Indoor Air and Air Exchange Rates

The air exchange rate (sometimes referred to as as the number of air changes per hour "ach") is a first order rate constant (k_e) for the ventilation of indoor air. It is related to the indoor air residence time (τ_e) as $k_e = 1/\tau_e$.

Taking into account air exchange processes only (i.e., no chemical loss mechanisms);

$$\text{Rate of infiltration of an outdoor contaminant} = \frac{d[X]}{dt} = k_e[X]_{outside}$$

$$\text{Rate of ventilation of an indoor contaminant} = \frac{d[X]}{dt} = -k_e[X]_{inside}$$

Taking into account both infiltration from outdoor sources and ventilation of indoor sources, the net rate of accumulation of a contaminant inside is given by;

$$\text{Rate} = d[X]/dt = k_e\,[X]_{outside} - k_e\,[X]_{inside}$$

The integrated form of the rate equation is given by;

$$ln\,([X]_o - [X]_i) = -\,k_e\,t + \text{Constant}$$

At steady state, Rate in = Rate out

$$\text{Rate in} = k_e\,[X]_{outside} + \text{ Rate of emission from an internal source}$$

and, assuming no chemical loss;

$$\text{Rate out} = k_e\,[X]_{inside}$$

Hence, at steady state;

$$k_e\,[X]_{inside} = k_e\,[X]_{outside} + \text{ Rate of emission from an internal source}$$

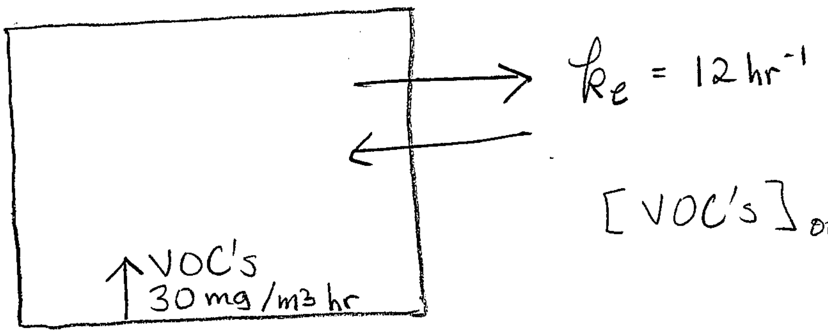
1. An open fire in a well ventilated home produces VOCs at a rate of 30 mg m^{-3} h^{-1}. A complete exchange of air takes place every 5 minutes. The ambient outdoor air concentration of VOCs is 75 μg m^{-3}. Calculate the steady state indoor concentration of VOCs from this source assuming no chemical loss mechanisms.

[*Answer = 2.6 mg m^{-3}*]

complete exchange of air every 5 mins

$\therefore \frac{60}{5} = 12$ air changes per hour

so $k_e = 12\ hr^{-1}$



$[VOC's]_{outside} = 0.075\ \frac{mg}{m^3}$

Rate VOC's out $= 12\ hr^{-1}\,[VOC]_{in}$

Rate VOC's in $= 12\ hr^{-1}\,[VOC]_{out} + 30\ \frac{mg}{m^3\ hr}$

$= 0.90\ \frac{mg}{m^3\ hr} + 30\ \frac{mg}{m^3\ hr} = 30.9\ \frac{mg}{m^3\ hr}$

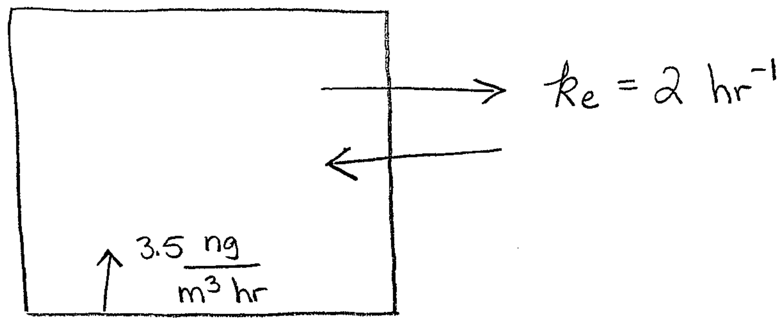
at steady state Rate in = Rate out

$\therefore 12\ hr^{-1}\,[VOC]_{in} = 30.9\ \frac{mg}{m^3\ hr}$

and $[VOC]_{in} = \dfrac{30.9\ \frac{mg}{m^3\ hr}}{12\ hr^{-1}} = 2.57\ \frac{mg}{m^3}$

2. In some rural communities, heating and cooking are often done with open fires. If the rate of emission of PAHs from indoor combustion is 3.5 ng m^{-3} h^{-1} and the outdoor concentration of PAHs is 0.60 ng m^{-3}, estimate the steady state indoor air concentration of PAH compounds if the air exchange rate is 2 h^{-1}. Assume that the only loss mechanism is by air exchange.

