

CHAPTER - VI

ULTRASONIC VELOCITY STUDIES IN SOME CARBOXYLIC ACIDS IN TETRAHYDROFURAN

6.1 INTRODUCTION

Earlier ultrasonic velocity studies carried out by Anbananthan et al. [1] in the solutions of o-hydroxy benzoic acid and p-hydroxy benzoic acid in dioxane indicated the possibility of hydrogen bonding in these solutions. These studies were carried out in the solute concentrations ranging from 0.06 mole fraction to 0.2 mole fraction at room temperature using optical diffraction method. Their results showed that, in the solutions of o-hydroxy benzoic acid in dioxane, the compressibility attained a minimum value at the solute concentration of 0.0952 mole fraction. Ultrasonic velocity at a frequency of 2 MHz and other calculated parameters of these systems at low concentrations and at several temperatures were studied by Sosamma et al [2]. In the solutions of o-hydroxy benzoic acid (OHBA) in dioxane (DN), the velocity initially increases with increase in solute concentration, attains a maximum value at 0.05 mole fraction (cm_1) and then decreases on further increase of solute concentration. This was followed by another maximum at a solute concentration of 0.08 mole fraction (cm_2). Similar behaviour was observed for p-hydroxy benzoic acid (PHBA) in dioxane (DN), with the exception that the velocity

maximum occurred at different solute concentrations. The first velocity maximum occurred at 0.03 mole fraction and the second maximum (cm_2) occurred at 0.08 mole fraction of solute concentration.

These studies were further confirmed by the High resolution H^1 NMR and proton magnetic relaxation (PMR) studies of Arulmozhi et al [3]. The high resolution proton studies carried out in the solutions of o-hydroxy benzoic acid in dioxane shows that the spectra corresponding to -OH and -COOH protons could be distinguished. Whereas the solutions of p-hydroxy benzoic acid in dioxane show only peak in the range of chemical shifts attributable to -OH and -COOH of protons. In the solution of o-hydroxy benzoic acid in dioxane, the chemical shift of the proton of the hydroxylic groups increases with increase of solute concentration and attains a maximum at a solute concentration of 0.04 mole fraction and then decreases with further increase of solute concentration. For the carboxyl group, the chemical shift increases with increase of solute concentration and attains a maximum at 0.08 mole fraction. In the case of p-hydroxy benzoic acid in dioxane, the chemical shift of the single line observed increases with increase of solute concentration and attains a maximum at a solute concentration of 0.05 mole fraction.

The complex formation between dioxane and certain solutes such as benzoic acid, succinic acid and oxalic acid dihydrate has been reported by Nambinarayanan [4]. These results have been further supported by the internal pressure

studies undertaken by the same authors in the solutions of benzoic acid and oxalic acid dihydrate in dioxane. The variation of internal pressure with concentration of benzoic acid and oxalic acid dihydrate in dioxane shows a maximum at the solute concentration where maximum hydrogen bonds are formed between the monomers carboxylic acids and the dioxane molecules.

The ultrasonic absorption studies were carried out by Srinivasa Manja [5] in the solutions of benzoic acid, succinic acid and oxalic acid dihydrate in dioxane in the concentration range 0.01 - 0.1 mole fraction. This study reveals that, the ultrasonic absorption increases with increasing solute concentration and reaches a maximum at 0.075 mole fraction of benzoic acid and oxalic acid dihydrate and then decreases with further increase in concentration. A similar behaviour was observed for succinic acid in dioxane except that the absorption maximum occurs at a different mole fraction i.e. at 0.045. In all these cases, the experimental absorption was found to be three to four times the classical absorption. This excess absorption has been explained on the basis of Hall's two state model. The two states assumed were the dimeric state of carboxylic acid and the hydrogen bonded state of monomeric carboxylic acids with dioxane molecules. An acoustic wave propagating through this solution will produce a change in the number of molecules in both the states by the breaking of intermolecular hydrogen bonds. This structural change lags behind the acoustical pressure which

is the cause for the excess absorption observed in these carboxylic acids in dioxane.

The solvents such as dimethylsulphoxide (DMSO), acetonitrile (AN), dioxane (DN) and tetrahydrofuran (THF) are called aprotic solvents, because these solvents have no proton donor groups. But these solvents are in fact not truly aprotic. Their protic character can be recognised in the reactions where strong bases are employed. Therefore, for these solvents, the term aprotic is more appropriately replaced by non-hydroxylic solvents or better still by non-hydrogen bonded donor (non-HBD) solvents [6].

According to Gutmann and Wychera [7], the donor number (D.N) and the acceptor number (A.N) of any aprotic solvent describe its ability to form specific bonds. Also for any solvent which has a greater value of acceptor number (A.N) or donor number (D.N), the specific interactions between the ion and the surrounding solvent becomes more important. The donor number, the dielectric constant and the dipole moment of the aprotic solvents such as dimethylsulphoxide, acetonitrile, dioxane and tetrahydrofuran are given in table 6.1. Also the earlier NMR studies [8,9] shows that, the non-hydroxylic solvents can be regarded as structure forming or structure breaking with respect to water depending on their capability to enhance or disrupt the network of hydrogen bonds linking the water molecules. Further, these studies also establish that, the dioxane (DN) is a stronger structure breaker compared to tetrahydrofuran (THF). Also, from the table 6.1

it can be seen that the donor number, dielectric constant and the dipole moment of tetrahydrofuran are larger compared to dioxane.

The present study has been undertaken to confirm these facts and to understand the nature of molecular interactions in the solutions of some carboxylic acids in tetrahydrofuran. The present work deals with the ultrasonic velocity studies in the solutions of benzoic acid, o-hydroxy benzoic acid, p-hydroxy benzoic acid, maleic acid, succinic acid and oxalic acid dihydrate in tetrahydrofuran at 2 MHz frequency and at three different temperatures viz., 303K, 313K and 323K respectively. These velocity studies have been compared with the earlier ultrasonic velocity studies in the solutions of same carboxylic acids in dioxane. The carboxylic acids studied in the present work are conveniently divided into two groups. Group-I consists of benzoic acid, o-hydroxy benzoic acid and p-hydroxy benzoic acid. Group-II deals about maleic acid, succinic acid and oxalic acid dihydrate.

6.2 RESULTS AND DISCUSSION

Ultrasonic velocity studies were carried out in this laboratory in the solutions of benzoic acid, o-hydroxy benzoic acid, p-hydroxy benzoic acid, maleic acid, succinic acid and oxalic acid dihydrate in tetrahydrofuran. The velocity was measured using a multi frequency variable path continuous wave ultrasonic interferometer at an RF frequency of 2 MHz and at three different temperatures

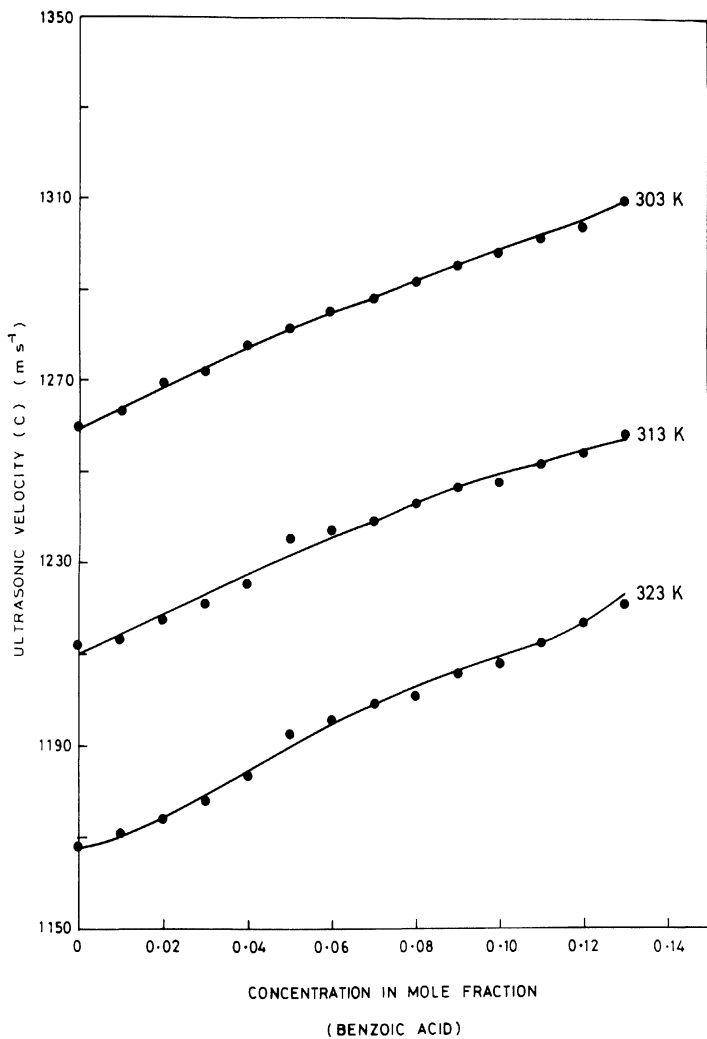
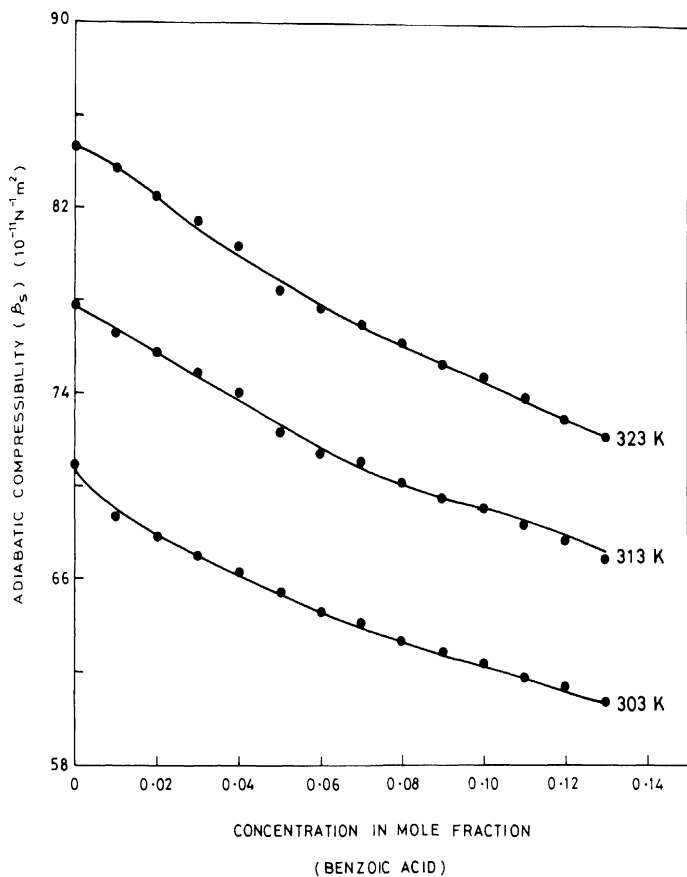


