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Soil Salinity Management with the Help of Ultrasonic Characterization

Paritosh L Mishra[1]*, Ajay B Lad[2], Urvashi P Manik[3]

[1]Department of Physics, Sardar Patel Mahavidyalaya, Maharashtra, India
[2]Department of Physics, Amolakchand Mahavidyalaya, Maharashtra, India
[3]Department of Physics, Sardar Patel Mahavidyalaya, Maharashtra, India

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***For correspondence:**
Paritosh L Mishra, Department of Physics, Sardar Patel Mahavidyalaya, Maharashtra, India.

E-mail: paritoshlmishra@gmail.com

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ABSTRACT

The present manuscript reports the ultrasonic characterization of fertilizer at varying concentration in different solvents at a fixed temperature. Sound speed or ultrasonic velocity (U) and density (ρ) measurement were carried out by 2 MHz frequency digital ultrasonic interferometer. With the help of observed experimental values of sound speed and density a number of acoustical and physical parameters have been estimated using the standard relations. The acoustical and physical studies clarify the nature of interaction between binary as well as ternary solutions. The variation in these parameters plays a significant role in understanding the solute-solute and solute-solvent interactions between the constituent molecules. This kind of approach lead to better understand of interactions exists in between the fertilizers and different solvents. Therefore the proposed study is worthwhile, interesting from number of aspects, and has applications in pure and applied research in the field of agriculture in view to increase fertility of soil or to counteract the problem of soil salinity.

INTRODUCTION

Use of fertilizers and manures is a key factor to sustain fertility of the soil. Fertilizers being a costly input, the scientific approach towards the profitable agriculture would imply the supplemental use of plant nutrients according to the actual need of the situation [1]. Numerous factors are involved in plant response to fertilizers under saline, sodic, or waterlogged conditions so a suitable fertilizer should be used for this purpose. Efficiencies of fertilizers applied to salt–affected soils are lower than when applied to non-saline soils. A decrease in the ability of the plants to absorb K or NH_4 usually takes place in saline soils containing excess Na, Mg, or Ca [2]. Also, P absorption may be decreased in presence of excess Cl or SO_4. Application of K, NH_4 or P fertilizers not only corrects their deficiencies but also decreases the adverse effects of Na, Cl, or SO_4 on the plants.

As ultrasonic speed along with density provides wealth of information regarding nature and strength of molecular interactions [3]. Utilizing density and ultrasonic speed data numerous acoustical parameters such as acoustic impedance, intermolecular free length, adiabatic compressibility, change in adiabatic compressibility, internal pressure, Pseudo-Grunseien Parameter and relative association are computed which delivers evidence about kind of interactions prevailing in the liquid mixtures.

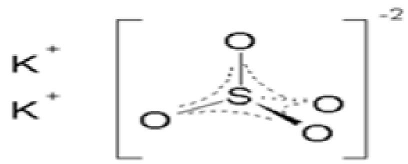
In view of the above fact, an attempt was made to fulfill the mentioned conditions and to carry out such studies on fertilizer: Potassium Sulfate of different concentration change by weight fraction *viz.* 0.02-0.2 $mol.kg^{-1}$ in different solvents like water and aqueous 0.5 $mol.kg^{-1}$ salt solutions namely: Sodium Chloride and Magnesium Chloride at a constant temperature 293.15 K with the help of Ultrasonic (NDT) technique [4]. Such data are expected to throw light on the intermolecular interaction (solute-solute, solute-solvent and ion-solvent) present between molecules of fertilizer-water-saline salts in view to find a way to increase the crop production by counteracting the problem of soil salinity.

MATERIALS AND METHODS

Materials

AR grade chemicals (mass fraction purity 99.9%) as Potassium Sulfate (CAS no: 7778-80-5), Sodium Chloride (CAS no.: 7647-14-5) and Magnesium Chloride (CAS no: 7786-30-3), were supplied from Himedia Lab. Pvt. Ltd., Mumbai. Entire chemicals were used without any further purification. The concentrations (0.02-0.2 $mol.kg^{-1}$) of Ammonium Sulfate in water and in 0.5 M aqueous saline salt solutions were changed by weight fraction. To maintain the accuracy of experimental data all the glassware's were washed with acetone as well as with double distilled water and well dried before use (Figure 1).

Figure 1. Molecular structure of potassium sulfate.



