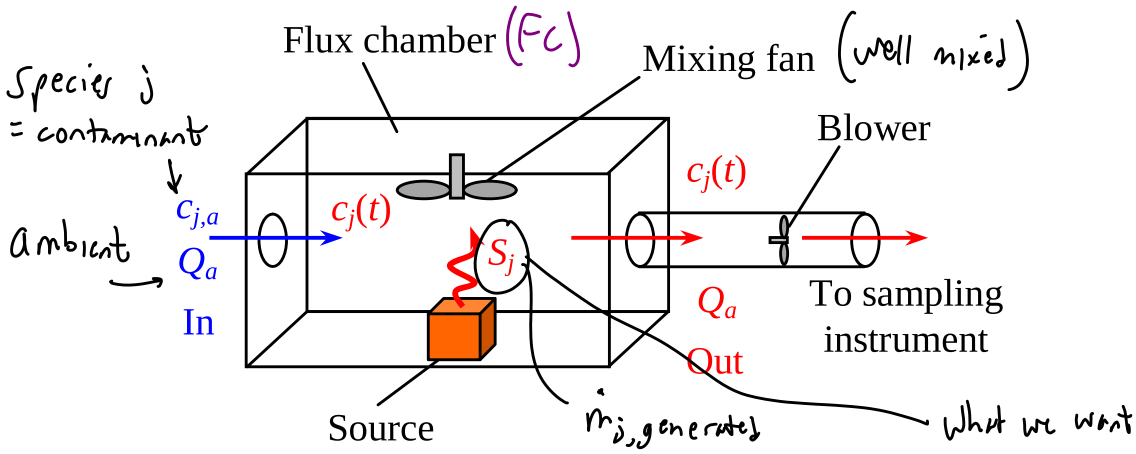
Today, we will:

- Continue to discuss **flux chambers**, and do an example problem
- Discuss EFs for tank-filling applications, and if time, do an example problem

Flux Chamber = an enclosure around a source of air pollutant with which we measure the source strength S_j of the pollutant.



Conservation of mass of species j: $$\boxed{\frac{dm_j}{dt} = c_{j,a}Q_a + S_j - c_j(t)Q_a} \qquad (1)$$

rate of change of mass of species j within the FC

rate of mass flow of species j into the FC from ambient air

rate of production or emission rate of species j (source strength)

rate of mass flow of species j out of the FC.

But $\frac{dm_j}{dt} = V \frac{dc_j(t)}{dt}$ (we approx. that c_j is uniform throughout the FC. & V = constant)

Volume of the FC

$$\left[\frac{\text{mass of } j}{\text{time}} = \frac{\text{Vol}}{\text{time}} \cdot \frac{\text{mass of } j}{\text{vol}}\right]$$

(1) becomes $$\boxed{V\frac{dc_j(t)}{dt} = c_{j,a}Q_a + S_j - c_j(t)Q_a}$$

$\div V$ $$\boxed{\frac{dc_j}{dt} = \underbrace{\frac{S_j + Q_a c_{j,a}}{V}}_{B} - \underbrace{\frac{Q_a}{V}}_{A} c_j}$$

of form $\boxed{\frac{dy}{dt} = B - Ay}$ 1st-order ODE

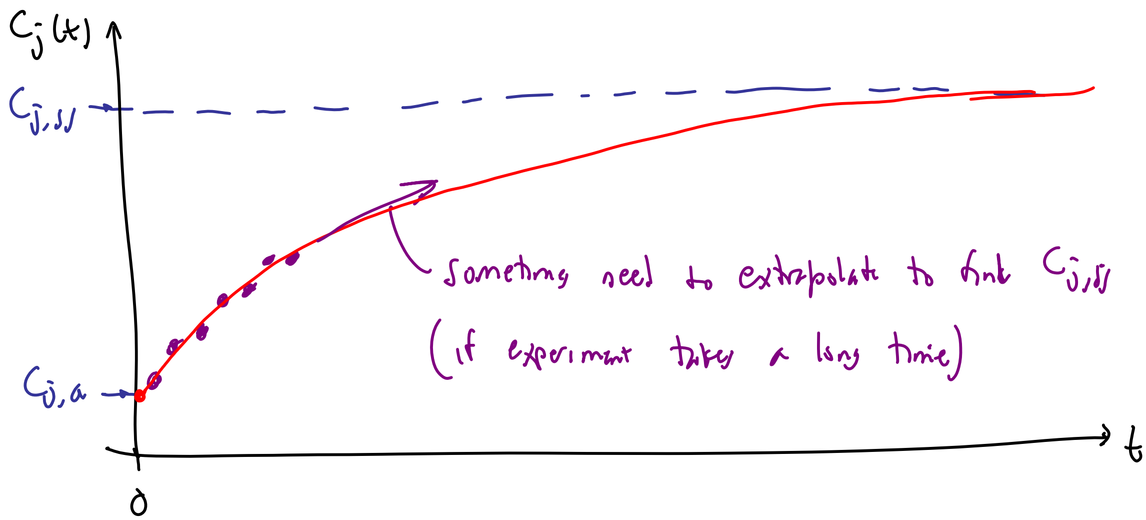
If we run the experiment for a long time → reach steady state

