

THEORETICAL FORMALISM OF THERMODYNAMIC PROPERTIES OF LIQUID MIXTURES ON THE BASIS OF FLORY'S STATISTICAL THEORY - PRESSURE DEPENDENT STUDIES

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ABSTRACT

Flory's statistical theory of liquid mixtures has been extended for computing the various thermodynamic properties of binary liquid mixtures at elevated pressures. The expressions for these properties have been derived on the basis of Flory theory and further applied to two binary liquid mixtures to test the validity of Flory's theory at elevated pressures.

KEYWORDS: Flory's Statistical Theory, Elevated Pressures, Binary Liquid Mixtures, Thermodynamic Properties

There has been an increasing interest in the study of thermodynamic functions as they are useful in understanding the nature of intermolecular interactions between component molecules of a mixture. Among all the theories, known so far, the Flory's statistical theory (Flory *et al.*, 1964a) (Flory *et al.*, 1964b) (Flory 1965) (Abe & Flory, 1965) has been the most widely applied theory of liquid mixtures. It has been employed to describe the thermodynamic behaviour of binary and multicomponent systems by various workers but it appears from literature survey that most of the studies have been limited to atmospheric pressure (Letcher and Baxter, 1989) (Pandey and Pant, 1982) (Pandey *et al.*, 1988) (Pandey and Sanguri, 2001) (Khanwalkar *et al.*, 1990) (Islam and Quadri, 1988) (Oswal *et al.*, 1992) (Aminabhavi *et al.*, 1999) and no attempt has been made, so far, to evaluate the thermodynamic properties of pure and binary liquid mixtures at elevated pressures. For the first time, Takagi and Teranishi (1982, 1985 and 1988) carried out experimental measurements of ultrasonic velocity and related thermodynamic properties of some binary liquid mixtures at elevated pressures.

In the present work, well-established Flory's statistical theory (Flory, 1965) has been modified and developed for high pressure. This pressure dependent Flory theory has been used for the computation of various thermodynamic properties of pure liquids and binary liquid mixtures at elevated pressures. Here, the reduced equation of state due to Flory is solved to get expressions for the thermal expansion coefficient (α) and isothermal compressibility (β_T) under the restriction of pressure considerations. Further, pressure-dependent expressions are derived for the reduced volume (\tilde{V}) and reduced pressure (\tilde{P}) which are used to get the different thermodynamic properties of binary liquid mixtures toluene + o-xylene and toluene + aniline and that of their constituent pure components.

THEORY

According to Flory's statistical theory (Flory, 1965), based on van der Waals potential energy model, the reduced equation of state is given by

$$\frac{\tilde{P}\tilde{V}}{\tilde{T}} = \frac{\tilde{V}^{1/3}}{\tilde{V}^{1/3}-1} - \frac{1}{\tilde{V}\tilde{T}} \quad (1)$$

where the reduced parameters \tilde{V} , \tilde{T} and \tilde{P} are given by

$$\tilde{V} = V/V^*$$

$$\tilde{T} = T/T^*$$

And

$$\tilde{P} = P/P^* \quad (2)$$

Rearranging eq. (1), we get,

$$\tilde{T} = \frac{(\tilde{V}^{1/3}-1)(\tilde{P}\tilde{V}^2+1)}{\tilde{V}^{4/3}} \quad (3)$$

Eq. (1) has been solved to get expressions for the thermal expansion coefficient (α) and isothermal compressibility (β_T) under the restriction of pressure considerations.

