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Thermo-acoustical study of silver nanoparticles in methanol and propanol in the temperature range 288.15 K–313.15 K

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Intermolecular interaction studies of silver nanoparticles (AgNPs) and organic solvents have been completed in the temperature range (288.15–318.15) K from the experimental ultrasonic velocity and density data. Many thermo dynamical and acoustic parameters such as isothermal compressibility, adiabatic compressibility, surface tension, acoustic impedance, Rao parameter, Wada parameter, intermolecular free length and pseudo-Gruneisen parameter have been calculated. Some of the non-linear parameters like Moelwyn Hughes parameter, reduced volume, Sharma's constants, Huggins parameter, isobaric acoustical parameter, isochoric acoustical parameter, isothermal acoustical parameter, fractional free volume, repulsive exponent, volume expansivity, Bayer's non linear parameters and internal pressure have also been calculated. Elastic parameters such as longitudinal wave velocity, Shear wave velocity, Young modulus, Shear modulus, Bulk modulus and Poisson's ratio have also been find out. The results have been examined in terms of variation in temperature and concentration which give us insight regarding nature and extent of interactions prevailing between nanoparticles and different solvents.

Keywords: Silver nanoparticles, intermolecular interactions, acoustical parameters, nonlinear parameters, elastic parameters.

Introduction

Nanotechnology is branch of science which deals with the synthesis, applications and understanding of novel materials in the atomic range of 1–100 nm[1]. The nanoparticle exhibited distinct physical, chemical, optical, magnetic and biological properties from their bulk counterpart due to their high surface to volume ratio[2]. The metal based nanoparticles are extensively used in medicine, cosmetics, renewable energies, environmental remediation and biomedical devices[3–5]. Recently silver nanoparticles (AgNPs) have attracted growing attention due to high electrical and thermal conductivity, surface-enhanced Raman scattering, chemical stability, catalytic activity and non linear optical behavior[6]. These properties are being exploited in the field of microelectronics and medical imaging[7]. The bactericidal and fungicidal activity[8] of the silver nanoparticles make them popular in a diverse range of consumer products, including plastics, soaps, pastes, food and textiles, increasing their market value and attention[9–11]. Many research papers related to the study of AgNPs are published in literature but only very few have elaborated in the field of ultrasonic study of these particles. The full potential of this technology is yet to be investigated. Lately nano fluids have revealed plethora of enhanced acoustical, thermophysical properties in distinctive medico-industrial applications[12].

The ultrasonic measurement of nanoparticles is an effective technique to evaluate the thermodynamic and acoustic parameters of the nanoparticles. An examination of the thermo acoustic properties provides critical information about the molecular interactions present in the system in terms of solute-solute and solute-solvent interactions[13]. It also assimilates the nature and magnitude of pattern of molecular aggregation within components. The interactions among liquid molecules arise due to several causes such as electrostatic forces, dispersion forces, cohesive forces, van der Waal's forces, donor-acceptor interactions and H-bonding etc.[14]. Recently, Latesh Taneja and Neeraj Dahiya reported the acoustic properties of AgNPs at various concentrations and temperature which are prepared from aqueous solution of $AgNO_3$ and tannic acid[15].

The experimental values of ultrasonic velocity and density reported earlier[16] are used to calculate various thermodynamic/thermoacoustic properties viz. isothermal compressibility (β_T or K_T), adiabatic compressibility (β_s or k_s), surface tension (σ), acoustic impedance (Z), Rao factor (R), Wada factor (W), intermolecular free length (L_f), pseudo-Gruneisen parameter (Γ), some of the non linear parameters like Moelwyn Hughes parameter (C or C_1= [d(1/β/dp)])T, reduced volume (V_r), Sharma's constants (S_0, S^*, S_0^*), Huggins parameter (F), isobaric acoustical parameter (K), isochoric acoustical parameter (K″), isothermal acoustical parameter (K′), fractional free volume (FF_V), repulsive exponent (n), volume expansivity ($V_2 = V_1 (1 + ¥'_\phi)$, Bayer's non linear parameters (B/A), average Gruneisen parameter (Γ_l), internal pressure (P) and elastic parameters such as longitudinal wave velocity (U_l), Shear wave velocity (V_s), Young modulus (E), Shear modulus (G), bulk modulus (K), Poission's ratio (ν'_ϕ). All these thermodynamic and acoustic parameter are very much important because they able to make improvements in the various machine to increase their efficiency as well as other operating performance. All the devices will become more cost-effective and environment-friendly by using these parameters[31–39]. The present investigation explains the molecular interaction, anharmonicity and structure information in the present system.

Material and methods

Materials:

AgNPs were prepared via green synthesis method by using $AgNO_3$ and aqueous extract of Luffa Acutangula. Synthesized AgNPs were characterized by UV-Visible spectrophotometer, FTIR spectroscopy, TEM and EDX as reported earlier[16].

Methods:

Density and ultrasonic speed were measured at varied temperatures T = (288.15, 293.15, 298.15, 303.15, 308.15, 313.15, 318.15) K for pure silver nanoparticles as well as mixtures of silver nanoparticles with methanol and propanol in the ratio (v/v) of 1:2, 1:4, 1:6 respectively. The measurements were carried out using density and sound velocity meter (Anton Paar DSA 5000 M) and the values are reported in our earlier study[16]. AgNP2, AgNP4 and AgNP6 stands for the AgNps and solvent in the ratio (v/v) of 1:2, 1:4, 1:6 respectively.

Theory

Several researchers have reported the versatility of the acoustic parameters as a tool to investigate molecular interactions in pure liquids and binary mixtures[17–21]. Some of the thermodynamically, nonlinear and elastic parameters of AgNPs after mixing with methanol and propanol have been calculated by using theoretical formulae available in literature[22–24] using following equations:

Adiabatic compressibility is expressed as:

$$K_s = \frac{1}{U^2 d} \tag{1}$$

$$K_T = \frac{1.71\times10^{-3}}{T^{4/9}U^2 d^{4/3}} \tag{2}$$

$$\gamma = \frac{K_T}{K_S} \tag{3}$$

$$\sigma_{ST} = 10^{-4}U^{3/4}dT^{1/3} \tag{4}$$

$$z = Ud \tag{5}$$

$$R = \left(\frac{M}{d}\right)U^{\frac{1}{3}} \tag{6}$$

$$W = \left(\frac{M}{d}\right)K_s^{-\frac{1}{7}} \tag{7}$$

$$V_a = v\left(1 - \frac{U}{U_\infty}\right) \tag{8}$$

where, U_∞ = 1600 m/s and V is molar volume

$$L_f = \frac{2V_a}{Y_S} \quad (9)$$

where $Y_S = \left(36\pi 6\pi_0^2\right)^{1/3}$ is molar surface area.

