Concept-Study Guide Problems

4.1

The electric company charges the customers per kW-hour. What is that in SI units?

Solution:

The unit kW-hour is a rate multiplied with time. For the standard SI units the rate of energy is in W and the time is in seconds. The integration in Eq.4.21 becomes

$$1 \text{ kW- hour} = 1000 \text{ W} \times 60 \frac{\text{min}}{\text{hour}} \text{hour} \times 60 \frac{\text{s}}{\text{min}} = 3\ 600\ 000 \text{ Ws}$$

$$= 3\ 600\ 000 \text{ J} = \mathbf{3.6\ MJ}$$

4.4

A 1200 hp dragster engine drives the car with a speed of 100 km/h. How much force is between the tires and the road?

Power is force times rate of displacement as in Eq.4.2

Power, rate of work $\dot{W} = F\,\mathbf{V} = P\,\dot{V} = T\,\omega$

We need the velocity in m/s: $\mathbf{V} = 100 \times 1000 / 3600 = 27.78$ m/s

We need power in watts: 1 hp = 0.7355 kW = 735.5 W

$$F = \dot{W} / \mathbf{V} = \frac{1200 \times 735.5}{27.78} \frac{W}{m/s} = 31\,771 \frac{Nm/s}{m/s}$$

$$= 31\,771 \text{ N} = \mathbf{31.8\ kN}$$

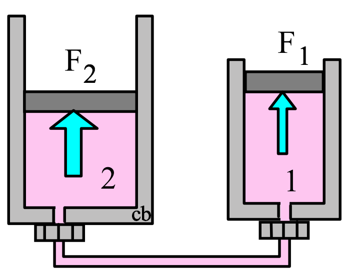
4.5

Two hydraulic piston/cylinders are connected through a hydraulic line so they have roughly the same pressure. If they have diameters of D_1 and $D_2 = 2D_1$ respectively, what can you say about the piston forces F_1 and F_2?

For each cylinder we have the total force as: $F = PA_{cyl} = P\,\pi\,D^2/4$

$$F_1 = PA_{cyl\,1} = P\,\pi\,D_1^2/4$$

$$F_2 = PA_{cyl\,2} = P\,\pi\,D_2^2/4 = P\,\pi\,4\,D_1^2/4 = 4\,F_1$$



The forces are the total force acting up due to the cylinder pressure. There must be other forces on each piston to have a force balance so the pistons do not move.

4.6

Normally pistons have a flat head, but in diesel engines pistons can have bowls in them and protruding ridges. Does this geometry influence the work term?

The shape of the surface does not influence the displacement

$$dV = A_n \, dx$$

where A_n is the area projected to the plane normal to the direction of motion.

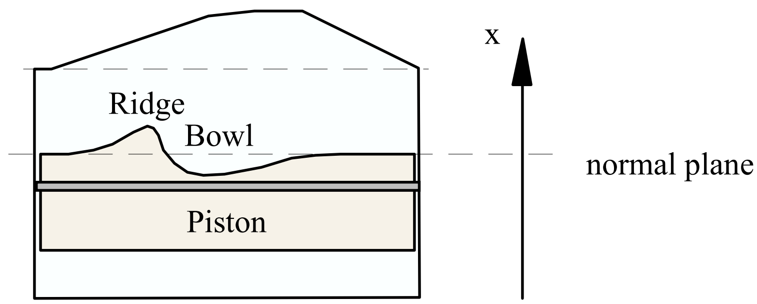
$$A_n = A_{cyl} = \pi D^2/4$$

Work is

$$dW = F \, dx = P \, dV = P \, A_n \, dx = P \, A_{cyl} \, dx$$

and thus unaffected by the surface shape.

Semi-spherical head is made to make room for larger valves.



Boundary work simple 1 step process

4.31

A constant pressure piston cylinder 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 work in the process.

