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Filtration Coefficient in Transport phenomenon across Ion Exchange membranes.

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Abstract: *Transport studies across membranes follows the principle of selective permeability and are very important from experimental and theoretical point of view. These studies could be utilized for better understanding of drug membrane interactions. Non equilibrium thermodynamics plays an important role in studying transport phenomenon Filteration CoefficientL_P is a measure of a membrane's permeability, it denotes the volume of fluid filtered per unit time per unit area of membrane per unit pressure differenceIn the present investigation membrane is prepared by mechanical compression of action exchange resin Indion 236 with adhesive araldite and has been characterized in terms of membrane constant A/l.Filteration CoefficientL_P for different concentrations of aqueous solutions of glucose and sucrose at different temperatures have been determined. The present study tries to establish a relationship betweenFilteration CoefficientL_P equivalent pore radius , concentration of solutes and temperature of study.*

Keywords: *Transport, permeability, Filtration coefficient, equivalent pore radius,pressure*

I. Introduction

Transport processes across natural and artificial membranes are important from experimental and theoretical point of view. Transport phenomenon arises because any system in non equilibriumstate will try to attain equilibrium state.At equilibrium the state variables remain constant and there is no net flow of matter or energy between the system and surroundings or between the parts of the system itself. Ion Exchange membranes are highly charged artificial membranes with ionic groups, in the form of solid films, foils, discs, ribbons, tubes and plugs etc. Structurally these membranes have characteristic pore size capillaries or channels, chemically the matrix consists of an irregular, macromolecular, three dimensional net work with charged ionic groups in its component polymer molecules. Electrical double layers are formed at the interface of ion Exchange membranes which involve the reversible interchange of ions between solid and liquid phase.. Mobile ions bearing the charge opposite to that born by the fixed ion are known as counter-ions, while those bearing the same charge are known as co - ions. Ion Exchange membranes have been used as simple models for the study of biological processes across biomembranes.

Transport phenomenon across membranes may be diffusion phenomenon or viscous phenomenon, transport across charged membranes can occur in a different manner executing anamolous osmosis instead of normal osmosis leading to transfer of solute in both directions[1-3].Transport phenomenon across a membrane depends on the nature of membrane[4-6] .Examination of relationship between Channel dimensions and filtration coefficient is very important for the understanding of transport phenomenon

There exist quantitative Hydrodynamic relationship between pore dimensions and friction as explained by various mathematical relations given by individual workers working on the subject. Fick's law can be used to describe free diffusion in one dimension in a solution and can be stated as

J_0 = - D (δ_c/ δ_x)

WhereJ_0 is solute flux in moles per unit, c is concentration ,x is distance and D is the diffusion coefficient in free solution. Pepenheimer et.al.[7] used following equation derived by Ladenburg to describe the friction of particles with in the membrane pores.

$g'/g^{0'}$=1+2.4α

$g'$is friction exerted on solute molecule as a consequence of interaction with in the pore. α is ratio of the radius of solute to pore.

Pepenheimer also emphasized on the need of an additional factor for accounting the probability that a particle will actually enter the pore, as a particle could only enter the pore, if it does not strike with the rim. Renkin however preferred equation derived by Faxen on theoretical grounds as compared to Ladenberg's equation

g^0 /g =1-2.104 α + 2.09α^3- 0.95α^5

Filteration CoefficientL_P is a measure of a membrane's permeability, it denotes the volume of fluid filtered per unit time per unit area of membrane per unit pressure difference. Both hydraulic and osmotic pressures are taken

into account. The volume flow J_V as a function of the applied pressure difference ΔP and osmotic pressure difference $\Delta\pi$ across the membrane is given by using Starling equation

$J_V = L_P \Delta P - L_P \Delta\pi\sigma$……..1.

Where J_V is volume flow

L_P isFilteration Coefficient

ΔP is applied pressure difference

$\Delta\pi$is osmotic pressure difference

It is convenient to determine the filtration coefficient $L_P$at $\Delta\pi = 0$, which can be achieved by taking equal concentrations of the solute on both sides of the membrane, so that (1) can be written as

$L_P = (J_V/\Delta P)_{\Delta\pi=0}$……..2.