Method

A digital ultrasonic velocity interferometer was used for measuring the speed of sound passing through experimental liquids, operating at frequency 2 MHz supplied from Vi Microsystems Pvt. Ltd., Chennai (Model VCT:71) with an overall accuracy 0.0001 m/s. The source of ultrasonic waves was a quartz crystal excited by a radio frequency oscillator. The cell was filled with the desired experimental solutions and water at constant temperature was circulated in the outer jacket of the cell. The cell was allowed to equilibrate for 30min. prior to making the measurements. The densities of the solutions were determined accurately and properly with the help of 10ml specific gravity density bottle having accuracy of ± $2*10^{-2}$ kg/m^3 and digital electronic balance (Contech CA-34) having accuracy ± 0.0001 gm for the measurement of weight. An average of triple measurements were taken into account for better accuracy. The experimental temperature was maintained constant by circulating water with the help of an automatic thermostatic water bath supplied by Lab-Hosp. Company Mumbai having an accuracy of ± 1 K temperature.

Table 1. Density and ultrasonic velocity of water at 293.15 K temperature.

Current work data		Literature data	
U. Vel. (U)	Density (ρ)	U. Vel. (U)	Density (ρ)
m/sec	kg/m^3	m/sec	kg/m^3
1481.496	998.2	1482.940	0998.202

Defining relations

For the derivation of several acoustical and physico-chemical parameters the following standard defining relations reported in the literature are used:

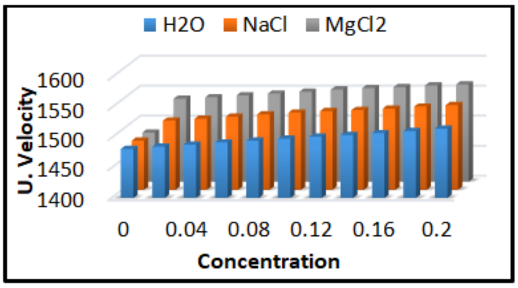
- Adiabatic Compressibility (β)=$1/(U^2\rho)$
- Change in Adiabatic Compressibility ($\Delta\beta$)={β-β_0}
  Here, β is the adiabatic compressibility of solute and β_0 is the adiabatic compressibility of solution.
- Intermolecular Free Length (L_f) = $K(\beta)^{1/2}$
  Where, K be the Jacobson temperature dependent constant.
- Acoustic Impedance (Z)=U_ρ
- Pseudo-Grunseien Parameter (Γ) = {(γ-1)/(αT)}
  Here, γ be the specific heat ratio and α is the thermal expansion coefficient.
- Internal Pressure (πi) = {(Tα)/kT}
  Here, T, α and k_T are the abbreviations used for temperature, isobaric thermal expansion coefficient and isothermal compressibility.
- Relative Association (R_A) = {(ρ/ρ_0) $(U_0/U)^{1/3}$}
  Here, ρ and ρ_0 is the density of the solute and solution at any temperature. Also, U and U_0 be the ultrasonic velocity of the solute and solution at any temperature.

RESULTS AND DISCUSSION

Ultrasonic velocity

The measured value of ultrasonic velocity for pure water 293.15 K temperature and the observed data tabulated. Comparison of observed data with literature data reported for water indicated that our results are in assent with the literature data. The ultrasonic velocity (U) of fertilizer of varying concentrations (0.02-0.2 mol.kg^{-1}) in 0.5 M solution of both the saline salts solvents: NaCl and $MgCl_2$ measured at 293.15 K temperature. The ultrasonic velocity versus concentration graph and it is observed that the value of ultrasonic velocity increases with increase in concentration of fertilizer. As concentration of liquid affects the propagation of ultrasonic wave through solution. The increase in sound speed is accredited due to the strong interaction between the fertilizer (Potassium Sulfate)-water and fertilizer (Potassium Sulfate)–aqueous saline salt solutions (Figure 2).

Figure 2. Ultrasonic velocity versus concentration at 293.15 K temperature.



Density

The measured density of pure water and the literature data of density at 293.15 K temperature have been tabulated. After Comparison of observed data with literature data reported for water indicated that our results are shows well agreement with the literature data [5]. The density of all the systems increases with rise in concentration. This indicates, there was improve in compactness of solvent by the addition of solute molecules. This indicates a good association between solute and solvent molecules [6]. The increase in density results increase in the molar volume and ultrasonic velocity, indicating the association in the components of the constituent molecules and confirms the structural rearrangement in the liquid solutions.

