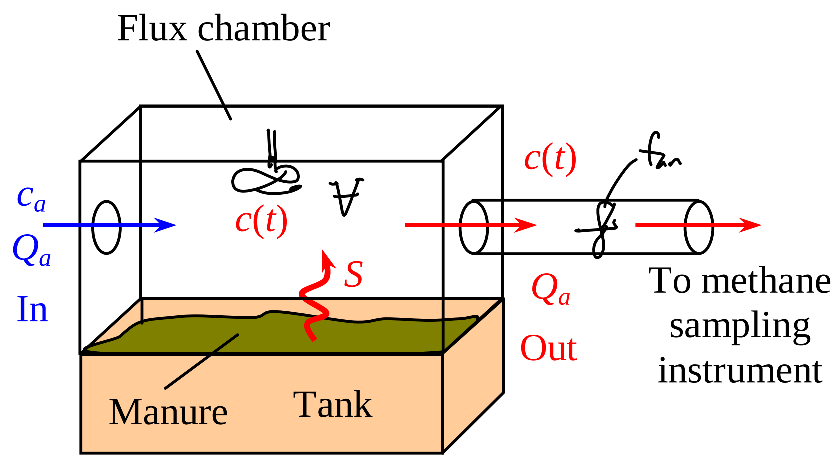
Today, we will:

- Do another example problem using flux chambers
- Discuss **empirical equations for emission rates** in **Section 4.2**
- Do some example problems
- Discuss **evaporation and diffusion** in **Section 4.5**

Example

Given: Methane (CH_4) is emitted from a 3 m × 1 m manure tank in a barn. A flux chamber is built on top of the tank to measure the emission rate. The following quantities are measured:
Note: We drop the subscript *j* since there is only one species of concern.



- $c_a = 0.0020$ mg/m^3 (ambient mass concentration of CH_4 in the barn)
- $Q_a = 0.018$ m^3/s (bulk air flow rate into the flux chamber)
- $c_{ss} = 0.15$ mg/m^3 (steady-state mass concentration of CH_4 leaving the flux chamber)

To do: Calculate *s*, the source strength per unit area (emission rate per unit area) of methane from the tank.

Solution:

Assume well mixed, so that $C_{out} = c(t)$ inside chamber

$s = \frac{S}{A_s}$ A_s = surface area of the manure

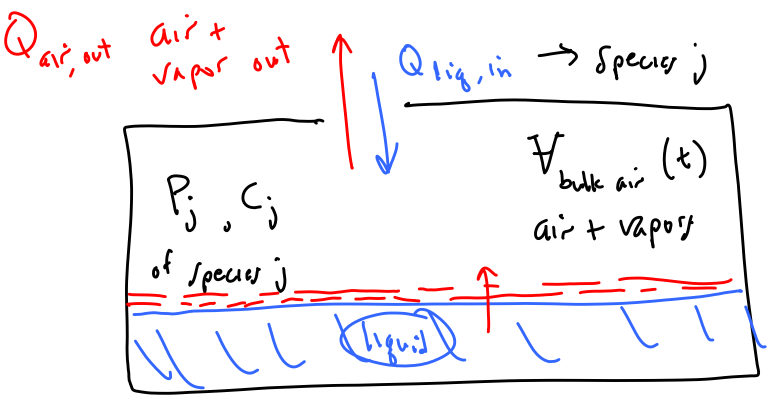
From our flux chamber eqs, At steady state, $\boxed{S_j = Q_a(c_{j,ss} - c_{j,a})}$

Let's drop the j subscript since only one gas of interest

$$s = \frac{Q_a(c_{ss} - c_a)}{A_s} = \boxed{8.9 \times 10^{-4}\ \frac{mg}{m^2 \cdot s} = s}$$

Sec. 4.2 → Other eq's for emission rates for various processes

- spills
- grinding
- pouring powders
- spraying
- vapors released by filling containers



$$\frac{Q_{liq.\,in} = Q_{air\ out}}{\text{(displaced air)}}$$

So, Emission rate $= S_{f,j} = \dot{m}_j = C_j Q_{air\ out}$

filling

$$\boxed{S_{f,j} = \frac{m_j}{\forall_{bulk\ air}} Q_{liq,in}}$$

Use ideal gas law: $\boxed{P_j \forall_{bulk\ air} = n_j R_u T}$

Solve for $\forall_{bulk\ air}$ → $\boxed{\forall_{bulk\ air} = \frac{n_j R_u T}{P_j}}$

