



Density, Viscosity and Ultrasonic Velocity Studies of Aqueous Sodium-Propionate at Different Temperatures

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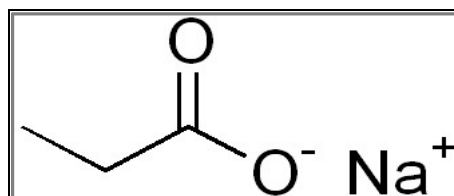
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ABSTRACT

Propionate is short chain fatty acid (SCFA) which improves physiological and pathophysiological properties. In the present investigation, the mixture of the sodium propionate and water is carried out as a function of volume concentration. The density(ρ), viscosity(η) and ultrasonic velocity (u) of aqueous solution of sodium propionate of binary liquid mixtures (0.01 to 1.0) mol.kg⁻¹ have been measured at different temperature range (298.15, 303.15, 308.15) K. The experimentally measured values have been used to calculate relaxation time(τ), acoustic impedance(Z), classical absorption(α/f^2)_{cb}, is entropic compressibility(K_s), apparent molal volume (ϕ_v) and apparent molal isentropic compressibility (ϕ_{ks}). The present study confirms that sodium propionate is water structure maker.

Graphical Abstract



Sodium propionate.

Keywords: Density, Viscosity, Ultrasonic velocity, Sodium propionate, Molecular interactions.

INTRODUCTION

Sodium propionate (salt form) is a short chain fatty acid (SCFA), naturally occurring carboxylic acid, which in its new state exists as a white deliquescent crystalline solid with an unpleasant odour [1, 2]. It is very helpful for improving the physiological and patho-physiological properties [3]. Propionate has the physical properties intermediate between those of the smaller carboxylic, formic acid, acetic acid and larger fatty acid. Solute solvent interaction is of great importance in biological chemistry, physical chemistry, environmental chemistry and geo chemistry. It is used over a wide area means extensively in industries to make pesticides and pharmaceuticals and also used as an intermediate in production of chemical [4]. Sodium propionate is an effective anti-microbial agent [5] and also used in biological applications as when it is infused directly in rodent's brains it produces the reversible

behaviour and also it acts as a metabolic toxic in liver cells [6]. From the literature survey it is revealed that there are no reports on density, viscosity and ultrasonic velocities studied at 298.15, 303.15 and 308.15K and its behaviour in aqueous medium.

MATERIALS AND METHODS

The AR grade sodium propionate having 99.5% purity, molecular weight 96.060 g mole⁻¹ was obtained from Sigma Aldrich and used in the present study. It is dried, crystalline, anhydrous substance. The density of the aqueous solution of the sodium propionate was measured by using the specific gravity bottle method known as pycnometer [7]. It was calibrated with double distilled water. The uncertainty in density measurement was $\pm 1 \times 10^{-4}$ g/cm³. The density of solution calculated using,

$$\rho_s = \frac{w_3 - w_1}{w_2 - w_1} \times \rho_w (\text{kgm}^{-3})$$

Where ρ_w = density of water, w_1 = weight of bottle, w_2 = weight of bottle with water, w_3 = weight of bottle with solution. The dynamic viscosities of aqueous solution were measured using by Ostwald's viscometers [8]. It was used to measure the viscosity of stock solution with known density. To measure the flow time of the aqueous solution of sodium propionate and water an electronic digital stop watch with an accuracy of +0.01 was used. Dynamic viscosity of solution was calculated using,

$$\eta_s = \left(\frac{\rho_s \times t_s}{\rho_w \times t_w} \right) \eta_w$$

Where t_s = Time of flow of solution in viscometer, t_w = Time of flow of water in viscometer. The digital ultrasonic interferometer (VCT-70A) [9] was used for ultrasonic velocity measurement. During all the measurements temperature was kept constant with digital temperature controller.

