# Accepted Manuscript

Volumetric and acoustic behaviour of myo-inositol in aqueous Natural Deep Eutectic Solvent solutions

Fernando Bergua, Montserrat Nuez, José Muñoz-Embid, Carlos Lafuente, Manuela Artal
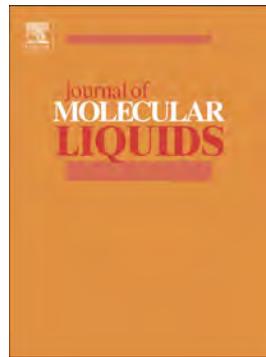
Please cite this article as: Fernando Bergua, Montserrat Nuez, José Muñoz-Embid, Carlos Lafuente, Manuela Artal , Volumetric and acoustic behaviour of myo-inositol in aqueous Natural Deep Eutectic Solvent solutions. The address for the corresponding author was captured as affiliation for all authors. Please check if appropriate. Molliq(2017), doi:10.1016/j.molliq.2018.02.128

Volumetric and acoustic behaviour of *myo*-inositol in aqueous Natural Deep Eutectic Solvent solutions

Fernando Bergua, Montserrat Nuez, José Muñoz-Embid, Carlos Lafuente, Manuela Artal*

Departamento de Química Física. Facultad de Ciencias. Universidad de Zaragoza. 50009. Zaragoza. Spain

*Corresponding author. Tel: +34876553765. e-mail: martal@unizar.es

Abstract

A study of the interactions in aqueous systems containing a sweetener, *myo*-inositol, and a NAtural Deep Eutectic Solvent, reline or glyceline, is presented. Both NADESs include the same acceptor group, choline chloride, and different donor groups, urea and glycerol. For this purpose, the density and speed of sound were measured for dilute mixtures, and several related properties were calculated: the standard partial molar volume, the standard partial molar isentropic compression, the standard transfer properties, Hepler´s constant, and the compressibility hydration number. The results were evaluated as a function of the temperature and composition, and they show the dominance of the ionic-hydrophilic and hydrophilic-hydrophilic interactions. Moreover, the glyceline disturbs the aqueous mixtures more than the reline.

1

1. Introduction

The solvent environment next to one solute molecule is different from around those in the bulk. This fact is reflected in the packaging of the system. For this reason, the determination of volumetric and acoustic properties has been used to evaluate the system interactions [1-5]. To avoid disturbance due to solute-solute interactions, these properties are calculated under conditions of infinite dilution. In addition, when a third compound is added to a binary mixture, the co-solute influence on solute hydration can be studied, determining whether or not its formation is favoured [6]. ~~Different methods, depending on the measured property, allow to calculate the moles of water per mole of solute confined in the hydration sphere, n_h. Those based in acoustic measures are preferred due to its experimental simplicity. However, the suppositions that are carried out provide excessively high values, although coherent in the same homologous series. Other methods utilize properties such as viscosity, isothermal compressibility, colligative properties, etc. A comprehensive review has been published by Burakowski and Glinski [7].~~

The hydration numbers, or the moles of water per mole of solute confined in the hydration sphere (n_h), can be calculated from different methods depending on the evaluated properties: isothermal and isentropic compressibility, dielectric relaxation, freezing point depression and boiling point elevation, spectroscopy techniques, viscosity measures, or MC simulation, among others. Those based on acoustic measures are preferred due to their experimental simplicity. However, the suppositions that are carried out provide excessively high values [7], although coherent in the same homologous series. A comprehensive review has been published by Burakowski and Glinski [8].

For aqueous mixtures containing a flavouring solute, the taste quality can be estimated from the apparent specific volume, ASV, indicating the hydrated molecule size [8-9] [9-10]. The addition of small amounts of another compound, called a co-solute, will modify the hydration sphere and modulated the flavour [10-11] [11-12]. In this work, we study the influence of two ecological co-solutes on the thermodynamic properties of sweetener aqueous solutions. Inositol (cyclohexane-1,2,3,4,5,6-hexol) is a cyclic sugar whose most abundant spatial isomer is *myo*-inositol (cis-1,2,3,5-trans-4,6- cyclohexanehexol). In the diet, different natural sources provide this sugar: fruits, vegetables, and cereals [12] [13]. On the other hand, organisms are capable of synthesizing it from glucose [13] [14]. Abnormal *myo*-inositol levels have been related to metabolic disorders (diabetes mellitus, polycystic ovary syndrome, thyroid function), neurological problems (depression, Alzheimer, eschlerosis) and certain cancer types (lymphoma, brain tumours) [14-20] [15-21].

A Deep Eutectic Solvent (DES) is a mixture of two or more compounds whose melting point is lower than that of the components separately. The decrease of the solid-liquid transition temperature occurs due to the association, mainly by hydrogen bonds, between acceptor (HBA) and donor (HBD) compounds. These solvents have appeared as a green technology alternative for replacing common organic solvents that have inherent toxicity and high volatility, highlighting its price and biodegradability. The NAtural Deep Eutectic Solvents are DESs with primary metabolites such as HBA and HBD substances. Choi et al. [21] [22] described NADES as the third cellular solvent. The authors concluded that unstable or poorly soluble biomolecules in water or lipids could be synthesized and stored in this type of compound, allowing survival in situations of extreme dryness. Common HBAs are choline chloride ([Ch]Cl) or (2-hydroxyethyl)trimethylammonium chloride and the betaine

3

((carboxymethyl)trimethylammonium hydroxide inner salt), and HBD examples are: urea, glycerol, amino acids, and sugars. A great NADES number with different physical-chemical properties is possible by combining several acceptors-donors [22] [23]. Some research areas where the NADESs have shown great possibilities are: enzymatic catalysis, molecular purification, electrochemistry, biocatalytic processes, production of zeolites, pharmacological solvents, and as antibacterial agents [23-33] [24-34]. Recently, *myo*-inositol and choline chloride have shown high potential as biomarkers for Alzheimers and prostate cancer diagnosis, among other diseases [34-35] [35,36]. Both compounds have significant nutritional importance and can be found in food supplements for infants and adults [36-37] [37,38]. Two NADESs with similar acceptor groups and different donors are used as co-solutes in this paper: [Ch]Cl:urea (1:2), is called reline; and [Ch]Cl:glycerol (1:2) is called glyceline. The comparison of the volumetric and acoustic behaviour between dilute solutions containing reline and glyceline allows us to evaluate the influence of the donor group, although in these conditions, the NADESs are binary mixtures. The isentropic compressibility, κ_S, calculated from the density and speed of sound measurements, is related to the free space within the solutions [39]. Then, κ_S variations indicate intermolecular interaction changes. Taking into account the particular nature of the eutectic compounds, the κ_S evaluation will be especially interesting [40].

In general, the system interactions are altered depending on the predominant acidic or basic forms. The number of hydrogen bonds between the solute and co-solute molecules is affected. *Myo*-inositol is slightly acidic, and the pH values of the pure reline and pure glyceline are 10 and 7.5, respectively [41]. In the concentrations included in this work, the pH of the aqueous reline solutions is practically neutral [42]. Thus, we have not considered this variable in our study.

4

The literature reports studies about the structures of *myo*-inositol, reline and glyceline as well as their thermophysical behaviour in aqueous solutions [38-57] [43-62]. However, we have not found any paper in which the effect of the NADES on the *myo*-inositol hydration has been evaluated. Here, we present experimental data for density, ρ, and speed of sound, u, of both *myo*-inositol in pure water and in NADES aqueous solutions at atmospheric pressure and at T= (293.15-318.15) K. From these values, we calculate several properties related to the interactions within the mixtures: standard partial molar volumes and isentropic compressions, standard transfer properties, Hepler's coefficient and the compressibility hydration number.

