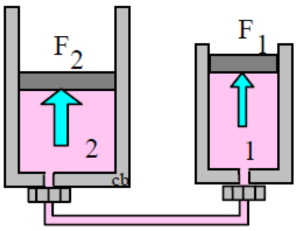
Chapter 04 Solved Problems

Problem 4.20

W = ∫ F dx = F Δx = 1500 N × 100 m =150 000 J = **150 kJ**
W = ∫ F dz = ∫ mg dz = mg ΔZ = 500 kg × 9.807 m/s^2 × 3 m = 14 710 J = **14.7 kJ**
$\mathbf{W_{total}}$ = 150 kJ+14.7 kJ= **164.7 kJ**

Problem 4.22

W = ∫ F dx = ∫ P dV = ∫ PA dx = PAx H = PΔV
ΔV = W/P = 1 kJ/1200 kPa = **0.000 833 m³**
Both cases the height is H = ΔV/A
H1 = 0.000833/0.01 = **0.0833 m**
H2 = 0.000833/0.03 = **0.0278 m**



Problem 4.27

Control volume radiator.
After the valve is closed no more flow, constant volume and mass.
1: $x_1 = 1$, P_1 = 110 kPa ⇒ $v_1 = v_g$ = 1.566 m3/kg from Table B.1.2
2: T_2 = 25°C
Process: $v_2 = v_1$ = 1.566 m³/kg = [0.001003 + x2 × 43.359] m3/kg
x_2 = 1.566 – 0.001003/43.359 = **0.0361**
State 2 : T_2 , x_2 From Table B.1.1 $\mathbf{P_2 = P_{sat}}$ **= 3.169 kPa**

Work is 0 since constant volume process

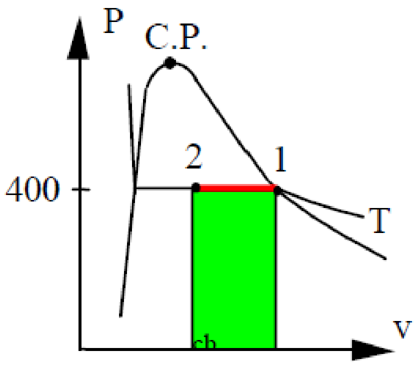
Problem 4.28

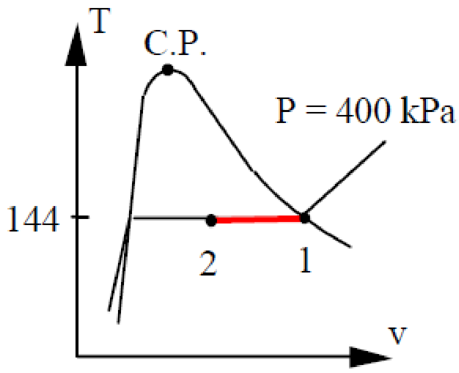
Table B.1.2 v_1= 0.4625 m³/kg $V_1 = mv_1$ = 0.0925 m³

$v_2 = v_1/ 2$ = 0.23125 m³/kg $V_2 = V_1 / 2$ = 0.04625 m³

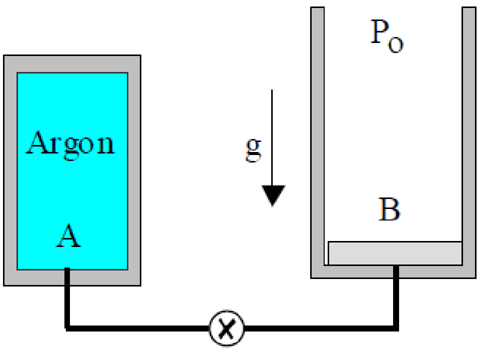
Process: P = Cst so the work term integral is

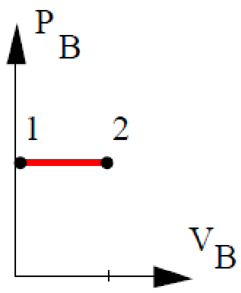
W = ∫ PdV = P(V_2-V_1) = 400 kPa × (0.04625 – 0.0925) m³ = -18.5 kJ





Problem 4.30





Taking a control volume enclosing all the argon in both A and B.
The boundary movement work done in cylinder B against constant external pressure of 150 kPa. Argon is an ideal gas, so writing out that the mass and temperature at state 1 and 2 are the same:

