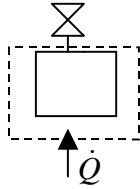


(P2.1) Energy Balance:Eqn. 2.27

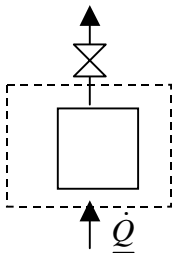
$$\frac{d}{dt} \left[m \left(U + \frac{u^2}{2g_c} + \frac{gz}{g_c} \right) \right] = \sum_{\text{inlets}} \left[H + \frac{u^2}{2g_c} + \frac{gz}{g_c} \right] \dot{m}^{\text{in}} - \sum_{\text{outlets}} \left[H + \frac{u^2}{2g_c} + \frac{gz}{g_c} \right] \dot{m}^{\text{out}} + \dot{Q} + \dot{W}_{EC} + \dot{W}_S$$



closed system, no mass flow $\Rightarrow \dot{m}^{\text{in}} = \dot{m}^{\text{out}} = 0$,
 valve stuck preventing any steam from going out $\Rightarrow \dot{m}^{\text{out}} = 0$, no change in volume
 occurs (no expansion or contraction) $\Rightarrow \dot{W}_{EC} = 0$, no work has been added
 or removed, and there is no pump nor turbine $\Rightarrow \dot{W}_S = 0$.
 Ignore K.E. and P.E.

\Rightarrow the final energy balance becomes.
$$\frac{d}{dt} (mU) = \dot{Q}$$

(P2.2)



Before the valve is stuck, \Rightarrow there is steam escaping and therefore, there is an enthalpy for the vapor leaving, no expansion / contraction work, no shaft work, no kinetic or potential energy occurred.

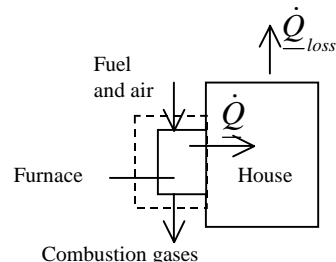
\Rightarrow energy balance will be
$$\frac{d}{dt} (mU) = -\dot{m}^{\text{out}} H^{\text{out}} + \dot{Q}$$
, note $\dot{m} = -\dot{m}^{\text{out}}$

(P2.3) (Solution for gas furnace). Assume the house is air-tight. Furnace has been heating the home steadily, \Rightarrow the system (furnace) is a steady-state open system, \Rightarrow

$$\frac{d}{dt} \left[m \left(U + \frac{u^2}{2g_c} + \frac{gz}{g_c} \right) \right] = 0 \therefore \dot{m}^{\text{in}} = \dot{m}^{\text{out}}$$

Furnace is fixed size, no expansion/contraction work occurs. Consider just the hot side of the heat exchanger.

$$\therefore \dot{m}^{\text{out}} H^{\text{out}} - \dot{m}^{\text{in}} H^{\text{in}} = \dot{Q}$$



(Chap 14 will consider reactions such as combustion, but the E-balance doesn't need to be written differently!)

Note: if the small shaft work from blower is included, then the boundary includes the house air in and out of the furnace, and the boundary includes both sides of the heat

Chapter 2 Practice Problems

exchanger. For this boundary, all heat transfer is within the furnace, and there is no Q term, but there are four mass flow terms (fuel/air in, combustion gas out, house air in, house air return) and a small (negligible compared to other terms) Ws term.

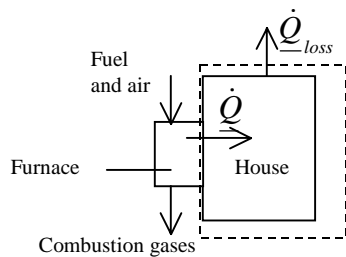
(P2.4) (Solution for gas furnace.) Assume house is air-tight, $m^{in} = m^{out} = 0$.

System: the house and all contents, *consider just the house side of heat exchanger* \Rightarrow closed, unsteady-state system.

\Rightarrow there is heat gain and heat lost in the house.

No expansion / contraction work nor kinetic, potential energy change.