FIG-6-1. ULTRASONIC VELOCITY VS CONCENTRATION OF BENZOIC ACID
IN TETRAHYDROFURAN



**FIG-6.2. ADIABATIC COMPRESSIBILITY VS CONCENTRATION BENZOIC ACID
IN TETRAHYDROFURAN**

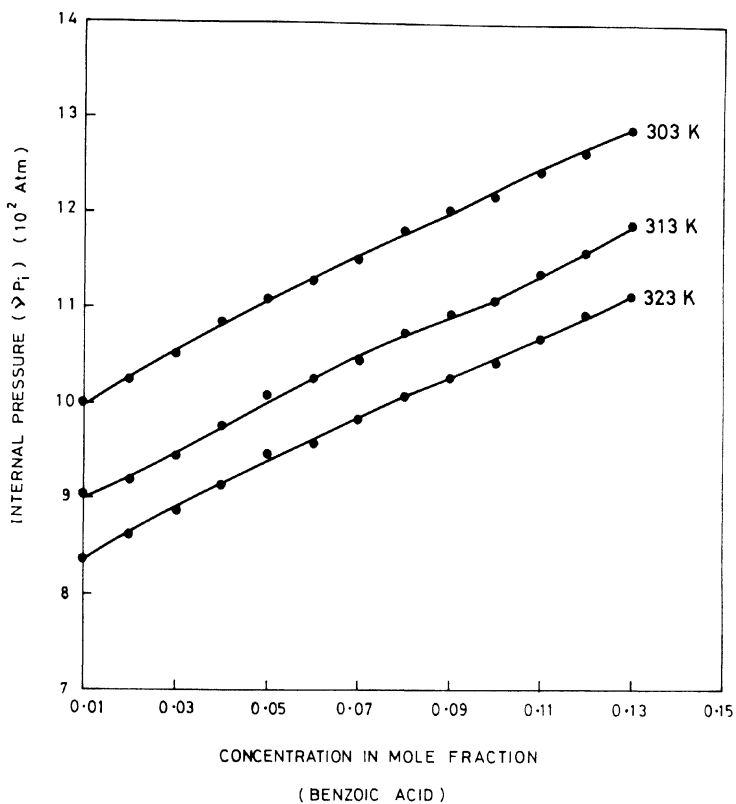


FIG. 6.3. INTERNAL PRESSURE VS CONCENTRATION OF BENZOIC ACID IN TETRAHYDROFURAN

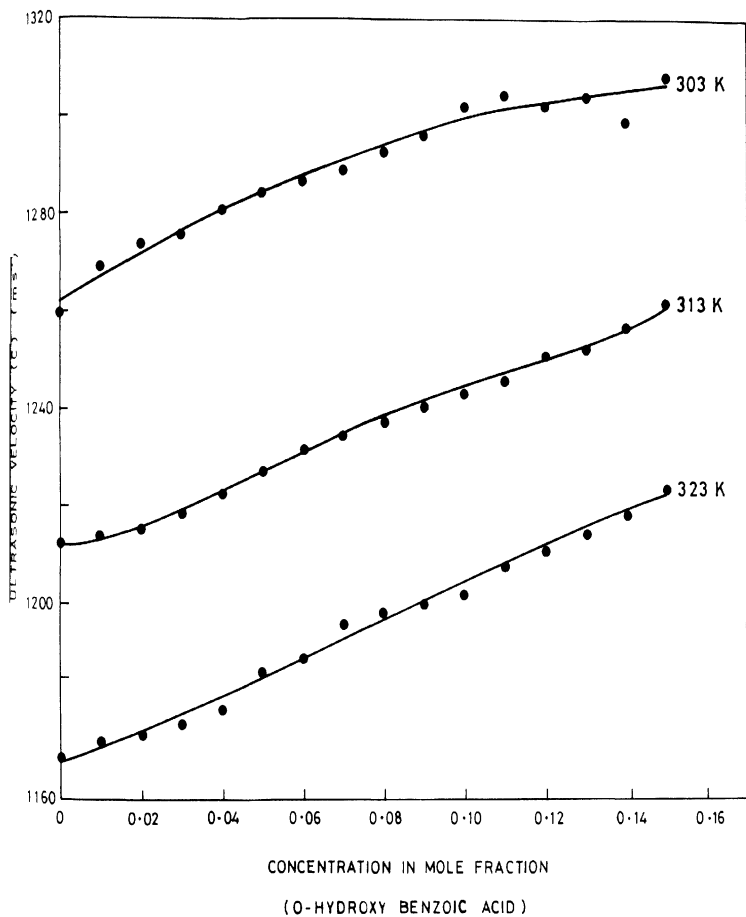


FIG-6-4. ULTRASONIC VELOCITY VS CONCENTRATION OF O-HYDROXY BENZOIC ACID IN TETRAHYDROFURAN

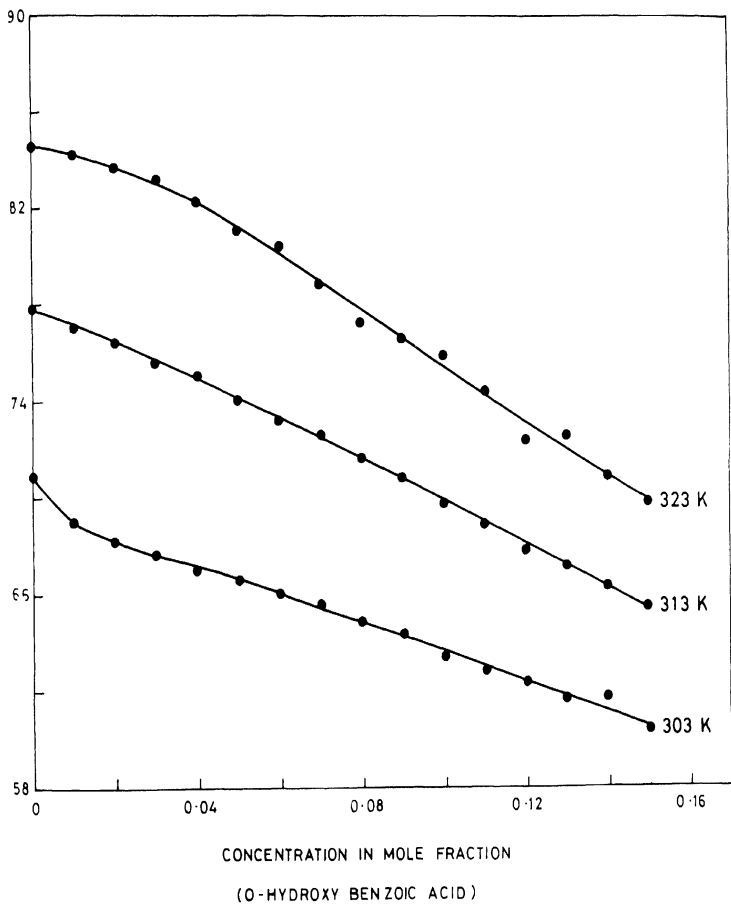


FIG. 6.5. ADIABATIC COMPRESSIBILITY VS CONCENTRATION OF O-HYDROXY BENZOIC ACID IN TETRAHYDROFURAN

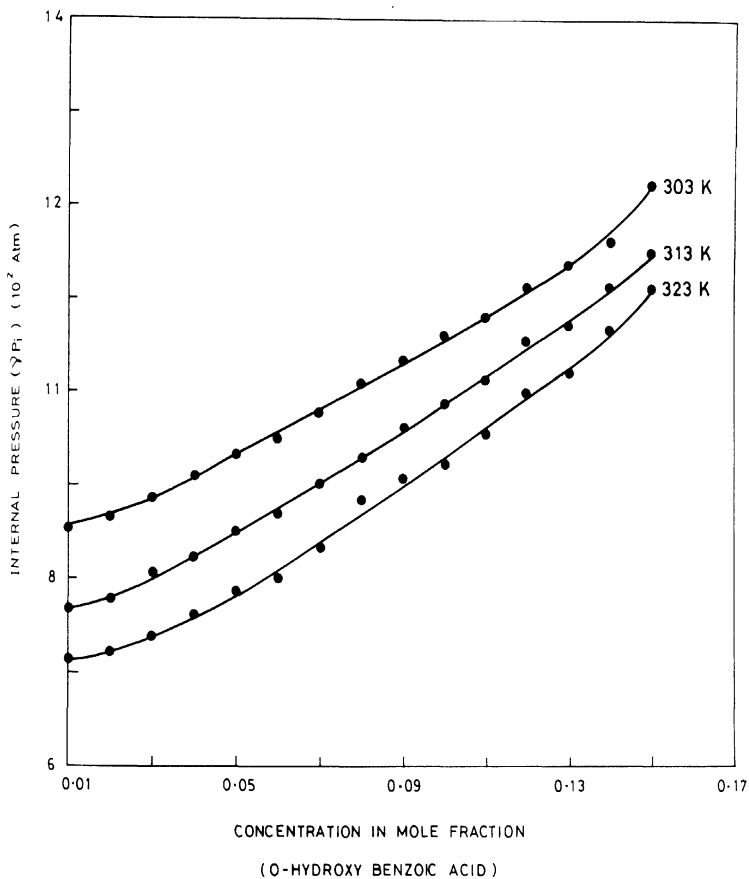


