_{sat} = 887.6$ kPa,

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

$$u = u_i + x\ u_{fg} = 248.34 + 0.4111\times148.68 = 309.46\ kJ/kg$$

5.26

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



5.27

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

a. Water at 5000 kPa, u = 3000 kJ/kg

b. Ammonia at 50^{o}C, v = 0.08506 m^3/kg

c. Ammonia at 28^{o}C, 1200 kPa

d. R-134a at 20^{o}C, u = 350 kJ/kg

a) Check in Table B.1.2 at 5000 kPa: $u > u_g = 2597$ kJ/kg

Goto B.1.3 it is found very close to **450^{o}C,** x = undefined, v = 0.0633 m^3/kg

b) Table B.2.1 at 50^{o}C: $v > v_g = 0.06337$ m^3/kg, so superheated vapor

Table B.2.2: close to 1600 kPa, u = 1364.9 kJ/kg, x = undefined

c) Table B.2.1 between 25 and 30^{o}C: We see $P > P_{sat} = 1167$ kPa (30^{o}C)

We conclude compressed liquid without any interpolation.

$$v = v_f = 0.001658 + \frac{28-25}{5}(0.00168 - 0.001658) = 0.00167 \text{ m}^3\text{/kg}$$

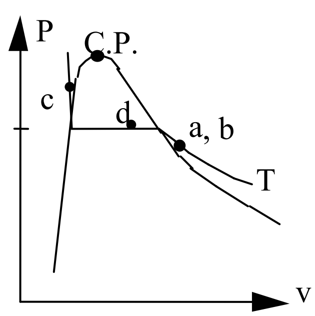
$$u = u_f = 296 + \frac{28-25}{5}(320.46 - 296.59) = 310.91 \text{ kJ/kg}$$

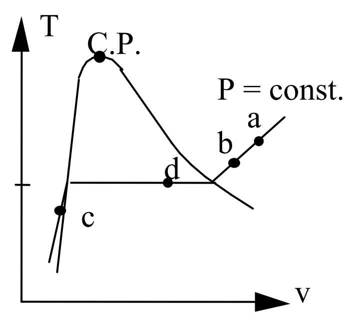
d) Table B.5.1 at 20^{o}C: $227.03 = u_f < u < u_g = 389.19$ kJ/kg so two-phase

$$x = \frac{u - u_f}{u_{fg}} = \frac{350 - 227.03}{162.16} = 0.7583, \quad P = P_{sat} = 572.8 \text{ kPa}$$

$$v = v_f + x\, v_{fg} = 0.000817 + x \times 0.03524 = 0.02754 \text{ m}^3\text{/kg}$$

all states are relative to the two-phase region, not to each other





5.28

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

a. T = 65°C, P = 600 kPa u = ? v = ?

b. T = 20°C, P = 100 kPa u = ? v = ? x = ?

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

Solution:

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

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

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

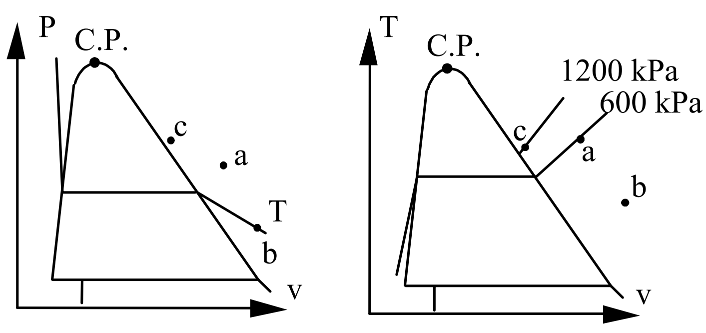
b) Table B.2.1: P < Psat => x = **undefined**, **superheated vapor**, from B.2.2:

v = **1.4153 m^3/kg** ; u = **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.



5.29

Find the missing properties of (u, h, and x)

a. H_2O $T = 120°C$, $v = 0.5\ m^3/kg$

b. H_2O $T = 100°C$, $P = 10$ MPa

c. N_2 $T = 100$ K, $x = 0.75$

d. N_2 $T = 200$ K, $P = 200$ kPa

e. NH_3 $T = 100°C$, $v = 0.1\ m^3/kg$

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 × 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.6.1: 100 K, x = 0.75

v = 0.001452 + 0.75 × 0.02975 = **0.023765 m^3/kg**

u = -74.33 + 0.75 ×137.5 = **28.8 kJ/kg**

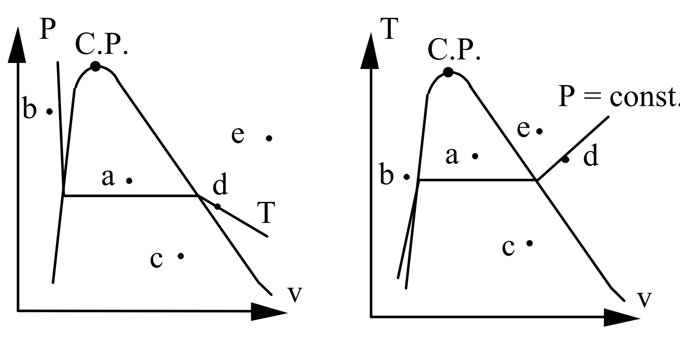
d) Table B.6.2: 200 K, 200 kPa

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

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

$$\text{B.2.2:}\quad P = 1600 + 400 \times \frac{0.1 - 0.10539}{0.08248 - 0.10539} = \mathbf{1694\ kPa}$$

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



5.30

Find the missing properties among (T, P, v, u, h and x if applicable) and indicate the states in a P-v and a T-v diagram for

a.	R-410a	P = 500 kPa, h = 300 kJ/kg
b.	R-410a	T = 10°C, u = 200 kJ/kg
c.	R-134a	T = 40°C, h = 400 kJ/kg

Solution:

a) Table B.4.1: $h > h_g$ => **superheated vapor**, look in section 500 kPa and interpolate

$$T = 0 + 20 \times \frac{300 - 287.84}{306.18 - 287.84} = 20 \times 0.66303 = \mathbf{13.26°C},$$

$$v = 0.05651 + 0.66303 \times (0.06231\text{-}0.05651) = \mathbf{0.06036\ m^3/kg},$$

$$u = 259.59 + 0.66303 \times (275.02 - 259.59) = \mathbf{269.82\ kJ/kg}$$

b) Table B.4.1: $u < u_g = 255.9$ kJ/kg => L+V mixture, P = **1085.7 kPa**

$$x = \frac{u - u_f}{u_{fg}} = \frac{200 - 72.24}{183.66} = \mathbf{0.6956},$$

$$v = 0.000886 + 0.6956 \times 0.02295 = \mathbf{0.01685\ m^3/kg},$$

$$h = 73.21 + 0.6956 \times 208.57 = \mathbf{218.3\ kJ/kg}$$

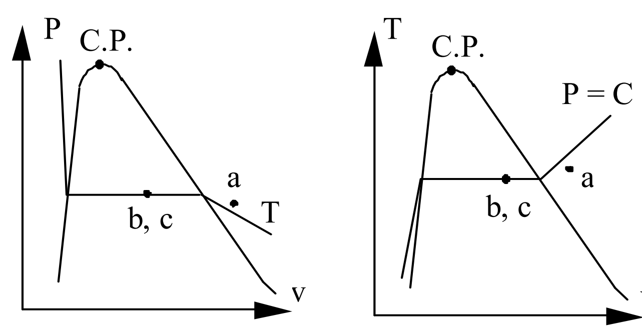
c) Table B.5.1: $h < h_g$ => **two-phase L + V,** look in B.5.1 at 40°C:

$$x = \frac{h - h_f}{h_{fg}} = \frac{400 - 256.5}{163.3} = 0.87875, \qquad P = P_{sat} = \mathbf{1017\ kPa},$$

$$v = 0.000\,873 + 0.87875 \times 0.01915 = \mathbf{0.0177\ m^3/kg}$$

$$u = 255.7 + 0.87875 \times 143.8 = \mathbf{382.1\ kJ/kg}$$

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



5.31

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

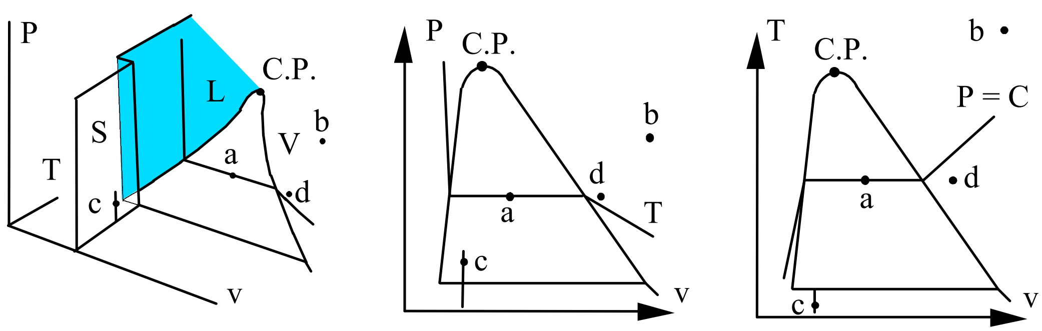
$u \cong u_i =$ **-337.62 kJ/kg** $v \cong v_i =$ **1.09×10^{-3} m³/kg**

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**



5.32

Find the missing properties of (P, T, v, u, h and x) and indicate the states in a P-v and T-v diagram for

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

b. R-134a at 20^{o}C, u = 300 kJ/kg

c. Nitrogen at 250 K, 200 kPa

Solution:

a) Compressed liquid: B.1.4 interpolate between 220^{o}C and 240^{o}C.

T = **233.3^{o}C**, 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**

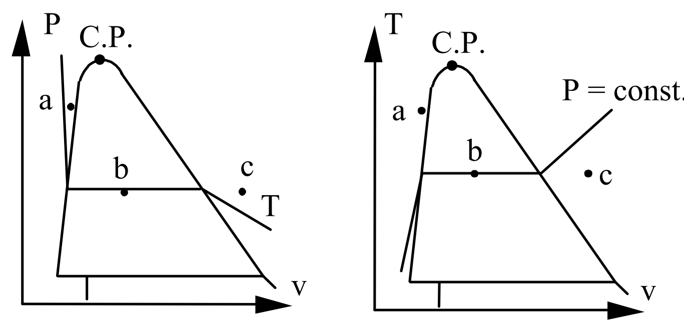
c) Table B.6.1: $T > T_{sat}$ (200 kPa) so superheated vapor in Table B.6.2

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.



5.33

Find the missing properties for CO_2 at:

a) 20°C, 2 MPa v = ? and h = ?

b) 10°C, x = 0.5 P = ?, u = ?

c) 1 MPa, v = 0.05 m³/kg, T = ?, h = ?

Solution:

a) Table B.3.1 $P < P_{sat} = 5729$ kPa so superheated vapor.

Table B.3.2: $v = 0.0245 \text{ m}^3/\text{kg}$, $h = 368.42$ kJ/kg

b) Table B.3.1 $P = P_{sat} = 4502$ kPa

$u = u_f + x\, u_{fg} = 107.6 + 0.5 \times 169.07 = 192.14$ kJ/kg

c) Table B.3.1 $v > v_g \approx 0.0383 \text{ m}^3/\text{kg}$ so superheated vapor

Table B.3.2: Between 0 and 20°C so interpolate.

$$T = 0 + 20 \times \frac{0.05 - 0.048}{0.0524 - 0.048} = 20 \times 0.4545 = 9.09^{o}\text{C}$$

$$h = 361.14 + (379.63 - 361.14) \times 0.4545 = 369.54 \text{ kJ/kg}$$

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

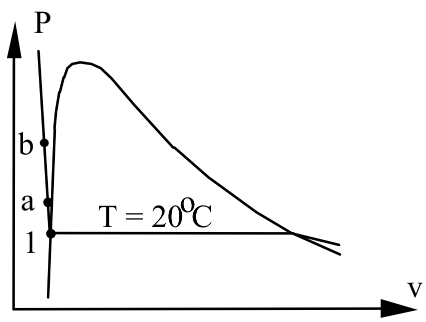
Solution:

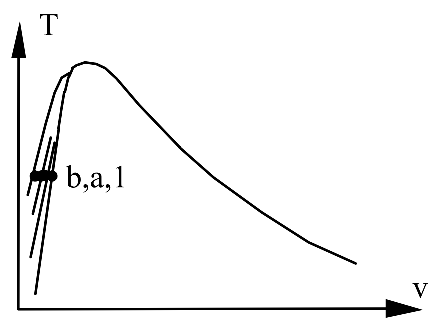
State 1 is located in Table B.1.1 and the states a-c are from Table B.1.4

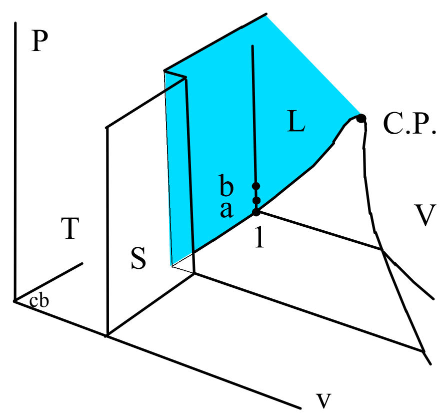
State	u [kJ/kg]	h [kJ/kg]	$\Delta u = u - u_1$	$\Delta h = h - h_1$	$\Delta(Pv)$
1	83.94	83.94			
a	83.91	84.41	-0.03	0.47	0.5
b	83.82	85.82	-0.12	1.88	2

For these states u stays nearly constant, dropping slightly as P goes up.

h varies with Pv changes.







Energy Equation: Simple Process

5.35

Saturated vapor R-410a at 0°C in a rigid tank is cooled to -20°C. Find the specific heat transfer.

Solution:

C.V.: R-410a in tank. $m_2 = m_1$;

Energy Eq.5.11: $(u_2 - u_1) = {}_1q_2 - {}_1w_2$

Process: V = constant, $v_2 = v_1 = V/m$ => $\mathbf{{}_1w_2 = \emptyset}$

Table B.4.1: State 1: $u_1 = 253.0$ kJ/kg

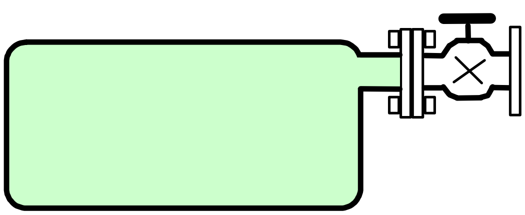
State 2: -20°C, $v_2 = v_1 = V/m$, look in Table B.4.1 at -20°C

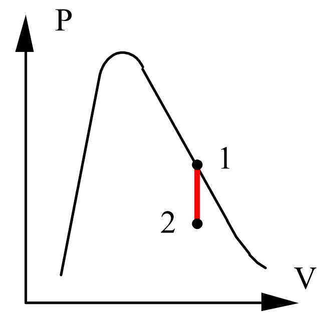
$$x_2 = \frac{v_2 - v_{f2}}{v_{fg2}} = \frac{0.03267 - 0.000803}{0.06400} = 0.4979$$

$$u_2 = u_{f2} + x_2\, u_{fg2} = 27.92 + x_2 \times 218.07 = 136.5 \text{ kJ/kg}$$

From the energy equation

$${}_1q_2 = (u_2 - u_1) = (\ 136.5 - 253.0\ ) = \mathbf{-116.5\ kJ/kg}$$





5.36

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:

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

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

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

5.37

Saturated vapor carbon dioxide at 2 MPa in a constant pressure piston cylinder is heated to 20^{o}C. Find the specific heat transfer.

Solution:

C.V. CO2: $m_2 = m_1 = m;$

Energy Eq.5.11 $(u_2 - u_1) = {}_1q_2 - {}_1w_2$

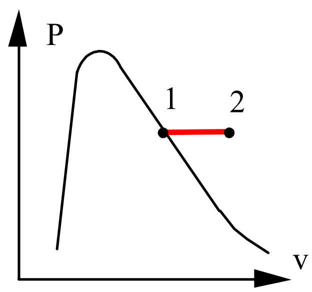
Process: P = const. $\Rightarrow {}_1w_2 = \int P dv = P\Delta v = P(v_2 - v_1)$

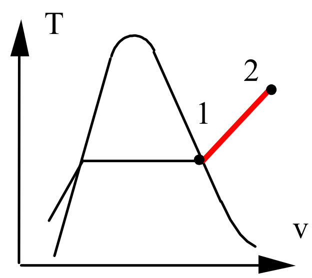
State 1: Table B3.2 (or B3.1) $h_1 = 323.95$ kJ/kg

State 2: Table B.3.2 $h_2 = 368.42$ kJ/kg

$${}_1q_2 = (u_2 - u_1) + {}_1w_2 = (u_2 - u_1) + P(v_2 - v_1) = (h_2 - h_1)$$

$${}_1q_2 = 368.42 – 323.95 = \mathbf{44.47\ kJ/kg}$$



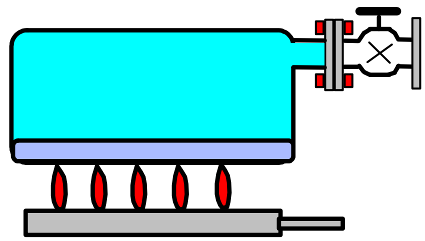


5.38

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. P5.38. 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 : $V = \text{constant}$

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

State 1: T, x_1 from Table B.1.1

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

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

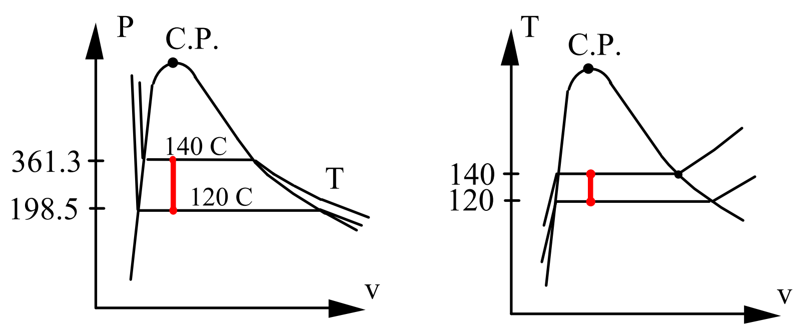
State 2: $T_2, v_2 = v_1 < v_{g2} = 0.50885\ m^3/kg$ so two-phase

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

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

From the energy equation

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

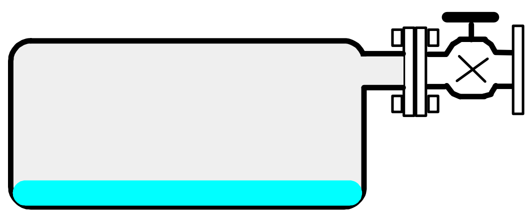


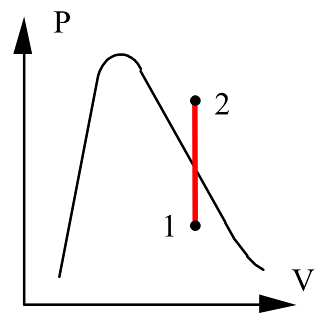
5.39

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

$\Rightarrow T_2 \cong 100°\text{C}, \quad u_2 \cong 1490.5 \text{ kJ/kg}$

So solve for heat transfer in the energy equation

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

5.40

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

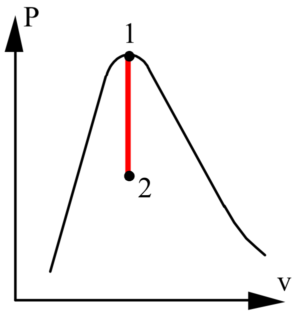
Process: Constant volume $\Rightarrow v_2 = v_1$

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**

5.41

A rigid tank holds 0.75 kg ammonia at 70°C as saturated vapor. The tank is now cooled to 20°C by heat transfer to the ambient. Which two properties determine the final state. Determine the amount of work and heat transfer during the process.

C.V. The ammonia, this is a control mass.

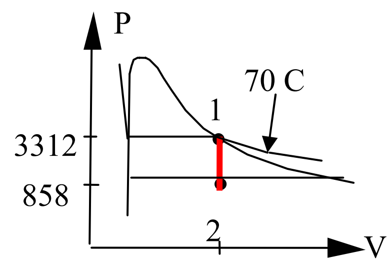
Process: Rigid tank V = C => v = constant & $_1W_2 = \int_1^2 PdV = \mathbf{0}$

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

State 1: $v_1 = 0.03787\ m^3/kg$,

$u_1 = 1338.9$ kJ/kg

State 2: **T, v** => two-phase (straight down in P-v diagram from state 1)



$x_2 = (v - v_f)/v_{fg} = (0.03787 - 0.001638)/0.14758 = 0.2455$

$u_2 = u_f + x_2\ u_{fg} = 272.89 + 0.2455 \times 1059.3 = 532.95$ kJ/kg

$_1Q_2 = m(u_2 - u_1) = 0.75\ (532.95 - 1338.9) =$ **-604.5 kJ**

5.42

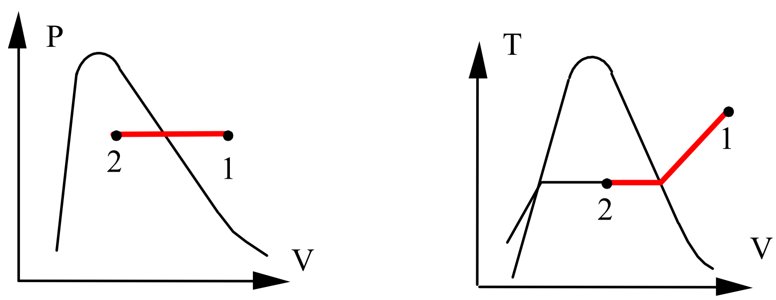
A cylinder fitted with a frictionless piston contains 2 kg of superheated refrigerant R-134a vapor at 350 kPa, 100^{o}C. The cylinder is now cooled so the R-134a remains at constant pressure until it reaches a quality of 75%. Calculate the heat transfer in the process.