The internal energy of the system could change with respect to time depending on heat gain and heat loss, or could be zero if they are balanced. If the furnace is properly sized, there will be a net gain in temperature of the house!



$$\frac{d}{dt}(mU) = \dot{Q}_{gain} + \dot{Q}_{loss}, \text{ where } \dot{Q}_{loss} \text{ is negative.}$$

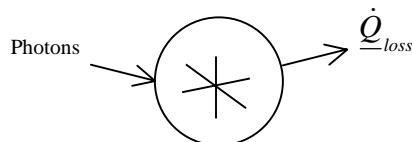
Note: if blower is included within system, then you also should be clear whether the boundary includes the entire heat exchanger (in which case the Q_{gain} term is replaced with enthalpy flow terms), or just the house side of the heat exchanger. In either event, the Ws term will be small relative to other terms since there is so much heat coming from furnace.

(P2.6) System: the bulb and its contents.

System is closed steady state system, $\Rightarrow \frac{d}{dt}(\forall) = 0 \dots \forall$ is left side of equation.

There is no work acting on the bulb and no mass flow in or out.

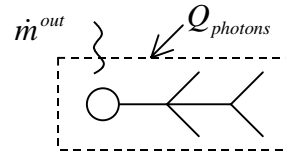
$$\Rightarrow \Delta U = 0$$



Consider photons as heat transfer by radiation $\dot{Q}_{photons}$ and heat loss from bulb, \dot{Q}_{bulb} ,

$$\dot{Q}_{net} = 0$$

- (P2.7) System: the sunbather at 12:00 noon (open system).
 No work has been done, no kinetic or potential energies.
 No mass flow in, but perspiration loss, $\dot{m}_{body} = -\dot{m}^{out}$



Unsteady state, still getting hot.

Consider photons to be heat transfer by radiation.

⇒ by using the equation 2.64 (text book) and drop out all the zero values,

$$\Rightarrow \text{energy balance will be: } \frac{d}{dt}(m_{body}U_{body}) = \dot{m}_{body}H^V + \underline{\dot{Q}}$$

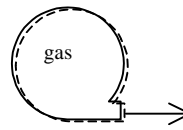
(steam tables could be used to estimate the enthalpy of the evaporating perspiration if the T is known or estimated).

- (P2.8) System: the balloon and its contents.

Unsteady state system, open system.

No heat gain or loss.

No shaft work.



Mass changing with respect to time, as it gets flat, $\dot{m} = -\dot{m}^{out}$

Volume of the balloon is changing the work of expansion / contraction occurs.

Kinetic energy effected by changing the velocity of the balloon.

No potential energy change.

$$\Rightarrow \text{energy balance is: } \frac{d}{dt} \left[mu + \frac{mu_{balloon}^2}{2g_c} \right] = + \left[H + \frac{u^2}{2g_c} \right]^{out} \frac{dm}{dt} + \dot{W}_{EC}$$

- (P2.9) (a) Potential energy (P.E), $\Rightarrow \Delta PE = m \cdot g \cdot \Delta h$, ($1J = 1Nm$)

where m = mass,

g = gravity,

h = height or distance that the body moved by.

$$\Rightarrow \Delta P.E = mg\Delta h / g_c, \Rightarrow \Delta h = \frac{\Delta P.E}{mg / g_c} = \frac{1000Nm}{1kg * 9.8066N / kg}$$

$$\Rightarrow h = 101.97m$$

This is why potential energy is often ignored when thermal changes are present– the height change must be very large to be significant.

(b) Kinetic energy = potential energy

$$\Rightarrow K.E = \frac{1}{2g_c} mu^2, \Rightarrow u = \left(\frac{2g_c K.E}{m} \right)^{\left(\frac{1}{2}\right)} = \left(\frac{2 * 1(kgm / Ns^2) * 1000Nm}{1kg} \right)^{1/2}$$

$$\therefore u = 44.72m / s$$

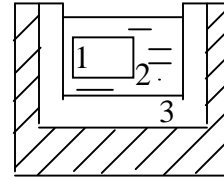
This is why kinetic energy is often ignored when thermal changes are present– the velocity change must be very large to be significant.

(P2.10) Closed system, unsteady-state, 1 block, 2 water, 3 tank.