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Adiabatic compressibility

Physico-chemical properties of liquid can be understood by the adiabatic compressibility (β) parameter. In the present study it was found that the adiabatic compressibility values falls with increase in concentration of Potassium sulfate fertilizer [7]. The decreases values of adiabatic compressibility listed and indicate the strong association of fertilize and saline salts molecules. The compressibility of the solvent is higher than that of solution and decreases with increase in concentration of the solution [8]. Because, as water is polar solvent and when salts and fertilizer mixed, the well intermolecular interaction occurred, resulting in close packing of molecules (Table 2 and Figures 3, 4).

Table 2. The values of ultrasonic velocity, density, adiabatic compressibility, as a function of concentration of system.

Conc. (M) (mol/kg)	Ultrasonic velocity			Density			A compressibility 10^{-10}		
	(m/sec)			(Kg/m^3)			(m^{2}N^{-1})		
	H_2O	NaCl	$MgCl_2$	H_2O	NaCl	$MgCl_2$	H_2O	NaCl	$MgCl_2$
0	1481.49	1481.49	1481.49	998.2	998.2	998.2	4.56	4.56	4.56
0.02	1485.41	1515.04	1537.76	1004.92	1021.13	1044.31	4.51	4.27	4.05
0.04	1488.79	1517.91	1540.17	1007.38	1023.7	1046.91	4.48	4.24	4.03
0.06	1492.18	1521.37	1543.20	1010.05	1026.67	1049.41	4.45	4.21	4
0.08	1495.02	1525.43	1546.24	1012.71	1029.64	1053.12	4.42	4.17	3.97
0.1	1498.45	1528.34	1549.29	1015.22	1032.22	1054.85	4.39	4.15	3.95
0.12	1501.88	1530.67	1552.97	1017.67	1035	1057.62	4.36	4.12	3.92
0.14	1504.76	1532.43	1555.43	1020.31	1037.12	1060.88	4.33	4.11	3.9
0.16	1507.65	1534.78	1557.28	1022.47	1040.52	1062.24	4.3	4.08	3.88
0.18	1511.13	1538.32	1559.76	1025.40	1043.5	1065.61	4.27	4.05	3.86
0.2	1515.21	1540.69	1561.62	1028.01	1046.08	1068.27	4.24	4.03	3.84

Figure 3. Density versus concentration at 293.15 K temperature.

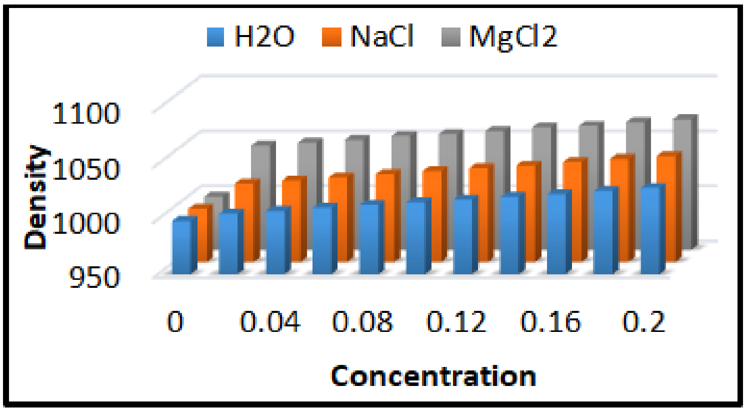
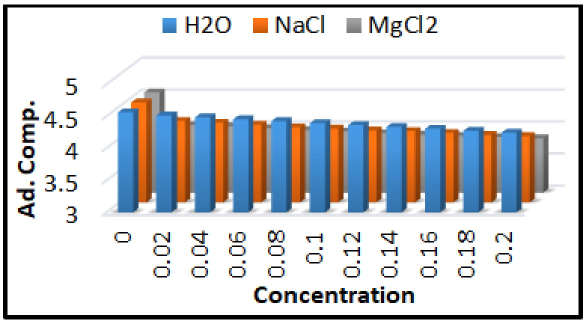


Figure 4. Adiabatic compressibility versus concentration at 293.15 K temperature.



