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THERMODYNAMIC STUDIES OF MOLECULAR INTERACTIONS IN TERNARY LIQUID MIXTURES AT VARIOUS TEMPERATURES

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ABSTRACT

Ultrasonic Velocity (U), density (ρ), and viscosity (η) were measured for mixtures of 1-alkanols namely 1-pentanol, 1-hexanol and 1-octanol with Methyl Methacrylate (MMA) in Cyclohexane at 303K, 313K, and 323K. The experimental data was used to calculate various acoustical parameters like adiabatic compressibility (β), Free length (L_f), Free volume (V_f), Internal pressure (π_i), Acoustical impedance(Z) and Viscous relaxation time (τ).

Keywords: 1-alknols, MMA, Ultrasonic velocity, Ternary liquid mixtures.

INTRODUCTION

In recent years, the measurement of ultrasonic velocity has been successfully employed in understanding the nature of molecular interactions in pure liquids and liquid mixtures. Ultrasonic velocity measurements are highly sensitive to molecular interactions and can be used to provide qualitative information about the physical nature and strength of molecular interaction in liquid mixtures[1-3]. The ultrasonic velocity of a liquid is fundamentally related to the binding forces between atom and molecules and has been successfully employed in understanding the nature of molecular interaction in pure liquids and binary and ternary mixtures[4-6]. Variations in ultrasonic velocity and related parameters have shed much light upon the structural changes associated with liquid mixtures of weakly[7] or strongly interacting compounds[8]. The study of molecular associations in ternary mixtures having an alcohol as one component is of particular interest since alcohols are strongly self-associated liquids with a three-dimensional network of hydrogen bonds[9] and can be associated with any other group having some degree of polar attractions[10]. A survey of literature has shown that a few attempts have been made to obtain ultrasonic velocity data for ternary liquid mixtures [11-13].

However, no thermo dynamical studies have been conducted for ternary mixture of Methyl Methacrylate (MMA), Cyclohexane and 1-alkanols. Hence, experimental studies were carried out by the authors to characterize Methyl Methacrylate + Cyclohexane + 1-pentanol, 1-hexanol and 1-octonal through Ultrasonic velocity measurements at 303K, 313K and 323K. The main purpose of this study is to determine the effect of the chain length of 1-alkanols.

EXPERIMENTAL

The chemicals used in the present work were analytical reagent (AR) grades with a minimum assay of 99.9%, obtained from S.D. Fine chemicals, (India) and E-Merck (Germany), without further purification. In all the systems, the various concentrations of the ternary liquid mixtures were prepared in terms of mole fraction, out of which the mole fraction of the second component, MMA (X_2=0.4) was kept fixed while the mole fraction of the remaining two (X_1 and X_3) were varied from 0.0 to 0.6. The densities of pure liquids and liquid mixtures were determined using a specific gravity bottle via the relative measurement method with an accuracy of ±0.1mg. An Ostwald's viscometer with 10 ml capacity was

used for the viscosity measurements of pure liquids and liquid mixtures. The viscometer was calibrated with fresh conductivity water immersed in a water bath that can be operated at various temperatures. The flow time of water (t_w) and the flow time of solution (t_s) were measured with a digital stop clock with an accuracy of 0.01s (RACER HS-10w). An ultrasonic interferometer supplied by M/s. Mittal Enterprises, New Delhi, with frequency of 2MHz and over all accuracy of ±2ms^{-1} was used for velocity measurement.

RESULTS AND DISCUSSION

Ultrasonic velocity (u)

$$U = n\lambda \ldots\ldots\ldots\ldots\ldots\ldots (ms^{-1}) \quad (1)$$

Where,

n- Frequency of the Ultrasonic wave in Hz.

λ- Wavelength of the Ultrasonic wave in solution under study in meter.

Viscosity (η_s)

$$\eta_s = \eta_w \left(\frac{\rho_s t_s}{\rho_w t_w}\right) \ldots\ldots\ldots\ldots (NSm^{-1}) \quad (2)$$

Where,

η_w-Coefficient of viscosity of water in NSm^{-1}

ρ_w-Density of water in Kg/m^3

t_w-Flow of time for water in seconds

ρ_s-Density of solution in Kg/m^3

t_s-Flow of time solution in seconds

Density (ρ_2)

$$\rho_2 = \frac{w_2}{w_1}\rho_1 \ldots\ldots\ldots\ldots (Kg/m^3) \quad (3)$$

Where,

w_1 & w_2-Weight of distilled water and experimental liquid

ρ_1 & ρ_2-Densities of water and experimental liquid.

