An outline of the calculations used to obtain final results from the experimental data

Annotations shown in red

SAMPLE CALCULATIONS

ALL for $Q_{AIR} = 70\ L/min$

Identify the basis for calculation

NH_3 Concentration of Liquid Stream, exit

$$2NH_3(aq.) + H_2SO_4(aq.) = 2NH_4^+ + SO_4^-$$

8.5 mL of 0.1 M H_2SO_4 was used to titrate a 25 mL sample.

$$C_{NH_3} = \left(\frac{8.5\ mL\ H_2SO_4}{25\ mL\ sample}\right)\left(\frac{0.1\ M\ H_2SO_4}{L}\right)\left(\frac{2\ mol\ NH_3}{mol\ H_2SO_4}\right)$$

$$\boxed{C_{NH_3} = 0.068\ \frac{mol\ NH_3}{L}}$$

Identify what is being calculated

Partial Pressure (P^*) @ Equilibrium w/ EXIT LIQUID

@ 20°C, the Henry's Law Constant $H = 7.37\times10^{-3}\ ATM\left(\frac{100\,g\,H_2O}{g\,NH_3}\right)$

State necessary constants and assumptions

$$P_{NH_3} = HC_{NH_3}$$

$$P^* = 7.37\times10^{-3}\ ATM\left(\frac{100\,g\,H_2O}{g\,NH_3}\right)\left(\frac{0.068\ mol\ NH_3}{L.\ Solution}\right)\left(\frac{17\,g\,NH_3}{mol\ NH_3}\right)\left(\frac{1\ L}{1000\,g\,H_2O}\right)$$

Show all units

$$\boxed{P^* = 8.55\times10^{-4}\ ATM}$$ → the density of the solution ≈ density of H_2O

$\Delta P_2 = P_{g2} - P^*_2$, driving force @ bottom of column

$$P_{g2} = (2/102) * 1\ ATM = 0.0196\ ATM$$

$$\boxed{\Delta P_2 = 0.0196\ ATM - 8.55\times10^{-4} = 0.0188\ ATM}$$

NH_3 Partial pressure in exit gas

Volume of Bleed gas titrated $= \frac{0.380\,L}{min} \cdot \frac{1\,min}{60\,s} \cdot 292\,s = 1.85\,L$

moles of Bleed gas ⇒ $n = \frac{PV}{RT} = \frac{1\ ATM * 1.85\,L}{0.0821\frac{L\cdot ATM}{mol\cdot K}(293\,K)} = 7.70\times10^{-2}\ mol$

n_{NH_3} = moles of NH_3 in Bleed gas sample $= \left(\frac{0.01\ M\ H_2SO_4}{L}\right)(0.01\,L)\left(\frac{2\ mol\ NH_3}{mol\ H_2SO_4}\right)$

$$= 2\times10^{-4}\ mol\ NH_3$$

$$\boxed{P_1 = \frac{n_{NH_3}}{n_{Bleed\,gas}} \times 1\ ATM = \frac{2\times10^{-4}}{7.70\times10^{-2}} \times 1 = 2.60\times10^{-3}\ ATM}$$

$\Delta P_1 = P_{g1} - P_1^*$, driving force @ top of column

$P_{g1} = 2.60 \times 10^{-3}$; $P_1^* = 0$, since there was no NH_3 in water feed

$$\boxed{\Delta P_1 = 2.60 \times 10^{-3} \text{ ATM}}$$

Overall mass transfer coefficient, K_{og}

$$K_{og} = \frac{W}{a z \Delta P_{LM}}$$

W = total NH_3 transferred $= Q_{EXIT\ Liquid} \times C_{NH_3} = 0.84\ \text{L/min} \left(\frac{1\text{min}}{60\text{s}}\right)\left(\frac{0.068\text{mol}}{\text{L}}\right)$