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)

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

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

5.43

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

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

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

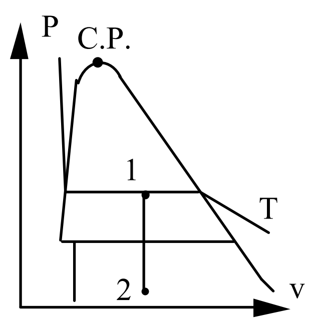
State 2: T_2, $v_2 = v_1$ ⇒ mix of saturated solid + vapor Table B.1.5

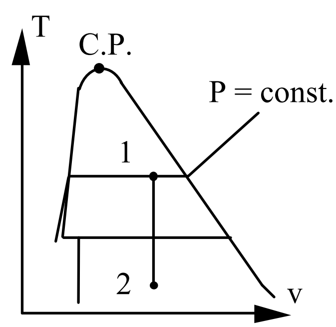
$$v_2 = 1.5057 = 0.0010891 + x_2 \times 466.7 \quad => \quad x_2 = 0.003224$$

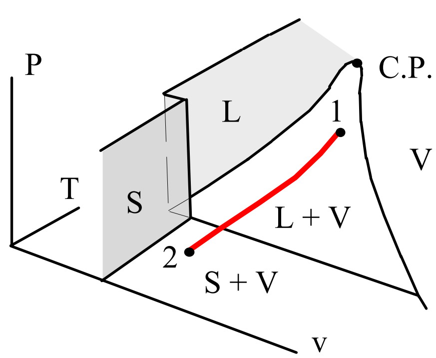
$$u_2 = -354.09 + 0.003224 \times 2715.5 = -345.34 \text{ kJ/kg}$$

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

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







5.44

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 $v_1 < v_g$

$$x_1 = \frac{v_1 - v_f}{v_{fg}} = \frac{0.002 - 0.001061}{0.88467} = 0.001061$$

$$h_1 = 504.68 + 0.001061 \times 2201.96 = 507.02\ kJ/kg$$

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

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

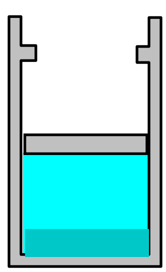
$$h_2 = 504.68 + 0.01010 \times 2201.96 = 526.92\ kJ/kg$$

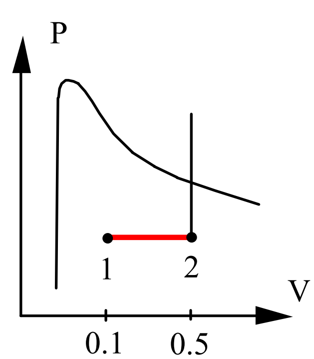
Find the heat transfer from the energy equation as

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

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

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





5.45

Find the heat transfer for the process in Problem 4.33

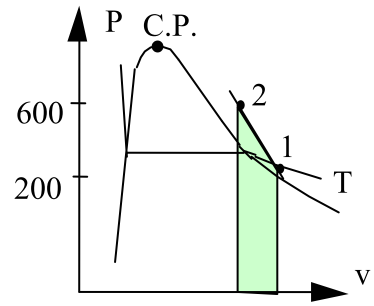
Take as CV the 1.5 kg of water. $m_2 = m_1 = m$;

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

Process Eq.: $\quad P = A + BV$ (linearly in V)

State 1: (P, T) => $v_1 = 0.95964\ m^3/kg$,

$u_1 = 2576.87\ kJ/kg$



State 2: (P, T) => $v_2 = 0.47424\ m^3/kg$, $u_2 = 2881.12\ kJ/kg$

From process eq.: $\quad {}_1W_2 = \int P\, dV = \text{area} = \frac{m}{2}(P_1 + P_2)(v_2 - v_1)$

$$= \frac{1.5}{2}\ \text{kg}\ (200 + 600)\ \text{kPa}\ (0.47424 - 0.95964)\ m^3/kg$$

$$= -291.24\ kJ$$

From energy eq.: $\quad {}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 1.5(2881.12 - 2576.87) - 291.24$

$$= \mathbf{165.14\ kJ}$$

5.46

A 10-L rigid tank contains R-410a 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-410a temperature is 40°C. What was the heat transfer to or from the tank during this process?

Solution:

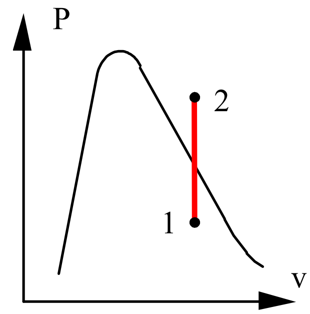
C.V. R-410a in tank. Control mass at constant V.

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

$v_1 = 0.000827 + 0.8 \times 0.04470 = 0.03659 \text{ m}^3/\text{kg}$

$u_1 = 42.32 + 0.8 \times 207.36 = 208.21 \text{ kJ/kg}$

$m = V/v = 0.010/0.03659 = 0.2733 \text{ kg}$

State 2: Table B.4.2 at 40°C and $v_2 = v_1 = 0.03659 \text{ m}^3/\text{kg}$

=> superheated vapor, so use linear interpolation to get

$P_2 = 800 + 200 \times (0.03659 – 0.04074)/(0.03170 – 0.04074)$

$= 800 + 200 \times 0.45907 = 892 \text{ kPa}$

$u_2 = 286.83 + 0.45907\times (284.35 – 286.83) = 285.69 \text{ kJ/kg}$

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

$${}_1Q_2 = m(u_2 – u_1) + {}_1W_2 = 0.2733\ (285.69 – 208.21) – 36 = \mathbf{–14.8\ kJ}$$

5.47

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 $\rightarrow$ ${}_1W_2 = 0$

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

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

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

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

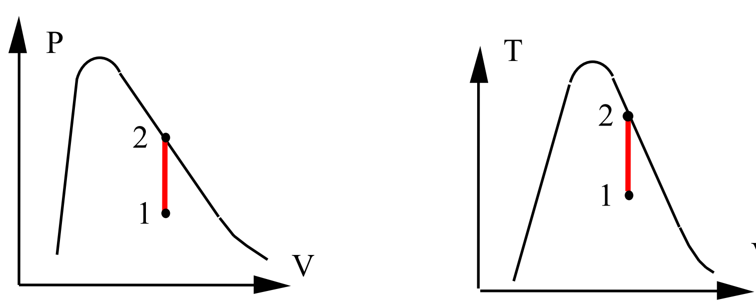
$\rightarrow$ found in Table B.1.1 between 210°C and 215° C

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

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

From the energy equation

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



5.48

A piston cylinder contains 1.5 kg water at 600 kPa, 350°C. It is now cooled in a process where pressure is linearly related to volume to a state of 200 kPa, 150°C. Plot the P-v diagram for the process and find both the work and the heat transfer in the process.

Take as CV the 1.5 kg of water.

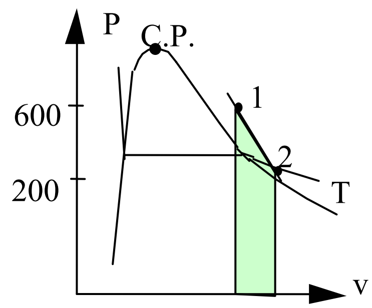
$$m_2 = m_1 = m \;;$$

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

Process Eq.: $P = A + BV$ (linearly in V)

State 1: (P, T) => $v_1 = 0.47424\ m^3/kg$,

$u_1 = 2881.12\ kJ/kg$



State 2: (P, T) => $v_2 = 0.95964\ m^3/kg$, $u_2 = 2576.87\ kJ/kg$

From process eq.: ${}_1W_2 = \int P\,dV = \text{area} = \frac{m}{2}(P_1 + P_2)(v_2 - v_1)$

$$= \frac{1.5}{2}\ kg\ (200 + 600)\ kPa\ (0.95964 - 0.47424)\ m^3/kg$$

$= \mathbf{291.24\ kJ}$

From energy eq.: ${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 1.5(2576.87 - 2881.12) + 291.24$

$= \mathbf{-165.14\ kJ}$

5.49

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

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

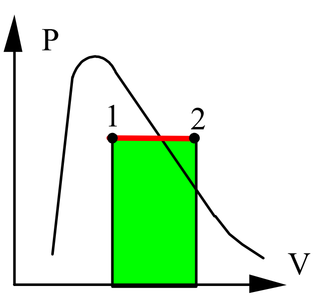
$${}_1W_2 = mP(v_2 - v_1) = 2 \times 200\ (0.9354 - 0.22223) = \mathbf{285.3\ kJ}$$

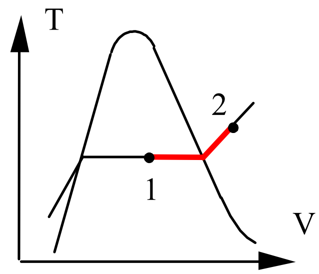
From the energy equation

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

$$= 2\ (2561.32 - 1010.725) + 285.3$$

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





5.50

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. P5.50. 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:

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

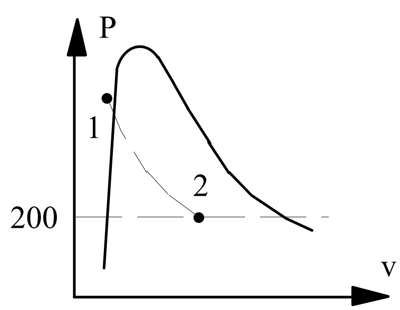
Energy equation then gives $u_2 = u_1 = 1702.8$ kJ/kg

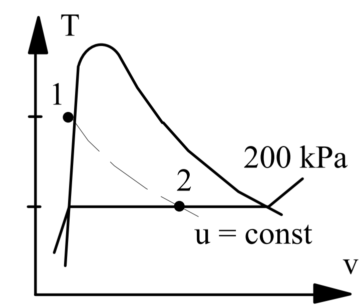
State 2: $P_2 = 200$ kPa, $u_2 < u_g$ => Two-phase Table B.1.2

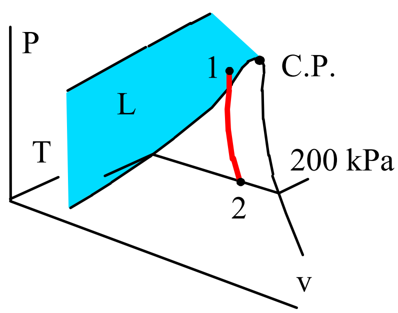
$x_2 = (u_2 - u_f)/ u_{fg} = (1702.8 – 504.47)/2025.02 = 0.59176$

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

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







5.51

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.

$$E_2 - E_1 = \Delta E = 0.5\ m\mathbf{V}^2 = 0.5 \times 25 \times 25^2/1000 = \mathbf{7.8125\ kJ}$$

C.V. The mass of water.

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

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

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

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

5.52

Find the heat transfer for the process in Problem 4.41

Solution:

Take CV as the Ammonia, constant mass.

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

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

Process: $P = A + BV$ (linear in V)

State 1: Superheated vapor $v_1 = 0.6193\ m^3/kg$, $u_1 = 1316.7\ kJ/kg$

State 2: Superheated vapor $v_2 = 0.63276\ m^3/kg$, $u_2 = 1542.0\ kJ/kg$

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

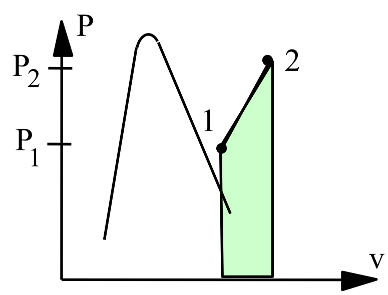
$${}_1W_2 = \int P\ dV = \text{area} = P_{avg}\ (V_2 - V_1) = \frac{1}{2}(P_1 + P_2)m(v_2 - v_1)$$

$$= ½(200 + 300)\ kPa \times 0.5\ kg\ (0.63276 - 0.6193)\ m^3/kg = 1.683\ kJ$$

Heat transfer is found from the energy equation

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 0.5\ kg\ (1542.0 - 1316.7)\ kJ/kg + 1.683\ kJ$$

$$= 112.65 + 1.683 = \mathbf{114.3\ kJ}$$



5.53

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. P5.53. 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: $P = \text{constant} = P_1$, $\Rightarrow$ ${}_1w_2 = \int_1^2 P\, dv = P_1(v_2 - v_1)$

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

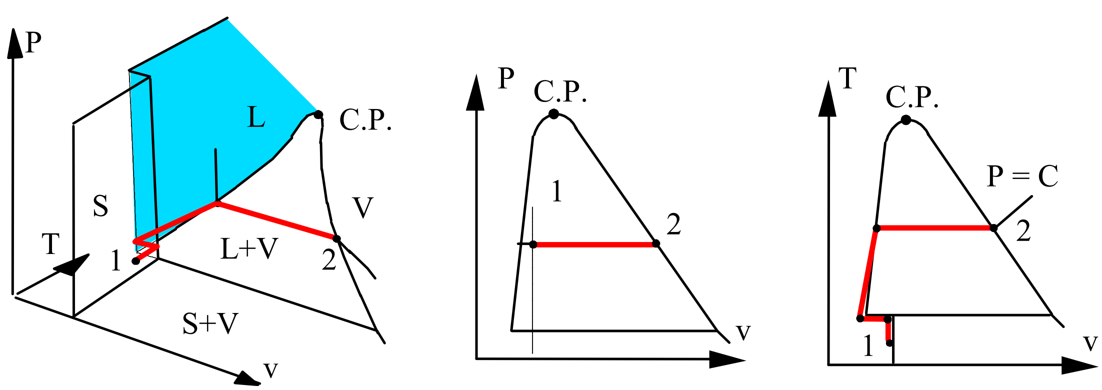
$$v_2 = v_g(P_2) = 1.1593\ m^3/kg, \quad T_2 = \mathbf{111.4°C}\ ; \quad u_2 = 2519.7\ kJ/kg$$

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

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



5.54

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

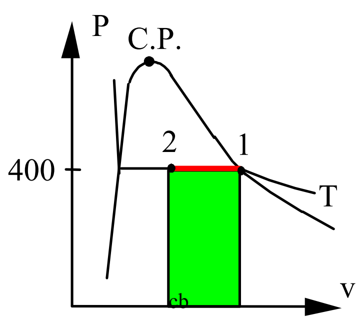
State 2: $v_2 = v_1 / 2 = 0.23123 = v_f + x\ v_{fg}$ from Table B.1.2

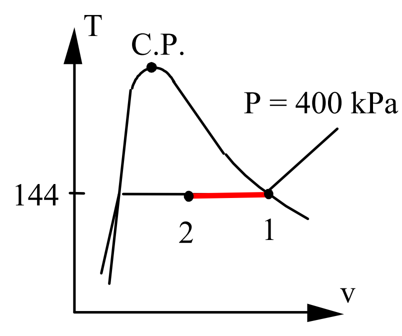
$$x_2 = (v_2 - v_f) / v_{fg} = (0.23123 - 0.001084) / 0.46138 = 0.4988$$

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

Now the heat transfer becomes

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





5.55

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. P5.55. 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 => $v_1 = 0.89186 \text{ m}^3\text{/kg}$, $u_1 = 2529.2 \text{ kJ/kg}$

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).

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

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

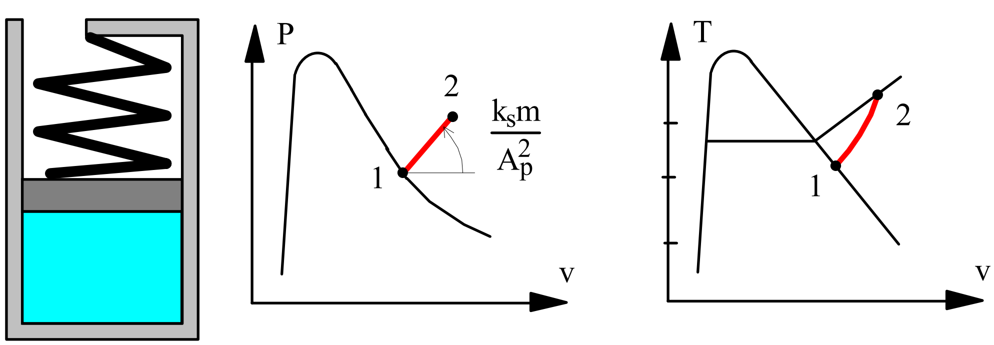
The process equation allows us to evaluate the work

$$ {}_1W_2 = \int PdV = \left(\frac{P_1 + P_2}{2}\right) m(v_2 - v_1) $$

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

Substitute the work into the energy equation and solve for the heat transfer

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



5.56

A piston cylinder arrangement with a linear spring similar to Fig. P5.55 contains R-134a at 15°C, x = 0.6 and a volume of 0.02 m^3. It is heated to 60°C at which point the specific volume is 0.03002 m^3/kg. Find the final pressure, the work and the heat transfer in the process.

Take CV as the R-134a.

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

State 1: T_1, x_1 => Two phase so Table B.5.1: $P_1 = P_{sat} = 489.5$ kPa

$$v_1 = v_f + x_1 v_{fg} = 0.000805 + 0.6 \times 0.04133 = 0.0256 \text{ m}^3\text{/kg}$$

$$u_1 = u_f + x_1 u_{fg} = 220.1 + 0.6 \times 166.35 = 319.91 \text{ kJ/kg}$$

$$m = V_1/v_1 = 0.02 \text{ m}^3/ 0.0256 \text{ m}^3\text{/kg} = 0.78125 \text{ kg}$$

State 2: (T, v) Superheated vapor, Table B.5.2.

$$P_2 = 800 \text{ kPa}, \; v_2 = 0.03002 \text{ m}^3\text{/kg}, \; u_2 = 421.2 \text{ kJ/kg}$$

$$V_2 = m\, v_2 = 0.78125 \times 0.03002 = 0.02345 \text{ m}^3$$

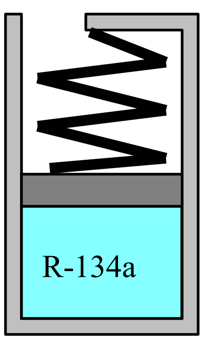
Work is done while piston moves at linearly varying pressure, so we get

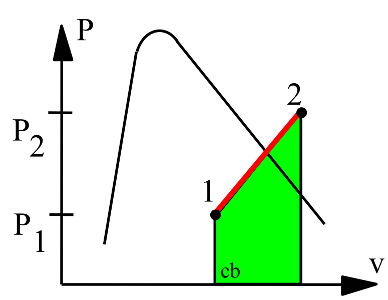
$${}_1W_2 = \int P\, dV = \text{area} = P_{avg} (V_2 - V_1) = 0.5(P_2 + P_1)(V_2 - V_1)$$

$$= 0.5 \times (489.5 + 800) \text{ kPa } (0.02345 - 0.02) \text{ m}^3 = \mathbf{2.22 \text{ kJ}}$$

Heat transfer is found from the energy equation

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 0.78125 \times (421.2 - 319.91) + 2.22 = \mathbf{81.36 \text{ kJ}}$$





5.57

A closed steel bottle contains CO_2 at −20°C, *x* = 20% and the volume is 0.05 m^3. It has a safety valve that opens at a pressure of 6 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.: CO_2 : $m_2 = m_1 = m$;

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

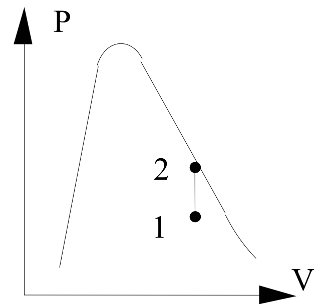
Process: constant volume process $\Rightarrow {}_1W_2 = 0$

State 1: (T, x) Table B.3.1

$v_1 = 0.000969 + 0.2 \times 0.01837 = 0.004643\ m^3/kg$

=> $m = V/v_1 = 0.05/0.004643 = 10.769$ kg

$u_1 = 39.64 + 0.2 \times 246.25 = 88.89$ kJ/kg



State 2: P_2 , $v_2 = v_1$ => very close to saturated vapor, use 6003 kPa in Table B.3.1: **T ≅ 22°C**, $x_2 = (0.004643 – 0.001332)/0.00341 = 0.971$

$u_2 = 142.03 + 0.971 \times 119.89 = 258.44$ kJ/kg

${}_1Q_2 = m(u_2 - u_1) = 10.769\ (258.44 – 88.89) =$ **1825.9 kJ**

5.58

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

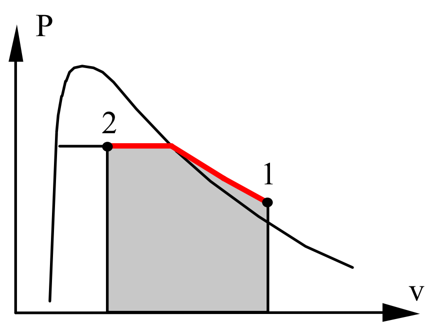
=> $V_1 = mv_1 =$ **0.211 m^3**

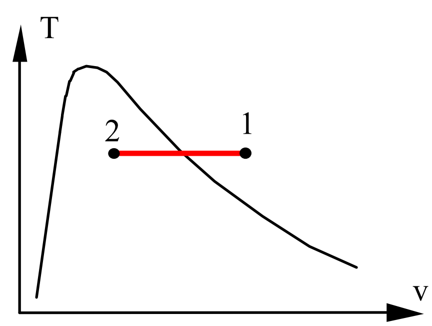
State 2: T_2 , x_2 ⇒ Table B.5.1

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

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

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





5.59

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 ${}_1Q_2 = \emptyset$, ${}_1W_2 = \emptyset$

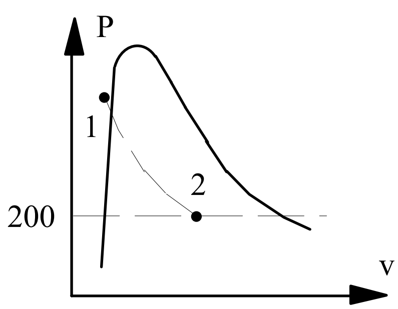
Energy: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2 = \emptyset \Rightarrow u_2 = u_1$

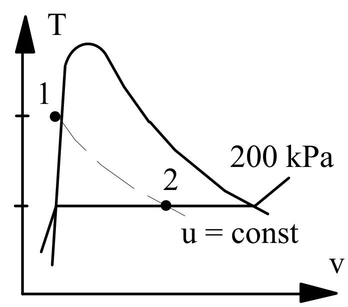
State 1: $v_1 \cong v_f = 0.001091$ m^3/kg; $u_1 \cong u_f = 631.66$ kJ/kg

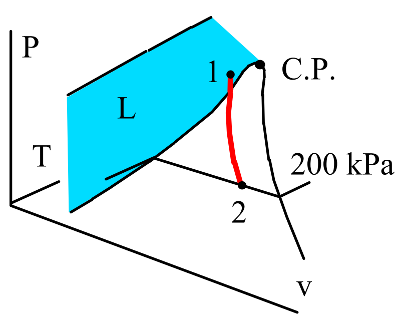
State 2: P_2 , u_2 $\Rightarrow$ $x_2 = \dfrac{631.66 - 444.16}{2069.3} = 0.09061$

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

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







5.60

A piston cylinder contains carbon dioxide at -20^{o}C and quality 75%. It is compressed in a process where pressure is linear in volume to a state of 3 MPa and 20^{o}C. Find the specific heat transfer.