Further, pressure dependent expressions are derived for the reduced volume (\tilde{V}) and reduced pressure (\tilde{P}) given as

$$\tilde{V} = \left[1 + \frac{\alpha T}{3(1-2\beta_T P + \alpha T)} \right]^3 \quad (4)$$

and

$$\tilde{P} = \frac{\beta_T P}{(\alpha T - \beta_T P)} \frac{1}{\left[1 + \frac{\alpha T}{3(1-2\beta_T P + \alpha T)} \right]^6} \quad (5)$$

Thus, with the knowledge of thermal expansion coefficient and isothermal compressibility, we can calculate reduced volume (\tilde{V}) and reduced pressure (\tilde{P}) for pure components at elevated pressures with the help of eqs. (4) and (5). Equations (4) and (5) are the pressure-dependent expressions for the reduced volume and

reduced pressure. Using these values of \tilde{V} and \tilde{P} , reduced temperature (\tilde{T}) can be calculated from eq. (3). Characteristic parameters can be obtained with the help of eq. (2).

Binary Liquid Mixtures

Segment fraction (ψ) and site fraction (θ) of liquid mixtures have been computed by the method suggested earlier (Pandey and Pant, 1982) (Pandey *et al.*, 1988) (Pandey and Sanguri, 2001) according to which

$$\psi_i = \frac{x_i V_i^*}{\sum x_i V_i^*} \tag{6}$$

where V_i^* is the characteristic volume of the i^{th} pure component and

$$\theta_i = \frac{\psi_i}{\psi_i + \sum_{k \neq i} \psi_k \left(\frac{V_i^*}{V_k^*}\right)^{1/3}} \tag{7}$$

thus, for binary mixtures, the segment fractions and site fractions will be

$$\psi_2 = \frac{x_2 V_2^*}{x_1 V_1^* + x_2 V_2^*} \quad \text{and} \quad \psi_1 = 1 - \psi_2 \tag{8}$$

and,

$$\theta_2 = \frac{\psi_2}{\psi_2 + \psi_1 \left(\frac{V_2^*}{V_1^*}\right)^{1/3}} \quad \text{and} \quad \theta_1 = 1 - \theta_2 \tag{9}$$

The interaction parameter X_{ij} , is defined as

$$X_{ij} = P_i^* \left[1 - \left(\frac{P_j^*}{P_i^*}\right)^{1/2} \left(\frac{V_j^*}{V_i^*}\right)^{1/6} \right]^2 \tag{10}$$

where P_i^* and P_j^* are characteristic pressures of pure components i and j .

For binary liquid mixtures, there is only one Flory's interaction parameter term X_{12} which is expressed as,

$$X_{12} = P_i^* \left[1 - \left(\frac{P_2^*}{P_1^*}\right)^{1/2} \left(\frac{V_2^*}{V_1^*}\right)^{1/6} \right]^2 \tag{11}$$

The characteristic pressure P^* and characteristic temperature T^* for the binary mixtures are obtained from the following expressions

$$P^* = [(\psi_1 P_1^* + \psi_2 P_2^*) - (\psi_1 \theta_2 X_{12})] \tag{12}$$

and

$$T^* = \frac{P^*}{\left[\frac{\psi_1 P_1^*}{T_1^*} + \frac{\psi_2 P_2^*}{T_2^*}\right]} \tag{13}$$

The reduced temperature (\tilde{T}) of the mixture is given by

$$\tilde{T} = \frac{T}{T^*} \tag{14}$$

The ideal reduced volume (\tilde{V}^0) is given by

$$\tilde{V}^0 = \sum X_i \tilde{V}_i \tag{15}$$

The ideal reduced temperature (\tilde{T}^0) is defined with the help of eq. (1) by rearranging it as

$$\tilde{T}^0 = \frac{(\tilde{V}^{0^{1/3}} - 1)(\tilde{P}^0 \tilde{V}^{0^2} + 1)}{\tilde{V}^{0^{4/3}}} \tag{16}$$

The excess reduced volume (\tilde{V}^E) is defined as (Flory *et al.*, 1964) (Abe and Flory, 1965)

$$\tilde{V}^E = \left(\frac{\partial \tilde{V}}{\partial \tilde{T}}\right)_P (\tilde{T} - \tilde{T}^0) \tag{17}$$

using the value of $\left(\frac{\partial \tilde{V}}{\partial \tilde{T}}\right)_P$, with negligible approximation, we get

$$\tilde{V}^E = \left[\tilde{P} - \tilde{V}^{0^{-2}} - \frac{2}{3} \tilde{P} \tilde{V}^{0^{-1/3}} + \frac{4}{3} \tilde{V}^{0^{-7/3}} \right]^{-1} (\tilde{T} - \tilde{T}^0) \tag{18}$$

