ChE 258
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7-5. Using the sweep-through purging method, inert a 100 gallon vessel containing 100% air until the oxygen concentration is 1%. What volume of nitrogen is required? Assume nitrogen with no oxygen and a temperature of 77°F.

Eq 7-10 applied

$$Q_v t = V \ln\left(\frac{C_1 - C_0}{C_2 - C_0}\right)$$

$C_1 = .21$
$C_0 = 0$
$C_2 = .01$

$$Q_v t = (100\,\text{gal})\left(\frac{\text{ft}^3}{7.481\,\text{gal}}\right)\ln\left[\frac{.21-0}{.01-0}\right] = \underline{40.7\ \text{ft}^3}$$

7-7. Use a vacuum purging technique to purge oxygen out of a 150 cubic ft tank containing air. Reduce the oxygen concentration to 1% using pure nitrogen as the inert. The temperature is 80°F. Assume the vacuum purge goes from atmospheric pressure to 20 mm Hg. absolute. Determine the number of purge cycles required, and the total moles of nitrogen used.

Relation 7-6

$$y_j = y_0\left(\frac{P_L}{P_H}\right)^j = y_0\left(\frac{n_L}{n_H}\right)^j \quad \ln\left(\frac{y_j}{y_0}\right) = j\ln\left(\frac{P_L}{P_H}\right)$$

$y_j = .01$

$y_0 = .21$

$$j = \frac{\ln\left(\frac{y_j}{y_0}\right)}{\ln\left(\frac{P_L}{P_H}\right)}$$

$P_L = 20 \text{ mmHg}$

$P_H = 760 \text{ mmHg}$

$$j = \frac{\ln\left(\frac{.01}{.21}\right)}{\ln\left(\frac{20}{760}\right)} = \frac{-3.045}{-3.638} = 0.837$$

So use one purge cycle

Total moles N_2 used - Eq 7-7

$$\Delta n_{N_2} = j(P_H - P_L)\frac{V}{R_g T} = \frac{(1)(760\text{ mmHg} - 20\text{ mmHg})(150\text{ ft}^3)}{\left(0.7302\ \frac{\text{ft}^3\text{ atm}}{\text{lbmol °R}}\right)(460 + 80\text{°R})}\left(\frac{\text{atm}}{760\text{ mmHg}}\right)$$

$\Delta n_{N_2} = 0.370$ lbmol N_2

7-10. Use the system described in Figure 7-2 to determine the voltage developed between the charging nozzle and the grounded tank, and the energy stored in the nozzle. Explain the potential hazard for cases a and b below.

Case	a	b
Hose length (ft)	20	20
Hose diameter (in)	2	2
Flow rate (gpm)	25	25
Liquid conductivity (mho/cm)	10^{-8}	10^{-18}
Dielectric constant	2.4	19
Density (gm/cm^3)	0.8	0.8
Viscosity (centipoise)	0.6	0.6
Diffusivity, D_m (cm^2/s)	2.2×10^{-5}	2.2×10^{-5}

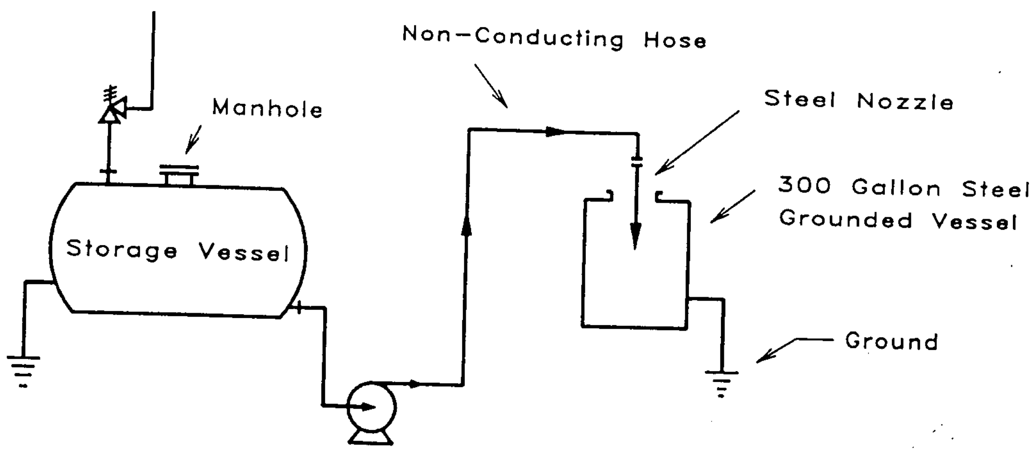

Figure 7-2

Since the nozzle & hose are not grounded, voltage generated at nozzle is $V = IR$