CV Carbon dioxide out to the source, both $_1Q_2$ and $_1W_2$

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

Process: $P = A + BV$ => $_1W_2 = \int P\, dV = ½\, m(P_1 + P_2)(v_2 - v_1)$

State 1: Table B.3.1 P = 1969.6 kPa

$v_1 = 0.000969 + 0.75 \times 0.01837 = 0.01475\ m^3/kg$,

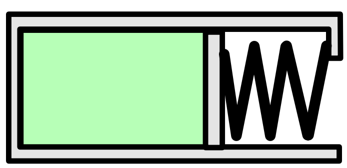
$u_1 = 39.64 + 0.75 \times 246.25 = 224.33$ kJ/kg,

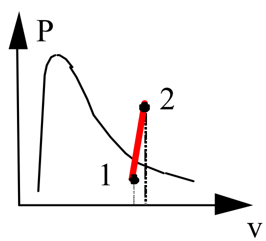
State 2: Table B.3 $v_2 = 0.01512\ m^3/kg$, $u_2 = 310.21$ kJ/kg,

$_1w_2 = ½\,(P_1 + P_2)(v_2 - v_1) = ½ \times (1969.6 + 3000)(0.01512 - 0.01475)$

$= \mathbf{0.92\ kJ/kg}$

$_1q_2 = u_2 - u_1 + {_1w_2} = 310.21 - 224.33 + 0.92$ **= 86.8 kJ/kg**



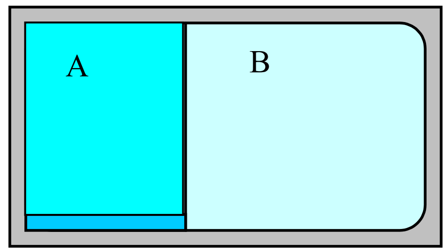


5.61

A rigid tank is divided into two rooms by a membrane, both containing water, shown in Fig. P5.61. 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

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

5.62

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 $\Rightarrow$ ${}_1W_2 = \int PdV = Pm(v_2 - v_1)$

State 1: Table B.6.1

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

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

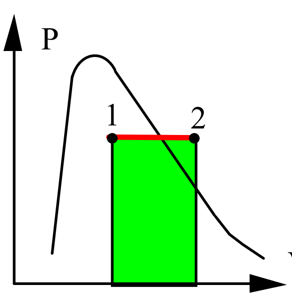
State 2: (P = 779.2 kPa , 300 K) => sup. vapor interpolate in Table B.6.2

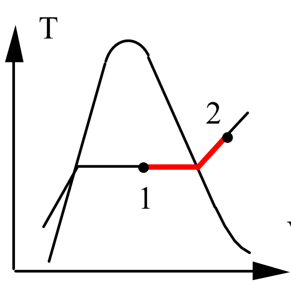
$$v_2 = 0.14824 + (0.11115-0.14824)\times 179.2/200 = 0.115 \text{ m}^3\text{/kg}, \ V_2 = \mathbf{0.23\ m^3}$$

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

Now solve for the heat transfer from the energy equation

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





5.63

Water in a tank A is at 250 kPa with a quality of 10% and mass 0.5 kg. It is connected to a piston cylinder holding constant pressure of 200 kPa initially with 0.5 kg water at 400°C. The valve is opened and enough heat transfer takes place to have a final uniform temperature of 150°C. Find the final P and V, the process work and the process heat transfer.

C.V. Water in A and B. Control mass goes through process: 1 -> 2

Continuity Eq.: $m_2 - m_{A1} - m_{B1} = 0 \quad => \quad m_2 = m_{A1} + m_{B1} = 0.5 + 0.5 = 1$ kg

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

State A1: $v_{A1} = 0.001067 + x_{A1} \times 0.71765 = 0.072832$; $V_{A1} = mv = 0.036416\ m^3$

$u_{A1} = 535.08 + 0.1 \times 2002.14 = 735.22$ kJ/kg

State B1: $v_{B1} = 1.5493\ m^3/kg$; $u_{B1} = 2966.69$ kJ/kg

$=> \quad V_{B1} = m_{B1}v_{B1} = 0.77465\ m^3$

State 2: If $V_2 > V_{A1}$ then P_2 = **200 kPa** that is the piston floats.

For (T_2, P_2) = (150°C, 200 kPa) => superheated vapor $u_2 = 2576.87$ kJ/kg

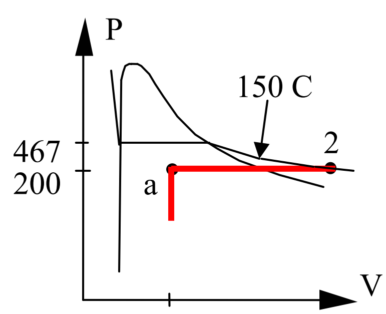
$v_2 = 0.95964\ m^3/kg \qquad V_2 = m_2v_2 = \mathbf{0.95964\ m^3} > V_{A1}$ checks OK.

The possible state 2 (P,V) combinations are shown. State a is

$$200 \text{ kPa}, \; v_a = \frac{V_{A1}}{m_2} = 0.036\ m^3/kg$$

and thus two-phase

$T_a = 120°C < T_2$



Process: ${}_1W_2 = P_2 (V_2 - V_1) = 200 (0.95964 - 0.77465 - 0.036416) = \mathbf{29.715\ kJ}$

From the energy Eq.:

$${}_1Q_2 = m_2u_2 - m_{A1}u_{A1} - m_{B1}u_{B1} + {}_1W_2$$
$$= 1 \times 2576.87 - 0.5 \times 735.222 - 0.5 \times 2966.69 + 29.715$$
$$= \mathbf{755.63\ kJ}$$

5.64

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. P5.64. 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**

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

State 2_A: $P_{A2} = P_0 + \frac{m_p g}{A} = \mathbf{120.8\ kPa}$; $v_{A2} = V_{tot}/\,m_A = \mathbf{0.5\ m^3/kg}$

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

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

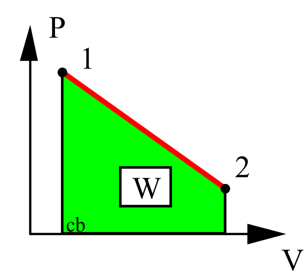
Continuity eq. in A: $m_{A2} = m_{A1}$

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

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

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

$= \mathbf{169.32\ kJ}$



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

5.65

Assume the same setup as in Problem 5.50, 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 => $v_2 = V_{room}/m_2 = 0.1823 \text{ m}^3/\text{kg}$

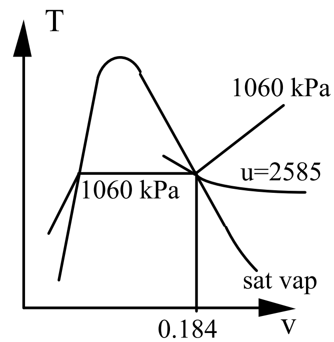
State 2: u_2 , v_2 Table B.1.1 see Figure.

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**

5.66

A piston cylinder has a water volume separated in $V_A = 0.2\ m^3$ and $V_B = 0.3\ m^3$ by a stiff membrane. The initial state in A is 1000 kPa, x = 0.75 and in B it is 1600 kPa and 250°C. Now the membrane ruptures and the water comes to a uniform state at 200°C. What is the final pressure? Find the work and the heat transfer in the process.

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: $P_2 = P_{eq} = \text{constant} = P_{1A}$ as piston floats and m_p, P_o do not change

State 1A: Two phase. Table B.1.2

$v_{1A} = 0.001127 + 0.75 \times 0.19332 = 0.146117\ m^3/kg$,

$u_{1A} = 761.67 + 0.75 \times 1821.97 = 2128.15\ kJ/kg$

State 1B: Table B.1.3 $v_{1B} = 0.14184\ m^3/kg$, $u_{1B} = 2692.26\ kJ/kg$

=> $m_{1A} = V_{1A}/v_{1A} = 1.3688\ kg$, $m_{1B} = V_{1B}/v_{1B} = 2.115\ kg$

State 2: 1000 kPa, 200°C sup. vapor => $v_2 = 0.20596\ m^3/kg$, $u_2 = 2621.9\ kJ/kg$

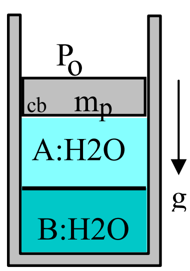
$m_2 = m_{1A} + m_{1B} = 3.4838\ kg$ => $V_2 = m_2v_2 = 3.4838 \times 0.20596 = 0.7175\ m^3$

So now

${}_1W_2 = \int P\,dV = P_{eq}(V_2 - V_1) = 1000\,(0.7175 - 0.5) = \mathbf{217.5\ kJ}$

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

$= 3.4838 \times 2621.9 - 1.3688 \times 2128.15 - 2.115 \times 2692.26 + 217.5 = \mathbf{744\ kJ}$



5.67

Two rigid tanks are filled with water. Tank A is 0.2 m^3 at 100 kPa, 150°C and tank B is 0.3 m^3 at saturated vapor 300 kPa. The tanks are connected by a pipe with a closed valve. We open the valve and let all the water come to a single uniform state while we transfer enough heat to have a final pressure of 300 kPa. Give the two property values that determine the final state and find the heat transfer.

State A1: $u = 2582.75$ kJ/kg, $v = 1.93636$ m^3/kg

$\Rightarrow$ $m_{A1} = V/v = 0.2/1.93636 =$ **0.1033 kg**

State B1: $u = 2543.55$ kJ/kg, $v = 0.60582$ m^3/kg

$\Rightarrow$ $m_{B1} = V/v = 0.3 / 0.60582 =$ **0.4952 kg**

The total volume (and mass) is the sum of volumes (mass) for tanks A and B.

$$m_2 = m_{A1} + m_{B1} = 0.1033 + 0.4952 = 0.5985 \text{ kg},$$

$$V_2 = V_{A1} + V_{B1} = 0.2 + 0.3 = 0.5 \text{ m}^3$$

$$\Rightarrow v_2 = V_2/m_2 = 0.5 /0.5985 = \mathbf{0.8354 \text{ m}^3/\text{kg}}$$

State 2: $[P_2, v_2] = [300 \text{ kPa}, 0.8354 \text{ m}^3/\text{kg}]$

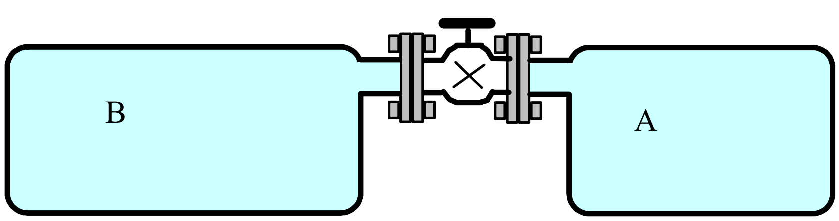
$$\Rightarrow T_2 = 274.76°C \text{ and } u_2 = 2767.32 \text{ kJ/kg}$$

The energy equation is (neglecting kinetic and potential energy)

$$m_2 u_2 - m_A u_{A1} - m_B u_{B1} = {}_1Q_2 - {}_1W_2 = {}_1Q_2$$

$${}_1Q_2 = 0.5985 \times 2767.32 - 0.1033 \times 2582.75 - 0.4952 \times 2543.55$$

$$= \mathbf{129.9 \text{ kJ}}$$



Energy Equation: Multistep Solution

5.68

A piston cylinder shown in Fig. P5.68 contains 0.5 m^3 of R-410a at 2 MPa, 150°C. The piston mass and atmosphere gives a pressure of 450 kPa that will float the piston. The whole setup cools in a freezer maintained at -20°C. Find the heat transfer and show the P-v diagram for the process when T_2 = -20°C.

C.V.: R-410a. Control mass.

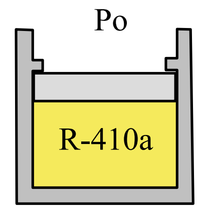
Continuity: m = constant,

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: $v_1 = 0.02247\ m^3/kg$, $u_1 = 373.49$ kJ/kg

$\Rightarrow \quad m = V/v = 22.252$ kg

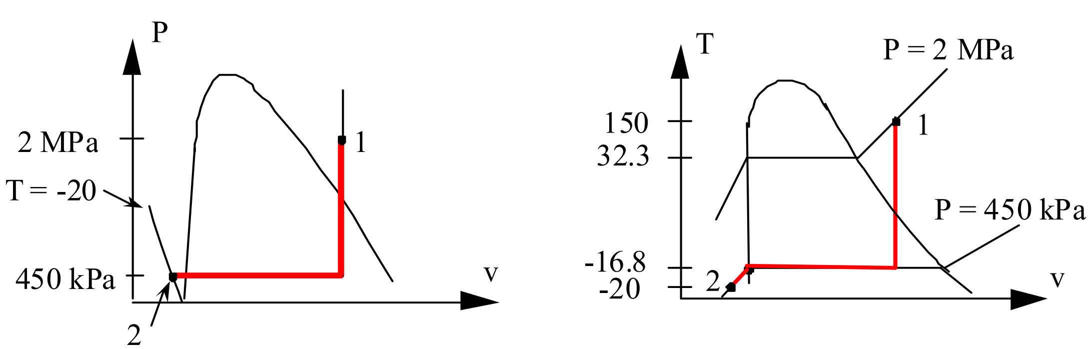
State 2: T_2 and on line ⇒ compressed liquid, see figure below.

$v_2 \cong v_f = 0.000\,803\ m^3/kg \Rightarrow V_2 = 0.01787\ m^3$; $u_2 = u_f = 27.92$ kJ/kg

${}_1W_2 = \int PdV = P_{lift}(V_2 - V_1) = 450\,(0.01787 - 0.5) = -217.0$ kJ ;

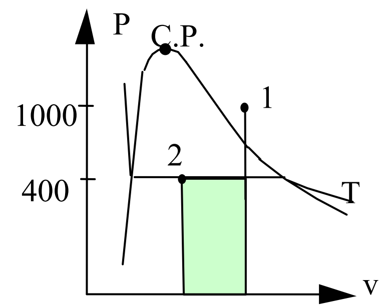
Energy eq. ⇒

${}_1Q_2 = 22.252\,(27.92 - 373.49) - 217.9 =$ **-7906.6 kJ**



5.69

A setup as in Fig. P5.68 has the R-410a initially at 1000 kPa, 50°C of mass 0.1 kg. The balancing equilibrium pressure is 400 kPa and it is now cooled so the volume is reduced to half the starting volume. Find the work and heat transfer for the process.



Take as CV the 0.1 kg of R-410a.

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

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

Process Eq.: $P = P_{float}$ or $v = C = v_1$,

State 1: (P, T) => $v_1 = 0.0332\ m^3/kg$,

$u_1 = 292.695$ kJ/kg

State 2: (P, v) => $v_2 = v_1/2 = 0.0166\ m^3/kg < v_g$, so it is two-phase.

$x_2 = (v_2 - v_f)/v_{fg} = (0.0166 - 0.000803)/0.064 = 0.2468$

$u_2 = u_f + x_2\, u_{fg} = 27.92 + x_2\, 218.07 = 81.746$ kJ/kg

From process eq.: ${}_1W_2 = \int P\, dV = \text{area} = mP_2 (v_2 - v_1)$

$= 0.1 \times 400\ (0.0166 - 0.0332) =$ -0.**664 kJ**

From energy eq.: ${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 0.1\times (81.746 - 292.695) - 0.664$

= **-21.8 kJ**

5.70

A vertical cylinder fitted with a piston contains 5 kg of R-410a at 10°C, shown in Fig. P5.70. 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 1.4 MPa.

a. What is the quality at the initial state?

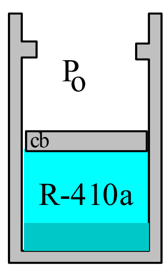
b. Calculate the heat transfer for the overall process.

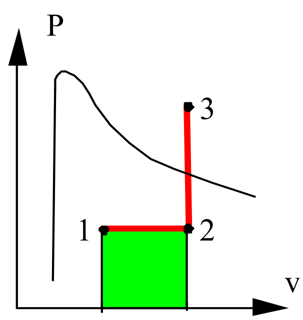
Solution:

C.V. R-410a. 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) $v_3 = 0.02249\ m^3/kg$, $u_3 = 287.91\ kJ/kg$





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

$v_1 = 0.011245 = 0.000886 + x_1 \times 0.02295 \quad => \quad x_1 = \mathbf{0.4514}$

b) $u_1 = 72.24 + 0.4514 \times 183.66 = 155.14\ kJ/kg$

State 2: $v_2 = 0.02249\ m^3/kg$, $P_2 = P_1 = 1086\ kPa$ this is still 2-phase.

We get the work from the process equation (see P-V diagram)

$${}_1W_3 = {}_1W_2 = \int_1^2 PdV = P_1(V_2 - V_1) = 1086 \times 5\ (0.011245) = 61.1\ kJ$$

The heat transfer from the energy equation becomes

$${}_1Q_3 = m(u_3 - u_1) + {}_1W_3 = 5(287.91 - 155.14) + 61.1 = \mathbf{725.0\ kJ}$$

5.71

Find the heat transfer in Problem 4.68.

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. $v = v_f(20) = 0.001002\ m^3/kg$, $u = u_f = 83.94$ 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

$$v = 0.002 = 0.001101 + x \times (0.3157-0.001101) \;\; => \;\; x = 0.002858$$

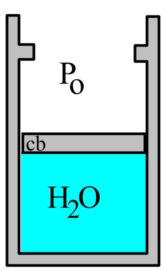
$$u = 669.88 + 0.002858 \times 1897.5 = 675.3 \text{ kJ/kg}$$

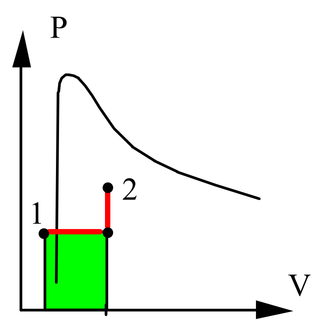
Work is done while piston moves at P_{lift}= constant = 300 kPa so we get

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

Heat transfer is found from energy equation

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





5.72

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. 5.72. Find the final temperature and the heat transfer in the process.

Solution:

Take CV as the water.

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

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

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

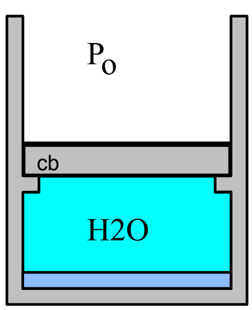
=> $V_2 = mv_2 = 25.425 \text{ m}^3$

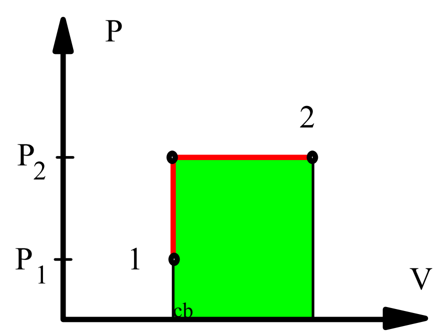
From the process equation (see P-V diagram) we get the work as

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

From the energy equation we solve for the heat transfer

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





5.73

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^{o}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 $v = (1\text{-}x) \times 0.001084 + x \times 0.4625 = 0.2318$ 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 $T_2 = 200^o$C and $u_2 = 2654.4$ kJ/kg

So now

$V_1 = 0.47982 + 0.1 =$ **0.5798 m^3**, $m_1 = 0.5 + 0.4314 =$ **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).