2. Materials and methods

2.1. Materials

Information about the chemicals used in this work is reported in Table 1, and their chemical structures are shown in Fig. S1 (Supplementary material). *Myo*-inositol (>99 %) and both the NADESs (>98 %) were supplied from Sigma and Scionix Ltd, respectively. Milli Pore MilliQ water with resistivity less than 18.2 μS·cm^{-1} was used for the aqueous solutions. Due to their hygroscopic character, reline and glyceline were subjected to vacuum for several hours; the water content was determined by the Karl Fischer method (automatic titrator Crison KF 1S-2B). The values were 253 ppm for reline and 275 ppm for glyceline and were accounted for in the solution preparation. The mixtures were prepared just before the property measurements by weighing with a Sartorius Semimicro balance CP225-D. The uncertainty of the mass determination was 0.01 mg.

2.2. Apparatus and procedure

Density, ρ, and speed of sound, u, at atmospheric pressure were simultaneously obtained from a (3 MHz) Anton Paar DSA 5000 vibrating tube densimeter and sound analyser thermostated at $\pm$ 0.005 K. The equipment was calibrated using ultra-pure water supplied by the GmbH SH calibration service, and dry air. The combined expanded uncertainties ($k \approx 2$) in the measurements of density and the speed of sound were $U_c(\rho)$ = 0.05 kg·m^{-3} and $U_c(u)$ = 0.5 m·s^{-1}, respectively. The apparatus was checked using benzene as a reference fluid and the deviations (equation A.1 in the supplementary information) between the literature and experimental data were [58] [63]: $AAD(\rho)$ = 0.03 kg·m^{-3}, $AAD(u)$ = 0.33 m·s^{-1}.

Table 1. Sample table

Chemical	Source	Purification method	Mass fraction purity[a]	Water content / ppm[b]	Molar mass / g·mol^{-1}	CAS No
Myo-inositol	Sigma-Aldrich	Non	>0.99		180.16	87-89-8
Reline (choline chloride:urea; 1:2)	Scionix Ltd.	Vacuum treatment	>0.98	253	86.58	-----------
Glyceline (choline chloride:glycerol; 1:2)	Scionix Ltd.	Vacuum treatment	>0.98	275	107.95	-----------

[a]As stated by the supplier

[b]Karl-Fischer method

3. Results and Discussion

This work presents experimental data for density, ρ, and the speed of sound, u, of *myo*-inositol in aqueous solutions of two NAtural Deep Eutectic Solvents (reline or glyceline). The composition ranges of the solutes (*myo*-inositol) and co-solutes (NADES) were m_B = 0 to 0.15 mol·kg^{-1} and m_A = 0 to 0.5 mol·kg^{-1}, respectively. The measurements were performed at p = 99.0 kPa and at six temperatures from 293.15 to 318.15 K. The experimental values are listed in the supplementary material (Table S1).

In the literature, we have found experimental measurements of ρ and u for *myo*-inositol in pure water [42-46] [47-51]. In Fig. 1, we have compared our data with those in the composition and temperature ranges of this work. The working pressure in the papers of Blodgett et al. [42] [47] and Romero et al. [45] [50] was p = 350 and 75 kPa, respectively. For the rest of references, p = 101 kPa. We can conclude that they are in good agreement.
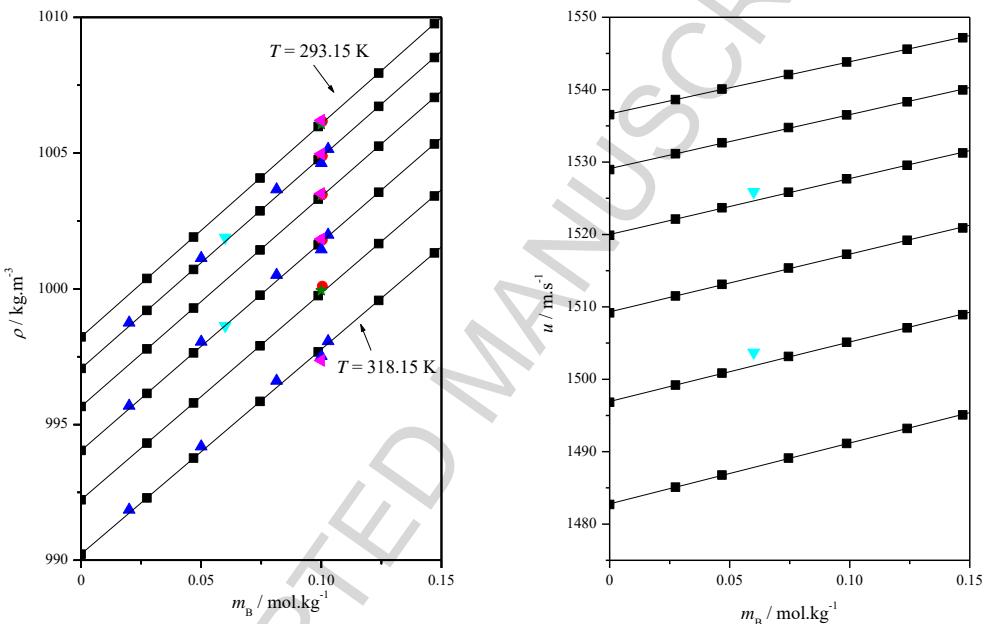
Figure 1. Density, ρ, of *myo*-inositol in aqueous solution against its molality, m_B, at p = 99.0 kPa, and at several temperatures, T. ■, this work; ▲, [42] [47]; ◀, [43] [48]; ▼, [44] [49]; ●, [45] [50]; ★, [46] [51].

3.1. Standard partial molar volume

The difference between the solution volume and the pure solvent volume per solute mole is called apparent molar volume, $V_{2,\phi}$, and it is a measure of the size of the hydrated solute molecules. From our ρ data, we calculated this property using the following equation:

$$V_{2,\phi} = \frac{M_B}{\rho} - \frac{(\rho - \rho_0)}{m_B \cdot \rho \cdot \rho_0} \tag{1}$$

Where m_B/mol·kg^{-1} is the solute molality; M_B/kg·mol^{-1} is the solute molar mass; ρ/kg·m^{-3} is the solution density; and ρ_0/kg·m^{-3} is the solvent (water or NADES+water) density. Given the uncertainty in the density measurement, $u(\rho)$, we estimated $u(V_{2,\phi})$ from the equation proposed by Hedwig [59] [64]:

$$u(V_{2,\phi}) = \left(M_B + \frac{1}{m_B}\right) \cdot \frac{u(\rho)}{\rho^2} \tag{2}$$

The uncertainties $u(V_{2,\phi})$ were within $\pm(0.16\text{-}1.1)\cdot10^{-6}$ m^3·mol^{-1} at high and low *myo*-inositol molality, respectively. Table S1 collects the $V_{2,\phi}$ data for the aqueous solutions studied in this work. These values increase with decreasing solute molality and with increasing temperature and NADES content (Fig. S2-S4).

For dilution solutions containing non-electrolyte solutes the apparent molar volume is well described by a linear equation of the solute molality:

$$V_{2,\phi} = V_2^0 + S_V \cdot m_B \tag{3}$$

Where the standard partial molar volume of the solute, V_2^0, is related to solute-solvent interactions because the solute-solute ones are negligible at infinite dilution. On the other hand, the slope, S_V, is the pair-wise interaction coefficient. Values for both parameters and the corresponding standard deviations are listed in Table 2.

For *myo*-inositol in aqueous solution, our V_2^0 calculated values agree with the literature [42,45] [47,50], although they are slightly higher. The mean relative deviation calculated with equation A.3 equation A.2 (supplementary information), was: $MRD(V_2^0)$ = 0.3 %.

