Viscometric study of *myo*-inositol in aqueous Deep Eutectic Solvent solutions

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Abstract

A viscometric study of *myo*-inositol in pure water and in Deep Eutectic Solvent (DES) aqueous solutions is presented. Two DES based on choline chloride as acceptor group and urea or glycerol as donor group are used. Experimental measurements of viscosities at p = 99.0 kPa and at six temperatures from 293.15 to 318.15 K were performed. In addition, the viscometric properties such as the B-coefficient, the hydration number, and the activation parameters of viscous flow were calculated. From these properties, the intermolecular interactions were evaluated. The results show that the studied sweetener is a structure-maker compound in all solvents of this work. The solute co-solute interactions are strongest in the system containing glycerol.

Keywords: *Myo*-inositol; DES; Viscosity; Hydration number; Activation parameters of viscous flow.

1. Introduction

Myo-inositol (cis-1,2,3,5-trans-4,6-cyclohexanehexol), MI, is the most abundant inositol stereoisomer. It is essential in the osmotic balance between the cell tissue and its surroundings so that its vital role as a precursor of the essential components of the cell signalling and membrane trafficking has been proved [1,2]. Different MI applications are [3-13]: (i) to overcame the abiotic stress in plants; (ii) as a biomarker in diseases such as Alzheimer, diabetes, encephalopathies, lupus, migraines, sclerosis, and cancer; (iii) as drug in the treatment of leishmaniosis, polycystic ovary syndrome, depression and other metabolic and endocrine disorders. Recently, *myo*-inositol has been proposed as a nutraceutical supplement for infant and adults [14,15].

According to the concept of Green Chemistry established by Anastas and Warner [16] find out innocuous solvents is an industry goal, since their elimination in the processes is not feasible. They are necessary, among others, in the reagents dissolution, as a mass and heat transfer medium. The so-called Deep Eutectic Solvents [17] are being postulated as the best alternative to both traditional organic solvents and ionic liquids [18-22]. They are mixtures of two or more substances which form a eutectic with a melting point lower than the corresponding of each individual component. The hydrogen bonds network between the species involved induces a sharp melting temperature decrease. The choline chloride, which belongs to the B-complex group of water soluble vitamins, is frequently used as hydrogen bond acceptor (HBA). As hydrogen bond donors (HBD), urea, polyols, organic acids, or amino acids can be used. NMR techniques (NOESY and DOSY experiments) have verified the existence of a supramolecular structure in the DES [23-25]. So that, the final compound properties are different from those of their constituent molecules. Sometimes, modifying the solvent physicochemical properties to adapt to a specific industrial process is suitable. For this, the water [21,26] is added as

48 modifier since allows to modulate the solvent thermophysical behavior. The great
49 advantages of DESs include high solvent capacity, biodegradability and biocompatibility,
50 as well as their low price and null reactivity with water [27]. Therefore, these compounds
51 are especially suitable for applications related to consumption in living beings. In
52 pharmacology, DESs are capable of increasing both the solubility of poorly water-soluble
53 drugs and their permeability through the membranes. In the agri-food industry, they
54 increase the extraction and separation processes efficiency [28-34].

55 Fluids viscosity data are very important in the industrial processes above cited.
56 This property is a direct consequence of the molecular internal friction. Therefore, its
57 study allows to establish the type of intermolecular interactions within the system. Taking
58 account both the DESs and their aqueous mixtures are the new green solvents, as we have
59 already indicated, the measure of the viscosity is required.

60 This paper is a continuation of our research line on the thermophysical
61 characterization of deep eutectic solvents, and the water effect on them [35,36]. Herein,
62 we study about the viscometric properties of the *myo*-inositol both in pure water and in
63 aqueous solutions containing a DES as co-solute, at atmospheric pressure and at T=
64 (293.15-318.15) K. The studied DESs are composed by choline chloride ([Ch]Cl) and
65 urea (U) or glycerol (Gly), in 1:2 mole relation. We have measured the kinematic
66 viscosity, ν, and using our previously published volumetric data [35] corresponding to
67 the same samples, we have calculated the dynamic viscosity, η. Moreover, different
68 properties such as the viscosity B-coefficient, the hydration number, n_{h}, and the
69 activation parameters of viscous flow (the free energy of activation per mole of solvent,
70 $\Delta\mu_1^{\neq}$, the free energy of activation per mole of solute, $\Delta\mu_2^{\neq}$, the enthalpy of
71 activation, $\Delta H_2^{\neq}$, and the entropy of activation, $T\Delta S_2^{\neq}$) are evaluated.