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

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

5.74

Calculate the heat transfer for the process described in Problem 4.65.

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.

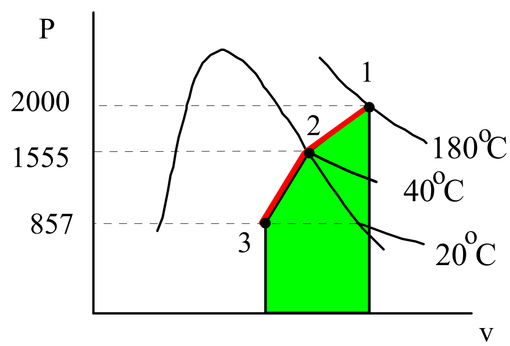
Continuity: m = constant,

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:

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

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

= **-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**

5.75

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.

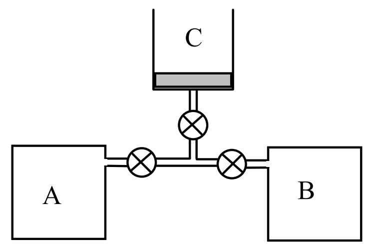
C.V.: A + B + C.

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

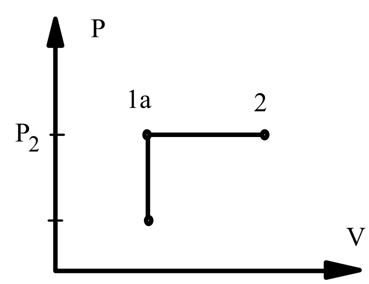
$V_2 = V_A + V_B + V_C = 1 + V_C$

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

$V_2 = m_2 v_2 = 4.1363$ kg $\times$ 0.29314 m^3/kg = **1.21 m^3**

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**

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

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

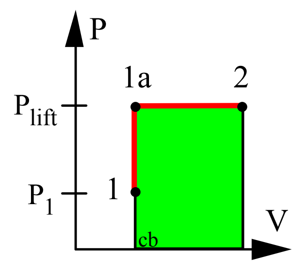
$= 11\,232 - 2867.7 - 2998.6 + 170 =$ **5536 kJ**

5.76

Calculate the heat transfer for the process described in Problem 4.73.

A piston cylinder setup similar to Problem 4.?? 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

$v_1 = 0.001043 + 0.25 \times 1.69296 = 0.42428 \text{ m}^3/\text{kg}$

$u_1 = 417.33 + 0.25 \times 2088.7 = 939.5 \text{ kJ/kg}$

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 $v_2 = 0.52256 \text{ m}^3/\text{kg}$; $u_2 = 2802.9 \text{ kJ/kg}$

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

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

5.77

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. P5.72. 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.

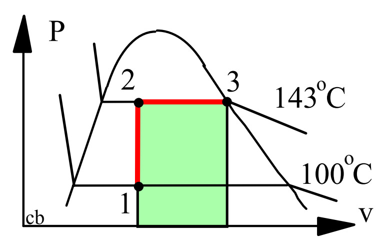
Solution:

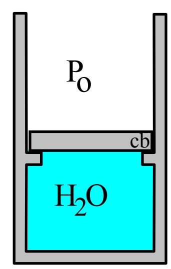
C.V. The 5 kg water.

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

5.78

I have 2 kg of liquid water at 20°C, 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.

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

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

c) Raised in gravitational field

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

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

Comment: Notice how fast (500 km/h) and how high it should by to have the same energy as raising the temperature just 2 degrees. I.e. in most applications we can disregard the kinetic and potential energies unless we have very high **V** or Z.

5.79

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. P5.79. 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

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

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

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

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

5.80

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°C liquid water at 100 kPa is cooled to 45°C as it heats 15 kg of copper pipe from 20 to 45°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:

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

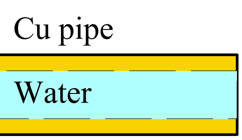
From the energy equation

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

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

or using Table B.1.1 for water

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



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

5.81

In a sink 5 liters of water at 70°C is combined with 1 kg aluminum pots, 1 kg of flatware (steel) and 1 kg of glass all put in at 20°C. What is the final uniform temperature neglecting any heat loss and work?

Energy Eq.: $U_2 - U_1 = \sum m_i(u_2 - u_1)_i = {}_1Q_2 - {}_1W_2 = 0$

For the water: $v_f = 0.001023\ m^3/kg$, $V = 5\ L = 0.005\ m^3$; $m = V/v = 4.8876\ kg$

For the liquid and the metal masses we will use the specific heats (Tbl A.3, A.4) so

$$\sum m_i(u_2 - u_1)_i = \sum m_iC_{v\ i}\ (T_2 - T_1)_i = T_2\sum m_iC_{v\ i} - \sum m_iC_{v\ i}T_{1\ i}$$

noticing that all masses have the same T_2 but not same initial T.

$$\sum m_iC_{v\ i} = 4.8876 \times 4.18 + 1 \times 0.9 + 1 \times 0.46 + 1 \times 0.8 = 22.59\ kJ/K$$

Energy Eq.: $22.59\ T_2 = 4.8876 \times 4.18 \times 70 + (1 \times 0.9 + 1 \times 0.46 + 1 \times 0.8) \times 20$

$= 1430.11 + 43.2$

$T_2 = \mathbf{65.2^oC}$

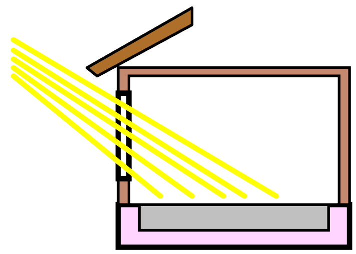
5.82

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.: Control mass concrete.

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



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

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

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

The available heat transfer is the change in U. From Eq.5.18 and C from table A.3

$$\Delta U = m\,C\,\Delta T = 15\,840 \text{ kg} \times 0.88 \frac{\text{kJ}}{\text{kg K}} \times 3 \text{ K} = 41818 \text{ kJ} = \mathbf{41.82\ MJ}$$

5.83

A closed rigid container is filled with 1.5 kg water at 100 kPa, 55^{o}C, 1 kg of stainless steel and 0.5 kg of PVC (polyvinyl chloride) both at 20^{o}C and 0.1 kg of air at 400 K, 100 kPa. It is now left alone with no external heat transfer and no water vaporizes. Find the final temperature and air pressure.

Energy Eq.: $U_2 - U_1 = \sum m_i(u_2 - u_1)_i = {}_1Q_2 - {}_1W_2 = 0$

For the liquid and the metal masses we will use the specific heats (Tbl A.3, A.4) so

$$\sum m_i(u_2 - u_1)_i = \sum m_iC_{v\,i}\,(T_2 - T_1)_i = T_2\sum m_iC_{v\,i} - \sum m_iC_{v\,i}T_{1\,i}$$

noticing that all masses have the same T_2 but not same initial T.

$$\sum m_iC_{v\,i} = 1.5 \times 4.18 + 1 \times 0.46 + 0.5 \times 0.96 + 0.1 \times 0.717 = 7.282 \text{ kJ/K}$$

Energy Eq.: $7.282\ T_2 = 1.5 \times 4.18 \times 55 + (1 \times 0.46 + 0.5 \times 0.96) \times 20$

$+ 0.1 \times 0.717 \times (400\text{-}273.15) = 372.745$ kJ

$T_2 = \mathbf{51.2^oC}$

The volume of the air is constant so from PV = mRT it follows that P varies with T

$$P_2 = P_1\ T_2/T_{1\ air} = 100 \times 324.34 / 400 = \mathbf{81\ kPa}$$

5.84

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.

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

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

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

$$\Rightarrow \Delta T = \mathbf{65.9\ °C}$$

5.85

A computer CPU chip consists of 50 g silicon, 20 g copper, 50 g polyvinyl chloride (plastic). It heats from 15^{o}C to 70^{o}C as the computer is turned on. How much energy does the heating require?

Energy Eq.: $U_2 - U_1 = \sum m_i(u_2 - u_1)_i = {}_1Q_2 - {}_1W_2$

For the solid masses we will use the specific heats, Table A.3, and they all have the same temperature so

$$\sum m_i(u_2 - u_1)_i = \sum m_i C_{v\,i} (T_2 - T_1)_i = (T_2 - T_1)\sum m_i C_{v\,i}$$

$$\sum m_i C_{v\,i} = 0.05 \times 0.7 + 0.02 \times 0.42 + 0.05 \times 0.96 = 0.0914 \text{ kJ/K}$$

$$U_2 - U_1 = 0.0914 \times (70 - 15) = \mathbf{5.03\ kJ}$$

5.86

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

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

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

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

5.87

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

$${}_1Q_2 = U_2 - U_1 = m_{st}(u_2 - u_1)_{st} + m_{H2O}(u_2 - u_1)_{H2O}$$
$$= m_{st}C_{st}\ (T_2 - T_1) + m_{H2O}(u_2 - u_1)_{H2O}$$

$${}_1Q_2 = 1\text{ kg} \times 0.46\,\frac{\text{kJ}}{\text{kg K}} \times (100 - 15)\text{ K} + 1\text{ kg} \times (418.91 - 62.98)\text{ kJ/kg}$$
$$= 39.1 + 355.93 = \mathbf{395\ kJ}$$

5.88

A piston cylinder (0.5 kg steel altogether) maintaining a constant pressure has 0.2 kg R-134a as saturated vapor at 150 kPa. It is heated to 40^{o}C and the steel is at the same temperature as the R-134a at any time. Find the work and heat transfer for the process.

C.V. The R-134a plus the steel. Constant total mass

$$m_2 = m_1 = m \quad ;$$

$$U_2 - U_1 = m_{R134a}(u_2 - u_1)_{R134a} + m_{steel}(u_2 - u_1) = {}_1Q_2 - {}_1W_2$$

State 1: B.5.2 sat. vapor $\quad v_1 = 0.13139$ m^3/kg, $u_1 = 368.06$ kJ/kg

State 2: B.5.2 sup. vapor $\quad v_2 = 0.16592$ m^3/kg, $u_2 = 411.59$ kJ/kg

$$V_1 = mv_1 = 0.2 \times 0.13139 = 0.02628 \text{ m}^3$$

$$V_2 = mv_2 = 0.2 \times 0.16592 = 0.03318 \text{ m}^3$$

Steel: A.3, $\quad C_{steel} = 0.46$ kJ/kg-K

Process: P = C for the R134a and constant volume for the steel $\Rightarrow$

$${}_1W_2 = \int P\, dV = P_1(V_2 - V_1) = 150 \text{ kPa } (0.03318 - 0.02628) \text{ m}^3$$

$$= \mathbf{1.035\ kJ}$$

$${}_1Q_2 = m_{R134a}\,(u_2 - u_1) + m_{steel}\,(u_2 - u_1) + {}_1W_2$$

$$= m_{R134a}\,(u_2 - u_1) + m_{steel}C_{steel}\,(T_2 - T_1) + {}_1W_2$$

$$= 0.2 \times (411.59 - 368.06) + 0.5 \times 0.46 \times [40 - (-17.29)] + 1.035$$

$$= 8.706 + 13.177 + 1.035 = \mathbf{22.92\ kJ}$$

5.89

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

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

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

Table 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

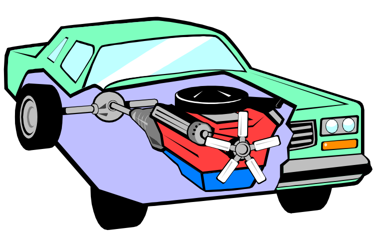
$$[\, m_{Fe}C_{Fe} + m_{Al}C_{Al} + m_{st}C_{st} + m_{oil}C_{oil} + m_{gly}C_{gly} \,]\,(T_2 - T_1) = {}_1Q_2$$

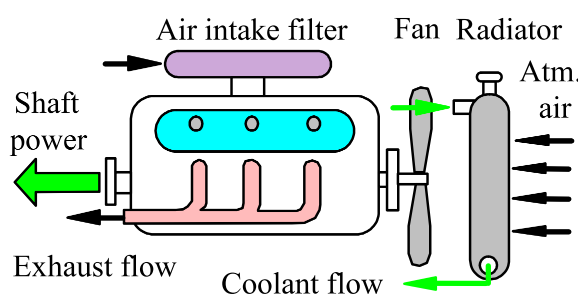
$$T_2 - T_1 = {}_1Q_2 / \Sigma m_i\, C_i$$

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

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

$T_2 = T_1 + 75 = 5 + 75 =$ **80°C**





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

5.90

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 :

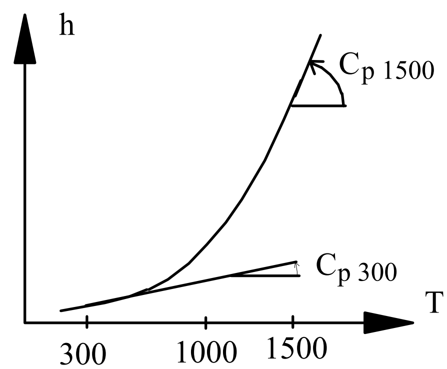
From Eq.5.24:

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

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

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

Notice an increase of 14%, 21% respectively.



5.91

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**

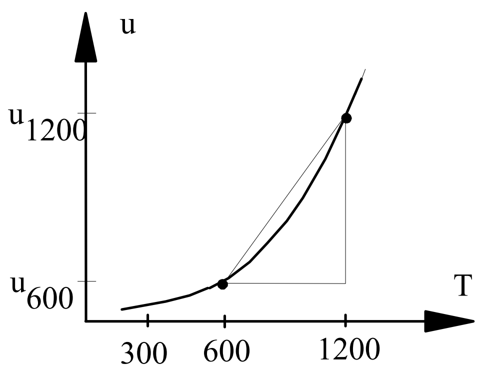
b) $T_{avg} = \frac{1}{2}(1200 + 600) = 900, \qquad \theta = \frac{T}{1000} = \frac{900}{1000} = 0.9$

$C_{po} = 0.45 + 1.67 \times 0.9 - 1.27 \times 0.9^2 + 0.39 \times 0.9^3 = 1.2086$ 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**



5.92

We want to find the change in u for carbon dioxide between 50^{o}C and 200^{o}C at a pressure of 10 MPa. Find it using ideal gas and Table A.5 and repeat using the B section table.

Solution:

Using the value of C_{vo} for CO_2 from Table A.5,

$\Delta u = C_{vo}\,\Delta T = 0{,}653 \times (200 - 50) =$ **97.95 kJ/kg**

Using values of u from Table B3.2 at 10 000 kPa, with linear interpolation between 40^{o}C and 60^{o}C for the 50^{o}C value,

$\Delta u = u_{200} - u_{50} = 437.6 - 230.9 =$ **206.7 kJ/kg**

Note: Since the state 50^{o}C, 10 000 kPa is in the dense-fluid supercritical region, a linear interpolation is quite inaccurate. The proper value for u at this state is found from the CATT software to be 245.1 instead of 230.9. This results is

$\Delta u = u_{200} - u_{50} = 437.6 - 245.1 =$ **192.5 kJ/kg**

5.93

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

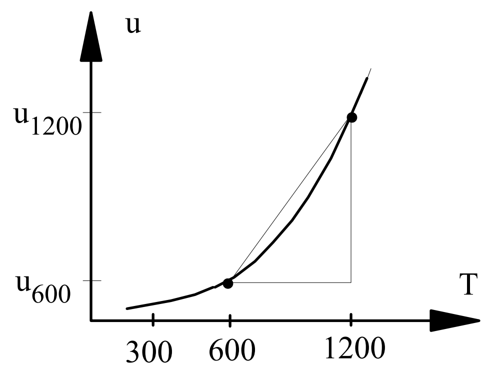
b) $T_{avg} = \frac{1}{2}(1200 + 600) = 900\ \text{K}, \qquad \theta = \frac{T}{1000} = \frac{900}{1000} = 0.9$

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

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

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

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



5.94

Estimate the constant specific heats for R-134a from Table B.5.2 at 100 kPa and 125^o C. Compare this to table A.5 and explain the difference.

Solution:

Using values at 100 kPa for h and u at 120^{o}C and 130^{o}C from Table B5.2, the approximate specific heats at 125^{o}C are

$$C_p \approx \frac{\Delta h}{\Delta T} = \frac{521.98 - 511.95}{130 - 120} = 1.003 \text{ kJ/kg K}$$

compared with 0.852 kJ/kg K for the ideal-gas value at 25^{o}C from Table A.5.

$$C_v \approx \frac{\Delta u}{\Delta T} = \frac{489.36 - 480.16}{130 - 120} = 0.920 \text{ kJ/kg K}$$

compared with 0.771 kJ/kg K for the ideal-gas value at 25^{o}C from Table A.5.

There are two reasons for the differences. First, R-134a is not exactly an ideal gas at the given state, 125^{o}C and 100 kPa. Second and by far the biggest reason for the differences is that R-134a, chemically CF_3CH_2 , is a polyatomic molecule with multiple vibrational mode contributions to the specific heats (see Appendix C), such that they are strongly dependent on temperature. Note that if we repeat the above approximation for C_p in Table B.5.2 at 25^{o}C, the resulting value is 0.851 kJ/kg K.

5.95

Water at 150°C, 400 kPa, is brought to 1200°C in a constant pressure process. Find the change in the specific internal energy, using a) the steam tables, b) the ideal gas water table A.8, and c) ≈the specific heat from A.5.

Solution:

a)

State 1: Table B.1.3 Superheated vapor $u_1 = 2564.48$ kJ/kg

State 2: Table B.1.3 $u_2 = 4467.23$ kJ/kg

$u_2 - u_1 = 4467.23 - 2564.48 =$ **1902.75 kJ/kg**

b)

Table A.8 at 423.15 K: $u_1 = 591.41$ kJ/kg

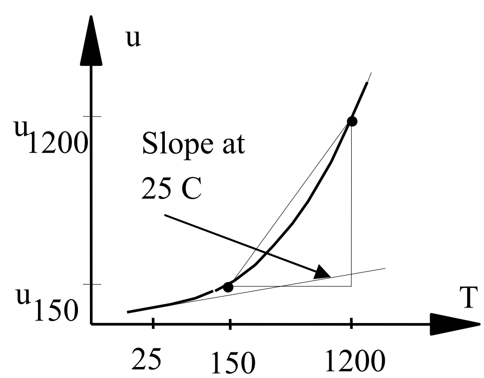
Table A.8 at 1473.15 K: $u_2 = 2474.25$ kJ/kg

$u_2 - u_1 = 2474.25 - 591.41 =$ **1882.8 kJ/kg**

c) Table A.5 : $C_{vo} = 1.41$ kJ/kgK

$u_2 - u_1 = 1.41$ kJ/kgK $(1200 – 150)$ K = **1480.5 kJ/kg**

Notice how the average slope from 150 C to 1200 C is higher than the one at 25 C (= C_{vo})



5.96

Nitrogen at 300 K, 3 MPa is heated to 500 K. Find the change in enthalpy using a) Table B.6, b) Table A.8, and c) Table A.5.

B.6.2 $h_2 - h_1 = 519.29 - 304.94 = 214.35$ kJ/kg

A.8 $h_2 - h_1 = 520.75 - 311.67 = 209.08$ kJ/kg

A.5 $h_2 - h_1 = C_{po} (T_2 - T_1) = 1.042$ kJ/kg-K $(500 - 300)$ K $= 208.4$ kJ/kg

Comment: The results are listed in order of accuracy (B.6.2 best).

5.97

For a special application we need to evaluate the change in enthalpy for carbon dioxide from 30^{o}C to 1500^{o}C at 100 kPa. Do this using constant specific heat from Table A.5 and repeat using Table A.8. Which is the more accurate one?

Solution:

Using constant specific heat:

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

Using Table A.8:

$$30°C = 303.15\text{ K} \;\;=>\;\; h = 214.38 + \frac{3.15}{50}(257.9 - 214.38) = 217.12\text{ kJ/kg}$$

$$1500°C = 1773.15\text{ K} \;\;=>$$

$$h = 1882.43 + \frac{73.15}{100}(2017.67 - 1882.43) = 1981.36\text{ kJ/kg}$$

$$\Delta h = 1981.36 - 217.12 = \mathbf{1764.2\ kJ/kg}$$

The result from A.8 is best. For large ΔT or small ΔT at high T_{avg}, constant specfic heat is poor approximation.

5.98

Repeat the previous problem but use a constant specific heat at the average temperature from equation in Table A.6 and also integrate the equation in Table A.6 to get the change in enthalpy.

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

Table A.6 $\Rightarrow$ $C_{po} = 1.2513$ kJ/kg-K

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

For the entry to Table A.6:

30°C = 303.15 K => $\theta_1 = 0.30315$

1500°C = 1773.15 K => $\theta_2 = 1.77315$

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

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

$$-1.27 \times \frac{1}{3}(\theta_2^3 - \theta_1^3) + 0.39 \times \frac{1}{4}(\theta_2^4 - \theta_1^4)] = \mathbf{1762.76\ kJ/kg}$$

5.99

Reconsider Problem 5.97 and examine if also using Table B.3 would be more accurate and explain.

Table B.3 does include non-ideal gas effects, however at 100 kPa these effects are extremely small so the answer from Table A.8 is accurate.

Table B.3. does not cover the 100 kPa superheated vapor states as the saturation pressure is below the triple point pressure. Secondly Table B.3 does not go up to the high temperatures covered by Table A.8 and A.9 at which states you do have ideal gas behavior. Table B.3 covers the region of states where the carbon dioxide is close to the two-phase region and above the critical point (dense fluid) which are all states where you cannot assume ideal gas.