Adiabatic compressibility (β)

$$\beta = \left(U^2\rho\right)^{-1} \ldots\ldots\ldots\ldots (N^{-1}m^2) \quad (4)$$

Where

U- Velocity in meter/sec

ρ- Density in Kg/m^3

Free Volume (V_f)

Suranarayana[14] obtained a formula for free volume in term of the ultrasonic velocity (U) and the viscosity of the liquid (η) as

$$V_f = \left[\frac{M_{eff}U}{K\eta}\right]^{\frac{3}{2}} \ldots\ldots\ldots (m^3 mol^{-1}) \quad (5)$$

Where, M_{eff} is the effective molecular weight ($M_{eff} = \sum m_i x_i$ in which m_i and x_i are the molecular weight and the mole fraction of the individual constituents respectively) and K is a temperature independent constant equal to 4.28×10^9 for all liquids.

Internal Pressure (π_i)

On the basis of statistical thermo dynamics, Surayanarayana[15] derived an expression for the determination of internal pressure through the use of the concept of free volume

$$\pi_i = bRT\left[\frac{K\eta}{U}\right]^{\frac{1}{2}}\left[\frac{\rho^{\frac{1}{3}}}{M^{\frac{7}{6}}}\right] \ldots\ldots\ldots\ldots (Pa) \quad (6)$$

Where,

T-Absolute temperature in kelvin,
ρ -The density in Kg/m^3 and
R-The universal gas constant.
B -The cubic packing fraction factor is assumed to be '2' for all liquid systems.

Viscous relaxation time (τ)

$$\tau = \frac{4}{3}\beta\eta \ldots\ldots\ldots (s) \quad (7)$$

Where,

η- Viscosity of the solution in Nsm^{-2}.
β- Adiabatic compressibility $N^{-1}m^2$

Acoustic impedance (z)

$$Z = U\rho \ldots\ldots\ldots (Kgm^{-2}s^{-1}) \quad (8)$$

Where,

U and ρ are density and velocity of liquid respectively.

Free Length (L_f)

$$L_f = K_T\beta^{\frac{1}{2}} \ldots\ldots\ldots (m) \quad (9)$$

Where,

K_T- Jacob's constant
B- Adiabatic compressibility in $N^{-1}m^2$

The experimentally determined values of density (ρ), Viscosity (η) and Ultrasonic velocity (U) for the tree systems at three temperatures are given in the Table -1. From these observed values various acoustical parameters like adiabatic compressibility (β), free length (L_f), free volume, internal pressure, acoustic impedance, viscous relaxation time have been evaluated and is presented in the Tables-2 and 3.

In all the three liquid systems, the value of density, viscosity and the ultrasonic velocity increases with increasing molar concentration of alcohols as well as with temperature. The value of viscosity increases with increasing concentrations of 1-alkanols and decreased with increasing temperature. As the number of hydro carbon groups or the chain length of the alcohol increased, a gradual increase in sound velocity was observed. This behavior of ideal mixtures and can be attributed to intermolecular interactions in the systems studied[16].

MMA is an industrial ester on other hand alcohols are polar liquids strongly associated with hydrogen bonding, with an extent of polymerization that may differ depending on temperature, chain length and position of OH group. When the compounds are mixed, the changes that occur in association equilibrium were evidently due to the rupture of the hydrogen bonds in pure Cyclohexane and 1- alcohols and MMA, dipole-dipole interactions and the formation of O-H….C=O hydrogen bonds between the components. It is well known that 1-alcohols form a variety of a species with different degree of association in the pure state; however, polymeric liner associates are expected to be predominant in the pure state. Thus, the additional of an acrylic ester (MMA) to a 1-alcohol (1-PeOH, 1-HeOH, or 1-OtOH) may result in the following effects: (i) rupturing or disruption of associate structures in alcohols, (ii) formation of new

species because of weak interaction between ester and alcohols, and (iii) free volume changes upon mixing of components of different sizes.