Change in adiabatic compressibility

The change in adiabatic compressibility's was calculated with the help of adiabatic compressibility values for solute and solvent. It is found that the negative values of 'Δβ' are due to the solute-solvent interaction [9]. Such an increase in 'Δβ' with increase in concentration of solute (Potassium Sulfate) in water as well as in both the salt solutions may be attributed to an increase in the cohesive forces in solutions [10]. The negatively increase in change in adiabatic compressibility values with rise in concentration confirms the increase of bulk modulus [11]. This increase in bulk modulus indicates that the hydrogen bonding between the unlike components in the solution increases.

Intermolecular free length

Intermolecular free length is one of the important parameter that helps in determining the mobility and understanding the nature as well as strength of interaction between the solute and solvent [12]. The average distance between the surfaces of two head-to-head molecules, this is termed as the intermolecular free length. Variation of free length is set down [13]. It is observed that the values of intermolecular free length decreases with increase in concentration of Potassium Sulfate fertilizer in all the three solvents (Table 3 and Figure 5, 6).

Table 3. The values of change in adiabatic compressibility, intermolecular free length and acoustic impedance as a function of concentration of system (Potassium Sulfate+0.5 M aq. Solution of (NaCl/ $MgCl_2$)) at temperature.

Conc. (M) (mol/kg)	Change in adiabatic compressibility 10^{-11} (m^2N^{-1})			Intermolecular free length 10^{-11} (m)			Acoustic impedance (kgm^2s^{-1})		
	H_2O	NaCl	$MgCl_2$	H_2O	NaCl	$MgCl_2$	H_2O	NaCl	$MgCl_2$
0	0	0	0	4.35	4.35	4.35	1478829	1478829	1478829
0.02	-0.5	-3	-5.1	4.33	4.21	4.1	1492729	1547059	1605904
0.04	-0.9	-3.2	-5.4	4.31	4.2	4.09	1499782	1553891	1612428
0.06	-1.2	-3.6	-5.6	4.3	4.18	4.08	1507184	1561950	1619458
0.08	-1.5	-3.9	-5.9	4.28	4.16	4.06	1514033	1570648	1628380
0.1	-1.8	-4.2	-6.1	4.27	4.15	4.05	1521256	1577585	1634275
0.12	-2.1	-4.4	-6.4	4.25	4.14	4.04	1528426	1584253	1642455
0.14	-2.4	-4.6	-6.7	4.24	4.13	4.02	1535327	1589320	1650130
0.16	-2.6	-4.8	-6.8	4.23	4.12	4.02	1541541	1596945	1654211
0.18	-2.9	-5.1	-7.1	4.21	4.1	4	1549517	1605241	1662097
0.2	-3.3	-5.4	-7.3	4.2	4.09	3.99	1557658	1611686	1668228

This indicates that there exists a significant interaction between the fertilizer and water also fertilizer and saline salt solution [14]. Among all the three solutions (H_2O, NaCl and $MgCl_2$) intermolecular free length values are found low in magnesium chloride solution, specifying strong intermolecular interaction of fertilizer with $MgCl_2$. This gives a passage for water to uptake by the plants. The observed order of variation of intermolecular free length in all the three solvents is: $MgCl_2<NaCl<H_2O$.

Figure 5. Change in adiabatic compressibility versus concentration at 293.15 K temperature.

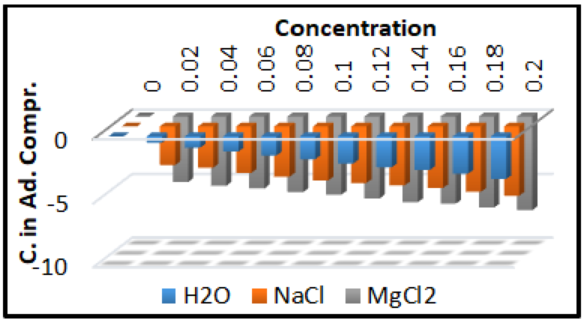
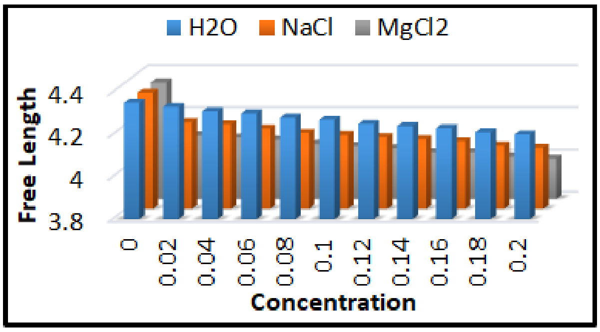


Figure 6. Intermolecular free length versus concentration at 293.15 K temperature.