Resistance calculated by (Eq 7-18)

$$R = \frac{L}{\gamma_c A}$$

Current, will be streaming current 7-12 or 7-14 depending (Laminar or turbulent)

Find Reynolds number $Re = \frac{d\bar{u}\rho}{\mu}$

$$\bar{u} = \left(25\,\frac{gal}{min}\right)\left(\frac{ft^3}{7.481\,gal}\right)\left(\frac{min}{60\,s}\right)\left(\frac{1}{\pi}\right)\left(\frac{1}{1\,in.}\right)^2\left(\frac{12\,in}{ft}\right)^2 = 2.553\ ft/s$$

$$Re = \frac{d\,\bar{u}\,\rho}{\mu} = \frac{(2\,in.)(2.553\,ft/s)(.8\,g/cm^3)}{(0.6\ centipoise)}$$

$$= 6.808\ \frac{in\,ft\,g}{s\,cm^3\,cP} \times \left(\frac{12\,in.}{1\,ft}\right)\left(\frac{2.54\,cm}{in.}\right)^2\left(\frac{100\,cP}{Poise}\right)\left(\frac{Poise}{.1\,kg/m\,s}\right)$$

$$\times \frac{kg}{1000\,g} \times \frac{100\,cm}{m} = \underline{\underline{52{,}707}}\ \text{turbulent}$$

Eq 7-14 apples

$$I_s = \left[\frac{5.89\times10^{-14}\,amp}{(ft/s)\,(volt)}\right]\frac{d\,\varepsilon_r\,\zeta\,\bar{u}}{\delta}$$

ζ = zeta potential 0.01 to 0.1

use 0.1 as worst case

δ = double layer thickness - given by Eq 7-15

$$\delta = \sqrt{D_m \tau}$$

τ = relaxation time given by Eq 7-16

$$\tau = \frac{\varepsilon_r \varepsilon_0}{\gamma_c}$$

$$\tau = \frac{(2.4)\left(8.85\times10^{-12}\ \frac{\text{coulomb}^2}{\text{J}\cdot\text{m}}\right)}{(10^{-8}\ \text{mho/cm})} \cdot \left(\frac{\text{m}}{100\text{cm}}\right) \cdot \left(\frac{\text{J/Volt}}{\text{coulomb}}\right)\left(\frac{\text{Amp}\cdot\text{s}}{\text{coulomb}}\right)\left(\frac{\text{mho}}{\text{amp/V}}\right)$$

$\underline{\tau = 2.12 \times 10^{-5}\ \text{sec}}$

$$\delta = \sqrt{D_m \tau} = \sqrt{\left(2.2\times10^{-5}\ \frac{\text{cm}^2}{\text{s}}\right)\left(2.12\times10^{-5}\ \text{s}\right)}$$

$\underline{\delta = 2.162\times10^{-5}\ \text{cm}}$

$$I_s = \left[\frac{5.89\times10^{-14}\ \text{amps}}{(\text{ft/s})\ (\text{volt})}\right] \frac{(2\ \text{in.})\ (2.4)(0.1\ \text{volt})(2.553\ \text{ft/s})}{(2.162\times10^{-5}\ \text{cm})}\left(\frac{2.54\ \text{cm}}{\text{in.}}\right)$$

$I_s = 8.48\times10^{-9}\ \text{amps}$

$$R = \frac{L}{\gamma_c A} = \frac{20\ \text{ft}}{(10^{-8}\ \text{mho/cm})\ (\pi\ (1\ \text{in.})^2} \left(\frac{12\ \text{in.}}{\text{ft}}\right)\left(\frac{\text{in}}{2.54\ \text{cm}}\right)$$

$\underline{R = 3.008\times10^{9}\ \text{ohm}}$

$$V = I_s R = (8.48\times10^{-9}\ \text{amps})(3.008\times10^{9}\ \text{ohm}) = \boxed{25.5\ \text{volts}}$$

