Today, we will:

- Continue example problem from last time – EFs from combustion chemistry
- Do some example problems
- Discuss how to *measure* emission rates and calculate EFs

Example: EFs from combustion of natural gas (assume it is all methane) (continued)

Given: Natural gas is burned in a power plant. There is no APCS. Exhaust gases go up the stack at T = 500 K and P = 100 kPa.

(a) To do: Estimate the mol fraction, mass fraction, mass concentration, and molar concentration of CO_2 going up the stack. Give all answers to 3 significant digits.

(b) To do: Estimate (from first principles and chemistry) the EF of CO_2 emitted by burning methane, and compare with EPA's published EFs for burning natural gas (NG).

Solution (continued from last class): We had,

Chemical equation:

$$CH_4 + a(O_2 + 3.76\ N_2) \rightarrow bCO_2 + cH_2O + dN_2$$

Solve for the molar coefficients: a = 2, b = 1, c = 2, d = 3.76a = 7.52. So, the equation is

$$CH_4 + 2(O_2 + 3.76\ N_2) \rightarrow CO_2 + 2H_2O + 7.52N_2$$

Notice that *all* the carbon in the fuel is converted to carbon dioxide in the products.

Our estimated EF was $\mathrm{EF} = 2740 \dfrac{\text{kg CO}_2}{\text{Mg CH}_4}$. Let's compare to published EFs of

$\mathrm{EF} = 53 \dfrac{\text{kg CO}_2}{\text{thousand SCF NG}}$ and $\mathrm{EF} = 120{,}000 \dfrac{\text{lbm CO}_2}{10^6\ \text{SCF NG}}$

↑ standard cubic ft

Convert ours → $P\forall = mRT$ — $R = \dfrac{R_u}{M_{CH_4}}$ @ STP

for methane, $v = \dfrac{\forall}{m} = \dfrac{RT}{P} = \dfrac{R_u}{M_{CH_4}}\dfrac{T}{P}$

$$v = \frac{\left(8.314 \frac{\text{kJ}}{\text{kmol}\cdot\text{K}}\right)(298.15\ \text{K})}{\left(16.04246 \frac{\text{kg}}{\text{kmol}}\right)\left(101.324 \frac{\text{kN}}{\text{m}^2}\right)}\left(\frac{\text{kN}\cdot\text{m}}{\text{kJ}}\right)\left(\frac{1\ \text{ft}}{0.3048\ \text{m}}\right)^3 = 53.85 \frac{\text{SCF of CH}_4}{\text{kg CH}_4}$$

$$\mathrm{EF} = 2743.3 \frac{\text{kg CO}_2}{\text{Mg CH}_4}\left(\frac{1\ \text{kg CH}_4}{53.85\ \text{SCF}_{CH_4}}\right)\left(\frac{1\ \text{Mg CH}_4}{1000\ \text{kg CH}_4}\right)\left(\frac{1000\ \text{SCF}_{CH_4}}{\text{thousand SCF}_{CH_4}}\right) = 50.9 \frac{\text{kg CO}_2}{\text{thousand SCF methane}}$$

Example: EFs and APCSs (Air Pollution Control Systems) in parallel

Given: On an average day, a chemical plant generates 40.0 Mg of a product, and in the process emits an air pollutant. The uncontrolled emission factor for the air pollutant is EF = 5.3 kg/Mg. The plant has in place an APCS with a removal efficiency E = 89.%.

(a) To do: Calculate the amount of the air pollutant actually emitted into the atmosphere on in one typical day. Give your answer in kg to two significant digits.

Solution:

m_g = mass generated = $EF \cdot m_{product}$ (no APCS → uncontrolled)

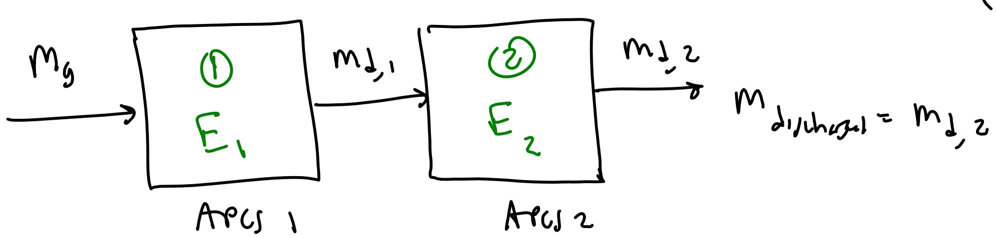
m_d = discharged mass $\quad m_d = (1-E)\, m_g \quad m_d = (1-E)(EF)\, m_{product}$

$$m_d = (1-0.89)\left(5.3\ \frac{kg}{Mg}\right)(40.0\ Mg) = 23.32\ kg \approx 23.\ kg$$