Acoustic impedance

The values of acoustic impedance for fertilizer: Potassium Sulfate of varying concentrations *viz*. 0.02-0.2 mol.kg^{-1} in water and in 0.5 M mol.kg^{-1} aqueous salt solutions of NaCl and $MgCl_2$ were calculated with the help of speed of sound and density of experimental solutions and lay [15]. It was observed that the acoustic impedance (Z) values of Potassium Sulfate fertilizer increases with addition of fertilizer in water and also in both the saline salt solutions. The increase in acoustic impedance with the increase in concentration indicates the superior association among the solute and solvent through hydrogen bonding [16]. Thus increase in acoustic impedance indicates associative nature of solute and solvent and enhancement in molecular interaction with less resistance and more viscous force. The order of variation of acoustic impedance (Z) in water as well as in salt solution is: $MgCl_2>NaCl>H_2O$.

Psuedo-Gruensien parameter

The Pseudo-Grunseien parameter (r) measures the degree of molecular or ionic association. The calculated values of Pseudo-Grunseien parameter have been listed and a graph is plotted against the fertilizer concentration at a constant 293.15 K temperature shown. It was observed that the values of Pseudo-Grunseien parameter are negative and shows a decreasing trend of variation with the addition of fertilizer in the solvent [17]. The negative values of Pseudo-Grunseien parameter suggests the probable formation of intermolecular complex in the system and strong intermolecular interaction between the solute and solvent (Table 4 and Figures 7, 8).

Table 4. The values Pseudo-Grunseien parameter, internal pressure and relative association of system.

Conc. (M) (mol/kg)	Pseudo-Grunseien parameter			Internal pressure 10^9			Relative association		
	-			(Nm^{-2})			$(Nm^{-2})^{1/2}$		
	H_2O	NaCl	$MgCl_2$	H_2O	NaCl	$MgCl_2$	H_2O	NaCl	$MgCl_2$
0	-3.12742	-3.1274	-3.1274	5.06	5.06	5.06	1	1	1
0.02	-3.13388	-3.1714	-3.2034	5.14	5.44	5.76	1.00584	1.01536	1.03327
0.04	-3.13837	-3.1754	-3.2068	5.17	5.48	5.8	1.00754	1.01727	1.03500
0.06	-3.14295	-3.1801	-3.2109	5.21	5.52	5.84	1.00944	1.01945	1.0371
0.08	-3.1469	-3.1854	-3.2153	5.25	5.57	5.89	1.01146	1.02149	1.04008
0.1	-3.15145	-3.1894	-3.2191	5.29	5.61	5.92	1.0132	1.02340	1.04110
0.12	-3.15599	-3.1928	-3.2240	5.33	5.64	5.97	1.01487	1.02564	1.04301
0.14	-3.15997	-3.1954	-3.2276	5.37	5.67	6.01	1.01685	1.02734	1.04567
0.16	-3.16381	-3.1990	-3.2300	5.4	5.71	6.04	1.01836	1.03017	1.04660
0.18	-3.16853	-3.2037	-3.2337	5.45	5.76	6.08	1.02048	1.03234	1.04936
0.2	-3.17381	-3.2071	-3.2366	5.49	5.8	6.11	1.02216	1.03436	1.05156

Figure 7. Acoustic impedance versus concentration at 293.15 K temperature.

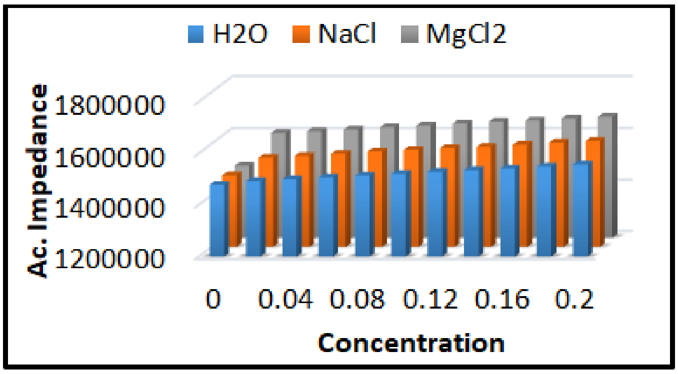
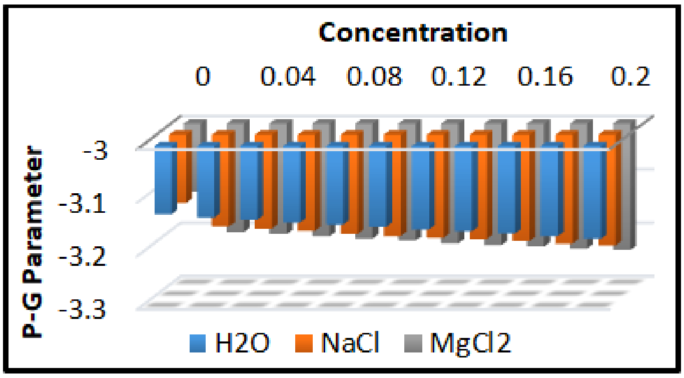