5.100

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.

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

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

5.101

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

5.102

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.: $u_2 - u_1 = {}_1q_2 - 0$ → ${}_1q_2 = u_2 - u_1$

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)

5.103

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 ideal gas.

Solution:

Ideal gas, constant volume

$$P_2 = P_1 \times (T_2 / T_1) = 1500 \times 300 / 500 = 900 \text{ kPa}$$

$$m = P_1V/RT_1 = \frac{1500 \times 0.25}{0.5183 \times 500} = \mathbf{1.447\ kg}$$

Use specific heat from Table A.5

$$u_2 - u_1 = C_v (T_2 - T_1) = 1.736 (300 - 500) = -347.2 \text{ kJ/kg}$$

$$_1Q_2 = m(u_2 - u_1) = 1.447(-347.2) = -\mathbf{502.4\ kJ}$$

5.104

A rigid tank has 1 kg air at 300 K, 120 kPa and it is heated by an external heater. Use Table A.7 to find the work and the heat transfer for the process.

CV Air in tank, this is a C.M. at constant volume.

This process is a constant volume process so $\mathbf{{}_1W_2 = 0}$ and ${}_1Q_2$ comes in.

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

Process & ideal gas: $V_2 = V_1$; $P_1V_1 = mRT_1$, $P_2V_2 = mRT_2$

$$P_2 = P_1\, T_2 / T_1 = 120 \times 1500 / 300 = \mathbf{600\ kPa}$$

Solving using Table A.7 gives:

$${}_1Q_2 = m(u_2 - u_1) = 1(1205.25 - 214.36) = \mathbf{990.89\ kJ}$$

5.105

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: $U_2 - U_1 = m (u_2 - u_1) = {}_1Q_2 - {}_1W_2$

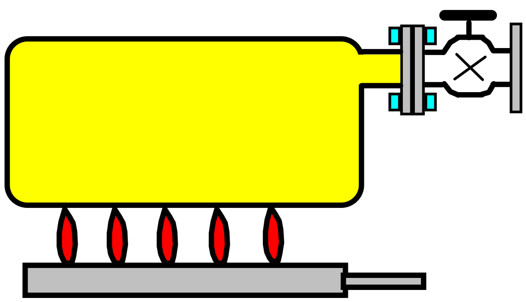
Process: $\Delta V = 0 \Rightarrow {}_1W_2 = 0$

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

$${}_1Q_2 = m (u_2 - u_1) = 2 \times (1218.38 - 996.64) = \mathbf{443.5\ kJ}$$



5.106

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: $U_2 - U_1 = m (u_2 - u_1) = {}_1Q_2 - {}_1W_2$

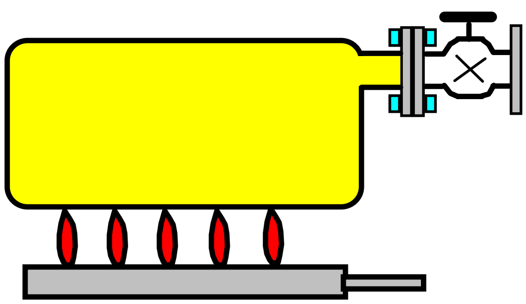
Process: $\Delta V = 0 \Rightarrow {}_1W_2 = 0$

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

$${}_1Q_2 = m (u_2 - u_1) = 2 \times (1141.35 - 957) = \mathbf{368.7\ kJ}$$



5.107

A tank has a volume of 1 m^3 with oxygen at 15°C, 300 kPa. Another tank contains 4 kg oxygen at 60°C, 500 kPa. The two tanks are connected by a pipe and valve which is opened allowing the whole system to come to a single equilibrium state with the ambient at 20°C. Find the final pressure and the heat transfer.

C.V. Both tanks of constant volume.

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

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

Process Eq.: $V_2 = V_A + V_B = \text{constant}, \quad {}_1W_2 = 0$

State 1A: $m_{1A} = \frac{P_{1A}V_A}{RT_{1A}} = \frac{300 \text{ kPa} \times 1 \text{ m}^3}{0.2598 \text{ kJ/kg-K} \times 288.15 \text{ K}} = 4.007 \text{ kg}$

State 1B: $V_B = \frac{m_{1B}RT_{1B}}{P_{1B}} = \frac{4 \text{ kg} \times 0.2598 \text{ kJ/kg-K} \times 333.15 \text{ K}}{500 \text{ kPa}} = 0.6924 \text{ m}^3$

State 2: $(T_2, v_2 = V_2/m_2) \quad V_2 = V_A + V_B = 1 + 0.6924 = 1.6924 \text{ m}^3$

$m_2 = m_{1A} + m_{1B} = 4.007 + 4 = 8.007 \text{ kg}$

$P_2 = \frac{m_2RT_2}{V_2} = \frac{8.007 \text{ kg} \times 0.2598 \text{ kJ/kg-K} \times 293.15 \text{ K}}{1.6924 \text{ m}^3} = \mathbf{360.3 \text{ kPa}}$

Heat transfer from energy equation

$${}_1Q_2 = m_2u_2 - m_{1A}u_{1A} - m_{1B}u_{1B} = m_{1A}(u_2 - u_{1A}) + m_{1B}(u_2 - u_{1B})$$
$$= m_{1A}C_v (T_2 - T_{1A}) + m_{1B} C_v (T_2 - T_{1B})$$
$$= 4.007 \text{ kg} \times 0.662 \text{ kJ/kg-K} \times (20 - 15) \text{ K} + 4 \text{ kg} \times 0.662 \text{ kJ/kg-K} \times (20 - 60) \text{ K}$$
$$= \mathbf{- 92.65 \text{ kJ}}$$

5.108

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: $T_2, P_2 = P_1$

$P_2V_2 = mRT_2$ $\quad\quad$ $V_2 = mR\, T_2 / P_2 = 3\times0.287\times600 / 300 = 1.722\ m^3$

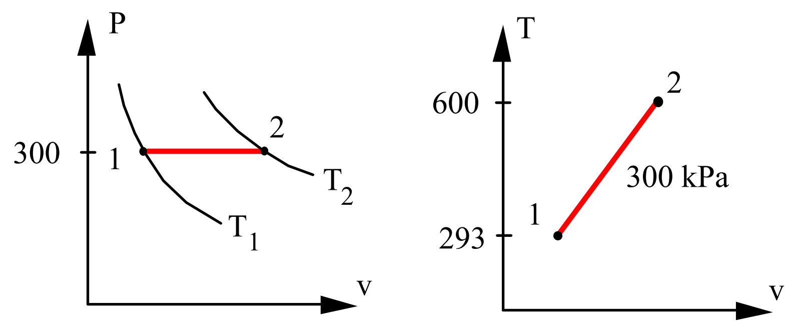
Process: P = constant,

$$_1W_2 = \int PdV = P (V_2 - V_1) = 300 (1.722 – 0.8413) = 264.2 \text{ kJ}$$

Energy equation becomes

$$U_2 - U_1 = {}_1Q_2 - {}_1W_2 = m(u_2 - u_1)$$

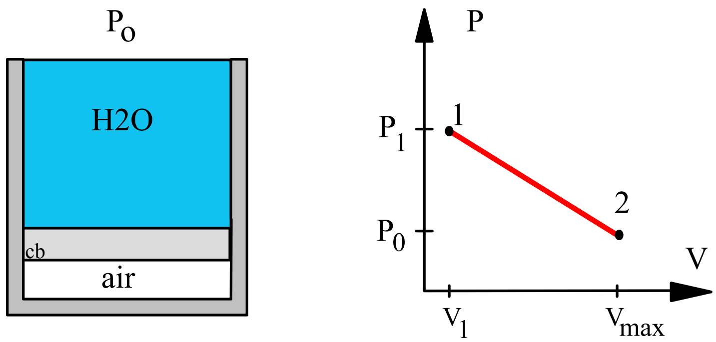
$$_1Q_2 = U_2 - U_1 + {}_1W_2 = 3(435.097 – 209.45) + 264.2 = \mathbf{941\ kJ}$$



5.109

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. P5.109. 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

$$P_1 = P_0 + m_{H_2O}g/A = 101.325 + \frac{698.6 \times 9.807}{0.1 \times 1000} = \mathbf{169.84 \text{ kPa}}$$

and then $\quad m_{air} = PV/RT = \dfrac{169.84 \times 0.3}{0.287 \times 300} = 0.592 \text{ kg}$

State 2: No liquid over piston: $P_2 = P_0 = 101.325$ kPa, $V_2 = 10 \times 0.1 = 1 \text{ m}^3$

State 2: P_2, V_2 $\Rightarrow$ $T_2 = \dfrac{T_1P_2V_2}{P_1V_1} = \dfrac{300 \times 101.325 \times 1}{169.84 \times 0.3} = 596.59 \text{ K}$

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

$$_1Q_2 = m(u_2 - u_1) + {}_1W_2 \cong mC_v(T_2 - T_1) + {}_1W_2$$

$$= 0.592 \times 0.717 \times (596.59 - 300) + 94.91 = \mathbf{220.7 \text{ kJ}}$$

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.

5.110

A piston cylinder contains air at 600 kPa, 290 K and a volume of 0.01 m^3. A constant pressure process gives 18 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 ${}_1W_2 = \int P\, dV = P(V_2 – V_1)$

$1 : P_1 , T_1,V_1$ $2 : P_1 = P_2 , ?$

$m_1 = P_1V_1/RT_1 = 600 \times 0.01 / 0.287 \times 290 = 0.0721$ kg

${}_1W_2 = P(V_2 – V_1) = 18$ kJ $\rightarrow$

$V_2 – V_1 = {}_1W_2 / P = 18$ kJ / 600 kPa $= 0.03$ m^3

$V_2 = V_1 + {}_1W_2 / P = 0.01 + 0.03 = 0.04$ m^3

Ideal gas law : $P_2V_2 = mRT_2$

$$T_2 = P_2V_2 / mR = \frac{P_2V_2}{P_1V_1} T_1 = \frac{0.04}{0.01} \times 290 = \mathbf{1160\ K}$$

Energy equation with u's from table A.7.1

${}_1Q_2 = m (u_2 – u_1) + {}_1W_2$

$= 0.0721 (898.04 – 207.19) + 18$

$=$ **67.81 kJ**

5.111

An insulated cylinder is divided into two parts of 1 m^3 each by an initially locked piston, as shown in Fig. P5.111. 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

$$m_A(u_2 - u_1)_A + m_B(u_2 - u_1)_B = 0$$

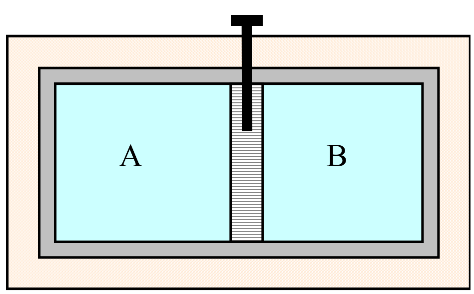
$$(m_A + m_B)u_2 = m_A u_{A1} + m_B u_{B1}$$

$$= 2.323 \times 214.364 + 3.484 \times 759.189 = 3143 \text{ kJ}$$

$$u_2 = 3143/(3.484 + 2.323) = 541.24 \text{ kJ/kg}$$

From interpolation in Table A.7: $\Rightarrow$ $\mathbf{T_2 = 736\ K}$

$$P = (m_A + m_B)RT_2/V_{tot} = 5.807 \text{ kg} \times 0.287 \frac{\text{kJ}}{\text{kg K}} \times 736 \text{ K}/ 2 \text{ m}^3 = \mathbf{613\ kPa}$$



5.112

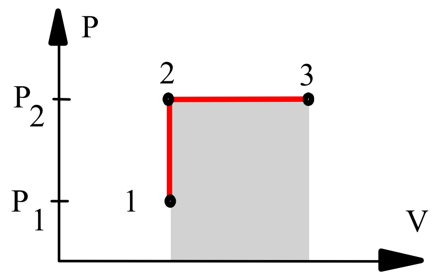
Find the specific heat transfer for the helium in Problem 4.62

A helium gas is heated at constant volume from a state of 100 kPa, 300 K to 500 K. A following process expands the gas at constant pressure to three times the initial volume. What is the specific work in the combined process?

Solution :

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

Energy Eq.5.11: $u_3 - u_1 = {}_1q_3 - {}_1w_3$



The two processes are:

1 -> 2: Constant volume $V_2 = V_1$

2 -> 3: Constant pressure $P_3 = P_2$

Use ideal gas approximation for helium.

State 1: T, P => $v_1 = RT_1/P_1$

State 2: $V_2 = V_1$ => $P_2 = P_1 (T_2/T_1)$

State 3: $P_3 = P_2$ => $V_3 = 3V_2$; $T_3 = T_2\, v_3/v_2 = 500 \times 3 = 1500$ K

We find the work by summing along the process path.

$${}_1w_3 = {}_1w_2 + {}_2w_3 = {}_2w_3 = P_3(v_3 - v_2) = R(T_3 - T_2)$$

$$= 2.0771(1500 - 500) = 2077 \text{ kJ/kg}$$

The heat transfer is from the energy equation

$${}_1q_3 = u_3 - u_1 + {}_1w_3 = C_{vo}\,(T_3 - T_1) + {}_1w_3$$

$$= 3.116\,(1500 - 300) + 2077 = \mathbf{5816\ kJ/kg}$$

5.113

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 500 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 = 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: $m_B = P_{B1}V_B/RT_{B1} = 500 \times 1/(0.287 \times 1000) = 1.742$ kg

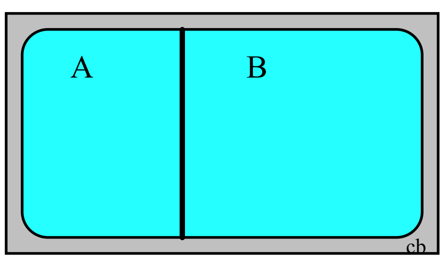
$u_{B1} = 759.189$ kJ/kg from Table A.7

$m_2 = m_A + m_B = 3.194$ kg

$$u_2 = \frac{m_A u_{A1} + m_B u_{B1}}{m_2} = \frac{1.452 \times 214.364 + 1.742 \times 759.189}{3.194} = 511.51 \text{ kJ/kg}$$

=> Table A.7.1: $\mathbf{T_2 = 698.6\ K}$

$P_2 = m_2 RT_2 /V = 3.194 \times 0.287 \times 698.6/1.5 =$ **426.9 kPa**



5.114

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: $V_2 = mRT_2/P_2 = 2 \times 0.18892 \times 313.15 /300 = 0.3944 \text{ m}^3$

$${}_1W_2 = \frac{1}{2}(500 + 300)(0.3944 - 0.5087) = -45.72 \text{ kJ}$$

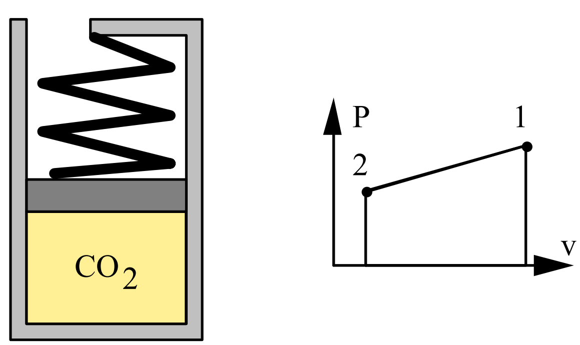
To evaluate $u_2 - u_1$ we will use the specific heat at the average temperature.

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

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = mC_{vo}(T_2 - T_1) + {}_1W_2$$

$$= 2 \times 0.83(40 - 400) - 45.72 = \mathbf{-643.3 \text{ kJ}}$$



Remark: We could also have used the ideal gas table in A.8 to get $u_2 - u_1$.

5.115

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.

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: $P = \text{constant} = F/A = P_1 \quad \text{if} \quad V > V\text{min}$

$V = \text{constant} = V_{1a} = V_{min} \quad \text{if} \quad P < P_1$

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 $V_2 = V_{1a} = V_{min} = 0.03\ m^3$.

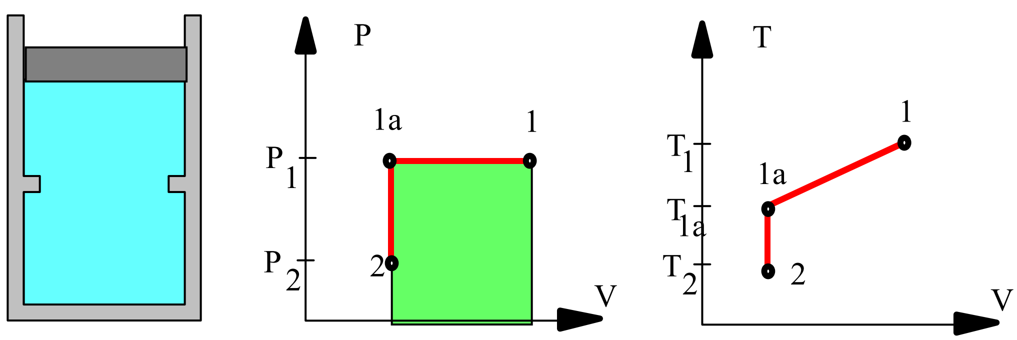
$$P_2 = P_1 \times \frac{T_2}{T_1} \times \frac{V_1}{V_2} = 2000 \times \frac{400}{1000} \times \frac{0.07175}{0.03} = 1913.3\ kPa$$

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,

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 0.5\ (286.49 - 759.19) - 83.5 = \mathbf{-319.85\ kJ}$$



5.116

A piston/cylinder contains 1.5 kg of air at 300 K and 150 kPa. It is now heated up in a two-step process. First constant volume to 1000 K (state 2) and then followed by a constant pressure process to 1500 K, state 3. Find the heat transfer for the process.

Solution:

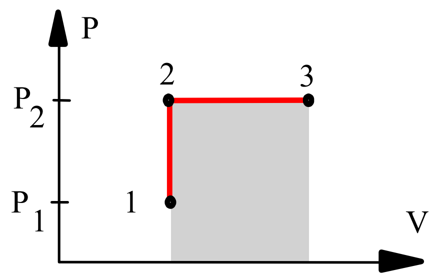
C.V. Helium. This is a control mass.

Energy Eq.5.11: $U_3 - U_1 = {}_1Q_3 - {}_1W_3$

The two processes are:

1 -> 2: Constant volume $V_2 = V_1$

2 -> 3: Constant pressure $P_3 = P_2$



Use ideal gas approximation for air.

State 1: T, P => $V_1 = mRT_1/P_1 = 1.5\times0.287\times300/150 = 0.861\ m^3$

State 2: $V_2 = V_1$ => $P_2 = P_1\ (T_2/T_1) = 150\times1000/300 = 500$ kPa

State 3: $P_3 = P_2$ => $V_3 = V_2\ (T_3/T_2) = 0.861\times1500/1000 = 1.2915\ m^3$

We find the work by summing along the process path.

$$ {}_1W_3 = {}_1W_2 + {}_2W_3 = {}_2W_3 = P_3(V_3 - V_2) $$

$$ = 500 \text{ kPa } (1.2915 - 0.861)\ m^3 = 215.3 \text{ kJ} $$

The heat transfer is from the energy equation and we will use Table A.7 for u

$$ {}_1Q_3 = U_3 - U_1 + {}_1W_3 = m\ (u_3 - u_1) + {}_1W_3 $$

$$ = 1.5\ (1205.25 - 214.36) + 215.3 = \mathbf{1701.6\ kJ} $$

Comment: We used Table A.7 due to the large temperature differences.

5.117

Air in a rigid tank is at 100 kPa, 300 K with a volume of 0.75 m^3. The tank is heated 400 K, state 2. Now one side of the tank acts as a piston letting the air expand slowly at constant temperature to state 3 with a volume of 1.5 m^3. Find the pressures at states 2 and 3, Find the total work and total heat transfer.

