MOLECULAR DIFFUSION IN GASES

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ABSTRACT

Diffusion is the one of the most fundamental properties of the substances in solutions. The diffusion occurs from high concentration to low concentration and the transfer of solute such as gas or liquid by concentration difference between the phases in which they exist. The determination of diffusion coefficient (D_{AB}) in gaseous is (acetone in air) is found to be 2.61*10^{-7} m^2/s. The molecular diffusion coefficient obtained theoretically is 2.32*10^{-6} m^2/s. The molecular diffusion is found by the method of Capillary tube attached with Vernier callipers to find the increase of liquid level with respect to time. Finally, the equilibrium is achieved by 50-60 minutes time (1 hour) and the diffusion stops.

Key words: Diffusion Coefficient, Concentration difference, Capillary tube, Vernier calipers, Equilibrium.

1. THEORITICAL BACKGROUND

Molecular diffusion or molecular transport can be defined as the transfer or movement of individual molecules through a fluid by means of the random, individual movements of the molecules. The diffusivity of the vapor of a volatile liquid in air can be determined by Winkelmann's method in which liquid is contained in a narrow diameter vertical tube, maintained at a constant temperature. A stream is passed over the top of the tube to ensure that the partial pressure of the vapor is transferred from the surface of the liquid to the air stream by molecular diffusion. With this method, the diffusion is the same as gas A diffusing in stagnant, non-diffusing B.

$$N_A = D\left(\frac{C_A}{L}\right)\left(\frac{C_T}{C_{Bm}}\right) \quad (1.1)$$

The evaporation of the liquid A is expressed as follows

$$\mathrm{N_A} = \frac{\rho_L}{M}\frac{dL}{dt} \quad (1.2)$$

Equating the above equations, integrating and rearranging the resulting equation, one can obtain as follows:

$$\frac{t}{(L-L_0)} = \left(\frac{\rho_L}{2MD}\right)\left(\frac{C_{Bm}}{C_A C_T}\right)(L-L_0) + \left(\frac{\rho_L C_{Bm}}{MDC_A C_T}\right)L_0 \quad (1.2)$$

The above equation is indeed a linear correlation between $\frac{t}{(L-L_0)}$ against $(L-L_0)$ with slope = $\left(\frac{\rho_L}{2MD}\right)\left(\frac{C_{Bm}}{C_A C_T}\right)$

Thus, by plotting $\frac{t}{(L-L_0)}$ versus $(L-L_0)$, one can easily calculate the slope and find the diffusivity coefficient of gas A in B.

$$C_T = \frac{1}{22.414}\left(\frac{T_{Abs}}{T_a}\right) \quad (1.4)$$

$$C_{Bm} = \frac{(C_{B1}-C_{B2})}{ln\left(\frac{C_{B1}}{C_{B2}}\right)} \quad (1.5)$$