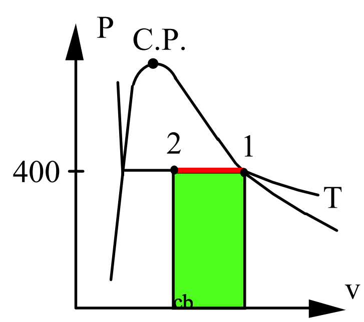
Solution:

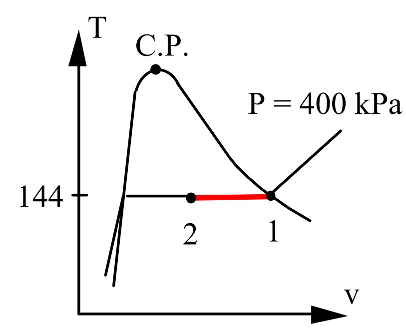
Table B.1.2 $v_1 = 0.4625 \text{ m}^3/\text{kg}$ $V_1 = mv_1 = 0.0925 \text{ m}^3$

$v_2 = v_1/ 2 = 0.23125 \text{ m}^3/\text{kg}$ $V_2 = V_1 / 2 = 0.04625 \text{ m}^3$

Process: P = C so the work term integral is

$W = \int PdV = P(V_2-V_1) = 400 \text{ kPa} \times (0.04625 – 0.0925) \text{ m}^3 = \mathbf{-18.5 \ kJ}$





4.33

A 400-L tank A, see figure P4.33, contains argon gas at 250 kPa, 30°C. Cylinder B, having a frictionless piston of such mass that a pressure of 150 kPa will float it, is initially empty. The valve is opened and argon flows into B and eventually reaches a uniform state of 150 kPa, 30°C throughout. What is the work done by the argon?

Solution:

Take C.V. as all the argon in both A and B. Boundary movement work done in cylinder B against constant external pressure of 150 kPa. Argon is an ideal gas, so write out that the mass and temperature at state 1 and 2 are the same

$$P_{A1}V_A = m_A RT_{A1} = m_A RT_2 = P_2(V_A + V_{B2})$$

$$\Rightarrow \quad V_{B2} = \frac{250 \times 0.4}{150} - 0.4 = 0.2667 \text{ m}^3$$

$${}_1W_2 = \int_1^2 P_{ext} dV = P_{ext}(V_{B2} - V_{B1}) = 150 \text{ kPa } (0.2667 - 0) \text{ m}^3 = \mathbf{40\ kJ}$$

4.35

Saturated water vapor at 200 kPa is in a constant pressure piston cylinder. At this state the piston is 0.1 m from the cylinder bottom and cylinder area is 0.25 m^2. The temperature is then changed to 200^{o}C. Find the work in the process.

Solution:

State 1 from B.1.2 (P, x): $v_1 = v_g = 0.8857$ m^3/kg (also in B.1.3)

State 2 from B.1.3 (P, T): $v_2 = 1.0803$ m^3/kg

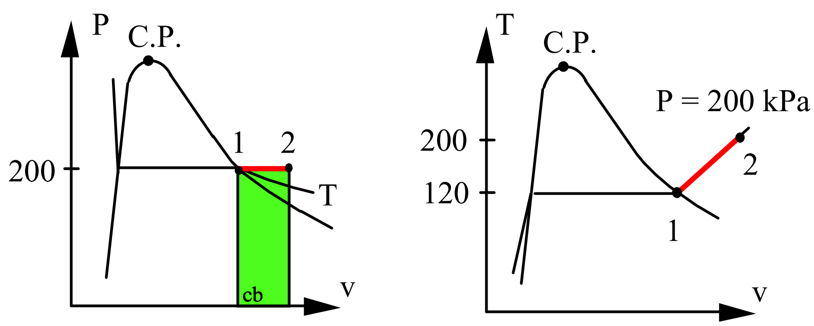
Since the mass and the cross sectional area is the same we get

$$h_2 = \frac{v_2}{v_1} \times h_1 = \frac{1.0803}{0.8857} \times 0.1 = 0.122 \text{ m}$$

Process: P = C so the work integral is

$$W = \int PdV = P(V_2 - V_1) = PA\,(h_2 - h_1)$$

$$W = 200 \text{ kPa} \times 0.25 \text{ m}^2 \times (0.122 - 0.1) \text{ m} = \mathbf{1.1\ kJ}$$



4.42

A piston cylinder contains 1 kg of liquid water at 20^{o}C and 300 kPa. There is a linear spring mounted on the piston such that when the water is heated the pressure reaches 3 MPa with a volume of 0.1 m^3.

a) Find the final temperature

b) Plot the process in a P-v diagram.

c) Find the work in the process.