Mathematical Formulation

Acoustic Impedance (Z): The specific acoustic impedance represents a characteristic of the medium. It is closely linked to electrical impedance. It is determined by all the elastic properties of the material and is defined as,

$$Z = u\rho (\text{Kg.m}^{-2}.\text{s}^{-1})$$

Relaxation Time (τ): The relaxation time can be calculated from the relation,

$$\tau = \frac{4}{3\beta\eta} \text{ (s)}$$

Where, η is the viscosity of solution, β is the isentropic compressibility.

Apparent molal volume (ϕ_v): The apparent molal volume of a solute can be measured from the density and compressibility of solution as,

$$\phi_v = \left(\frac{M}{\rho_o} \right) + \left[\left(\frac{1000(\rho_o - \rho)}{m\rho\rho_o} \right) \right]$$

Where, M is the molar mass, ρ is density of solution, ρ_o is density of water, m is the molal concentration.

Isentropic compressibility (K_s): The isentropic compressibility is the fractional decrease of volume per unit increase of pressure, when no heat flows in or out. It is calculated from the speed of sound and density (ρ) of the medium by using the equation of Newton Laplace as,

$$k_s = \frac{1}{u^2 \rho}$$

Where, ρ is the density and 'u' is the ultrasonic velocity

Apparent molar isentropic compressibility (ϕ_{k_s}):

$$\phi_{k_s} = \left(\frac{1000}{m\rho_o} \right) ((k_s - k_{sol}) + k_s \phi_v)$$

Where, k_s = Isentropic compressibility of solution, k_{sol} = Isentropic compressibility of solvent.

Classical absorption ($(\alpha/f^2)_{cl}$): The classical absorption is always several times less than the actual measured absorption, since it only due to the viscosity of medium.

$$(\alpha/f^2)_{cl} = \frac{8\pi^2\eta}{3\rho U^3}$$

Where, f = frequency of the ultrasonic wave

RESULTS AND DISCUSSION

The experimentally obtained values of basic parameter of ultrasonic velocity (u), density(ρ) and viscosity(η) of aqueous sodium propionate solution of different concentration from 0.01 to 1.0 mol.kg⁻¹ at different temperature (298.15K,303.15K,308.15K) are given in [table 1](#). By using these basic parameter the various acoustic parameter such as Acoustic Impedance (Z), Isentropic compressibility (K_s), Relaxation Time (τ), Classical absorption ($(\alpha/f^2)_{cl}$), Apparent molar isentropic compressibility(ϕ_{k_s}), Apparent molar volume (ϕ_v) are calculated and are given in [table 2](#). [Figure 1](#) and [2](#) shows the variation of basic and derived parameters respectively.

The density variation of aqueous sodium propionate ([Figure 1a](#)) indicates no abnormal change. This result is as expected. Increase in density is due to increase of solute particles in solution and decrease in density is due to rise of volume of solution with increase temperature [[10-12](#)]. Also the decrease in density with increase in temperature might be due to decrease in intermolecular forces due to increase in thermal energy of the system [[13](#)]. The viscosity ([Figure 1b](#)) of aqueous sodium propionate was increases with concentration increases and decreases with the temperature increases. This is because the intermolecular attractive forces do not permit free flow of molecule in liquids. At lower temperature, viscosity is found greater because of intermolecular forces due to the increase in solute which cause attraction between the solvent and solute it shows the structure making capability of solute in the solution [[14](#)]. With increasing temperature there is weakening of cohesive forces that result in decrease in viscosity [[15, 16](#)]. The ultrasonic velocity in the present investigation increases with concentration and temperature increases. The closed-packed structure forms stiff material medium for the propagation of ultrasonic wave due to which ultrasonic velocity increases [[17, 18](#)]. This indicates that there is significant interaction between ion and solvent molecule suggesting a structure promoting behavior solute [[19](#)]. It is observed that isentropic compressibility (k_s) values are positive and become smaller at higher concentration of sodium propionate and with increase of temperature. The decrease in isentropic compressibility (k_s) may be attributed to weak ion-solvent interactions [[20-22](#)]. This effect can be attributed to the strong attractive interaction due to the hydration of ions and also incorporation of ionic species.