Adiabatic compressibility (β) is found to be decreased with increasing concentration of alcohols. It is primarily the compressibility that changes with structure which leads to change ultrasonic velocity.

The change in adiabatic compressibility in liquid mixtures indicates there is a definite contraction on mixing and the variation is may be due to complex formation. This clearly shows that there is significant interaction between the ester and alcohols molecules[17]. The decrease in value of compressibility (β) also indicates a domination contribution from structure-breaking effect in MMA by the globular cyclohexane molecule. Intermolecular free length (L_f) shows a similar behavior as reflected by adiabatic compressibility. The decrease in compressibility brings the molecules to a closer packing resulting into a decrease of intermolecular free length. Intermolecular free length is a predominant factor in determining the variation of ultrasonic velocity in the mixtures. As L_f increases, U decreases and vice-versa, shows an inverse behavior[18]. The decrease in the value of adiabatic compressibility and the free length with increase in ultrasonic velocity further strengthens the molecular association between the unlike molecules through hydrogen bonding.

It is seen that for all the three systems, the values free volume (V_f) decrease and the internal pressure (π_i) increase. Further, the decrease in free volume and increase in internal pressure with rise in concentration of alcohols in all the three systems clearly show the increasing magnitude of interactions. Such an increase in internal pressure generally indicates association through hydrogen bonding and hence supports the present investigation. In the systems, studied, the complex formation is likely to occur between $H^{\delta+}$ of alcohols and $O^{\delta-}$ of C=O group of MMA. Oxygen atom is sp^3 hybridized and in the MMA structure there are a lot voids available for O-H to penetrate and enter into complexation, and also provides information regarding the hydrogen bond between interacting components.

In the present investigation, it is observed that these acoustic impedance (Z) values increase with increasing concentration of alcohols. Such increasing trends of acoustic impedance further support the possibility of molecular interaction due to H-bonding between the MMA-alcohol molecules. The viscous relaxation time (τ) decreases with increases in mole fraction of alcohol and alkoxyethanols and increase in temperature. The relaxation time that is in the order of 10^{-12} sec is due to the structural relaxation process showing the presence of molecular interaction. The relaxation time (τ) shows continuous increase with chain length of alcohols and offer hindrance to the rotation of the molecule.

The increase in relaxation time with chain length is to be expected in view of the fact that hydroxyl group reorientation depends to some extent on the length of the alkyl group, and the viscosity of the liquid. At high concentration of alcohol in the mixture, there are a large number of alcohol molecules surrounding the ester molecules. At low concentration of alcohol in the mixtures, there are only a small number of alcohol molecules to enable dipole-dipole interaction through hydrogen bonding with the non-associative ester molecules. The associative alcohol molecules act as proton donor enabling hydrogen bonding with MMA molecules. At low concentration of alcohol in the mixtures, there are only a small number of alcohol molecules to enable dipole-dipole interaction through hydrogen bonding with the non associative ester molecules

As a result weak intermolecular interaction occurs. The relaxation time increases with increasing the alkyl chain length of alcohol indicating that the degree of cooperation for reorientation of the molecules increases with increasing length and the bulk of cluster increases.

CONCLUSION

The results obtained for the present study indicate that the thermodynamic parameters are sensitive to the molecular interactive present in liquid mixtures. From Ultrasonic velocity and related acoustical parameters for ternary mixtures of 1- alkanols with MMA in Cyclohexane at different concentrations and at varying temperature, it is concluded that there exists a molecular interaction between MMA and 1-alkanols due to hydrogen bonding and degree of complexation varies with the carbon chain length of 1-alkanols.