State 1: $m = P_1V_1 / RT_1 = \frac{100 \times 0.75}{0.287 \times 300} \frac{\text{kPa m}^3}{\text{kJ/kg}} = 0.871 \text{ kg}$

Process 1 to 2: Constant volume heating, $dV = 0 \;\Rightarrow\; {}_1W_2 = 0$

$$P_2 = P_1 T_2 / T_1 = 100 \times 400 / 300 = \mathbf{133.3\ kPa}$$

Process 2 to 3: Isothermal expansion, $dT = 0 \;\Rightarrow\; u_3 = u_2$ and

$$P_3 = P_2 V_2 / V_3 = 133.3 \times 0.75 / 1.5 = \mathbf{66.67\ kPa}$$

$${}_2W_3 = \int_2^3 P\, dV = P_2V_2 \ln\left(\frac{V_3}{V_2}\right) = 133.3 \times 0.75 \ln(2) = 69.3 \text{ kJ}$$

The overall process:

$${}_1W_3 = {}_1W_2 + {}_2W_3 = {}_2W_3 = \mathbf{69.3\ kJ}$$

From the energy equation

$${}_1Q_3 = m(u_3 - u_1) + {}_1W_3 = m\, C_v\, (T_3 - T_1) + {}_1W_3$$

$$= 0.871 \times 0.717\, (400 - 300) + 69.3 = \mathbf{131.8\ kJ}$$

5.118

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: $P = \text{constant}$ => ${}_1w_2 = P (v_2 - v_1)$

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

$$h_2 - h_1 \cong C_{po} (T_2 - T_1)$$

$$T_2 = T_1 + {}_1q_2 / C_{po} = 400 + 700 / 1.872 = 773.9\text{K} = \mathbf{500.8°C}$$

5.119

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 $Pv = RT \Rightarrow T_2 = T_1 v_2/v_1 = 2T_1 = \mathbf{1200\ K}$

$P_2 = P_1 = 200$ kPa, ${}_1w_2 = RT_1 = \mathbf{172.2\ kJ/kg}$

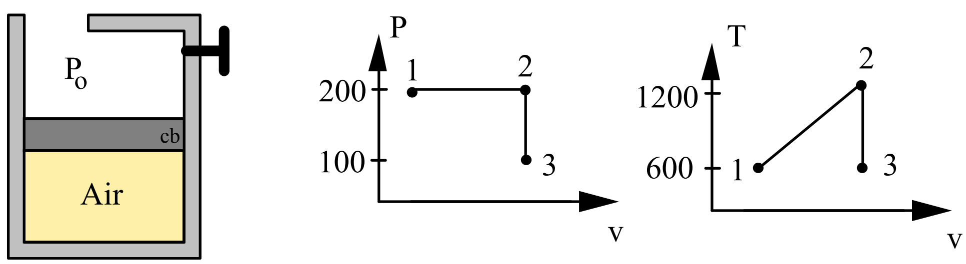
Table A.7 $\mathbf{h_2 = 1277.8\ kJ/kg}$, $\mathbf{h_3 = h_1 = 607.3\ kJ/kg}$

${}_1q_2 = u_2 - u_1 + {}_1w_2 = h_2 - h_1 = 1277.8 - 607.3 = \mathbf{670.5\ kJ/kg}$

Process 2→3: $v_3 = v_2 = 2v_1 \Rightarrow \mathbf{{}_2w_3 = 0},$

$P_3 = P_2T_3/T_2 = P_1T_1/2T_1 = P_1/2 = \mathbf{100\ kPa}$

${}_2q_3 = u_3 - u_2 = 435.1 - 933.4 = \mathbf{-498.3\ kJ/kg}$



5.120

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.

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

Process: $P = A + BV \;\Rightarrow\; {}_1W_2 = \int P\, dV = \text{area} = 0.5(P_1 + P_2)(V_2 - V_1)$

State 1: Ideal gas. $\quad V_1 = mRT_1/P_1 = 1.5\times 0.287 \times 300/160 = 0.8072 \text{ m}^3$

Table A.7 $\quad u_1 = u(300) = 214.36$ kJ/kg

State 2: $P_2V_2 = mRT_2$ $\quad$ so ratio it to the initial state properties

$$P_2V_2 /P_1V_1 = P_2 2 /P_1 = mRT_2 /mRT_1 = T_2 /T_1 \;\Rightarrow$$

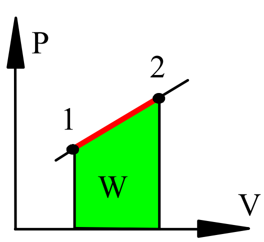
$$P_2 = P_1 (T_2 /T_1)(1/2) = 160 \times (900/300) \times (1/2) = 240 \text{ kPa}$$

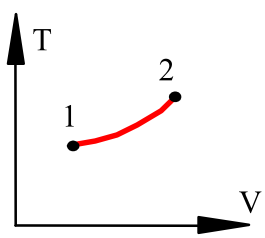
Work is done while piston moves at linearly varying pressure, so we get

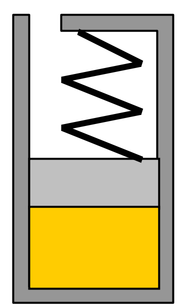
$${}_1W_2 = 0.5(P_1 + P_2)(V_2 - V_1) = 0.5\times(160 + 240) \text{ kPa} \times 0.8072 \text{ m}^3 = \mathbf{161.4\ kJ}$$

Heat transfer is found from energy equation

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 1.5\times(674.824 - 214.36) + 161.4 = \mathbf{852.1\ kJ}$$







Energy Equation: Polytropic Process

5.121

A helium gas in a piston cylinder is compressed from 100 kPa, 300 K to 200 kPa in a polytropic process with n = 1.5. Find the specific work and specific heat transfer.

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

Process Eq.: $Pv^n = \text{Constant}$ (polytropic)

We can calculate the actual specific work from Eq.4.5 and heat transfer from the energy equation be first finding T_2 as:

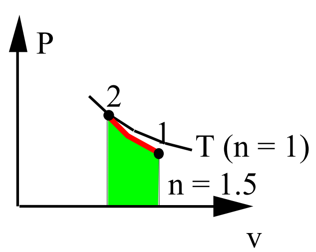
Process: $T_2 = T_1 (P_2/P_1)^{\frac{n-1}{n}} = 300\ (2)^{\frac{0.5}{1.5}} = 377.98\text{ K}$

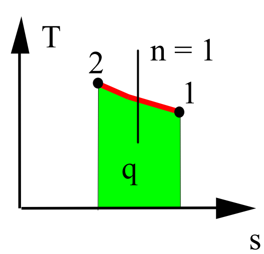
$${}_1w_2 = \frac{1}{1-n}(P_2v_2 - P_1v_1) = \frac{R}{1-n}(T_2 - T_1)$$

$$= \frac{2.0771}{1-1.5}(377.98 - 300) = -323.9\text{ kJ/kg}$$

$u_2 - u_1 = C_v(T_2 - T_1) = 242.99\text{ kJ/kg},$

Energy Eq.: ${}_1q_2 = u_2 - u_1 + {}_1w_2 = -80.9\text{ kJ/kg}$





Helium Table A.5

$k = \gamma = 1.667$ so $n < k$

$C_v = 3.116\text{ kJ/kgK},$

$R = 2.0771\text{ kJ/kgK}$

5.122

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

$$\Rightarrow m = \frac{P_1V_1}{RT_1} = \frac{300 \times 0.1 \text{ m}^3}{0.25983 \times 373.15} = 0.309 \text{ kg}$$

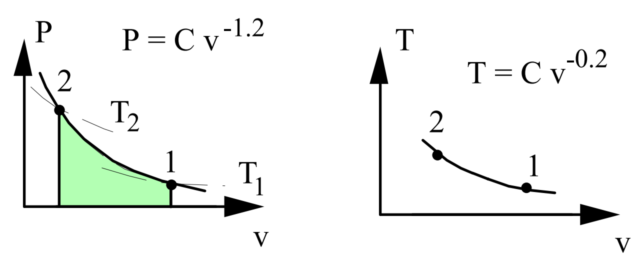
Process: PV^n = constant

$${}_1W_2 = \frac{1}{1\text{-}n}(P_2V_2 - P_1V_1) = \frac{mR}{1\text{-}n}(T_2 - T_1) = \frac{0.309 \times 0.25983}{1 - 1.2}(200 - 100)$$

$$= -40.2 \text{ kJ}$$

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 \cong mC_v(T_2 - T_1) + {}_1W_2$$

$$= 0.3094 \times 0.662\ (200 - 100) - 40.2 = \mathbf{-19.7\ kJ}$$



5.123

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

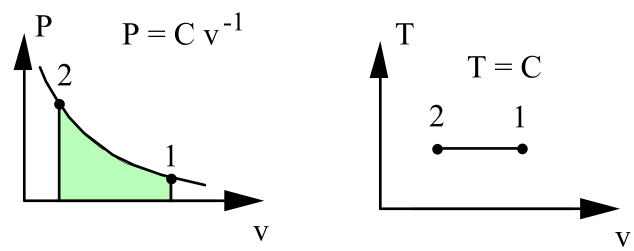
$$_1W_2 = \int P dV = \int \frac{mRT}{V} dV = mRT \ln \frac{V_2}{V_1} = mRT \ln \frac{P_1}{P_2}$$

$$= 0.1 \times 0.287 \times 300 \ln (100 / 250) = \mathbf{-7.89\ kJ}$$

since $T_1 = T_2 \Rightarrow u_2 = u_1$

The energy equation thus becomes

$$_1Q_2 = m \times (u_2 - u_1) + {_1W_2} = {_1W_2} = \mathbf{-7.89\ kJ}$$



5.124

A piston cylinder contains 0.1 kg nitrogen at 100 kPa, 27°C and it is now compressed in a polytropic process with n = 1.25 to a pressure of 250 kPa. Find the heat transfer.

Take CV as the nitrogen. $m_2 = m_1 = m$;

Process Eq.: $Pv^n = \text{Constant}$ (polytropic)

From the ideal gas law and the process equation we can get:

State 2: $$T_2 = T_1 \left(P_2 / P_1\right)^{\frac{n-1}{n}} = 300.15 \left(\frac{250}{100}\right)^{\frac{0.25}{1.25}} = 360.5 \text{ K}$$

From process eq.:

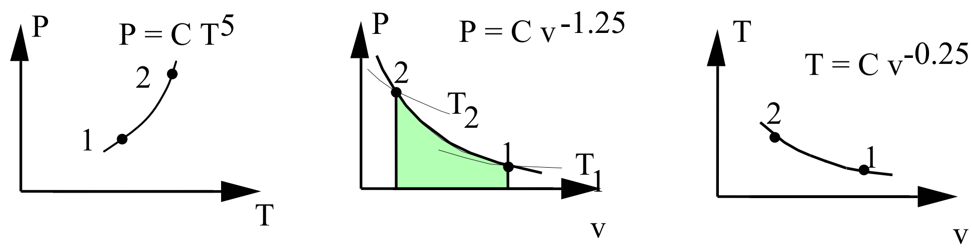
$$_1W_2 = \int P\,dV = \text{area} = \frac{m}{1-n}(P_2v_2 - P_1v_1) = \frac{mR}{1-n}(T_2 - T_1)$$

$$= \frac{0.1 \times 0.2968}{1 - 1.25}(360.5 - 300.15) = -7.165 \text{ kJ}$$

From energy eq.:

$$_1Q_2 = m(u_2 - u_1) + {}_1W_2 = mC_v(T_2 - T_1) + {}_1W_2$$

$$= 0.1 \times 0.745(360.5 - 300.15) - 7.165 = \mathbf{-2.67\ kJ}$$



5.125

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

$${}_1W_2 = \frac{P_2V_2 - P_1 V_1}{1-n} = \frac{100\times 0.2852 - 125\times 0.25}{1 - 1.667} \text{ kPa m}^3 = 4.09 \text{ kJ}$$

Use specific heat from Table A.5 to evaluate $u_2 - u_1$**,** $C_v = 3.116$ kJ/kg K

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = m\, C_v\, (T_2 - T_1) + {}_1W_2$$
$$= 0.043 \times 3.116 \times (319.4 - 350) + 4.09 = \mathbf{-0.01\ kJ}$$

5.126

Find the specific heat transfer for problem 4.52

Air goes through a polytropic process from 125 kPa, 325 K to 300 kPa and 500 K. Find the polytropic exponent n and the specific work in the process.

Solution:

Process: $Pv^n = \text{Const} = P_1 v_1^n = P_2 v_2^n$

Ideal gas $Pv = RT$ so

$$v_1 = \frac{RT}{P} = \frac{0.287 \times 325}{125} = 0.7462 \text{ m}^3\text{/kg}$$

$$v_2 = \frac{RT}{P} = \frac{0.287 \times 500}{300} = 0.47833 \text{ m}^3\text{/kg}$$

From the process equation

$$(P_2/P_1) = (v_1/v_2)^n \quad \Rightarrow \quad \ln(P_2/P_1) = n \ln(v_1/v_2)$$

$$n = \ln(P_2/P_1) \Big/ \ln(v_1/v_2) = \frac{\ln 2.4}{\ln 1.56} = 1.969$$

The work is now from Eq.4.4 per unit mass

$$_1w_2 = \frac{P_2v_2 - P_1v_1}{1-n} = \frac{R(T_2 - T_1)}{1-n} = \frac{0.287(500 - 325)}{1-1.969} = -51.8 \text{ kJ/kg}$$

The energy equation (per unit mass) gives

$$_1q_2 = (u_2 - u_1) + {_1w_2} \cong C_v(T_2 - T_1) + {_1w_2}$$

$$= 0.717\ (500 - 325) - 51.8 = \mathbf{73.67\ kJ/kg}$$

5.127

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

$${}_1w_2 = \int P dv = \frac{1}{1 - n} (P_2v_2 - P_1v_1) = \frac{R}{1 - n} (T_2 - T_1)$$

$$= \frac{0.2968}{1 - 1.2}(668 - 750) = \mathbf{121.7\ kJ/kg}$$

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

$${}_1q_2 = C_v(T_2 - T_1) + {}_1w_2 = 0.745(668 - 750) + 121.7 = \mathbf{60.6\ kJ/kg}$$

5.128

A gasoline engine has a piston/cylinder with 0.1 kg air at 4 MPa, 1527^{o}C after combustion and this is expanded in a polytropic process with n = 1.5 to a volume 10 times larger. Find the expansion work and heat transfer using Table A.5 heat capacity.

Take CV as the air. $m_2 = m_1 = m$;

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

Process Eq.: $Pv^n = \text{Constant}$ (polytropic)

From the ideal gas law and the process equation we can get:

State 2: $P_2 = P_1 \left(v_2 / v_1\right)^{-n} = 4000 \times 10^{-1.5} = 126.5 \text{ kPa}$

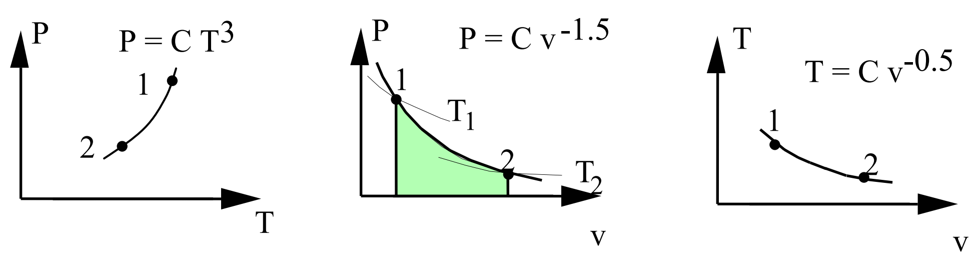
$$T_2 = T_1 \ (P_2v_2 / P_1v_1) = (1527 + 273) \frac{126.5 \times 10}{4000} = 569.3 \text{ K}$$

From process eq.: $${}_1W_2 = \int P\, dV = \frac{m}{1-n} (P_2v_2 - P_1v_1) = \frac{mR}{1-n} (T_2 - T_1)$$

$$= \frac{0.1 \times 0.287}{1 - 1.5} (569.3 - 1800) = \mathbf{70.64\ kJ}$$

From energy eq.: $${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = mC_v(T_2 - T_1) + {}_1W_2$$

$$= 0.1 \times 0.717(569.3 - 1800) + 70.64 = \mathbf{-17.6\ kJ}$$



5.129

Solve the previous problem using Table A.7

Take CV as the air. $m_2 = m_1 = m$;

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

Process Eq.: $Pv^n = \text{Constant}$ (polytropic)

From the ideal gas law and the process equation we can get:

State 2: $P_2 = P_1 \left(v_2 / v_1\right)^{-n} = 4000 \times 10^{-1.5} = 126.5 \text{ kPa}$

$$T_2 = T_1 \ (P_2v_2 / P_1v_1) = (1527 + 273) \frac{126.5 \times 10}{4000} = 569.3 \text{ K}$$

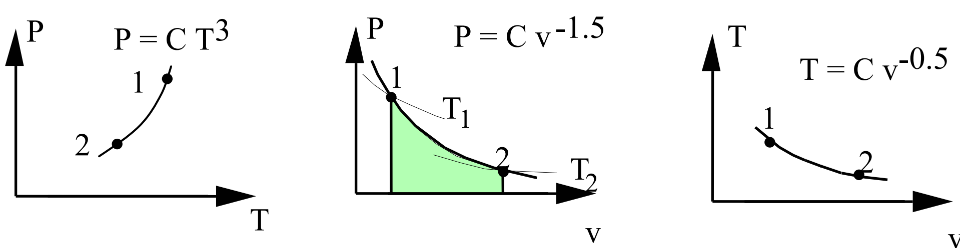
From process eq.: $${}_1W_2 = \int P\, dV = \frac{m}{1-n} (P_2v_2 - P_1v_1) = \frac{mR}{1-n} (T_2 - T_1)$$

$$= \frac{0.1 \times 0.287}{1 - 1.5} (569.3 - 1800) = \mathbf{70.64 \ kJ}$$

From energy eq.: $${}_1Q_2 = m(u_2 - u_1) + {}_1W_2$$

$$= 0.1\ (411.78 - 1486.33) + 70.64 = \mathbf{-36.8 \ kJ}$$

The only place where Table A.7 comes in is for values of u_1 and u_2



5.130

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 ,

$$m = V/v_1 = 0.025/0.19405 = 0.129 \text{ kg}$$

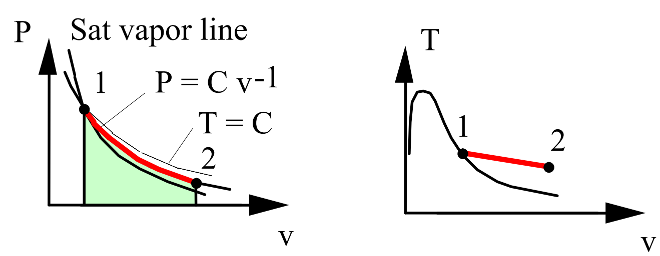
Process: $Pv = \text{const.} = P_1v_1 = P_2v_2$; polytropic process $n = 1$.

$$\Rightarrow v_2 = v_1P_1/P_2 = 0.19405 \times 1002.1/200 = 0.9723 \text{ m}^3\text{/kg}$$

State 2: $P_2, v_2 \Rightarrow$ Table B.1.3 $T_2 \cong 155°C$, $u_2 = 2585$ kJ/kg

$$_1W_2 = \int PdV = P_1V_1 \ln\frac{v_2}{v_1} = 1002.2 \text{ kPa} \times 0.025 \text{ m}^3 \ln\frac{0.9723}{0.19405} = 40.37 \text{ kJ}$$

$$_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 0.129(2585 - 2583.7) + 40.37 = \mathbf{40.54\ kJ}$$



Notice T drops, it is not an ideal gas.

5.131

A piston/cylinder in a car contains 0.2 L of air at 90 kPa, 20°C, shown in Fig. P5.131. 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: $m_2 = m_1$

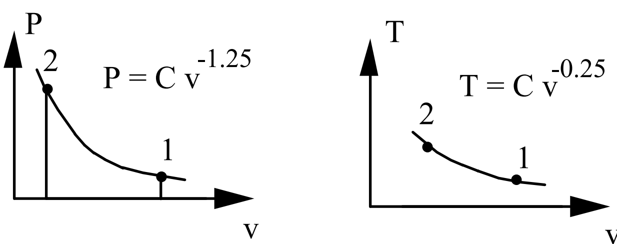
Energy Eq.5.11: $m(u_2 - u_1) = {}_1Q_2 - {}_1W_2$

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: $Pv = RT$

$$T_2 = T_1(P_2v_2/P_1v_1) = 293.15(845.15/90 \times 6) = \mathbf{458.8\ K}$$



$$m = \frac{PV}{RT} = \frac{90 \times 0.2{\times}10^{-3}}{0.287 \times 293.15} = 2.14{\times}10^{-4}\ \text{kg}$$

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

$${}_1q_2 = u_2 - u_1 + {}_1w_2 = 329.4 - 208.03 - 190.17 = -68.8\ \text{kJ/kg}$$

$${}_1Q_2 = m\ {}_1q_2 = \mathbf{-0.0147\ kJ} \quad \text{(i.e a heat loss)}$$

5.132

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: $P = P_{ext} = CV^2 \Rightarrow \quad PV^{-2} = \text{constant}$, 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

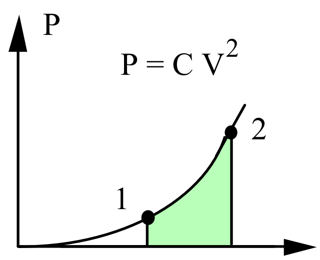
$${}_1W_2 = \int_1^2 PdV = \frac{P_2V_2 - P_1V_1}{1 - n} = \frac{mR(T_2 - T_1)}{1 - n}$$

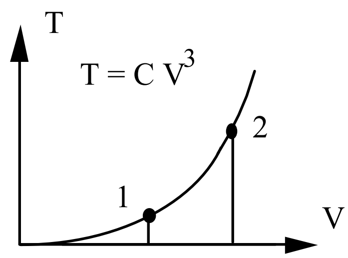
$$= \frac{1\times 0.18855 \times (700-40)}{1-(-2)} = \mathbf{41.48\ kJ}$$

The energy equation with specific heat from Table A.5 becomes

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = mC_v(T_2 - T_1) + {}_1W_2$$

$$= 1 \times 1.490 \times (700 - 40) + 41.48 = \mathbf{1024.9\ kJ}$$





5.133

A piston cylinder contains pure oxygen at ambient conditions 20°C, 100 kPa. The piston is moved to a volume that is 7 times smaller than the initial volume in a polytropic process with exponent n = 1.25. Use constant heat capacity to find the final pressure and temperature, the specific work and the specific heat transfer.