Table 1. Experimental data of density, viscosity and ultrasonic velocity of aqueous Sodium propionate at 298.15K, 303.15K, and 308.15K

T(K)	Molality (mol.kg ⁻¹)	Density (Kg.m ⁻³)	Viscosity (m ⁻¹ .kg.s ⁻¹)	Ultrasonic velocity (m.s ⁻¹)
298.15	0.01	998.116	9.266E-04	1492.348
	0.03	999.103	9.559E-04	1494.733
	0.05	1000.089	9.890E-04	1497.726
	0.07	1001.075	1.006E-03	1499.528
	0.09	1006.007	1.016E-03	1500.731
	0.1	1008.965	1.032E-03	1504.958
	0.2	1011.924	1.066E-03	1516.553
	0.3	1014.883	1.112E-03	1531.457
	0.4	1017.842	1.141E-03	1542.193
	0.5	1021.787	1.163E-03	1554.371
	0.6	1023.760	1.252E-03	1564.122
	0.7	1028.691	1.287E-03	1577.315
303.15	0.01	995.710	8.019E-04	1503.748
	0.03	996.697	8.072E-04	1506.171
	0.05	998.670	8.320E-04	1507.601
	0.07	999.657	8.472E-04	1508.937
	0.09	1001.631	8.543E-04	1509.819
	0.1	1006.565	8.774E-04	1513.485
	0.2	1009.526	8.955E-04	1524.590
	0.3	1013.473	9.478E-04	1533.713
	0.4	1016.433	9.710E-04	1544.741
	0.5	1020.381	1.034E-03	1551.148
	0.6	1022.354	1.059E-03	1553.080
	0.7	1026.302	1.077E-03	1577.315
308.15	0.01	994.999	7.216E-04	1511.113
	0.03	994.999	7.292E-04	1513.485
	0.05	996.977	7.366E-04	1514.097
	0.07	998.955	7.535E-04	1518.400
	0.09	1000.933	7.639E-04	1520.252
	0.1	1003.901	7.734E-04	1521.870
	0.2	1005.879	7.902E-04	1532.713
	0.3	1008.846	8.212E-04	1539.653
	0.4	1010.824	8.443E-04	1548.937
	0.5	1018.737	8.757E-04	1566.087
	0.6	1021.704	8.947E-04	1576.670
	0.7	1025.660	9.390E-04	1583.325
0.8	1028.627	9.836E-04	1592.765	
0.9	1031.594	1.002E-03	1595.483	
1.0	1034.562	1.064E-03	1610.598	

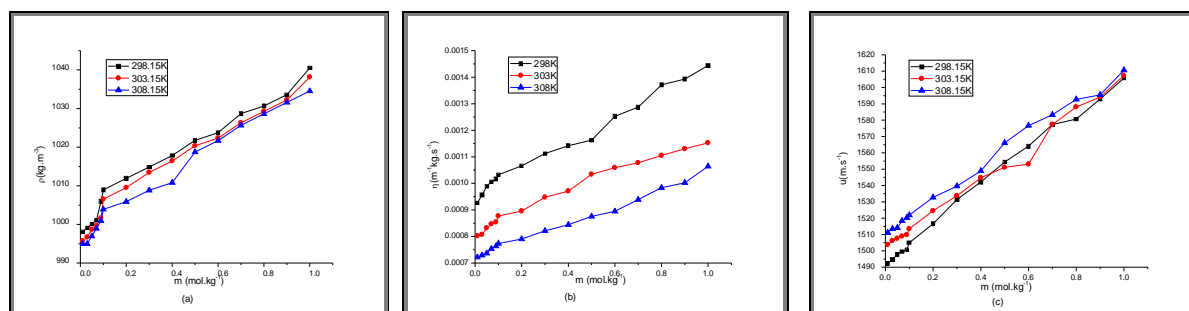
**Figure 1.** Variation of (a)Density, (b) Viscosity and (c)Ultrasonic velocity with Molality at 298.15K,303.15K,308.15K for aqueous sodium propionate solution.