Table-1:Density (ρ), Viscosity (η) and Velocity (U) of Methyl Methacrylate + Cyclohexane + 1-Pentanol, Methyl Methacrylate + Cyclohexane + 1-Hexonal and Methyl Methacrylate + Cyclohexane + 1-Octanol

Mole Fraction		Density(ρ)			Viscosity(η)			Velocity(U)		
		(Kgm^{-3})			($10^{-3}NSm^{-2}$)			(ms^{-1})		
X_1	X_3	303K	313K	323K	303K	313K	323K	303K	313K	323K
Methyl Methacrylate + Cyclohexane + 1-Pentanol										
0.100	0.600	0.8224	0.8144	0.7920	0.5301	0.4922	0.4322	1158.2	1138.6	1074.2
0.050	0.550	0.8256	0.8156	0.7932	0.5313	0.5002	0.4402	1175.3	1155.7	1091.2
0.100	0.500	0.8262	0.8182	0.7958	0.5398	0.5087	0.4487	1183.8	1164.2	1099.8
0.150	0.450	0.8274	0.8194	0.7970	0.5412	0.5102	0.4502	1192.4	1172.8	1108.4
0.200	0.400	0.8312	0.8232	0.8008	0.5458	0.5148	0.4548	1196.3	1176.7	1112.3
0.250	0.350	0.8350	0.8270	0.8046	0.6022	0.5712	0.5112	1217.8	1198.2	1133.8
0.300	0.300	0.8390	0.8310	0.8086	0.6254	0.5944	0.5344	1240.0	1220.0	1156.0
0.350	0.250	0.8406	0.8326	0.8102	0.6886	0.6576	0.5976	1260.0	1240.0	1176.0
0.400	0.200	0.8426	0.8346	0.8122	0.7422	0.7112	0.6512	1272.0	1252.2	1187.8
0.450	0.150	0.8457	0.8377	0.8159	0.7866	0.7556	0.6956	1282.0	1262.0	1197.6
0.500	0.100	0.8477	0.8397	0.8179	0.8076	0.7766	0.7166	1247.6	1228.0	1163.6
0.550	0.050	0.8490	0.8410	0.8192	0.8122	0.7812	0.7212	1237.8	1218.2	1153.8
0.600	0.000	0.8088	0.8008	0.7790	1.4872	1.4562	1.3962	1248.0	1233.3	1169.1
Methyl Methacrylate + Cyclohexane + 1-Hexonal										
0.100	0.600	0.8259	0.8164	0.7954	0.5624	0.5075	0.4432	1164.2	1140.6	1083.6
0.050	0.550	0.8299	0.8204	0.7994	0.5844	0.5295	0.4652	1183.2	1159.6	1102.6
0.100	0.500	0.8319	0.8219	0.8009	0.6124	0.5575	0.4932	1191.8	1168.2	1111.2
0.150	0.450	0.8366	0.8271	0.8061	0.6428	0.5875	0.5232	1199.6	1176.0	1119.0
0.200	0.400	0.8381	0.8286	0.8076	0.6758	0.6205	0.5562	1204.0	1180.4	1123.4
0.250	0.350	0.8394	0.8299	0.8089	0.7066	0.6513	0.5870	1234.0	1210.4	1153.4
0.300	0.300	0.8424	0.8329	0.8119	0.7444	0.6891	0.6248	1285.0	1261.0	1204.0
0.350	0.250	0.8461	0.8366	0.8156	0.8122	0.7569	0.6926	1286.0	1263.0	1206.0
0.400	0.200	0.8472	0.8377	0.8167	0.8734	0.8181	0.7538	1290.0	1266.5	1209.2
0.450	0.150	0.8499	0.8404	0.8194	0.9233	0.868	0.8037	1292.0	1268.0	1211.0
0.500	0.100	0.8520	0.8425	0.8242	0.9865	0.9312	0.8669	1261.1	1238.0	1181.0
0.550	0.050	0.8547	0.8452	0.8266	1.1376	1.0823	1.0180	1258.5	1235.4	1178.4
0.600	0.000	0.8136	0.8043	0.7903	2.6448	2.5895	2.5252	1444.4	1421.3	1364.3
Methyl Methacrylate + Cyclohexane + 1-Octanol										
0.100	0.600	0.8326	0.8188	0.7999	0.5822	0.5658	0.5466	1170.6	1150.8	1130.0
0.050	0.550	0.8348	0.8210	0.8021	0.5878	0.5714	0.5522	1178.4	1158.6	1137.8
0.100	0.500	0.8364	0.8226	0.8037	0.5936	0.5772	0.5580	1186.8	1167.0	1146.2
0.150	0.450	0.8402	0.8264	0.8075	0.5998	0.5834	0.5642	1192.6	1172.8	1152.0
0.200	0.400	0.8482	0.8344	0.8155	0.6122	0.5958	0.5766	1204.2	1184.4	1163.6