$W = 9.07 \times 10^{-4}$ mol/s

$az = \pi d z = 3.14\,(0.0254\text{ m})(1.79\text{ m}) = 0.143\text{ m}^2$

$$\Delta P_{LM} = \frac{\Delta P_1 - \Delta P_2}{\ln \Delta P_1/\Delta P_2} = \frac{2.60 \times 10^{-3} - 0.0188}{\ln\left(2.60 \times 10^{-3}/0.0188\right)} = 8.19 \times 10^{-3} \text{ ATM}$$

$$\boxed{K_{og} = \frac{9.07 \times 10^{-4} \text{ mol/s}}{0.143\text{ m}^2 \cdot 8.19 \times 10^{-3} \text{ ATM}} = 0.775 \frac{\text{mol } NH_3}{\text{m}^2 \cdot \text{s} \cdot \text{atm}}}$$

U = Average gas velocity

$$U = (71.4\text{ L/min})\left(\frac{\text{min}}{60\text{s}}\right)\left(\frac{4}{\pi (0.0254\text{m})^2}\right)\left(1\text{m}^3/1000\text{L}\right)$$

$U = 2.42$ m/s

Calculation of k_g and k_L

$$1/K_{og} = 1/k_g + H/k_L = 1/BU^{0.83} + H/k_L$$

Linear regression was used to fit the plot of $1/K_{og}$ vs. $1/U^{0.83}$ (see Figure 2)

The slope $= 1/B = 2.36$; the intercept $= H/k_L = 0.096 \frac{\text{m}^2 \text{s atm}}{\text{mol } NH_3}$

For $Q_{air} = 70$ L/min

$$\boxed{k_g = BU^{0.83} = \left(\frac{1}{2.36}\right)(2.42)^{0.83} = 0.86 \text{ mol } NH_3/\text{m}^2 \cdot \text{s} \cdot \text{atm}}$$

$$k_L = H/\text{intercept} = 7.37 \times 10^{-3} \text{ atm}\left(\frac{105\text{ g } H_2O}{\text{g } NH_3}\right)\left(\frac{17\text{g } NH_3}{\text{mol } NH_3}\right)\left(\frac{\text{L}}{1000\text{g } H_2O}\right) \cdot \frac{\text{mol } NH_3}{0.096\text{ m}^2 \cdot \text{s} \cdot \text{atm}}$$

$$\boxed{k_L = 1.31 \times 10^{-4} \text{ m/s}}$$

CALCULATION of k_g using Sherwood-Gilliland Correlation

$$SH = 0.023\ Re^{0.83}\ Sc^{0.44}$$

$$Sc = \frac{\mu}{\rho_{air} D_{NH_3-AIR}} = \frac{1.7 \times 10^{-5}}{1.30\ (2.2 \times 10^{-5})} = 0.595$$

$$@\ 0^\circ C,\ D_{NH_3-AIR} = 1.98 \times 10^{-5}\ m^2/s$$ (TREYBAL, R.E., Mass Transfer Operations, 3rd Ed. McGraw-Hill, 1980)

$$D \propto T^{3/2} \text{ so } @\ 20^\circ C,\ D_{NH_3-AIR} = \left(\frac{293}{273}\right)^{3/2} \times 1.98 \times 10^{-5} = 2.20 \times 10^{-5}\ m^2/s$$

$$\mu_{air} = 0.017\ C_p = 1.7 \times 10^{-5}\ Pa\,s.$$

$$\rho = 1.30\ kg/m^3$$

$$Re = \frac{d u \rho}{\mu} = \frac{(0.0254 m)(2.42\ m/s)(1.30\ kg/m^3)}{1.7 \times 10^{-5}\ Pa \cdot s} = 4630$$

$$SH = 0.023(4630)^{0.83}(0.595)^{0.44} = 20.3 = \frac{k_g R T d}{D_{NH_3-AIR}}$$

$$k_g = \frac{SH \cdot D_{NH_3-air}}{RTd} = \frac{20.3\ (2.2 \times 10^{-5}\ m^2/s)(1.013 \times 10^5\ Pa/atm)}{(8.314 \frac{m^3\,Pa}{mol \cdot K})(293\ K)(0.0254 m)}$$

$$\boxed{k_g = 0.073 \frac{mol\ NH_3}{m^2 \cdot s \cdot atm}}$$

Clearly box final answers or significant calculations