Energy balance $\Delta U = 0$

$$m_1 \Delta U_1 + m_2 \Delta U_2 + m_3 \Delta U_2 = 0$$

$$(\Delta U = \int_{T_1}^{T_2} C_v dT), \Delta U = C_v \Delta T$$



$$Q = 0$$

$$W_{EC} = 0$$

$$(T - 400) * 200 * 0.380 + 4.184 * 4000 * (T - 300) + 500 * 0.380 * (T - 300) = 0$$

Solve for T, $\Rightarrow T = 300.447\text{K}$

$$\Delta U_{\text{BLOCK}} = 200 * 0.38 * (400 - 300.447) = \mathbf{-7566\text{J}}$$

$$\Delta U_{\text{WATER}} = 4000 * 4.184 * (300.447 - 300) = \mathbf{7480.9\text{J}}$$

(P2.11) Unsteady-state, closed system, Energy balance with block at 50m deep in the water.

$$m_1 \Delta U_1 + m_2 \Delta U_2 + m_3 \Delta U_2 + m_4(\text{kg}) * \Delta z(\text{m}) * g/gc(\text{N/kg}) = 0 \quad (1\text{J} = 1\text{kgm}^2/\text{s}^2)$$

$$200 * .38 * (T - 400) - 0.2 * 50 * 9.81 + 4000 * 4.184 * (T - 300) + 500 * .38 * (T - 300) = 0 \Rightarrow$$

$$T = 300.453 \quad \Rightarrow \Delta U_{\text{BLOCK}} = \mathbf{-7566}$$

(P2.12) a. Unsteady-state closed system

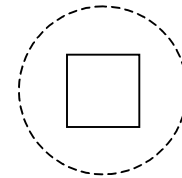
$$W_{EC} = 0(\text{rigid}) \quad \Delta U = Q$$

$$\Delta U_{\text{gas}} = n C_v \Delta T = 5 \text{mole} * 200 * 5 \text{cal/mol-K} = \mathbf{5000\text{cal.};}$$

with gas AND vessel

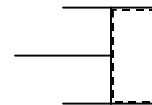
$$\Delta U = n_{\text{gas}} C_{v_{\text{gas}}} \Delta T + m_{\text{vessel}} C_{v_{\text{vessel}}} \Delta T =$$

$$5000 + m_{\text{vessel}} C_v \Delta T = 5000 + 80(0.125)200 = 7000 \text{ cal}$$



b. $\Delta U = Q + W_{EC} \Rightarrow \Delta U - W_{EC} = Q \Rightarrow \Delta H = Q = m C_p \Delta T$

$$5 \text{mole} * 200 * 7 \text{cal/mol-K} = \mathbf{7000\text{cal}}$$



(P2.13) Unsteady state, closed system.

Assume Ideal Gas. $\Rightarrow C_p = C_v + R$, and $C_p = 7R/2$ (diatomic)

$$\Rightarrow 7R/2 - R = C_v; \quad \Rightarrow C_v = 5R/2 = 5 * 8.314/2 = 20.785\text{J/g-k}$$

$$Q = \Delta U + W \quad (\text{no work})$$

$$\Rightarrow Q = \Delta U = 20.785 * (400 - 300)$$

$$\Rightarrow \mathbf{Q = 2079\text{J/mol}}$$

To accompany *Introductory Chemical Engineering Thermodynamics*

© J.R. Elliott, C.T. Lira, 2001, all rights reserved. (7/31/2001)

(P2.14) Steady state, open system.

$$660^{\circ}\text{F} = 348.88^{\circ}\text{C} \quad T(^{\circ}\text{C}) = (T(^{\circ}\text{F}) - 32) * 5/9$$

$$\text{Through the valve} \Rightarrow 0 = \dot{m}^{in} H^{in} - \dot{m}^{out} H^{out} \Rightarrow H^{in} = H^{out}$$

From steam tables (back of the book).

Interpolate for 348.88°C to find H^{in}

$$\Rightarrow \frac{350 - 348.88}{350 - 345} = \frac{2563.64 - H}{2563.64 - 2594.9} \quad \Rightarrow H^{in} = \mathbf{2570.64 \text{ J/g}}$$

Outlet at 1 atm. Use sat T table to find $P=1.014 \text{ MPa}$ (close enough to 1 atm). H^{out} is less than $H^{\text{satV}} = 2676 \text{ J/g}$, so the outlet is two-phase.

$$\Delta H^{\text{vap}} = 2256 \text{ J/g} \text{ and find } H^{\text{satL}} = 419.2 \text{ J/g}$$

$$H = q \Delta H^{\text{vap}} + H^{\text{SatL}}$$

$$\Rightarrow 2570.64 = q * (2256) + 419.2$$

$$\Rightarrow \mathbf{q = 0.954}$$

(P2.16) Steady state, open system.

