Today, we will:
- Do another emission factor (EF) example problem
- Continue discussing EFs: **Tank filling**, and do some example problems
- Begin to discuss some basics of meteorology: **Coriolis effect, global wind patterns, atmospheric stability**

**Example: Methane from a Manure Tank – a practical agricultural example**

**Given:** Methane (CH₄) is emitted from a 2 m × 1 m manure tank in a barn. A flux chamber (FC) is built on top of the tank to measure the emission rate. The following quantities are measured:
- \( c_{j,a} = 0.0020 \text{ mg/m}^3 \) (ambient mass concentration of CH₄ in the barn)
- \( Q_a = 0.18 \text{ m}^3/\text{s} \) (bulk air flow rate into the flux chamber)
- \( c_{j,ss} = 1.5 \text{ mg/m}^3 \) (steady-state mass concentration of CH₄ leaving the flux chamber)

**To do:** Generate an emission factor, \( EF \), for methane gas emitted from a manure tank.

**Solution:**

**Assumptions and Approximations (A&A):**
- The air in the FC is **well mixed**. Therefore \( c_j \) at the outlet = \( c_j \) inside the FC.
- All variables except \( c_j(t) \) are constant.
- After sufficient time, \( c_j(t) \) levels off (steady-state conditions); \( c_j = c_{j,ss} = 1.5 \text{ mg/m}^3 \).

Recall our equation for steady-state conditions,

\[
m_{j,\text{generated}} = S_j = \left( c_{j,ss} - c_{j,a} \right) Q_a
\]

Now create an emission factor:

\[
EF = \frac{m_{j,\text{generated}}}{\text{some appropriate denom.}} = \frac{S_j}{\text{some appropriate denom.}}
\]
Another Emission Factor Example:
Tank Filling – consider filling a tank with some liquid volatile organic compound (VOC):

\[ Q_{\text{liquid, in}} \]

Air + VOC vapors, \( V_{\text{bulk air}} \)

\[ P_j, c_j \]

Evaporation

Liquid VOC, \( V_{\text{liquid}} \)
**Tank Filling (continued)** – consider filling a tank with some liquid volatile organic compound (VOC) for the case in which *a small amount of the VOC has been sitting in the tank for a long time* (e.g., filling a nearly empty gas tank in your car):

\[ Q_{\text{liquid, in}} \]

Air + VOC vapors, \( V_{\text{bulk air}} \)

\( P_j = P_{v,j} \)  No evaporation since air is saturated with VOC vapors!

Liquid VOC, \( V_{\text{liquid}} \)
Example: Emissions from filling your car’s gasoline tank

**Given:** You need gasoline in your car. The tank is nearly empty, but there is still a small amount of liquid gasoline at the bottom of the tank. The tank volume is 15 gallons.

**To do:** Estimate (to 2 digits) the mass of gasoline vapors emitted into the atmosphere during one fill-up at the gas station.

**Solution:** First look up the molecular weight and vapor pressure of gasoline at SATP conditions:

- Average molecular weight is $M_j = 110 \text{ kg/kmol}$
- Average vapor pressure is $P_{v,j} = 169 \text{ mm Hg} = 22.5 \text{ kPa}$

Use the equation we derived for filling up a tank – displacement vapors are emitted in the bulk air that must come out of the tank as we add liquid (the liquid pushes the bulk air out),

In terms of mass and volume flow rates: $m_{j, \text{displaced}} = \frac{M_j P_j}{R_u T} Q_{\text{liquid in}}$

In terms of mass and volume (not rates): $m_{j, \text{displaced}} = \frac{M_j P_j}{R_u T} V_{\text{liquid in}}$

**Key:** Here, since liquid gasoline has been sitting in the tank for a long time, the partial pressure of the gasoline vapors is equal to the vapor pressure of the gasoline.

So, we set $P_j = P_{v,j}$ and plug our numbers into the second equation above,

$$m_{j, \text{displaced}} = \frac{M_j P_j}{R_u T} V_{\text{liquid in}}$$

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

**Result:** We estimated that approximately **0.057 kg** of gasoline vapors are emitted into the atmosphere for each 15-gallon fill-up of gasoline at a gas station.

