ISSN: 0974-2115
www.jchps.com Journal of Chemical and Pharmaceutical Sciences

Diffusion through Bio-Membranes

[1]Surekha V. Munde, [2]Khan A.R, [3]Rabbani G, [4]Yusuf H. Shaikh*
[1]Department of Physics, P.E.S. College of Engineering, Aurangabad, India-431001
[2]Department of Computer science Dr.Rafiq Zakaria Campus, Maulana Azad College Aurangabad, India -431001
[3]Department of Physics, Dr.Rafiq Zakaria Campus, Maulana Azad College Aurangabad, India -431001
[4]Department of Physics, Shivaji Arts, Commerce and Science College, Kannad, India -431103
***Corresponding author: E-Mail: shaikhyh@gmail.com**

ABSTRACT

Study of diffusion of solute finds application in a vast variety of areas of modern technology including health sciences and drug delivery. Diffusion of NaCl through bio-membranes is studied using aqueous solutions in Franz cell with two side arms for measurement of conductivity. The upper compartment is filled with a solution of known concentration and the concentration in the lower compartment (on the other side of the membrane) is monitored with time using conductivity. The diffusion is governed by Fick's laws of diffusion and thus the properties and characteristics of the diffusing membrane can be estimated. Performance of three typical bio-membranes is presented.

KEY WORDS: Diffusion, Fick's laws, Concentration, bio membranes.

1. INTRODUCTION

Diffusion of solute through membranes has wide application in areas of modern technology including health sciences and drug delivery (Patricia Connolly, 2002; Azad Khan, 2011). Modern advances in drug delivery systems are making use of diffusion in administration of drugs through patches and using approaches like Iontophoresis (Munde, 2015; Prasanjeet Patnaik, 2011). Diffusion of NaCl through three different bio-membranes is studied using aqueous solutions in Franz cell with two side arms for measurement of conductivity. The upper compartment is filled with a Sodium Chloride solution of known concentration and the concentration in the lower compartment (on the other side of the membrane) is monitored with time using conductivity. The diffusion through bio-membranes is governed by Fick's laws of diffusion (Jean Philibert, 2005; Helmut Mehrer, 2009; Richard DiDomizio, 2006). Diffusion equation is obtained from Fick's diffusion equation applicable for this experimental method thus the properties and characteristic of the diffusing membrane can be estimated. Performance of three typical bio-membranes is studied and presented.

For large concentration differences of the solutions, while the transport across the membrane will be due to advection while transmission across the membrane will be predominant at lower concentration differences (Puthenveettil, 2005; Puthenveettil, 2008; Ramareddy, 2010). In addition to the importance of understanding the phenomenology of such a system, the effects encountered in such a configuration are of considerable practical interest in systems where unstable concentration boundary layers affect the transport across membranes (Slezak, 1985; Slezak, 2010; Dworecki, 2005). In this work, a much simpler method of estimating the diffusion coefficient from the measured molar conductivity data was applied. Electrical conductivity measurements (with NaCl solution in water) could be used to predict the infinite dilution diffusion coefficients in water via the used of the Fick's diffusion equation. The applied method has been used previously to predict infinite dilution diffusion coefficients (Jacques Loeb, 1922) and was proven to produce reasonably accurate results with comparison to that of the usual methods mentioned previously.

2. EXPERIMENTAL

To determine the mass transfer of solute through the biomembrane (Paul, 1976) and for the measurement diffusion constant (Crank, 1979; Siepmann, 2008; Baeumer, 2008; Abad, 2010; Chen, 2007) through bio membrane concentration of the solute in the lower compartment is measured. We used a simple method of measuring conductivity of the solution. For measurement of conductivity a conductivity meter is used. Also a Franz cell with two arms is used. In between the upper and lower compartment the biomembrane is kept. For leakage control it may be fixed with the help of paper clips. In one of the arm the conductivity meter cell is inserted which is connected to the conductivity meter. In lower compartment pure water is filled and in the lower compartment the solute with known concentration is filled. The chemical used is NaCl. The Standard table of readings of Relation between conductivity and concentration (% w/w) of NaCl solution in the conductivity range of 0.0001 to 2 mS is given below.

Table.1. Relation between conductivity and concentration (% w/w) of NaCl solution in the conductivity range of 0.0001 to 2 mS.

NaCl % w/w	Normality	Conductivity		NaCl % w/w	Normality	Conductivity	
		micro symen	mili symen			micro symen	mili symen
0.0001	1.72E-05	2.2	0.0022	0.03	0.005172414	617	0.617
0.0003	5.17E-05	6.5	0.0065	0.1	0.017241379	1990	1.99
0.001	0.000172414	21.4	0.0214	0.3	0.051724138	5690	5.69
0.003	0.000517241	64	0.064	1	0.172413793	17600	17.6
0.01	0.001724138	210	0.21	3	0.517241379	---	48.6

In figure.1, the points plotted represent actual standard data and the straight line joining those points is the best fitting straight line and the equation of the straight line is shown in the inset.