FIG. 6.6. INTERNAL PRESSURE VS CONCENTRATION OF O-HYDROXY BENZOIC ACID IN TETRAHYDROFURAN

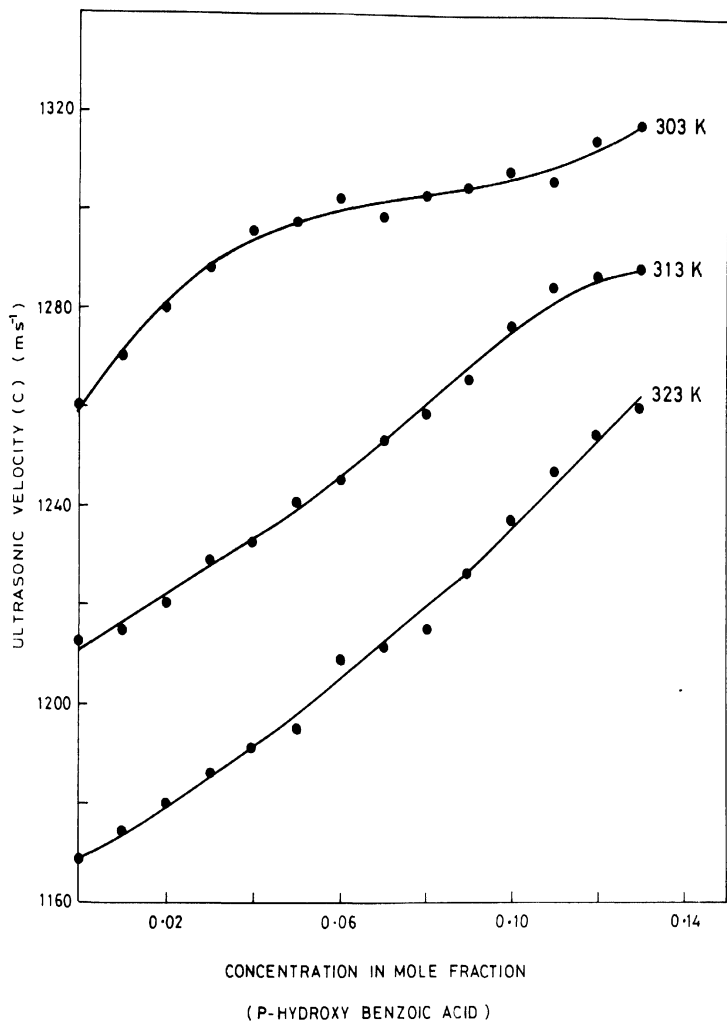


FIG-6-7. ULTRASONIC VELOCITY VS CONCENTRATION OF P-HYDROXY BENZOIC ACID IN TETRAHYDROFURAN

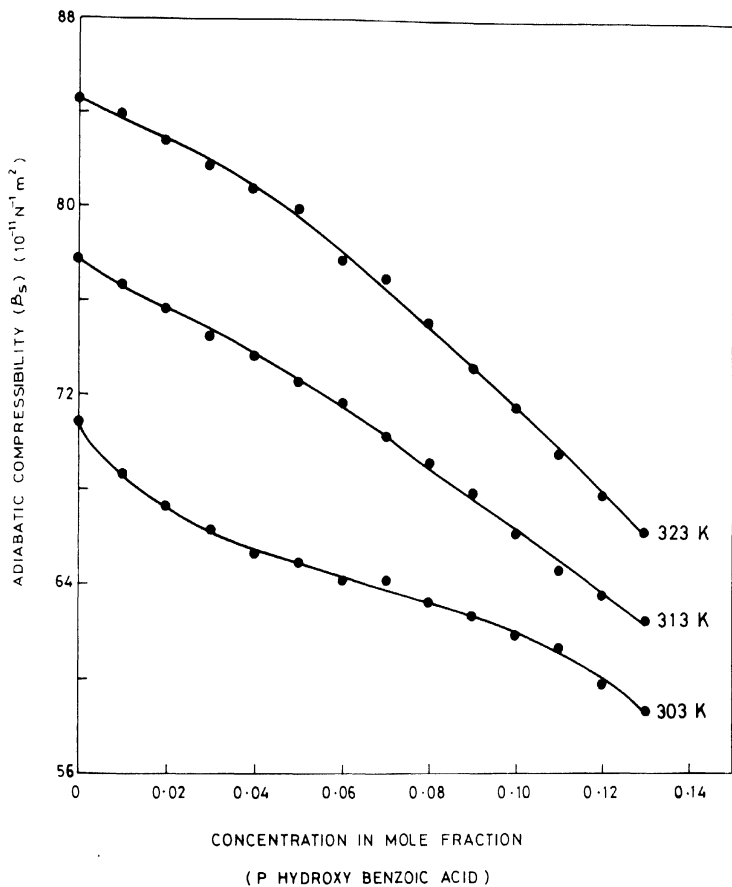


FIG. 6.8. ADIABATIC COMPRESSIBILITY VS CONCENTRATION OF P-HYDROXY BENZOIC ACID IN TETRAHYDROFURAN

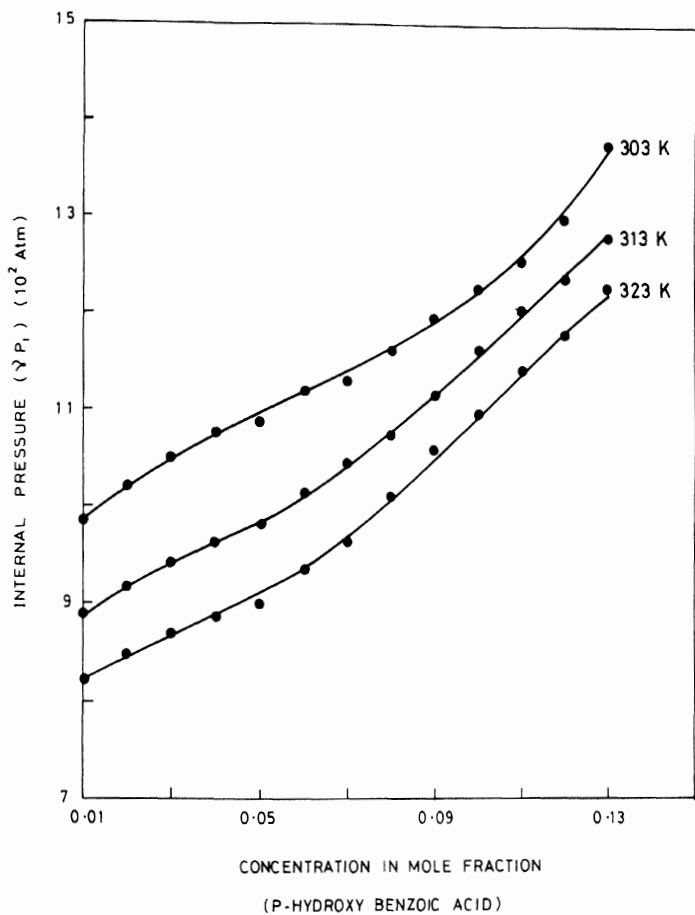


FIG. 6.9. INTERNAL PRESSURE VS CONCENTRATION OF P-HYDROXY
BENZOIC ACID IN TETRAHYDROFURAN

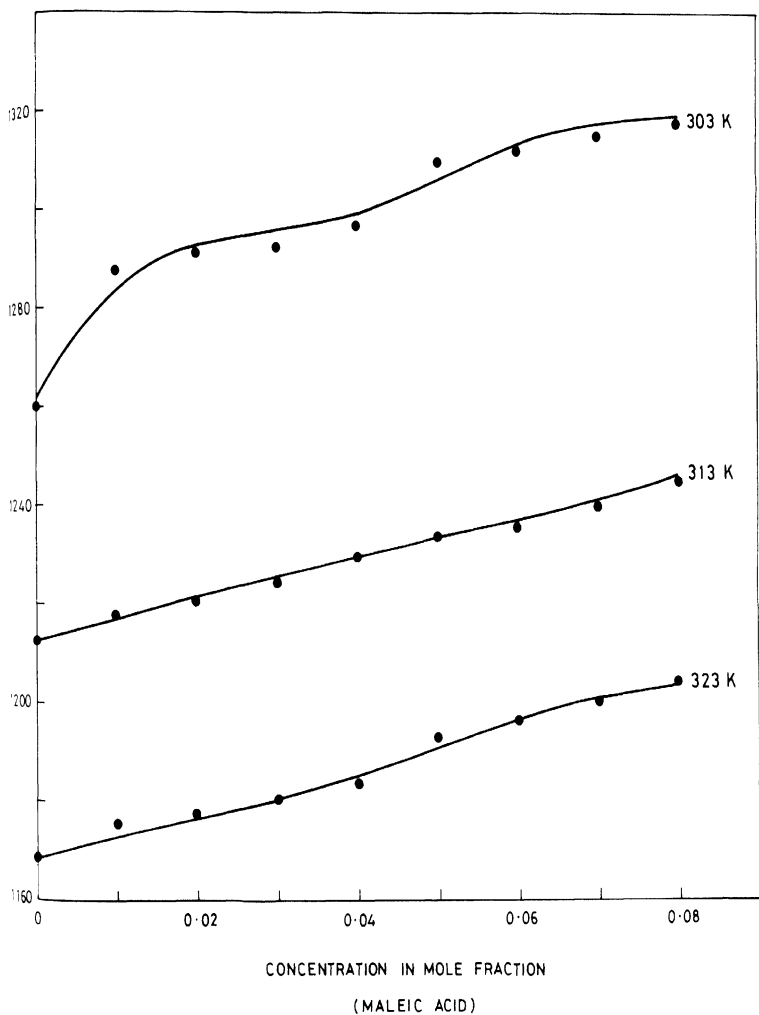
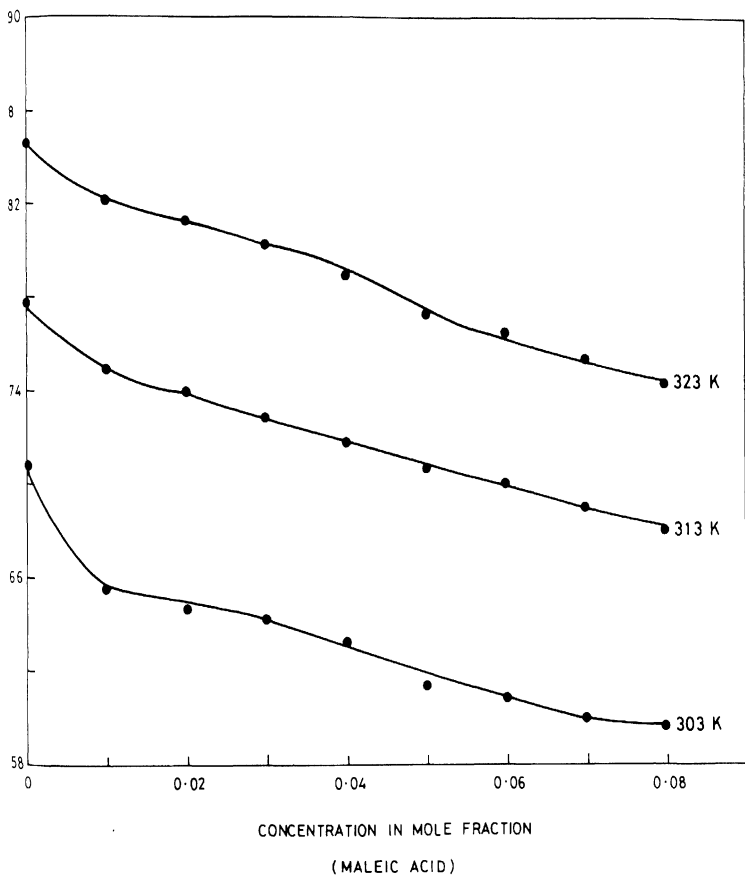
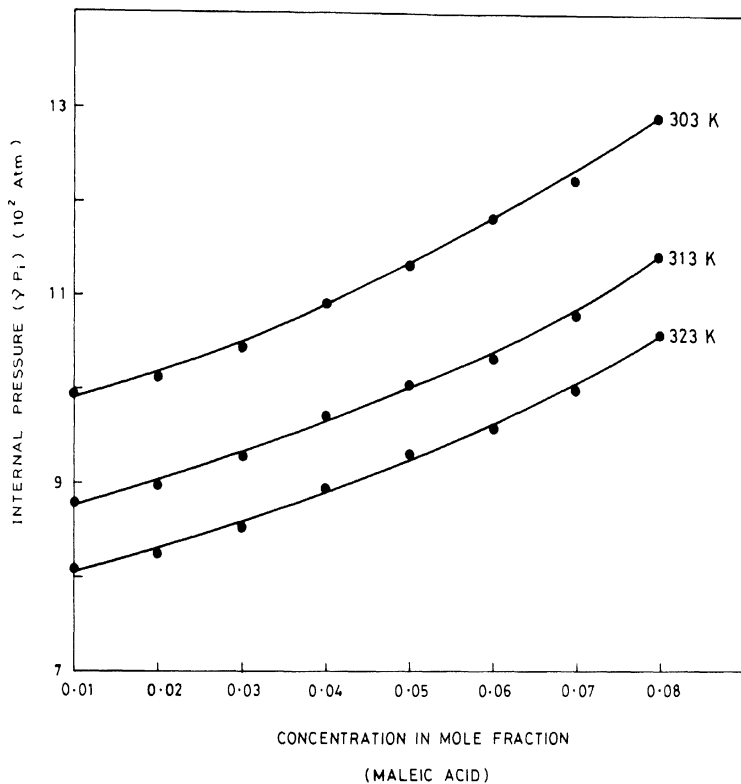


