Today, we will:

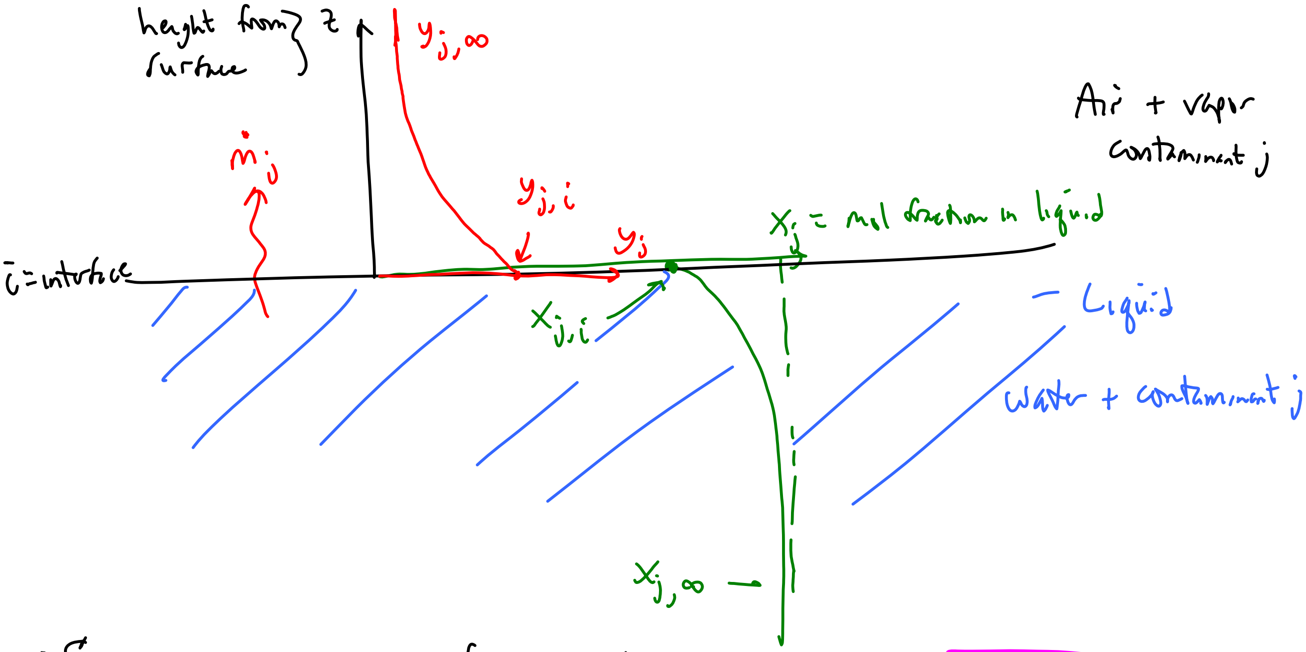
- Begin **Chapter 4 – Emission Rates**
- Discuss some definitions and notation
- Discuss **Emission Factors** in **Section 4.3**
- Do some example problems
- Discuss **Flux Chambers** in **Section 4.1**
- Do some example problems

2 s's, one m (know how to spell emission & emitted)

- Goal – to predict how much pollution is being emitted by a source
- Definitions & notation:

Subscripts: j = species eg. y_j = mol fraction of species j

i = interface (between a liquid & air + vapor)



- S_j = source strength of species j
- $\dot m_j$ = emission rate of species j

} same thing. $\boxed{\dot m_j = S_j}$ = generation rate

Recall, in a duct, or a stack (chimney) $\boxed{\dot m_j = c_j Q} = c_j \dot{V}$

- s_j (lower case) = $\frac{S_j}{A}$ = source strength per unit area

$$\{\dot{m}_j\} = \{S_j\} = \left\{\frac{\text{mass}}{\text{time}}\right\}$$

$$\{s_j\} = \left\{\frac{\text{mass}}{\text{time}\cdot\text{area}}\right\}$$

☆ Define $\boxed{EF = \underline{\text{Emission factor}} \equiv \frac{\text{mass of contaminant emitted}}{\text{mass of raw material used}}}$ ☆

EPA publishes EF's for various processes

See App. A-2 through A-7, also see EPA's website

EF's are "quick & dirty" estimates for emission rate calculations

EPA document for EF's is called AP-42

"AP-42 Emission Factors"

<u>Note</u>: ALL THE EF's are for <u>uncontrolled</u> processes (no air pollution control system) (APCS) to cut down the emission

If an APCS is used, define $\eta \equiv$ removal efficiency

(e.g. $\eta = 90\%$ means that 90% of the pollutant is removed before discharging to the atmosphere)

☆ $$\boxed{\underset{\text{discharged}}{\dot{m}_d} = (1-\eta)\,\underset{\text{generated}}{\dot{m}_g}}$$ — EF's correspond to $\dot{m}_g$, not $\dot{m}_d$

[<u>EF has many different units</u>]

EF's are "ballpark" estimates — typically good to only 1 or at most 2 significant digits.