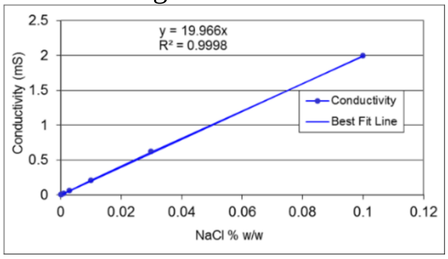

Figure.1. Relation between conductivity and concentration (% w/w) of NaCl solution in the conductivity range of 0.0001 to 2 mS

The conductivity versus concentration relationship is linear for sodium chloride (Surekha & Munde, 2014). The exact relationship obtained from the graph shown in Figure 1is,

$$Conductivity(mS) = 19.966 \cdot concentration\ of\ \ NaCl\ (\%w/w) \qquad [1]$$

During the study concentration of NaCl in the lower compartment (accepter compartment) was monitored for 60 minutes by measuring the conductivity with time and converted finally to the concentration using the above relationship.

If (ϕ_1) is the concentration of the solution in the upper compartment at any time T and (ϕ_2) is the mass transfer through the membrane, then the Driving force $\partial\phi/\partial x$ is given by the relation

$$\frac{\partial \phi}{\partial x} = \frac{(\phi_2 - \phi_1)}{(x_2 - x_1)} \qquad [2]$$

$(\phi_2 - \phi_1)$ is the Concentration difference between the concentration in upper compartment and concentration in lower compartment

$(x_2 - x_1)$ is the thickness of membrane.

Figure.2. Mass transfer through membrane and thickness of membrane

The diffusion flux J in a particular direction is directly proportional to the Driving force in the same direction i.e. $\frac{\partial \phi}{\partial x}$

$$\therefore J \propto \frac{\partial \phi}{\partial x} \qquad [3]$$

$$OR \quad J = -D \times \frac{\partial \phi}{\partial x} \qquad [4]$$

Where D is Diffusion constant and it is a property of membrane which depends on many factors like type of solution, type of membrane, Concentration etc.

At time t_1 the mass transferred in the lower compartment through the membrane is m_1 and the conductivity measured is C_1 and at time t_2 the mass transferred in lower compartment through the membrane is m_2 and the conductivity measured is C_2 then, Mass flow through the membrane per unit time is given by,

$$Mass\ flow\ per\ unit\ time = \frac{(m_2 - m_1)}{(t_2 - t_1)} \quad [5]$$

Diffusion flux J can be given by Mass flow per unit time per unit area

$$Flux\ J = \frac{\left[\frac{(m_2 - m_1)}{(t_2 - t_1)}\right]}{(A)} \quad [6]$$

As for all the conductivity measurements membrane used is cylindrical in shape therefore above equation can be written as,

$$Flux\ J = \frac{\left[\frac{(m_2 - m_1)}{(t_2 - t_1)}\right]}{(\pi r^2)} \quad [7]$$

Therefore Diffusion constant D is given by

$$D = \frac{-J}{\left[\frac{\partial \phi}{\partial x}\right]} \quad [8]$$

Equation (8) is for Diffusion Constant

To study the diffusion of solute through a membrane a Franz cell is used and the concentration in the second compartment is measured using a conductivity probe and meter as shown in Figure.1. Schematic of the Franz cell is shown in Figure 2, upper compartment contains concentrated solution and the bottom compartment contains pure solvent that is water in the present study. Diffusion of sodium chloride (NaCl) is studied and the details for three different membranes studied are presented. The concentrated solution used in the upper compartment (donor) was 1M sodium chloride. Comparison of diffusion through three different membranes is presented. One membrane is the egg membrane obtained removing the outer shell and the inner content of a common hen egg. The thickness of egg membrane measured was 0.0055 cm. The other two membranes are also bio-membranes obtained from animal membranes, the thickness and consistency of the two membranes is different. The thickness of wet membrane-1 and wet membrane-2 were 0.0385 cm and 0.0542 cm. Wet membrane – 1 is one of these membranes that was thinner as compared to the other one i.e. the Wet membrane – 2. Sodium Chloride solution, prepared to the desired initial concentration C0 that is 1 M in the present study, is then filled in the upper compartment of the Franz Cell. In the lower compartment of the Franz cell the distilled water is used and the conductivity cell is inserted through one of the side arms of the Franz cell to record the concentration of the diffused NaCl in lower compartment through the membrane as shown in Figure 3. The conductivity cell is attached with the conductivity meter. The conductivity meter is used to note down the difference between the conductivity of lower compartment with respect to time. A stop watch is used for timing purpose to record the conductivity of the solution in the lower compartment with time. For longer duration experiments we designed, constructed and tested an automatic data acquisition system (Surekha Munde, 2014)


Figure.3. Actual set up for conductivity measurement in diffusion experiment and Franz cell also seen kept on magnetic stirrer, conductivity probe is also seen

It was observed that during the experiment, it was observed that the effect of diffusion, i.e. increase in concentration in the lower compartment takes time and is a bit slow, our interest was to estimate the amount of solute transferred as a function of time. In view of this a magnetic stirrer was use to allow uniform mixing of the solution in the lower compartment as shown in figure.3.

