Gaseous Diffusion Coefficients Apparatus
Instruction Manual

Issue 13
September, 1999

Engineering Teaching and Research Equipment

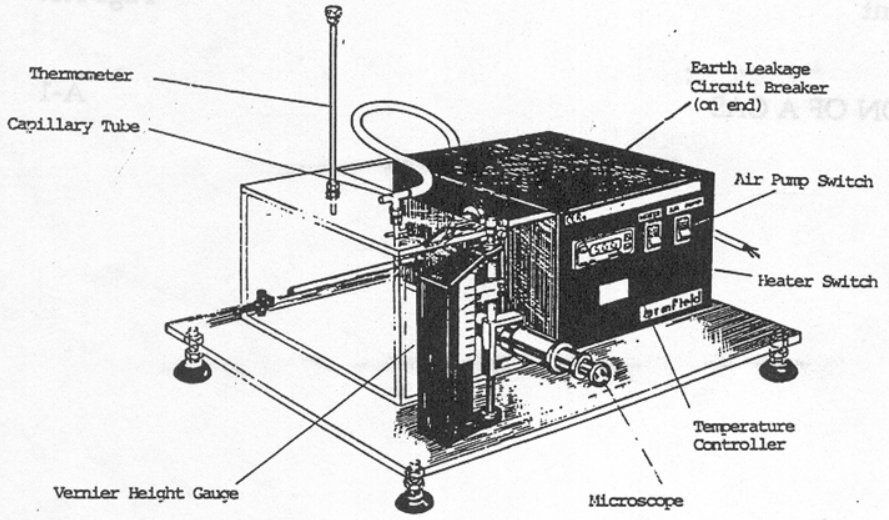
CERa - DIFFUSION OF A GAS APPARATUS

EXPERIMENT A

OBJECT OF EXPERIMENT:

To determine the diffusion coefficient of a gas by evaporation from a liquid surface.

EQUIPMENT SET-UP

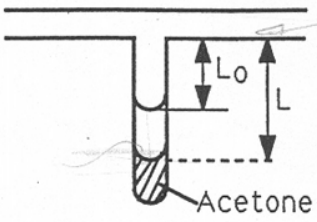


SUMMARY OF THEORY:

The diffusivity of the vapour of a volatile liquid in air can be conveniently determined by Winklemann's method in which liquid is contained in a narrow diameter vertical tube, maintained at a constant temperature, and an air stream is passed over the top of the tube to ensure that the partial pressure of the vapour is transferred from the surface of the liquid to the air stream by molecular diffusion.

The rate of mass transfer is given by:

$$N'_A = D\left(\frac{C_A}{L}\right)\left(\frac{C_T}{C_{Bm}}\right)$$



where D = Diffusivity (m^2/s)
C_A = Saturation concentration at interface ($kmol/m^3$)
L = Effective distance of mass transfer (mm)

C_{Bm} = Logarithmic mean molecular concentration of vapour (kmol/m^3)

C_T = Total molar concentration = $C_A + C_{Bm}$ (kmol/m^3)

Considering the evaporation of the liquid:

$$N'_A = \left(\frac{\rho_L}{M}\right)\frac{dL}{dt}$$

where ρ_L is the density of the liquid.

Thus $$\left(\frac{\rho_L}{M}\right)\frac{dL}{dt} = D\left(\frac{C_A}{L}\right)\left(\frac{C_T}{C_{Bm}}\right)$$

Integrating and putting $L = L_0$ at $t = 0$

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

Note: L_0 and L cannot be measured accurately but $L-L_0$ can be measured accurately using the vernier on the microscope.

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

or

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

where M = molecular weight (kg/mol)

t = time (s)

If s is the slope of a graph of $\frac{t}{(L - L_0)}$ against $(L-L_0)$ then:

$$s = \frac{(\rho_L C_{Bm})}{(2MDC_A C_T)} \quad \text{or} \quad D = \frac{(\rho_L C_{Bm})}{s(2MC_A C_T)}$$

where:

$$C_T = \left(\frac{1}{\text{Kmol Vol}}\right)\left(\frac{T_{abs}}{T_a}\right) \qquad \text{(Kmol Volume} = 22.414\ m^3/\text{kmol)}$$

$$C_{B1} = C_T$$

$$C_{B2} = \left(\frac{P_a - P_v}{P_a}\right) C_T$$

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

$$C_{A2} = \left(\frac{P_v}{P_a}\right) C_T$$

READINGS TO BE TAKEN:

Note: To prevent the acetone from boiling do not set the temperature controller above 50 degrees Celsius.

Partially fill the capillary tube with Acetone to a depth of approximately 35mm (see page A-6 for priming procedure). Remove top nut from metal fitting. Carefully insert capillary tube through the rubber ring, inside the metal nut until the top of the tube rests on the top of the nut. Gently screw this assembly onto the top plate, with the 'T' piece normal to the microscope. Connect flexible air tube to one end of the 'T' piece. With the microscope set up as shown, adjust the object lens to within 20-30mm from the tank.