$$C_{B1} = C_T \quad (1.6)$$

$$C_{B2} = \left(\frac{P_a-P_V}{P_a}\right)C_T \quad (1.7)$$

$$C_A = \left(\frac{P_V}{P_a}\right)C_T \quad (1.8)$$

1.2 DESCRIPTION OF THE EQUIPMENT

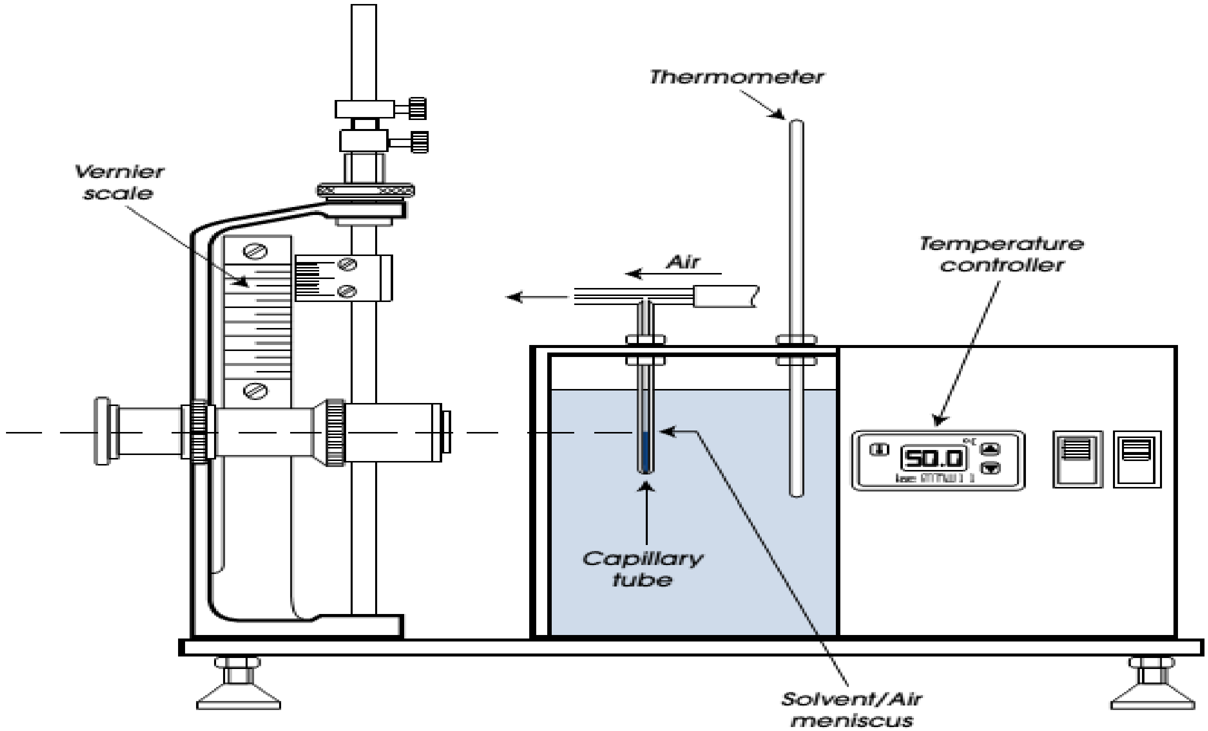

Figure 1.1. Gaseous diffusion apparatus

The liquid that is to be volatilized is placed in capillary tube. The capillary tube is placed inside a water bath whose temperature is carefully controlled by a controller. The height of the liquid that decreases by time is observed using microscope equipped with Vernier height gauge.

1.3 Methodology/Procedure for gaseous diffusion

1. Fill the capillary tube with acetone to a depth of approximately 35 mm.
2. Insert capillary tube through a rubber ring, inside the metal nut until the top of tube rest on the top of the nut.
3. Screw gently the above assembly onto the top plate, with the ‘T’ piece normal to the microscope
4. Connect flexible air tube to one end of the ‘T’ piece.
5. Set up the microscope as shown in figure 4.1. and adjust the object lens to within 20-30 mm from the tank.
6. Adjust the vertical height of the microscope until the capillary tube is visible (if the capillary tube is still not visible adjust the distance from the object lens to the tank until it is visible).

7. Adjust viewing microscope until the meniscus inside the capillary tube clear and well defined (note that the image in the microscope is upside down. That means the top of the image is the bottom of the capillary tube).
8. Make sure that the sliding Vernier scale should be aligned with a suitable graduation on the fixed scale.
9. Switch on the air pump.
10. Adjust the air flow rate using the Hoffman clip on the flexible tube so the flow rate is low.
11. Record the level inside the capillary tube.
12. Switch on the temperature-controlled water bath and adjust set point on controller to 40 ^oC to obtain steady temperature at 40 ^oC.
13. Switch off the temperature-controlled water bath after approximately 60 minutes to prevent air bubbles.
14. Record the change in level inside the capillary tube.
15. Repeat #12 - #14.

Data & Graph

Table 1: Data of liquid level of acetone vs time (min)

		L_0 =22 mm
Time (min)	**Increase of Liquid level (mm) (L)**	**Difference in Liquid level ($L-L_0$), mm**
0	22	0
10	22.1	0.1
20	22.25	0.25
30	22.35	0.35
40	22.6	0.6
50	22.9	0.9
60	22.99	0.00

The table 1 describes about the evaporation /Diffusion of acetone gas (A) in air (B) and the data has been collected for almost 1 hr time and the increase of liquid level and its difference is noted (mm).

Table 2: Calculation of $t/(L-L_o)$ vs ($L-L_o$)

Time (min)	**Increase of Liquid level (mm) (L)**	**Difference of Liquid level ($L-L_0$) (mm)**	**$t/(L-L_0)$, min/mm**
0	22	0	Infinity
10	22.1	0.1	100
20	22.25	0.25	80

30	22.35	0.35	85.714
40	22.6	0.6	66.7
50	22.9	0.9	55.6

Table 2 describes about the calculation of t/(L-L$_o$) and (L-L$_o$), and the graph is plotted to find the slope (m) and further D_{AB} is calculated from the slope. The value of the slope from the plot is 13.9 min/mm^2