The experiments to measure filtration coefficient in biological systems were performed by Pappenheimer, Renkin, and Borrero [8,9,10,] to determine changes in tissue fluid content

II. Experimental

2.1 materials

2.1.1chemical reagents

Sucrose and Glucose of analytical grade and used as such after drying over P_2O_5 in a vacuum dessicator.

2.1.2 water

Water required for the preparation of solutions and for the calibration of Viscometer and Pycnometer was prepared by distilling twice in an all glass double distillation unit supplied by Systronics India Ltd. Specific conductance of water thus prepared was of the order of $10^{-6} ohm^{-1} cm^{-1}$.Water was stored in Borosilicate glass bottles.

2.1.3 cation exchange resin

Indion 236 from sd fine Chemicals India was used for the preparation of membrane.

2.2 Preperation of membrane

The cation exchange resin (Indion 236)was swollen in conductivity water and casted in the form of plug as described below

9 gm. of ion-exchange resin along with small amount of (5-7%)of an adhesive (araldite)was placed in a Pyrex glass assembly having constriction in the middle and compressed mechanically at the site of constriction with the help of mechanical device consisting of wooden rods having diameter slightly less than that of glass tube. The screws of the device were tightened and assembly was left as such for 24 hours for the complete setting of the plug. The thickness and diameter of the plug thus prepared were 2.29 cms and 1.398 cms respectively. The maximum variation in the permeability of the ion –exchange membrane , thus prepared for a period of one week was only of the order of 5%.

In order to know about the directional character of the membrane for the permeation of water the hydraulic permeability was measured in both the directions at $35^{\circ}C$ and the values were found to be same in both the directions, thereby indicating the isotropic character of the membrane.

2.3 apparatus

The apparatus consists of a pyrex glass tube of 24 cms. In length having a slight constriction in the middle with an internal diameter 1.398 cm, where the plug of cation exchange resin is set up.This tube has two standard female joints B-24 at the ends. To the standard B-24 male joints are fixed the coiled platinum electrodes F and G. The ends of the electrodes are fused in glass tubes of diameter 5 mm. so that the electrode ends are insulated from the permeant . The lengths of these glass tubes are adjusted in such a way that when standard joints are kept in position, the electrodes touch the cross-sectional surface of the membrane. The main tube has two side tubes H and K, bearing B-14 female standard joints D and E. Through the joint E a capillary tube J, of known diameter, bent at 90° of length 25 cm. is connected to the side tube K. A graduated tube I of about 30 cms in length and 1.0 cm. in diameter is connected to the side tube H, through another standard joint D.The design of apparatus and experimental set up is shown in “Fig”1

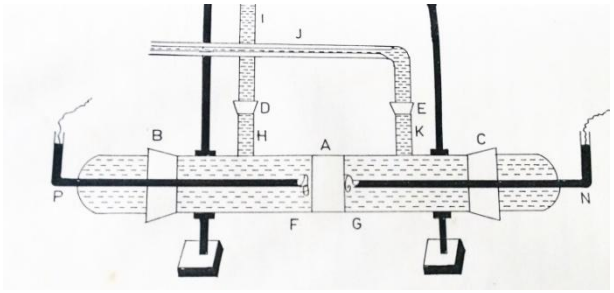


fig.1. schematic set up of the apparatus.

2.4 working procedure

The experimental cell was filled with water and left overnight for equilibration of the plug. The cell was then thoroughly washed with fresh distilled water under pressure gradient to ensure thorough cleanliness. The cell was then filled, by adding the solution under investigation on both sides of the membrane and left overnight. Next day the solution was thrown. The apparatus was then filled by adding the solution under investigation on one side of the membrane and then forcing it to the other side under the pressure gradient by vacuum pump. This ensures the complete filling of the capillaries of the membrane. The whole apparatus was then kept in air thermostat maintained at the desired temperature with in $\pm 0.05℃$. For the measurement of hydrodynamic permeability, desired pressure difference was applied across one side of the cell with the help of a pressure head.The system was kept in the thermostat for about two hours to allow the experimental solution to attain the temperature of the thermostat. At desired pressure difference, the rate of flow of liquid was measured by noting the time taken by the solution to move a certain distance i.e one cm. through horizontal capillary. Time of flow was recorded by using a stopwatch of least count 0.1s.The flow was recorded at different pressures and temperatures.