Table 2. Volumetric and acoustic properties at infinite dilution for *myo*-inositol in aqueous and NADES aqueous solutions at p = 99.0 kPa, at several temperatures, T, and at reline or glyceline compositions, m_A, with standard partial molar volumes (V_2^0) and slopes (S_V) from equation 3, and standard partial molar isentropic compressions (K_2^0) and slopes (S_K) from equation 9. The corresponding standard deviations are also included.

T / K	m_A / mol·kg^{-1}	$V_2^0 \cdot 10^6$ / m^3·mol^{-1}	$S_V \cdot 10^6$ / m^3·kg·mol^{-2}	$\sigma(V_{2.\phi}) \cdot 10^6$ / m^3·mol^{-1}	$K_2^0 \cdot 10^3$ / TPa^{-1}·m^3·mol^{-1}	$S_K \cdot 10^3$ / TPa^{-1}·m^3·kg·mol^{-2}	$\sigma(K_{2.\phi}) \cdot 10^3$ / TPa^{-1}·m^3·mol^{-1}
			Myo-inositol in aqueous solution				
293.15	0	101.59	-6.86	0.024	-43.77	15.96	0.039
298.15		102.23	-7.55	0.026	-41.99	21.85	0.057
303.15		102.84	-7.77	0.015	-39.70	23.88	0.053
308.15		103.57	-8.07	0.026	-36.43	19.21	0.055
313.15		104.20	-7.67	0.031	-34.53	22.94	0.079
318.15		104.80	-6.30	0.037	-31.34	16.50	0.031
			Myo-inositol in aqueous reline solution				
293.15	0.1109	102.22	-9.20	0.045	-41.01	-3.70	0.044
298.15		102.51	-8.32	0.051	-35.95	-3.94	0.034
303.15		103.08	-8.76	0.033	-31.57	-3.31	0.035
308.15		103.54	-8.27	0.033	-27.73	-3.65	0.036
313.15		104.26	-8.80	0.064	-24.13	-4.03	0.039
318.15		104.87	-8.45	0.043	-20.97	-4.71	0.038
293.15	0.2219	102.16	-8.39	0.040	-39.46	-2.14	0.011
298.15		102.54	-8.01	0.037	-35.77	-2.95	0.021
303.15		103.00	-7.64	0.018	-32.53	-2.17	0.012
308.15		103.63	-8.22	0.047	-29.03	-3.90	0.020
313.15		104.12	-7.41	0.061	-26.18	-2.40	0.016
318.15		104.68	-6.53	0.045	-22.96	-4.27	0.032
293.15	0.3833	102.18	-7.48	0.037	-37.09	-1.26	0.020
298.15		102.69	-8.29	0.026	-35.50	-1.43	0.013
303.15		103.20	-8.30	0.018	-33.46	-2.19	0.024
308.15		103.60	-7.47	0.032	-31.19	-2.64	0.021
313.15		104.43	-8.99	0.054	-28.66	-2.33	0.006

T / K		$V_2^0 \cdot 10^6$/	$S_V \cdot 10^6$ /	$\sigma(V_{2,\phi}) \cdot 10^6$/	$K_2^0 \cdot 10^3$/	$S_K \cdot 10^3$/	$\sigma(K_{2,\phi}) \cdot 10^3$/
318.15		104.98	-8.02	0.046	-25.64	-3.54	0.027

Table 2. (Continuation).

T / K	m_A / mol·kg⁻¹	$V_2^0 \cdot 10^6$/ m³·mol⁻¹	$S_V \cdot 10^6$ / m³·kg·mol⁻²	$\sigma(V_{2,\phi}) \cdot 10^6$/ m³·mol⁻¹	$K_2^0 \cdot 10^3$/ TPa⁻¹·m³·mol⁻¹	$S_K \cdot 10^3$/ TPa⁻¹·m³·kg·mol⁻²	$\sigma(K_{2,\phi}) \cdot 10^3$/ TPa⁻¹·m³·mol⁻¹
293.15	0.5081	102.19	-6.90	0.066	-35.65	-2.23	0.020
298.15		102.66	-7.25	0.052	-35.04	-2.51	0.026
303.15		103.24	-7.89	0.047	-34.11	-3.13	0.033
308.15		103.85	-8.60	0.042	-32.68	-2.41	0.035
313.15		104.31	-7.66	0.014	-30.61	-2.03	0.011
318.15		104.86	-7.28	0.030	-27.97	-1.63	0.024
Myo-inositol in aqueous glyceline solution							
293.15	0.1252	101.22	-6.41	0.024	-31.43	-38.84	0.164
298.15		101.83	-7.68	0.063	-28.26	-36.89	0.206
303.15		102.33	-7.67	0.019	-25.17	-35.53	0.101
308.15		102.84	-8.22	0.055	-22.16	-40.41	0.248
313.15		103.50	-8.10	0.057	-18.89	-47.72	0.193
318.15		104.30	-9.51	0.039	-16.82	-48.91	0.217
293.15	0.2538	101.64	-8.85	0.030	-29.89	-50.72	0.230
298.15		102.22	-8.12	0.028	-27.57	-44.51	0.199
303.15		102.90	-7.57	0.010	-24.79	-44.19	0.146
308.15		103.54	-6.33	0.043	-23.13	-35.71	0.175
313.15		104.71	-8.24	0.036	-20.44	-40.66	0.158
318.15		105.66	-8.14	0.038	-17.62	-47.73	0.174
293.15	0.3742	101.56	-8.21	0.024	-31.86	-38.41	0.160
298.15		102.66	-8.87	0.067	-28.95	-39.76	0.218
303.15		103.49	-7.68	0.029	-27.22	-35.16	0.249
308.15		104.65	-7.85	0.029	-25.23	-31.61	0.171
313.15		105.70	-7.30	0.054	-23.55	-28.49	0.108
318.15		107.06	-8.04	0.014	-21.93	-24.03	0.080
293.15	0.4986	101.46	-6.81	0.038	-33.19	-38.75	0.144
298.15		102.83	-8.11	0.033	-30.15	-38.66	0.191
303.15		104.14	-7.85	0.044	-27.48	-38.10	0.225
308.15		105.51	-7.88	0.035	-25.42	-34.45	0.181
313.15		106.90	-7.63	0.037	-22.63	-36.22	0.094

| 318.15 | 108.63 | -8.86 | 0.063 | -20.39 | -35.23 | 0.137 |

Standard uncertainties, u, are: $u(m_A)$=0.0001 mol·kg^{-1}; $u(T)$=0.005 K; $u(p)$=0.5 kPa.

For all studied systems, the standard partial molar volumes are positive and increase with increasing temperature. The mixtures containing glyceline, V_2^0 are larger than in the system with reline and the effect of temperature is more pronounced (Fig. 2). The results are as expected taking into account: (a) that the glycerol component of the glyceline has a greater H-bonding formation capacity than the urea in the reline; and (b) in dilute solutions in our T range, H-bond formation is favoured by increasing the temperature since a higher number of molecules can overcome the corresponding energy barrier. In relation to the slope, S_V, no clear trends with temperature and composition are observed indicating that solute-solute interactions are influenced by several factors [60] [65]. Positive V_2^0 and negative S_V values suggest that solute-solvent interactions are predominant in these systems.

