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THE STUDY OF IONIC INTERACTIONS OF POTASSIUM IODIDE IN THE VEGETABLE OIL-N,N-DIMETHYLFORMAMIDE SOLVENT BY ELECTRICAL CONDUCTIVITY MEASUREMENTS

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ABSTRACT. The electrical and molar conductivities of potassium iodide solutions in different concentrations of sunflower oil-DMF and corn oil-DMF solvents were measured at temperatures of 303.15, 308.15, 313.15, 318.15 and 323.15 K. The electrical and molar conductivity increased with an increase in temperature while an increase in the concentration of oil in the solvent had a decreasing effect. The electrical conductivity increased while the molar conductivity decreased with an increase in the concentration of potassium iodide in the solution. The limiting molar conductivities of the potassium iodide solution evaluated by the plots of the Debye-Huckel relation were used to determine the strength of ion-ion and ion-solvent interactions. The ion-ion interaction coefficient (A) varied irregularly with temperature while the ion-solvent interaction coefficient (B) increased with temperature in a pattern characteristic of structure-breaking electrolytes. The limiting molar conductivity of potassium iodide solutions obeyed the Arrhenius model of temperature dependence.

Keywords: *Vegetable oil; Electrical conductivity; N, N-Dimethylformamide (DMF), Ion-ion interaction; Ion-solvent interaction*

INTRODUCTION

Sunflower and corn oil are among the most suitable edible oils due to their cholesterol-controlling ability and consequent prevention of heart diseases.

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In recent times, vegetable oils have found numerous industrial applications such as base stock for biofuels, lubricants, caulking compounds, anti-corrosion, anti-static agents, pesticides, electrical insulation, epoxies, linoleum backing, and paints [1-11]. The ability of vegetable oils to serve as a carrier for biologically important molecules like vitamins has led to their use in commercial pharmaceutical preparations [12]. The metal-based nanofluids such as water, mineral oils, vegetable oils, and ionic liquids exhibit enhanced electrical conductivity and heat-exchange capacity which has found useful applications in car radiators, refrigerators, solar collectors, aeronautics, and electronic equipment [13]. The chemical inertness and dielectric constant of vegetable oil are critical parameters for its use as a dielectric in electrical devices [14]. The electrically conductive derivatives of vegetable oils have the potential to replace mineral oils as the dielectric medium in transformers, circuit breakers, cables, and capacitors due to their environmental-friendly nature via high biodegradability and high fire point as compared to mineral oils which protect the transformers from fire hazard, and higher moisture affinity which keeps the paper insulation dry and enhances the functional life of transformers [15-17].

The increasing use of vegetable oils in hydraulic fluids, cosmetics, pharmaceutics, and biofuels has led to extensive research on their various physicochemical properties [18]. The knowledge of ionic interactions that develop upon the addition of electrolytes to vegetable oils due to the change of their inherent bulk structural arrangement is very important for industrial process engineering [19]. Conductometry is a very simple and reliable method for studying the ion-ion and ion-solvent interactions in an electrolyte solution. In the available literature, the electrical conductivity data of polymers, biomolecules and drugs, acids and bases, ionic liquids, and non-nutritional electrolytes are abundant but very little data is published on the electrical conductivity of solutes and solvents of nutritional importance like potassium iodide and vegetable oils [19-29]. The dimethylformamide is used as a solvent because of its solvency for almost all vegetable oils, and inorganic salts. This research work presents the electrical properties and solvation behavior of potassium iodide in sunflower oil-DMF and corn oil-DMF solvents. The main aim of this study is to investigate the electrostatic ionic interactions and structure-making/breaking ability of potassium iodide in the vegetable oil-DMF solvent by applying the Debye-Huckel-Onsager relation. The results are discussed in terms of the structural effects produced by the orientation of ions in the solution and the temperature dependence of the ionic interactions.

RESULTS AND DISCUSSION

The electrical conductivity, molar conductivity, limiting molar conductivity, and ionic interaction coefficients of potassium iodide solutions having concentrations ranging from 1.0 to 9.0 × 10^{-2} mol.dm^{-3} were measured in different compositions (1.0%, 2.0%, 3.0%, 4.0%, 5.0% v/v) of sunflower oil-DMF and corn oil-DMF solvents at different temperatures from 303.15 to 323.15 K with a difference of 5 K. The results are tabulated in Tables 1 to 7. The uncertainty in the fundamental experimental results is expressed along with each value.