Combine:

$$S_{f,j} = \frac{m_j}{n_j} \frac{P_j Q_{liq,in}}{R_u T}$$

M_j

Also let $\boxed{P_j = f\, P_{v,j}}$ ✲

$P_{v,j}$ = max. possible P_j for species j [$P_{v,j}$ = vapor pressure]

f = dimensionless filling factor $(0 < f < 1)$

$$\therefore \quad \boxed{S_{f,j} = \frac{M_j\, f\, P_{v,j}\, Q_{liq,in}}{R_u T}}$$

In book, we introduce L_r = loading rate = # containers filled per unit time

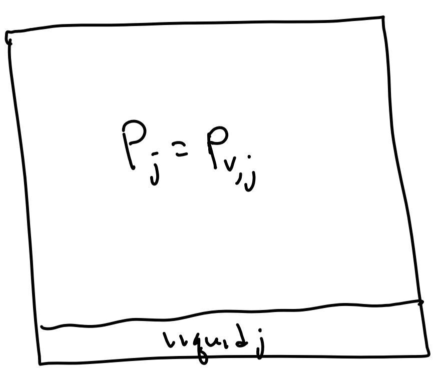
$$\boxed{L_r = \frac{Q_{liq,in}}{\forall_{tank}}}$$

(empty tank volume)

$$\boxed{S_{f,j} = f\,\frac{\forall_{tank}\, P_{v,j}\, M_j\, L_r}{R_u T}} \qquad (4\text{-}10)$$

What is f? $\quad f = \frac{P_j}{P_{v,j}}$ (like a relative humidity)

Useful rule to remember:

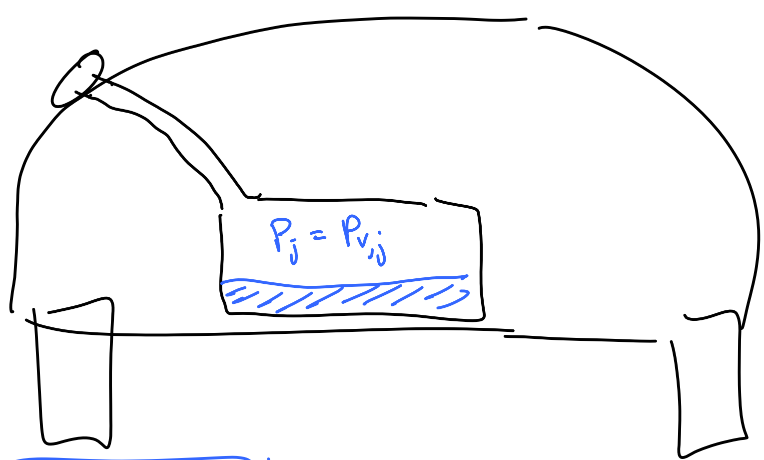


If a closed container sits for a "long" time with liquid at the bottom, then $P_j = P_{v,j}$

$\therefore f = 1$

The air is saturated with the vapor

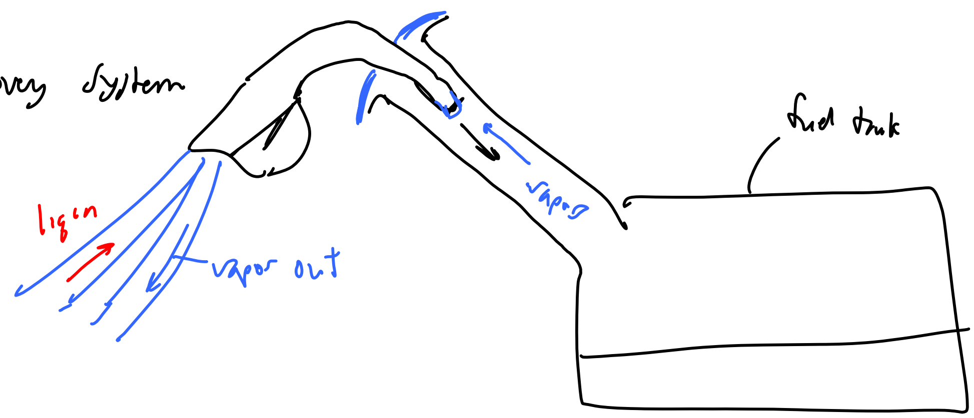
E.g. → gas tank in your car



Filling your gas tank, $\boxed{P_{j,out} = P_{v,j}}$

This is a source of air pollution

Vapor recovery system



How do we know what f is?