The taste perception includes the correct substance placement in the receptor site, so that the compound must have an optimal size and shape. In addition, the taste quality can be modulated by adding other components because the hydration sphere is modified. Since 1999, the apparent specific volume, ASV, is used to define the flavour quality [8,11] [9,12]:

$$ASV = V_{2,\phi}/M_B \tag{4}$$

where $V_{2,\phi}$ is the apparent molar volume, and M_B is the solute molar mass. Different ASV ranges have been established according to the different flavours (sweet, sour, bitter ...); for sweet taste, the apparent specific volume ranges from 0.52 to 0.71 cm^3·g^{-1} with 0.618 cm^3·g^{-1} being the ideal sweetness. For *myo*-inositol in pure water at 308.15 K (close to corporal temperature), ASV = 0.571 cm^3·g^{-1}. The reline addition hardly modifies the

11

sweetness ($ASV = 0.572$ cm$^3\cdot$g^{-1}) whereas the glyceline addition increases it to 0.581 cm$^3\cdot$g^{-1} (at $m_A = 0.5$ mol$\cdot$kg^{-1}).
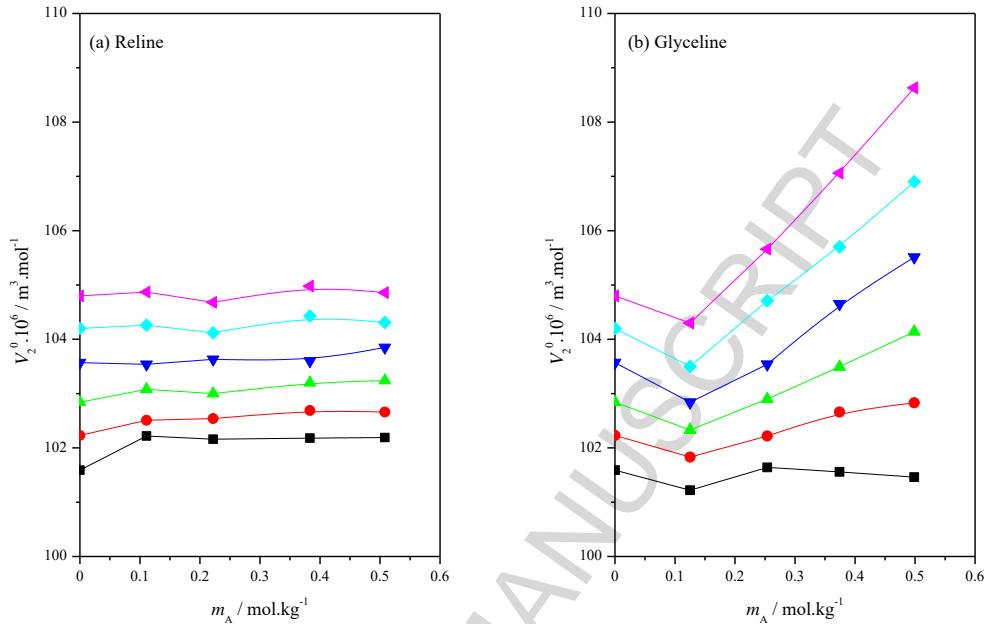


Figure 2. Standard partial molar volumes, V_2^0, against the NADES molality, m_A, at $p = 99.0$ kPa, and at several temperatures: ■, $T = 293.15$ K; ●, $T = 298.15$ K; ▲, $T = 303.15$ K; ▼, $T = 308.15$ K; ◆, $T = 313.15$ K; ◄, $T = 318.15$ K.

3.2. Standard partial molar isentropic compression

From our density and speed of sound experimental data (Table S1), we have obtained the isentropic compressibility, κ_S, and the apparent molar isentropic compression, $K_{2,\phi}$. The values, calculated using the following equations, are also reported in Table S1.

$$\kappa_S = 1/(\rho \cdot u^2) \tag{5}$$

12

$$K_{2,\phi} = \left[\frac{\kappa_S \cdot M_B}{\rho}\right] + \left[\frac{\kappa_S \cdot \rho_0 - \kappa_S^0 \cdot \rho}{m_B \cdot \rho \cdot \rho_0}\right] \tag{6}$$

where m_B/mol·kg^{-1} is the solute molality; M_B/kg·mol^{-1} is the solute molar mass; ρ/kg·m^{-3} and u/m·s^{-1} are the solution density and the speed of sound; ρ_0/kg·m^{-3} and u_0/m·s^{-1} are the solvent density and the speed of sound (water or NADES+water); and κ_S and κ_S^0 are the isentropic compressibilities of the solution and solvent (water or NADES+water), respectively. The standard uncertainties in $K_{2,\phi}$ can be calculated [61]:

$$u(\kappa_S) = 2 \cdot [u(u)]/(\rho \cdot u^3) \tag{7}$$

$$u(K_{2,\phi}) = \left(M_B + \frac{1}{m_B}\right) \cdot u(\kappa_S)/\rho \tag{8}$$

Considering the uncertainty in the speed of sound measurements, $u(u)$, given in section 2.2, $u(\kappa_S)$ and $u(K_{2,\phi})$ range from (1.3 to 1.5)·10^{-13} Pa^{-1} and from (0.8 to 6)·10^{-15} Pa^{-1}·m^3·mol^{-1}, respectively.

A mixture, κ_S includes two contributions: (i) the isentropic compressibility by solvent network compression and (ii) that due to the inclusion of solvent molecules within the solute free volume [1,62] [1,67]. The results (Table S1) show that *myo*-inositol aqueous solutions are more compressible than NADES containing solutions. Furthermore, κ_S decreases with both increasing temperature and solute molality for all the studied systems. That is, both the incorporation of reline or glyceline into the solution as well as an increase in thermal agitation or the solute amount causes a decrease in the number of bulk solvent molecules. The second contribution to κ_S cited above is predominant.

The apparent molar isentropic compression, $K_{2,\phi}$, indicates the solution isentropic compression variation when the solute is added under isothermal-isobaric conditions and therefore, it is a very sensitive property to changes in the solvation structure [1,63] [1,68]. In all our systems, the calculated $K_{2,\phi}$ values are negative and decrease (less negative)

13

with increasing temperature (Table S1, Fig. S5 and S6). The negative sign indicates strong solute - solvent interactions as it shows the loss of medium compressibility. These interactions weaken with increasing the temperature so that some water molecules are released into the bulk, making the medium less compact. Noteworthy is the different behaviour of the $K_{2,\phi}$ variation with the solute concentration found for the studied systems. In pure water, an increase in the amount of *myo*-inositol makes the medium more compressible (Fig. S2b). However, when NADES is added as a co-solute, the intrinsic effect becomes predominant since there is an increase in the H-bond number and the medium is more compact. This effect, as expected, is especially important in the system containing glyceline (Fig. S5 and S6).

Similar to apparent molar volume, the apparent molar isentropic compression is a linear function of the solute molality:

$$K_{2,\phi} = K_2^0 + S_K \cdot m_B \tag{9}$$

where K_2^0 and S_K are the standard partial molar isentropic compressions of the solute and the slope, respectively, and the values are listed in Table 2. In an aqueous mixture, different water structures can coexist depending on the solute-solvent interaction type: electrostricted water, unstructured water, hydrophobic hydration water, and water attached by H-bond to the solute. Only the last type contributes positively to K_2^0 since an increase in the pressure provokes a network collapse [64] [69]. For all the studied systems, the calculated K_2^0 values are negative and decrease (less negative) with increasing T and when the co-solute is added. The decrease is more pronounced with glyceline as the added NADES (Fig. 3). The slope, S_K, for the aqueous solutions is positive and decreases to negative values when the NADES as co-solute is added. For the system containing reline, the absolute values are small indicating that, in this system, the solute-solvent interactions are predominant.