$$\Gamma = \frac{\gamma - 1}{T\alpha} \quad (10)$$

The Moelwyn Hughes parameter (C_1) is obtained as:

$$C_1 = (13/3) + (1/\alpha/\,) + (4\alpha\alpha T/\,) \quad (11)$$

The reduced volume ($\tilde{V}$) and reduced compressibility ($\tilde{\beta}$) are obtained from α as follows:

$$\tilde{V} = [1 + \alpha T/3\,(1 + \alpha T)]^3 \quad (12)$$

Sharma parameters are expressed as:

$$S_0 = (X/2)(3 + 4\alpha) \quad (13)$$

$$S^* = 1 + 4/3\alpha T \quad (14)$$

$$S_0^* = (1 + 2\alpha\alpha/+ (4/3)2\alpha) \quad (15)$$

Huggins parameter is related to (S_o), (S_0^*) and (S*)as follows:

$$F = 2 - S^* + S_0\,(S_0^* - 1)/\alpha\alpha \quad (16)$$

Assuming the sound velocity (U) is the function of both volume (V) and temperature, the isobaric (K), isothermal (K′) and isochoric (K″) thermo acoustical parameters are related as

$$K = 5/3 + (2\alpha)^{-1} + 2\alpha\alpha/ \quad (17)$$

$$K'' = -1/\bar{V}^{C_1}\left[(2\alpha) - 1 - \bar{V}^{C_1} + 1\right] \quad (18)$$

$$K' = K + K'' \quad (19)$$

The fractional free volume (f) as a measure of disorder due to increased mobility of molecules in a liquid and the repulsive exponent (n) of the intermolecular potential can be expressed in terms of (K′) as:

$$f = V_a/V = (K' + 1)^{-1} \quad (20)$$

$$n = 3(2K' - 3) \quad (21)$$

$$B/A = C_1 - 1 \quad (22)$$

The internal pressure is given as

$$P_i = T\alpha/\beta \quad (23)$$

$$\alpha = \frac{75.6\times10^{-3}}{T^{1/9}U^{1/2}d^{1/3}} \quad (24)$$

$$U_1 = 1\Big/\left[(dK_T)\left(\frac{1+\sigma}{3(1-\sigma)}\right)\right]^{1/2} \quad (25)$$

$$U_S = 1\Big/\left[(dK_T)\left(\frac{2(1+\sigma)}{3(1-2\sigma)}\right)\right]^{1/2} \quad (26)$$

$$E = U_1^2 d \quad (27)$$

$$G = U_s^2 d \quad (28)$$

$$K = \frac{(3E - 4G)}{3} \quad (29)$$

$$\sigma = \frac{(3K - 2G)}{(6K + 2G)} \quad (30)$$

Result and discussion

The variation of ultrasonic speed and other thermodynamic parameters like isentropic compressibility, isothermal compressibility, surface tension, acoustic impedance, Rao parameter, Wada parameter, intermolecular free length and internal pressure in the temperature range 288.15 K–313.15 K by varying the concentration of solvents methanol and propanol is shown in Fig. 1 to Fig. 9.

Isentropic and adiabatic compressibility are compression and expansion process. A diabatic and isentropic compressibility will be same when a process is carried out in such a manner that there is no heat transfer into or out the system for example Q = 0, then isentropic and adiabatic compressibility will be same. This process may be reversible or irreversible.

It is clear from Fig. 1 that ultrasonic speed is directly proportional to temperature for the pure AgNPs. The Brownian motion in the fluid resulting in increase in velocity with the proliferation of ultrasonic vibrations through the nanofluids. The ultrasonic speed is inversely proportional to temperature after the addition of solvents like methanol and propanol to the AgNPs in which amount of AgNPs is kept fixed and concentration of solvents is varied. The random movements

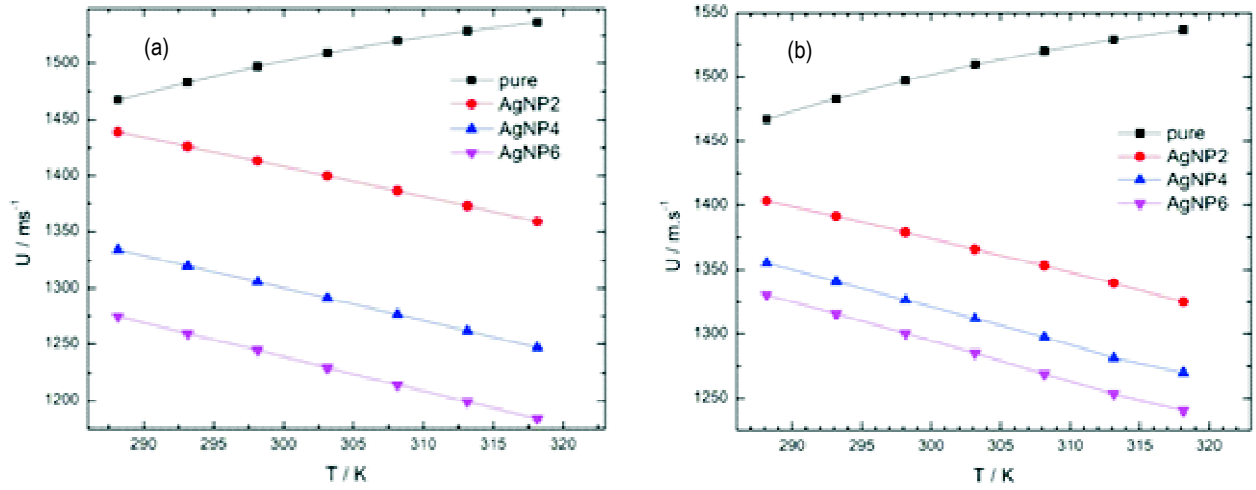

Fig. 1. Variation of ultrasonic velocity with temperature: (a) different proportion of nanoparticles and methanol, (b) different proportion of nanoparticles and propanol.

of nanoparticles are directly proportional to concentration[25] and as a result the decrease in intermolecular interactions took place.

It is observed from Figs. 2 and 3 that when temperature increases, there is decrease in K_s and K_T in case of pure AgNPs which indicates the molecules are closely packed and availability of free volume is less[26] but value of K_s and K_T increases after mixing with the solvents. As solvents are added to the AgNPs, the bonding between the molecules of AgNPs decreases. With an increase in the concentration of solvent, the molecular interaction is weakened.

It reveal from Figs. 4 and 5 it is found that in case of pure AgNPs, the surface tension ($\sigma_{S.T.}$) and acoustic impedence (Z) increases with increase in temperature. After mixing the AgNPs with methanol and propanol, the curves show the decrease in the surface tension and acoustic impedence. The trend of variation in surface tension in AgNPs is different from ordinary liquids where surface tension decreases with