2. Materials and methods

2.1. Materials

Table 1 summarizes the information about the compounds, including the abbreviations used in this work, and Fig. S1 (supplementary material) shows their chemical structures. *Myo*-inositol (>99 %) was supplied from Sigma Aldrich, and the DESs were acquired already synthesized from Scionix Ltd. DESs were subjected to vacuum for several hours before the solutions preparation. The water content, m_w=253 ppm for [Ch]Cl:U and m_w=275 ppm for [Ch]Cl:Gly, was determined by the Karl Fischer method (automatic titrator Crison KF 1S-2B). These values were accounted for the solution preparation. For each molality, the mixtures were obtained by adding *myo*-inositol to a suitable amount of solvent. The latter was prepared by mixing the commercial DES with Milli Pore MilliQ water of resistivity < 18.2 μS·cm^{-1}. A Sartorius Semimicro balance (CP225-D), with an uncertainty of 0.01 mg, was used in the mass determination.

Table 1

Sample table

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

[a]As stated by the supplier

[b]Karl-Fischer method

2.2. Apparatus and procedure

An Ubbelohde capilar viscosimeter along with an automatic measuring unit Schott-Geräte AVS-440 was used to determine the kinematic viscosity, ν, of the mixtures. The temperature was kept constant within ± 0.01 K by means of a Schott-Geräte CT52 thermostat. The calibration was carried out with ultra-pure water (SH calibration service GmbH) and the kinematic viscosity uncertainty was $U_c(\nu)$ = 1 %. Apparatus was checked using benzene as a reference fluid [37] and the mean relative deviation between the literature and experimental data, equation S.1 (supplementary material), was $MRD(\nu)$ = 0.28%.

3. Results and discussion

3.1. Viscosity

In this section, we present experimental data for kinematic viscosity, ν, of *myo*-inositol in pure water, and in [Ch]Cl:U and [Ch]Cl:Gly aqueous solutions. The values are reported in the supplementary material (Table S1). The composition ranges of the solute (*myo*-inositol) and co-solutes (DES) 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. From our ν (this work) and ρ (previously published [35]) data, we have calculated the dynamic viscosities, $\eta = \rho \cdot \nu$. The estimated combined expanded uncertainty ($k \approx 2$) was $U_c(\eta)$ = 1% and the values are also listed in Table S1.

We have found literature viscosity data for the aqueous solutions of MI [38,39], [Ch]Cl:U [40-42], and [Ch]Cl:Gly [43]. It can be seen (Fig. 1) that our results for the sweetener are very similar to published by Zhang et al. [39] and slightly higher than those from Romero et al [38]. These latter were measured at p = 75 kPa. In the published data for both DESs, our experimental data are not directly comparable since composition do

not match but a qualitative comparison can be carried out. For [Ch]Cl:U mixtures (Fig. 2a), this work is agreed with Xie et al. [41] data whereas the other values are slightly inferior to both. The discrepancies may be due to a different water content, m_w, in the [Ch]Cl:U because the viscosity values depend very much on the water content. [Ch]Cl:U with m_w=5000 ppm was used by Shekaari et al. [42]. The paper of Yadav et al. [40] does not include the m_w values or drying procedure of the compounds. Fig. 2b shows a good agreement between the experimental data (this work) and those from literature [43] for [Ch]Cl:Gly in pure water.