The reduced volume (\tilde{V}) for the mixture is given

by

$$\tilde{V} = \tilde{V}^0 + \tilde{V}^E \tag{19}$$

with this value of reduced volume \tilde{V} of the mixture, various parameters for the liquid mixture can be calculated as follows:

Excess Volume (V^E)

The excess volume of the mixture is calculated with the help of equation (Pandey *et al.*, 1988).

$$V^E = (\sum x_i V_i^*) \tilde{V}^E \tag{20}$$

Thermal Expansion Coefficient (α)

Thermal expansion coefficient of the mixture is calculated with the help of pressure- dependent expression given by

$$\alpha = \frac{1}{T} \left[\frac{2\tilde{P}\tilde{V}^2}{(\tilde{P}\tilde{V}^2 + 1)} + \frac{1}{3(\tilde{V}^{1/3} - 1)} - 1 \right]^{-1} \tag{21}$$

Isothermal Compressibility (β_T)

The pressure-dependent expression for the isothermal compressibility is given as

$$\beta_T = \frac{1}{P} \left[\left\{ 1 + \frac{1}{\tilde{P}\tilde{V}^2} \right\} \left\{ \frac{1}{3(\tilde{V}^{1/3} - 1)} - 1 \right\} + 2 \right]^{-1} \tag{22}$$

Internal Pressure (P_i)

Internal pressure is related to the thermal expansion coefficient and isothermal compressibility through the relation,

$$P_i = \frac{\alpha T}{\beta_T} - P \tag{23}$$

Heat Capacity at Constant Pressure (C_p)

Heat capacity at constant pressure of the mixture is defined as,

$$C_p = C_p(idl.) + C_p^E \tag{24}$$

where $C_p(idl.)$ is the ideal heat capacity of the mixture and is defined as,

$$C_p(idl.) = \sum X_i C_{pi} \tag{25}$$

where C_{pi} is the heat capacity of i^{th} pure component.

The excess heat capacity (C_p^E) is defined by (Khanwalkar *et al.*, 1990) according to Flory theory as,

$$C_p^E = \frac{P^*V^*}{T^*} \left[\frac{1}{\left(\frac{4}{3}\tilde{V}^{-1/3-1}\right)} - \sum_i \left\{ \frac{X_i}{\left(\frac{4}{3}\tilde{V}_i^{-1/3-1}\right)} \right\} \right] \tag{26}$$

For binary mixtures, this equation reduces to

$$C_p^E = \frac{P^*V^*}{T^*} \left[\frac{1}{\left(\frac{4}{3}\tilde{V}^{-1/3-1}\right)} - \left\{ \frac{X_1}{\left(\frac{4}{3}\tilde{V}_1^{-1/3-1}\right)} + \frac{X_2}{\left(\frac{4}{3}\tilde{V}_2^{-1/3-1}\right)} \right\} \right] \tag{27}$$

Adiabatic Compressibility (β_s)

From the well-known thermodynamic relation

$$\beta_T - \beta_s = \frac{\alpha^2TV}{c_p} \tag{28}$$

therefore,

$$\beta_s = \beta_T - \frac{\alpha^2TV}{c_p} \tag{29}$$

with the help of this equation, we can calculate the value of adiabatic compressibility for the liquid mixtures knowing α , β_T and C_p .

