VAPOR IN AIR DIFFUSION

1. OBJECTIVE:

To study the molecular diffusion of vapors in air.

2. AIM:

1. To determine the diffusivity coefficient of the vapor(acetone) in air using Stephen tube at specific temperature.
2. To Compare the experimental value of diffusivity coefficient with standard correlation.

3. INTRODUCTION:

Mass transfer phenomenon involves process of molecular diffusion and convection. Diffusion involves the movement of the molecules from high concentration zone to the low concentration zone. Diffusion is directly proportional to the concentration gradient at a fixed temperature and the proportionality factor is known as diffusivity coefficient.
Using Stephen tube we shall be able to determine the diffusivity coefficient and also study its dependency on temperature.

4. THEORY:

Under the pseudo steady state condition, the mass balance for component A the system at zero rate of generation w.r.t time is

$$\text{In} = \text{Out}$$

$$(A\,dz)\,\rho_L = N_A\,A\,M_A\,dt$$

$$N_A = (\rho_L/M_A)\,dz/dt \qquad \text{................(1)}$$

The Mass flux for the species A is

$$N_A = -D_{AB}\left(\frac{dC_A}{dz}\right) + \left(\frac{C_A}{C}\right)(N_A + N_B)$$

where N_B is zero because component B is non diffusing

Then

$$N_A = -D_{AB}\left(\frac{dC_A}{dz}\right) + \left(\frac{C_A}{C}\right)(N_A)$$

Solving this we get,

$$N_A = -D_{AB}\left(\frac{C}{C - C_A}\right)\left(\frac{dC_A}{dz}\right)$$

Substitute

$$C = \frac{P}{RT}$$

$$N_A = -\left(\frac{D_{AB}}{RT}\right)\left(\frac{P_T}{P_T - P_A}\right)\left(\frac{dP_A}{dz}\right)$$

On integrating this equation, At B.C. At z=0 $P_A = P_{A2}$ and At z =z $P_A = P_{A1}$ we get

$$N_A = \left(\frac{D_{AB}}{RT}\right)\left(\frac{P_T}{z}\right) ln\left(\frac{P_T - P_{A2}}{P_T - P_{A1}}\right) \quad \text{.......................(2)}$$

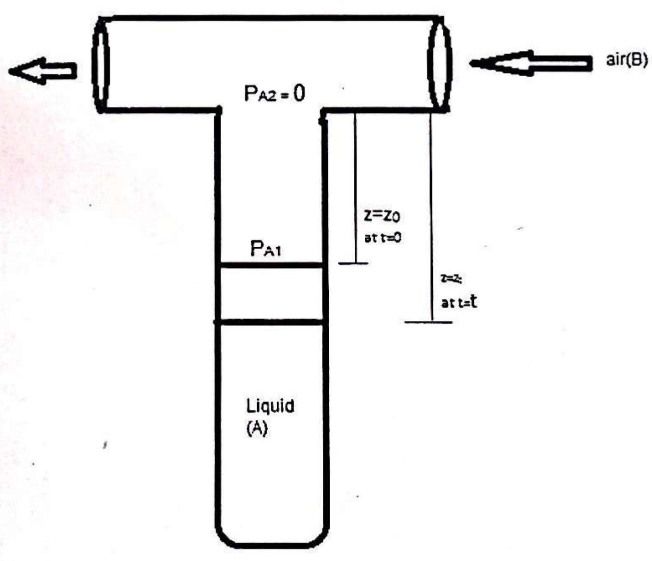
Substitute the value of the mass flux of eq. (2) in eq. (1)

$$\left(\frac{\rho_L}{M_A}\right)\left(\frac{dz}{dt}\right) = \left(\frac{D_{AB}}{RT}\right)\left(\frac{P_T}{z}\right) ln\left(\frac{P_T - P_{A2}}{P_T - P_{A1}}\right) \quad \text{.......................(3)}$$

Solve the equation (3) at the initial condition (I.C.)