(filling factor)

$0 < f < 1$

$f = 1$ if $P_j = P_{v,j}$ (e.g. gas tank filling)

See Fig. 4.3

Splash filling

let $\boxed{f \approx 1}$

$[P_j = P_{v,j}]$

Submerged filling:

$P_j < P_{v,j}$

let $\boxed{f \approx 0.5}$

Bottom filling

$\boxed{f \approx 0.5}$

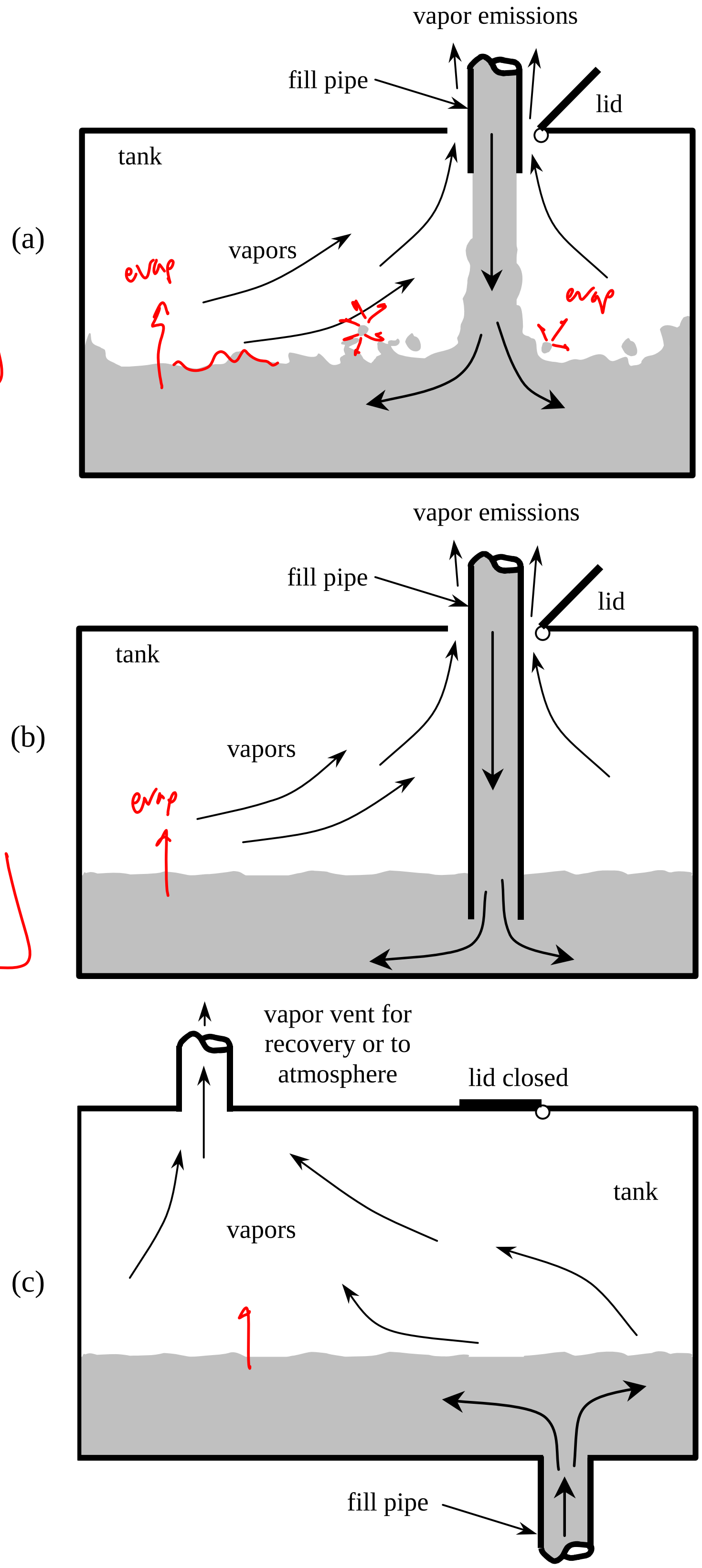
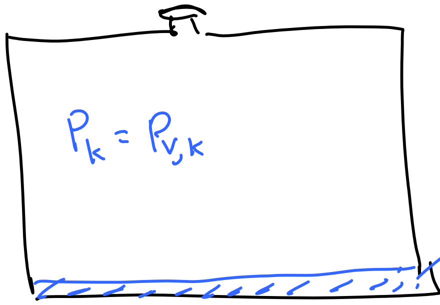


Figure 4.3 Methods to fill vessels with liquids; (a) splash filling, (b) submerged filling, and (c) bottom filling (redrawn from AWMA Handbook on Air Pollution Control, 2000).