[*Answer = 2.4 ng* m^{-3}]



$$\text{Rate in} = \frac{3.5\ ng}{m^3\ h} + 2\,h^{-1}\left(0.60\ \frac{ng}{m^3}\right) = 4.7\ \frac{ng}{m^3\ h}$$

$$\text{Rate out} = k_e\,[PAH]_{in} = 2\,h^{-1}\,[PAH]_{in}$$

At steady state:

$$4.7\ \frac{ng}{m^3\ h} = 2\,h^{-1}\,[PAH]_{in}$$

$$\therefore [PAH]_{in} = 2.35\ \frac{ng}{m^3}$$

3. A one compartment home of volume 330 m^3 has an infiltration rate of 0.25 ach with doors and windows closed. During an episode of photochemical smog, the outdoor concentration of PAN is 85 ppb_V. If the family remains indoors and the initial concentration of PAN inside is 18 ppb_v, how long will it take before the PAN concentration inside rises to 45 ppb_V.

[*Answer = 2.0 hr*]

To relate conc. to time, we must use the integrated form of the rate expression

$$\ln([X]_o - [X]_i) = -k_e t + \text{Const.}$$

we use the $t=0$ data to calculate the magnitude of constant

at $t=0$, $[X]_o = 85$ ppbv, $[X]_i = 18$ ppbv

$\therefore$ Constant $= \ln(85-18) = 4.20$

at $t=?$, $[X]_o = 85$ ppbv, $[X]_i = 45$ ppbv

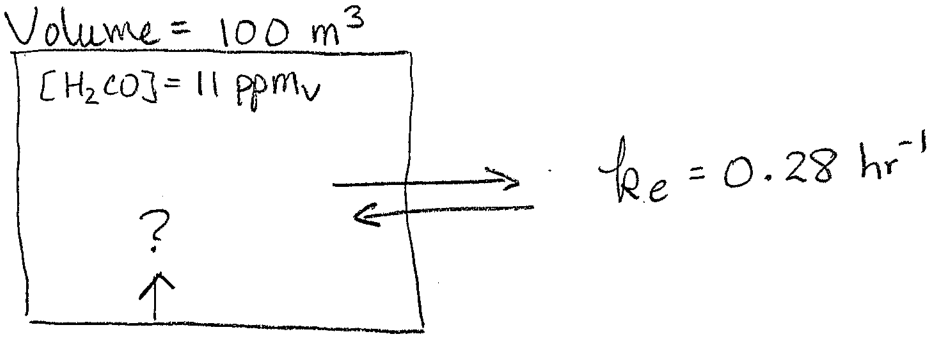
$$\therefore \ln(85-45) = -0.25\ hr^{-1}\ t + 4.20$$

$$\text{So } t = \frac{\ln(85-45) - 4.20}{-0.25\ h^{-1}}$$

$$= 2.0\ hr$$

4. A mobile home has a volume of 100 m^3 and a ventilation rate of 0.28 ach. If the concentration of formaldehyde in the home has reached a steady state concentration of 11 ppm$_v$, what is the rate of emission of formaldehyde from the materials in the home in mg per hour?

[*Answer = 38 mg h^{-1}*]



Rate formaldehyde into home = Rate emission + Rate infilteration

since outdoor conc of H_2CO not given, assumed to be very low ($\simeq 0$)

$$\text{Rate out} = k_e[H_2CO] = 0.28\ h^{-1}\ (11\ ppm_v) = 3.1\ ppm_v\ h^{-1}$$

∴ At steady state, Rate emission = 3.1 ppm$_v$ h^{-1}

We need to convert this to mg per hour

$$\frac{3.1\times10^{-6}\ \text{mol } H_2CO}{1\ \text{mol air}} \times \frac{30{,}000\ \text{mg } H_2CO}{1\ \text{mol } H_2CO} \times \frac{1\ \text{mol air}}{24.45\ L} \times \frac{10^3\ L}{1\ m^3}$$

$$= 3.8\ \frac{mg}{m^3}\ \text{per hour}$$

∴ Rate H_2CO into home (emission source) $= 3.8\ \frac{mg}{m^3} \times 100\ m^3 \times \frac{1}{hr}$

$= 38\ mg/hr$