Adjust the vertical height of the microscope until the capillary tube is visible, if the capillary tube is not visible, adjust the distance from the object lens to the tank until it is. For a clearer and well defined view of the meniscus inside the capillary tube, adjust the position of the viewing lens in or out of the microscope body as necessary. Note that when viewing the capillary tube the image will be upside down, so that the bottom of the tube is at the top of the image. When the meniscus has been determined, the sliding vernier scale should be aligned with a suitable graduation on the fixed scale. Switch on air pump. (Airflow should only be low velocity across the capillary tube and can be adjusted using the Hoffman clip on the flexible tube.) Record the level inside the capillary tube. Switch on temperature controlled water bath (adjust setpoint on controller to 40°C) and obtain a steady temperature. After approximately 60 minutes switch off water bath (to prevent air bubbles from obscuring the reading) and record the change in level inside the capillary tube. Switch on bath and repeat the procedure approximately every 60 minutes.

$(L-L_0)$ at time t = Initial reading on vernier - reading on vernier of time t.

RESULTS:

Time from commencement of Experiment	Liquid Level $(L-L_0)$	$\frac{t}{(L-L_0)}$
ks	mm	ks/mm

Plot $t/(L - L_o)$ against $(L - L_o)$ and determine the gradient s from the graph.

Calculate the diffusivity D using your results.

Note: The vapour pressure of acetone changes with temperature. At 313K (40°C) the vapour pressure P_v is $56kN/m^2$. If the experiment is performed with the water bath set to different temperatures it will be necessary to obtain suitable values for P_v.

The density of acetone is $790kg/m^3$. Take the kmol volume as $22.4m^3$. The molecular weight is 58.08 kg/mol.

Repeat the experiment at different temperatures and comment on the effect of temperature on the diffusivity D.

A set of typical results is presented overleaf for information.

TYPICAL RESULTS

Diffusivity of Acetone in air at 313k (40°C) and atmospheric pressure (P_a = 101.3) from the following experimental data.

Time from commencement of Experiment	Liquid Level $(L-L_0)$	$\frac{t}{(L-L_0)}$
ks	m m	ks/mm
0.000	0.00	0.000
3.60	2.20	1.636
7.20	4.20	1.714
11.160	6.30	1.771
15.900	8.80	1.807
19.980	10.80	1.850
23.400	12.40	1.887
78.780	34.50	2.233
83.520	36.10	2.313
87.240	37.30	2.339
91.800	38.90	2.360
97.320	40.80	2.385
101.100	42.00	2.407

From resulting graph

$s = 0.0175$ ks/mm^2 or 1.75×10^7/s/m^2

$C_T = (1/22.4)\ (273/313) = 0.0389$ kmol/m^3

$M = 58.08$ kg/mol

$C_A = (56/101.3)\ 0.0389 = 0.0215$ kmol/m^3

$\rho_L = 790$ kg/m^3

$C_{B1} = 0.0389$

$C_{B2} = [(101.3 - 56)/101.3]\ 0.0389 = 0.0174$ kmol/m^3

$C_{Bm} = (0.0389 - 0.0174)/\ln\ (0.0389/0.0174) = 0.0267$ kmol/m^3

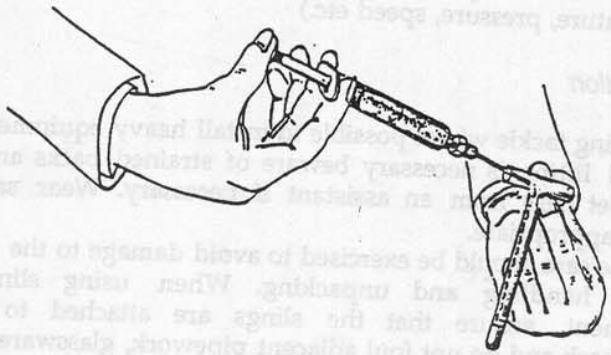
$\therefore\ D = (790 \times 0.0267)/(2 \times 58.08 \times 0.0215 \times 0.0389 \times 1.75 \times 10^7)$

$D = 21.09/1.700 \times 10^6$

$D = 12.4 \times 10^{-6}$ m^2/s

PRIMING PROCEDURE FOR CAPILLARY TUBE

1. Before using the capillary tube in an experiment using Acetone, it will be necessary to clean the inside of the tube by using a detergent such as washing-up liquid. A weak solution of the detergent should be injected into the tube slowly as shown below.



With the point of the hypodermic needle over the edge of the capillary tube, gently press the syringe, so that droplets of solution fall down onto the inside wall of the capillary tube. If the solution does not flow down into the bottom of the tube, but instead forms a meniscus with air trapped beneath it, gently tap the outside wall of the tube near the meniscus with your finger. Repeat this procedure until the capillary tube is full.

To empty the tube simply shake the tube whilst it is upside down until all the solution has gone.

The capillary tube can now be primed with Acetone using the same procedure, but this time there should be no need to tap the tube as it should fill easily. The depth of Acetone should be approximately 35mm when filled.