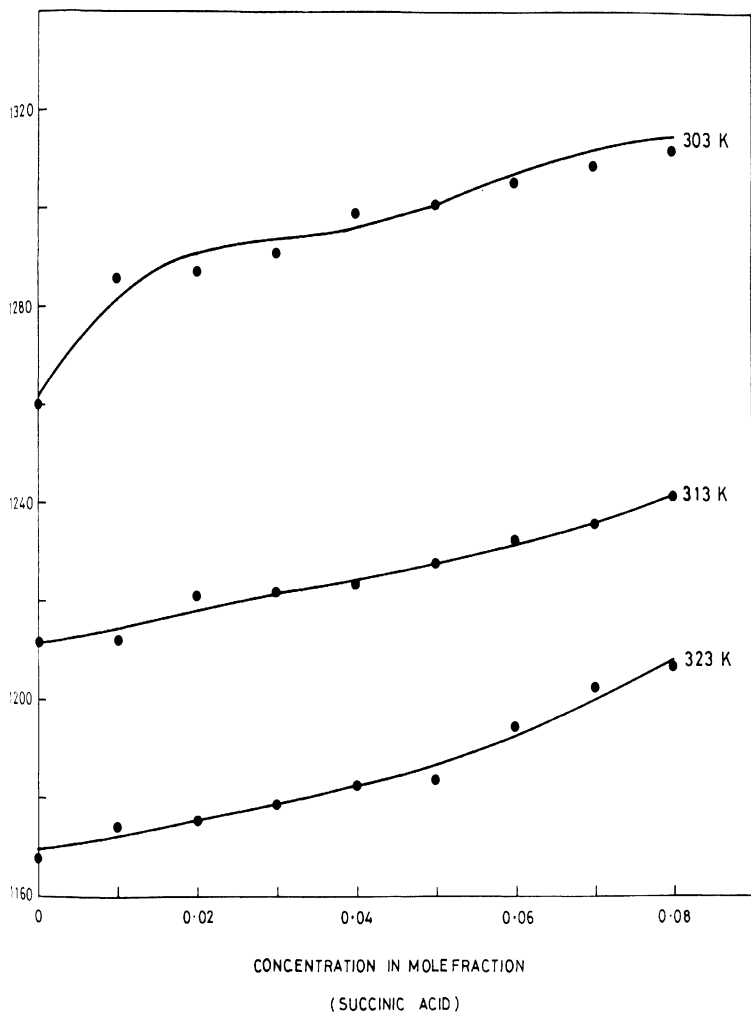
FIG-6-10. ULTRASONIC VELOCITY VS CONCENTRATION OF MALEIC ACID IN TETRAHYDROFURAN



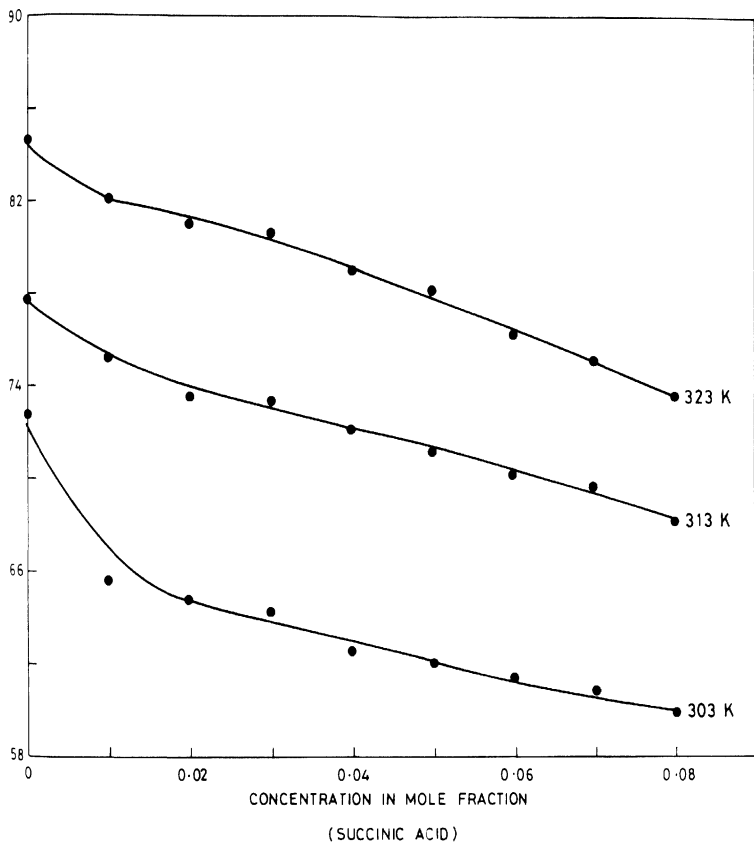
**FIG-6-11. ADIABATIC COMPRESSIBILITY VS CONCENTRATION OF MALEIC ACID
IN TETRAHYDROFURAN**



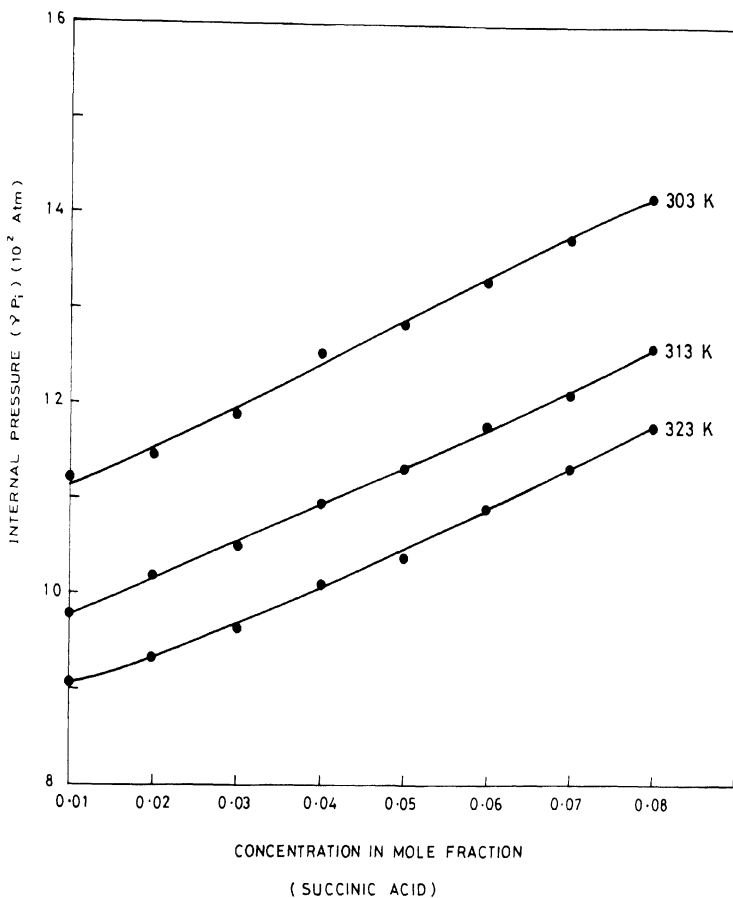
**FIG-6-12. INTERNAL PRESSURE VS CONCENTRATION OF MALEIC ACID
IN TETRAHYDROFURAN**



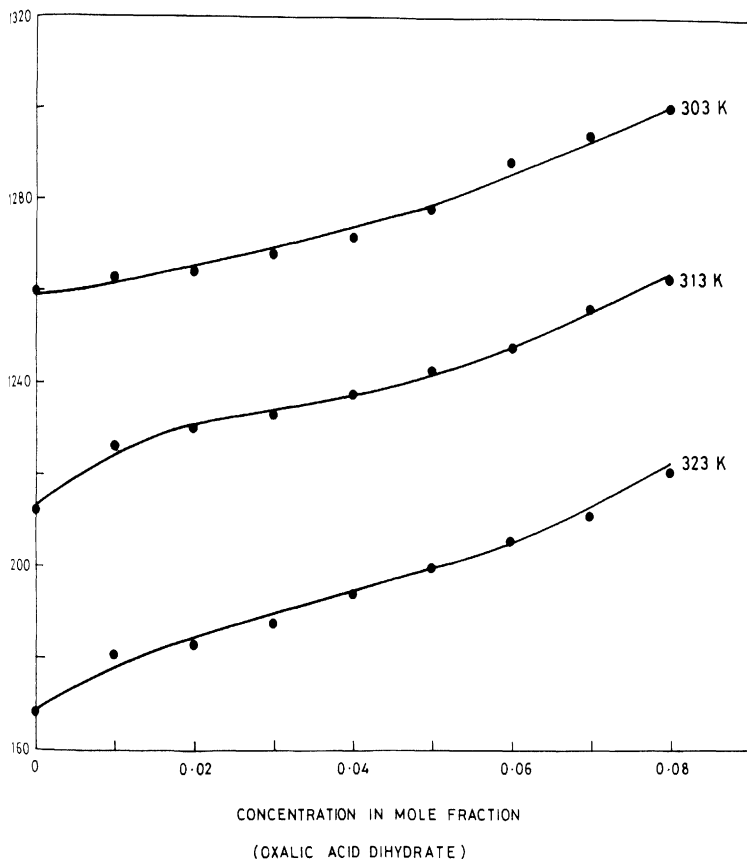
**FIG.6.13. ULTRASONIC VELOCITY VS CONCENTRATION OF SUCCINIC ACID
IN TETRAHYDROFURAN**