14
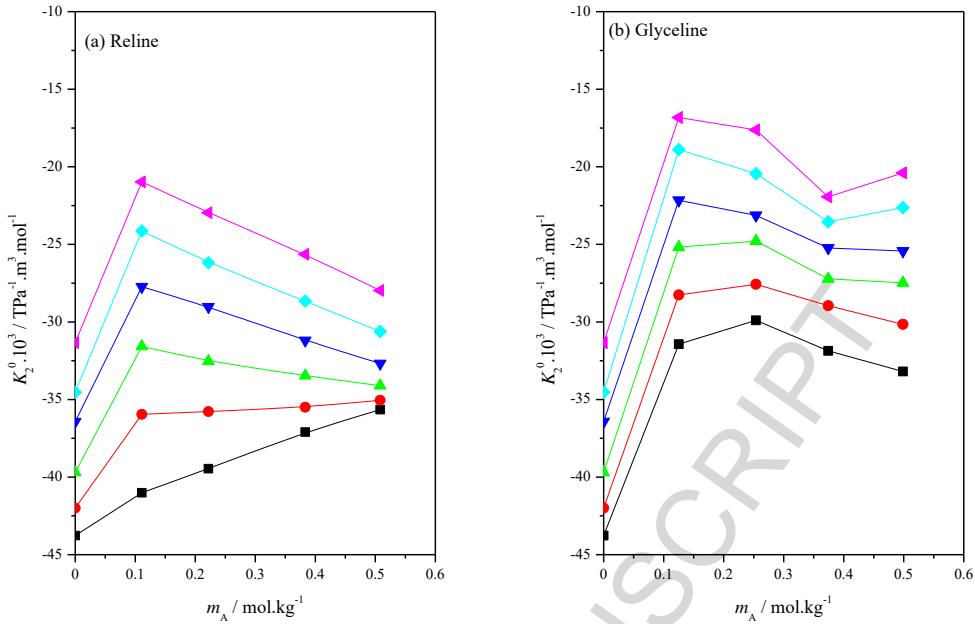
Figure 3. Standard partial molar isentropic compression, K_2^0, against the NADES molality, m_A, at p = 99.0 kPa, and at several temperatures: ■, T = 293.15 K; ●, T = 298.15 K; ▲, T = 303.15 K; ▼, T = 308.15 K; ◆, T = 313.15 K; ◄, T = 318.15 K.

3.3. Standard transfer properties

The effect of the co-solute on the interactions can be studied in a simple way through the transfer properties, $\Delta_t Z$. We compare the volumetric and acoustic properties of the systems with and without NADES, so:

$$\Delta_{tr}Z = Z(\text{NADES aqueous solutions}) - Z(\text{aqueous solutions}) \qquad (10)$$

where Z is V_2^0 or K_2^0.

According to the Gurney model [65] [70], both the ionic-hydrophilic and hydrophilic-hydrophilic interactions contribute positively to the transfer properties. On the other hand, the interactions that include hydrophobic groups do so negatively. For the

15

system containing reline, the $\Delta_{tr}V_2^0$ values are small and positives. They increase with decreasing temperature and scarcely vary with the reline concentration, m_A (Fig. S7a). In contrast, for glyceline aqueous solutions the $\Delta_{tr}V_2^0$ values are negative at any temperature, T, at the lowest molality, m_A, and at any m_A at the lowest T. With increasing T a strong dependence with m_A is observed (Fig. S7b). In relation to the transfer isentropic compression, $\Delta_{tr}K_2^0$, both systems have similar behavior, the values are positive and higher when the NADES glyceline is added (Fig. S8). These results show that: (i) the interactions with positive contribution are predominant in both systems, and (ii) unlike the reline mixtures, the glyceline mixtures present important interactions, favoured at higher temperatures, between the hydrophilic groups of *myo*-inositol and the NADES donor species.

3.4. Hydration behaviour

Quantitative information about solute hydration can be obtained by evaluating the variation of V_2^0 with temperature, which is expressed as:

$$V_2^0 = a + b(T - T_m) + c(T - T_m)^2 \tag{11}$$

where T/K is the temperature, and T_m/K is the midpoint of the temperature range. The constants a, b, c are listed in Table 3. The system sensibility with respect to temperature can be evaluated through the limiting apparent molar expansibility, E_2^0, and the isobaric thermal expansion coefficient, α_2:

$$\alpha_2 = E_2^0 / V_2^0 = \frac{1}{V_2^0}\left(\frac{\partial V_2^0}{\partial T}\right)_P \tag{12}$$

The values calculated for both parameters are reported in Table S2. At all conditions, the E_2^0 data are positive and increase with NADES molality and temperature. All the above may be due to the appearance of the packing effect that in turn suggests

interactions between *myo*-inositol and NADES [66] [71]. The α_2 values allow a comparative study of solute-solvent interactions for different systems [67] [72]. The higher the value the stronger the interactions. In our study, the highest value corresponded to a glyceline aqueous mixture at the highest temperature and composition. The results accord with the fact that hydrogen bonding is favoured in these conditions, as we have already described in the previous sections.

Table 3. Variation of the standard partial molar volume, V_2^0, with temperature, T, for *myo*-inositol in aqueous and NADES aqueous solutions at $p = 99.0$ kPa, and at several reline or glyceline compositions, m_A. The coefficients a, b, c are from equation 11. The corresponding standard deviations (equation A.2 equation A.3 in the supplementary information), and the Hepler's constant, $(\partial^2 V_2^0/\partial T^2)_p$, are from equation 12.

Solvent	m_A / mol·kg^{-1}	$a \cdot 10^6$ / m^3·mol^{-1}	$b \cdot 10^6$ / m^3·mol^{-1}·K^{-1}	$c \cdot 10^6$ / m^3·mol^{-1}·K^{-2}	$\sigma(V_2^0) \cdot 10^6$/ m^3·mol^{-1}	$(\partial^2 V_2^0/\partial T^2)_p \cdot 10^9$ / m^3·mol^{-1}·K^{-2}
Water	0	103.21	0.130	-8.571E-05	0.038	-0.17(±0.25)
Reline+	0.1109	103.30	0.108	1.571E-03	0.065	3.14(±0.49)
Water	0.2219	103.30	0.103	7.286E-04	0.055	1.46(±0.36)
	0.3833	103.44	0.112	1.057E-03	0.096	2.11(±0.63)
	0.5081	103.49	0.107	2.286E-04	0.024	4.57(±0.16)
Glyceline+	0.1252	102.59	0.120	1.136E-03	0.073	2.27(±0.48)
Water	0.2538	103.25	0.161	2.721E-03	0.099	5.44(±0.65)
	0.3742	104.07	0.216	1.557E-03	0.099	3.11(±0.64)
	0.4986	104.80	0.282	1.514E-03	0.086	3.03(±0.56)

The variation of the limiting apparent molar expansibility with temperature is called Hepler's constant [68] [73], $(\partial^2 V_2^0/\partial T^2)_P$. The parameter sign is related to the solute ability to modify the water structure in the solution. Thereby, a positive value is related to a structure maker solute (kosmotrope), whereas a large negative means a structure breaker (chaotrope). Separately and in pure water, all the components involved

17

in this study have negative Hepler's constants: urea and choline chloride are known structure breakers with values, (-2.4 and -2.3)·10^{-9} m^3·mol^{-1}·K^{-2} [69, 70] [74,75]; the glycerol coefficient is smaller, -0.75·10^{-9} m^3·mol^{-1}·K^{-2} [45, 71] [50,76]; last, the magnitude for *myo*-inositol is less than the error in the calculation, -0.17(±0.25) ·10^{-9} m^3·mol^{-1}·K^{-2}. However, in NADES aqueous solutions, the calculated values (Table 3) are positives so that the *myo*-inositol acts as a kosmotrope solute stabilizing the hydration structure. This fact is evidence for complex interactions in our systems.

From volumetric and acoustic measurements, the compressibility hydration number can be calculated. The Pasynski method [7] [8], widely used for the n_h calculation (equation 13) in carbohydrates among others, assumes that the molecule compressibility of both the solute and solvent in the hydration sphere is zero. Therefore, the obtained values using the following equation are not accurate but allow a quantitative study.

$$n_h = (n_w/n_s)(1 - \kappa_s/\kappa_{s,0}) \tag{13}$$

where n_w and n_s are the mole numbers (mol/kg of solution) of water and solute, respectively; and κ_s and $\kappa_{s,0}$ are the isentropic compressibility (equation 5) of the solution and solvent. Table S3 lists the compressibility hydration number at infinite dilution, n_h^0, which represents the number of water molecules disturbed by the presence of one solute molecule. The higher the value the better the packing within the water structure, so this number decreases with temperature and the solute-NADES interaction increases. The obtained sequence for the different solvents is pure water > reline+water > glyceline+water.

