Nitrogen pumpout calc

We ask how much nitrogen is present, and how long to pump out. Assume a light tube of PMMA that is saturated with N2 at 1 atm to start. We then pull a good vacuum on it at t=0, and compute the diffusion out through the surfaces

Solubility: again from NIST reference:

Experimental Data

Henry's law solubility constants S for gases in PMMA

Gas	Pressure/atm	$S/(\mathrm{cm^3(STP)/g\ atm})$
He	3.8–7.2	0.066
Ne	2.7	0.126
Ar	3.2–7.4	0.105 ± 0.063
Kr	2.6–4.6	0.122
N_2	5.7–15.0	0.045 ± 0.028
CO_2	4.0–19.0	0.260 ± 0.024

$S_{N2\_PMMA} := .045 \dfrac{scc}{gm \cdot atm}$ $\quad M_{a\_N2} := 28 \dfrac{gm}{mol}$ $\quad scc = 4.464 \times 10^{-5}\, mol$

Light tube dims:

$t_{lt} := 3mm \quad l_{lt} := 1.3m \quad r_{lt} := 53cm$

buffer support and SiPM plane are not included here

Light tube area, volume, mass:

$A_{lt} := 4\pi r_{lt} \cdot l_{lt} \quad V_{lt} := 2\pi r_{lt} \cdot l_{lt} \cdot t_{lt} \quad M_{lt} := V_{lt} \cdot \rho_{PMMA}$

$A_{lt} = 8.658\, m^2 \quad V_{lt} = 0.013\, m^3 \quad M_{lt} = 15.585\, kg$

Mass, number of moles N2

$M_{N2\_lt} := S_{N2\_PMMA} M_{lt} \cdot 1atm \cdot M_{a\_N2} \quad M_{N2\_lt} = 0.877\, gm$

(note purifier has 30 gm removal capacity, below)

$N_{N2\_lt} := S_{N2\_PMMA} \cdot M_{lt} \cdot 1atm \quad N_{N2\_lt} = 0.031\, mol$

$S_m := \dfrac{M_{N2\_lt}}{M_{lt}} \quad S_m = 5.625 \times 10^{-5}$

Molar concentration, initial

$C_{i\_N2} := S_{N2\_PMMA} \cdot \rho_{PMMA} \cdot 1atm \quad C_{i\_N2} = 2.411 \dfrac{mol}{m^3}$

Diffusion constant for N2 in polymers

$D_{N2\_PMMA} := 5 \cdot 10^{-9} \dfrac{m^2}{s}$ from: -->

Solubilities and diffusion coefficients of carbon dioxide and nitrogen in polypropylene, high-density polyethylene, and polystyrene under high pressures and temperatures H.Masuoka, et al.)

Finite thickness plane (1D) Fick's 2nd law solution:

diffusion constant:

$D := D_{N2\_PMMA}$

for plate of half thickness h, and distance from plate centerplane x, and some time after initial vacuum aplication

$h := 0.5t_{lt} \quad x := h \quad h = 1.5\, mm \quad x = 1.5\, mm$

time unit

$u := 1min$

range variable

$t := 1u, 2u .. 100u$

For an infinite sheet of width 2l, with initial concentration C_i suddently exposed to a surface concentration of C_l, total (integrated) mass flow through surface at time t divided by the total for t = infinity:

$l := h \quad l = 1.5\, mm$

$$f_M(t) := 1 - \sum_{n=0}^{\infty}\left[\frac{8}{(2n+1)^2\pi^2}e^{\left[\frac{-D\cdot(2n+1)^2\pi^2 t}{4l^2}\right]}\right]$$

<u>Mathematics of Diffusion</u>, Crank, eq. 4.18

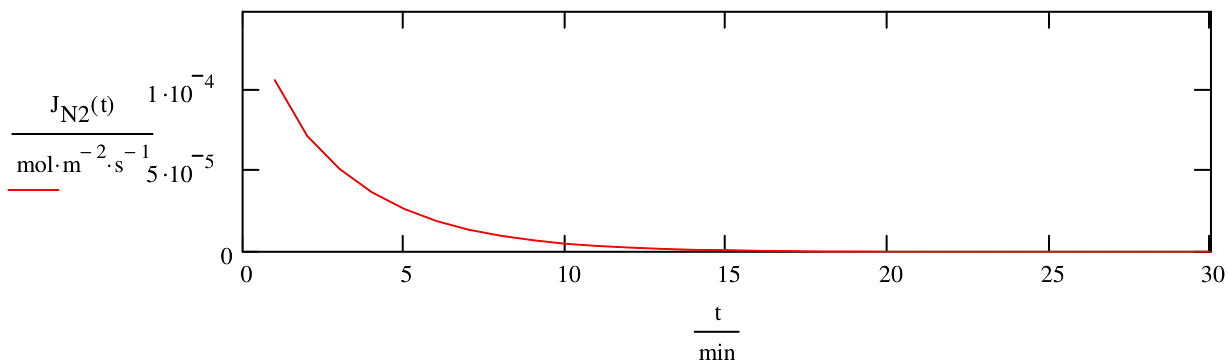
differentiating this with respect time gives us (dimensionless) flux (flow rate):

$$dfMdt(t) := \sum_{n=0}^{100}\left[2\frac{D}{l^2}\cdot e^{\left[\frac{-D\cdot(2n+1)^2\pi^2 t}{4l^2}\right]}\right]$$

first few terms of summation are sufficient for long times

and outgassing flux is then:

$$J_{N2}(t) := V_{lt}\cdot C_{i\_N2}\cdot dfMdt(t)$$



check --> $\int_{0s}^{1day} J_{N2}(t)\,dt = 0.031\,mol$ initial gas load --> $N_{N2\_lt} = 0.031\,mol$

95% removal time

$t_{95} := 8min$ $\int_{0s}^{t_{95}} J_{N2}(t)\,dt = 0.029\,mol$

outgas rate after 0.1, 1 hr

$$t_{1hr} := \begin{pmatrix} 0.1 \\ 1 \end{pmatrix} hr$$

$$J_{N2}(t_{1hr}) = \begin{pmatrix} 1.933\times 10^{-5} \\ 3.723\times 10^{-13} \end{pmatrix}\frac{mol}{s}$$

$P_{1hr} := J_{N2}(t_{1hr})\cdot R\cdot T$ $P_{1hr} = \begin{pmatrix} 0.353 \\ 6.802\times 10^{-9} \end{pmatrix}\frac{torr\cdot L}{s}$