**FIG-6-14. ADIABATIC COMPRESSIBILITY VS CONCENTRATION OF SUCCINIC ACID
IN TETRAHYDROFURAN**



**FIG-6.15. INTERNAL PRESSURE VS CONCENTRATION OF SUCCINIC ACID
IN TETRAHYDROFURAN**



FIG·6·16. ULTRASONIC VELOCITY VS CONCENTRATION OF OXALIC ACID DIHYDRATE IN TETRAHYDROFURAN

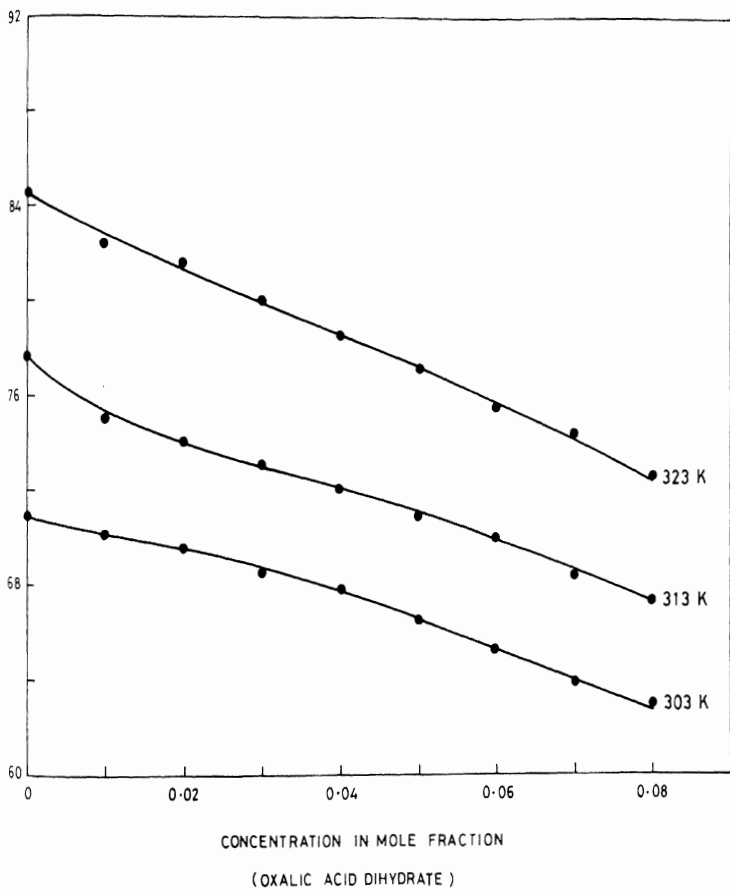
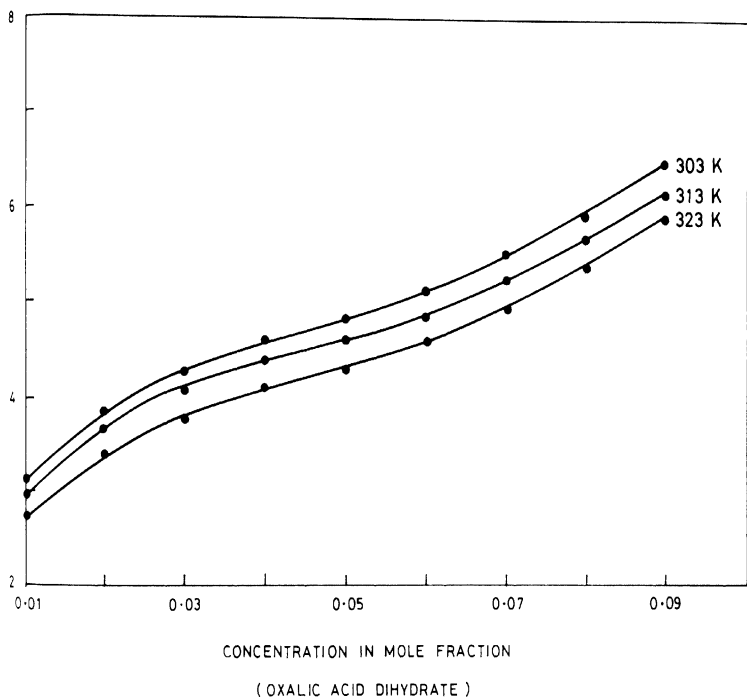


FIG-6-17. ADIABATIC COMPRESSIBILITY VS CONCENTRATION OF OXALIC ACID DIHYDRATE IN TETRAHYDROFURAN



**FIG-6-18. INTERNAL PRESSURE VS CONCENTRATION OF OXALIC ACID
DIHYDRATE IN TETRAHYDROFURAN**

namely 303 K, 313 K and 323 K. The temperature of the solutions was maintained at the required temperature by circulating water from a thermostatically controlled water bath, with an accuracy of ± 0.1 K.

All the solutions were prepared by taking AR/BDH chemicals. The ultrasonic velocity measurements were carried out at various solute concentrations ranging from 0.01 mole fraction to 0.15 mole fraction for those carboxylic acids in group-I. For the group-II carboxylic acids, the concentration range was from 0.01 mole fraction to 0.08 mole fraction. The density of these solutions at different temperatures was determined using a dilatometer as described in chapter-II. The measured values of ultrasonic velocity (C), density (ρ) and coefficient of volume expansion (α_v) were used for the computation of the parameters like adiabatic compressibility (β_a), internal pressure (νP_i) and intermolecular free length (L_f) using the standard relations given in chapter-I. For the solutions of carboxylic acids in tetrahydrofuran, the ultrasonic velocities at several concentrations and the other calculated parameters are listed in tables 6.2 - 6.19. The variation of ultrasonic velocity, adiabatic compressibility and the internal pressure with concentration are shown graphically in figures 6.1 - 6.18 .

The figures 6.1, 6.4 and 6.7 show the variation of ultrasonic velocity (C) with concentration of group-I carboxylic acids in the concentration range 0.01 to 0.15 mole fractions at 303 K. The ultrasonic velocity increases

non-linearly with increase of solute concentration. For the temperatures 313K and 323K, the variation of velocity with concentration shows the similar behaviour. The figures 6.4 and 6.7 show that the ultrasonic velocity measured in the solutions of p-hydroxy benzoic acid in tetrahydrofuran is greater than the ultrasonic velocity measured in the solutions of o-hydroxy benzoic acid in tetrahydrofuran at any given concentration. A similar behaviour was observed with increase of temperature. From the figures 6.10, 6.13 and 6.16, it can be seen that the variation of ultrasonic velocity with concentration of group-II carboxylic acids in tetrahydrofuran in the concentration range 0.01 to 0.08 mole fraction also shows a similar behaviour as that of group-I carboxylic acids in tetrahydrofuran.

The variation of adiabatic compressibility (β_g) with concentration of benzoic acid, o-hydroxy benzoic acid and p-hydroxy benzoic acid in tetrahydrofuran is shown in figures 6.2, 6.5 and 6.8. The adiabatic compressibility decreases non-linearly with increase of concentration of group-I carboxylic acids in tetrahydrofuran at 303K. The same trend is observed for the temperatures 313K and 323K. From the figures 6.11, 6.14 and 6.17, it can be seen that the variation of adiabatic compressibility follows the same trend with increase of solute concentration of group-II carboxylic acids in tetrahydrofuran at all temperatures studied.

The variation of internal pressure (νP_i) with increase in concentration of carboxylic acids is shown in figures 6.3, 6.6, 6.9, 6.12, 6.15 and 6.18 for all the temperatures. From these figures, it can be seen that, at 303 K the internal pressure increases non-linearly with increase of solute concentration of the carboxylic acids. The behaviour at 313 K and 323 K is also similar to the behaviour at 303K with increase of solute concentration.

From the tables 6.2 - 6.19, it can be seen that the intermolecular free length (L_f) also decreases with increase of solute concentration of these carboxylic acids.

The salient features of all these studies are summarised as follows:

1. The ultrasonic velocity increases non-linearly with increase in solute concentration of benzoic acid, o-hydroxy benzoic acid, p-hydroxy benzoic acid, maleic acid, succinic acid and oxalic acid dihydrate in tetrahydrofuran.
2. In all the carboxylic acids studied, for any particular concentration the ultrasonic velocity decreases with increase of temperature.
3. The adiabatic compressibility decreases non-linearly with increase in solute concentration of carboxylic acids in tetrahydrofuran.
4. For any particular concentration of carboxylic acids in tetrahydrofuran, the magnitude of the adiabatic compressibility increases with increase of temperature.

5. The internal pressure also increases non-linearly with increase of solute concentration of carboxylic acids in tetrahydrofuran. For any particular concentration of the carboxylic acids in tetrahydrofuran, the internal pressure decreases with increase of temperature.
6. In group-I carboxylic acids, the ultrasonic velocity measured in the solutions of p-hydroxy benzoic acid in tetrahydrofuran is found to be greater than the ultrasonic velocity measured in the solutions of o-hydroxy benzoic acid in tetrahydrofuran at any particular concentration and temperature.

6.2.1 Group - I Carboxylic acids:

The ultrasonic velocity increases non-linearly with increase in the concentration of benzoic acid, o-hydroxy benzoic acid and p-hydroxy benzoic acid in tetrahydrofuran. This type of variation of ultrasonic velocity with solute concentration generally indicates association between the solute and solvent molecules. In the present study, it is likely that the oxygenated solvent tetrahydrofuran breaks the acid dimers into monomer form and the hydrogen bonds are formed between the free oxygen of tetrahydrofuran and the monomers (-OH and -COOH) of carboxylic acids [9-11]. This hydrogen bond formation strengthens the intermolecular forces resulting in a decrease of compressibility and an increase of ultrasonic velocity as shown in the figures 6.1, 6.4 and 6.7.

The variation of adiabatic compressibility (β_g) shown in figures 6.2, 6.5 and 6.8 indicates that the compressibility decreases with increase in the solute concentration of benzoic acid, o-hydroxy benzoic acid and p-hydroxy benzoic acid in tetrahydrofuran. This indicates that the intermolecular forces get strengthened to greater extent with increasing concentration of group-I carboxylic acids in tetrahydrofuran. From the figures 6.5 and 6.8 it can be seen that, the compressibility is lowered to a greater extent in the solutions of p-hydroxy benzoic acid in tetrahydrofuran than in the solutions of o-hydroxy benzoic acid in tetrahydrofuran. This can be attributed to the fact that o-hydroxy benzoic acid is a chelated compound forming strong intramolecular hydrogen bonds and hence the intermolecular bonds formed with tetrahydrofuran are likely to be weaker. As p-hydroxy benzoic acid is not chelated, it forms stronger intermolecular hydrogen bonds with tetrahydrofuran and hence the compressibility is lowered to a greater extent. The melting points of p-hydroxy benzoic acid and o-hydroxy benzoic acid are 213°C and 159°C respectively. This indicates clearly that the hydrogen bonding involving the formation of dimers is stronger in the case of p-hydroxy benzoic acid than in o-hydroxy benzoic acid. These ultrasonic studies suggest that compressibility may be used as a means to distinguish chelated hydrogen bonded compound from the non-chelated.