Solution:

Take CV as the water. This is a constant mass:

$$m_2 = m_1 = m \ ;$$

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

B.1.1: $v_1 = v_f(20) = 0.001002 \text{ m}^3\text{/kg}$,

State 2: $v_2 = V_2/m = 0.1/1 = 0.1 \text{ m}^3\text{/kg}$ and P = 3000 kPa from B.1.3

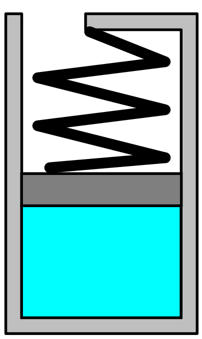
=> Superheated vapor close to T = 400^{o}C

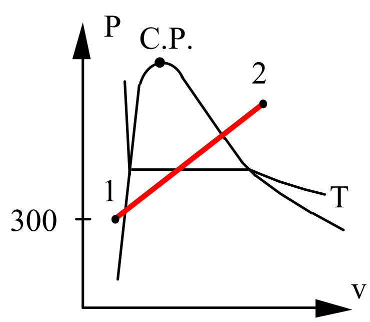
Interpolate: $T_2 = \mathbf{404^oC}$

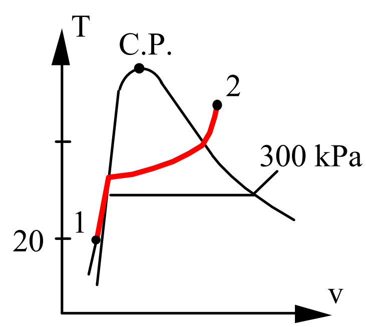
Work is done while piston moves at linearly varying pressure, so we get:

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

$$= 0.5\ (300 + 3000)(0.1 - 0.001) = \mathbf{163.35\ kJ}$$







4.48

The piston/cylinder shown in Fig. P4.48 contains carbon dioxide at 300 kPa, 100°C with a volume of 0.2 m^3. Mass is added at such a rate that the gas compresses according to the relation $PV^{1.2}$ = constant to a final temperature of 200°C. Determine the work done during the process.

Solution:

From Eq. 4.4 for the polytopic process $PV^n = \text{const} \; (n \neq 1)$

$$ {}_1W_2 = \int_1^2 PdV = \frac{P_2V_2 - P_1V_1}{1 - n} $$

Assuming ideal gas, PV = mRT

$$ {}_1W_2 = \frac{mR(T_2 - T_1)}{1 - n} , $$

But $\quad mR = \frac{P_1V_1}{T_1} = \frac{300 \times 0.2}{373.15} \; \frac{\text{kPa m}^3}{\text{K}} = 0.1608 \text{ kJ/K}$

$$ {}_1W_2 = \frac{0.1608(473.2 - 373.2)}{1 - 1.2} \frac{\text{kJ K}}{\text{K}} = \mathbf{-80.4\ kJ} $$

4.61

A piston/cylinder arrangement shown in Fig. P4.61 initially contains air at 150 kPa, 400°C. The setup is allowed to cool to the ambient temperature of 20°C.

a. Is the piston resting on the stops in the final state? What is the final pressure in the cylinder?

b. What is the specific work done by the air during this process?