1. Electrical conductivity (*K*)

The electrical conductivity of the potassium iodide solution at different temperatures is presented in Tables 1 and 2. The electrical conductivity of the potassium iodide solution is higher in corn oil-DMF as compared to that in sunflower oil-DMF due to its lower viscosity. In a mixed solvent, the electrical conductivity is affected by the ion-solvent interactions, the three-dimensional structure of the solvent, the viscosity and dielectric constant of the solvent, and the solvation of ions [30]. The electrical conductivity increased with an increase in the concentration of potassium iodide and temperature while it decreased with an increase in the concentration of oil in the solution. Potassium iodide is a strong electrolyte and completely dissociates in the relatively polar solvent; vegetable oil-DMF. The increased electrical conductivity at higher concentrations of potassium iodide is due to the increased number of conducting ions in the solution while the increased electrical conductivity at higher temperatures is due to the greater mobility of ions caused by the increased kinetic energy and decreased viscosity of the solution [22,31]. The decrease in electrical conductivity with an increased oil concentration is due to ion-solvent interaction which results in the solvation of ions by the bulky oil molecules and therefore there is less number of free ions available for transportation of electric charge [23]. The effect of potassium iodide concentration is much more pronounced than the concentration of oil because the number of ions is directly related to the charge transferred while the oil molecules cause a decrease in the number of free ions by interacting with ions and hindering their movement.

Table 1. Electrical conductivity of potassium iodide solution in different compositions of sunflower oil-DMF at different temperatures

[KI] x 10^2 ($mol.dm^{-3}$)	Electrical Conductivity (K) x 10 ($mS.cm^{-1}$)				
	303.15 K	**308.15 K**	**313.15 K**	**318.15 K**	**323.15 K**
	1.0% Sunflower Oil-DMF				
1.0	3.9	4.2	4.5	5.0	5.6
3.0	8.6	8.8	9.1	9.4	9.9
5.0	12.6	12.8	13.0	13.5	14.1
7.0	16.0	16.2	16.5	16.9	17.5
9.0	19.5	19.7	19.9	20.5	21.2
	2.0% Sunflower Oil-DMF				
1.0	3.7	4.0	4.3	4.7	5.1
3.0	8.4	8.6	8.8	9.0	9.4
5.0	12.0	12.5	12.7	13.2	13.6
7.0	15.3	15.7	15.9	16.4	16.9
9.0	18.7	18.9	19.3	19.8	20.5
	3.0% Sunflower Oil-DMF				
1.0	3.2	3.6	3.9	4.3	4.7
3.0	8.0	8.2	8.5	8.8	9.1
5.0	11.5	12.1	12.4	12.8	13.2
7.0	14.7	15.2	15.5	16.0	16.5
9.0	18.2	18.4	18.9	19.3	19.8
	4.0% Sunflower Oil-DMF				
1.0	2.8	3.2	3.5	4.0	4.4
3.0	7.5	7.7	8.1	8.4	8.7
5.0	11.1	11.7	12.0	12.4	12.8
7.0	14.2	14.7	15.1	15.6	16.0
9.0	17.6	17.9	18.5	18.8	19.3
	5.0% Sunflower Oil-DMF				
1.0	2.5	2.8	3.1	3.5	4.0
3.0	7.1	7.3	7.7	8.0	8.3
5.0	10.6	11.2	11.6	12.0	12.3
7.0	13.6	14.2	14.6	15.1	15.6
9.0	17.1	17.4	18.0	18.3	18.8
Note: The uncertainty in the tabulated values is ±0.05 to 0.40%.					