$P_{A1}V_A = m_ART_{A1} = m_ART_2 = P_2(V_A + V_{B2})$
$\Rightarrow V_{B2} = 250 \times 0.4/150 - 0.4 = 0.2667\ m^3$
$W_{12} = \int P_{ext}dV = P_{ext}(V_{B2} - V_{B1}) = 150\ kPa\ (0.2667 - 0)\ m^3 =$ **40 kJ**

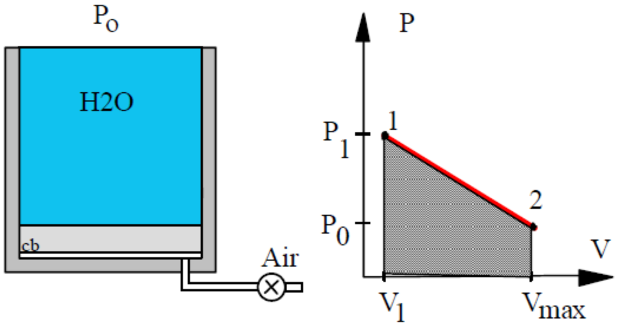
Problem 4.33

$P_1 = P_0 + \rho gH$

$= 101.32 + 997 \times 9.807 \times 5 / 1000 = 150.2\ kPa$

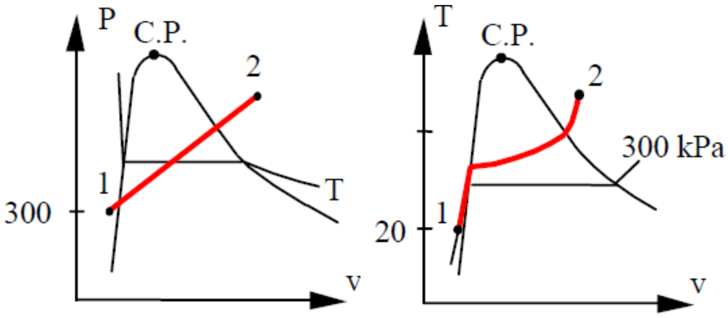
$\Delta V = H \times A = 5 \times 0.1 = 0.5\ m^3$

$W_{12} = AREA = \int P\ dV = ½\ (P_1 + P_0)/(V_{max} - V_1) = ½\ (150.2 + 101.32)\ kPa \times 0.5\ m^3 =$ **62.88 kJ**



Problem 4.35

a. State 1: Compressed liquid, saturated liquid at same temperature.
B.1.1: $v_1 = v_f(20°C) = 0.001002$ m³/kg,
State 2: $v_2 = V_2/m = 0.1/1 = 0.1$ m³/kg and P = 3000 kPa from B.1.3
=> Superheated vapor close to T = 400°C so by interpolating: **T_2 = 404°C**



c. Work is done while piston moves at linearly varying pressure, so we get:
$W_{12} = \int P\,dV = P_{ave}(V_2 - V_1) = 1/2(P_1+P_2)(V_2-V_1) = 0.5\ (300+3000)(0.1-0.001)$ **= 163.35 kJ**

Problem 4.47

Process: $Pv^n = Const = P_1v^n_1 = P_2\ v^n_2$
Ideal gas so : $Pv = RT$
$v_1 = RT/P = 0.287 \times 325/125 = 0.7462$ m³/kg
$v_2 = RT/P = 0.287 \times 500/300 = 0.47833$ m³/kg
From the process equation
$(P_2/ P_1) = (v_1/ v_2)^n \Rightarrow \ln(P_2/ P_1) = n \ln(v_1/ v_2)$
$n = \ln(P_2/ P_1) / \ln(v_1/ v_2) = \ln 2.4/\ln 1.56 =$ **1.969**
The work per unit mass (specific work) is:

$$w_{12} = \frac{P_2v_2 - P_1v_1}{1-n} = \frac{R(T_2 - T_1)}{1-n} = \frac{0.287(500-325)}{-0.969} = -51.8\ kJ$$

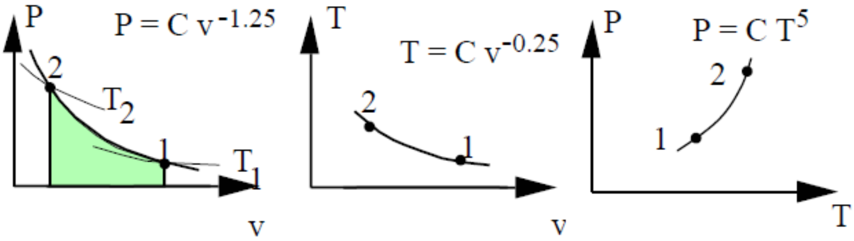
Problem 4.50

Process: $Pv^n = Const = P_1v^n_1 = P_2\ v^n_2$

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

To evaluate the work:

$$W_{12} = \frac{P_2V_2 - P_1V_1}{1-n} = m.\frac{P_2v_2 - P_1v_1}{1-n} = m.\frac{R(T_2 - T_1)}{1-n} = 0.1\frac{0.2968(360.5 - 300.15)}{-0.25}$$
$$= -7.165\ kJ$$



