THE INTERNATIONAL JOURNAL OF SCIENCE & TECHNOLEDGE

Study of Mass Transfer Coefficient for Vaporisation of Naphthalene in Air Using a Packed Bed of Spherical Particles of Naphthalene

Ashutosh Mishra
Assistant Professor, Dr. Ambedkar Institute of Technology for Handicapped, Awadhpuri, Kanpur, India
Chandra Pal Singh
Lecturer, Dr. Ambedkar Institute of Technology for Handicapped, Awadhpuri, Kanpur, India
Samreen Ahmed
Lecturer, Dr. Ambedkar Institute of Technology for Handicapped, Awadhpuri, Kanpur, India

Abstract:
Diffusivity or diffusion coefficient is proportionality constant between the molar flux due to molecular diffusion and the gradient in the concentration of the species (or the driving force for diffusion). A solution is presented to the general problem of the transient behavior of a linear fixed bed system where the total mass transfer rate to inertia forces is determined by the effect of air into solid spherical particles. Further we have plotted sh/sc$^{1/3}$ vs Re on a log-log graph and determine the functional relationship.

1. Introduction

Considering the diffusion from a sphere to its surrounding medium:

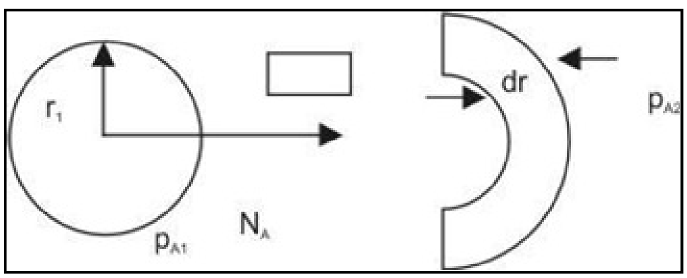

Figure 1

For component A (Naphthalene) diffusing through non-diffusing B (air), mass flux is given by:

$$N_A = \text{kg moles of A diffusing / area / time} = \frac{-D_{AB}}{RT} \frac{dp_A}{\left(1 - \frac{p_A}{P}\right) dr}$$

Its integration yields:

$$N_A = \frac{D_{AB} P (p_{A1} - p_{A2})}{RT r_1 p_{bm}} \quad (1)$$

Where
$$p_{BM} = \frac{(p_{B2} - p_{B1})}{\ln\left(\frac{p_{B2}}{p_{B1}}\right)} = \frac{(p_{A1} - p_{A2})}{\ln\left(\frac{P - p_{A2}}{P - p_{A1}}\right)}$$

P is the total pressure, Pa; p is the partial pressure. Pa In case $p_{B1} \approx p_{B2} = (p_{B1} + p_{B2})/2$

Where
$p_{B1} = P - p_{A1}$
$p_{B2} = P - p_{A2}$

equation 1 can be expressed in terms of mass transfer coefficient as :
$N_A = k_G (p_{A1} - p_{A2})$
The mass transfer coeff., $\mathbf{k_G}$ has the units of **kg mol./s-m^2 – Pa**
In case of mass transfer in a packed bed:
$Sh = 0\text{-}91\ \psi\ Re^{0.49}\ Sc^{1/3}$ for $0.01 < Re < 50$
And
$Sh = 0.61\ \psi\ Re^{0.59}\ Sc^{1/3}$ for $50 < Re < 1000$
Where, Sh is the Sherwood number = $k_c\ d_p / D_{AB}$
Sc is the Schmidt number = $\mu / D_{AB}\ \rho$
Re is the Reynolds number, defined as : $V\ \rho / (\mu\psi\ a)$;
Where a = surface area of particle / volume of the particle = $6\ (1-\varepsilon) / d_p$
ψ is the sphericity: $\psi = 0.91$ for spheres and $\psi = 0.81$ for cylinders D_{AB} is the diffusivity coeff. Of naphthalene in air
ρ, μ are the density and viscosity of air at ambient condition

2. For Naphthalene – Air system
A plot of $Sh/Sc^{1/3}$ vs Re should yield a straight line
At 0°C $D_{AB} = 5.16 \times 10^{-6}$ m^2/s
At 45 °C $D_{AB} = 6.92 \times 10^{-6}$ m^2/s
At 20 °C $D_{AB} = 6.04 \times 10^{-6}$ m^2/s (interpolated value)

3. Vapour Pressure Data for Naphthalene

Temp (t °C)	15	37	40	45	52.6	74.2	85.8
Vap. Pressure (p, mm Hg)	0.032	0.278	0.349	0.555	1	5	10

This data can be represented by:
In $(p_A) = 24.061 - 7808.444/T$, where T is the temp. in K and p_A is the v.p. in mm Hg From this equation Vap. Pressure of naphthalene at **20 °C = $\mathbf{p_A}$ = 0.076 mm HG**