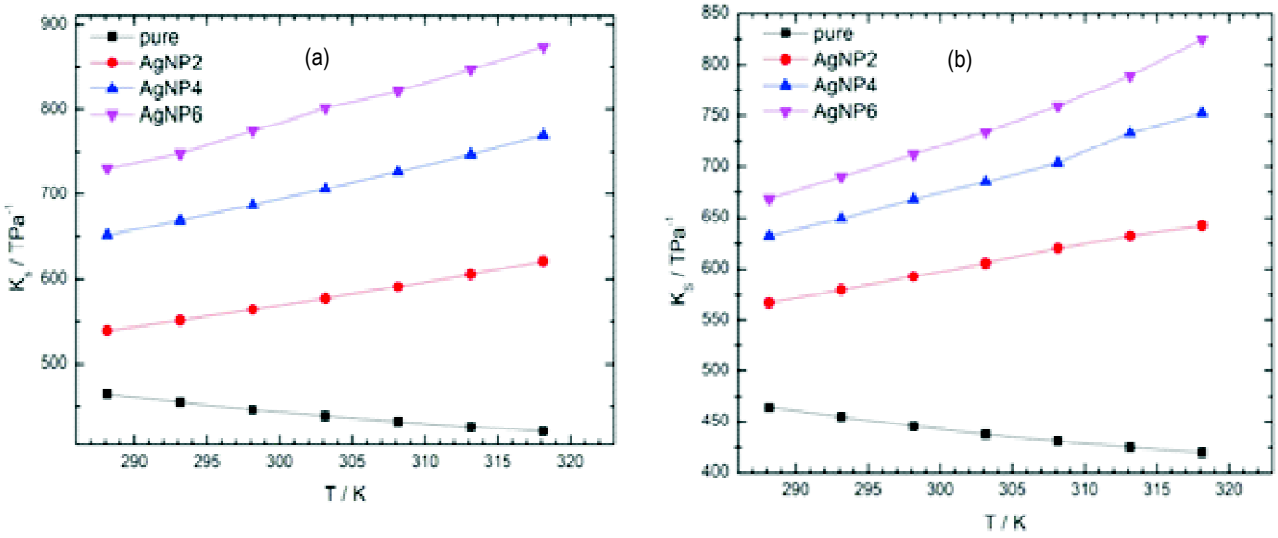

Fig. 2. Variation of isentropic compressibility with temperature: (a) different proportion of nanoparticles and methanol, (b) different proportion of nanoparticles and propanol.

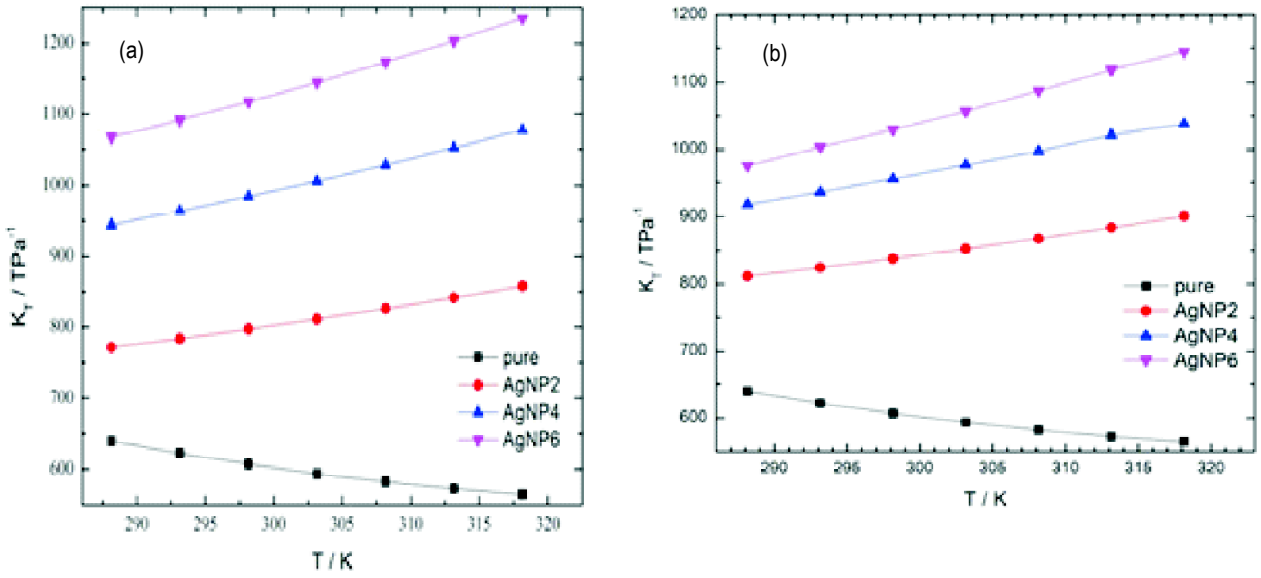

Fig. 3. Variation of isothermal compressibility with temperature: (a) different proportion of nanoparticles and methanol, (b) different proportion of nanoparticles and propanol.

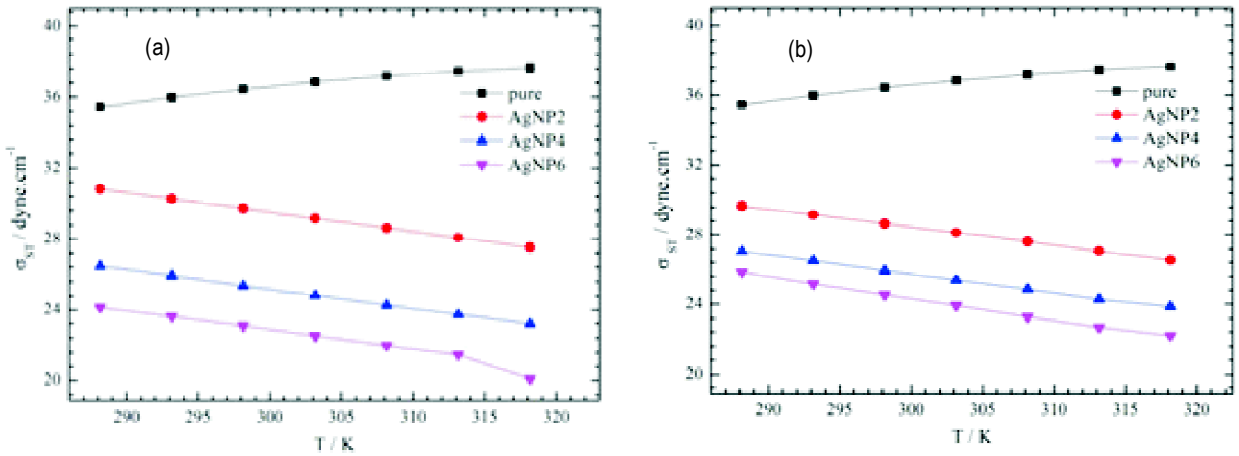

Fig. 4. Variation of surface tension with temperature: (a) different proportion of nanoparticles and methanol, (b) different proportion of nanoparticles and propanol.

the increase in temperature usually. Which implies that the as temperature increases, the particle-particle interaction in pure AgNPs become more but when solvents were added in AgNPs, they weakening the particle-particle interaction of AgNPs and helps in the dispersion of NPs.

The perusal of Figs. 6 and 7 shows the variation of R and W. Both have the constant behavior as expected.

It is clear from Fig. 8 that in case of pure NPs, the L_f is almost independent of temperature but when solvents are added, there is increase in L_f value which indicates the weaker forces between the NPs and solvent molecules.