Conductance of the system and specific conductance was noted with the help of Digital conductivity meter. The conductivity cell consisted of two platinum electrodes fused with glass.Density of the solution is noted with pre calibrated Pycnometer and viscosity was measured with a suspended lebel type viscometer.

2.5 Sources of Error

The main source of error and factor responsible for affecting reproducibility of results is the incomplete wetting of the membrane, as rate of flow of liquid depends upon the actual number of capillaries transmitting the liquid. This was ensured by introducing the solution after evacuation of the apparatus and by preparing the solution from degassed water

III. 3.Results And Discussion

Indian 236 ion exchange membrane is characterized before putting into the practical use.Effective cross-sectional area, equivalent pore radius and the electrical character of the membrane is determined.

3.1Membrane Characterization

The thickness of the membrane is measured with the help of cathetometer of 0.001cm.measurement limits and found out to be equal to 2.29 cm., Diameter of the membrane is noted with the help of travelling microscope of 0.001 cm. sensitivity and found out to be equal to 1.398 cm.

The rate of permeation through the membrane ,under the influence of hydrostatic pressure depends upon the effective cross-sectional area, which is difficult to determine due to the complex geometry of the opening with in the membrane. However determination of the ratio A/l,so called membrane constant is possible , in terms of which the permeant behavior of any membrane can be expressed quantitatively.

For a membrane having 'n' pores of equivalent radius 'r', the effective cross-sectional area 'A', through which permeation occurs is $n\pi r^2$. The electrical conductance K of the membrane equilibrated with a permeant having specific conductance k is given by

$K= n\pi r^2 . k/l = (A/l).k$

So that the membrane constant is

$A/l =K/k$

Membrane constant is characteristic parameter of the membrane and is independent of the permeating liquid as long as the interaction between the permeant and the membrane matrix is not strong enough to alter pore radius. values of membrane constant are found out to be fairly constant for different solutions as listed in table 1. and are in accordance with the findings of singh et.al.[11]. Thus the membrane constant, A/l is a characteristic of membrane only and is independent of the nature of permeating liquid. The data is previously reported in the paper published by the author itself [12]

Table 1.

Membrane characteristics for different solutions of Glucose and Sucrose at different Temperatures (ascertained from Hydrodynamic permeability data)

For glucose

Concentration C×10^2mol l^{-1}	K×$10^6 ohm^{-1}$	k×$10^6 ohm^{-1}cm^{-1}$	A/l (cm)
	Glucose in Water temperature 308K		
0.099	8.45	65.00	0.13
0.29	8.90	69.00	0.13
0.49	9.20	71.00	0.13
0.69	9.40	67.85	0.14
0.99	9.10	70.00	0.13
2.96	9.65	74.20	0.13
4.92	11.56	82.60	0.14
6.91	11.28	99.00	0.11
	Temperature 313K		
0.099	8.70	67.00	0.13
0.29	9.10	70.10	0.13
0.49	9.43	72.50	0.13
0.69	9.90	76.40	0.13
0.99	9.70	81.00	0.12
2.96	10.00	76.90	0.13
4.92	11.00	84.60	0.13
6.91	12.00	92.30	0.13
	Temperature 318 K		
0.099	9.00	69.23	0.13
0.29	9.50	73.07	0.13
0.49	10.00	76.92	0.13
0.69	10.50	80.77	0.13
0.99	11.00	84.61	0.12
2.96	11.70	83.15	0.14
4.92	12.00	100.00	0.12
6.91	13.00	102.00	0.13