(b) To do: The government regulation gets more strict, and the plant is allowed to emit only 10 kg of the air pollutant per day. Calculate the minimum efficiency of a second APCS that is to be put in series with the existing one in order to meet the new regulation. (%)

2 digits

Solution:



$m_d = m_{d,2} = (1-E_2)\, m_{d,1}$ → we know $m_{d,1}$ from part (a)

Solve for E_2 → $E_2 = 1 - \dfrac{m_{d,1}}{m_{d,2}}$ → $1 - \dfrac{10\ kg}{23.32\ kg} = 0.57118$

$$E_2 = 57\%$$

Example: Emissions from a natural gas power plant

Given: A power plant burns natural gas (NG), and produces electricity at a rate of 860 MW (on average over the course of a year).

To do: Estimate (to 2 digits) how many million tons of CO_2 are emitted by this power plant per year.

Solution: First look up the EF of CO_2 emissions in an NG plant: EF = 1135 lbm CO_2/MWh.

$$m_{CO_2} = EF \cdot \left(\text{Electrical Energy produced}\right)$$

$$= \frac{1135 \text{ lbm } CO_2}{MW \cdot hr}(860 \text{ MW})(365.25 \text{ days})\left(\frac{24 \text{ hr}}{\text{day}}\right)\left(\frac{\text{ton}}{2000 \text{ lbm}}\right)$$

NG →

$$= 4.278 \times 10^6 \text{ ton} \rightarrow m_{CO_2} = 4.3 \text{ million tons}$$

Comparison → Coal

$$EF = \frac{2249 \text{ lbm } CO_2}{MWh}$$

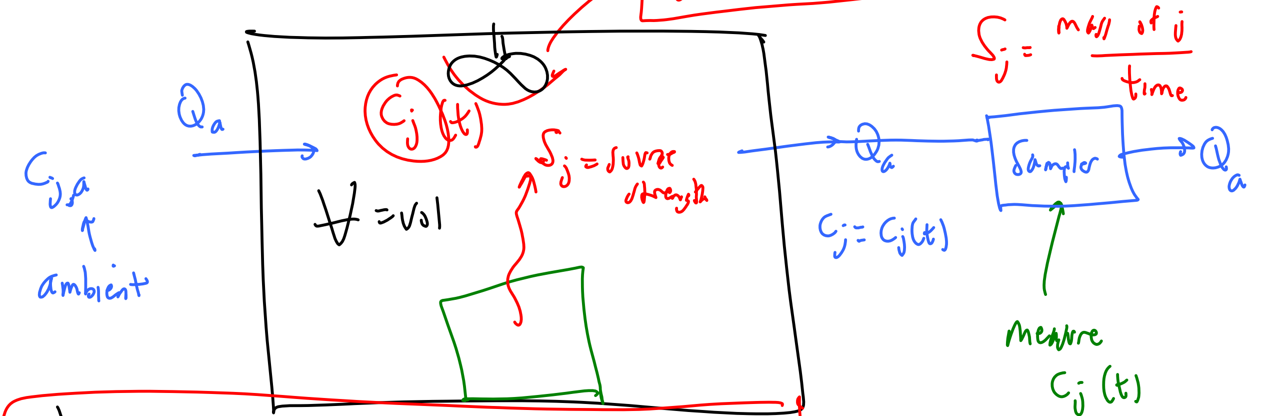
Factor of 2 higher than NG

HOW TO MEASURE EFs

One way is with a Flux Chamber → enclosure (box, plastic bag)

assume well-mixed conditions inside $\forall$

$S_j = \frac{\text{mass of } j}{\text{time}}$



$$\frac{dm_j}{dt} = C_{j,a} Q_a + S_j - C_j(t) Q_a$$

rate of change = IN + SOURCE − OUT

★ ← Conservation of mass of species j

"DEFLATE GATE"

Given: • Football initially @ 13 psi gage pressure in locker room @ $T = 20°C$, $P_{atm} = 14.7$ psi

• After being outside @ $T = 0°C$ for some long time,

Calculate the decrease in P_{gage} of the football in psi ΔP

Assume $\forall$ does not change significantly

(2 sig digits)

m = const

$$P\forall = mRT \rightarrow m = \frac{P_1 \forall_1}{RT_1} = \frac{P_2 \forall_2}{RT_2}$$

$$P_2 = \frac{P_1 T_2}{T_1} \rightarrow \frac{(13 + 14.7)\text{ psi}\,(273.15\text{ K})}{(293.15\text{ K})} = 25.81 \text{ psi}$$

Diff $\rightarrow$ $27.7 - 25.81 = $ **1.9 psi**