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

Process Eq: $Pv^n = C;\quad P_2 = P_1 (v_1/v_2)^n = 100\ (7)^{1.25} = 1138.6$ kPa

From the ideal gas law and state 2 (P, v) we get

$$T_2 = T_1(P_2/P_1)(v_1/v_2) = 293 \times \frac{1138.6}{100} \times (1/7) = 476.8 \text{ K}$$

We could also combine process eq. and gas law to give: $T_2 = T_1 (v_1/v_2)^{n-1}$

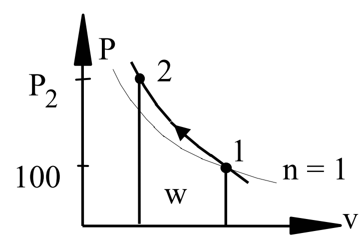
Polytropic work Eq. 4.5: $${}_1w_2 = \frac{1}{1-n} (P_2v_2 - P_1v_1) = \frac{R}{1-n} (T_2 - T_1)$$

$${}_1w_2 = \frac{0.2598}{1 - 1.25}\ \frac{\text{kJ}}{\text{kg K}} \times (476.8 - 293.2) \text{ K} = \mathbf{-190.88\ kJ/kg}$$

$${}_1q_2 = u_2 - u_1 + {}_1w_2 = C_v (T_2 - T_1) + {}_1w_2$$

$$= 0.662\ (476.8 - 293.2) - 190.88 = \mathbf{-69.3\ kJ/kg}$$

The actual process is on a steeper curve than n = 1.



5.134

An air pistol contains compressed air in a small cylinder, shown in Fig. P5.134. 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: $PV = \text{const} = P_1V_1 = P_2V_2 \Rightarrow V_2 = V_1P_1/P_2 = \mathbf{10\ cm^3}$

$${}_1W_2 = \int PdV = \int \frac{P_1V_1}{V} dV = P_1V_1 \ln (V_2/V_1) = \mathbf{2.303\ J}$$

$${}_1W_{2,ATM} = P_0(V_2 - V_1) = 101 \times (10 - 1) \times 10^{-6} \text{ kJ} = \mathbf{0.909\ J}$$

$$W_{bullet} = {}_1W_2 - {}_1W_{2,ATM} = 1.394 \text{ J} = \frac{1}{2} m_{bullet}(V_{exit})^2$$

$$V_{exit} = (2W_{bullet}/m_B)^{1/2} = (2 \times 1.394/0.015)^{1/2} = \mathbf{13.63\ m/s}$$

5.135

Calculate the heat transfer for the process described in Problem 4.58.

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

$v_1 = 0.09921\ m^3/kg, \quad u_1 = 372.27$ kJ/kg

2: (P, process)

$$v_2 = v_1 (P_1/P_2)^{(1/1.5)} = 0.09921\times (201.7/500)^{0.667} = 0.05416\ m^3/kg$$

=> Table B.5.2 superheated vapor, $T_2 = 79°C$, $V_2 = mv_2 = 0.027\ m^3$

$u_2 = 440.9$ kJ/kg

Process gives $P = C\ v^{(-1.5)}$, which is integrated for the work term, Eq.4.4

$${}_1W_2 = \int P\ dV = m(P_2v_2 - P_1v_1)/(1-1.5)$$

$$= -2\times0.5\times (500\times0.05416 - 201.7\times0.09921) = -7.07 \text{ kJ}$$

${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 0.5(440.9 - 372.27) + (-7.07) =$ **27.25 kJ**

Energy Equation in Rate Form

5.136

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

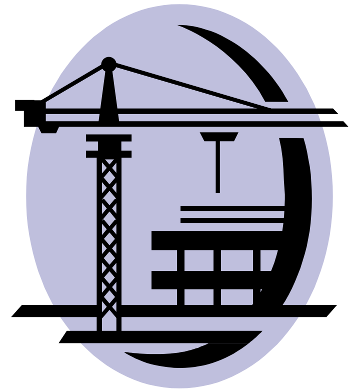
$$\text{Power} = \dot{W} = F\mathbf{V} = mg\mathbf{V} = mg\frac{L}{t}$$

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

5.137

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

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

$\mathbf{V} = \frac{\dot{W}}{mg} = \frac{1000}{450 \times 9.806} \frac{W}{N} = \mathbf{0.227\ m/s}$

5.138

A pot of 1.2 kg water at 20^{o}C is put on a stove supplying 1250 W to the water. What is the rate of temperature increase (K/s)?

Energy Equation on a rate form: $\frac{dE_{water}}{dt} = \frac{dU_{water}}{dt} = \dot{Q} - \dot{W} = \dot{Q} - P\dot{V}$

$$\dot{Q} = \frac{dU_{water}}{dt} + P\dot{V} = \frac{dH_{water}}{dt} = m_{water}C_p \frac{dT_{water}}{dt}$$

$$\frac{dT_{water}}{dt} = \dot{Q} / m_{water}C_p = 1.250 / (1.2 \times 4.18\ ) = \mathbf{0.2492\ K/s}$$

5.139

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:

$$\dot{Q} = n\,\dot{q} = 100 \times 400 = \mathbf{40\ 000\ kJ/h} = \mathbf{666.7\ kJ/min}$$

$$\frac{dE_{air}}{dt} = \dot{Q} = m_{air} C_v \frac{dT_{air}}{dt}$$

$$m_{air} = PV/RT = 101 \times 1500 / 0.287 \times 300 = 1759.6\ kg$$

$$\frac{dT_{air}}{dt} = \dot{Q}/mC_v = 666.7 / (1759.6 \times 0.717) = \mathbf{0.53°C/min}$$

5.140

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?

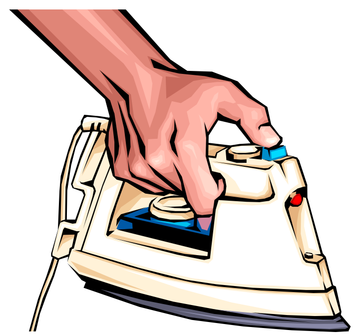
To answer this we must assume all the power goes into the water and that the process takes place at atmospheric pressure 101 kPa, so T = 100°C.

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

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

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

5.141

A pot of 1.2 kg water at 20^oC is put on a stove supplying 1250 W to the water. After how long time can I expect it to come to a boil (100^oC)?

Energy Equation on a rate form: $$\frac{dE_{water}}{dt} = \frac{dU_{water}}{dt} = \dot{Q} - \dot{W} = \dot{Q} - P\dot{V}$$

$$\dot{Q} = \frac{dU_{water}}{dt} + P\dot{V} = \frac{dH_{water}}{dt} = m_{water}C_p\frac{dT_{water}}{dt}$$

Integrate over time

$$Q = \dot{Q}\,\Delta t = \Delta H = m_{water}\,(h_2 - h_1) \approx m_{water}C_p\,(T_2 - T_1)$$

$$\Delta t = m_{water}\,(h_2 - h_1)/\dot{Q} \approx m_{water}C_p\,(T_2 - T_1)/\dot{Q}$$

$$= 1.2\,(419.02 - 83.94)/1.25 \;\approx\; 1.2 \times 4.18\,(100 - 20)/1.25$$

$$= \mathbf{321.7\ s} \;\approx\; 5.5\ \text{min}$$

Comment: Notice how close the two results are, i.e. use of constant C_p is OK.

5.142

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

Process: V = C → $_1W_2 = 0$

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

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

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

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%.

5.143

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.

$V_{wood} = m/\rho = 50/510 = 0.098\ m^3$; $V_{steel} = 25/7820 = 0.003\ m^3$

$V_{air} = 200 - 0.098 - 0.003 = 199.899\ m^3$

$$m_{air} = PV/RT = 101.325 \times 199.899/(0.287 \times 300) = 235.25 \text{ kg}$$

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**

5.144

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

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

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

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

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

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

5.145

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: $\dot{m}_{tot} = 0 = \dot{m}_{vapor} + \dot{m}_{liq} \quad \Rightarrow \quad \dot{m}_{liq} = -\dot{m}_{vapor}$

Energy Eq.: $\frac{dE}{dt} = \frac{d}{dt}(m_{vapor}u_g + m_{liq}u_f) = \dot{m}_{vapor}(u_g - u_f) = \dot{m}_{vapor}u_{fg} = \dot{Q} - \dot{W}$

$V_{vapor} = m_{vapor} v_g$, $\quad V_{liq} = m_{liq} v_f$; $\quad V_{tot} = V_{vapor} + V_{liq}$

$\dot{V}_{tot} = \dot{V}_{vapor} + \dot{V}_{liq} = \dot{m}_{vapor}v_g + \dot{m}_{liq}v_f = \dot{m}_{vapor} (v_g - v_f) = \dot{m}_{vapor} v_{fg}$

$\dot{W} = P\dot{V} = P\,\dot{m}_{vapor} v_{fg}$

Substitute the rate of work into the energy equation and solve for the heat transfer

$\dot{Q} = \dot{m}_{vapor}u_{fg} + \dot{W} = \dot{m}_{vapor}u_{fg} + P\,\dot{m}_{vapor} v_{fg} = \dot{m}_{vapor} h_{fg}$

$= 0.001 \times 2114.26 =$ **2.114 kW**

5.146

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:

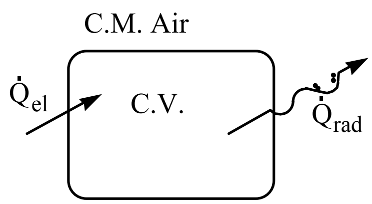
$m = 4 \times 75 = 300 \text{ kg}$; $\Delta Z = 100 \text{ m}$; $\Delta t = 2 \text{ minutes}$

$$-\dot{W} = \Delta \dot{PE} = mg \frac{\Delta Z}{\Delta t} = \frac{300 \times 9.807 \times 100}{1000 \times 2 \times 60} = \mathbf{2.45\ kW}$$

5.147

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: $\frac{dM}{dt} = 0$ $\quad\quad \dot{W} = 0$

Energy Eq: $\frac{dE}{dt} = \dot{Q}_{el} - \dot{Q}_{rad}$ $\quad\quad \dot{KE} = 0$, $\dot{PE} = 0$

$$\dot{E} = \dot{U} = \dot{Q}_{el} - \dot{Q}_{rad} = \dot{Q}_{net} \Rightarrow \quad U_2 - U_1 = m(u_2 - u_1) = \dot{Q}_{net}(t_2 - t_1)$$

$$\text{Ideal gas: } m = \frac{P_1V_1}{RT_1} = \frac{100 \times 10}{0.287 \times 298.15} = 11.688 \text{ kg}$$

$$m(u_2 - u_1) = m\, C_{v0}(T_2 - T_1) = 11.688 \times 0.717\ (-20 - 25) = -377.1 \text{ kJ}$$

$$t_2 - t_1 = m\,(u_2 - u_1)/\dot{Q}_{net} = \ (-377.1 \text{ kJ})\ /(-25 \text{ kJ/h}) = \mathbf{15.08\ h}$$

5.148

A steam generating unit heats saturated liquid water at constant pressure of 800 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

$$\dot{U} = (\dot{m}u) = \dot{m}\Delta u = \dot{Q} - \dot{W} = \dot{Q} - P\dot{V} = \dot{Q} - P\,\dot{m}\Delta v$$

Rearrange to solve for heat transfer rate

$$\dot{Q} = \dot{m}(\Delta u + \Delta vP) = \dot{m}\,\Delta h = \dot{m}\,h_{fg}$$

So now

$$\dot{m} = \dot{Q}/\,h_{fg} = 1500 / 2048.04 = \mathbf{0.732\ kg/s}$$

5.149

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:

$\dot{U} = (m\dot{u}) = mC_V\dot{T} = \dot{Q} = m\dot{q}$

$\dot{T} = \dot{q}/C_V = 2\times10^{-3} / 0.9$

$\quad = 2.222 \times 10^{-3}$ °C/sec

$\Delta T = \dot{T}\Delta t = 2.222 \times 10^{-3} \times 3600 =$ **8 °C**

5.150

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 $\dot{m}_{vapor}$

$$\dot{m}_{vapor}\,(u_{fg} + Pv_{fg}) = \dot{m}_{vapor}\, h_{fg} = \dot{Q}$$

$$\dot{m}_{vapor} = \dot{Q}/h_{fg} = \frac{2.5}{2066.3}\,\frac{\text{kW}}{\text{kJ/kg}} = \mathbf{0.0012\ kg/s}$$

5.151

A 500 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 saturated solid at same temperature.

$v = v_i(-10) = 0.0010891 \text{ m}^3\text{/kg}, \;\; h = h_i = -354.09 \text{ kJ/kg}$

State 2: Compressed liquid, take saturated liquid at same temperature

$v = v_f = 0.001, \;\; h = h_f = 20.98 \text{ kJ/kg}$

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

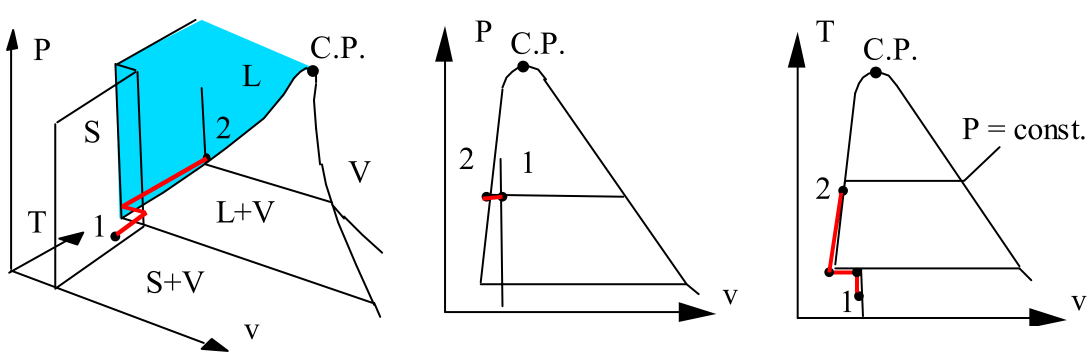
$${}_1W_2 = \int P\, dV = \text{area} = P(V_2 - V_1) = -150 \times 0.000178 = -0.027 \text{ kJ} = -27 \text{ J}$$

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

$$t = {}_1Q_2/\dot{Q} = (750 \text{ kJ }/500 \text{ W}) \times 1000 \text{ J/kJ} = 1500 \text{ s} = \mathbf{25\ min}$$



Problem Analysis (no numbers required)

5.152

Consider Problem 5.57 with the steel bottle as C.V. Write the process equation that is valid until the valve opens and plot the P-v diagram for the process.

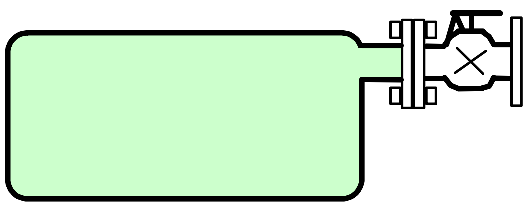
Process: constant volume process

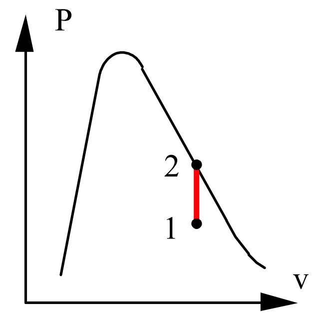
constant mass

$V = mv = C \quad \Rightarrow \quad v_2 = v_1$

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

State 1: (T, x) so two-phase in Table B.3.1





5.153

Consider Problem 5.50. Take the whole room as a C.V. and write both conservation of mass and energy equations. Write some equations for the process (two are needed) and use those in the conservation equations. Now specify the four properties that determines initial (2) and final state (2), do you have them all? Count unknowns and match with equations to determine those.

C.V.: Containment room and reactor.

Mass: $m_2 - m_1 = 0$; $m_2 = m_1 = V_{reactor}/v_1$

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

Process: Room volume constant $V = C$ ⇨ ${}_1W_2 = 0$

Room insulated ⇨ ${}_1Q_2 = 0$

Using these in the equation for mass and energy gives:

$m_2 = V_2/v_2 = m_1$; $m(u_2 - u_1) = 0 - 0 = 0$

State 1: P_1, T_1 so Table B.1.4 gives v_1, u_1 ⇨ m_1

State 2: P_2, ?

We do not know **one** state 2 property and the total room volume

Energy equation then gives $u_2 = u_1$ (a state 2 property)

State 2: P_2, u_2 ⇨ v_2

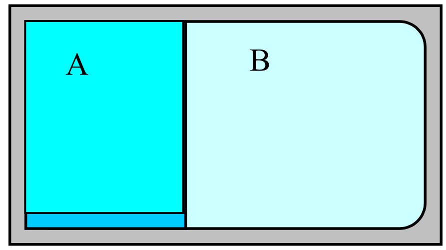
Now we have the room volume as

Continuity Eq.: $m_2 = V/v_2 = m_1$ so $V = m_1 v_2$

5.154

Take problem 5.61 and write the left hand side (storage change) of the conservation equations for mass and energy. How do you write m_1 and Eq. 5.5?

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



Continuity Eq.: $m_2 - m_{A1} - m_{B1} = 0$;

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

Notice how the state 1 term split into two terms

$$m_1 = \int \rho\, dV = \int (1/v)\, dV = V_A/v_{A1} + V_B/v_{B1} = m_{A1} + m_{B1}$$

and for energy as

$$m_1u_1 = \int \rho u\, dV = \int (u/v)\, dV = (u_{A1}/v_{A1})V_A + (u_{B1}/v_{B1})V_B$$

$$= m_{A1}u_{A1} + m_{B1}u_{B1}$$

Formulation continues as:

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

$$m_2 = m_{A1} + m_{B1} \;\Rightarrow\; v_2 = V_{tot}/m_2$$

etc.

5.155

Consider Problem 5.70 with the final state given but that you were not told the piston hits the stops and only told $V_{stop} = 2\ V_1$. Sketch the possible P-v diagram for the process and determine which number(s) you need to uniquely place state 2 in the diagram. There is a kink in the process curve what are the coordinates for that state? Write an expression for the work term.

C.V. R-410a. Control mass goes through process: 1 -> 2 -> 3

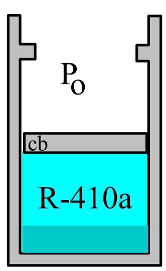
As piston floats pressure is constant (1 -> 2) and the volume is constant for the second part (2 -> 3). So we have: $v_3 = v_2 = 2 \times v_1$

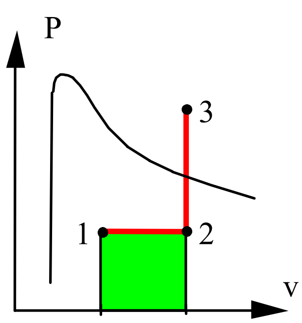
State 2: $V_2 = V_{stop} \;\Rightarrow\; v_2 = 2 \times v_1 = v_3$ and $P_2 = P_1 \;\Rightarrow\; T_2 = \dots$

State 3: Table B.4.2 (P, T) Compare $P_3 > P_2$ and $T_3 > T_2$

$v_3 = 0.02015\ m^3/kg,\ u_3 = 248.4\ kJ/kg$

$W = \int P\, dV = P(V_2 - V_1) = Pm\,(v_2 - v_1)$





5.156

Look at problem 5.115 and plot the P-v diagram for the process. Only T_2 is given, how do you determine the 2nd property of the final state? What do you need to check and does it have an influence on the work term?