Table 2. Evaluated thermodynamic parameters of sodium propionate at 298.15K, 303.15K and 308.15K

T(K)	Concentration (mol.kg ⁻¹)	Ks (Pa ⁻¹)	Z (kg.m-2.s ⁻¹)	τ (s)	(α/f ²)cl (m3.mol)	ϕ _v (m3mol ⁻¹)	ϕ _{ks} (m3mol ⁻¹ .Pa ⁻¹)
298.15	0.01	4.499E-10	1489536.836	5.346E-13	7.352E-15	-9.900E-02	-6.441E-09
	0.03	4.480E-10	1493391.570	5.492E-13	7.541E-15	-6.590E-02	-1.708E-09
	0.05	4.458E-10	1497859.062	5.654E-13	7.747E-15	-5.925E-02	-1.007E-09
	0.07	4.442E-10	1501140.178	5.731E-13	7.844E-15	-5.636E-02	-7.213E-10
	0.09	4.414E-10	1509745.183	5.752E-13	7.867E-15	-9.823E-02	-7.972E-10
	0.1	4.376E-10	1518450.507	5.794E-13	7.902E-15	-1.175E-01	-8.363E-10
	0.2	4.297E-10	1534636.702	5.874E-13	7.949E-15	-7.321E-02	-3.577E-10
	0.3	4.201E-10	1554249.761	5.993E-13	8.031E-15	-5.838E-02	-2.472E-10
	0.4	4.131E-10	1569708.652	6.049E-13	8.050E-15	-5.092E-02	-1.943E-10
	0.5	4.051E-10	1588236.116	6.043E-13	7.979E-15	-4.831E-02	-1.685E-10
	0.6	3.993E-10	1601284.889	6.414E-13	8.416E-15	-4.338E-02	-1.464E-10
	0.7	3.907E-10	1622569.728	6.451E-13	8.394E-15	-4.386E-02	-1.374E-10
303.15	0.01	4.441E-10	1497296.921	4.749E-13	6.234E-15	9.647E-05	-1.393E-10
	0.03	4.423E-10	1501195.859	4.760E-13	6.239E-15	-3.305E-02	-5.996E-10
	0.05	4.406E-10	1505596.623	4.888E-13	6.400E-15	-5.945E-02	-6.266E-10
	0.07	4.393E-10	1508419.909	4.963E-13	6.493E-15	-5.656E-02	-4.457E-10
	0.09	4.380E-10	1512281.471	4.989E-13	6.523E-15	-6.587E-02	-4.067E-10
	0.1	4.337E-10	1523421.202	5.074E-13	6.618E-15	-1.082E-01	-5.904E-10
	0.2	4.262E-10	1539112.634	5.089E-13	6.589E-15	-6.862E-02	-2.443E-10
	0.3	4.195E-10	1554376.583	5.301E-13	6.823E-15	-5.858E-02	-1.696E-10
	0.4	4.123E-10	1570126.346	5.338E-13	6.821E-15	-5.109E-02	-1.364E-10
	0.5	4.073E-10	1582761.503	5.616E-13	7.147E-15	-4.847E-02	-1.165E-10
	0.6	4.055E-10	1587798.126	5.727E-13	7.279E-15	-4.353E-02	-9.658E-11
	0.7	3.916E-10	1618801.042	5.626E-13	7.041E-15	-4.267E-02	-1.013E-10
308.15	0.01	4.401E-10	1503556.022	4.235E-13	5.532E-15	-9.991E-02	-4.580E-09
	0.03	4.388E-10	1505916.159	4.266E-13	5.564E-15	-3.324E-02	-5.872E-10
	0.05	4.375E-10	1509520.179	4.297E-13	5.603E-15	-5.979E-02	-6.099E-10
	0.07	4.342E-10	1516813.763	4.363E-13	5.672E-15	-7.105E-02	-5.510E-10
	0.09	4.323E-10	1521671.083	4.403E-13	5.717E-15	-7.722E-02	-4.783E-10
	0.1	4.301E-10	1527806.277	4.435E-13	5.753E-15	-9.902E-02	-5.451E-10
	0.2	4.232E-10	1541723.477	4.459E-13	5.743E-15	-5.926E-02	-2.192E-10
	0.3	4.181E-10	1553272.724	4.579E-13	5.871E-15	-4.922E-02	-1.479E-10
	0.4	4.123E-10	1565702.848	4.642E-13	5.916E-15	-4.174E-02	-1.171E-10
	0.5	4.002E-10	1595430.172	4.673E-13	5.890E-15	-4.874E-02	-1.227E-10
	0.6	3.937E-10	1610889.748	4.697E-13	5.881E-15	-4.535E-02	-1.103E-10
	0.7	3.889E-10	1623953.230	4.869E-13	6.071E-15	-4.425E-02	-1.006E-10
0.8	3.832E-10	1638361.504	5.026E-13	6.229E-15	-4.222E-02	-9.388E-11	
0.9	3.808E-10	1645891.420	5.090E-13	6.298E-15	-4.063E-02	-8.534E-11	
1	3.726E-10	1666262.927	5.278E-13	6.480E-15	-3.934E-02	-8.422E-11	