4. Apparatus Used
The equipment consists of a cylindrical glass tube of 45 mm inside dia and 240 mm height. The column is fitted with a mesh near the base to hold the naphthalene balls, the height of the packing may be around 15 cm of naphthalene balls having an average diameter of about 18 mm. This will amount to about 23 balls. Dry air is supplied from the below and the outlet from the packed bed passes through the wet gas meter (for the measurement of air flow rate). The experiment is conducted at ambient conditions at different air flow rates. (at least three flow rates of air should be used in the range of 10 to 30 LPM)

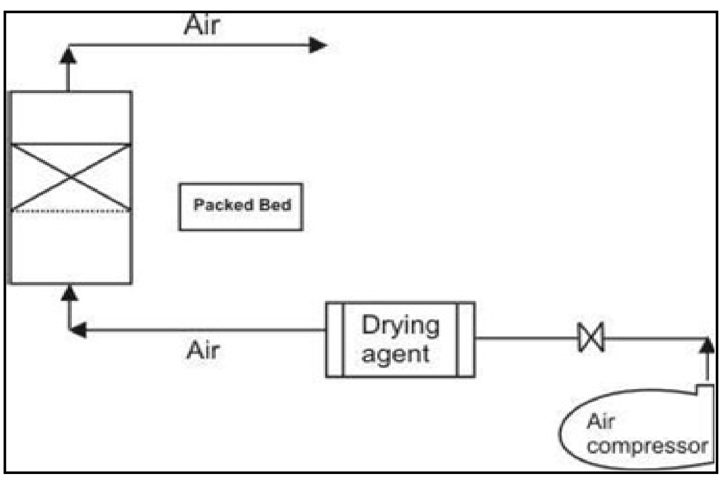

Figure 2

5. Methodology
Pack the glass tube with known number (Np) and known weight (w_o) of naphthalene balls up to a height of about 15 cm. Record the average diameter of the naphthalene ball. Now connect the air line from the compressor to the inlet at the base of the column and connect the outlet at the top of the column with the wet gas meter. Record the ambient temperature (t, K) and allow the air to flow through the packed bed for a known amount of time. (θ) say for 60 min. During this period record the air flow rate and also the cumulative air supplied during the time period (θ, sec). Stop the air supply and weigh the naphthalene balls. Let the final weight after evaporation for (θ, sec) be w_f. Repeat the experiment with at least three air flow rates.

5.1. Observations and Calculations

Ambient temperature: T, K = 293.15 K
Column I.D, D_c = 45mm = 45×10^{-3}, m
Packed height, H = 15 cm = 0.15 m

Average diameter of one naphthalene ball = d_p = 18.25 mm = 1.825×10^{-2} m Number of naphthalene balls in the bed = Np = 27
Mol. Wt of naphthalene = M_s = 128.175
Mol. Wt. of air = M_a = 29

Properties of air at ambient temp. of 293.15 K
Density = ρ = 1.1915 kg/m^3
Viscosity = $\mu = 1.84 \times 10^{-5}$ Pa.S

Diffusivity of naphthalene in air at ambient temp of 293.15 = $D_{AB} = 6.04 \times 10^{-6}$ ^{m2}/s Gas law constant = R = 8314 ^{m3} Pa /kg mol –K

Void fraction of packed bed = $\in$ = 0.5

RECORDINGS				
Run no.	Cumulative air flow, Q, L	In time, θ, min	Initial weight of naphthalene balls, w_o, gm	Final weight of naphthalene balls, w_f
1	1085	65	104.1	103.7
2	1418	60	103.7	103.3
3	1858	60	103.3	102.8

Table 1

5.2. Detailed Calculations

- RUN NO 1:

Column cross sectional area = $A_c = \pi/4 .D_t^2$ = $\pi/4 (0.045)^2 = 0.00159$ ^{m2}
Superficial air velocity = V = Q/(θ × 1000 × A_c) = 1085/(65×60×1000×0.00159)

V = 0.1749 m/s

Average diameter of one naphthalene balls = d_p = 0.01825 m
Number of spherical naphthalene balls in the bed = N_p = 27
Total surface area of naphthalene balls = a = $N_p \times (\pi d_p^2) = 27 \times \pi \times (0.01825)^2$
= 0.02825 m^2
Rate of loss in weight of naphthalene = mass flux = $\mathbf{N_A = (w_o\text{-}w_f)/(1000 \times \theta \times M_s \times a)}$

Kg mol/m^2 –s
=(104.1-103.7)/(1000×65×60×128.175×0.02825)

$\mathbf{N_A = 2.8325 \times 10^{-8}}$ **kg mol/m^2 –s**

At T=293.15 K, vapor pressure of naphthalene = p_A = 0.076 mmHg
Total pressure = P = 1atm = 1.01325×10^5 Pa
Therefore, partial pressure of naphthalene near its surface = p_{A1}
= $(0.076/760) \times 1.01325 \times 10^5 = 10.132$ Pa
(the value of vapor pressure should be verified from the literature before use) Partial pressure of naphthalene vapor in air at far off position (position 2) =
= p_{A2} = 0 (assuming pure air)
Partial pressure of air at position 1 (near the surface of the ball) = $p_{B1} = P\text{-}p_{A1}$