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) $V_1 = mRT_1/P_1 = 0.5 \times 0.287 \times 1000/2000 = 0.07175 \text{ m}^3$

The only possible P-V combinations for this system are 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: $P_{1a} = P_1$, $V_{1a} = V_{min}$, Ideal gas so $T_{1a} = T_1 \dfrac{V_{1a}}{V_1}$

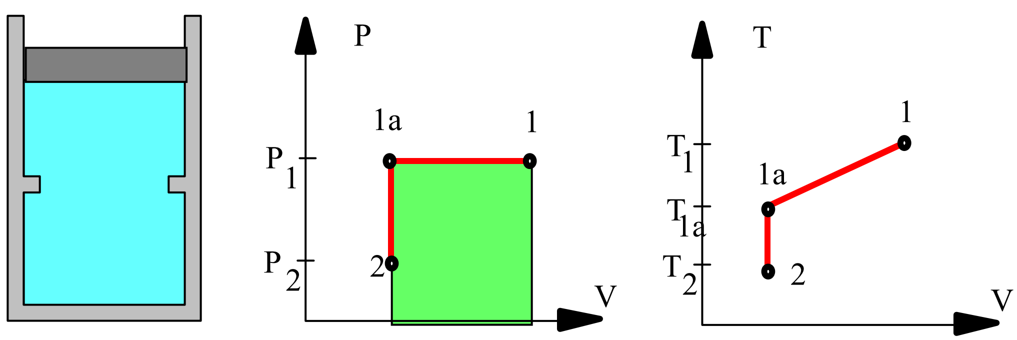
We see if $T_2 < T_{1a}$ then state 2 must have $V_2 = V_{1a} = V_{min} = 0.03 \text{ m}^3$. So state 2 is known by (T_2, v_2) and $P_2 = P_1 \times \dfrac{T_2}{T_1} \times \dfrac{V_1}{V_2}$

If it was that $T_2 > T_{1a}$ then we know state 2 as: $T_2, P_2 = P_1$ and we then have

$$V_2 = V_1 \times \frac{T_2}{T_1}$$

The work is the area under the process curve in the P-V diagram and so it does make a difference where state 2 is relative to state 1a. For the part of the process that proceeds along the constant volume V_{min} the work is zero there is only work when the volume changes.

$$_1W_2 = \int_1^2 P\, dV = P_1 (V_{1a} - V_1)$$



Review

5.157

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

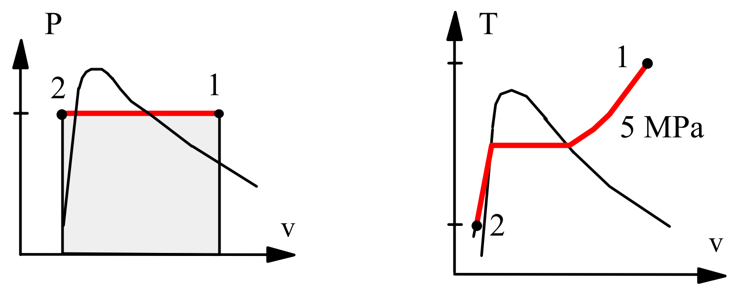
Process: $P = C \quad \Rightarrow \quad {}_1W_2 = mP(v_2 - v_1)$

State 1: $(T, v_1 = 0.633/10 = 0.0633 \text{ m}^3/\text{kg})$ Table B.1.3

$P_1 = 5 \text{ MPa}, \quad h_1 = 3316.2 \text{ kJ/kg}$

State 2: (P = P = 5 MPa, 20°C) $\Rightarrow$ Table B.1.4

$v_2 = 0.000\ 999\ 5 \text{ m}^3/\text{kg}; \qquad h_2 = 88.65 \text{ kJ/kg}$



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

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

$${}_1Q_2 = 10 \times (88.65 - 3316.2) = \mathbf{-32276\ kJ}$$

5.158

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:

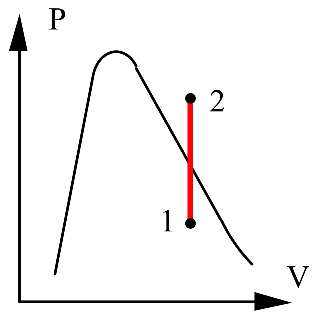
Continuity Eq.: $m_2 = m_1$;

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

$$P_2 = 1000 + 200 \frac{0.14538 - 0.17389}{0.14347 - 0.17389} = \mathbf{1187\ kPa}$$



$u_2 = 1490.5 + (1485.8 - 1490.5) \times 0.935$

$= 1485.83$ 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

$${}_1q_2 = u_2 - u_1 = 1485.83 - 748.84 = \mathbf{737\ kJ/kg}$$

5.159

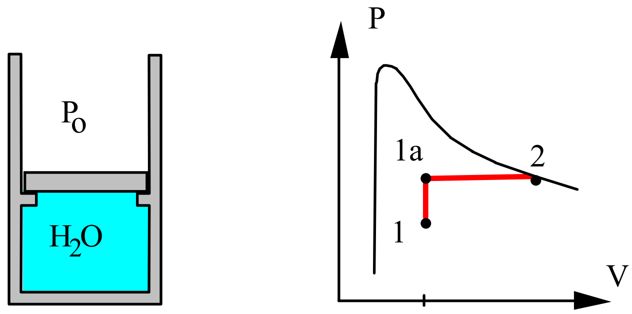
Find the heat transfer in Problem 4.122.

A piston/cylinder (Fig. P4.122) 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

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

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

To find state 2 check on state 1a:

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

Table B.1.2: $v_f < v < v_g = 0.4625$ 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 , $V_2 = m\, v_2 = 0.4625$ m^3, $u_2 = u_g = 2553.6$ kJ/kg

Pressure is constant as volume increase beyond initial volume.

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

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

5.160

A piston/cylinder contains 1 kg of ammonia at 20°C with a volume of 0.1 m^3, shown in Fig. P5.160. 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.

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

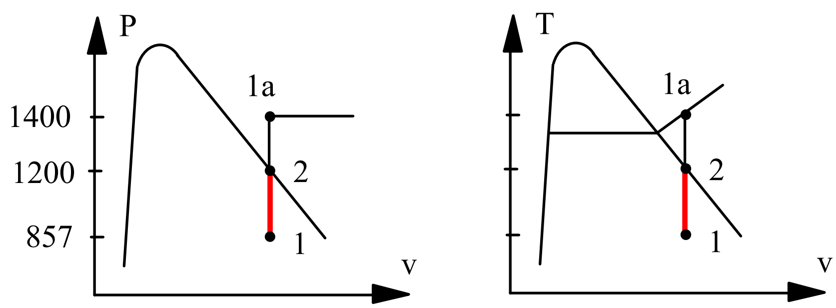
State 1: 20°C; $v_1 = 0.10 < v_g \;\Rightarrow\; x_1 = (0.1 - 0.001638)/0.14758 = 0.6665$

$$u_1 = u_f + x_1\, u_{fg} = 272.89 + 0.6665 \times 1059.3 = 978.9 \text{ kJ/kg}$$

Process: Piston starts to lift at state 1a (P_{lift}, v_1)

State 1a: 1400 kPa, v_1 Table B.2.2 (superheated vapor)

$$T_a = 50 + (60 - 50)\,\frac{0.1 - 0.09942}{0.10423 - 0.09942} = 51.2 \text{ °C}$$



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**

5.161

Consider the system shown in Fig. P5.161. 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

$$m = V/v_1 = 0.1 / 0.02671 = 3.744 \text{ kg}$$

State 2: 30°C, 200 kPa superheated vapor Table B.5.2

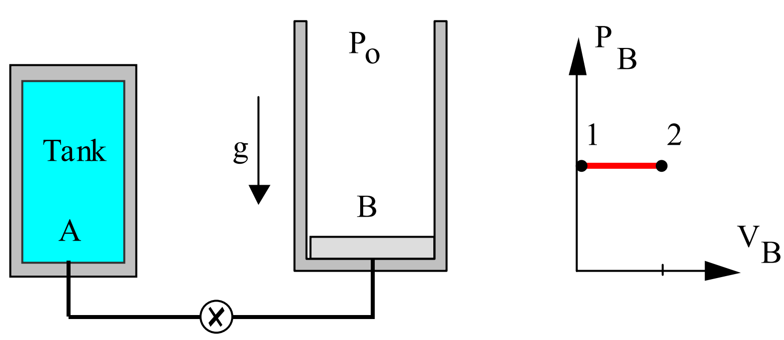
$$v_2 = 0.11889 \text{ m}^3/\text{kg}, \quad u_2 = 403.1 \text{ kJ/kg}$$

From the process equation

${}_1W_2 = P_{float} m(v_2 - v_1) = 200 \times 3.744 \times (0.11889 - 0.02671) = 69.02$ kJ

From the energy equation

${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 3.744 \times (403.1 - 394.48) + 69.02 =$ **101.3 kJ**



5.162

Water in a piston/cylinder, similar to Fig. P5.160, is at 100^{o}C, x = 0.5 with mass 1 kg and the piston rests on the stops. The equilibrium pressure that will float the piston is 300 kPa. The water is heated to 300^{o}C by an electrical heater. At what temperature would all the liquid be gone? Find the final (P,v), the work and heat transfer in the process.

C.V. The 1 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.

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

$$v_1 = 0.001044 + 0.5 \times 1.6719 = 0.83697 \text{ m}^3/\text{kg}$$

$$u_1 = 418.91 + 0.5 \times 2087.58 = 1462.7 \text{ kJ/kg}$$

State 1a: (300 kPa, $v = v_1 > v_{g\ 300\ kPa} = 0.6058 \text{ m}^3/\text{kg}$) so superheated vapor

Piston starts to move at state 1a, ${}_1W_{1a} = 0$, $u_{1a} = 2768.82$ kJ/kg

$${}_1Q_{1a} = m(u – u) = 1\ (2768.82 – 1462.7) = 1306.12 \text{ kJ}$$

State 1b: reached before state 1a so $v = v_1 = v_g$ see this in B.1.1

$$T_{1b} = 120 + 5\ (0.83697 – 0.8908)/(0.76953 – 0.8908) = \mathbf{122.2^oC}$$

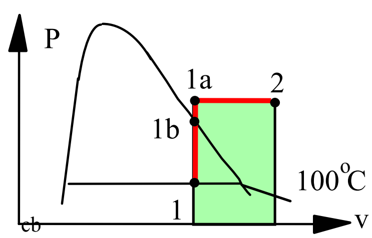
State 2: $(T_2 > T_{1a})$ Table B.1.3 => $v_2 = 0.87529$, $u_2 = 2806.69$ kJ/kg

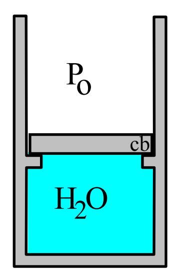
Work is seen in the P-V diagram (when volume changes $P = P_{lift}$)

$${}_1W_2 = {}_{1a}W_2 = P_2\, m(v_2 - v_1) = 300 \times 1(0.87529 - 0.83697) = \mathbf{11.5\ kJ}$$

Heat transfer is from the energy equation

$${}_1Q_2 = 1\ (2806.69 - 1462.7) + 11.5 = \mathbf{1355.5\ kJ}$$





5.163

A rigid container has two rooms filled with water, each 1 m^3 separated by a wall (see Fig. P5.61). 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: $U_2 - U_1 = m_2u_2 - m_{A1}u_{A1} - m_{A1}u_{A1} = {}_1Q_2 - {}_1W_2 = {}_1Q_2$

Process: $V = V_A + V_B =$ 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, $v_2 = V_2/m_2 = 2/(1.411 + 6.614) = 0.24924\ m^3/kg$

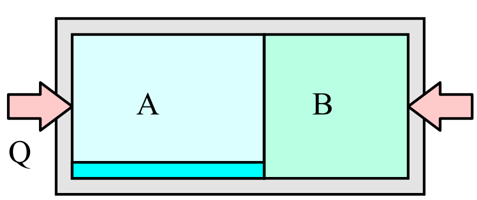
Table B.1.3 superheated vapor. 800 kPa < P_2 < 1 MPa

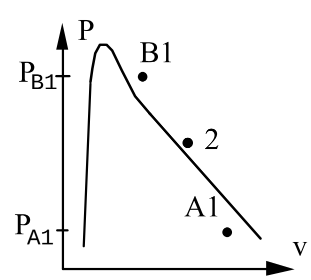
Interpolate to get the proper v_2

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

From the energy equation

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





5.164

A piston held by a pin in an insulated cylinder, shown in Fig. P5.164, 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)

$$P_2 = P_{float} = P_0 + m_p g/A = 100 + \frac{102 \times 9.807}{100\times10^{-4} \times 10^3} = 200 \text{ kPa}$$

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

$$u_2 + P_2v_2 = h_2 = u_1 + P_2v_1$$

$$h_2 = u_1 + P_2v_1 = 2464.8 + 200 \times 1.6395 = 2792.7 \text{ kJ/kg}$$

State 2: (P_2, h_2) Table B.1.3 => $T_2 \cong$ **161.75°C**

5.165

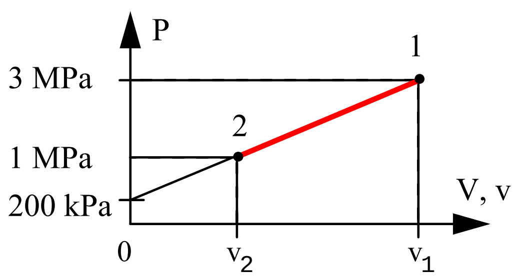
A piston/cylinder arrangement has a linear spring and the outside atmosphere acting on the piston, shown in Fig. P5.165. It contains water at 3 MPa, 400°C with the volume being 0.1 m^3. If the piston is at the bottom, the spring exerts a force such that a pressure of 200 kPa inside is required to balance 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**

5.166

A piston/cylinder, shown in Fig. P5.166, contains R-410a at − 20°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-410a, this is a control mass. Properties in Table B.4.

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: $v_1 = 0.000803 + 0.2 \times 0.0640 = 0.0136\ m^3/kg$

$u_1 = 27.92 + 0.2 \times 218.07 = 71.5\ kJ/kg$

$m = m_1 = V_1/v_1 = 14.706\ kg$

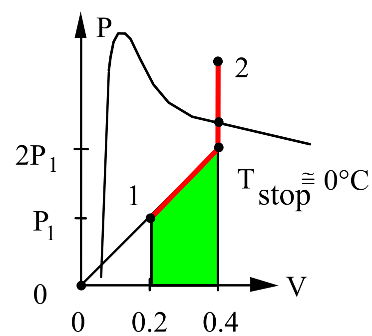
System: on line

$V \le V_{stop}$;

$P_1 = 399.6\ kPa$

$P_{stop} = 2P_1 = 799.2\ kPa$

$v_{stop} = 2v_1 = 0.0272\ m^3/kg$



State stop: (P,v) $\Rightarrow T_{stop} \cong 0°C$ TWO-PHASE STATE

Since $T_2 > T_{stop} \Rightarrow v_2 = v_{stop} = 0.0272\ m^3/kg$

State 2: (T_2, v_2) Table B.4.2: Interpolate between 1000 and 1200 kPa

$P_2 = 1035\ kPa$; $u_2 = 366.5\ kJ/kg$

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

$${}_1W_2 = \int PdV = \frac{1}{2}(P_1 + P_{stop})(V_{stop} - V_1) = \frac{1}{2}(399.6 + 799.2)0.2 = \mathbf{119.8\ kJ}$$

From the energy equation

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 14.706(266.5 - 71.5) + 119.8 = \mathbf{2987.5\ kJ}$$

5.167

Consider the piston/cylinder arrangement shown in Fig. P5.167. 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.

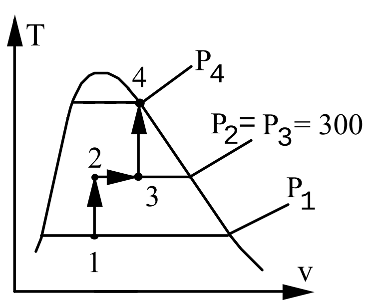
State 4: $v_4 = v_3 = 0.5095$ m^3/kg $= v_G$ at P_4 From Table B.1.2

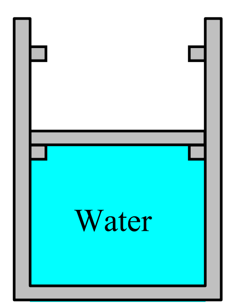
=> $P_4 =$ **361 kPa,** $u_4 = 2550.0$ kJ/kg

${}_1W_4 = {}_1W_2 + {}_2W_3 + {}_3W_4 = 0 + {}_2W_3 + 0$

${}_1W_4 = P_2(V_3 - V_2) = 300 \times (0.6 - 0.4) =$ **60 kJ**

${}_1Q_4 = m(u_4 - u_1) + {}_1W_4 = 1.178(2550.0 - 835.1) + 60 =$ **2080 kJ**





5.168

A spherical balloon contains 2 kg of R-410a at 0°C, 30% quality. This system is heated until the pressure in the balloon reaches 1 MPa. 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-410a 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 = 798.7 kPa

$$v_1 = 0.000855 + 0.3 \times 0.03182 = 0.01040 \text{ m}^3\text{/kg}$$

$$u_1 = 57.07 + 0.3 \times 195.95 = 115.86 \text{ kJ/kg}$$

Process: $P \propto D$, $V \propto D^3$ => $PV^{-1/3}$ = constant, polytropic n = -1/3.

$$\Rightarrow \quad V_2 = mv_2 = V_1 \,(P_2 /P_1)^3 = mv_1 \,(P_2 /P_1)^3$$

$$v_2 = v_1 \,(P_2 /P_1)^3 = 0.01040 \times (1000 / 798.7)^3 = 0.02041 \text{ m}^3\text{/kg}$$

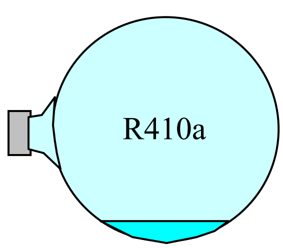
State 2: P_2 = 1 MPa, process : v_2 = 0.02041 → Table B.4.2, T_2 = 7.25°C (sat)

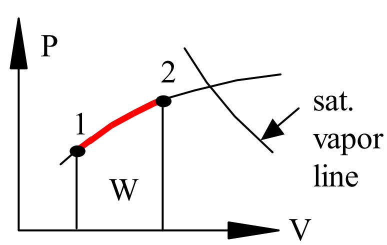
$$v_f = 0.000877,\ v_{fg} = 0.02508 \text{ m}^3\text{/kg},\ u_f = 68.02,\ u_{fg} = 187.18 \text{ kJ/kg}$$

$$x_2 = 0.7787, \quad u_2 = 213.7 \text{ kJ/kg},$$

$${}_1W_2 = \int P\, dV = m\,\frac{P_2v_2 - P_1v_1}{1 - n} = 2\,\frac{1000 \times 0.02041 - 798.7 \times 0.0104}{1 - (-1/3)} = 18.16 \text{ kJ}$$

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 2\,(213.7 - 115.86) + 18.16 = \mathbf{213.8\ kJ}$$





Notice: The R-410a is not an ideal gas at any state in this problem.

5.169

A 1 m^3 tank containing air at 25°C and 500 kPa is connected through a valve to another tank containing 4 kg of air at 60°C and 200 kPa. Now the valve is opened and the entire system reaches thermal equilibrium with the surroundings at 20°C. Assume constant specific heat at 25°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: $T_2 = 20°\text{C}$, $v_2 = V_2/m_2$

$$m_2 = m_{A1} + m_{B1} = 4 + 5.84 = 9.84 \text{ kg}$$

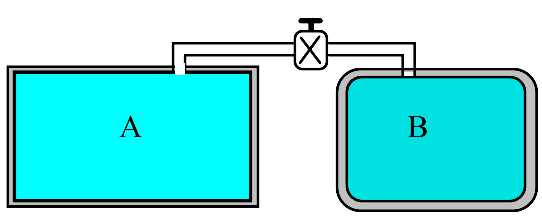
$$V_2 = V_{A1} + V_{B1} = 1 + 1.91 = 2.91 \text{ m}^3$$

$$P_2 = \frac{m_2RT_2}{V_2} = \frac{(9.84 \text{ kg})(0.287 \text{ kJ/kgK})(293.2 \text{ K})}{2.91 \text{ m}^3} = \mathbf{284.5 \text{ kPa}}$$

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.



5.170

Ammonia (2 kg) in a piston/cylinder is at 100 kPa, -20°C and is now heated in a polytropic process with n = 1.3 to a pressure of 200 kPa. Do not use ideal gas approximation and find T_2, the work and heat transfer in the process.

Take CV as the Ammonia, constant mass.

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

Process: $Pv^n = \text{constant}$ (n = 1.3)

State 1: Superheated vapor table B.2.2.

$$v_1 = 1.2101 \text{ m}^3\text{/kg}, \quad u_1 = 1307.8 \text{ kJ/kg}$$

Process gives: $v_2 = v_1 (P_1/P_2)^{1/n} = 1.2101 (100/200)^{1/1.3} = 0.710 \text{ m}^3\text{/kg}$

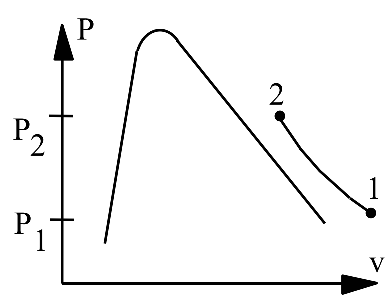
State 2: Table B.2.2 at 200 kPa interpolate: $u_2 = 1376.49$ kJ/kg, $T_2 = 24°C$

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

$${}_1W_2 = \frac{m}{1 - n}(P_2v_2 - P_1v_1) = \frac{2}{1 - 1.3}(200\times0.71 - 100\times1.2101) = \mathbf{-139.9\ kJ}$$

Heat transfer is found from the energy equation

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2$$
$$= 2\ (1376.49 - 1307.8) - 139.9$$
$$= \mathbf{-2.52\ kJ}$$



5.171

A piston/cylinder arrangement B is connected to a 1-m^3 tank A by a line and valve, shown in Fig. P5.171. 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.

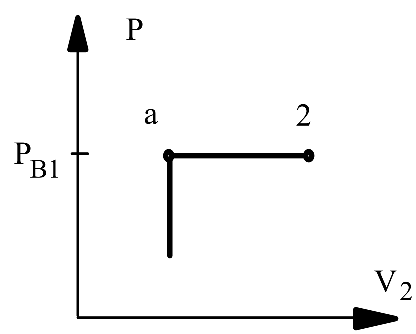
Continuity equation: $m_2 - (m_{A1} + m_{B1}) = 0$;

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 × 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**

5.172

A small flexible bag contains 0.1 kg ammonia at –10°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°C at which time the pressure is 1000 kPa. Find the work and heat transfer in the process and the elapsed time.

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.

$$v_1 = v_{f\,-10} = 0.001534 \text{ m}^3/\text{kg}, \qquad u_1 = u_f = 133.96 \text{ kJ/kg}$$

State 2: Table B.2.1 at 30°C : $P < P_{sat}$ so superheated vapor

$$v_2 = 0.13206 \text{ m}^3/\text{kg}, \;\; u_2 = 1347.1 \text{ kJ/kg}, \qquad V_2 = mv_2 = \mathbf{0.0132\ m^3}$$

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

$${}_1W_2 = ½(300 + 1000)*0.1(0.13206 - 0.001534) = \mathbf{8.484\ kJ}$$

Heat transfer is found from the energy equation

$${}_1Q_2 = m(u_2 - u_1) + {}_1W_2 = 0.1\ (1347.1 - 133.96) + 8.484$$

$$= 121.314 + 8.484 = \mathbf{129.8\ kJ}$$

$$\dot{Q}_{net} = 75 - 25 = 50 \text{ Watts}$$

Assume the constant rate $\dot{Q}_{net} = dQ/dt = {}_1Q_2 / t$, so the time becomes

$$t = {}_1Q_2 / \dot{Q}_{net} = \frac{129800}{50} = \mathbf{2596\ s = 43.3\ min}$$