$$\Rightarrow 0 = \dot{m}^{in} H^{in} - \dot{m}^{out} H^{out} + \underline{Q}$$

$$\text{a) } P_1 = 15 \text{ MPa}, T_1 = 600^{\circ}\text{C} \quad \Rightarrow H_1 = 3583.1 \text{ kJ/kg} \quad (\text{Steam Table})$$

$$P_2 = 10 \text{ MPa}, T_2 = 700^{\circ}\text{C} \quad \Rightarrow H_2 = 3870 \text{ kJ/kg} \quad (\text{Steam Table})$$

$$\Delta H = \text{Heat} = Q = H_2 - H_1 = -287 \text{ kJ/kg}$$

b) for H^{ig} take lowest P at 600°C and 0.01 MPa

$$H^{ig} = 3706 \text{ J/g} \quad (\text{at } 600^{\circ}\text{C} \text{ and } 0.1 \text{ MPa})$$

$$\frac{H^{in} - H^{ig}}{R * T^{in}} = \frac{(3583.1 \text{ J/g} - 3706 \text{ J/g}) * 18 \text{ g/mole}}{8.314 \text{ J/mole-K} * (600 + 273.15) \text{ K}} = -\mathbf{0.305}$$

NOTE: (answer typed wrong in the book printings 1-3)

(P2.17) There are several ways to look at this problem, and some choices of system boundaries are more difficult than others. One method is presented.

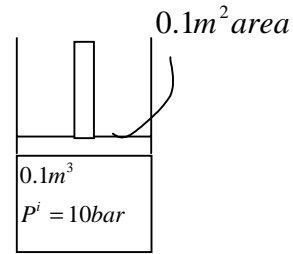
(a). System: piston, denote with subscript p

closed system,

no Q (neglect)

no flow (rigid body)

no change of internal energy (piston doesn't change T)



$$m_p \frac{g}{g_c} \Delta Z + m_p \frac{\Delta u^2}{2g_c} = \underline{W}_{s,p}$$

surface forces cause movement; treat this as \underline{W} s.

Now we need to determine \underline{W} s. The work done by the gas (subscript g) and the atmosphere (subscript a) will be equal to the work done on the piston. The gas and atmosphere are closed systems that change size.

System: gas

$$\underline{W}_{EC,g} = -\int P_g dV_g \dots\dots\dots(2)$$

System: atmosphere.

Note : $dV_g = -dV_a$

$$\underline{W}_{EC,a} = -\int P_a dV_a = \int P_a dV_g \dots\dots\dots(3)$$

Combining work interaction at boundary

$$\underline{W}_{s,p} = -\underline{W}_{EC,g} - \underline{W}_{EC,a}$$

Which results in the working equation.

$$m_p \frac{g}{g_c} \Delta Z + m_p \frac{\Delta u^2}{2g_c} = \underline{W}_{s,p} = \int P_g dV_g - \int P_a dV_g \dots\dots\dots(4)$$

$$\underline{W}_{s,p} = n_g \int (RT/V) dV - \int P_a dV$$

$$\underline{W}_{s,p} = (n_g RT_1 * \ln \frac{V_2}{V_1} - 0.1 * (0.25 - 0.1)) = (P_1 V_1 * \ln \frac{0.25}{0.1} - (0.1 * .015)) \dots\dots(5)$$

$$\underline{W}_{s,p} = (1.0 * 0.1 * \ln 2.5 - .015) * 1E6 \text{cm}^3/\text{m}^3 = 76629\text{J}$$

From E. Bal.

$$m u^2 / 2g_c = \underline{W}_{s,p} - m g \Delta z / g_c = 76629\text{J} - 700 * 9.81 * (2.5\text{m} - 1\text{m}) = 66328.6\text{J} \dots\dots(6)$$

$$u = 13.76\text{m/s}$$

Chapter 2 Practice Problems

- (b) Free flight, system: Piston, closed system, constant T.

