Methane on a hot summer day

We will use Henry's law to look at methane in the atmosphere and discuss methane emissions from a wastewater treatment plant (WWTP).

Question. Calculate the mole fraction of methane (CH_4) in a lake that is in contact with air at 30°C.

The ambient concentration of methane in the atmosphere is about 2 ppm, and we will assume we are at or near sea level and therefore the total pressure is 1 atm. We will also assume we are at equilibrium as a lake and the atmosphere should have had plenty of time to come to equilibrium since we haven't recently introduced anything new to either in this situation.

Look at **table B.3** in your textbook. $H_{CH4}(30°C) = 4.49 \times 10^4$ atm/mol. frac. Note that you need to multiply the value in the table by 10^4. Also note that if you are looking up tables outside of the context of this class, Henry's Law constant tables have important footnote information. This order of magnitude (OOM) information as well as whether the values are P/x or x/P.

First we will determine the gas mole fraction (y_{CH4}) from the concentration.

$$2ppm = \frac{2}{10^6} = 2 \times 10^{-5}$$

From this we can determine the partial pressure of methane in the atmosphere using equation 10.2.

$$\begin{aligned} P_{CH_4} &= y_{CH_4} P = P_{vCH_4} \text{ at equilibrium} \\ P_{CH_4} &= 2 \times 10^{-5} \times 1 \text{ atm} \\ P_{CH_4} &= 2 \times 10^{-5} \text{ atm} \end{aligned}$$

Now we haveenough information to use Henry's Law to find the mole fraction.

$$\begin{aligned} P_{CH_4} &= H_{CH_4} x_{CH_4} \\ 2 \times 10^{-5} \text{ atm} &= 4.49 \times 10^4 x_{CH_4} \\ x_{CH_4} &= 4.45 \times 10^{-10} \end{aligned}$$

So a typical lake doesn't have a very high concentration of methane.

WWTP

As part of our environmental science/engineering work, we have read that methane emissions from wastewater treatment are important sources of greenhouse gases (GHG). We would like to compare the mole fraction of methane in this lake to that at a wastewater treatment facility. Due to health and safety protocols, we are not permitted to sample the sludge ponds, so we cannot analyze the water itself. However, we have access to some atmospheric monitoring equipment that we can use to take measurements of the air near the facility. Upon taking measurements, we find that the atmospheric emissions (the air above the processing wastewater that is in equilibrium contact with sea level air) have a concentration of 100 $g_{CH_4/}$m^3.

We'll say that we took these measurements on the same day or at least at the same temperature, so the Henry's law constant we had looked up previously is still valid. So we can recalculate the mole fraction in water (x_{CH_4}) for this new body of water.

$$C_{mass} = \frac{1000 C_{ppm} MW}{24.45}$$

eq. 1.9, 30°C is close to standard, so we'll use this form.

note, the units for this equation are $\mu g/m^3$

$$100 \times 10^6 \mu g/m^3 = \frac{1000 \times 16 \times C_{ppm}}{24.45}$$

$$C_{ppm} = 152,812 ppm \approx 150,000 ppm$$

Now we will redo the calculations above with this new, higher concentration

$$150,000 ppm = \frac{150,000}{10^6} = 0.15 = y_{CH4}$$

$$P_{\mathrm{CH}_4} = y_{\mathrm{CH}_4} P = P_{v\mathrm{CH}_4}$$
$$P_{\mathrm{CH}_4} = 0.15 \times 1 \text{ atm} = 0.15 \text{ atm}$$

$$P_{\mathrm{CH}_4} = H_{\mathrm{CH}_4} x_{\mathrm{CH}_4}$$
$$0.15 \text{ atm} = 4.49 \times 10^4 x_{\mathrm{CH}_4}$$
$$= 3.36 \times 10^{-6}$$

So you can see that the methane levels in the water at a wastewater treatment facility are much higher than those at a typical lake.

There are many things we can do with this information. Some WWTP capture the gaseous methane which can then be sold or combusted on site to supply heat or energy. Methane is the key component of natural gas (fuel) in addition to being a potent GHG, so by utilizing it we can reduce the GHG load in the atmosphere as well as reducing the use of other combustion that might add even more GHGs to the atmosphere. It is also a clean burning fuel so we can reduce the effort spent on some of the other pollution control measures we discuss in this course.