Example

Given: A steel mill has an open hearth furnace with which it does melting and refining. The furnace refines about 8 tons of steel per hour on average.

To do: Estimate the uncontrolled emission rate of particles in kg/hr.

Solution:

See App. A.2 (p. 781)   open hearth furnace → $EF = 10.55 \frac{\text{kg particles}}{\text{Mg steel}}$

Comments · $Mg = 10^6 \; g$

· EPA should know better than to list EF to 4 sig. digits!

$$\dot{m}_{particles} = 8 \frac{\cancel{\text{ton steel}}}{\text{hr}} \times \frac{10.55 \text{ kg part}}{\text{Mg } \cancel{\text{steel}}} \left(\frac{2000 \text{ } \cancel{\text{lbm steel}}}{\cancel{\text{ton steel}}} \right) \left(\frac{1 \text{ } \cancel{\text{kg steel}}}{2.205 \text{ } \cancel{\text{lbm steel}}} \right) \times$$

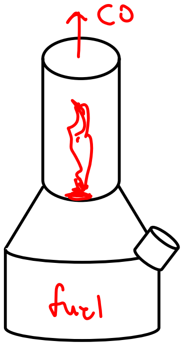
$$\times \left(\frac{1 \text{ } \cancel{\text{Mg}} \text{ steel}}{1000 \text{ } \cancel{\text{kg steel}}} \right) = 76.5 \frac{\text{kg part.}}{\text{hr}}$$

$$\boxed{\dot{m}_{particles} \cong 80 \text{ kg/hr}}$$

Example

Given: A small kerosene space heater is used for supplemental heating of a home. It burns 1 gallon of kerosene in about 5 hours.

To do: Estimate the uncontrolled emission rate of carbon monoxide into the room in units of g/hr.



Solution:

Table A-7 → $EF = 632 \frac{\mu g\ CO}{kcal}$ (of heat produced)

- Look up for kerosene

$\rho = 804\ kg/m^3$

$LHV = 860\ kcal/mol$ (lower heating value)

$M = 90\ g/mol$

$$\dot{m}_{co} = \underset{\uparrow\ EF}{\left(\frac{632\ \mu g}{kcal}\right)} \underset{\uparrow\ \text{burn rate}}{\left(\frac{1\ gal}{5\ hr}\right)} \underset{\uparrow\ LHV}{\left(860\ \frac{kcal}{mol}\right)} \underset{\uparrow\ 1/M}{\left(\frac{mol}{90\ g}\right)} \underset{\uparrow\ \rho}{\left(\frac{804\ kg}{m^3}\right)} \left(\frac{3.785\times10^{-3}\ m^3}{gal}\right) \left(\frac{g}{10^6\ \mu g}\right) \left(\frac{1000\ g}{kg}\right)$$

$$\dot{m}_{co} = 3.7\ g/hr \longrightarrow \boxed{\text{Answer } \dot{m}_{co} = 4\ \frac{g}{hr}}$$

eg. Paint → typical oil-based paint use a VOC (volatile organic compound) typically a hydrocarbon (HC) like toluene

typical paint contains 56% solvent } by mass
44% pigment & other stuff

When you paint, all of solvent eventually goes into the air

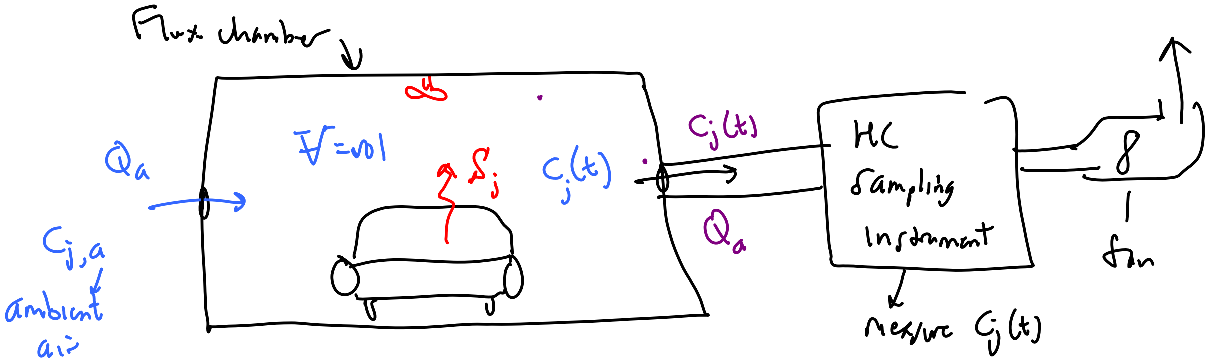
Eg. if I use 1 Mg of paint
then ≈ 0.56 Mg (56%) or 560 kg of solvent

$$\therefore \quad EF = 560 \frac{\text{kg of vapors of HC}}{\text{Mg of paint}}$$