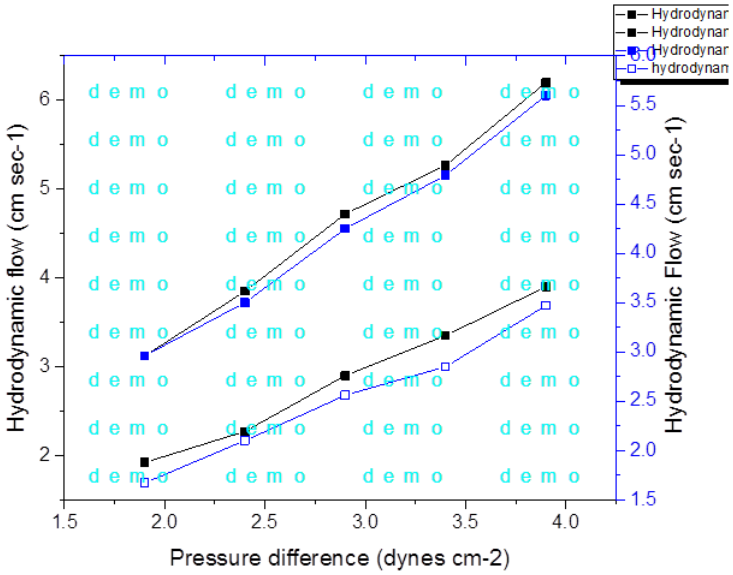
Table For sucrose

Concentration C×10^2mol l^{-1}	K×$10^6 ohm^{-1}$	k×$10^6 ohm^{-1}cm^{-1}$	A/l (cm)
	Sucrose in Water temperature 308K		
0.099	12.45	95.80	0.13
0.29	12.76	98.20	0.13
0.49	13.75	105.80	0.13
0.69	14.88	114.50	0.14
0.99	15.08	116.00	0.13
2.96	16.77	119.80	0.14
4.92	16.32	125.60	0.13
6.91	17.03	131.00	0.13
	Temperature 313K		
0.099	12.80	98.46	0.13
0.29	13.00	100.00	0.13
0.49	14.00	107.69	0.13
0.69	15.50	119.23	0.13
0.99	16.00	133.33	0.12
2.96	17.00	121.42	0.14
4.92	17.00	130.76	0.13
6.91	18.00	138.46	0.13
	Temperature 318 K		
0.099	13.00	100.00	0.13

0.29	14.00	107.69	0.13
0.49	15.00	114.89	0.13
0.69	16.00	121.77	0.13
0.99	17.00	130.76	0.13
2.96	18.50	142.30	0.13
4.92	19.00	146.15	0.13
6.91	22.00	157.14	0.14

3.2Filteration CoefficientL_P

The experimental data reveals that the volume transported per unit time is linearly proportional to the pressure head as shown in plot 1 (TABLE 2)for sucrose in water at 313K. Similar plots have been observed for sucrose and glucose in water at different temperatures. The slope of linear plot gives the value of filtration coefficient L_P.Variation of L_P with concentrations at specific temperatures was studied for both the solutes and corresponding values are given in TABLE 3.



Plot 1.