4. Conclusions

In this paper, the density and speed of sound of *myo*-inositol in pure water and NADES aqueous solutions were presented. The Natural Deep Eutectic Solvents added as

co-solutes were reline (choline chloride:urea, in mole 1:2) and glyceline (choline chloride:glycerol, in mole 1:2). The working pressure and temperature range were: $p = 99.0$ kPa and $T = (293.15\text{-}318.15)$ K. Measured data were used to calculate several limiting properties and parameters related to the hydration.

From the results, we can conclude the following: (i) The glyceline disturbs the system more than the reline; (ii) The solute intrinsic effect is dominant on isentropic compression; (iii) Ionic-hydrophilic and hydrophilic-hydrophilic interactions are predominant within the mixtures; (iv) A temperature increase (in the studied range) favours the hydrogen bonds; (v) The glyceline donor group (glycerol) exhibits an H-bonds number higher than the reline (urea); and (vi) *Myo*-inositol acts as a structure maker in the solvents.

Supplementary data

Supplementary data to this article can be found in the online version.

Acknowledgments

Appendix A

Average absolute deviation:

$$AAD(Y) = \frac{1}{n}\sum_{i=1}^{n}\left|Y_i - Y_{i,exp}\right| \qquad\qquad\qquad (A.1)$$

Standard deviation:

$$\sigma(Y) = \left(\frac{\sum_{i=1}^{n}\left(Y_i - Y_{i,exp}\right)^2}{n-p}\right)^{1/2} \qquad\qquad (A.2)$$

Mean relative deviation:

$$MRD(Y)/\% = \frac{100}{n} \sum_{i=1}^{n} \left| \frac{Y_t - Y_{t,exp}}{Y_{t,exp}} \right| \qquad (A.3)$$

where:

Y_t The literature, calculated or correlated value for the Y property

$Y_{t,exp}$ The experimental value for the Y property

n The number of points

n The number of parameters

References

[1] M. J. Blandamer, M. I. Davies, G. Douhéret, J. C. Reis, Apparent molar isentropic compressions and expansions of solutions, Chem. Soc. Rev. 30 (2001), 8-15. Doi: 10.1039/a908547e.

[2] T. V. Chalikian, On the molecular origins of volumetric data, J. Phys. Chem. B 112 (2008), 911-917. Doi: 10.1021/jp709578u.

[3] T. V. Chalikian, R.B. Macgregor, Nucleic acid hydration: a volumetric perspective, Phys. Life Rev. 4 (2007), 91-115. Doi: 10.1016/j.plrev.2006.11.001.

[4] Zhang, L. E. M. Desdier, M. G. Scanlon, Ergometric Studies of Proteins: New Insights into Protein Functionality in Food Systems, Trends Food Sci. Technol. 45 (2015), 251-263. Doi: 10.1016/j.tifs.2015.06.006.

[5] I. Bahadur, T. M. Letcher, S. Singh, G. G. Redhi, P. Venkatesu, D. Ramjugernath, Excess molar volumes of binary mixtures (an ionic liquid + water): A review, J. Chem. Thermodyn. 82 (2015), 34-46. Doi: 10.1016/j.jct.2014.10.003.

[6] T. V. Chalikian, Volumetric measurements in binary solvents: theory to experiment, Biophys. Chem. 156 (2011), 3-12. Doi: 10.1016/j.bpc.2010.12.004.

[7] Y. Marcus, Concentration dependence of ionic hydration numbers, J. Phys. Chem. B 118 (2014), 10471-10476. Doi: 10.1021/jp5039255.

[8] A.Burakowski, J.Glinski, Hydration numbers of nonelectrolytes from acoustic methods, Chem. Rev. 112 (2012), 2059-2081. Doi: 10.1021/cr2000948.

[9] S.A. Parke, G.G Birch, R. Dijk, Some taste molecules and their solution properties, Chem. Senses 24 (1999), 271-279. Doi: 10.1093/chemse/24.3.271.

[10] S. C. Eggers, T. E. Acree, R. S. Shallenberger, Sweetness chemoreception theory and sweetness transduction, Food Chem. 68 (2000), 45-49. Doi: 10.1016/s0308-8146(99)00154-5.

[11] G.G. Birch, Role of water in sweet taste chemoreception, Pure Appl. Chem. 74 (2002), 1103-1108. Doi: 10.1351/pac200274071103.

[12] F. Hutteau, M. Mathlouthi, M. O. Portmann, D. Kilcast, Physicochemical and psychophysical characteristics of binary mixtures of bulk and intense sweeteners, Food Chem. 63 (1998), 9-16. Doi: 10.1016/s0308-8146(97)00243-4.

[13] R.S. Clements, B. Darnell, Myo-inositol content of common foods: development of a high-myo-inositol diet, Am. J. Clin. Nutr. 33 (1980), 1954-1967. PMID: 7416064.

[14] M.W. Loewus, F.A. Loewus, G.U. Brillinger, H. Otsuka, H.G. Floss, Stereochemistry of the myo-inositol-1-phosphate synthase reaction, J. Biol. Chem., 255 (1980), 11710-11712. PMID: 7002927.

[15] E.M. Wright, B.A. Hirayama, D.F. Loo, Active sugar transport in health and disease, J. Int. Med. 261 (2007), 32-43. Doi: 10.1111/j.1365-2796.2006.01746.x.

[16] M. Mueckler, B. Thorens, The SLC2 (GLUT) family of membrane transporters, Mol. Asp. Med., 34 (2012), 121-138. Doi: 10.1016/j.mam.2012.07.001.

[17] S. Benvenga, A. Antonelli, Inositol(s) in thyroid function, growth and autoimmunity, Rev. Endocr. Metab. Disord. 17 (2016), 471-484. Doi: 10.1007/s11154-016-9370-3.

[18] J. Pundir, D. Psaroudakis, P. Savnur, L. Sabatini, H. Teede, A. Coomarasamy, S. Thangaratinam, Inositol treatment of anovulation in women with polycystic ovary syndrome: a meta-analysis of randomised trials, BJOG (2017). Doi: 10.1111/1471-0528.14754.

[19] C.C. Barron, P. J. Bilan, T. Tsakiridis, E. Tsiani, Facilitative glucose transporters: Implications for cancer detection, prognosis and treatment, Metab. Clin. Exp. 65 (2015), 124-139. Doi: 10.1016/j.metabol.2015.10.007.

[20] M. Castillo, J.K. Smith, L. Kwock, Correlation of myo-inositol levels and grading of cerebral astrocytomas, AJNR, 21 (2000), 1645-1649. PMID: 11039343.

[21] Y. Kinoshita, A. Yokota, Absolute concentrations of metabolites in human brain tumors using *in vitro* proton magnetic resonance spectroscopy, NMR Biomed. 10 (1997), 2-12. Doi: 10.1002/(SICI)1099-1492(199701)10:1<2::AID-NBM442>3.0.CO;2-N.

[22] Y.H. Choi, J.Van Spronse, Y.Dai, M.Verbene, F.Holllmann, I.W.C.E. Arends, G.J Witkamp, R. Verpoote, Are Natural Deep Eutectic Solvents the Missing Link in Understanding Cellular Metabolism and Physiology?, Plant Physiol. 2011, 156, 1701-1705. Doi: 10.1104/pp.111.178426.