Table 2. Electrical conductivity of potassium iodide solutions in different compositions of corn oil-DMF at different temperatures

[KI] x 10^2 (mol.dm^{-3})	Electrical Conductivity (K) x 10 (mS.cm^{-1})				
	303.15 K	**308.15 K**	**313.15 K**	**318.15 K**	**323.15 K**
	1.0% Corn Oil-DMF				
1.0	5.0	5.8	6.7	7.8	8.7
3.0	12.5	13.5	14.4	15.3	16.0
5.0	17.7	19.2	20.0	21.0	21.9
7.0	22.7	24.6	25.5	26.5	27.4
9.0	27.5	29.4	30.4	32.3	33.1
	2.0% Corn Oil-DMF				
1.0	4.6	5.3	6.1	7.1	8.0
3.0	12.1	12.9	13.9	14.7	15.3
5.0	17.2	18.5	19.3	20.3	21.1
7.0	22.1	23.7	24.8	25.8	26.6
9.0	26.8	28.6	29.6	30.7	31.4
	3.0% Corn Oil-DMF				
1.0	4.3	4.8	5.5	6.5	7.4
3.0	11.6	12.1	13.3	14.1	14.7
5.0	16.7	17.7	18.6	19.6	20.3
7.0	21.6	22.9	24.2	25.1	25.8
9.0	26.3	27.7	28.8	30.0	30.7
	4.0% Corn Oil-DMF				
1.0	4.0	4.4	5.0	5.8	6.8
3.0	11.1	11.4	12.8	13.3	14.0
5.0	16.2	16.8	17.9	19.0	19.6
7.0	21.1	23.1	23.4	24.5	25.1
9.0	25.8	26.9	28.1	29.2	29.9
	5.0% Corn Oil-DMF				
1.0	3.6	3.9	4.5	5.2	6.1
3.0	10.6	10.7	12.1	12.8	13.3
5.0	15.7	16.1	17.2	18.3	18.9
7.0	20.7	22.5	22.7	23.9	24.4
9.0	25.3	26.1	27.4	28.6	29.2
Note: The uncertainty in the tabulated values is ±0.03 to 0.28%.					

2. Molar conductivity (Λ_m)

The values of molar conductivity are presented in Table 3. The molar conductivity increased with the temperature while it decreased with an increase in the concentration of potassium iodide and oil in the solution [33]. The increase in molar conductance at higher temperatures is due to increased ionic mobility caused by the increased fluidity of the solution [23, 32]. The molar conductivity decreased with an increase in the concentration of potassium iodide in the solution due to a decrease in the number of free ions per unit volume of the solution. The decrease in the number of free ions is due to the ionic association caused by the frequent collision of ions in a concentrated solution. The increase in the concentration of oil in the solution decreased the molar conductivity due to the decreased ionic mobility caused by the viscous oil molecules and increased ion-solvent interactions.

3. Limiting molar conductivity (Λ_m^o)

The limiting molar conductivity is the molar conductivity of a solution at infinite dilution and it is the intercept of the plot of the Debye-Huckel-Onsager relation shown in equation 3.1 [32-36].

$$\Lambda_m = \Lambda_m^o - [A + B\,\Lambda_m^o]\,C^{1/2} \qquad 3.1$$

Where A and B are the ion-ion and ion-solvent interaction coefficients respectively as derived from the molar conductivity values of the potassium iodide solution. The unit of Λ_m and A is $S.cm^2.mol^{-1}$, B has units of $S^{-1}.cm^{-2}.mol$, and C is expressed in $mol.dm^{-3}$. The values of limiting molar conductivity are presented in Table 4 while a representative plot of the Debye-Huckel-Onsager relation is shown in Figure 1.

4. Ion-ion and ion-solvent interactions

The ion-ion and ion-solvent interactions were evaluated from a modified form of the Debye-Huckel-Onsager relation presented in equation 3.2 [35-37].

$$\Lambda_m = \Lambda_m^o - [\{(82.4/(DT)^{1/2}\eta_o + \{8.2 \times 10^5/(DT)^{1/2}\}\Lambda_m^o]\,C^{1/2} \qquad 3.2$$

Table 3. Molar conductivity of potassium iodide solution in different compositions of oil-DMF solvent at different temperatures