Heat Capacities Ratio (γ)

The well-known thermodynamic relation for the heat capacities ratio is given as,

$$\gamma = \frac{\beta_T}{\beta_s} \tag{30}$$

Heat Capacity at Constant Volume (C_v)

The heat capacity at constant volume of the mixture is calculated by the relation

$$C_v = \frac{c_p}{\gamma} \tag{31}$$

Pseudo- Grüneisen Parameter (Γ)

Pseudo- Grüneisen parameter of the mixture can be expressed as

$$\Gamma = \frac{\gamma-1}{\alpha T} \tag{32}$$

Density (ρ)

The molar volume (V) of the mixture is related with the characteristic volume (V^*) and reduced volume (\tilde{V}) of the mixture as,

$$V = V^*\tilde{V} \tag{33}$$

where,

$$V^* = \sum x_i V_i^* \tag{34}$$

and \tilde{V} is obtained from eq. (20)

We know that density is defined as

$$\rho = \frac{M_m}{V} \tag{35}$$

where M_m is the molecular weight of the mixture given by

$$M_m = \sum X_i M_i \tag{36}$$

where M_i is the molecular weight of the i^{th} pure component.

Thus, with the help of eq. (35), theoretical value of density for the mixture can be calculated.

Ultrasonic Velocity (u)

Ultrasonic velocity of the mixture can be calculated with the help of equation,

$$u = \left(\frac{1}{\beta_s \rho} \right)^{1/2} \tag{37}$$

RESULTS AND DISCUSSION

To compute the values of various thermodynamic properties of binary liquid mixtures at elevated pressures using Flory's statistical theory described above, we need several parameters of the constituent pure components. The reduced and characteristic parameters are calculated with the help of thermal expansion coefficient and isothermal compressibility of pure components. The thermal expansion coefficient and isothermal compressibility are calculated using empirical relations (Pandey *et al.*, 1997). The other parameters of pure components are calculated using well known thermodynamic relations and are reported in tables 1-3. Using these values of pure components, various thermodynamic and other properties (V^E , α , β_T , P_i , C_p , C_p^E , β_s , γ , C_v , Γ , ρ and u) of two binary liquids mixtures namely, toluene+ o-xylene and toluene+ aniline have been computed at elevated pressures (0.1 MPa to 160 MPa) at 303.15K (Singh, 2003) which will be reported in separate papers. An excellent agreement has been observed between the theoretical and experimental values of the above-mentioned properties, confirming the validity of the present approach.

Table 1: Properties of Toluene at 303.15 K

Pressure (MPa)	ρ (gm/ cm ³)	u (m/ s)	$\alpha \times 10^3$ (K ⁻¹)	$\beta_T \times 10^{12}$ (cm ² / dyn)	\tilde{V}	V* (cm ³ / mol)	T* (K)	\tilde{P}	P* $\times 10^{-7}$ (dyn/ cm ²)	$\beta_S \times 10^{12}$ (cm ² / dyne)	C _P (J/K mol)	γ	C _V (J/K mol)	P _i $\times 10^{-7}$ (dyn/ cm ²)
0.1	0.8580	1285.8	1.176	100.09	1.2865	83.4810	4840.31	0.00017	589.34	70.50	152.14	1.420	107.16	505.56
10	0.8657	1334.3	1.151	91.84	1.2858	82.7837	4721.67	0.01635	611.54	64.88	158.54	1.416	112.00	527.74
20	0.8729	1378.7	1.129	85.08	1.2851	82.1462	4615.28	0.03168	631.41	60.27	164.46	1.412	116.50	547.92
30	0.8796	1421.6	1.109	79.21	1.2842	81.5773	4522.06	0.04611	650.59	56.26	170.20	1.408	120.88	567.66
40	0.8858	1461.3	1.091	74.26	1.2834	81.0536	4437.05	0.05988	667.96	52.87	175.55	1.405	124.97	585.82
50	0.8917	1499.9	1.075	69.87	1.2825	80.5779	4360.98	0.07301	684.83	49.85	180.78	1.402	128.98	603.65
60	0.8972	1535.1	1.060	66.15	1.2817	80.1283	4288.80	0.08576	699.64	47.30	185.60	1.399	132.69	619.59
70	0.9025	1567.0	1.047	63.00	1.2812	79.6989	4219.06	0.09826	712.38	45.13	190.01	1.396	136.11	633.62
80	0.9075	1601.0	1.034	59.91	1.2802	79.3183	4159.36	0.11009	726.70	42.99	194.68	1.393	139.71	649.32
90	0.9122	1630.3	1.023	57.37	1.2796	78.9402	4097.85	0.12196	737.92	41.24	198.78	1.391	142.90	662.05
100	0.9168	1659.3	1.013	55.02	1.2790	78.5883	4041.01	0.13350	749.05	39.62	202.84	1.389	146.07	674.77
110	0.9212	1688.0	1.002	52.83	1.2783	78.2597	3988.36	0.14472	760.08	38.10	206.87	1.387	149.20	687.48
120	0.9253	1716.1	0.993	50.80	1.2775	77.9502	3938.95	0.15568	770.80	36.70	210.82	1.384	152.28	699.95
130	0.9294	1742.0	0.984	49.02	1.2770	77.6476	3889.47	0.16666	780.03	35.46	214.50	1.382	155.16	711.02
140	0.9333	1769.2	0.975	47.26	1.2762	77.3718	3845.91	0.17714	790.32	34.23	218.34	1.380	158.16	723.20
150	0.9370	1794.0	0.967	45.71	1.2756	77.0984	3801.21	0.18775	798.95	33.16	221.89	1.379	160.95	733.77
160	0.9407	1816.0	0.960	44.38	1.2752	76.8235	3754.22	0.19862	805.56	32.24	225.09	1.377	163.48	742.40