The variation of internal pressure (νP_i) with solute concentration of group-I carboxylic acids in tetrahydrofuran is shown in figures 8.3, 8.8 and 8.9. The non-linear increase in the internal pressure generally indicates association through hydrogen bonding [13] and hence, it can be concluded that variation of internal pressure data generally supports the above discussion given for the variation of velocity.

The decrease in the value of intermolecular free length with increase in solute concentration of group-I carboxylic acids in tetrahydrofuran indicates association between the solute and solvent molecules [14]. Such a decrease in free length with increase in solute concentrations has been reported in the solutions of carboxylic acids in acetone and pyridine [15]. Hence, the variation of free length with concentration of group-I carboxylic acids in tetrahydrofuran generally supports the discussion offered for the variation of ultrasonic velocity with concentration in these systems.

For the same concentration of benzoic acid, o-hydroxy benzoic acid and p-hydroxy benzoic acid in tetrahydrofuran, the ultrasonic velocity decreases with increase of temperature and this is to be expected as the increase of thermal vibrations weakens the intermolecular forces between the monomers of carboxylic acids and the tetrahydrofuran molecules.

The earlier ultrasonic velocity studies [1,2] on o-hydroxy benzoic acid and p-hydroxy benzoic acid in dioxane

showed that there are two well defined maxima in the ultrasonic velocity curve. For o-hydroxy benzoic acid in dioxane, the two maxima were observed at 0.05 mole fraction and at 0.08 mole fraction. But in the case of p-hydroxy benzoic acid in dioxane, these maxima were observed at mole fractions of 0.03 and 0.08 respectively. This had been explained on the grounds that the maxima observed at lower concentration were due to the formation of hydrogen bonds between the oxygens of dioxane and the hydroxyl protons of the o- and p-hydroxy benzoic acids and the one at higher solute concentration range was due to the carboxylic protons i.e. -COOH. This fact was further confirmed by the proton magnetic relaxation studies and the high resolution NMR studies of Arulmozhi et al [3]. But in the present ultrasonic velocity studies on o-hydroxy benzoic acid and p-hydroxy benzoic acid in tetrahydrofuran, no such well defined maxima were observed in the velocity variation. This may be due to the fact that the solvent tetrahydrofuran behaves as a weaker structure breaker compared to dioxane although it has greater values of donor number, dipole moment and dielectric constant. Also, hydrogen bonds formed between the hydroxylic and carboxylic protons of o- and p-hydroxy benzoic acids and the oxygen of tetrahydrofuran molecules may be weaker compared to the hydrogen bonds formed in the solutions of o-hydroxy benzoic acid and p-hydroxy benzoic acid in dioxane. This may also be attributed to the fact that, the tetrahydrofuran molecule has only a single free oxygen for hydrogen

bonding, whereas the dioxane molecule has two free oxygens for hydrogen bonding.

6.2.2 Group - II carboxylic acids:

From the figures 6.10, 6.13 and 6.16, it can be seen that, the ultrasonic velocity increases non-linearly with increasing concentration of maleic acid, succinic acid and oxalic acid dihydrate in tetrahydrofuran. This trend was similar to the one observed for group-I carboxylic acids in tetrahydrofuran. Hence the explanation proposed for the velocity variation in the solutions of group-I carboxylic acids in tetrahydrofuran also holds good for the velocity variation in the solutions of group-II carboxylic acids in tetrahydrofuran.

In the solutions of oxalic acid dihydrate in tetrahydrofuran, it is likely that the tetrahydrofuran breaks the oxalic acid dihydrate into free water and oxalic acid monomers. The hydrogen bonds are formed between the oxalic acid monomers and the tetrahydrofuran molecules. Since the carboxylic protons are highly electropositive, the formation of O-H...O hydrogen bonds of oxalic acid monomers with tetrahydrofuran molecules is more favoured than the water-tetrahydrofuran molecules.

The variation of adiabatic compressibility (β_g) with concentration shown in figures 6.11, 6.14 and 6.17 indicates that the compressibility decreases non-linearly with increase in concentration of maleic acid, succinic acid and oxalic acid dihydrate in tetrahydrofuran. This indicates

that the intermolecular forces gets strengthened with increasing concentration of group - II carboxylic acids in tetrahydrofuran.

The variations of internal pressure (figures 6.12, 6.15 & 6.18) and intermolecular free length with increase in concentration of group - II carboxylic acids in tetrahydrofuran follow a similar behaviour as that observed for group-I carboxylic acids in tetrahydrofuran. Hence the discussion offered for the variation of internal pressure and intermolecular free length for group-I carboxylic acids in tetrahydrofuran holds good for this case also.

For the same concentration of maleic acid, succinic acid and oxalic acid dihydrate in tetrahydrofuran, the ultrasonic velocity decreases with increase of temperature and this is to be expected as the increase of thermal vibrations weakens the intermolecular forces between the monomers of carboxylic acids and tetrahydrofuran molecules.

The ultrasonic velocity measured in the solutions of maleic acid, succinic acid and oxalic acid dihydrate in tetrahydrofuran at various solute concentrations and at different temperatures was found to be less compared to the ultrasonic velocity measured in the solutions of maleic acid, succinic acid and oxalic acid dihydrate in dioxane [4]. Also, in the previous study on maleic acid, succinic acid and oxalic acid dihydrate in dioxane a definite maximum was observed in the velocity variation curve. But in the present study, no such maximum was observed. As discussed earlier for group - I carboxylic acids in

tetrahydrofuran, this may be due to the fact that the tetrahydrofuran behaves as a weaker structure breaker compared to dioxane eventhough it has got greater values of donor number, dipole moment and dielectric constant. This behaviour may also be attributed to the fact that the tetrahydrofuran has got only one free oxygen compared to dioxane which has got two free oxygens for hydrogen bonding.

6.3 CONCLUSION

The ultrasonic velocity studies in the solutions of benzoic acid, o-hydroxy benzoic acid, p-hydroxy benzoic acid, maleic acid, succinic acid and oxalic acid dihydrate in tetrahydrofuran throw some light on the nature of solute-solvent interactions in these systems. It appears that, the solvent tetrahydrofuran breaks the carboxylic acid dimers into monomer form and hydrogen bonds are formed between the monomers of carboxylic acids and the free oxygen of tetrahydrofuran molecules. Also, the velocity measured in the solutions of p-hydroxy benzoic acid in tetrahydrofuran is more than the velocity measured in the solutions of o-hydroxy benzoic acid in tetrahydrofuran. This indicates that the ultrasonic velocity is more in non-chelated compounds than in the chelated compounds. This study also confirms the earlier fact that the tetrahydrofuran behaves as a weaker structure breaker compared to dioxane eventhough it has got greater values of donor number, dipole moment and dielectric constant.

TABLE - 6.1

Donor Number, dipole moment and dielectric constant for some aprotic solvents

solvent	donor number (D.N) Kcal/mol	dipole moment (μ) Debye	dielectric constant ϵ
DMSO	29.8	3.9	48.7
DMF	28.8	3.9	36.7
THF	20.0	1.7	7.4
DO	19.0	0.4	2.2
AN	14.1	3.2	36.0

TABLE - 6.2

Ultrasonic velocity and related parameters in the solutions of benzoic acid in tetrahydrofuran at 303K.

mole fraction X	ρ Kgm^{-3}	C ms^{-1}	β_s $10^{-10} \text{ N}^{-1} \text{ m}^2$	η_s 10^{-3} Nsm^{-2}	νP_i 10^2 Atm.	L_f A°
0.01	911.28	1263.6	6.872	0.643	10.012	0.523
0.02	915.08	1269.6	6.779	0.679	10.251	0.519
0.03	921.79	1272.2	6.702	0.719	10.520	0.516
0.04	926.27	1277.4	6.616	0.739	10.863	0.513
0.05	930.97	1281.6	6.539	0.785	11.094	0.510
0.06	936.79	1285.4	6.460	0.818	11.280	0.507
0.07	940.37	1288.0	6.410	0.859	11.532	0.505
0.08	946.86	1291.8	6.328	0.905	11.839	0.502
0.09	949.32	1295.4	6.277	0.926	12.043	0.499
0.10	950.89	1298.6	6.236	0.964	12.175	0.498
0.11	954.24	1302.2	6.179	0.981	12.451	0.496
0.12	957.38	1304.2	6.140	1.016	12.640	0.494
0.13	960.29	1310.0	6.068	1.058	12.906	0.491

X - mole fraction of benzoic acid in tetrahydrofuran;

ρ - density of the solution;

C - ultrasonic velocity;

β_s - adiabatic compressibility;

η_s - shear viscosity;

P_i - internal pressure;

L_f - free length

TABLE - 6.3

Ultrasonic velocity and related parameters in the solutions of benzoic acid in tetrahydrofuran at 313K.

mole fraction X	ρ Kgm ⁻³	C ms ⁻¹	β_s 10 ⁻¹⁰ N ⁻¹ m ²	η_s 10 ⁻³ Nsm ⁻²	νP_i 10 ² Atm.	L _f A°
0.01	886.08	1213.6	7.663	0.449	9.014	0.562
0.02	890.01	1217.4	7.581	0.464	9.209	0.559
0.03	896.28	1220.8	7.486	0.476	9.460	0.555
0.04	900.89	1225.2	7.395	0.497	9.762	0.552
0.05	905.26	1236.0	7.231	0.524	10.077	0.546
0.06	910.35	1237.0	7.135	0.552	10.252	0.542
0.07	915.94	1239.0	7.112	0.567	10.455	0.541
0.08	922.53	1243.0	7.016	0.578	10.747	0.538
0.09	926.24	1246.4	6.950	0.599	10.961	0.535
0.10	929.48	1247.6	6.912	0.592	11.091	0.534
0.11	934.58	1251.2	6.835	0.621	11.388	0.531
0.12	938.34	1254.6	6.771	0.630	11.601	0.528
0.13	944.26	1258.6	6.685	0.675	11.899	0.525

X - mole fraction of benzoic acid in tetrahydrofuran;

ρ - density of the solution;

C - ultrasonic velocity;

β_s - adiabatic compressibility;

η_s - shear viscosity;

P_i - internal pressure;

L_f - free length

TABLE - 6.4

Ultrasonic velocity and related parameters in the solutions of benzoic acid in tetrahydrofuran at 323K.