[KI] x 10^2 (mol.dm^{-3})	Molar Conductivity (Λ_m) (S.cm^2.mol^{-1})									
	303.15 K	**308.15 K**	**313.15 K**	**318.15 K**	**323.15 K**	**303.15 K**	**308.15 K**	**313.15 K**	**318.15 K**	**323.15 K**
	1.0% Sunflower Oil-DMF					**1.0% Corn Oil-DMF**				
1.0	39.0	42.0	45.0	50.0	56.0	50.0	58.0	67.0	78.0	87.0
3.0	28.7	29.3	30.3	31.3	33.0	41.7	45.0	48.0	51.0	53.3
5.0	25.2	25.6	26.0	27.0	28.2	35.4	38.4	40.0	42.0	43.8
7.0	22.9	23.1	23.6	24.1	25.0	32.4	35.1	36.4	37.9	39.1
9.0	21.67	21.9	22.1	22.8	23.6	30.6	32.7	33.8	34.9	36.8
	2.0% Sunflower Oil-DMF					**2.0% Corn Oil-DMF**				
1.0	37.0	40.0	43.0	47.0	51.0	46.0	53.0	61.0	71.0	80.0
3.0	28.0	28.7	29.3	30.0	31.3	40.3	43.0	46.3	49.0	51.0
5.0	24.0	25.0	25.4	26.4	27.2	34.4	37.0	38.6	40.6	42.2
7.0	21.9	22.4	22.7	23.4	24.1	31.6	33.9	35.4	36.9	38.0
9.0	20.8	21.0	21.4	22.0	22.8	29.8	31.8	32.9	34.1	34.9
	3.0% Sunflower Oil-DMF					**3.0% Corn Oil-DMF**				
1.0	32.0	36.0	39.0	43.0	47.0	43.0	48.0	55.0	65.0	74.0
3.0	26.7	27.3	28.3	29.3	30.3	38.7	40.3	44.3	47.0	49.0
5.0	23.0	24.2	24.8	25.6	26.4	33.4	35.4	37.2	39.2	40.6
7.0	21.0	21.7	22.1	22.9	23.6	30.9	32.7	34.6	35.9	36.8
9.0	20.2	20.4	21.0	21.4	22.0	29.2	30.8	32.0	33.3	34.1
	4.0% Sunflower Oil-DMF					**4.0% Corn Oil-DMF**				
1.0	28.0	32.0	35.0	40.0	44.0	40.0	44.0	50.0	58.0	68.0
3.0	25.0	25.7	27.0	28.0	29.0	37.0	38.0	42.7	44.3	46.7
5.0	22.2	23.4	24.0	24.8	25.6	32.4	33.6	35.8	38.0	39.2
7.0	20.3	21.0	21.6	22.3	22.9	30.1	33.0	33.4	35.0	35.9
9.0	19.6	19.9	20.6	20.9	21.4	28.7	29.9	31.2	32.4	33.2
	5.0% Sunflower Oil-DMF					**5.0% Corn Oil-DMF**				
1.0	25.0	28.0	31.0	35.0	40.0	36.0	39.0	45.0	52.0	63.0
3.0	23.7	24.3	25.7	26.7	27.7	35.3	35.7	40.3	42.7	44.3
5.0	21.2	22.4	23.2	24.0	24.6	31.4	32.2	34.4	36.6	37.8
7.0	19.4	20.3	20.8	21.6	22.3	29.6	32.1	32.4	34.1	34.9
9.0	19.0	19.3	20.0	20.3	20.9	28.1	29.0	30.4	31.8	32.4
Note: The uncertainty in the tabulated values is ±0.14 to 0.51%.										

Table 4. Limiting molar conductivity of potassium iodide solution in sunflower oil-DMF and corn oil-DMF at different temperatures