Table 2: Properties of o-xylene at 303.15 K

Pressure	ρ	u	$\frac{\alpha \times 10^3}{10^3}$	$\beta_T \times 10^{12}$	\tilde{V}	V^*	T^*	\tilde{P}	$P^* \times 10^{-7}$	$\beta_S \times 10^{12}$	C_P	γ	C_V	$P_i \times 10^7$
(MPa)	(gm/cm ³)	(m/s)	(K ⁻¹)	(cm ² /dyn)		(cm ³ /mol)	(K)		(dyn/cm ²)	(cm ² /dyne)	(J/K mol)		(J/K mol)	(dyn/cm ²)
0.1	0.8714	1329.5	1.150	91.70	1.2815	95.0708	4893.98	0.00016	62447	64.92	182.57	1.412	129.26	537.08
10	0.8784	1377.4	1.127	84.52	1.2808	94.3691	4782.68	0.01546	646.77	60.00	189.87	1.409	134.79	559.51
20	0.885	1418.4	1.108	78.91	1.2803	93.6991	4678.64	0.03008	664.92	56.16	196.24	1.405	139.66	578.11
30	0.8912	1459.8	1.090	73.81	1.2795	93.1043	4588.35	0.04389	683.56	52.65	202.66	1.402	144.57	597.40
40	0.8971	1504.1	1.071	68.92	1.2782	92.5906	4513.58	0.05679	704.40	49.27	209.50	1.399	149.77	619.04
50	0.9026	1539.8	1.057	65.23	1.2775	92.0727	4436.97	0.06947	719.78	46.73	215.14	1.396	154.11	635.44
60	0.9079	1584.0	1.040	61.16	1.2759	91.6575	4381.16	0.08095	741.17	43.90	221.97	1.393	159.32	657.94
70	0.9129	1607.3	1.030	58.97	1.2761	91.1429	4301.36	0.09353	748.40	42.40	225.87	1.391	162.42	666.53
80	0.9176	1638.7	1.019	56.34	1.2754	90.718	4239.74	0.10508	761.33	40.58	230.92	1.388	166.33	680.86
90	0.9222	1667.7	1.008	54.04	1.2748	90.3087	4179.78	0.11648	772.70	38.99	235.62	1.386	170.00	693.73
100	0.9266	1690.6	1.000	52.25	1.2747	89.8867	4114.50	0.12824	779.80	37.76	239.46	1.384	173.04	702.47
110	0.9308	1721.8	0.989	50.07	1.2738	89.5467	4067.50	0.13872	792.97	36.24	244.47	1.382	176.94	717.28
120	0.9349	1748.9	0.980	48.25	1.2731	89.2023	4017.64	0.14938	803.31	34.97	248.91	1.380	180.41	729.36
130	0.9388	1773.2	0.972	46.68	1.2727	88.8603	3966.57	0.16016	811.68	33.88	252.95	1.378	183.59	739.54
140	0.9426	1797.0	0.964	45.20	1.2722	88.5345	3917.89	0.17078	819.76	32.85	256.91	1.376	186.72	749.50
150	0.9463	1820.4	0.957	43.82	1.2718	88.2239	3871.56	0.18124	827.61	31.89	260.82	1.374	189.80	759.28
160	0.9498	1847.6	0.948	42.33	1.2709	87.9555	3835.05	0.19083	838.45	30.84	265.27	1.372	193.29	772.06