To calculate accumulated charge, Eq 7-22

$$Q = I_s t$$

Time to fill tank

$$\frac{(300 \text{ gallon})}{(25 \text{ gallon/min})}\left(\frac{60s}{min}\right) = \underline{720 \text{ seconds}}$$

$$Q = (8.48 \times 10^{-9} \text{ amps})(720 \text{ seconds}) = \underline{6.106 \times 10^{-6} \text{ coulombs}}$$

Calculate capacitance

$$C = Q/V = \frac{6.106 \times 10^{-6} \text{ coulombs}}{25.5 \text{ volts}} = \underline{2.394 \times 10^{-7} \text{ farads}}$$

Calculate accummulated energy

$$J = \frac{Q^2}{2C} = \frac{(6.106 \times 10^{-6})^2}{2(2.394 \times 10^{-7})} = \boxed{7.786 \times 10^{-5} \text{ J}}$$

0.078 mJ

This is below MIE - no problem, but safest to have the system bonded and grounded.

(b) Repeat- only changes $\varepsilon_r = 19$, $\gamma_c = 10^{-18}$
Hence, fluid more of an insulator, less conductive

No change in Reynolds number

Relaxation time will change

$$\tau = \frac{\varepsilon_r \varepsilon_0}{\gamma_c} = \frac{(19)(8.85\times10^{-12}\ \text{coulomb}^2/\text{J}\cdot\text{m})}{(10^{-18}\ \text{mho/cm})}\left(\frac{\text{m}}{100\text{cm}}\right)\left(\frac{\text{J/Volt}}{\text{coulomb}}\right)\left(\frac{\text{Amps}}{\text{Coul}}\right)\left(\frac{\text{mho}}{\text{amp/V}}\right)$$

$$\tau = \underline{1.6815\times10^{6}\ \text{sec}}$$

Determine double layer thickness

$$\delta = \sqrt{D_m \tau} = \sqrt{(2.2\times10^{-5}\ \text{cm}^2/\text{s})(1.6815\times10^{6}\ \text{sec})} = \underline{6.082\ \text{cm}}$$

Determine streaming current

$$I_s = \left[\frac{5.89\times10^{-14}\ \text{amp}}{(\text{ft/s})(\text{volt})}\right]\frac{d\ \varepsilon_r\ \zeta\ \bar{u}}{\delta}$$

$$I_s = \frac{5.89\times10^{-14}\ \text{amp}}{(\text{ft/s})(\text{volt})}\ \frac{(2\text{in.})(19)(.1\ \text{volt})(2.553\ \text{ft/s})}{6.082\ \text{cm}}\left(\frac{2.54\text{cm}}{\text{in.}}\right) = \underline{2.386\times10^{-13}\ \text{amp}}$$

Calculate resistance

$$R = \frac{L}{\gamma_c A} = \frac{20\ \text{ft}}{(10^{-18}\ \text{mho/cm})(\pi)(1\ \text{in})^2}\left(\frac{12\text{in}}{\text{ft}}\right)\left(\frac{\text{in.}}{2.54\text{cm}}\right) = 3.008\times10^{19}\ \text{ohm}$$

Calculate Voltage

$$V = I_s R = (2.386\times10^{-13}\,\text{amp})(3.008\times10^{19}\,\text{ohm}) = \underline{7.177\times10^{6}\,\text{volt}}$$

Calculate Accumulated charge Eq 7-22

$$Q = I_s t$$

$$Q = (2.386\times10^{-13}\,\text{amp})(720\,\text{s}) = 1.718\times10^{-10}\,\text{coulombs}$$

Calculate Capacitance

$$C = Q/V = \frac{1.718\times10^{-10}\,\text{coulombs}}{7.177\times10^{6}\,\text{volts}} = 2.394\times10^{-17}\,\text{farads}$$

Calculate accumulated energy

$$J = \frac{Q^2}{2C} = \frac{(1.718\times10^{-10})^2}{2(2.394\times10^{-17})} = 0.00617\,\text{J}$$

$$= \underline{0.617\,\text{mJ}}$$

The voltage and energy are high enough to cause a spark which will explode.

Need to bond & ground nossle.