It is seen that at each working temperature as concentration of sodium propionate is increased, isentropic compressibility (k_s) of solution decreases due to the combined effect of hydration of ions and breaking [23]. Figure 2(b), Shows the variation in acoustic impedance with concentration and temperature. The behavior of acoustic impedance becomes accountable for the transmission of ultrasonic waves [24-26]. The linear variation of acoustic impedance with concentration confirms the presence of molecular association between the solute-solvent molecules. The increasing trends of acoustic impedance suggest increase in molecular packing in the medium and further support the possibility of molecular interaction due to hydrogen bonding between sodium propionate and water molecules [27-29]. The relaxation time (τ) increases with increase in concentration and decrease in temperature of solution. The variation of relaxation time is a cumulative effect of the density, viscosity and ultrasonic velocity [30, 31]. Viscous relaxation time is increasing monotonically as expected [32]. The relaxation time (τ) values are almost independent of molality where the coupling

force resulting from ion-solvent interactions governs the relaxation time τ values. The relaxation time (τ) values increase exponentially with molality where ion pairing occurs extensively [33]. From figure 2(d), it is observed that the classical absorption factor (α/f^2) decreases with increase in temperature and increases with increase in concentration. This is due to aggregation of solvent molecules of ions suggesting weak solute-solvent interaction [34]. The decrease in the value defines the dissociation of molecules and association for increasing nature [35]. The variation in classical absorption in each curve with concentration strongly supports the presence of strong ion-dipole intermolecular interactions between the constituent molecules of this binary liquid system [36].

