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Transport studies of aqueous solutions of organic solvents across composite cellophane separator at 298.15K

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ABSTRACT

Studies of hydrodynamic flow of aqueous solutions of Dimethyl sulfoxide (DMSO) and Acetonitrile (ACN) at different concentrations through commercially available Acroshield™ H 69008 composite cellophane membrane at 298.15K are described. The hydrodynamic flow studies have been used to evaluate transport properties such as Permeability coefficient, L_p and Frictional coefficient, F_{wm}. The data has been analyzed in terms of interactions between membrane and solution.

Keywords: Acroshield™ H 69008 composite cellophane membrane, Permeability coefficient, *Lp*, Frictional coefficient, F_{wm}.

INTRODUCTION

A membrane [1] is a "*a selective barrier between two phases, the term selective being inherent to a membrane or a membrane process*". The study of transport phenomena through membranes has attracted the attention of chemists and chemical engineers since the last three decades [2-8]. The transport studies have been successfully explained with the help of thermodynamics of irreversible processes [9]. The hydrodynamic flow of a fluid through a porous medium can either be viscous flow (developed due to pressure difference) or diffusional flow (developed due to chemical potential gradient); or a combination of the two as characterized by irreversible thermodynamics [10].
Gordan et.al [11] reported cellophane as the first semi-permeable membrane used for haemodialysis. Mckeever [12] reported the use of cellophane as an interposition membrane in synovectomy. DMSO is considered as a supersolvent because of its wide applications in industrial and medicinal fields [13]. It is used as anti-inflammatory agent and reduces swelling. ACN is used mainly as a solvent in the purification of butadiene in refineries. It is widely used in battery applications because of its relatively high dielectric constant and ability to dissolve electrolytes. Hence, it was of interest to study the transport properties of DMSO and ACN across commercially available Acroshield™ H 69008 composite cellophane membrane.

MATERIALS AND METHODS

DMSO (AR grade) was used as such. ACN (AR grade) after keeping over anhydrous calcium oxide for about 48 hours was shaken with phosphorus pentoxide and was distilled. Ordinary water distilled thrice over alkaline $KMnO_4$ and acidic $K_2Cr_2O_7$ in all glass apparatus was used for preparing the solutions. The specific conductance of this water was $1.30x10^{-4}Sm^{-1}$.

The Acroshield ™ H 69008 composite cellophane membrane was thoroughly cleaned with distilled water, dried and weighed. The membrane was kept in the solutions of different concentrations of the two experimental liquids for 48 hours. After 48 hours, membrane was again thoroughly cleaned with distilled water, dried and weighed. The membrane was found to be stable over entire range of DMSO concentration but it disintegrated above 40% concentration of ACN. Therefore, low concentrations for preparation of solutions were chosen. The apparatus and procedure used in the present investigation is the same as described elsewhere [14]. All the measurements were carried out at constant temperature of 298.15K by placing the cell in an air thermostat, where the temperature could be controlled to within ± 0.5°C.

Table 1: Hydrodynamic permeability, J_V, Permeability coefficient, L_p and Frictional coefficient, F_{wm} for aqueous solutions of DMSO and ACN at varying concentrations and pressures across Acroshield™ H 69008 composite cellophane membrane at 298.15K