mole fraction X	ρ Kg m^{-3}	C ms $^{-1}$	β_s 10^{-10} N $^{-1}m^2$	η_s 10^{-3} Nsm $^{-2}$	νP_i 10^2 Atm.	L_f A $^\circ$
0.01	871.54	1171.0	8.388	0.388	8.384	0.596
0.02	879.52	1174.0	8.249	0.397	8.632	0.592
0.03	885.64	1178.0	8.137	0.410	8.877	0.588
0.04	889.10	1183.8	8.029	0.430	9.157	0.584
0.05	894.35	1193.8	7.848	0.445	9.466	0.578
0.06	899.33	1196.0	7.774	0.473	9.591	0.575
0.07	904.60	1197.8	7.705	0.484	9.837	0.572
0.08	910.70	1200.8	7.615	0.498	10.084	0.569
0.09	913.40	1206.0	7.527	0.518	10.300	0.566
0.10	916.45	1208.0	7.478	0.516	10.430	0.564
0.11	920.87	1212.4	7.388	0.533	10.711	0.560
0.12	924.94	1217.2	7.297	0.544	10.953	0.557
0.13	929.43	1220.4	7.224	0.564	11.186	0.554

X - mole fraction of benzoic acid in tetrahydrofuran;

ρ - density of the solution;

C - ultrasonic velocity;

β_s - adiabatic compressibility;

η_s - shear viscosity;

P_i - internal pressure;

L_f - free length

TABLE - 6.5

Ultrasonic velocity and related parameters in the solutions of
o-hydroxy benzoic acid in tetrahydrofuran at 303K.

mole fraction X	ρ Kgm ⁻³	C ms ⁻¹	β_s 10 ⁻¹⁰ N ⁻¹ m ²	η_s 10 ⁻³ Nsm ⁻²	νP_i 10 ² Atm.	L _f A ^o
0.01	903.16	1269.2	6.873	0.595	8.533	0.523
0.02	905.25	1273.8	6.808	0.614	8.665	0.520
0.03	907.71	1276.0	6.766	0.631	8.869	0.519
0.04	909.50	1280.6	6.704	0.639	9.103	0.516
0.05	911.29	1284.0	6.655	0.683	9.323	0.514
0.06	913.98	1286.8	6.607	0.727	9.490	0.512
0.07	917.34	1289.0	6.560	0.718	9.768	0.511
0.08	921.36	1293.0	6.491	0.697	10.079	0.508
0.09	925.17	1296.0	6.435	0.742	10.325	0.506
0.10	931.21	1301.8	6.336	0.788	10.592	0.502
0.11	937.03	1304.0	6.276	0.832	10.803	0.499
0.12	945.75	1302.2	6.235	0.844	11.142	0.498
0.13	952.24	1304.2	6.170	0.892	11.372	0.495
0.14	959.18	1299.0	6.178	1.137	11.630	0.496
0.15	969.24	1308.2	6.028	1.029	12.261	0.489

X - mole fraction of o-hydroxy benzoic acid in tetrahydrofuran;

ρ - density of the solution;

C - ultrasonic velocity;

β_s - adiabatic compressibility;

η_s - shear viscosity;

P_i - internal pressure;

L_f - free length

TABLE - 6.6

Ultrasonic velocity and related parameters in the solutions of o-hydroxy benzoic acid in tetrahydrofuran at 313K.

mole fraction X	ρ Kgm ⁻³	C ms ⁻¹	β_s 10 ⁻¹⁰ N ⁻¹ m ²	η_s 10 ⁻³ Nsm ⁻²	νP_i 10 ² Atm.	L _f A ^o
0.01	881.41	1213.5	7.705	0.435	7.670	0.564
0.02	885.85	1215.6	7.639	0.453	7.844	0.561
0.03	890.83	1218.4	7.582	0.465	8.044	0.558
0.04	891.65	1222.4	7.506	0.478	8.233	0.556
0.05	895.66	1227.2	7.414	0.487	8.496	0.553
0.06	899.30	1231.6	7.331	0.503	8.693	0.550
0.07	904.52	1234.4	7.256	0.522	8.994	0.547
0.08	910.17	1237.6	7.173	0.545	9.307	0.544
0.09	917.92	1240.4	7.081	0.582	9.615	0.540
0.10	927.05	1243.0	6.982	0.586	9.885	0.536
0.11	934.68	1246.0	6.891	0.621	10.136	0.533
0.12	942.88	1250.8	6.779	0.636	10.553	0.529
0.13	948.17	1252.4	6.724	0.713	10.733	0.526
0.14	954.15	1256.8	6.635	0.780	11.129	0.523
0.15	959.27	1261.2	6.554	0.813	11.528	0.520

X - mole fraction of o-hydroxy benzoic acid in tetrahydrofuran;

ρ - density of the solution;

C - ultrasonic velocity;

β_s - adiabatic compressibility;

η_s - shear viscosity;

P_i - internal pressure;

L_f - free length

TABLE - 6.7

Ultrasonic velocity and related parameters in the solutions of o-hydroxy benzoic acid in tetrahydrofuran at 323K.

mole fraction X	ρ Kgm ⁻³	C ms ⁻¹	β_s 10 ⁻¹⁰ N ⁻¹ m ²	η_s 10 ⁻³ Nsm ⁻²	νP_i 10 ² Atm.	L_f A ^o
0.01	864.78	1172.0	8.419	0.383	7.149	0.598
0.02	867.88	1173.4	8.370	0.388	7.201	0.598
0.03	870.15	1175.7	8.314	0.395	7.378	0.594
0.04	875.33	1178.4	8.227	0.409	7.609	0.591
0.05	877.50	1185.4	8.110	0.423	7.853	0.587
0.06	878.99	1188.8	8.041	0.438	7.992	0.585
0.07	884.96	1198.0	7.899	0.461	8.341	0.579
0.08	902.31	1198.0	7.722	0.493	8.843	0.573
0.09	907.17	1200.0	7.855	0.513	9.071	0.570
0.10	912.12	1202.0	7.588	0.503	9.234	0.568
0.11	921.27	1207.6	7.443	0.533	9.546	0.562
0.12	936.58	1214.4	7.240	0.570	10.013	0.555
0.13	944.07	1210.8	7.255	0.592	10.218	0.555
0.14	950.05	1218.4	7.090	0.614	10.898	0.549
0.15	956.54	1223.6	6.983	0.636	11.132	0.545

X - mole fraction of o-hydroxy benzoic acid in tetrahydrofuran;

ρ - density of the solution;

C - ultrasonic velocity;

β_s - adiabatic compressibility;

η_s - shear viscosity;

P_i - internal pressure;

L_f - free length

TABLE - 6.8

Ultrasonic velocity and related parameters in the solutions of p-hydroxy benzoic acid in tetrahydrofuran at 303K.

mole fraction X	ρ Kgm ⁻³	C ms ⁻¹	β_s 10 ⁻¹⁰ N ⁻¹ m ²	η_s 10 ⁻³ Nsm ⁻²	νP_i 10 ² Atm.	L_f A ^o
0.01	903.24	1270.8	6.855	0.686	9.840	0.522
0.02	906.37	1280.2	6.731	0.715	10.226	0.517
0.03	909.28	1288.0	6.629	0.742	10.485	0.513
0.04	911.74	1295.6	6.534	0.732	10.738	0.510
0.05	914.87	1297.6	6.491	0.798	10.865	0.508
0.06	918.68	1302.4	6.417	0.794	11.203	0.504
0.07	923.38	1298.4	6.424	0.861	11.297	0.505
0.08	929.42	1303.4	6.333	0.877	11.620	0.502
0.09	936.35	1305.2	6.269	1.027	11.953	0.499
0.10	943.74	1308.4	6.189	1.096	12.275	0.496
0.11	954.03	1306.8	6.137	1.284	12.547	0.494
0.12	967.01	1314.9	5.981	1.488	12.988	0.488
0.13	980.21	1318.2	7.739	1.941	13.773	0.555

X - mole fraction of p-hydroxy benzoic acid in tetrahydrofuran;

ρ - density of the solution;

C - ultrasonic velocity;

β_s - adiabatic compressibility;

η_s - shear viscosity;

P_i - internal pressure;

L_f - free length

TABLE - 6.9

Ultrasonic velocity and related parameters in the solutions of p-hydroxy benzoic acid in tetrahydrofuran at 313K.

mole fraction X	ρ Kgm^{-3}	C ms^{-1}	β_s $10^{-10} \text{ N}^{-1} \text{ m}^2$	η_s 10^{-3} Nsm^{-2}	νP_i 10^2 Atm.	L_f A°
0.01	883.45	1215.0	7.668	0.487	8.889	0.562
0.02	886.86	1220.4	7.571	0.500	9.186	0.558
0.03	889.04	1229.2	7.445	0.515	9.427	0.554
0.04	892.55	1232.8	7.372	0.536	9.622	0.551
0.05	895.06	1240.8	7.257	0.595	9.819	0.547
0.06	899.55	1245.6	7.165	0.609	10.147	0.543
0.07	905.36	1253.4	7.031	0.674	10.447	0.538
0.08	911.14	1259.2	6.923	0.745	10.759	0.534
0.09	918.61	1266.0	6.792	0.825	11.172	0.529
0.10	926.73	1277.2	6.615	0.929	11.642	0.522
0.11	936.64	1285.2	6.464	0.984	12.074	0.516
0.12	949.34	1287.4	6.356	1.078	12.386	0.512
0.13	962.59	1289.0	6.252	1.108	12.816	0.508

X - mole fraction of p-hydroxy benzoic acid in tetrahydrofuran;

ρ - density of the solution;

C - ultrasonic velocity;

β_s - adiabatic compressibility;

η_s - shear viscosity;

P_i - internal pressure;

L_f - free length

TABLE - 6.10

Ultrasonic velocity and related parameters in the solutions of
p-hydroxy benzoic acid in tetrahydrofuran at 323K.

mole fraction X	ρ Kgm ⁻³	C ms ⁻¹	β_s 10 ⁻¹⁰ N ⁻¹ m ²	η_s 10 ⁻³ Nsm ⁻²	νP_i 10 ² Atm.	L_f A ^o
0.01	864.83	1174.0	8.389	0.389	8.206	0.597
0.02	867.40	1180.0	8.280	0.401	8.477	0.593
0.03	870.71	1186.0	8.165	0.432	8.686	0.589
0.04	873.36	1191.2	8.069	0.456	8.876	0.588
0.05	876.57	1195.2	7.986	0.504	9.007	0.583
0.06	880.77	1209.2	7.765	0.535	9.459	0.575
0.07	886.24	1211.4	7.689	0.591	9.653	0.572
0.08	901.77	1215.2	7.509	0.656	10.132	0.565
0.09	908.61	1226.6	7.315	0.714	10.588	0.558
0.10	913.32	1237.4	7.151	0.785	10.955	0.551
0.11	923.85	1247.8	6.952	0.849	11.427	0.544
0.12	935.89	1255.2	6.782	0.882	11.808	0.537
0.13	948.71	1261.0	6.629	0.920	12.292	0.531

X - mole fraction of p-hydroxy benzoic acid in tetrahydrofuran;