At time t=0 $z=z_0$

t=t $z=z_t$



$$D_{AB} = \frac{RT\rho_L(z_2^2 - z_1^2)}{2M_A P_T t}\left(\frac{1}{ln\left(\frac{P_T - P_{A2}}{P_T - P_{A1}}\right)}\right) \qquad \text{..................(4)}$$

Equation (4) modified Using $P_{B1} = P_T - P_{A1}$

$P_{B2} = P_T - P_{A2}$

$$P_{BM} = \frac{((P_T - P_{A1}) - (P_T - P_{A2}))}{ln\left(\frac{P_T - P_{A2}}{P_T - P_{A1}}\right)}$$

$$D_{AB} = \frac{R \times T \times P_{BM} \times \rho_L (z_2^{\,2} - z_1^2)}{2 \times P_t \times M_A \times \left(P_{A1} - P_{A2}\right) \times t}$$

where

P_{A1} = vapor pressure of the liquid (A) at $z=z_1$

P_{A2} = vapor pressure of the liquid (A) at z=0

R = Universal Gas Constant

P_T = Ambient atmospheric pressure

ρ_L = density of the liquid (A)

M_A= Molar mass of the liquid (A)

Theoretical value of the diffusivity of a Acetone at a given temperature is calculated by Fuller's equation

$$D_{AB} = \frac{1.013 \times 10^{-2} \times T_o^{1.75} \times (\frac{1}{M_A} + \frac{1}{M_B})^{0.5}}{P_t \times \left[(\sum v_A)^{0.333} + (\sum v_B)^{0.333}\right]^2} \quad (m^2/s) \text{............ (5)}$$

where T = Temperature, Kelvin

D_{AB} = Diffusivity ,m^2/sec

M_a , M_b = Molar masses of compound A and B

P = Total pressure , bar

$\sum v_a$, $\sum v_b$ = Summation of the special diffusion volume coefficient for components

5. Description:

The equipment consists of a T tube made of glass, placed in a water bath. Water bath is provided with heater. Temperature of the bath is controlled by the digital temperature controller. Stirrer is given to maintain the constant temperature in bath. Air pump is provided to supply the air, passed through the tube. Change in the liquid level is observed by the traveling microscope with sliding vernier scale.

6. Utilities Required:

6.1 Electricity Supply: Single Phase, 220 V AC, 50 Hz, 5-15 Amp combined socket with earth connection.

6.2 Water Supply (Initial fill)

6.3 Floor Drain Required.

6.4 Floor Area Required: 1.5 m x 0.75 m

6.5 Chemicals:

Acetone	:	200 ml
Water	:	10 Ltrs

7. Experimental Procedure:

7.1 Starting Procedure:

7.1.1 Clean the apparatus and make it free from dust.

7.1.2 Note the ambient pressure P_T of the atmosphere.

7.1.3 Ensure that switches given on the panel are at OFF position.

7.1.4 Fill the water bath with water $3/4^{th}$ of its capacity.

7.1.5 Set the water bath temperature (approx 30°C).

7.1.6 Switch ON the main power supply.

7.1.7 Switch ON the heater.

7.1.8 Switch ON the stirrer.

7.1.9 Wait till the bath attains the set temperature. Note the steady temperature of the bath.

7.1.10 Fill the T-tube with Acetone solution up to two centimeters of the capillary leg. Note: It is preferred that the liquid injected into the Stephen Tube must be at the same temperature as the water bath.

7.1.11 Note down the initial height of liquid in the capillary.

7.1.12 Make the connection with air pump and allow of air to flow over the capillary through rotameter.

7.1.13 Record the height of liquid in the capillary after 40-50 min.

7.1.14 Repeat the experiment for different water bath temperatures.

7.1.15 Repeat the experiment for different organic liquids like: ethanol, toluene, and hexane.

7.2 CLOSING PROCEDURE:

7.2.1 When experiment is over stop the air supply.

7.2.2 Switch OFF heater and stirrer.

7.2.3 Switch OFF the main power supply.

7.2.4 Clean the tube and drain the water bath by open the valve.

8. OBSERVATION & CALCULATION:

8.1 DATA:	
Total pressure P_t	= 1.01325×10^5 N/m^2
Real gas constant R	= 8.314 (N/m^2)-m^3 /mole-K
Molecular weight of the liquid M_A	= 58.08 g/mole
Molecular weight of the Air M_B	= 29 g/mole
Partial pressure of liquid at the top of the tube P_{A2}	= 0 N/m^2
Antoine equation P(mmHg), T(K) $P = e^{\left(A - \frac{B}{T+C}\right)}$ For Acetone Antoine constants:	
Constant A	= 16.651
Constant B	= 2940.4
Constant C	= -35.93