TABLE 2

Pressure difference $\Delta P \times 10^{-4}$ Dyne cm^{-2}	$J_v \times 10^5$ $Cmsec^{-1}$							
Conc.(moll^{-1})	0.099	0.29	0.49	0.69	0.99	2.96	4.92	6.91
Temperature 308K	Glucose in Water							
3.9	3.69	3.54	3.44	3.20	5.05	5.49	5.83	7.19
3.4	3.25	3.10	2.90	2.75	4.39	4.81	4.99	6.43
2.9	2.75	2.60	2.55	2.35	3.68	4.18	4.32	5.43
2.4	2.30	2.15	2.05	2.00	3.05	3.45	3.65	4.55
1.9	2.00	1.75	1.60	1.40	2.50	2.74	2.86	3.56
Temperature 313 K								
3.9	3.75	4.17	4.45	5.60	6.52	6.00	6.48	6.95
3.4	3.20	3.29	3.75	4.85	6.00	5.33	5.73	5.82
2.9	2.30	3.00	3.21	4.10	4.90	4.45	4.79	5.30
2.4	2.40	2.56	2.62	3.27	4.11	3.65	4.07	4.32
1.9	1.80	2.00	2.10	2.99	3.17	2.75	2.88	3.55
Temperature 318 K								
3.9	6.80	8.60	13.10	14.20	12.30	15.10	20.20	21.00
3.4	6.00	7.90	10.00	12.30	10.20	12.60	17.50	18.70
2.9	4.80	6.30	8.40	10.50	8.60	10.40	15.00	15.80
2.4	4.20	5.00	7.00	8.70	7.10	8.90	12.30	12.90
1.9	2.40	4.20	4.60	5.50	4.10	7.04	7.90	9.02
Pressure difference $\Delta P \times 10^{-4}$ Dyne cm^{-2}	$J_v \times 10^5$ $Cmsec^{-1}$							
Conc.(moll^{-1})	0.099	0.29	0.49	0.69	0.99	2.96	4.92	6.91

Temperature 308K	Sucrose in Water							
3.9	4.22	3.95	3.79	3.33	3.94	5.07	6.43	6.66
3.4	3.52	3.48	3.36	2.89	3.29	4.54	5.32	5.56
2.9	3.10	2.90	2.86	2.50	2.78	3.79	4.55	4.97
2.4	2.51	2.41	2.43	1.97	2.36	3.06	3.71	4.10
1.9	1.97	1.70	1.87	1.63	1.84	2.57	3.04	3.21
Temperature 313 K								
3.9	6.20	5.60	3.90	3.47	2.56	1.96	1.34	1.15
3.4	5.27	4.79	3.35	2.85	2.26	1.60	1.20	1.07
2.9	4.72	4.25	2.90	2.56	1.93	1.40	1.05	0.78
2.4	3.85	3.50	2.27	2.10	1.54	1.15	0.88	0.70
1.9	3.12	2.96	1.92	1.67	1.31	1.03	0.69	0.55
Temperature 318 K								
3.9	7.56	7.12	5.93	4.00	3.48	2.10	1.96	1.65
3.4	5.95	5.83	5.22	3.30	2.93	1.87	1.69	1.45
2.9	5.60	4.42	4.17	2.82	2.33	1.55	1.35	1.25
2.4	4.62	4.05	3.65	2.40	2.05	1.39	1.25	0.90
1.9	3.79	3.20	2.25	1.84	1.65	1.00	0.96	0.85

Table III

Density, Viscosity and Filtration coefficient for Glucose and Sucrose in water at different Temperatures

Concentration $C\times10^2\ moll^{-1}$	Density D gcm^{-3}	Viscosity $\dot{\eta}$	Filtration coefficient $L_P\times 10^{-9} cm^3 dyn^{-1} sec^{-1}$
Glucose in Water Temperature 308K d° =0.9941 $\dot{\eta}^\circ$ =0.7225			
0.099	0.99411	0.72350	1.00
0.29	0.99450	0.72701	0.91
0.49	0.99479	0.72768	0.86
0.99	0.99502	0.72829	1.29
2.96	0.99518	0.73270	1.42
6.91	0.99878	0.73930	1.81
Temperature 313K d° =0.9922 $\dot{\eta}^\circ$ =0.6560			
0.099	0.99221	0.66320	1.00
0.29	0.99229	0.66571	1.09
0.49	0.99238	0.66849	1.20
0.99	0.99270	0.67501	1.39
2.96	0.99469	0.67939	1.60
6.91	0.99721	0.68578	1.76
Temperature 318K d° =0.99025 $\dot{\eta}^\circ$ =0.5960			
0.099	0.99030	0.59761	1.70
0.29	0.99039	0.60040	2.25
0.49	0.99061	0.60189	2.87
0.69	0.99069	0.60538	3.64
2.96	0.99248	0.61901	3.67
4.92	0.99712	0.62710	5.33
Concentration $C\times10^2\ moll^{-1}$	Density D gcm^{-3}	Viscosity $\dot{\eta}$	
Sucrose in Water Temperature 308K d° =0.9941 $\dot{\eta}^\circ$ =0.7225			
0.099	0.99440	0.73109	1.14
0.29	0.99469	0.73288	1.00
0.6 9	0.99501	0.73390	0.86
0.99	0.99708	0.73879	0.9 2
2.96	0.99871	0.74010	1.33
6.91	1.01109	0.75292	1.70
Temperature 313K d° =0.9922 $\dot{\eta}^\circ$ =0.6560			
0.099	0.99231	0.66810	1.67
0.29	0.99260	0.66989	1.41
0.49	0.99279	0.67161	1.00
0.99	0.99361	0.67701	0.63
2.96	0.99630	0.68149	0.55
6.91	1.00122	0.69349	0.33
Temperature 318K d° =0.99025 $\dot{\eta}^\circ$ =0.5960			
0.099	0.99030	0.61160	1.94
0.29	0.99051	0.61549	1.67
0.49	0.99119	0.61910	1.56
0.99	0.99172	0.62288	0.86
2.96	0.99410	0.62731	0.56
6.91	0.99958	0.63601	0.45