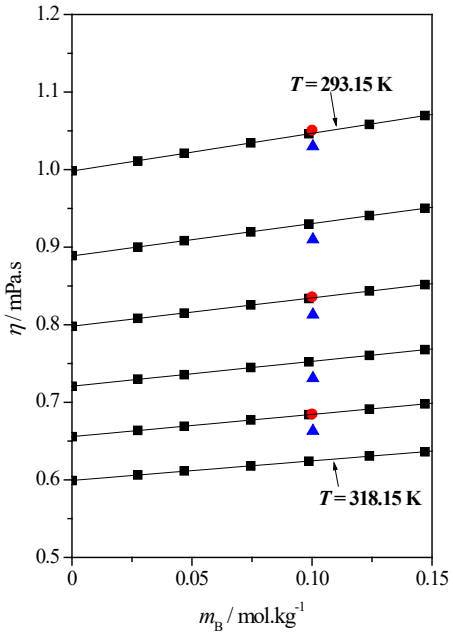
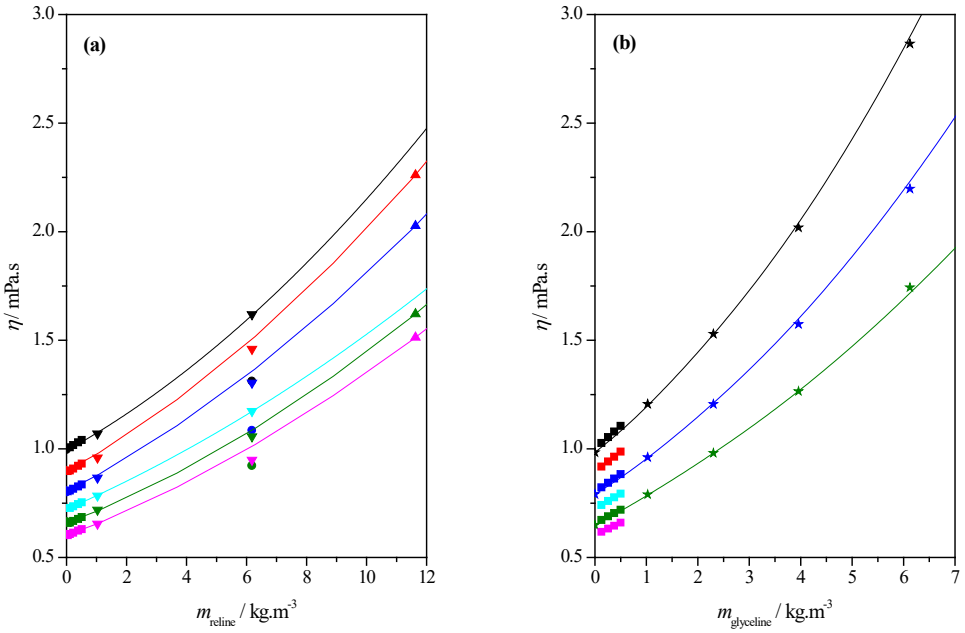


Fig. 1. Dynamic viscosity, η, for *myo*-inositol in pure water against its molality, m_B, at several temperatures, T. ■, this work; ●, Ref. [39.]; ▲, Ref. [38.].