Fig. 9 specifies the variation of internal pressure with temperature at different concentrations of solvent. Internal pressure is high in case of pure NPs as compared to the NPs mixed with solvents. As we are moving towards higher concentration of solvent, particle-particle interaction increases

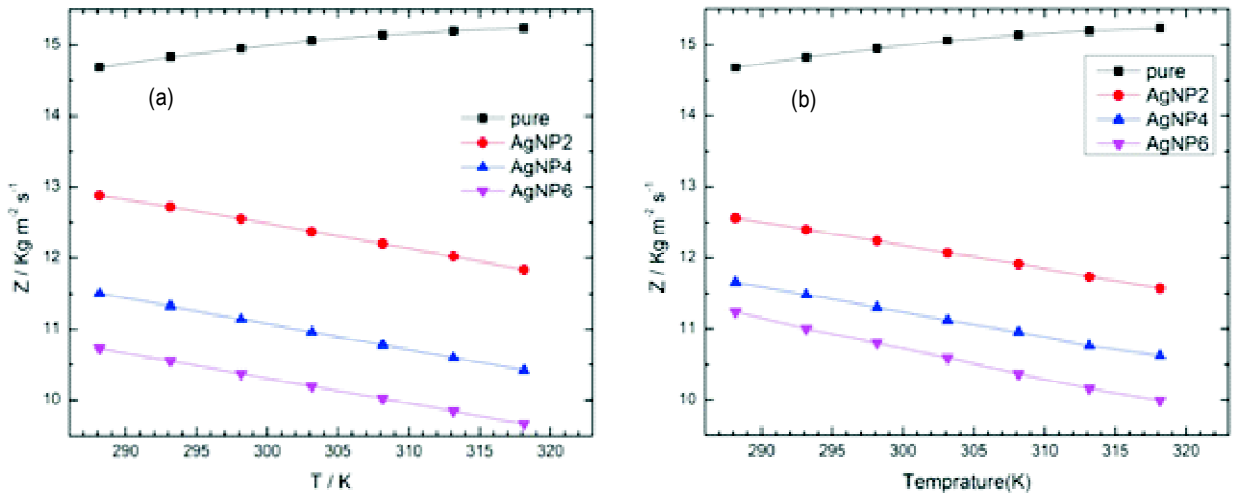

Fig. 5. Variation of acoustic impedence with temperature: (a) different proportion of nanoparticles and methanol, (b) different proportion of nanoparticles and propanol.

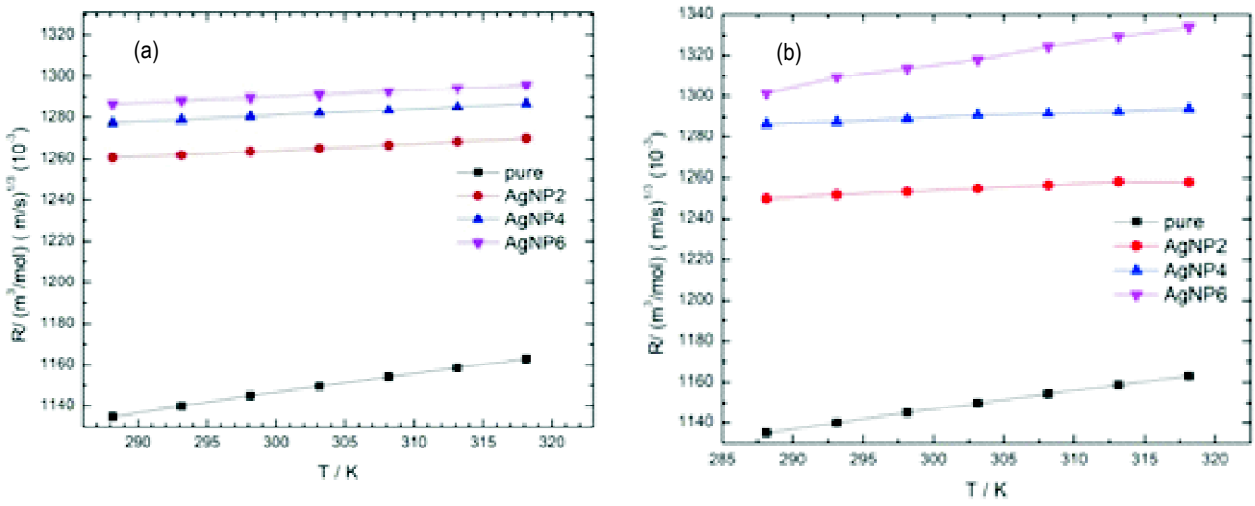

Fig. 6. Variation of Rao parameter with temperature: (a) different proportion of nanoparticles and methanol, (b) different proportion of nanoparticles and propanol.

and as a result clusters are formed[15]. The P_i values increases for pure AgNPs which indicates the intermolecular association and as the polarity of solvent changes, the value of P_i inversely proportional to the concentration of solvents the orientation of solvent molecules around the solute changes and association becomes weaker.

Some nonlinear parameters are reported in Tables 1 and 2. The perusal of Table 1 indicates the variation in different parameters α, C, S_0, S*, S_0*, γ with the change in temperature for pure AgNPs and as well as after adding methanol and propanol to the AgNPs. The value of α is almost constant for pure AgNPs as well as after addition of solvents. The value of C_1 varies from 8.0378 to 7.8496 for pure AgNPs and decreases from 7.9064 to 7.3954 by adding methanol of different concentrations. These values are in the range of values for liquids which have weak association in between the molecules as reported by Tiwari *et al.*[27] which indicates the associating tendency of AgNPs and solvents. The value

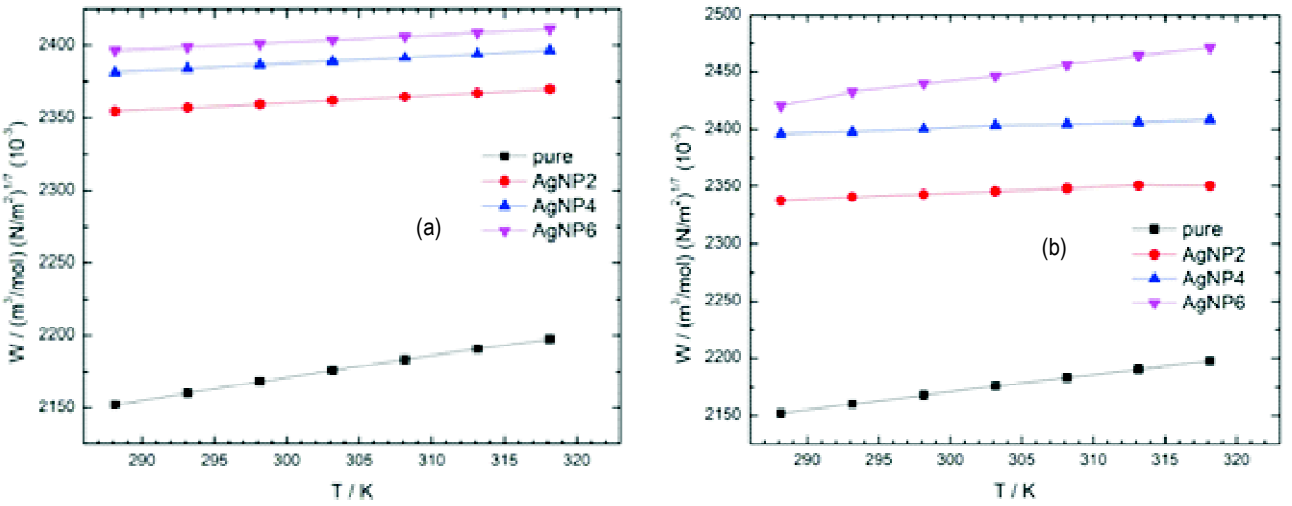

Fig. 7. Variation of Wada parameter with temperature: (a) different proportion of nanoparticles and methanol, (b) different proportion of nanoparticles and propanol.