Concentration of Solvent (%v/v)	Limiting Molar Conductivity (Λ_m^o) ($S.cm^2.mol^{-1}$)				
	303.15 K	308.15 K	313.15 K	318.15 K	323.15 K
	Sunflower Oil-DMF				
1.0	45.68 ± 0.6	49.38 ± 0.6	53.22 ± 0.6	59.16 ± 0.7	66.54 ± 0.8
2.0	43.61 ± 0.5	47.32 ± 0.6	50.88 ± 0.6	55.51 ± 0.7	60.36 ± 0.7
3.0	37.49 ± 0.5	42.33 ± 0.5	46.01 ± 0.6	50.86 ± 0.6	55.66 ± 0.7
4.0	32.40 ± 0.4	37.18 ± 0.5	40.94 ± 0.5	47.02 ± 0.6	51.85 ± 0.6
5.0	28.61 ± 0.3	32.19 ± 0.4	35.97 ± 0.4	40.88 ± 0.5	46.82 ± 0.6
	Corn Oil-DMF				
1.0	59.20 ± 0.7	68.77 ± 0.8	80.09 ± 1.0	94.36 ± 1.1	104.30 ± 1.3
2.0	54.36 ± 0.7	62.54 ± 0.8	72.80 ± 0.9	85.05 ± 1.0	96.06 ± 1.2
3.0	50.36 ± 0.6	55.96 ± 0.7	65.30 ± 0.8	77.53 ± 0.9	88.55 ± 1.1
4.0	46.35 ± 0.6	50.28 ± 0.6	59.16 ± 0.7	68.53 ± 0.8	80.91 ± 1.0
5.0	41.15 ± 0.5	43.77 ± 0.5	52.63 ± 0.6	61.08 ± 0.7	72.04 ± 0.9

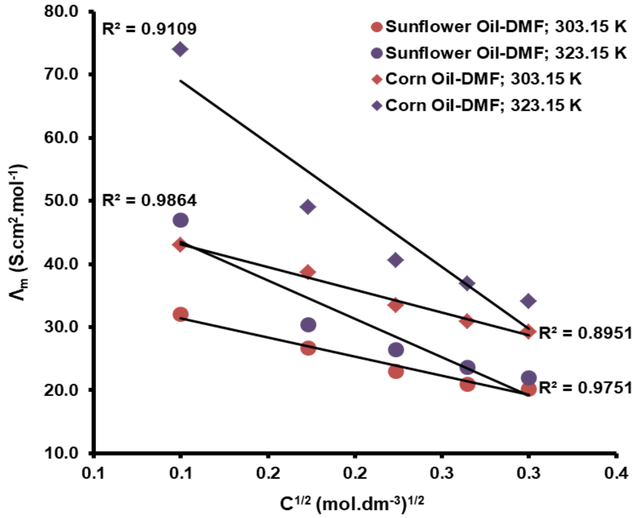

Figure 1. A plot of the Debye-Huckel-Onsager relation at different temperatures

The unit of Λ_m is $S.cm^2.mol^{-1}$, η has units of Pa-s, T has units of K, and C is expressed in $mol.dm^{-3}$. The values of viscosity of the solvent are presented in Table 5 while the ion-ion and ion-solvent interactions evaluated from the Debye-Huckel-Onsager equation are presented in Table 6. The value of A is positive under all experimental conditions indicating significant ion-ion interaction in potassium iodide solution. The ion-ion interaction in the corn oil-DMF is higher as compared to sunflower oil-DMF due to low viscosity which allows free movement of ions and ionic collisions. The variation of the ion-ion interaction due to temperature is rather irregular due to multiple contributing factors such as viscosity, degree of dissociation, and concentration of potassium iodide [38]. The ion-solvent interaction is a specific and additive property of the ions of a strong electrolyte at a given temperature and is strongly influenced by the nature of the solvent [39]. DMF is a dipolar aprotic solvent in which the cation (K^+) is strongly solvated while anion (I^-) is poorly solvated [40,41]. By viewing the two resonating forms of DMF, it is realized that the probability of interaction between the positively charged nitrogen atom and the I^- ions is considerably less due to the steric hindrance whereas the negatively charged oxygen atom is much more available to interact with the K^+ ions for their solvation. There is very less possibility of solvent-solvent interactions due to the very dilute nature of potassium iodide solution which may produce DMF-DMF dimers [41-43].