During the study concentration of NaCl in the lower compartment (accepter compartment) was monitored for 60 minutes by measuring the conductivity with time and converted finally to the concentration using the above relationship. Figure 4 shows the results of the experiment using the three different membranes discussed above in the form of graph of conductivity versus time. The same data when converted into concentration of sodium chloride as a function of time is shown in Figure.5. Out of the three membranes used, egg membrane was thin and more uniform and thus diffusion was relatively fast and the plot for egg membrane is seen above the rest of the two membranes. Both the plots shown in figure 6 and 7 are identical except for the linear conversion factor shown in the equation used for conversion of conductivity into concentration. The two bio-membranes used (Wet membrane – 1 and 2) were relatively thicker and had relatively uneven texture, among the two, the wet membrane – 1 was relatively thinner and thus the diffusion process was a bit faster as compared to that for wet membrane – 2 which is clearly visible in the two figures.

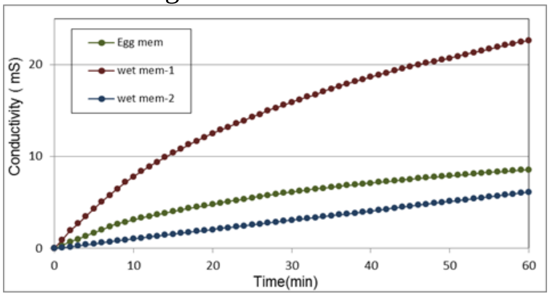

Figure.4. Conductivity versus time plot for the three membranes used.

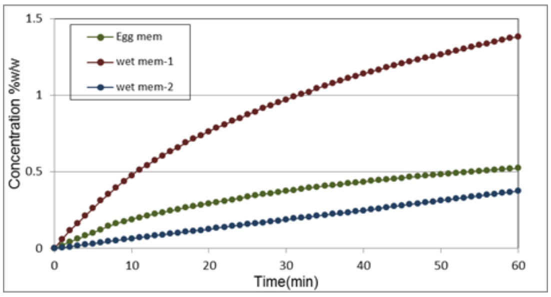

Figure.5. Concentration (%w/w) versus time plot for the three membranes used

The cumulative amount of total mass transfer across the biomembrane can be calculated for the concentration (%w/w) using the actual volume of the lower compartment of the Franz Cell (60 cc). The total amount of NaCl transported across the membrane as a function of time is shown in Figure 6 and diffusion coefficient calculated from equation (8) is shown in figure.7. It is clearly seen from the figures that the diffusion for egg membrane is the highest and that for the wet membrane – 2 is the lowest and thus the diffusion coefficient for the egg membrane is the highest and then comes the wet membrane – 1 and the wet membrane – 2 has the lowest diffusion coefficient which is in agreement with the expectation as the egg membrane was the thinnest and the wet membrane was the thickest.

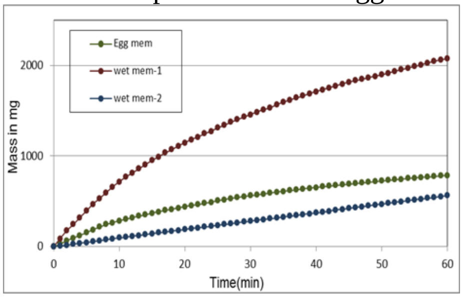

Figure.6. Total mass diffused (gm) versus time for the three membranes used

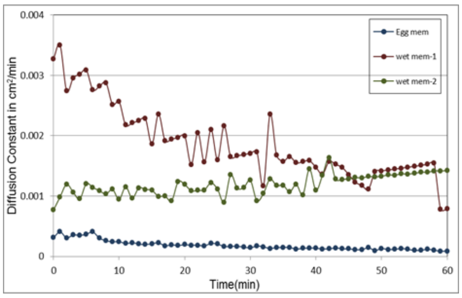

Figure.7. Diffusion constant versus time for the three membranes used

3. RESULTS

The Diffusion through biomembranes can be calculated for the concentration (%w/w) using the actual volume of the lower compartment of the Franz Cell. The total amount of NaCl transported across the membrane as a function of time. It is clearly seen that the diffusion for egg membrane is the highest and that for the wet membrane – 2 is the lowest and thus the diffusion coefficient for the egg membrane is the highest and then comes the wet membrane – 1 and the wet membrane – 2 has the lowest diffusion coefficient which is in agreement with the expectation as the egg membrane was the thinnest and the wet membrane was the thickest.

4. CONCLUSION

Diffusion of sodium chloride (NaCl) is studied in three selected bio-membranes, namely the hen egg membrane and two animal wet membranes of different thickness using Franz cell. Concentration of the diffused sodium chloride is estimated using conductivity meter and the concentration is recorded for one hour at an interval of 1 minute. The diffusion through egg membrane was faster as compared to the rest of the two animal membranes which also depended on the thickness of the membranes. The results of concentration of NaCl in the lower (acceptor) compartment, its concentration in % w/w and total mass diffused as a function of time are presented. Also the diffusion equation applicable to the experimental procedure is presented and diffusion constant using the equation is obtained for all three membranes and graph of diffusion constant related to the time is presented.

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