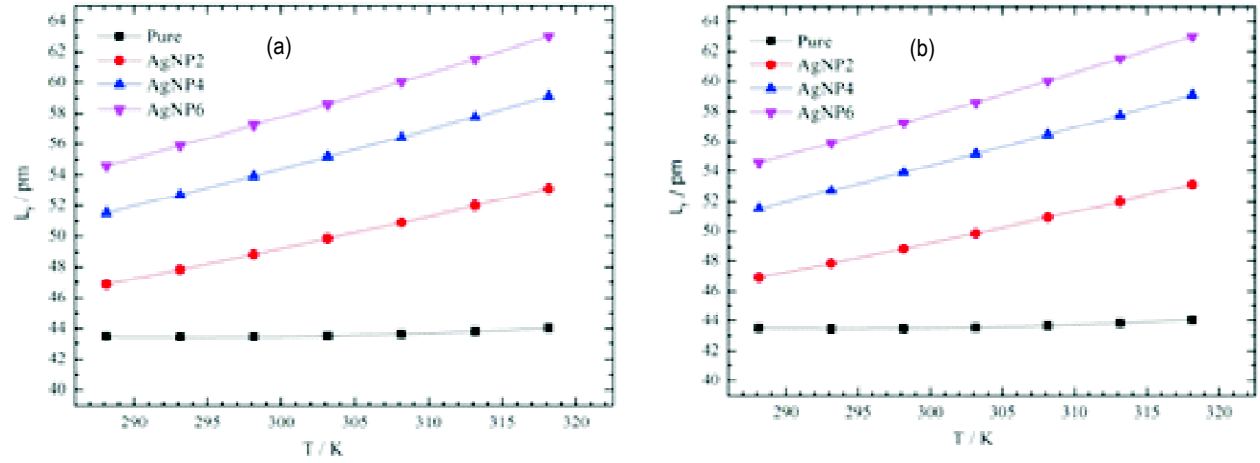

Fig. 8. Variation of intermolecular free length with temperature: (a) different proportion of nanoparticles and methanol, (b) different proportion of nanoparticles and propanol.

of $\tilde{\nu}$ in case of pure AgNPs shows the nonlinear variation but shows somewhat variation after addition of solvents. The S_0 was remained constant. This particular value is in agreement with the values as reported by Sharma[28,29]. The S* lies in the range 1.40 to 1.51 which can be compared with the value 1.41±0.01 for PAN and PAN/clay composite as reported by Upmanyu *et al.*[26]. The S_0* value lies in the range of 1.14 to 1.17 which is higher than the polycrystalline solids [?]. The γ values are less for pure AgNPs and more for mixture of AgNPs and solvents.

The perusal of Table 2 indicates the variation in different parameters F, K″, K′, f, n, B/A with the change in temperature for pure AgNPs and as well as after addition of methanol and propanol to the AgNPs. The values of F lie in the range of 2.0866 to 2.0562 for pure AgNPs and lies in the range of 2.0660 to 1.9648 after the addition of solvents to the AgNPs.

The values of K, K″, K′ for pure AgNPs lies in the range 3.52 to 3.42, 0.562 to 0.599 and 4.0809 to 4.0242 respectively but after the addition of solvents the values lie in the range 3.45 to 3.22, 0.588 to 0.684 and 4.0413 to 3.9014

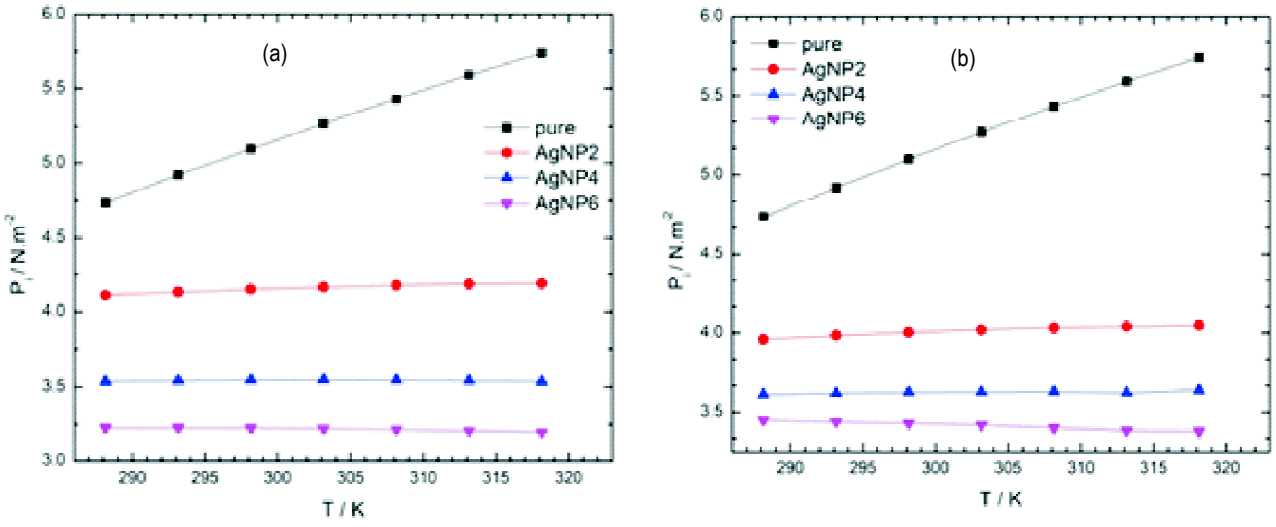

Fig. 9. Variation of internal pressure with temperature: (a) different proportion of nanoparticles and methanol, (b) different proportion of nanoparticles and propanol.

Table 1. Nonlinear parameters of pure AgNPs, (AgNPs + methanol) and (AgNPs + propanol) at different temperatures