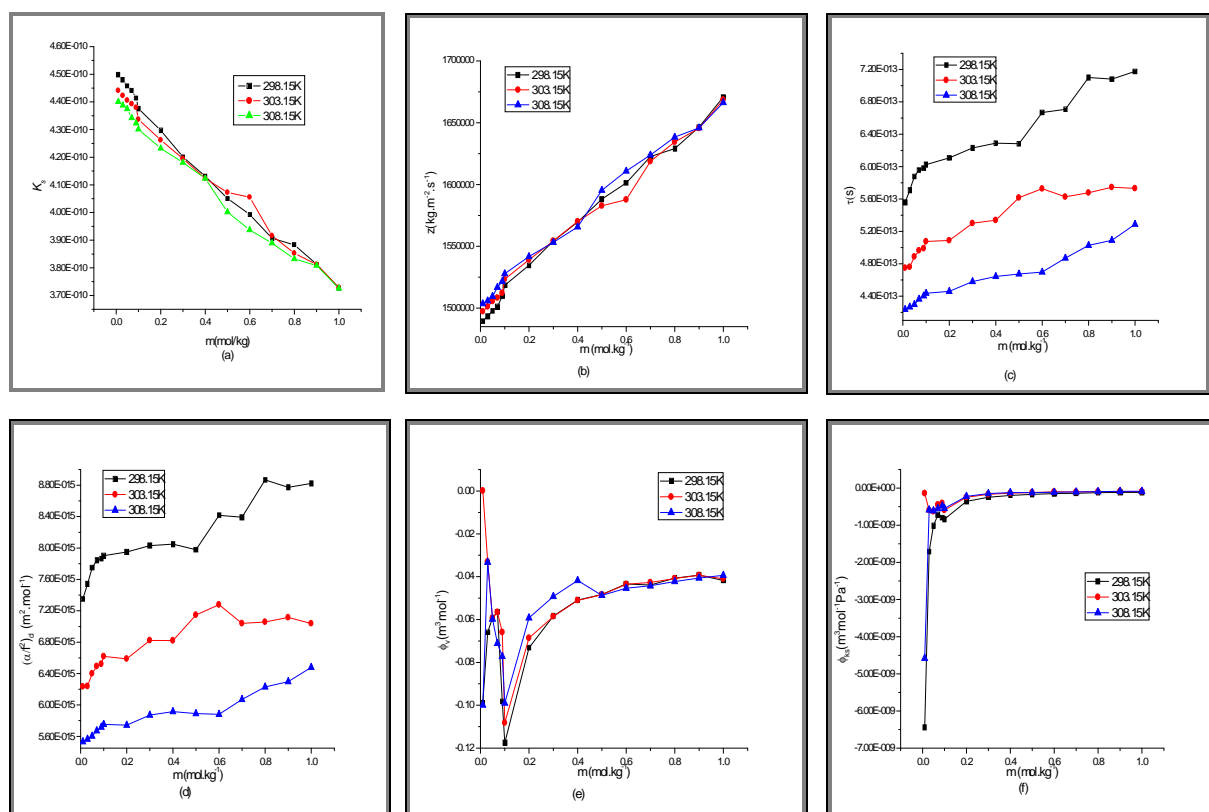


Figure 2. Variations of Isentropic compressibility(a), Acoustic Impedance (b), Relaxation time(c), Classical absorption(d), Apparent molal volume(e) and Apparent molal isentropic compressibility(f) with Molality at 298.15K,303.15K,308.15K for aqueous sodium propionate solution.

Figure 2(e), shows the variation in apparent molal volume. It increases with increasing temperature and concentration. The presence of ion-solvent interaction between the molecules promotes the structure making effect of solutes in water [37]. This suggests weak interactions between ion-solvent and ion-ion systems [38]. The ion solvent interaction would also be more and consequently will be large [39, 40]. In dilute solutions apparent molal volume ϕ_v values of the solution investigated decreases at all temperatures with increase of the square root of the molar concentration.

From figure 2(f), it is observed that the apparent molar compressibility values are negative at all temperatures and concentration. This shows the weak electrostatic attractive force in the vicinity of ions causing electrostatic solvation of ions [41, 42]. The negative values of compressibility are due to the solute – solvent interaction [43]. Such an increase in compressibility values with increase in concentration may be attributed to an overall increase in the cohesive forces in the solutions [44, 45].

APPLICATION

The study of solute-solvent interaction in the present investigation is of great importance in biological chemistry, physical chemistry, environmental chemistry and geo chemistry. It is used over a wide area means extensively in industries to make pesticides and pharmaceuticals and also used as an intermediate in production of chemicals.

CONCLUSION

The concentration, nature of solute and solvent plays an important role in determining the interaction occurs in solution. The linear variation of experimentally measured parameters with molality shows the presence of enhanced solute-solvent interactions and strong intermolecular forces through the hydrogen bonding. The variation in apparent molal volume and apparent molal compressibility also strongly supports the facts indicated by other basic and derived parameters.

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