**Quick comment about bias in the media:** Which sounds more alarming to the average person on the street?

1. You emit only 0.057 kg of gasoline vapors into the atmosphere by filling up your car.
2. You emit 57 g of gasoline vapors into the atmosphere every time you fill up your car.
3. You emit 57,000 mg of gasoline vapors into the atmosphere every time you fill up your car.
4. *You* pollute and contaminate the air that we all have to breathe by emitting **57,000 mg** of toxic and odorous gasoline vapors into the atmosphere *each and every* time you fill up your car!
Question: How much does this lost gasoline vapor emission cost per fill-up?

Gas price record every January or February since I have taught ME 433:

<table>
<thead>
<tr>
<th>Year</th>
<th>Gasoline cost per gallon</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014</td>
<td>$3.50</td>
</tr>
<tr>
<td>2015</td>
<td>$2.50</td>
</tr>
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<td>2016</td>
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<tr>
<td>2019</td>
<td>$2.60</td>
</tr>
<tr>
<td>2020</td>
<td>$2.60</td>
</tr>
</tbody>
</table>

Solution:
- From above, we calculated $m_{j, emitted} = 0.057 \text{ kg}$
- Gasoline cost = $2.60/\text{gallon}$
- Look up specific gravity of liquid gasoline: $SG_{\text{gasoline}} = 0.75$
- So, the density of the gasoline is $\rho_{\text{gasoline}} = SG_{\text{gasoline}} \rho_{\text{gasoline}} =$
- Conversion: $1 \text{ m}^3 = 264.17 \text{ gallons}$

Now we can calculate the money (in cents) wasted (lost as vapor into the atmosphere) each time we fill up our gas tank with gasoline:
Vapor Recovery System at a gas station:
Meteorology Basics

1. The Coriolis Effect and how it affects plumes, dispersion of air pollutants
2. The effect of Lapse Rate on plume stability and weather

The Coriolis Effect:

*Coriolis force* is an *apparent* force that an object “feels” when moving in a *rotating reference frame.*

Simplest example: a merry-go-round or “roundabout.”

**Case 1:** Throw a ball from the middle of the roundabout towards a target at the outer part of the roundabout.

View from the top:

Stationary (absolute) reference frame

Rotating reference frame
**Case 2:** Throw a ball from the outer part of the roundabout towards a target in the middle of the roundabout.

View from the top:

- **Stationary (absolute) reference frame**
  - Thrower at $t_1$
  - Thrower at $t_2$
  - Target at $t_1$ and $t_2$
  - Coriolis force

- **Rotating reference frame**
  - Thrower at $t_1$
  - Thrower at $t_2$
  - Target at $t_1$ and $t_2$

**Conclusion:** The Coriolis force is an apparent force that a moving object “feels” when observed in a rotating reference frame. The Coriolis force is perpendicular to the direction of motion. Here, since the roundabout is rotating counterclockwise (mathematically positive when looking from above), the Coriolis force appears, to someone in the rotating reference frame, to pull the object to the right. In reality, however, the object is actually moving in a straight line – as observed by someone in a stationary (non-rotating) reference frame.
Global Wind Patterns

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[Diagram showing global wind patterns with labels for polar highs, subtropical highs, intertropical convergence zone (ITCZ), Hadley cell, Ferrel cell, and polar easterlies.]

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Recall this picture of smoke plumes with tracers [when we discussed acid rain]. This shows that plumes in the USA veer to the north and east due to the prevailing westerly winds:

The Science Behind the Polar Vortex

The polar vortex is a large area of low pressure and cold air surrounding the Earth’s North and South poles. The term vortex refers to the counterclockwise flow of air that helps keep the colder air close to the poles (left globe). Often during winter in the Northern Hemisphere, the polar vortex will become less stable and expand, sending cold Arctic air southward over the United States with the jet stream (right globe). The polar vortex is nothing new — in fact, it’s thought that the term first appeared in an 1853 issue of E. Littell’s Living Age.