Table 5. The viscosity of the solvent at different temperatures

Concentration of Solvent (%v/v)	Viscosity x 10^4 (η_o) (Pa-s)				
	303.15 K	**308.15 K**	**313.15 K**	**318.15 K**	**323.15 K**
	Sunflower Oil-DMF				
1.0	13.03 ± 0.31	12.16 ± 0.29	11.41 ± 0.27	10.63 ± 0.26	9.83 ± 0.24
2.0	13.16 ± 0.32	12.26 ± 0.29	11.50 ± 0.28	10.70 ± 0.26	9.95 ± 0.24
3.0	13.32 ± 0.32	12.37 ± 0.30	11.60 ± 0.28	10.73 ± 0.26	10.04 ± 0.24
4.0	13.43 ± 0.32	12.46 ± 0.30	11.66 ± 0.28	10.88 ± 0.26	10.14 ± 0.24
5.0	13.49 ± 0.32	12.56 ± 0.30	11.80 ± 0.28	10.96 ± 0.26	10.36 ± 0.25
	Corn Oil-DMF				
1.0	7.17 ± 0.17	6.27 ± 0.15	5.75 ± 0.14	5.31 ± 0.13	4.84 ± 0.12
2.0	7.52 ± 0.18	6.87 ± 0.17	6.34 ± 0.15	5.71 ± 0.14	5.14 ± 0.12
3.0	7.85 ± 0.19	7.40 ± 0.18	6.76 ± 0.16	6.24 ± 0.15	5.75 ± 0.14
4.0	8.01 ± 0.19	7.64 ± 0.18	7.29 ± 0.18	6.78 ± 0.16	6.26 ± 0.15
5.0	8.37 ± 0.20	7.88 ± 0.19	7.39 ± 0.18	6.96 ± 0.17	6.59 ± 0.16

The value of B is positive and increased with the increase in temperature. The ion-solvent interaction in the sunflower oil-DMF is stronger as compared to corn oil-DMF due to the higher viscosity of sunflower oil. The ion-solvent interaction also varied with the concentration of oil in the solvent because it affects the viscosity and electrical conductivity of the potassium iodide solution. The ion-solvent interaction is a measure of the effective solvodynamic volume of solvated ions, the charge density and geometry of ions, and the induced structural effects due to the ionic interactions. The dissolved ions attract the solvent molecules per their charge density and disturb the natural three-dimensional structure of the bulk solvent by wrenching out the solvent molecules from the three-dimensional solvent structure. This ion-solvation process results in the formation of ion-molecule clusters of large solvodynamic radii and decreases the limiting molar conductivity of the electrolytes [44]. The limiting molar conductivity is a measure of the solute-solvent interactions [35]. As the temperature is increased, the limiting molar conductivity of the ions increases due to the increased kinetic energy of the ions and decrease in the viscosity of the solvent but at the same time, the formation of ion-molecule clusters produces a decreasing effect on the limiting molar conductivity of the ions. An increase in the limiting molar conductivity with the temperature indicates that the increment due to the increase in temperature has outweighed the decrement due to the formation of ion-molecule clusters. The ion-solvent interaction decreased with the increase in the concentration of oil in the solvent due to decreased ionic motion. A useful parameter to interpret the ion-solvent interactions is the Walden product; $\Lambda_m^o\eta_o$ [45]. The Walden product increased with the increase in temperature confirming that the effect of electrical conductivity has more dominant than the effect of the viscosity of the solvent (Table 7). The first derivative of B concerning temperature (dB/dT) is used as a criterion for the structure-making or the structure-breaking ability of the electrolyte in the vegetable oil-DMF solvent [46].

The increase of B with temperature shows that dB/dT is positive and potassium iodide behaves as a structure-breaker in the vegetable oil + DMF solvent. The same conclusion has been obtained by the viscometric analysis of the ionic interactions of KI in the vegetable oil-DMF solvent [47]. The viscometric studies have reported that the potassium iodide also behaves like a structure-breaker in dimethylacetamide-water mixtures, N-formylmorpholine-water, ethylene glycol, glycerol, and urea [48-51].

Table 6. The ion-ion and ion-solvent interactions of potassium iodide solution at different temperatures by the Debye-Huckel equation