Figure 8. Psuedo-Gruensien parameter versus concentration at 293.15 K temperature.



Internal pressure

Acoustical parameters have potential to illuminate the ilk and strength of the interaction taking place in solutions [18]. In the present work the internal pressure (πi) increases with increase in concentration of fertilizer: Potassium Sulfate in all the three solvents is shown. This increasing behavior of the internal pressure in all the three solutions indicates the more intermolecular interactions between the fertilizer and soil salt solutions as compared to fertilizer and water [19]. The order of variation found to be: $MgCl_2$>NaCl>H_2O.

Relative association

The trends of relative association of the system. The increase of 'RA' with concentrations is due to increase in solvation of ions of solute and there exist intermolecular interactions (Figures 9 and 10).

Figure 9. Internal pressure versus concentration at 293.15 K temperature.

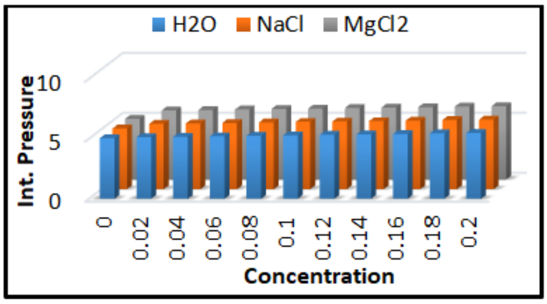
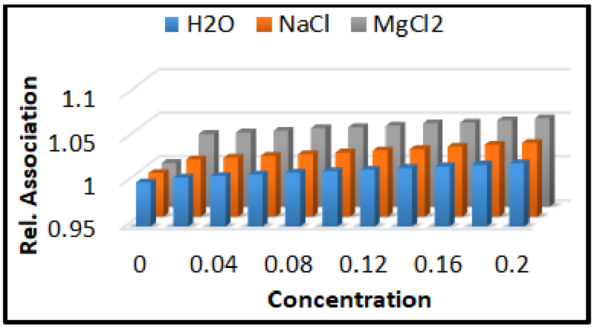


Figure 10. Relative association versus concentration at 293.15 K temperature.



CONCLUSION

The various acoustical and physico-chemical parameters determined by using the measured values of density and speed of sound for PS fertilizer in all the solvents (H_2O, NaCl and $MgCl_2$) at 293.15 K temperature. All parameters confirm that the intermolecular interactions are present between the molecules of Potassium Sulfate fertilizer and solvents. The impact of concentration on these parameters were observed and explained with the help of physico-chemical study. In the light of obtained results and discussions, it was concluded that: the variation in concentration, nature of solute, nature of solvent and its position plays a major role in determining the kind of interactions occurring in the solution. Also it is concluded that H-bonding is strong at higher concentration. Moreover, all the parameters exhibits the maximum values for Potassium Sulfate fertilizer mixed in $MgCl_2$ solution, coz it has weak interaction with water molecules among the electrolyte solution and ergo can bind with saline salt molecules more effectively. The overall intermolecular interaction order of variation for Potassium Sulfate fertilizer in different solvents are found to be: $MgCl_2$>NaCl>H_2O.

FUTURE SCOPE

This kind of information can be useful in improving fertilizer activity according to soil salinity treatment and in other application by changing the ilk of its molecule. Physico-chemical studies could also be used successfully and well supported in this regard. In view of the above interpretation, this kind of study has a bright future scope in the field of agriculture in order to feed the peoples and increase the economy of farmers with the help of proper fertilizer selection for specific kind of soil.

CONFLICTS OF INTEREST

The authors declare no conflict of interest in the present research work.

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