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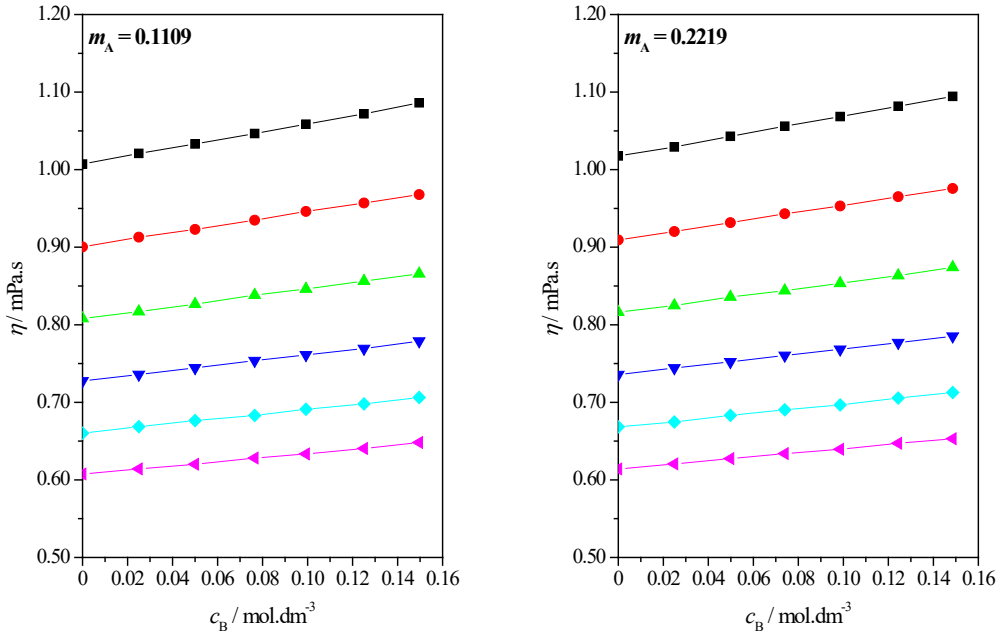
126 **Fig. 2**. Dynamic viscosity, η, for DESs aqueous solutions ((a), [Ch]Cl:U; (b),
127 [Ch]Cl:Gly) against its molality, at several temperatures, T. ■, this work; ●, Ref. [40];
128 ▲, Ref. [41] ; ▼, Ref. [42]; ★, Ref. [43]. Black, T = 293.15 K; red, T = 298.15 K; blue,
129 T = 303.15 K; cyan, T = 308.15 K; green, T = 313.15 K; magenta, T = 318.15 K.

130

131 The measured viscosity for the ChCl:U aqueous solutions was similar to those for
132 the ChCl or U in pure water [44,45] mixtures. On the other hand, the ChCl:Gly η is higher
133 than for the ChCl+water and Gly+water systems [38,44]. For the mixtures with *myo*-
134 inositol, the viscosity is higher in the systems containing co-solute and the change is more
135 significant for the [Ch]Cl:Gly mixtures (Fig. 3 and 4). Glycerol is able to establish a
136 greater H-bonds number than urea, so the [Ch]Cl:Gly hinders the molecules movement
137 more than the [Ch]Cl:U. Moreover, η increases with increasing m_A and decreases when
138 T increases because the fluidity is lower in these conditions.



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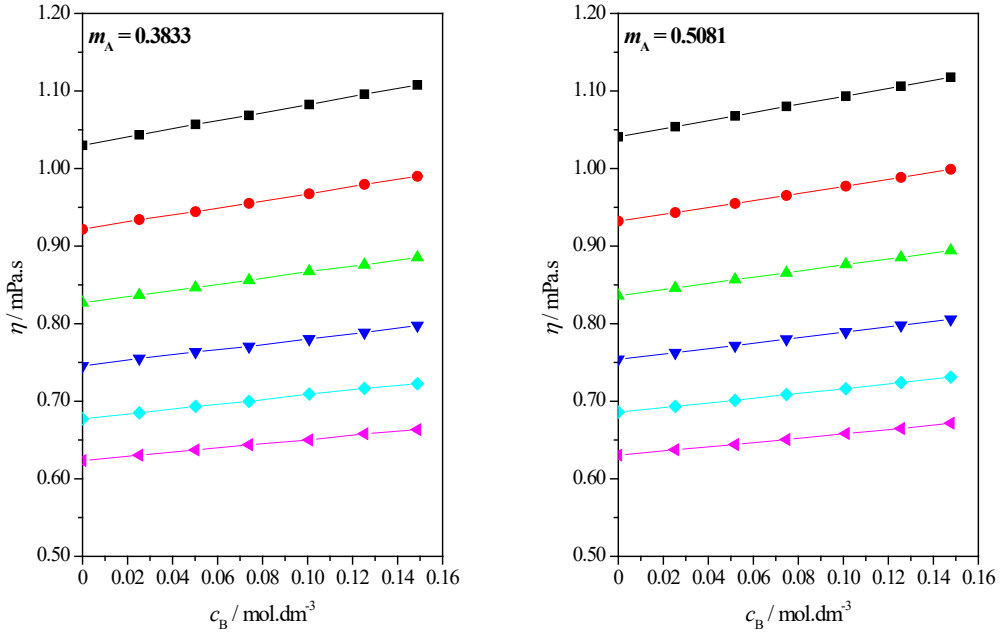