Concentration of Solvent (%v/v)	**Temperature (K)**				
	303.15 K	**308.15 K**	**313.15 K**	**318.15 K**	**323.15 K**
	A ($S.cm^2.mol^{-1}$)				
	Sunflower Oil-DMF				
1.0	5.9952	6.3738	6.7366	7.1724	7.6988
2.0	5.9391	6.3233	6.6856	7.1315	7.6037
3.0	5.8678	6.2671	6.6268	7.1076	7.5408
4.0	5.8197	6.2218	6.5938	7.0128	7.4612
5.0	5.8612	6.1688	6.5145	6.9616	7.3021
	Corn Oil-DMF				
1.0	10.9028	12.3573	13.3782	14.3759	15.6508
2.0	10.3854	11.2831	12.1286	13.3610	14.7307
3.0	9.9591	10.4734	11.3715	12.2356	13.1718
4.0	9.7601	10.1510	10.5520	11.2435	12.0959
5.0	9.3333	9.8303	10.4063	10.9622	11.4933
	B ($S^{-1}.cm^{-2}.mol$)				
	Sunflower Oil-DMF				
1.0	1.7459	1.8730	1.9818	2.1177	2.2479
2.0	1.7309	1.8457	1.9518	2.0565	2.1427
3.0	1.4660	1.6761	1.7966	1.9364	2.0478
4.0	1.1861	1.4531	1.6011	1.8371	1.9701
5.0	0.9398	1.1721	1.3674	1.6007	1.8294
	Corn Oil-DMF				
1.0	1.5018	1.6647	1.8943	2.1046	2.2116
2.0	1.3642	1.5378	1.7714	1.9886	2.1438
3.0	1.2362	1.3713	1.6062	1.8746	2.0663
4.0	1.0812	1.2211	1.4566	1.6900	1.9650
5.0	0.8108	0.9185	1.2429	1.4898	1.7989

Table 7. The Walden product of potassium iodide solutions at different temperatures

Concentration of Solvent (%v/v)	**Walden Product x 10^2 ($S.cm^2.mol^{-1}.Pa\text{-}s$)**				
	303.15 K	**308.15 K**	**313.15 K**	**318.15 K**	**323.15 K**
	Sunflower Oil-DMF				
1.0	5.9535	6.0041	6.0732	6.2927	6.5406
2.0	5.7372	5.7991	5.8500	5.9370	6.0071
3.0	4.9922	5.2341	5.3374	5.4581	5.5855
4.0	4.3503	4.6308	4.7728	5.1140	5.2590
5.0	3.8605	4.0435	4.2447	4.4788	4.8526
	Corn Oil-DMF				
1.0	4.2426	4.3129	4.6026	4.9438	5.0429
2.0	4.0903	4.2957	4.6141	4.8557	4.9346
3.0	3.9506	4.1414	4.4143	4.8346	5.0871
4.0	3.7110	3.8390	4.3094	4.6488	5.0623
5.0	3.4444	3.4507	3.8874	4.2500	4.7436

5. Temperature dependence of limiting molar conductivity

The temperature dependence of limiting molar conductivity was evaluated by using the Arrhenius relation shown in equation 3.3 [35].

$$\Lambda_m^o = A\, e^{-Ea/RT} \qquad 3.3$$

Where A is the pre-exponential factor, Λ_m^o is the limiting molar conductivity in units of $S.cm^2.mol^{-1}$, T is the absolute temperature of the potassium iodide solution in kelvin, R is the universal gas constant having the value of 8.314 $J.K^{-1}.mol^{-1}$ and E_a is the activation energy in units of $J.mol^{-1}$. A plot of the Arrhenius equation is presented in Figure 2. The straight lines with correlation coefficients of 0.978 to 0.999 are indicative of a directly proportional relationship between the limiting molar conductivity of potassium iodide solution with temperature. The energy of activation was positive (15.169 to 19.925 kJ in 1.0% to 5.0% sunflower oil-DMF and 23.418 to 23.623 kJ in 1.0% to 5.0% corn oil-DMF). The energy of activation for the ionic conductance increased with the increase in the concentration of oil in the solvent which perfectly complements the simultaneous decrease in the limiting molar conductivity and its increase with the increase of the temperature.

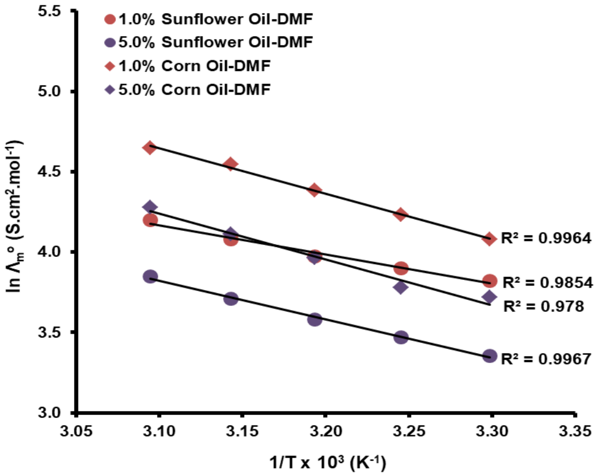

Figure 2. The dependence of limiting molar conductivity of potassium iodide solution on temperature