Atomic Diffusion Volumes			
Atomic and structural diffusion volume Increments			
C	16.5	Cl	19.5
H	1.98	S	17.0
0	5.48		
(N)[a]	5.69		
Diffusion volumes of simple molecules			
H_2	7.07	CO_2	26.9
D_2	6.70	N_2O	35.9
He	2.88	NH_3	14.9
N_2	17.9	H_2O	12.7
O_2	16.6	Cl_2	37.7
Air	20.1	Br_2	67.2
Ne	5.59	SO_2	41.1
CO	18.9		

OBSERVATIONS:

8.2 OBSERVATION TABLE:

S.no.	T (°C)	Q (lph)	t' (min)	Z_0 (cm)	Z (cm)

8.3 CALCULATIONS:

t (sec) = t' (min) × 60

$z_0 = Z_0/100$ (m)

$z_1 = Z/100$ (m)

$\rho = 812.637 - (1.130 \times T)$, (kg/m^3)

$$T_o = 273.15 + T\,(K)$$

$$P_{A1} = e^{\left(A - \frac{B}{C+T_o}\right)} \times 133.32\ (N/m^2)$$

$$P_{B1} = P_t - P_{A1}\ \ (N/m^2)$$

$$P_{B2} = P_t - P_{A2}\ \ (N/m^2)$$

$$P_{BM} = \frac{P_{B2} - P_{B1}}{\ln \frac{P_{B2}}{P_{B1}}}\ (N/m^2)$$

$$D_{AB} = \frac{R \times T_o \times P_{BM} \times 1000 \times \rho\ (z_o^2 - z^2)}{2 \times P_t \times M_A \times P_{A1} \times t}\ (m^2/s),\ \textbf{(Experimental)}$$

$$D_{AB} = \frac{1.013 \times 10^{-2} \times T_o^{1.75} \times (\frac{1}{M_A} + \frac{1}{M_B})^{0.5}}{P_t \times \left[(\sum v_A)^{0.333} + (\sum v_B)^{0.333}\right]^2}\ (m^2/s),\ \textbf{(Theoretical)}$$

For Acetone $\sum v_a = 66.89$ and For air $\sum v_b = 20.1$

$$ERROR(\%) = \left[\frac{D_{AB}(\text{Theo}) - D_{AB}(\text{Experi})}{D_{AB}(\text{Theo})}\right] \times 100\ (\%)$$

CALCULATION TABLE:

S.No.	t (sec)	z_o (m)	z (m)	$D_{AB\ (Exp)}$	$D_{AB\ (Theo)}$	Error (%)

9. NOMENCLATURE:

Nom	Column Heading	Units	Type
A, B, C	Constant	*	Given
D_{AB}	Diffusivity coefficient (Theortical & Experimental)	m^2/s	Calculated
M_A	Molecular weight of the liquid	g/mole	Given
M_B	Molecular weight of the Air	g/mole	Given
P_t	Total pressure	N/m^2	Calculated
P_{A1}	Partial pressure of liquid at the liquid surface	N/m^2	Calculated
P_{A2}	Partial pressure of liquid at the top	N/m^2	Given
P_{B1}	Partial pressure of air at the liquid surface	N/m^2	Calculated
P_{B2}	Partial pressure of air at the top	N/m^2	Calculated
P_{BM}	Log mean pressure	N/m^2	Calculated
R	Real gas constant	(N/m^2)-m^3 /mole-K	Given
T	Temperature of the bath	°C	Measured
T_o	Temperature of the bath	K	Calculated
t'	Time	min	Measured
T	Time	S	Calculated
Z	Height of the liquid in tube from the top at time t	cm	Measured
Z_o	Initial Height of the liquid in tube from the top	cm	Measured
z_o	Initial height of the liquid in tube from top	m	Calculated
z	Height of the liquid in tube from top at time t	M	Calculated
ρ	Density of the liquid	kg/m^3	Calculated
Q	Flow rate of air	LPH	Measured

* Symbols are unit less.