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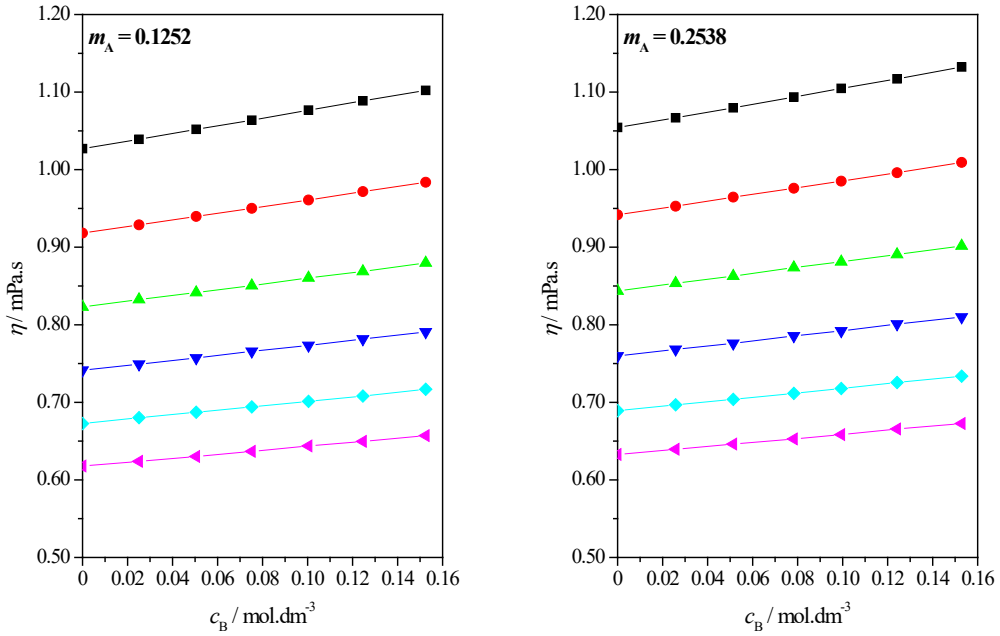
141 **Fig. 3**. Dynamic viscosity, η, for *myo*-inositol in aqueous [Ch]Cl:U solutions against its

142 molarity, c_B, at p = 99.0 kPa, and at several temperatures: ■, T = 293.15 K; ●, T = 298.15

143 K; ▲, T = 303.15 K; ▼, T = 308.15 K; ◆, T = 313.15 K; ◀, T = 318.15 K.



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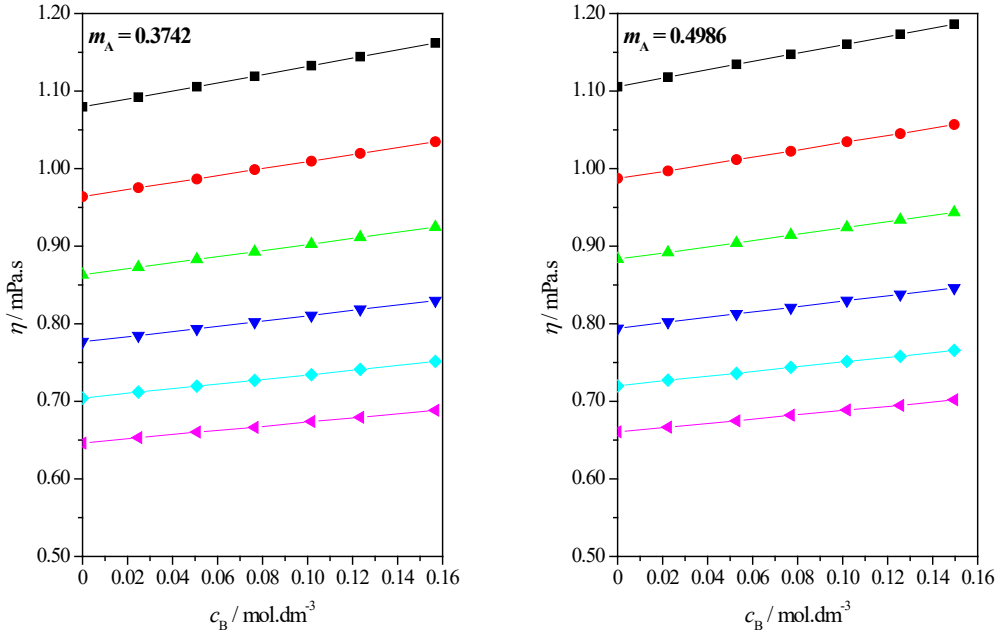