0.250	0.350	0.8524	0.8386	0.8197	0.6196	0.6032	0.5840	1226.2	1206.4	1185.6
0.300	0.300	0.8533	0.8395	0.8206	0.6204	0.6040	0.5848	1268.0	1249.0	1228.0
0.350	0.250	0.8568	0.8430	0.8241	0.6722	0.6558	0.6366	1299.0	1279.0	1258.0
0.400	0.200	0.8608	0.8470	0.8281	0.6902	0.6738	0.6546	1320.0	1300.4	1279.6
0.450	0.150	0.8654	0.8516	0.8327	0.7944	0.7780	0.7588	1378.0	1358.6	1337.8
0.500	0.100	0.8663	0.8525	0.8336	0.8066	0.7902	0.7710	1304.0	1284.2	1263.6
0.550	0.050	0.8672	0.8534	0.8345	0.8122	0.7958	0.7766	1298.0	1278.2	1257.6
0.600	0.000	0.8239	0.8101	0.7912	1.6722	1.6558	1.6366	1348.8	1329.0	1308.4

Table-2:Adiabatic compressibility (β), Free Volume (V_f), and Free Length (L_f) of Methyl Methacrylate+ Cyclohexane + 1-Pentanol, Methyl Methacrylate + Cyclohexane + 1-Hexonal and Methyl Methacrylate+ Cyclohexane + 1-Octanol

Mole Fraction		Adiabatic Compressibility (β)			Free Volume (V_f)			Free Length (L_f)		
		($10^{-10}N^{-1}m^{-2}$)			(10^{-7} m^3 mol^{-1})			(10-10m)		
X_1	X_3	303k	313k	323k	303k	313k	323k	303k	313k	323k
Methyl Methacrylate + Cyclohexane + 1-Pentanol										
0.100	0.600	9.0646	9.4715	10.9422	3.0987	3.3759	3.7596	1.8890	1.9645	2.1476
0.050	0.550	8.7686	9.1797	10.5879	3.2062	3.4224	3.8033	1.8579	1.9340	2.1125
0.100	0.500	8.6369	9.0174	10.3889	3.2140	3.4263	3.7977	1.8439	1.9168	2.0926
0.150	0.450	8.5004	8.8727	10.2129	3.2865	3.5024	3.8822	1.8290	1.9014	2.0748
0.200	0.400	8.4064	8.7733	10.0933	3.3112	3.5263	3.9028	1.8191	1.8907	2.0626
0.250	0.350	8.0753	8.4224	9.6682	2.9793	3.1476	3.4220	1.7829	1.8525	2.0187
0.300	0.300	7.7516	8.0796	9.2544	2.9364	3.0943	3.3463	1.7468	1.8144	1.9750
0.350	0.250	7.4980	7.8112	8.9307	2.6415	2.7647	2.9459	1.7180	1.7840	1.9402
0.400	0.200	7.3373	7.6414	8.7267	2.4299	2.5309	2.6687	1.6995	1.7645	1.9179
0.450	0.150	7.1991	7.4953	8.5455	2.2877	2.3744	2.4850	1.6834	1.7476	1.8979
0.500	0.100	7.5789	7.8973	9.0301	2.1436	2.2199	2.3100	1.7273	1.7938	1.9510
0.550	0.050	7.6876	8.0124	9.1695	2.1316	2.2063	2.2926	1.7396	1.8069	1.9660
0.600	0.000	7.9383	8.2099	9.3920	0.8838	0.8961	0.8809	1.7677	1.8290	1.9914
Methyl Methacrylate + Cyclohexane + 1-Hexonal										
0.100	0.600	8.9334	9.4152	10.7072	2.8577	3.2329	3.6681	1.8753	1.9586	2.1244
0.050	0.550	8.6071	9.0647	10.2896	2.8036	3.1540	3.5512	1.8407	1.9218	2.0826
0.100	0.500	8.4629	8.9155	10.1120	2.6802	2.9945	3.3387	1.8252	1.906	2.0645
0.150	0.450	8.3063	8.7423	9.9072	2.5535	2.8366	3.1329	1.8082	1.8874	2.0435
0.200	0.400	8.2309	8.6615	9.8114	2.4169	2.6667	2.9174	1.8000	1.8786	2.0336
0.250	0.350	7.8234	8.2246	9.2927	2.3804	2.6132	2.8409	1.7549	1.8306	1.9791
0.300	0.300	7.1902	7.5469	8.4923	2.3742	2.5925	2.8016	1.6824	1.7536	1.8920
0.350	0.250	7.1443	7.4980	8.4356	2.1179	2.2897	2.4408	1.677	1.7479	1.8856
0.400	0.200	7.0952	7.4422	8.3741	1.9365	2.0785	2.1923	1.6712	1.7414	1.8788
0.450	0.150	7.0530	7.4007	8.3217	1.8130	1.9347	2.0267	1.6662	1.7365	1.8729
0.500	0.100	7.3800	7.7444	8.6989	1.6085	1.7059	1.7696	1.7044	1.7764	1.9148
0.550	0.050	7.3872	7.7522	9.1936	1.3153	1.3786	1.4079	1.7053	1.7773	1.9685