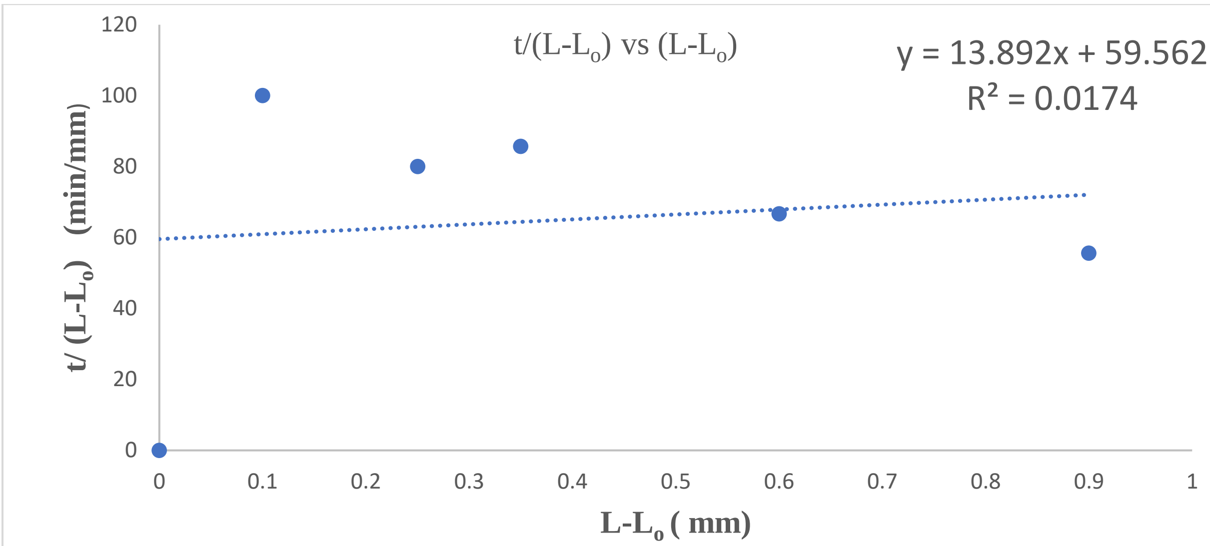

Figure 1.2 Plot of t/(L-L$_o$) vs (L-L$_o$)

Model Calculation

From the graph, the slope (m) is determined as 13.9 min/mm^2 which is also equal to a

$$\text{From eq 1.3, m= a} = \left(\frac{\rho_L}{2MD}\right)\left(\frac{C_{Bm}}{C_A C_T}\right)(L - L_0) = 13.9 \quad \textbf{(1.9)}$$

The diffusion coefficient can be evaluated from eq 1.9

At T = 40^o C = 313K,

$$C_T = \frac{1}{22.414}\left(\frac{T_{Abs}}{T_a}\right) = \frac{1}{22.414}\left(\frac{273}{313}\right) = 0.03891 \text{ Kmol/m}^3$$

$$C_{B1} = C_T$$

The physical properties of Acetone are given as follows [1-2] [4-6]

M : Molecular weight of Acetone: 58.08 g/mol

P_a : Atmospheric pressure, atm =101.325 K Pa

P_V : Vapor pressure of acetone, atm = 56 K Pa

ρ_L : Density of acetone, kg/m^3 = 790

$$C_{B2} = \left(\frac{P_a - P_V}{P_a}\right) C_T = \left(\frac{(101.325-56)}{101.325}\right) (0.03891) = 0.0174 \text{ Kmol/m}^3$$

$$C_{Bm} = \frac{(C_{B1} - C_{B2})}{ln\left(\frac{C_{B1}}{C_{B2}}\right)} = \frac{(0.03891-0.0174}{\ln(\frac{0.03891}{0.0174})} = 0.02673 \text{ Kmol/m}^3$$

$$C_A = \left(\frac{P_V}{P_a}\right) C_T = \left(\frac{56}{101.325}\right) (0.03891) = 0.0215 \text{ Kmol/m}^3$$

The molecular diffusion coefficient is found as $DAB = \left(\frac{\rho_L}{2M\,(a)}\right)\left(\frac{C_{Bm}}{C_A C_T}\right) = \left(\frac{790}{2*58.08*13.9}\right) \left(\frac{0.0267}{0.03891*0.0215}\right)$

$$D_{AB} = 2.61*10^{-7} \text{ m}^2/\text{s}$$

Results & Discussion

The diffusion of acetone depends on the atmospheric conditions and it is a phenomenon of transferring the molecules from higher concentration to the lower concentration level. So, the increase of liquid level indicates that the acetone concentration increases wrt time and certain level has been obtained which confirms that the complete diffusion of acetone in air has taken place and achieved an equilibrium state. The very less increase of diffence of liquid level wrt time confirms that the equpibriun conditions are attained. Further a plot of t/(L-L$_o$) and (L-L$_o$), indicates the slope and based on the physical properties of acetone, the calculations have been made and the diffusion coefficient is found experimentally [3, 7].

Conclusion

The molecular diffusion coefficient obtained theoretically is $2.32*10^{-6}$ m^2/s. The percentage error is found to be 89% from both the theoretical and experimental values. Hence it can be concluded that the experiment /practical conditions achieved are in the good range. The molecular diffusion coefficient of acetone is found experimentally as $D_{AB} = 2.61*10^{-7}$ m^2/s

NOTATION

C_A	:	Saturation concentration of acetone at interface, kmol/m^3
C_{Bm}	:	Logarithmic mean molecular concentration of vapor, kmol/m^3
C_T	:	Total concentration, kmol/m^3
D	:	Diffusivity coefficient, m^2/s
L	:	Effective distance of mass transfer (m)
M	:	Molecular weight of acetone, kg/mol
N_A	:	Molar flux, mol/m^2.sec

P_a	:	Atmospheric pressure, atm
P_V	:	Vapor pressure of acetone, atm
ρ_L	:	Density of acetone, kg/m^3
T	:	Time, sec
T_a	:	Bath temperature, K
T_{abs}	:	Absolute temperature, K

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