Look at Table A.3 → $EF_{paint} = 560 \frac{kg}{Mg}$ ✓

Sec. 4.1.2 → Flux chambers ≡ a clever way to measure emission rates

E.g.
- A new couch (simulated leather)
- HCs are released — concern is raised
- Build a flux chamber to measure $\dot{m}_{HC} = S$



Assume the air inside the flux chamber is well mixed

Mass balance for species j (the HC)

$$\frac{dm_j}{dt} = \dot{m}_{j_{in}} + S_j - \dot{m}_{j\,out}$$

[use $\dot{m}_j = C_j Q$]

$$\boxed{\forall \frac{dC_j}{dt} = C_{j,a} Q_a + S_j - C_j Q_a} \qquad (1)$$

1st-order ODE

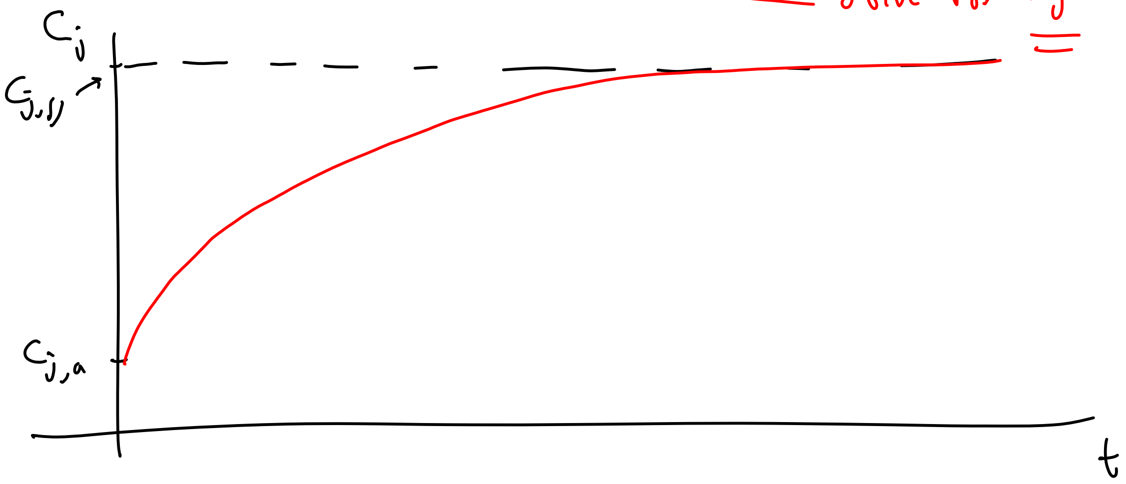
Write (1) in standard form $\frac{dy}{dt} = B - Ay$

(1) becomes $$\boxed{\frac{dC_j}{dt} = \underbrace{\frac{\dot{S}_j + Q_a C_{j,a}}{\forall}}_{B} - \underbrace{\frac{Q_a}{\forall}}_{A} C_j} \quad (2)$$

So, if $\dot{S}_j$, Q_a, $C_{j,a}$, & $\forall$ = const, we know the analytical solution,

$$\boxed{C_{j,ss} = \frac{B}{A} = \frac{\dot{S}_j + Q_a C_{j,a}}{Q_a}} = \text{steady-state mass concentration}$$

Solve for $\underline{\underline{\dot{S}_j}}$



PROCEDURE:

- measure $C_{j,a}$ (ambient air mass concentration)
- Measure C_j until it levels off → $C_j = C_{j,ss}$
- Then solve for $\dot{S}_j$, i.e.

$$\boxed{\dot{S}_j = Q_a \left(C_{j,ss} - C_{j,a} \right)} \circledast$$

= Source strength = $\dot{m}_j$ of HC species j emitted from the couch.

Note: We assume that $\dot{S}_j$ = constant. In reality, $\dot{S}_j$ will decay with time, but this takes <u>weeks</u> or <u>months</u>, whereas our experiment takes <u>minutes</u>.