145

146 **Fig. 4**. Dynamic viscosity, η, for *myo*-inositol in aqueous [Ch]Cl:Gly solutions against its
147 molarity, c_B, at p = 99.0 kPa, and at several temperatures: ■, T = 293.15 K; ●, T = 298.15
148 K; ▲, T = 303.15 K; ▼, T = 308.15 K; ◆, T = 313.15 K; ◀, T = 318.15 K.

149

150 *3.2. Hydration behaviour*

151 Solute-solvent interactions can also be analysed via viscosity B-coefficient with
152 the Jones-Dole equation [46] that expresses the relative viscosity, η_r, as a function of the
153 solution molarity, c_{B}. This equation for dilute solutions of non-electrolyte solutes is the
154 following:

$$\eta_r = \eta/\eta_0 = 1 + B \cdot c_B \quad (1)$$

155 where η and η_0 are the viscosities of the solution and solvent (water or DES+water),
156 respectively; and B is a coefficient related to solute-solvent interactions. Normally, a B
157 positive value means that the solute is strongly hydrated, and therefore behaves as a
158 structure-making or kosmotrope agent. However, some large solutes as the
159 tetramethylammonium cation have positive coefficients but they are structure-breaking
160 or chaotropics substances [47]. Therefore, other parameter is preferred to check the
161 system interactions. According to the Eyring's theory of viscosity [48], if $dB/dT < 0$ the
162 viscous flow activation energy for the solution is greater than for the solvent; i.e., the
163 solute is a kosmotrope. On the other hand, when $dB/dT > 0$, the solute is a chaotrope.
164 The sign of dB/dT shows the net balance between the structure stabilization carried out
165 by the hydrophobic groups and the disruption caused by hydrophilic groups.

166 For all the studied systems, B-coefficient (Table 2) was positive and decreased
167 with T increasing ($dB/dT < 0$). So that, we can conclude, that the *myo*-inositol in pure
168 water, and in [Ch]Cl:U and [Ch]Cl:Gly aqueous solutions behaves like a kosmotropic
169 compound. No clear trends with composition were found, which points out to the
170 complexity of our systems. These conclusions are in agreement with those obtained from
171 the volumetric study [35].

172

The hydration number, n_{h}, is a parameter related to the solvent molecules distribution around the solute. It can be calculated from the experimental measurements carried out in this work. The B-coefficient is divided into two contributions with the Einstein equation [49]:

$$B = B_{\mathrm{size}} + B_{\mathrm{structure}} = 2.5\, V_2^0 + B_{\mathrm{structure}} \quad (2)$$

$$n_{\mathrm{h}} = B_{\mathrm{structure}}/2.5\, V_1 \quad (3)$$

where V_2^0 is the standard partial molar volume of the solute and V_1 is the solvent (water or DES+water) molar volume. These values were taken from our previously published paper [35]. B_{size} indicates the effect of the solute size on the viscosity, and $B_{\mathrm{structure}}$ suggests the effect of the solute on the solvent structure. Therefore, the $B_{\mathrm{structure}}$ sign can be a viable criterion to determine the solute hydration behaviour. A positive value is related to structure-maker solutes whereas a negative sign indicates structure-breaker solutes. Fig. 5 shows this effect for several substances [38,44,45,50] including those studied in this work. It is observed that different sugars in aqueous solutions are kosmotropes whereas the components forming the [Ch]Cl:U and [Ch]Cl:Gly (choline chloride, urea, and glycerol) are chaotrope solutes.