6. Interrelationship of viscosity and electrical conductivity

There is a significant interrelation between the viscosity and electrical conductivity of electrolyte solutions [30,50]. The interrelationship of viscosity and electrical conductivity was evaluated by the graphical analysis presented in Figure 3. The straight lines with a correlation coefficient of 0.96 indicate a directly proportional relationship between the viscosity and electrical conductivity of potassium iodide solution in the vegetable oil-DMF solvent at different temperatures.

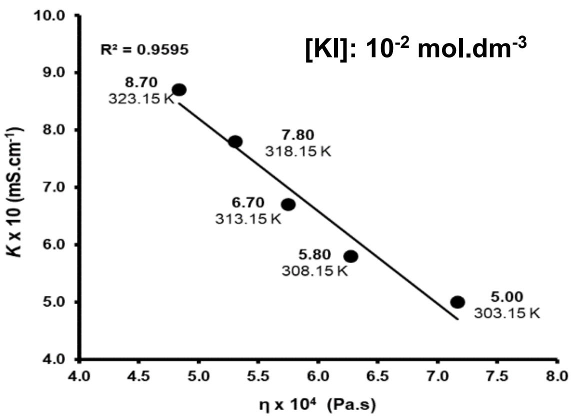

Figure 3. A plot of electrical conductivity vs viscosity of potassium iodide solution in 1.0% corn oil-DMF solvent

CONCLUSION

The potassium iodide solution exhibited higher electrical conductivity in corn oil-DMF as compared to sunflower oil-DMF due to lower viscosity. The electrical conductivity and molar conductivity increased with the increase in temperature while a decrement was observed with the increase in the concentration of oil in the solution. The electrical conductivity increased while molar conductivity decreased with the increase in the concentration of potassium iodide. The ion-ion and ion-solvent interaction coefficients indicated the presence of significant ion-ion and ion-solvent interactions in the potassium iodide solution. The value of B increased with the increase of temperature so that dB/dT is positive and potassium iodide behaves as a structure-breaker in the oil-DMF solvent. A directly proportional relationship exists between the viscosity and electrical conductivity of the potassium iodide solution.

EXPERIMENTAL SECTION

The potassium iodide (99.98% pure solid salt) of RDH, Germany, and dimethylformamide (99.99% pure solvent) of Lab-Scan, Thailand was used with any further processing. The sunflower oil and corn oil were extracted from dried, dehulled, and powdered oil seeds obtained from Empress Market, Karachi, and filtered before use to remove any suspended particles. The 1.0%, 2.0%, 3.0%, 4.0%, and 5.0% v/v sunflower oil-DMF and corn oil-DMF to be used as the solvent was prepared by mixing the required amount of oil and DMF. Potassium iodide solutions with concentrations ranging from 1.0×10^{-2} to $9.0 \times 10^{-2} \pm 1.06 \times 10^{-5}$ mol.dm^{-3} were prepared in different concentrations of the solvent. The volume measurements were done by calibrated glassware having a tolerance of ±0.1 cm^3 whereas a digital electronic weighing balance (BL-150S, Sartorius, Germany) having a least count of ±0.0001 g was used for mass determination. The electrical conductivity of potassium iodide solutions was measured by a digital conductivity meter (Jenway 4510) with a least count of 0.01 mS.cm^{-1}, uncertainty of ±0.001 mS.cm^{-1}, and cell constant of 0.99 cm^{-1}. The density of potassium iodide solutions was measured at different temperatures by an R.D. bottle of 10.0 cm^3 whereas the viscosity of the solutions was measured by recording their time of flow between the two specified marks of an Ostwald viscometer (Techniconominal constant 0.1 cSt/s capillary ASTM D 445) by using a calibrated stopwatch with the least count of 0.01 s (CBM Corporation, Japan). A thermostatic water bath (YCM-01, Taiwan) was used to maintain the desired temperature. The observations were recorded in triplicate.

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