[23] F. Pena-Pereira, A. Kloskowski, J. Namiesnik, Perspectives on the replacement of harmful organic solvents in analytical methodologies: a framework toward the implementation of a generation of eco-friendly alternatives, Green Chem. 17 (2015), 3687-3705. Doi: 10.1039/c5gc00611b.

[24] R. J. Davey, J. Garside, A. M. Hilton, D. McEwan, J. W. Morrison, Purification of molecular mixtures below the eutectic by emulsion crystallization, Nature 375 (1995), 664-666. Doi: 10.1038/375664a0.

[25] Y. K. Fang, M. Osama, W. Rashmi, K. Shabaz, M. Khalid, F. S. Mjalli, M. M. Farid, Synthesis and thermo-physical properties of deep eutectic solvent-based graphene nanofluids, Nanotechnology 27 (2016), 075702. Doi: 10.1088/0957-4484/27/7/075702.

[26] I. Gill, E. Vulfson, Enzymic catalysis in heterogeneous eutectic mixtures of substrates, Trends Biotechnol. 12 (1994), 118-122. Doi:10.1016/0167-7799(94)90088-4.

[27] M. C. Gutiérrez, M. L. Ferrer, L. Yuste, F. Rojo, F. del Monte, Bacteria incorporation in Deep-eutectic Solvents through freeze-drying, Angew. Chem. Int. Ed. 49 (2010), 2158-2162. Doi: 10.1002/anie.200905212.

[28] K. Haerens, E. Matthijs, A. Chmielarz, B. Van der Bruggen, The use of ionic liquids based on choline chloride for metal deposition: A green alternative? J. Environ. Manage. 90 (2009), 3245-3252. Doi: 10.1016/j.jenvman.2009.04.013.

[29] H. Tateishi-Karimata, N. Sugimoto, Structure, stability and behaviour of nucleic acids in ionic liquids, Nucleic Acids Res. 42 (2014), 8831-8844. Doi: 10.1093/nar/gku499.

[30] L. Liu, D. S. Wragg, H. Zhang, Y. Kong, P. J. Byrne, T. J. Prior, J. E. Warren, Z. Lin, J. Dong, R. E. Morris, Ionothermal synthesis, structure and characterization of three-dimensional zinc phosphates, Dalton Trans. 38 (2009), 6715-6718. Doi: 10.1039/b906934h.

[31] P. W. Stott, A. C. Williams, B. W. Barry, Transdermal delivery from eutectic systems: enhanced permeation of a model drug, ibuprofen, Journal Control. Release 50 (1998), 297-308. Doi: 10.1016/s0168-3659(97)00153-3.

[32] S. Tuntarawongsa, T. Phaechamud, Polymeric eutectic drug delivery system, Journal of Metals, Materials, and Minerals 22 (2012), 27-32.

[33] V. Fischer, Ph. Thesis. Properties and Applications of Deep Eutectic Solvents and Low-Melting Mixtures, University of Regensburg, 2015.

[34] Y. Dai, Ph. Thesis. Natural deep eutectic solvents and their application in natural product research and development. Leiden University, 2013.

[35] H. Wang, L. Tan, H.F. Wang, Y. Liu, R.H. Yin, W.Y. Wang, X.L. Chang, T. Jiang, J.T. Yu, Magnetic Resonance Spectroscopy in Alzheimer's Disease: Systematic Review and Meta-Analysis, J. Alzheimers Dis. 46 (2015), 1049-1070. Doi: 10.3233/JAD-143225.

[36] B. K. Sarkar, C. Chakraborty, A. R. Sharma, K.J. Bae, G. Sharma, G. P. Doss, D. Dutta, S. Ding, B. Ganbold, J. S. Nam, S. S. Lee, Novel biomarker for prostate cancer diagnosis by MRS, Front. Biosci (Landmark, Ed.) 19 (2014), 1186-1201. Doi: 10.2741/4275.

[37] B.D. Gill, H.E. Indyk, D.C. Woollard, Current methods for the analysis of selected novel nutrients in infant formulas and adult nutritionals, J. AOAC Int. 99 (2016), 30-41. Doi: 10.5740/jaoacint.15-0247.

[38] Commission Regulation Nº609/2013; http://data.europa.eu/eli/reg/2013/609/oj, 2013 (accessed 12 June 2013).

[39] B. Jacobson, Ultrasonic velocity in liquids and liquid mixtures, J. Chem. Phys. 20 (1952) 927-928. Doi:10.1063/1.1700615.

[40] A. Basaiahgari, S. Panda, R.L. Gardas, Acoustic, volumetric, transport, optical and rheological properties of benzyltripropylammonium based Deep Eutectic Solvents, Fluid Phase Equilib. 448 (2017), 41-49. Doi: 10.1016/j.fluid.2017.03.011.

[41] F.S. Mjalli, O.U. Ahmed, Characteristics and intermolecular interaction of eutectic binary mixtures: Reline and Glyceline, Korean J. Chem. Eng. 33 (2016), 337-343. Doi: 10.1007/s11814-015-0134-7.

[42] D. Shah, F.S. Mjalli, Effect of water on the thermo-physical properties of Reline: An experimental and molecular simulation based approach, Phys. Chem. Chem. Phys. 16 (2014), 23900-23907. Doi: 10.1039/c4cp02600d.

[43] R.T. Alarco, C. Caglieri, F. J. Caires, A. G. Magdalena, R. A. Esteves de Castro, G. Bannach, Thermoanalytical study of sweetener myo-inositol: α and β polymorphs, Food Chem. 237 (2017), 1149-1154. Doi: 10.1016/j.food.chem.2017.06.072.

[44] N. Siddiqui, V. Singh, M. M. Deshmukh, R. Gurunath, Structures, stability and hydrogen bonding in inositol conformers, PCCP 17 (2015), 18514-18523. Doi: 10.1039/c5cp02690c.

[45] T. Shikata, M. Okuzono, Hydration/dehydration behavior of polyalcoholic compounds governed by development of intramolecular hydrogen bonds, J. Phys. Chem. B. 117 (2013), 2782-2788. Doi: 10.1021/jp400290b.

[46] M. Liu, D. Sun, R. Lin, X. Qu, X. Wang, Studies on the enthalpic interactions of formamide and *N,N*-dimethylformamide with *myo*-inositol in aqueous sodium chloride solutions at 298.15 K, J. Chem. Eng. Data 52 (2007), 783-788. Doi: 10.1021/je060401f.

[47] M. B. Blodgett, S. P. Ziemer, B. R. Brown, T. L. Niederhauser, E. M. Woolley, Apparent molar volumes and apparent molar heat capacities of aqueous adonitol, dulcitol, glycerol, meso-erythritol, myo-inositol, D-sorbitol, and xylitol at

temperatures from (278.15 to 368.15) K and at the pressure 0.35 MPa, J. Chem. Thermodyn. 39 (2007), 627-644. Doi: 10.1016/j.jct.2006.08.009.

[48] Q. Zhao, Z. J. Sun, Q. Zhang, S. K. Xing, M. Liu, D. Z. Sun, L. W. Li, Densities and apparent molar volumes of myo-inositol in aqueous solutions of alkaline earth metal salts at different temperatures, Thermochim. Acta 487 (2009), 1-7. Doi: 10.1016/j.tca.2009.01.003.

[49] S. P. Jengathe, S. S. Dhondghe, L. J. Paliwal, V. M. Tangde, S. Mondal, Effect of sodium chloride and myo-inositol on diphenhydramine hydrochloride drug in aqueous solution at different temperatures: Volumetric and acoustic approach, J. Chem. Thermodyn. 87 (2015), 78-87. Doi: 10.1016/j.jct.2015.03.020.

[50] C. M. Romero, M. S. Páez, M. J. Puchana, Effect of temperature on the volumetric and viscometric properties of polyols in aqueous solutions, J. Mol. Liq. 223 (2016), 1192-1196. Doi: 10.1016/j.molliq.2016.09.045.