Pressure difference $\Delta P \times 10^3$ (Nm^{-2})	Hydrodynamic Permeability $J_v \times 10^{-4}$ (ms^{-1})		Permeability coefficient $Lp \times 10^{-7}$ ($m^3N^{-1}s^{-1}$)		Frictional Coefficient $F_{wm} \times 10^9$ ($mNmol^{-1}s$)	
	10.0%DMSO	10.0%ACN	10.0%DMSO	10.0%ACN	10.0%DMSO	10.0%ACN
0.9818	5.3112	7.4513	5.4097	7.5894	3.4996	2.4945
1.4321	8.2206	11.2521	5.7402	7.8571	3.2981	2.4095
1.8811	11.4915	15.2706	6.1089	8.1179	3.0990	2.3321
2.3307	14.6721	19.5632	6.2951	8.3937	3.0074	2.2555
2.7814	18.0643	24.7116	6.4947	8.8846	2.9149	2.1308
	12.5%DMSO	12.5%ACN	12.5%DMSO	12.5%ACN	12.5%DMSO	12.5%ACN
0.9818	5.1859	7.0541	5.2820	7.1849	3.5842	2.6349
1.4321	7.9757	10.8268	5.5692	7.5601	3.3994	2.5042
1.8811	11.1021	14.9429	5.9019	7.9437	3.2077	2.3832
2.3307	14.1526	19.3186	6.0723	8.2888	3.1177	2.2840
2.7814	17.5187	23.9457	6.2985	8.6092	3.0057	2.1990
	15.0%DMSO	15.0%ACN	15.0%DMSO	15.0%ACN	15.0%DMSO	15.0%ACN
0.9818	5.0614	6.6556	5.1552	6.7790	3.6724	2.7927
1.4321	7.7325	10.4019	5.3994	7.2634	3.5063	2.6065
1.8811	10.7116	14.6142	5.6943	7.7690	3.3247	2.4368
2.3307	13.6321	19.0753	5.8489	8.1844	3.2368	2.3131
2.7814	16.9743	23.1821	6.1028	8.3347	3.1021	2.2714
	17.5%DMSO	17.5%ACN	17.5%DMSO	17.5%ACN	17.5%DMSO	17.5%ACN
0.9818	4.9258	6.4837	5.0171	6.6039	3.7734	2.8667
1.4321	7.4736	9.8731	5.2186	6.8941	3.6277	2.7461
1.8811	10.3137	13.5682	5.4828	7.2129	3.4529	2.6247
2.3307	13.1831	17.5975	5.6563	7.5503	3.3470	2.5074
2.7814	16.4146	21.6361	5.9016	7.7789	3.2079	2.4337
	20.0%DMSO	20.0%ACN	20.0%DMSO	20.0%ACN	20.0%DMSO	20.0%ACN
0.9818	4.7914	6.3112	4.8802	6.4282	3.8793	2.9451
1.4321	7.2137	9.3453	5.0371	6.5256	3.7585	2.9011
1.8811	9.9151	12.5212	5.2709	6.6563	3.5917	2.8442
2.3307	12.7334	16.1207	5.4633	6.9167	3.4652	2.7371
2.7814	15.8541	20.0914	5.7000	7.2235	3.3214	2.6208
	22.5%DMSO	22.5%ACN	22.5%DMSO	22.5%ACN	22.5%DMSO	22.5%ACN
0.9818	4.6929	4.4513	4.7799	4.5338	3.9607	4.1757
1.4321	7.0928	6.7931	4.9527	4.7435	3.8225	3.9911
1.8811	9.7247	9.3513	5.1697	4.9712	3.6621	3.8083
2.3307	12.5024	11.9793	5.3642	5.1398	3.5293	3.6834
2.7814	15.6924	14.7615	5.6419	5.3072	3.3556	3.5672
	25.0%DMSO	25.0%ACN	25.0%DMSO	25.0%ACN	25.0%DMSO	25.0%ACN
0.9818	4.5935	4.3313	4.6787	4.4116	4.0464	4.2913
1.4321	6.9727	6.4907	4.8689	4.5323	3.8883	4.1771
1.8811	9.5336	9.0319	5.0681	4.8014	3.7355	3.9430
2.3307	12.2721	11.7604	5.2654	5.0459	3.5955	3.7519
2.7814	15.5319	14.1728	5.5842	5.0956	3.3902	3.7153
	27.5%DMSO	27.5%ACN	27.5%DMSO	27.5%ACN	27.5%DMSO	27.5%ACN
0.9818	4.4915	4.2211	4.5748	4.2993	4.1383	4.4034
1.4321	6.8517	6.3661	4.7844	4.4453	3.9570	4.2588
1.8811	9.3472	8.9487	4.9690	4.7572	3.8100	3.9796
2.3307	12.0229	11.5064	5.1585	4.9369	3.6700	3.8347
2.7814	15.3426	13.9673	5.5161	5.0217	3.4321	3.7700
	30.0%DMSO	30.0%ACN	30.0%DMSO	30.0%ACN	30.0%DMSO	30.0%ACN
0.9818	4.3907	4.1114	4.4721	4.1876	4.2333	4.5209
1.4321	6.7314	6.2423	4.7004	4.3588	4.0277	4.3433
1.8811	9.1621	8.8651	4.8706	4.7127	3.8869	4.0172
2.3307	11.7743	11.2532	5.0518	4.8282	3.7475	3.9211
2.7814	15.1535	13.7626	5.4482	4.9481	3.4749	3.8261

RESULTS AND DISCUSSION

In the present study the liquid on both sides of the membrane has same composition and hence the volume flow, J_V is given by the expression [15-17]

$$L_p = {J_v}/{\Delta P} \quad (1)$$

where 'L_P' is the permeability of the membrane for the liquid and 'ΔP' is the pressure difference. L_p has the character of mobility and represents the velocity of the fluid per unit pressure difference for the unit cross-sectional area of membrane.

The hydrodynamic volume flux 'J_v' of the solution through the membrane is estimated from the following relations:

$$J_v = {\pi r^2 x}/{\pi R^2 t} \quad (2)$$

where 'x' is the distance moved in the capillary of the apparatus in time 't', 'r' is the radius of the capillary and 'R' is the radius of the membrane.

The permeability coefficient for aqueous solutions of DMSO and ACN is determined by using equation 1. The flow measurements were repeated 3 times and the flow rate was reproducible within 0.5% accuracy.

On translating thermodynamic coefficients into frictional coefficient, the permeability coefficient L_P can be related to the coefficient of friction F_{wm} by a simple relation as:

$$F_{wm} = {\Phi_w \overline{V}_w}/{L_p \delta} \quad (3)$$

where '$\overline{V}_w$' is the water content of the membrane and is expressed as the volume fraction of the total membrane volume, 'Φ_w' is numerically equal to the fraction of membrane surface available for the permeation of the solution. It was determined by the method described by Ginzberg and Katchalsky [18] and the value obtained was 0.4417391 in the case of Acroshield™ H 69008 composite cellophane membrane, δ is the thickness of the membrane and its value in the given case is 0.42 x 10^{-2} m, $\overline{V}_w$ is the molar volume of water.

CONCLUSION

From table 1 it is observed that both hydrodynamic permeability and permeability coefficient increases with increase in pressure but decreases with increase in concentration for both the experimental solvents. Also it is observed that values of hydrodynamic permeability and permeability coefficient for aqueous solutions of ACN were greater than aqueous solutions of DMSO upto 20% (i.e mole fraction of 0.09), thereafter the trend was reversed. This is due to formation of clathrate-like hydrates of ACN with water [19]. As the pore size of the membrane was small, formation of large sized hydrates by ACN resulted in decrease in permeability of the membrane beyond 20% concentration of ACN as compared to DMSO. Values of frictional coefficient also support the same result. Hence various transport properties support the formation of clathrate-like hydrates by ACN with water at 298.15K.

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