Sample	T (K)	$\alpha\times10^{-3}$	C_1	$\bar{\nu}$	S_0	S*	S_0*	γ
				Pure AgNPs				
AgNPs (pure)	288.15	1.051	8.0378	1.2510	1.118	1.4040	1.1439	1.3793
	293.15	1.044	8.0083	1.2532	1.118	1.4081	1.1449	1.3692
	298.15	1.038	7.9780	1.2554	1.118	1.4125	1.1460	1.3595
	303.15	1.032	7.9468	1.2577	1.117	1.4171	1.1471	1.3501
	308.15	1.027	7.9149	1.2602	1.117	1.4220	1.1483	1.3410
	313.15	1.023	7.8824	1.2627	1.117	1.4270	1.1496	1.3323
	318.15	1.019	7.8496	1.2654	1.117	1.4324	1.1509	1.3238
				AgNPs + Methanol				
AgNP2	288.15	1.102	7.9064	1.2609	1.117	1.4233	1.1487	1.4315
	293.15	1.106	7.8493	1.2654	1.117	1.4324	1.1509	1.4226
	298.15	1.111	7.7942	1.2700	1.116	1.4416	1.1532	1.4140
	303.15	1.116	7.7410	1.2746	1.115	1.4510	1.1554	1.4056
	308.15	1.121	7.6894	1.2793	1.115	1.4605	1.1576	1.3975
	313.15	1.126	7.6395	1.2840	1.114	1.4701	1.1599	1.3897
	318.15	1.132	7.5911	1.2888	1.113	1.4800	1.1622	1.3821
AgNP4	288.15	1.159	7.7729	1.2718	1.116	1.4453	1.1540	1.4500
	293.15	1.165	7.7170	1.2768	1.115	1.4553	1.1564	1.4412
	298.15	1.171	7.6630	1.2818	1.114	1.4655	1.1588	1.4328
	303.15	1.177	7.6109	1.2868	1.114	1.4759	1.1612	1.4246
	308.15	1.184	7.5607	1.2919	1.113	1.4865	1.1636	1.4166
	313.15	1.191	7.5122	1.2970	1.112	1.4972	1.1661	1.4089
	318.15	1.198	7.4654	1.3021	1.111	1.5081	1.1685	1.4015
AgNP6	288.15	1.195	7.6967	1.2786	1.115	1.4591	1.1573	1.4609
	293.15	1.202	7.6416	1.2838	1.114	1.4697	1.1598	1.4522

Table-1 (contd.)

	298.15	1.209	7.5885	1.2890	1.113	1.4805	1.1623	1.4439
	303.15	1.216	7.5375	1.2943	1.112	1.4915	1.1648	1.4357
	308.15	1.224	7.4883	1.2996	1.112	1.5027	1.1673	1.4279
	313.15	1.231	7.4410	1.3049	1.111	1.5141	1.1698	1.4202
	318.15	1.239	7.3954	1.3103	1.110	1.5257	1.1723	1.4129
				AgNPs + Propanol				
AgNP2	288.15	1.116	7.8723	1.2636	1.117	1.4287	1.1500	1.4314
	293.15	1.120	7.8167	1.2681	1.116	1.4378	1.1522	1.4226
	298.15	1.125	7.7682	1.2727	1.116	1.4471	1.1545	1.4139
	303.15	1.129	7.7107	1.2773	1.115	1.4565	1.1567	1.4056
	308.15	1.134	7.6602	1.2820	1.114	1.4661	1.1590	1.3975
	313.15	1.140	7.6108	1.2868	1.114	1.4759	1.1612	1.3897
	318.15	1.145	7.5635	1.2916	1.113	1.4859	1.1635	1.3815
AgNP4	288.15	1.151	7.7913	1.2703	1.116	1.4421	1.1533	1.4509
	293.15	1.156	7.7352	1.2751	1.115	1.4520	1.1557	1.4420
	298.15	1.162	7.6809	1.2801	1.115	1.4621	1.1580	1.4335
	303.15	1.169	7.6283	1.2851	1.114	1.4728	1.1604	1.4253
	308.15	1.175	7.5784	1.2901	1.113	1.4827	1.1628	1.4170
	313.15	1.182	7.5288	1.2952	1.112	1.4935	1.1652	1.4092
	318.15	1.187	7.4857	1.2998	1.115	1.5033	1.1674	1.4012
AgNP6	288.15	1.168	7.7526	1.2736	1.115	1.4489	1.1549	1.4595
	293.15	1.177	7.6926	1.2790	1.115	1.4599	1.1575	1.4531
	298.15	1.184	7.6366	1.2843	1.114	1.4707	1.1600	1.4457
	303.15	1.192	7.5827	1.2896	1.113	1.4818	1.1626	1.4385
	308.15	1.201	7.5297	1.2951	1.112	1.4932	1.1652	1.4323
	313.15	1.209	7.4793	1.3005	1.112	1.5048	1.1677	1.4259
	318.15	1.216	7.4340	1.3057	1.110	1.5158	1.1701	1.4191

Table 2. Nonlinear parameters of pure AgNPs, (AgNPs + methanol) and (AgNPs + propanol) at different temperatures

Sample	T (K)	F	K	K″	K′	f	n	B/A	Γ_I
				Pure AgNPs					
AgNPs (pure)	288.15	2.0866	3.5189	0.5620	4.0809	0.1968	12.1134	7.0378	7.5378
	293.15	2.0822	3.5041	0.5678	4.0720	0.1972	12.0249	7.0083	7.5083
	298.15	2.0775	3.4890	0.5738	4.0628	0.1975	11.9340	6.9780	7.478
	303.15	2.0726	3.4734	0.5800	4.0534	0.1979	11.8405	6.9468	7.4468
	308.15	2.0674	3.4574	0.5863	4.0438	0.1983	11.7445	6.9149	7.4149
	313.15	2.0619	3.4412	0.5928	4.0340	0.1986	11.6473	6.8824	7.3824
	318.15	2.0562	3.4248	0.5993	4.0242	0.1990	11.5487	6.8496	7.3496
				AgNPs + Methanol					
AgNP2	288.15	2.0660	3.4532	0.5880	4.0413	0.1984	11.7191	6.9064	7.4064
	293.15	2.0562	3.4247	0.5994	4.0241	0.1990	11.548	6.8493	7.3493
	298.15	2.0463	3.3971	0.6105	4.0076	0.1997	11.3827	6.7942	7.2942
	303.15	2.0361	3.3705	0.6212	3.9917	0.2003	11.2229	6.7410	7.241
	308.15	2.0258	3.3447	0.6317	3.9764	0.2010	11.0682	6.6894	7.1894
	313.15	2.0152	3.3197	0.6418	3.9616	0.2015	10.9184	6.6395	7.1393
	318.15	2.0044	3.2956	0.6517	3.9473	0.2021	10.7733	6.5911	7.0911

Table-2 (contd.)