0.600	0.000	5.8913	6.1547	6.6922	0.4635	0.4670	0.4560	1.5229	1.5836	1.6795
Methyl Methacrylate + Cyclohexane + 1-Octanol										
0.100	0.600	8.7648	9.2219	9.7905	2.7355	2.7832	2.8520	1.8575	1.9384	2.0314
0.050	0.550	8.6264	9.0738	9.6303	2.7574	2.8048	2.8732	1.8428	1.9228	2.0147
0.100	0.500	8.4885	8.9262	9.4707	2.7814	2.8285	2.8966	1.8280	1.9071	1.9980
0.150	0.450	8.3681	8.7975	9.3315	2.7950	2.8414	2.9086	1.8150	1.8933	1.9832
0.200	0.400	8.1302	8.5433	9.0566	2.7877	2.8322	2.8969	1.7890	1.8658	1.9538
0.250	0.350	7.8025	8.1933	8.6789	2.8529	2.8984	2.9641	1.7525	1.8271	1.9126
0.300	0.300	7.2842	7.6406	8.0837	3.0392	3.0900	3.1628	1.6933	1.7644	1.8459
0.350	0.250	6.9210	7.2538	7.6675	2.8336	2.8735	2.9315	1.6506	1.7192	1.7977
0.400	0.200	6.6673	6.9817	7.3751	2.8345	2.8734	2.9290	1.6200	1.6866	1.7631
0.450	0.150	6.0835	6.3618	6.7101	2.4884	2.5129	2.5492	1.5475	1.6100	1.6818
0.500	0.100	6.7885	7.1127	7.5131	2.2757	2.2937	2.3229	1.6347	1.7024	1.7796
0.550	0.050	6.8443	7.1721	7.5768	2.2753	2.2926	2.3209	1.6414	1.7095	1.7871
0.600	0.000	6.6716	6.9889	7.3830	0.8050	0.8243	0.8195	1.6206	1.6875	1.7641

Table-3:Internal Pressure (π_i), Acoustic impedance (Z) and Viscous Relaxation Time (τ) of Methyl Methacrylate + Cyclohexane + 1-Pentanol, Methyl Methacrylate + Cyclohexane + 1-Hexonal and Methyl Methacrylate+ Cyclohexane + 1-Octanol