Table 2

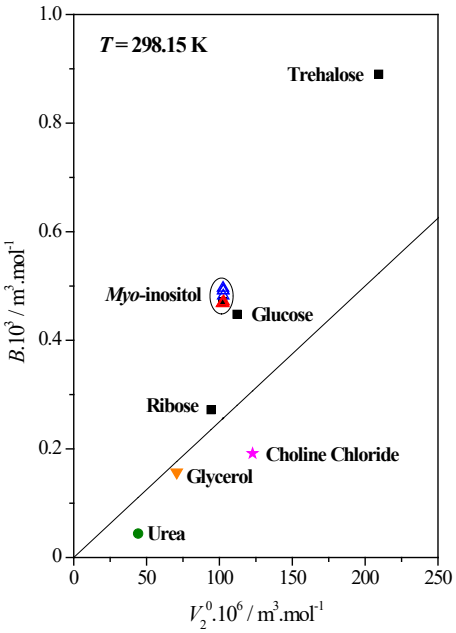
Calculated properties for *myo*-inositol in pure water and DES ([Ch]Cl:U or [Ch]Cl:Gly) aqueous solutions at p = 99.0 kPa, at several temperatures, T, and at DES molality, m_A. The viscosity B–coefficients are from equation 1, the corresponding standard deviations (equation S.2, supplementary material), $\sigma(\eta_r)$, and the temperature coefficients, (dB/dT). The hydration numbers, n_h, are from equation 3.

T / K	m_A / mol·kg^{-1}	$B\cdot10^3$ / m^3·mol^{-1}	$\sigma(\eta_r)$	$\left(\frac{dB}{dT}\right)\cdot10^3$ / m^3·mol^{-1}·K^{-1}	n_h

		Myo-inositol in aqueous solution				
293.15	0	0.4879	(±0.0019)	0.0002	-0.0024	5.18
298.15		0.4707	(±0.0021)	0.0003	(±0.0002)	4.76
303.15		0.4598	(±0.0026)	0.0003		4.48
308.15		0.4464	(±0.0018)	0.0002		4.14
313.15		0.4410	(±0.0017)	0.0002		3.98
318.15		0.4244	(±0.0037)	0.0005		3.57
		Myo-inositol in aqueous [Ch]Cl:U solutions				
293.15	0.1109	0.5149	(±0.0050)	0.0007	-0.0027	5.72
298.15		0.4963	(±0.0052)	0.0007	(±0.0002)	5.29
303.15		0.4788	(±0.0045)	0.0006		4.86
308.15		0.4668	(±0.0042)	0.0005		4.57
313.15		0.4585	(±0.0072)	0.0009		4.34
318.15		0.4436	(±0.0070)	0.0009		3.97
293.15	0.2219	0.5108	(±0.0036)	0.0005	-0.0032	5.60
298.15		0.4916	(±0.0031)	0.0004	(±0.0003)	5.15
303.15		0.4742	(±0.0064)	0.0008		4.74
308.15		0.4504	(±0.0021)	0.0003		4.18
313.15		0.4493	(±0.0069)	0.0009		4.12
318.15		0.4284	(±0.0045)	0.0006		3.62
293.15	0.3833	0.5023	(±0.0023)	0.0003	-0.0027	5.36
298.15		0.4918	(±0.0048)	0.0006	(±0.0002)	5.10
303.15		0.4719	(±0.0040)	0.0005		4.64
308.15		0.4599	(±0.0061)	0.0008		4.35
313.15		0.4530	(±0.0070)	0.0009		4.15
318.15		0.4316	(±0.0054)	0.0007		3.64
		Myo-inositol in aqueous [Ch]Cl:Gly solutions				
293.15	0.5081	0.4952	(±0.0018)	0.0002	-0.0022	5.18
298.15		0.4821	(±0.0028)	0.0004	(±0.0001)	4.86
303.15		0.4693	(±0.0025)	0.0003		4.55