Table 3: Properties of Aniline at 303.15 K

Pressure	ρ	u	$\alpha \times 10^3$	$\beta_T \times 10^{12}$	\tilde{V}	V^*	T^*	\tilde{P}	$P^* \times 10^{12}$	$\beta_S \times 10^{12}$	C_P	γ	C_V	$P_i \times 10^{-7}$
(MPa)	(gm/cm ³)	(m/s)	(K ⁻¹)	(cm ² /dyn)		(cm ³ /mol)	(K)		(dyn/cm ²)	(cm ² /dyne)	(J/K mol)		(J/Kmol)	(dyn/cm ²)
0.1	0.9871	1624.2	0.998	52.03	1.2508	75.4263	5273.69	0.00011	910.03	38.40	209.20	1.355	154.40	788.11
10	0.9917	1653.3	0.988	49.91	1.2507	75.0828	5188.15	0.01083	923.31	36.89	213.56	1.353	157.86	802.00
20	0.9962	1682.1	0.978	47.92	1.2506	74.7548	5107.79	0.02136	936.42	35.48	217.88	1.351	161.30	815.82
30	1.0005	1710.1	0.969	46.10	1.2504	74.4432	5032.60	0.03161	949.04	34.18	222.10	1.349	164.66	829.26
40	1.0047	1737.3	0.960	44.42	1.2501	74.1463	4961.94	0.04162	961.17	32.98	226.23	1.347	167.95	842.30
50	1.0088	1763.9	0.951	42.86	1.2498	73.8632	4895.50	0.05139	972.96	31.86	230.28	1.345	171.19	855.08
60	1.0127	1787.7	0.944	41.51	1.2497	73.5837	4829.99	0.06106	982.66	30.90	233.96	1.343	174.16	865.87
70	1.0166	1814.9	0.935	40.07	1.2493	73.3321	4772.92	0.07034	995.16	29.86	238.10	1.342	177.46	879.47
80	1.0203	1839.3	0.928	38.82	1.2489	73.0817	4715.99	0.07956	1005.54	28.97	241.87	1.340	180.49	891.06
90	1.0240	1862.9	0.921	37.67	1.2486	72.8399	4661.40	0.08864	1015.38	28.14	245.54	1.338	183.45	902.16
100	1.0275	1885.9	0.914	36.58	1.2483	72.6067	4609.13	0.09758	1024.82	27.36	249.13	1.337	186.35	912.92
110	1.0310	1908.1	0.908	35.58	1.2480	72.3805	4558.64	0.10641	1033.69	26.64	252.62	1.335	189.17	923.17
120	1.0343	1929.7	0.902	34.63	1.2477	72.1614	4509.97	0.11515	1042.16	25.96	256.04	1.334	191.94	933.05
130	1.0376	1950.5	0.896	33.76	1.2475	71.9481	4462.61	0.12381	1050.03	25.33	259.35	1.333	194.62	942.40
140	1.0409	1970.5	0.891	32.94	1.2472	71.7398	4416.36	0.13241	1057.30	24.74	262.55	1.331	197.23	951.19
150	1.0440	1989.9	0.885	32.17	1.2470	71.537	4371.35	0.14096	1064.13	24.19	265.68	1.330	199.78	959.57
160	1.0471	2008.5	0.880	31.45	1.2468	71.3384	4327.11	0.14949	1070.33	23.67	268.70	1.329	202.25	967.38