AgNP4	288.15	2.0423	3.3865	0.6147	4.0012	0.2000	11.3188	6.7729	7.2729
	293.15	2.0314	3.3585	0.6261	3.9846	0.2006	11.1509	6.7170	7.217
	298.15	2.0202	3.3315	0.6370	3.9685	0.2013	10.9889	6.6630	7.163
	303.15	2.0089	3.3054	0.6477	3.9531	0.2019	10.8326	6.6109	7.1109
	308.15	1.9973	3.2803	0.6580	3.9383	0.2025	10.682	6.5607	7.0607
	313.15	1.9854	3.2561	0.6681	3.9241	0.2030	10.5365	6.5122	7.0122
	318.15	1.9733	3.2327	0.6778	3.9105	0.2036	10.3962	6.4654	6.9654
AgNP6	288.15	2.0273	3.3484	0.6302	3.9785	0.2009	11.0901	6.6967	7.1967
	293.15	2.0157	3.3208	0.6414	3.9622	0.2015	10.9248	6.6416	7.1416
	298.15	2.0038	3.2943	0.6523	3.9465	0.2022	10.7656	6.5885	7.0885
	303.15	1.9917	3.2687	0.6628	3.9315	0.2028	10.6124	6.5375	7.0375
	308.15	1.9793	3.2442	0.6730	3.9172	0.2034	10.4649	6.4883	6.9883
	313.15	1.9667	3.2205	0.6829	3.9034	0.2039	10.3229	6.4410	6.941
	318.15	1.9537	3.1977	0.6926	3.8902	0.2045	10.1861	6.3954	6.8954
				AgNPs + Propanol					
AgNP2	288.15	2.0602	3.4361	0.5948	4.0310	0.1988	11.6168	6.8723	7.3723
	293.15	2.0504	3.4083	0.6060	4.0143	0.1994	11.4500	6.8167	7.3167
	298.15	2.0403	3.3814	0.6168	3.9982	0.2001	11.2885	6.7628	7.2682
	303.15	2.0301	3.3553	0.6273	3.9827	0.2007	11.1320	6.7107	7.2107
	308.15	2.0197	3.3301	0.6376	3.9677	0.2013	10.9806	6.6602	7.1602
	313.15	2.0089	3.3054	0.6477	3.9531	0.2019	10.8324	6.6108	7.1108
	318.15	1.9980	3.2818	0.6574	3.9392	0.2025	10.6905	6.5635	7.0635
AgNP4	288.15	2.0457	3.3957	0.6111	4.0067	0.1997	11.3740	6.7913	7.2913
	293.15	2.0350	3.3676	0.6224	3.9900	0.2004	11.2057	6.7352	7.2352
	298.15	2.0240	3.3404	0.6334	3.9738	0.2011	11.0426	6.6809	7.1809
	303.15	2.0128	3.3141	0.6441	3.9583	0.2017	10.8850	6.6283	7.1283
	308.15	2.0014	3.2892	0.6544	3.9435	0.2023	10.7351	6.5784	7.0784
	313.15	1.9896	3.2644	0.6646	3.9290	0.2029	10.5863	6.5288	7.0288
	318.15	1.9786	3.2428	0.6736	3.9164	0.2034	10.4570	6.4857	6.9857
AgNP6	288.15	2.0383	3.3763	0.6189	3.9952	0.2002	11.2577	6.7526	7.2526
	293.15	2.0264	3.3463	0.6310	3.9773	0.2009	11.0778	6.6926	7.1926
	298.15	2.0146	3.3183	0.6424	3.9607	0.2016	10.9098	6.6366	7.1366
	303.15	2.0025	3.2913	0.6535	3.9448	0.2022	10.7481	6.5827	7.0827
	308.15	1.9898	3.2649	0.6644	3.9293	0.2029	10.5892	6.5297	7.0297
	313.15	1.9770	3.2397	0.6749	3.9146	0.2035	10.4380	6.4793	6.9793
	318.15	1.9648	3.2170	0.6844	3.9014	0.2040	10.3022	6.4341	6.934

respectively. The value of 'f' is in the significance range for all the samples in comparison with the universal value of 'f' at the glass transition temperature reported by William *et al.*[30]. The average value of n for pure AgNPs is 11.8361 and for mixture of AgNPs and solvents is approximately 10.6238. The trend in the values of B/A and Γ_1 indicates the anharmonicity and intramolecular modes of vibrations. The value of B/A as well as Γ_1 decreases after the addition of solvents to the AgNPs which indicates the presence of harmonicity and increase in intramolecular modes of vibration in the mixture of AgNPs and solvents.

The perusal of Table 3 indicates the variation in different elastic parameters U_l, U_s, E, G, K with the change in temperature for pure AgNPs and as well as after addition of

Table 3. Elastic parameters of pure AgNPs, (AgNPs + methanol) and (AgNPs + propanol) at different temperatures

Sample	T (K)	U_l	U_s	E×10^{10}	G×10^9	K×10^{10}	σ
			AgNPs				
AgNPs	288.15	5336	3107	2.85	9.7	1.56	0.2436
	293.15	5405	3142	2.92	9.9	1.61	0.2450
	298.15	5469	3173	2.99	10.0	1.65	0.2463
	303.15	5525	3200	3.05	10.2	1.68	0.2476
	308.15	5575	3223	3.10	10.4	1.72	0.2489
	313.15	5620	3244	3.14	10.5	1.74	0.2501
	318.15	5658	3261	3.18	10.6	1.77	0.2513
			AgNPs + Methanol				
AgNP2	288.15	5178	3042	2.40	8.3	1.30	0.2364
	293.15	5140	3015	2.36	8.1	1.28	0.2377
	298.15	5102	2989	2.31	7.9	1.25	0.2388
	303.15	5063	2962	2.27	7.8	1.23	0.2400
	308.15	5023	2934	2.22	7.6	1.21	0.2411
	313.15	4982	2906	2.17	7.4	1.19	0.2422
	318.15	4940	2877	2.13	7.2	1.17	0.2432
AgNP4	288.15	4783	2819	1.97	6.8	1.06	0.2340
	293.15	4740	2789	1.93	6.7	1.04	0.2351
	298.15	4696	2759	1.88	6.5	1.02	0.2363
	303.15	4651	2729	1.84	6.3	0.99	0.2374
	308.15	4606	2699	1.79	6.2	0.97	0.2385
	313.15	4560	2669	1.75	6.0	0.95	0.2395
	318.15	4513	2638	1.70	5.8	0.93	0.2405
AgNP6	288.15	4558	2691	1.75	6.1	0.94	0.2325
	293.15	4512	2660	1.71	5.9	0.91	0.2337
	298.15	4466	2629	1.66	5.8	0.90	0.2348
	303.15	4419	2598	1.62	5.6	0.87	0.2359
	308.15	4372	2567	1.58	5.4	0.85	0.2368
	313.15	4324	2536	1.53	5.3	0.83	0.2380
	318.15	4276	2504	1.49	5.1	0.81	0.2390
			AgNPs + Propanol				
AgNP2	288.15	5048	2966	2.28	7.9	1.23	0.2365
	293.15	5015	2942	2.24	7.7	1.21	0.2376
	298.15	4978	2916	2.20	7.6	1.19	0.2388
	303.15	4941	2890	2.16	7.4	1.17	0.2400
	308.15	4903	2864	2.12	7.2	1.15	0.2411
	313.15	4862	2836	2.07	7.0	1.13	0.2422
	318.15	4818	2806	2.03	6.9	1.11	0.2433
AgNP4	288.15	4857	2863	2.03	7.1	1.09	0.2338
	293.15	4814	2833	1.98	6.9	1.07	0.2350
	298.15	4770	2803	1.94	6.7	1.05	0.2362
	303.15	4726	2773	1.89	6.5	1.02	0.2373
	308.15	4681	2743	1.85	6.4	1.00	0.2384
	313.15	4631	2710	1.80	6.2	0.98	0.2395
	318.15	4598	2688	1.77	6.0	0.96	0.2406

Table-3 (contd.)

AgNP6	288.15	4759	2809	1.91	6.7	1.02	0.2327
	293.15	4712	2778	1.86	6.5	1.00	0.2335
	298.15	4664	2747	1.81	6.3	0.97	0.2345
	303.15	4615	2715	1.76	6.1	0.95	0.2354
	308.15	4565	2683	1.70	5.9	0.92	0.2363
	313.15	4515	2650	1.65	5.7	0.89	0.2372
	318.15	4474	2623	1.61	5.5	0.87	0.2381

methanol and propanol to the AgNPs. The value of U_l, U_s, E, G, K increases with increase in temperature for pure AgNPs but decreases after the addition of solvents which indicates that the solvent weaken the molecular association and as result decrease in the denseness of the system.