It is evident from Table III that the filtration coefficientL_P, in case of glucose as well as sucrose at 308K first decreases and then again increases with the increase of concentration of solute in water i.e. the filtration coefficient or permeability of the membrane is reversed with the increase of concentration of glucose and sucrose after some concentration. This effect has been observed only at 308 K, while it is not seen for higher temperatures studied. Further filtration coefficient decreases continuously with the increase in concentration of sucrose at 313 K and 318 K. On the other hand L_P continuously increases with increase in concentration of glucose. The behavior of the membrane just opposite in case of glucose and sucrose. It may be concluded from permeability data that the friction between water and membrane is further enhanced on the addition of sucrose, where as it is reduced on the addition of more and more of glucose. Equivalent pore radius data and filtration coefficient value for the membrane can also clearly be related as equivalent pore radius also shows the same trend [12]

3.3Application on Biomembranes

Bio membranes protect tissues and cells from foreign molecules in human body and select the cellular penetration of compounds with a biochemical or physiological role. Drug molecule meets variety of bio membranes after its administration in the human body, time and concentration being the main factors responsible for drug distribution in the body. Besides structural role bio membranes selectively control the passage of compounds and maintain the bio chemical integrity and communication between the extra- and intracellular environment. The alterations in the structure or functions of bio membranes are thus responsible for the etiology of many disease.Right bio membrane models are very important to understand the pharmacokinetics and pharmacodynamics of the drug molecule for in vitro studies, which includes partitioning, binding and permeability of the bio membrane. [13,14]. The drug molecule is shaped and tailor made according to these parameters

Natural cell membranes present a great complexity of structure, cross-connections and functionality, artificial model membrane systems have to be developed which help the scientists to understand the effects of membrane lipids in drug transport and uptake into cells, drug activity, and even toxicity. Permeability and reflection coefficient can prove to be deciding factors in understanding the behavior of bio membranes through non equilibrium thermodynamics.

IV. Conclusion

In the present investigation cation exchange membrane has been prepared with Indion- 236.Transport studies viz. hydrodynamic permeabilities of aqueous solutions of glucose and sucrose in water across the membrane at various concentrations and different temperatures have been carried out. The membrane was characterized in terms of membrane constant A/l.As suggested by experimental data the membrane constant has been found to be fairly constant for glucose and sucrose solutions, indicating that the membrane constant is characteristic of the membrane only and is independent of the nature of the permeating liquid.It can be concluded from experimental data that hydrodynamic flow depends linearly on the pressure applied. However the values of reflection coefficient $L_P$observed at different temperatures can be attributed to the different permeability of membrane with different solutes and concentrations at different temperature. The behavior can be attributed to different frictional forces which leads to change in the permeability of membrane reflected through values of equivalent pore radius and reflection coefficient.

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