$C_j(t) \longrightarrow$ constant $\rightarrow \therefore$ LHS $= \frac{dC_j}{dt} \rightarrow 0$

$C_{j_{ss}}$ = steady state value = $\boxed{C_{j_{ss}} = \frac{B}{A} = \frac{S_j + Q_a C_{j,a}}{Q_a} = C_{j,a} + \frac{S_j}{Q_a}}$ ☆

Solve for S_j → $\boxed{S_j = \left(C_{j,ss} - C_{j,a}\right) Q_a = \dot{m}_{j \text{ generated}}}$

This is a 1st-order ODE



EXTRA NOTES ADDED AFTER CLASS:

NOTE: For a 1st-order ODE with a step function input (sudden change @ t=0), we know the solution:

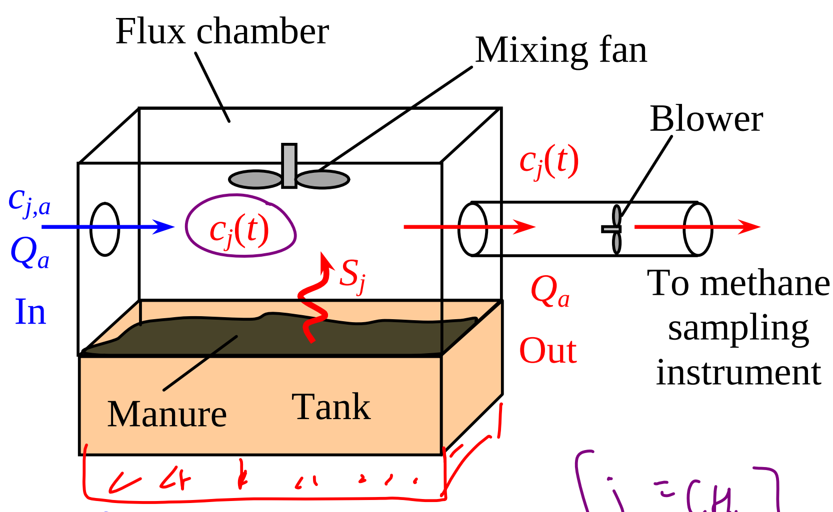
For $y = y(t)$; $\boxed{\frac{dy}{dt} = B - Ay}$ with $y(0)$ = initial state @ t=0

$y_{ss} = y(\infty)$ = final steady-state case, $\boxed{y_{ss} = B/A}$

Soln: $\boxed{\frac{y(t) - y(0)}{y_{ss} - y(0)} = 1 - \exp\left(-\frac{t}{\tau}\right)}$ ✻ where τ = 1st-order time constant $\boxed{\tau = \frac{1}{A}}$

Example: Methane from a Manure Tank

Given: Methane (CH_4) is emitted from a 2 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:



- $c_{j,a}$ = 0.0020 mg/m^3 (ambient mass concentration of CH_4 in the barn)
- Q_a = 0.18 m^3/s (bulk air flow rate into the flux chamber)
- $c_{j,ss}$ = 1.5 mg/m^3 (steady-state mass concentration of CH_4 leaving the flux chamber)

[$j = CH_4$]

To do: Generate an emission factor, EF, for methane from a manure pile.

Solution:

- Approx → well-mixed → c_j is uniform everywhere inside the FC
  $\therefore$ c_j @ outlet $= c_j(t)$

- Eq. for steady-state:

$$S_j = \dot{m}_{j,\text{generated}} = (c_{j,ss} - c_{j,a})Q_a$$

$$= \left(1.5\ \frac{mg}{m^3} - 0.0020\ \frac{mg}{m^3}\right)\left(0.18\ \frac{m^3}{s}\right)$$

$$\dot{m}_{j,\text{generated}} \rightarrow \boxed{S_j = 0.26964\ mg/s}$$

Convert this to an EF:

$$\boxed{EF = \frac{\dot{m}_{j,\text{generated}}}{\text{Denom}}}$$

Surface area of the manure is best choice

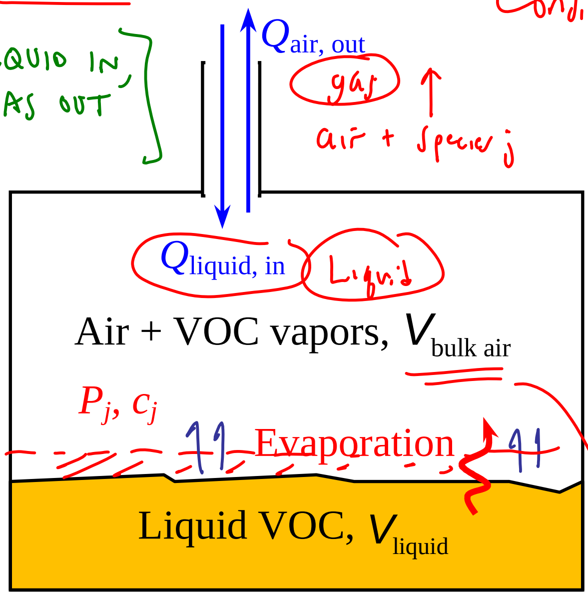
$$EF = \frac{\dot{m}_{j\text{ generated}}}{A_s} = \frac{0.26964\ mg/s}{2 \times 1\ m^2}\left(\frac{1\ kg}{10^6\ mg}\right)\left(\frac{3600\ s}{hr}\right)$$

$$EF = 4.8535 \times 10^{-4} \cong \boxed{EF = 4.9 \times 10^{-4}\ \frac{kg}{m^2 \cdot hr}}$$ ✱

Tank Filling

[LIQUID IN, GAS OUT]

Consider filling a tank of some VOC



Key → the liquid surface acts like a piston pushing the air + contaminant gas out

$\forall_{bulk\ air} \downarrow$ as $t \uparrow$

$$\boxed{Q_{air\ out} = Q_{liquid\ in}}$$

(air + species j)

→ The Displacement effect

Air is displaced by liquid

[If you fill up the tank, all the air originally in the tank escapes]

Emission rate $\dot{m}_j = c_j Q_{air\ out} = c_j Q_{liquid\ in}$

But $c_j = \dfrac{m_j}{\forall_{bulk\ air}}$ i.e. $m_j = n_j M_j$

Ideal gas for species j:

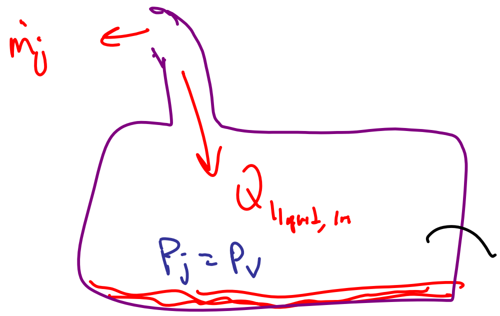
$$\boxed{P_j \forall_{bulk\ air} = n_j R_u T}$$

Some algebra ...

$$\boxed{\dot{m}_j = \frac{M_j P_j}{R_u T} Q_{liquid,in}} \quad (1)$$

If tank is being re-filled & some liquid is left at bottom, then $P_j = P_v$ = vapor pressure of the VOC (it's saturated)

Eg. filling up your car with gasoline



Estimate the mass of gasoline vapors you put into the atmosphere

$\forall = 15$ gal

MSDS → gasoline → $M_j = 110 \frac{kg}{kmol}$, $VP = 38$ to 300 mm Hg (vapor pressure)

take avg = 169 mm Hg

$$P_j = P_v = (169 \text{ mm Hg})\left(\frac{101.325 \text{ kPa}}{760 \text{ mm Hg}}\right) = 22.5 \text{ kPa}$$

Eq. (1) in mass form (we write Eq (1) as mass instead of mass flow rate)

$$m_j = \frac{M_j P_j}{R_u T}\forall_{tank} =$$

$$m_j = \frac{(110 \text{ kg}/\cancel{\text{kmol}})(22.5 \cancel{\text{kPa}})}{(8.314 \frac{\cancel{\text{kJ}}}{\cancel{\text{kmol}}\cdot\cancel{\text{K}}})(298.15 \cancel{\text{K}})}\left(\frac{\cancel{\text{kJ}}}{\cancel{\text{kN}\cdot\text{m}}}\right)\left(\frac{\cancel{\text{kN}}}{\cancel{\text{m}^2}\cdot\cancel{\text{kPa}}}\right)(15 \cancel{\text{gal}})\left(\frac{1 \cancel{\text{m}^3}}{264.17 \cancel{\text{gal}}}\right) = \boxed{0.057 \text{ kg}}$$

☆ Every time you fill up your tank, you emit 0.057 kg of gasoline vapors into the atmosphere!