Conclusions

The given value (U_l, U_s, E, G, K) increases with increase in temperature for pure silver nanoparticles but decreases after the addition of solvents which indicates that the solvent weaken the molecular association and as result decrease in the denseness of the system.

By using ultrasonic velocity and density various thermodynamic and thermoacoustic parameters were evaluated. The solute-solvent interaction and effect of temperature was discussed in terms of these parameters. When different temperatures T = (288.15, 293.15, 298.15, 303.15, 308.15, 313.15, 318.15) K for pure silver nanoparticles as well as mixtures of silver nanoparticles with methanol and propanol in the ratio (v/v) of 1:2, 1:4, 1:6 respectively, were carried out, consequentially it can be concluded that concentration and temperature affects the intermolecular interactions.

It is also concluded methanol or propanol tends to break the extent of hydrogen bond and reduce dielectric constant of the system. As the stability of nanoparticles is highly dependent on the polarity of the solvent, this indicates that work has definitely shown a different approach of studying the solute-solvent interaction.

Future scope of the work

The foremost use of pure silver nanoparticles is that it is crucial for cancer diagnosis and plethora of medical treatments, agriculture and industry. Although numerous methods are available for synergistic effects of silver nanoparticles. But antibiotics for antibacterial agents, multiple therapeutic agents for anti-cancer treatment and tumor reduction are highly untraversed and unexplored fields. Therefore, further exploration and more in-depth studies are required to explicitly elaborate the synergistic effect of the two dissimilar cytotoxic agents at a single point of time. These types of studies could deliver us to understand the intricate mechanisms, competence of the synergistic effect of two different agents or multiple agents. Finally, if we succeed in this crucial rendezvous, it would help the researchers of the nanoscience and nanotechnology community to develop safer, biocompatible, efficient cancer or anti-antigenic agents containing AgNPs.

References

1. V. Vadlapudi and D. S. V. G. K. Kaladhar, *Middle-East J. Sci.*, 2014, **19**, 834.
2. C. N. R. Rao, G. U. Kulkarni, P. J. Thomas and P. P. Edwards, *Chem. Eur. J.*, 2002, **8**, 28.
3. M. De, P. S. Ghosh and V. M. Rotello, *Adv. Mater.*, 2008, **20**, 4225.
4. A. H. Lu, E. L. Salabas and F. Schuth, *Angew. Chem. Int. Ed. Engl.*, 2007, **46**, 1222.
5. R. G. Chaudhuri and S. Paria, *Chem. Rev.*, 2012, **112**, 2373.
6. Y. A. Krutyakov, A. A. Kudrynskiy, A. Y. Olenin and G. V. Lisichkin, *Russ. Chem. Rev.*, 2008, **77**, 233.
7. D. R. Monteiro, L. F. Group, A. S. Takamiya, A. C. Ruvollo Filho, E. R. de-Camatgo and D. B. Barbosa, Int. J. Antimicrob. Agents, 2009, **34**, 103.
8. M. Ahamed, M. S. Alsalhi and M. K. Siddiqui, *Clin. Chim. Acta,* 2010, **411**, 1841.
9. J. Garc´ýa-Barrasa, J. M. L´opez-de-luzuriaga and M. Mong, *Cent. Eur. J. Chem.*, 2011, **9**, 7.
10. J. Fabrega, S. N. Luoma, C. R. Tyler, T. S. Galloway and J. R. Lead, *Environ. Internat.*, 2011, **37**, 517.
11. P. Dallas, V. K. Sharma and R. Zboril, *Adv. Colloid Interface Sci.*, 2011, **166**, 119.
12. N. Ali, A. T. Joao and A. Abdulmajid, *J. Nanomater.*, 2018, **2018**, 1.

13. S. Parveen, S. Singh, D. Shukla, M. Yasmin, M. Gupta and J. P. Shukla, *J. Solution Chemistry,* 2012, **41**, 156.
14. O. P. Chimankar, N. N. Padole1, N. R. Pawar and V. A. Tabhane, *J. Pure Appl. Ultrson.*, 2017, **39**, 79.
15. L. Taneja and N. Dhaiya, *Integr. Ferroelectr.*, 2017, **184**, 101.
16. Taruna, J. Kaushal, J. Bhatti and P. Kumar, *J. Mol. Liq.*, 2016, **224**, 991.
17. W. P. Mason, "Physical Acoustics:principles and methods", Vol. 3, Part B, Academic, New York, 1965, 52.
18. D. E. Gray, "American Institute of Physics hand book", 3rd ed., 1972.
19. D. P. Singh and A. P. Singh, *J. Acoust. Soc. America,* 1993, **93**, 3220.
20. D. P. Singh and A. Upmanyu, *Int. J. Pure Appl. Phys.*, 2009, **5**, 203.
21. D. P. Singh and A. P. Singh, *Acoustica*, 1995, **81**, 177.
22. A. Upmanyu and D. P. Singh, *Acta Acust. United. Ac*, 2014, **100**, 434.
23. D. P. Singh and B. Singh, *Indian J. Phys.*, 1992, **66A**, 671.
24. O. P. Chimankar, R. S. Shriwas, S. Jajodia and V. A. Tabhane, *Adv. Appl. Sci. Res.*, 2011, **2**, 500.
25. V. S. SaiKumar and K. V. Rao, *J. Ovonic. Res.,* 2017, **13**, 91.
26. D. P. Singh and A. Upmanyu, *J. Polym. Biopolymer Phys. Chem.*, 2014, **2**, 73.
27. T. D. Fornes and D. R. Paul, *Polymer,* 2003, **44**, 4993.
28. M. Alexandre and P. Dubois, *Mater. Sci. Eng.*, 2000, **28**, 1.
29. G. Sanchez-Olivares, A. Sanchez-Solis and O. Manero, *Int. J. Polym. Mater.*, 2008, **57**, 417.
30. S. K. Swain and A. I. Isayev, *Polymer,* 2007, **48**, 281.
31. H. Kumar, V. Kumar and M. Sharma, *J. Chem. Thermodynam.*, 2019, **139**, 105877.
32. H. Kumar, V. Kumar and M. Sharma, *J. Chem. Eng. Data*, 2018, **63(10)**, 3769.
33. H. Kumar, V. Kumar, M. Sharma and I. Behal, *J. Chemical Thermodynam.*, 2017, **119**, 1.
34. T. Ahamad, Ruksana, A. A. Chaudhary, M. Naushad and S. Alshehri, *Int. J. Biol. Macromol.*, 2019, **134**, 180.
35. A. K. Balasubram, N. Sivarajasekar and M. Naushad, *J. Mol. Liq.*, 2020, **301**, 112426.
36. M. Naushad, *Chem. Eng. J.*, 2014, **235**, 100.
37. Saruchi, P. Thakur and V. Kumar, *J. Environ. Health Sci. Eng.*, 2019, **17(1)**, 367.
38. Saruchi, B. S. Kaith, R. Jindal, V. Kumar and M. Bhatti, *RSC Adv.*, 2014, **4(75)**, 39822.
39. Saruchi, V. Kumar, V. Rehani and B. S. Kaith, *Iranian Polym. J.*, 2018, **27(11)**, 913.