$P_{B1} = 1.01325 \times 10^5 - 10.132 = 1.0131 \times 10^5$ Pa Partial pressure of air at position 2 (far off from solid surface) = $p_{B2} = P\text{-}p_{A2}$
$P_{B2} = 1.01325 \times 10^5$ Pa
$P_{BM} = (P_{B1} + P_{B2})/2 = 1.01319 \times 10^5$ Pa Mass transfer coefficient = $k_G = N_A / (p_{A1} - p_{A2}) = 2.8325 \times 10^{-8} / (10.132-0)$
$K_G = 2.796 \times 10^{-9}$ kg mol/m^2 –s-Pa
$K_c = k_G \times RT = 2.796 \times 10^{-9} \times 8314 \times 293.15 = 6.8145 \times 10^{-3}$ m/s
Sherwood number = Sh = $k_c d_p / D_{AB} = 6.8145 \times 10^{-3} \times 0.01825/6.04 \times 10^{-6}$ = **20.59** Sc is the Schmidt number = $\mu / D_{AB} \rho = 1.84 \times 10^{-5} / 6.04 \times 10^{-6} \times 1.1915$ = **2.556**

$Sh/Sc^{1/3}$ = 15.059

Re is the Reynolds number, defined as: $V \rho / (\mu\psi a_p)$;

Assuming the void fraction of the bed = $\varepsilon = 0.5$

Where a_p = surface area of the particle / vol. of the particle = $6(1-\varepsilon)/d_p$

$= 6 \times (1\text{-}0.5)/0.01825 = 164.40\ m^2/m^3$

Re = $V \rho / (\mu\psi a_p) = 0.1749 \times 1.1915 / (1.84 \times 10^{-5} \times 0.91 \times 164.40) =$ **75.74**

ψ is the sphericity: $\psi = 0.91$ for spheres and $\psi = 0.81$ for cylinders

6. Results

Run no.	Re	K_G, kg mol/m^2 –s-Pa	Sh / Sc$^{1/3}$
1	75.74	2.796×10^{-9}	10.059
2	119.16	3.0286×10^{-9}	16.31
3	156	3.786×10^{-9}	20.39

Table 2

Plot of Sh / Sc$^{1/3}$ vs Re on a log-log scale should yield a straight line

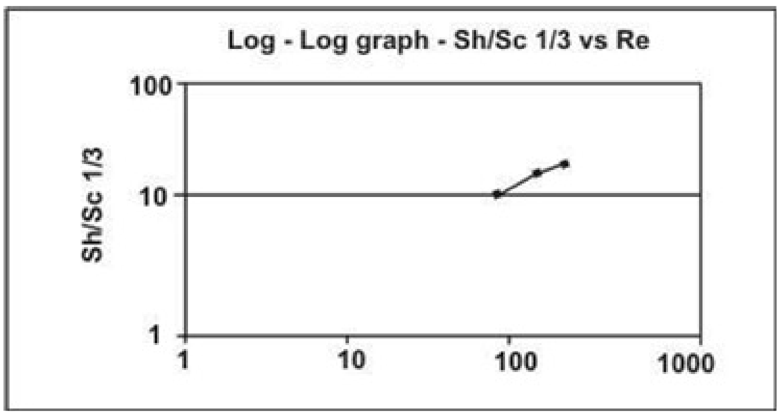

Figure 3

$Sh / Sc^{1/3} = 0.142\ Re^{0.98}$

7. References

i. Bennet and Myers: Momentum, Heat and Mass Transfer
ii. Sherwood, pigford and Wilke: Mass Transfer
iii. Treybal: Mass transfer Operations: Part 1, Diffusion and mass transfer Pp:21-123
iv. How Do Grazers Achieve Their Distribution? A Continuum of Models from Random Diffusion to the Ideal Free Distribution Using Biased Random Walks K. D. Farnsworth and J. A. Beecham The American Naturalist Vol. 153, No. 5 (May 1999), pp. 509-526
v. A Prospective and Retrospective Look at the Diffusion Model: Journal of Health Communication: International Perspectives Volume 9, Supplement 1, 2004
vi. Vapor-liquid equilibriums of water-hydrogen chloride solutions below 0. Degree C Eugene Miller J. Chem. Eng. Data, 1983, 28 (4), pp 363–367 DOI: 10.1021/je00034a005 Publication Date: October 1983
vii. CHEMICAL ENGINWS' HANDBOOK John H. Perry, Chemical Engineer, E. I. du Pont de Nernours and Co., Editor. Third edition. McGraw-Hill Book Co., New Yo*, 1950