ρ - density of the solution;

C - ultrasonic velocity;

β_s - adiabatic compressibility;

η_s - shear viscosity;

P_i - internal pressure;

L_f - free length

TABLE - 6.11

Ultrasonic velocity and related parameters in the solutions of maleic acid in tetrahydrofuran at 303k

mole fraction X	ρ Kgm ⁻³	C ms ⁻¹	β_s 10 ⁻¹⁰ N ⁻¹ m ²	η_s 10 ⁻³ Nsm ⁻²	νP_i 10 ² Atm.	L_f A ^o
0.01	921.18	1287.8	6.545	0.694	9.936	0.510
0.02	926.44	1291.2	6.474	0.729	10.149	0.507
0.03	932.57	1292.2	6.421	0.773	10.445	0.505
0.04	939.58	1296.8	6.328	0.832	10.918	0.502
0.05	949.65	1309.8	6.138	0.894	11.471	0.494
0.06	953.59	1312.0	6.092	0.964	11.778	0.492
0.07	961.92	1314.8	6.013	1.042	12.270	0.489
0.08	965.86	1317.4	5.965	1.079	12.932	0.487

X - mole fraction of maleic acid in tetrahydrofuran;

ρ - density of the solution;

C - ultrasonic velocity;

β_s - adiabatic compressibility;

η_s - shear viscosity;

P_i - internal pressure;

L_f - free length

TABLE - 6.12

Ultrasonic velocity and related parameters in the solutions of maleic acid in tetrahydrofuran at 313K.

mole fraction X	ρ Kg m^{-3}	C ms $^{-1}$	β_s 10^{-10} N m^{-2}	η_s 10^{-3} Nsm $^{-2}$	νP_i 10^2 Atm.	L_f A $^\circ$
0.01	901.43	1217.4	7.485	0.445	8.782	0.555
0.02	907.24	1220.6	7.398	0.469	8.978	0.552
0.03	914.56	1225.6	7.291	0.504	9.298	0.548
0.04	921.36	1229.6	7.179	0.527	9.732	0.544
0.05	929.54	1233.6	7.069	0.557	10.072	0.540
0.06	934.04	1235.6	7.013	0.571	10.347	0.538
0.07	941.20	1240.0	6.910	0.611	10.802	0.533
0.08	946.69	1245.2	6.813	0.641	11.455	0.529

X - mole fraction of maleic acid in tetrahydrofuran;

ρ - density of the solution;

C - ultrasonic velocity;

β_s - adiabatic compressibility;

η_s - shear viscosity;

P_i - internal pressure;

L_f - free length

TABLE - 6.13

Ultrasonic velocity and related parameters in the solutions of maleic acid in tetrahydrofuran at 323K

mole fraction X	ρ Kgm ⁻³	C ms ⁻¹	β_s 10 ⁻¹⁰ N ⁻¹ m ²	η_s 10 ⁻³ Nsm ⁻²	νP_i 10 ² Atm.	L_f A ^o
0.01	883.36	1174.0	8.213	0.391	8.093	0.591
0.02	888.84	1176.4	8.130	0.412	8.260	0.588
0.03	896.04	1179.4	8.023	0.432	8.544	0.584
0.04	903.22	1183.6	7.903	0.446	8.939	0.580
0.05	909.05	1193.2	7.727	0.467	9.317	0.573
0.06	914.51	1195.6	7.650	0.491	9.590	0.570
0.07	920.48	1200.0	7.544	0.520	10.003	0.566
0.08	927.52	1204.0	7.437	0.554	10.610	0.562

X - mole fraction of maleic acid in tetrahydrofuran;

ρ - density of the solution;

C - ultrasonic velocity;

β_s - adiabatic compressibility;

η_s - shear viscosity;

P_i - internal pressure;

L_f - free length

TABLE - 6.14

Ultrasonic velocity and related parameters in the solutions of succinic acid in tetrahydrofuran at 303K

mole fraction X	ρ Kg m^{-3}	C ms^{-1}	β_s $10^{-10} \text{ N}^{-1} \text{ m}^2$	η_s 10^{-3} Nsm^{-2}	νP_i 10^2 Atm.	L_f \AA°
0.01	925.56	1286.8	6.524	0.741	11.188	0.509
0.02	930.82	1287.4	6.482	0.767	11.463	0.508
0.03	935.20	1290.4	6.421	0.825	11.888	0.505
0.04	947.46	1299.2	6.252	0.940	12.533	0.499
0.05	952.28	1301.0	6.204	0.994	12.851	0.497
0.06	956.66	1304.8	6.139	1.012	13.320	0.494
0.07	958.41	1309.2	6.087	1.057	13.768	0.492
0.08	969.36	1312.0	5.993	1.222	14.213	0.488

X - mole fraction of succinic acid in tetrahydrofuran;

ρ - density of the solution;

C - ultrasonic velocity;

β_s - adiabatic compressibility;

η_s - shear viscosity;

P_i - internal pressure;

L_f - free length

TABLE - 6.15

Ultrasonic velocity and related parameters in the solutions of succinic acid in tetrahydrofuran at 313K.

mole fraction X	ρ Kgm ⁻³	C ms ⁻¹	β_s 10 ⁻¹⁰ N ⁻¹ m ²	η_s 10 ⁻³ Nsm ⁻²	νP_i 10 ² Atm.	L _f A ^o
0.01	904.55	1211.6	7.531	0.463	9.784	0.557
0.02	911.87	1221.4	7.351	0.482	10.205	0.550
0.03	915.02	1220.0	7.343	0.516	10.485	0.549
0.04	928.34	1223.4	7.213	0.532	10.958	0.545
0.05	932.83	1228.0	7.109	0.559	11.313	0.541
0.06	937.81	1232.8	7.016	0.616	11.756	0.537
0.07	939.44	1236.0	6.968	0.638	12.131	0.535
0.08	950.93	1242.0	6.187	0.672	12.603	0.530

X - mole fraction of succinic acid in tetrahydrofuran;

ρ - density of the solution;

C - ultrasonic velocity;

β_s - adiabatic compressibility;

η_s - shear viscosity;

P_i - internal pressure;

L_f - free length

TABLE - 6.16

Ultrasonic velocity and related parameters in the solutions of succinic acid in tetrahydrofuran at 323K

mole fraction X	ρ Kgm ⁻³	C ms ⁻¹	β_s 10 ⁻¹⁰ N ⁻¹ m ²	η_s 10 ⁻³ Nsm ⁻²	νP_i 10 ² Atm.	L_f A ^o
0.01	883.16	1174.6	8.270	0.389	9.045	0.591
0.02	892.42	1176.0	8.102	0.409	9.327	0.587
0.03	894.54	1178.0	8.056	0.431	9.636	0.585
0.04	905.91	1182.8	7.890	0.453	10.100	0.579
0.05	913.57	1183.6	7.814	0.490	10.376	0.576
0.06	918.78	1194.8	7.624	0.521	10.912	0.569
0.07	920.47	1202.8	7.509	0.529	11.354	0.565
0.08	932.54	1207.0	7.380	0.546	11.773	0.559

X - mole fraction of succinic acid in tetrahydrofuran;

ρ - density of the solution;

C - ultrasonic velocity;

β_s - adiabatic compressibility;

η_s - shear viscosity;

P_i - internal pressure;

L_f - free length

TABLE - 6.17

Ultrasonic velocity and related parameters in the solutions of oxalic acid dihydrate in tetrahydrofuran at 303K

mole fraction X	ρ Kgm ⁻³	C ms ⁻¹	β_s 10 ⁻¹⁰ N ⁻¹ m ²	η_s 10 ⁻³ Nsm ⁻²	νP_i 10 ² Atm.	L_f A ^o
0.01	896.38	1262.8	6.996	0.655	3.096	0.528
0.02	898.61	1264.3	6.962	0.668	3.888	0.527
0.03	908.55	1267.8	6.848	0.735	4.283	0.522
0.04	911.12	1271.7	6.787	0.760	4.628	0.520
0.05	921.14	1278.0	6.645	0.840	4.819	0.514
0.06	923.98	1288.8	6.516	0.868	5.114	0.509
0.07	934.44	1294.8	6.383	0.942	5.509	0.504
0.08	939.07	1300.5	6.296	1.023	5.907	0.501

X - mole fraction of oxalic acid dihydrate in tetrahydrofuran;

ρ - density of the solution;

C - ultrasonic velocity;

β_s - adiabatic compressibility;

η_s - shear viscosity;

P_i - internal pressure;

L_f - free length

TABLE - 6.18

Ultrasonic velocity and related parameters in the solutions of oxalic acid dihydrate in tetrahydrofuran at 313K

mole fraction X	ρ Kg m^{-3}	C ms $^{-1}$	β_s 10^{-10} N $^{-1}$ m 2	η_s 10^{-3} Nsm $^{-2}$	νP_i 10^2 Atm.	L_f A $^\circ$
0.01	866.77	1226.3	7.499	0.561	2.952	0.556
0.02	891.92	1230.0	7.411	0.598	3.731	0.553
0.03	899.81	1233.0	7.310	0.631	4.086	0.549
0.04	906.15	1237.5	7.208	0.680	4.461	0.545
0.05	913.52	1242.7	7.088	0.717	4.627	0.541
0.06	916.44	1247.9	7.007	0.738	4.872	0.537
0.07	926.38	1256.4	6.838	0.791	5.266	0.531
0.08	930.50	1263.0	6.737	0.851	5.650	0.527

X - mole fraction of oxalic acid dihydrate in tetrahydrofuran;

ρ - density of the solution;

C - ultrasonic velocity;

β_s - adiabatic compressibility;

η_s - shear viscosity;

P_i - internal pressure;

L_f - free length

TABLE - 6.19

Ultrasonic velocity and related parameters in the solutions of oxalic acid dihydrate in tetrahydrofuran at 323K

mole fraction X	ρ Kgm ⁻³	C ms ⁻¹	β_s 10 ⁻¹⁰ N ⁻¹ m ²	η_s 10 ⁻³ Nsm ⁻²	νP_i 10 ² Atm.	L_f A ^o
0.01	872.20	1180.8	8.223	0.525	2.759	0.592
0.02	875.48	1183.2	8.159	0.539	3.448	0.589
0.03	888.77	1187.5	7.997	0.562	3.799	0.583
0.04	892.28	1194.0	7.861	0.607	4.171	0.578
0.05	900.49	1200.0	7.712	0.666	4.328	0.573
0.06	910.95	1205.7	7.551	0.685	4.638	0.567
0.07	916.78	1211.0	7.438	0.728	4.944	0.562
0.08	924.50	1220.7	7.258	0.784	5.377	0.555

X - mole fraction of oxalic acid dihydrate in tetrahydrofuran;

ρ - density of the solution;

C - ultrasonic velocity;

β_s - adiabatic compressibility;

η_s - shear viscosity;

P_i - internal pressure;

L_f - free length

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