Problem 4.59

a) From Table B.4.2: v_1 = 0.17732 m³/kg,
m = V/v = 0.010/0.17732 = 0.056395 kg

For the final state, if the piston were at the final stop, then V_{1a} would have been of 11 L
Then v_{1a}= V/m= 0.011/0.056395=0.19505 m³/kg
=> T_{1a} = -9.4°C but T_2 = 15°C so $T_2 > T_{1a}$
=> $P_2 > P_1$

If the piston didn't reach the stops yet, the pressure would have remained constant at 150 kPa and by using 150 kPa and 15°C, we would have obtained the right specific volume

Problem 4.86

Process: P = constant :
Boundary work: δW = P dV => W= PΔV
Assuming ideal gas behavior for air
$V_2 = V_1 \times (T_2/T_1)$ = 0.1 × (600/300) = 0.2 m³
$\dot{W}$ = P ΔV/Δt = 300 × (0.2 - 0.1)/30 kPa m³/s = **1 kW**

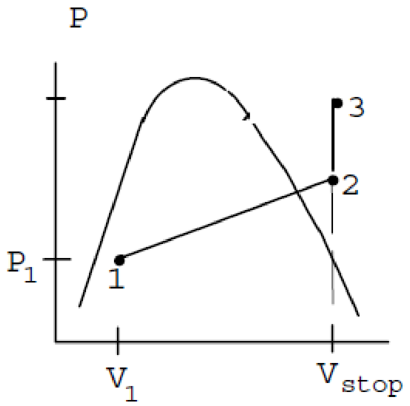
Problem 4.90

Steady conduction through the bottom of the steel pot.
Assume the inside surface is at the liquid water temperature.
$\dot{Q}$ = k A ΔT/Δx ⇒ ΔT = $\dot{Q}$ Δx / kA
ΔT = 250 W × 0.005 m /(50 W/m-K × π/4 × 0.22 m²) = 0.796 K
T = 15 + 0.796 ≅ **15.8°C**

Problem 4.103

State 1: v_1 = V/m = 0.2 / 2 = 0.1 m³/kg
Process: 1 → 2 → 3 or 1 → 3'

State at stops: 2 or 2'
$v_2 = V_{stop}/m$ = 0.4 m³/kg & T_2 = 600°C
Table B.1.3 ⇒ P_{stop} = 1 MPa < P_3 since P_{stop} < P then the process is as 1 → 2 → 3



State 3: P_3 = 1.2 MPa, $v_3 = v_2$ = 0.4 m^3/kg ⇒ T_3 ≅ 770°C

$W_{13} = W_{12} + W_{23}$ =

$W_{12} = 0.5(P_1 + P_2)(V_2 - V_1)$ =0.5(100 + 1000) kPa × (0.8 - 0.2) m^3 (this is only possible because the spring is linear and the force it applies, induces a pressure that varies linearly with the displacement and hence the swept volume

W_{23} = 0 (constant volume)

Hence W_{13}**= 330 kJ**

Problem 4.109

The process equation and T determines state 2. Use ideal gas law to say

$P_2 = P_1 \left(\frac{T_1}{T_2}\right)^{\frac{n}{n-1}} = 100 \left(\frac{340}{300}\right)^{\frac{1.1}{0.1}}$= 396 kPa

$V_2 = V_1 \left(\frac{P_1}{P_2}\right)^{\frac{1}{n}}$ = 0.2 (100/396)1/1.1 = 0.0572 m^3

For propane Table A.2: Tc = 370 K, Pc = 4260 kPa, Figure D.1 gives Z.

Tr_1 = 0.81, Pr_1 = 0.023 => Z_1 = 0.98

Tr_2 = 0.92, Pr_2 = 0.093 => Z_2 = 0.95

Ideal gas model OK for both states, work is integrated to give:

$${}_1W_2 = \int P\, dV = \frac{P_2V_2 - P_1V_1}{1-n} = \frac{(396 \times 0.0572) - (100 \times 0.2)}{1 - 1.1} \text{ kPa m}^3$$

W_{12}**= -26.7 kJ**