[51] J. Zhang, T. Fu, C. Zhu, Y. Ma, Volumetric and viscometric properties of amino acids in aqueous myo -inositol solution at T = (293.15 to 323.15) K and p = 0.101 MPa, J. Mol. Liq. 242 (2017), 190-203. Doi: 10.1016/j.molliq.2017.07.001.

[52] C. D'Agostino, L. F. Gladden, M. D. Mantle, A. P. Abbott, E. I. Ahmed, A. Y. M. Al-Murshed, R. C. Harris, Molecular and ionic diffusion in aqueous – deep eutectic solvent mixtures: probing inter-molecular interactions using PFG NMR, PCCP 17 (2015), 1529715304. Doi: 10.1039/c5cp01493j.

[53] D. V. Wagle, G. A. Baker, E. Mamontov, Differential microscopic mobility of components within a Deep Eutectic Solvent, J. Phys. Chem. Letters 6 (2015), 2924-2928. Doi: 10.1021/acs.jpclett.5b01192.

[54] T. Zhekenov, N. Toksanbayev, Z. Kazakbayeva, D. Shah, F. S. Mjalli, Formation of type III Deep Eutectic Solvents and effect of water on their intermolecular

interactions, Fluid Phase Equilib. 441 (2017), 43-48. Doi: 10.1016/j.fluid.2017.01.022.

[55] R. Stefanovic, M. Ludwig, G. B. Webber, R. Atkin, A. J. Page, Nanostructure, hydrogen bonding and rheology in choline chloride deep eutectic solvents as a function of the hydrogen bond donor, PCCP 19 (2017), 3297-3306. Doi: 10.1039/c6cp07932f.

[56] M. K. Hadj-Kali, K. E. Al-Khidir, I. Wazeer, L. El-Blidi, S. Mulyono, I. M. Alnashef, Application of deep eutectic solvents and their individual constituents as surfactants for enhanced oil recovery, Colloids Surf. A 487 (2015), 221-231. Doi: 10.1016/j.colsurfa.2015.10.005.

[57] R. B. Leron, M. H. Li, High-pressure density measurements for choline chloride: Urea deep eutectic solvent and its aqueous mixtures at T = (298.15 to 323.15) K and up to 50 MPa, J. Chem. Thermodyn. 54 (2012), 293-301. Doi: 10.1016/j.jct.2012.05.008.

[58] R. B. Leron, D. S. H. Wong, M. H. Li, Densities of a deep eutectic solvent based on choline chloride and glycerol and its aqueous mixtures at elevated pressures, Fluid Phase Equilib. 335 (2012), 32-38. Doi: 10.1016/j.fluid.2012.08.016.

[59] R. B. Leron, M. H. Li, Molar heat capacities of choline chloride-based deep eutectic solvents and their binary mixtures with water, Thermochim. Acta 530 (2012), 52-57. Doi: 10.1016/j.tca.2011.11.036.

[60] A. Yadav, S. Trivedi, R. Rai, S. Pandey, Densities and dynamic viscosities of (choline chloride + glycerol) deep eutectic solvent and its aqueous mixtures in the temperature range (283.15–363.15) K, Fluid Phase Equilib. 367 (2014), 135-142. Doi: 10.1016/j.fluid.2014.01.028.

[61] P. Abbott, G. Capper, D. L. Davies, R. K. Rasheed, V. Tambyrajah, Novel solvent properties of choline chloride/urea mixtures, Chem. Commun. 0 (2003), 70-71. Doi: 10.1039/b210714g.

[62] C. Ma, Y. Gao, D. Li, J. Zong, X. Ji, C. Liu, Molar enthalpy of mixing and refractive indices of choline chloride-based deep eutectic solvents with water, J. Chemical Thermodyn. 105 (2017), 30-36. Doi: 10.1016/j.jct.2016.10.002.

[63] V. Antón, H. Artigas, J. Muñoz-Embid, M. Artal, C. Lafuente, Thermophysical study of 2-acetylthiophene: Experimental and modelled results, Fluid Phase Equilib. 433 (2017), 126-134. Doi: 10.1016/j.fluid.2016.10.026.

[64] G. R. Hedwig, Thermodynamic properties of peptide solutions 3. Partial molar volumes and partial molar heat capacities of some tripeptides in aqueous solution, J. Solution Chem. 17 (1988), 383-397. Doi: 10.1007/bf00650418.

[65] Z. Yan, J. Wang, H. Zheng, D. Liu, Volumetric Properties of Some α-Amino Acids in Aqueous Guanidine Hydrochloride at 5, 15, 25, and 35°C, J. Solution Chem. 27 (1998), 473-477. Doi: 10.1023/a:1022608906767.

[66] G. R. Hedwig, H. Høiland, Thermodynamic properties of peptide solutions: 7. Partial molar isentropic pressure coefficients of some dipeptides in aqueous solution, J. Solution Chem. 20 (1991), 1113-1127. Doi: 10.1007/bf00649100.

[67] R. Sadeghi, H. Shekaari, R. Hosseini, Effect of alkyl chain length and temperature on the thermodynamic properties of ionic liquids 1-alkyl-3-methylimidazolium bromide in aqueous and non-aqueous solutions at different temperatures, J. Chem. Thermodyn. 41(2009), 273-289. Doi: 10.1016/j.jct.2008.09.005.

[68] R. Gardas, D. H. Dagade, S. S. Teerdale, J. A. P. Coutinho, K. J. Patil, Acoustic and volumetric properties of aqueous solutions of imidazolium based ionic liquids at 298.15 K, J. Chem. Thermodyn. 40 (2008), 695-701. Doi: 10.1016/j.jct.2007.10.007.

[69] J. G. Mathieson, B. E. Conway, H$_2$O–D$_2$O solvent isotope effects in adiabatic compressibility and volume of electrolytes and non-electrolytes: relation to specificities of ionic solvation, J. Chem. Soc. Faraday Trans. 1 70 (1974), 752-768. Doi: 10.1039/f19747000752.

[70] R. Gurney, Ionic processes in solution. McGraw Hill, New York, 1953.

[71] F. J. Millero, in: R.A. Horne (Ed.), Structure and transport process in water and aqueous solutions, Wiley-Interscience, New York, 1972.

[72] S. Cabani, G. Conti, E. Matteoli, Partial molal expansibilities of organic compounds in aqueous solution. I. Alcohols and ethers, J. Solution Chem. 5 (1976), 751-763. Doi: 10.1007/bf00651485.

[73] L. Hepler, Thermal expansion and structure in water and aqueous solutions, Can. J. Chem. 47 (1969), 4613-4617. Doi: 10.1139/v69-762.

[74] D. Hamilton, R. H. Stokes, Apparent molar volumes of urea in several solvents as functions of temperature and concentration, J. Solution Chem. 1 (1972), 213-221. Doi: 10.1007/bf00645102.

[75] S. Shaukat, R. Buchner, Densities, Viscosities [from (278.15 to 318.15) K], and Electrical Conductivities (at 298.15 K) of Aqueous Solutions of Choline Chloride and Chloro-Choline Chloride, J. Chem. Eng. Data 56 (2011), 4944-4949. Doi: 10.1021/je200856f.

[76] G. Egorov, D. M. Makarov, A. M. Kolker, Volume properties of liquid mixture of water+glycerol over the temperature range from 278.15 to 348.15K at atmospheric pressure, Thermochim. Acta 570 (2013), 16-26. Doi: 10.1016/j.tca.2013.07.012.

Highlights

- Experimental densities and speeds of sound of *myo*-inositol in aqueous solutions are presented.
- NAtural Deep Eutectic Solvents are used as co-solutes.
- Effects of temperature and NADES composition on the interactions are evaluated.
- Hepler's coefficients are calculated.
- Compressibility hydration numbers are obtained.