10. PRECAUTION & MAINTENANCE INSTRUCTIONS:

10.1 Acetone should be colorless.

10.2 Don't switch ON the heater before filling water in the bath.

10.3 Microscope focus should be clear, if not then adjust it.

10.4 Record the zero error of vernier scale if any.

10.5 For every set of reading wait at least for 40 min.

11. TROUBLESHOOTING:

11.1 If the temperature is not increasing after switch ON the heater, check the continuity of heater.

11.2 If the DTC displays 1 on the screen it means the computer socket is not connected so connect it.

11.3 If the meniscus is not clear adjusted focus the lens.

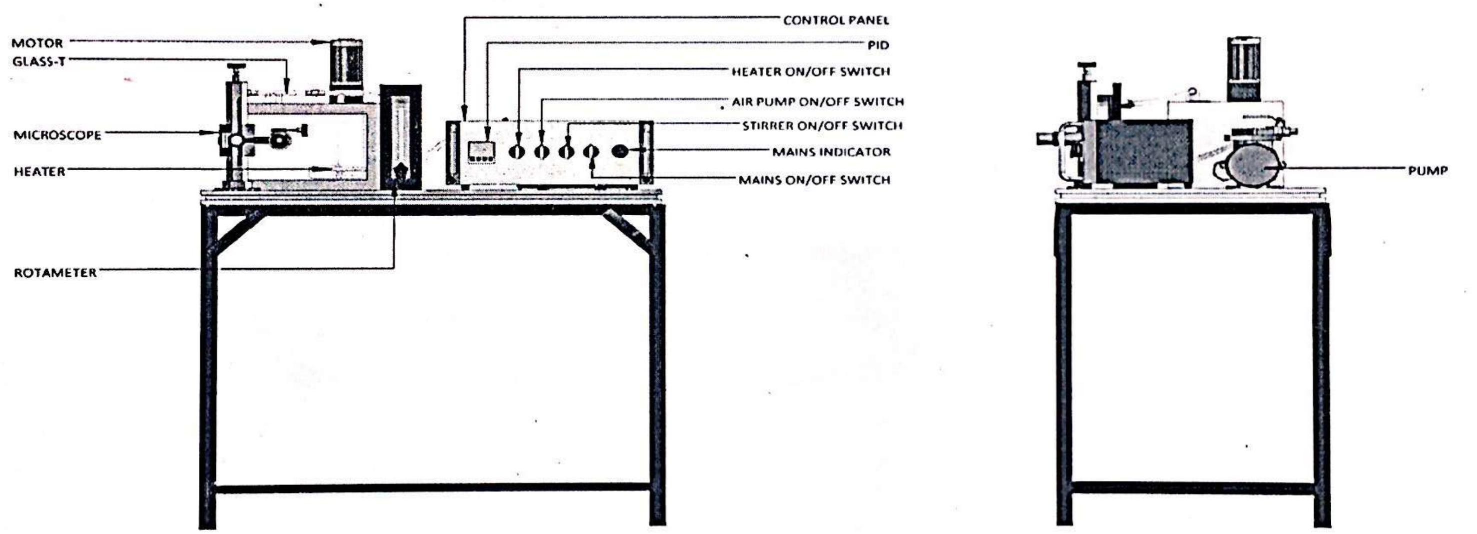
11.4 If the movement of the microscope is not smooth put some lubricating oil on it.

12. REFERENCES:

12.1 McCabe, Warren L. Smith, Julian C. Harriott, Peter (2005). *Unit Operations of Chemical Engineering.* 7th Ed. NY: McGraw-Hill. pp 528, 531-532.

12.2 Dutta K. Binay (2007). *Principles of Mass Transfer and Separation Processes.* ND: Prentice Hall of India Pvt. Ltd. pp 39-40,328-329.

13. Block Diagram:



BLOCK DIAGRAM
NAME : VAPOUR IN AIR DIFFUSION APPARATUS
CODE : KCMT-131/19-20/03