Solution:

State 1: $P_1 = 150$ kPa, $T_1 = 400°C = 673.2$ K

State 2: $T_2 = T_0 = 20°C = 293.2$ K

For all states air behave as an ideal gas.

a) If piston at stops at 2, $V_2 = V_1/2$ and pressure less than $P_{lift} = P_1$

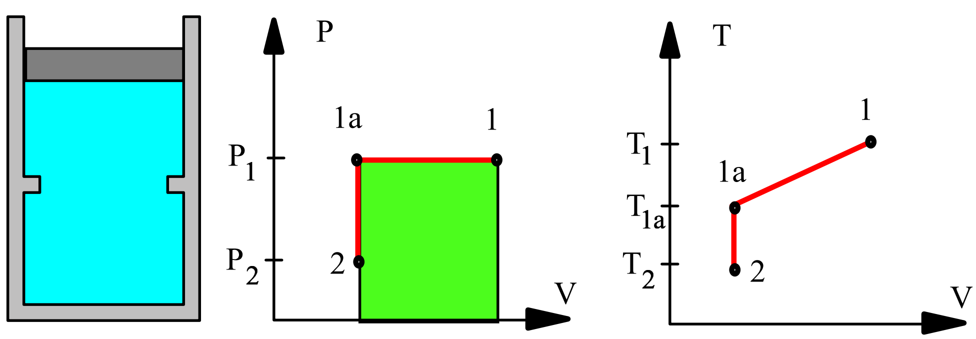
$$\Rightarrow P_2 = P_1 \times \frac{V_1}{V_2} \times \frac{T_2}{T_1} = 150 \times 2 \times \frac{293.2}{673.2} = 130.7 \text{ kPa} < P_1$$

$\Rightarrow$ Piston is resting on stops at state 2.

b) Work done while piston is moving at constant $P_{ext} = P_1$.

$$_1W_2 = \int P_{ext}\, dV = P_1 (V_2 - V_1) \;; \quad V_2 = \frac{1}{2} V_1 = \frac{1}{2} m\ RT_1/P_1$$

$$_1w_2 = {_1W_2}/m = RT_1 (\frac{1}{2} - 1) = -\frac{1}{2} \times 0.287 \times 673.2 = \mathbf{-96.6\ kJ/kg}$$



4.63

A piston/cylinder assembly (Fig. P4.63) has 1 kg of R-134a at state 1 with 110°C, 600 kPa, and is then brought to saturated vapor, state 2, by cooling while the piston is locked with a pin. Now the piston is balanced with an additional constant force and the pin is removed. The cooling continues to a state 3 where the R-134a is saturated liquid. Show the processes in a P-V diagram and find the work in each of the two steps, 1 to 2 and 2 to 3.

Solution :

CV R-134a This is a control mass.

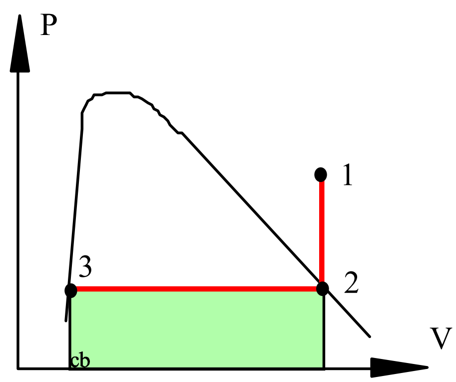
Properties from table B.5.1 and 5.2

State 1: (T,P) B.5.2 => $v = 0.04943\ m^3/kg$

State 2: given by fixed volume $v_2 = v_1$ and $x_2 = 1.0$ so from B.5.1

$$v_2 = v_1 = v_g = 0.04943\ m^3/kg \quad => \quad T = 10°C$$

State 3 reached at constant P (F = constant) $v_3 = v_f = 0.000794\ m^3/kg$



Since no volume change from 1 to 2 => $\mathbf{{}_1W_2 = 0}$

$${}_2W_3 = \int P\,dV = P(V_3 - V_2) = mP(v_3 - v_2) \qquad \text{Constant pressure}$$

$$= 415.8\ (0.000794 - 0.04943)\ 1 = \mathbf{-20.22\ kJ}$$