Equation (1) applies where $\underline{W}_{S,p} = 0$ (no surface forces acting on piston, because we will ignore air resistance). The kinetic energy will go to zero at the top of flight. The initial kinetic energy from part (a).

$$m_p \frac{g}{g_c} \Delta z + m_p \frac{\Delta u^2}{2g_c} = 700(9.81)\Delta z - 66328.6J = 0 \dots \dots \dots (7)$$

$$\Delta z = 9.6m$$

(not counting 2.5 meters of tube).

- (c) $P_g V_g = \text{constant}$, since isothermal, $P_2 = P_1 V_1 / V_2 = \mathbf{4 \text{ bar}}$

(d) $\frac{V_2}{V_1} = 5.88, \Rightarrow V_2 = 0.588$

plugging into (5)

$$\underline{W}_{S,p} = (1.0 * 0.1 * \ln 5.88 - 0.1 * (0.588 - 0.1)) * 1E6 \text{ cm}^3/\text{m}^3$$

$$\underline{W}_{S,P} = \mathbf{128350 \text{ J}}$$

Using (6)

$$\mu^2 / 2g_c = 128350 - 700 * 9.81 (5.88 - 1) = \mathbf{94840 \text{ J}}$$

plugging into (7)

$$\Rightarrow 700 * 9.81 * \Delta z = 94840J,$$

$$\Rightarrow \Delta z = 13.8m, \text{ free, flight}$$

- (e) the piston will accelerate when the upward force (F_{up}) > downward force (F_{down}). The piston will decelerate when $F_{up} < F_{down}$. The maximum exit velocity will be obtained if the piston leaves the cylinder at the condition $F_{up} = F_{down}$.

$$F_{up} = P_2 A$$

$$F_{down} = P_a A + \frac{mg}{g_c}$$

$$P_2 A = P_a A + \frac{mg}{g_c} \dots \dots \dots (8)$$

P_2 can be related to V_2 since gas is isothermal, $PV_g = \text{constant}$,

$$P_2 = \frac{P_1 V_1}{V_2} \dots \dots \dots (9)$$

Substituting (9) into (8), and inserting the values.

$$(1E6 Pa)(V_1 / V_2)(0.1m^2) = (0.1E6 Pa)(0.1m^2) + 700 * 9.81$$

Chapter 2 Practice Problems

$$\frac{V_2}{V_1} = 5.93, \Rightarrow V_2 = 0.593m^3$$

Answer will be almost the same as (d)

Plugging into (5)

$$\underline{W}_{S,p} = (1.0 \cdot 0.1 \cdot \ln 5.93 - 0.1 \cdot (0.593 - 0.1)) \cdot 1E6 \text{ cm}^3/\text{m}^3$$

$$\underline{W}_{S,p} = \mathbf{128700 \text{ J}}$$

Using (6),

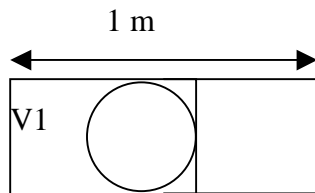
$$m\Delta u^2/2g_c = 128700 - 700 \cdot 9.81(5.93 - 1) = \mathbf{94846 \text{ J}}$$

sub. Into (7)

$$\Rightarrow 700 \cdot 9.81 \cdot \Delta z = 94846 \text{ J},$$

$$\Rightarrow \Delta z = 13.8 \text{ m, free, flight}$$

(P2.18)



Initial and final conditions , P1 = 50 psig = 64.7 psia = **0.4462MPa**.

ball: 3in*2.54cm/in=**7.62 cm dia**

cylinder volume: V2=100cm*3.14*(7.62/2)² = **4558.1cm³**

ball mass: 0.125lbm*.454kg/lbm=**0.057kg** ;

exit velocity: 40mi/hr *5280ft/mi*0.3048m/ft*1hr/3600sec = **17.88 m/s**

Energy Balance:

see E. Bal. From (P2.17), except potential energy is not included since piston is horizontal, ball replaces the piston of (P2.17).

adapting (4), (5) from (P.2.17)

$$W_{S,ball} = 0.057/2 \cdot (17.88)^2 = \mathbf{9.11 \text{ J}}$$

$$m\Delta u^2/2g_c = W_{S,ball} = 0.4462 \cdot V1 \cdot \ln(V2/V1) - 0.1 \cdot (4558.1 - V1) = \mathbf{9.11 \text{ J}}$$

Using solver $\Rightarrow V1 = 387 \text{ cm}^3$ not counting Vball.