REFERENCES

- Abe A. and Flory P.J., 1965. The Thermodynamics Properties of Mixtures of Small, Non- Polar Molecules. *J. Am. Chem. Soc.*, **87**: 1838.
- Aminabhavi T.M., Banerjee K. and Balundgi R.H., 1999. Thermodynamic Interactions in Binary Mixtures of 1-Chloronaphthalene and Monocyclic Aromatics. *Ind. J. Chem.*, **38A**: 768.
- Flory P.J., 1965. Statistical Thermodynamics of Liquid Mixtures. *J. Am. Chem. Soc.*, **87**: 1833.
- Flory P.J., Orwoll R.A. and Vrij A., 1964 (a). Statistical Thermodynamics of Chain Molecule Liquids I. *J. Am. Chem. Soc.*, **86**: 3507.
- Flory P.J., Orwoll R.A. and Vrij A., 1964 (b). Statistical Thermodynamics of Chain Molecule Liquids II. *J. Am. Chem. Soc.*, **86**: 3515.
- Islam M.R. and Quadri S.K., 1988. Applicability of Flory's Statistical Theory for the Evaluation of Excess Volume, Sound Velocity and Viscosity. *Acoust Lett.*, **11**: 237.
- Khanwalkar M.S., Murty J.S. and Deshpande D.D., 1990. Ultrasonic Velocity in Binary Liquid Mixtures. *Acoust Lett.*, **13**: 121.
- Letcher T.M. and Baxter R.C., 1989. Application of the Prigogine- Flory- Patterson Theory. *J. Soln. Chem.*, **18**: 65(I), 81(II), 89(III).
- Oswal S.L., Dave J.P. and Managoli V., 1992. Theoretical Estimation of Isentropic Compressibility and Speed of Sound in Binary Liquid Mixtures. *Acoust. Lett.*, **16**: 143.
- Pandey J.D., Dubey G.P., Tripathi N. and Singh A.K., 1997. Evaluation of Internal Pressure of Multicomponent Liquid Mixtures Using Velocity and Density Data. *J. Int. Acad. Phys. Sci.*, **1**: 117.
- Pandey J.D. and Pant N., 1982. Surface Tension of a Ternary Polymeric Solution. *J. Am. Chem. Soc.*, **104**: 3299.
- Pandey J.D., Shukla R.K., Shukla A.K. and Rai R.D., 1988. Prediction of Excess Volumes of Ternary Liquid Mixtures. *J. Chem. Soc. Faraday Trans. I.*, **84**: 1853.
- Pandey J.D. and Sanguri V., 2001. Prediction of Density of Liquid Mixtures using Flory's Statistical Theory. *J. Chem. Research (S)*, pp.344.
- Singh V.K., 2003. D Phil Thesis, Statistical Mechanics and Thermodynamics of Liquids and Liquid Mixtures, Department of Chemistry, University of Allahabad.
- Takagi T. and Teranishi H., 1982. Ultrasonic Speed and Thermodynamic Properties of (benzene+ nitrobenzene) Under High Pressure. *J. Chem. Therm.*, **14**: 1167.
- Takagi T. and Teranishi H., 1985. Ultrasonic Speed and Thermodynamics of (toluene+ o-xylene) and (toluene+ aniline) Under High Pressure. *J. Chem. Therm.*, **17**: 1057.
- Takagi T. and Teranishi H., 1988. Ultrasonic Speed and Thermodynamics of (benzonitrile+ nitrobenzene) Under High Pressure. *J. Chem. Therm.*, **20**: 809.