Mole Fraction		Internal Pressure (π_i)			Acoustic impedance (Z)			Viscous Relaxation Time (τ)		
		(10^{-6} Pa)			($10^3 Kgm^{-2}s^{-1}$)			(10-12 s)		
X_1	X_3	303k	313k	323k	303k	313k	323k	303k	313k	323k
Methyl Methacrylate + Cyclohexane + 1-Pentanol										
0.100	0.600	286.301	285.556	279.055	95.250	92.727	85.076	6.406	6.215	6.305
0.050	0.550	281.848	282.580	276.350	97.032	94.258	86.553	6.211	6.122	6.214
0.100	0.500	279.83	281.138	275.197	97.805	95.254	87.522	6.216	6.116	6.215
0.150	0.450	276.135	277.460	271.600	98.659	96.099	88.339	6.133	6.035	6.130
0.200	0.400	274.424	275.812	270.145	99.436	96.865	89.072	6.117	6.022	6.120
0.250	0.350	283.204	285.405	281.233	101.682	99.091	91.225	6.483	6.414	6.589
0.300	0.300	283.574	286.032	282.376	104.503	101.415	93.474	6.463	6.403	6.594
0.350	0.250	292.174	295.378	293.052	105.988	103.242	95.247	6.884	6.848	7.116
0.400	0.200	298.961	302.735	301.418	107.161	104.508	96.473	7.261	7.246	7.577
0.450	0.150	303.706	307.906	307.503	108.384	105.717	97.712	7.550	7.551	7.925
0.500	0.100	308.814	313.323	313.525	105.759	103.115	95.170	8.160	8.177	8.627
0.550	0.050	307.689	312.240	312.596	105.089	102.450	94.519	8.325	8.345	8.817
0.600	0.000	396.906	405.425	413.094	100.938	98.762	91.072	0.157	0.159	0.174
Methyl Methacrylate + Cyclohexane + 1-Hexonal										
0.100	0.600	294.967	290.180	282.160	96.151	93.118	86.189	6.698	6.370	6.327
0.050	0.550	295.935	291.688	284.381	98.193	95.133	88.141	6.706	6.399	6.382
0.100	0.500	298.982	295.253	288.808	99.145	96.014	88.996	6.91	6.627	6.649
0.150	0.450	303.037	299.966	294.376	100.355	97.266	90.202	7.119	6.848	6.911

0.200	0.400	307.014	304.593	299.873	100.907	97.807	90.725	7.416	7.166	7.276
0.250	0.350	306.874	304.974	300.887	103.581	100.451	93.298	7.345	7.142	7.273
0.300	0.300	305.845	304.497	301.036	108.239	105.053	97.777	7.136	6.934	7.074
0.350	0.250	316.518	316.184	314.044	108.825	105.629	98.328	7.736	7.567	7.790
0.400	0.200	324.198	324.640	323.585	109.271	106.094	98.755	8.262	8.117	8.416
0.450	0.150	329.844	330.940	330.640	109.773	106.562	99.229	8.682	8.565	8.917
0.500	0.100	341.469	343.316	344.899	107.445	104.301	97.338	9.707	9.615	9.798
0.550	0.050	363.386	366.806	357.298	107.563	104.416	92.304	5.095	5.065	5.135
0.600	0.000	494.351	505.500	525.13	117.516	114.315	109.530	1.116	1.111	1.116
Methyl Methacrylate + Cyclohexane + 1-Octanol										
0.100	0.600	300.909	305.632	303.238	97.464	94.227	90.388	6.803	6.957	7.135
0.050	0.550	298.993	303.718	301.386	98.372	95.121	91.262	6.760	6.913	7.090
0.100	0.500	296.825	301.547	299.273	99.263	95.997	92.120	6.718	6.869	7.046
0.150	0.450	295.511	300.259	298.057	100.202	96.920	93.024	6.692	6.843	7.019
0.200	0.400	295.856	300.702	298.621	102.142	98.826	94.891	6.636	6.786	6.962
0.250	0.350	292.727	297.542	295.518	104.521	101.168	97.183	6.445	6.589	6.758
0.300	0.300	284.984	289.601	287.557	108.232	104.819	100.751	6.025	6.153	6.303
0.350	0.250	290.58	295.556	293.810	111.264	107.802	103.671	6.203	6.342	6.508
0.400	0.200	289.461	294.468	292.827	113.625	110.143	105.963	6.135	6.272	6.437
0.450	0.150	301.231	306.851	305.659	119.269	115.698	111.407	6.443	6.599	6.788
0.500	0.100	308.278	314.236	313.197	112.965	109.478	105.332	7.300	7.494	7.723
0.550	0.050	306.168	312.122	311.135	112.562	109.081	104.950	7.411	7.610	7.845
0.600	0.000	410.777	420.619	421.499	111.127	107.662	103.527	0.148	0.154	0.161

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