Refilling a tank (initially not empty)



liquid k

$\downarrow$

k is saturated

$\therefore$ $f = 1$ for species k

$$\therefore \quad \boxed{S_{d,k} = \frac{V P_{v,k} M_k L_r}{R_u T}} \rightarrow \text{DISPLACEMENT FILLING} *$$

Now, suppose we fill with species j (liquid)

have $S_{f,j}$ (same eq. as before)

$$\boxed{\text{Total emission is } \quad S_{f,j} + S_{d,k}}$$

SEC 4.5 Evaporation & Diffusion

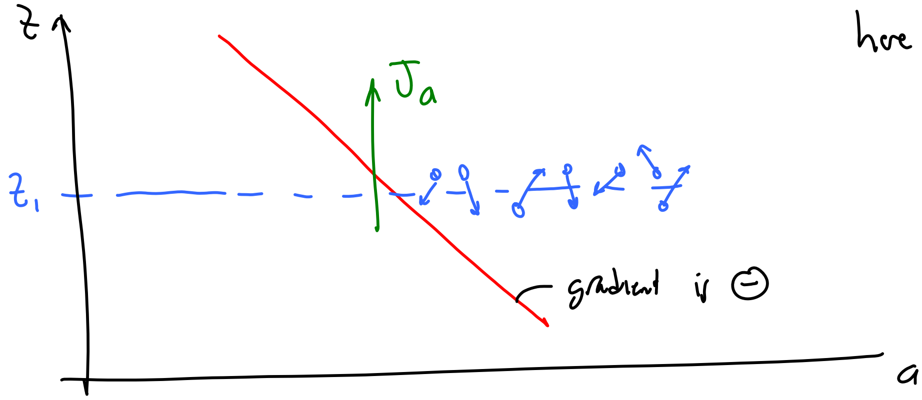
First – general discussion of diffusion

Then – some specifics about evaporation

Gradient Diffusion [not in text] (ONE-DIMENSIONAL ANALYSIS)

Let a = some property in a gas, $a = a(z)$ z = direction (e.g. vertical)

a has a gradient in the z-direction, da/dz



here $\frac{da}{dz} < 0$

J_a = net amount of property a transported per unit time per unit area in the ⊕ z direction

[a is <u>diffusing</u> due to molecular motion of molecules]

J_a is ⊕ for a negative gradient

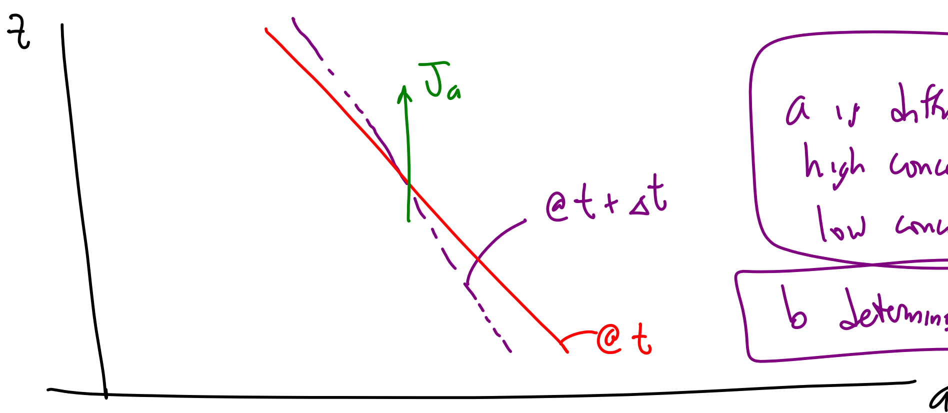
J_a is ⊖ ... positive gradient

General 1-D expression for <u>gradient diffusion</u> of quantity a

$$\star \quad \boxed{J_a = -b\,\frac{da}{dz}}$$

b = <u>diffusion coefficient</u>

☆ Property a diffuses from regions of high magnitude (of a) to regions of low magnitude (of a)



a is diffusing from high concentration to low concentration

b determines how fast this takes place

$$\boxed{J_a = -b \frac{da}{dz}}$$ ✫ ✫

Property a	gradient diffusion eq.	J_a	b	Property being diffused
T temperature	$\boxed{q = -k \frac{dT}{dz}}$ Fourier's Law	q rate of heat flow per unit area	k coeff of thermal conductivity	energy (heat)
U velocity	$\boxed{-\tau = -\mu \frac{dU}{dz}}$ Newton's law	$-\tau$ - shear stress	μ coeff. of viscosity	momentum
$C_{molar,j}$	$\boxed{J_j = -D_{aj} \frac{dC_{molar,j}}{dz}}$ Fick's law	J_j molar flux of species j	D_{aj} binary diffusion coeff	mass or mols of species j

a = air, j = species

✫ D_{aj} = binary diffusion coeff. between air (a) & species j

Important point — All 3 of these 1-D gradient diffusion eq's are basically identical, but with different variables used

Why? Because the physics of gradient diffusion is the same regardless of what quantity is being diffused.