308.15		0.4635	(±0.0015)	0.0002		4.39
313.15		0.4451	(±0.0038)	0.0005		3.96
318.15		0.4403	(±0.0044)	0.0006		3.81
293.15	0.1252	0.4809	(±0.0020)	0.0003	-0.0024	5.01
298.15		0.4682	(±0.0020)	0.0003	(±0.0002)	4.69
303.15		0.4509	(±0.0029)	0.0004		4.28
308.15		0.4395	(±0.0032)	0.0004		3.99
313.15		0.4280	(±0.0035)	0.0005		3.70
318.15		0.4226	(±0.0036)	0.0005		3.53
293.15	0.2538	0.4839	(±0.0028)	0.0004	-0.0027	5.01
298.15		0.4685	(±0.0023)	0.0003	(±0.0002)	4.63
303.15		0.4500	(±0.0021)	0.0003		4.19
308.15		0.4351	(±0.0032)	0.0004		3.82
313.15		0.4246	(±0.0033)	0.0004		3.53
318.15		0.4177	(±0.0035)	0.0005		3.32
293.15	0.3742	0.4877	(±0.0023)	0.0003	-0.0027	5.05
298.15		0.4682	(±0.0020)	0.0003	(±0.0002)	4.57
303.15		0.4538	(±0.0019)	0.0003		4.21
308.15		0.4385	(±0.0031)	0.0004		3.81
313.15		0.4277	(±0.0030)	0.0004		3.51
318.15		0.4191	(±0.0039)	0.0005		3.24
293.15	0.4986	0.4860	(±0.0014)	0.0002	-0.0027	4.98
298.15		0.4714	(±0.0029)	0.0004	(±0.0002)	4.59
303.15		0.4581	(±0.0021)	0.0003		4.23
308.15		0.4399	(±0.0027)	0.0003		3.76
313.15		0.4262	(±0.0034)	0.0004		3.39
318.15		0.4212	(±0.0036)	0.0005		3.18

193 Standard uncertainties, u, are: $u(m_A)$=0.0001 mol·kg^{-1}; $u(T)$=0.01 K; $u(p)$=0.5 kPa.



194

195 **Fig. 5**. Viscosity B–coefficients, B, against the standard partial molar volumes of the
196 solute, V_2^0, at T=298.15 K. Solid symbols, several compounds in aqueous solutions
197 [38,44,45,50]; △, *myo*-inositol in aqueous [Ch]Cl:U solutions; △, *myo*-inositol in
198 aqueous [Ch]Cl:Gly solutions; line, B_{size}.

199 The hydration numbers (Table 2) were lower than those estimated from
200 volumetric data [35] using the Pasynski method. This result is usual due to the hydrate
201 compressibility is despised in this method [51,52]. The highest values are found for the
202 mixtures with [Ch]Cl:U, which suggests that, in this system, the number of solvent
203 molecules disturbed by the solute is greater. In relation to the effect of the DES
204 concentration on this parameter, n_{h} decreases slightly when m_A increases for [Ch]Cl:U
205 solutions and remains practically constant in those containing [Ch]Cl:Gly. We have
206 calculated the hydration number average values, $\overline{n_h}$, in our working composition range.
207 The $\overline{n_h}$ values decrease with T increasing (Fig. S2) following a type-Arrhenius equation:

$$\overline{n_h} = A \exp(E_a/RT) \quad (4)$$

where A and E_a are the fitting parameters (Table 3), R is the gas constant, and T is the temperature. The A pre-exponential factor indicates the hydration number only due to the geometric factor since the interactions become negligible when $T \to \infty$. The highest energetic barrier to overcome for the hydration process of the *myo*-inositol, E_a, is obtained when the solvent contains [Ch]Cl:Gly. The other two systems show similar energies. The higher the E_a value the stronger intermolecular interactions. Again, results suggest that the [Ch]Cl:U presence favours the hydration structure more than [Ch]Cl:Gly, and the mixtures containing this latter DES have the greatest solute co-solute interactions. Anyway, the calculated values were small, indicating stable hydration structures in all cases.

Table 3

Arrhenius fitting parameters (equation 4) for *myo*-inositol in pure water and DES ([Ch]Cl:U or [Ch]Cl:Gly) aqueous solutions.

Solvent	A	E_a / kJ·mol^{-1}	R^2
Pure water	0.0566	11.008	0.990
[Ch]Cl:U + water	0.0519	11.365	0.995
[Ch]Cl:Gly + water	0.0229	13.144	0.998

3.3. Activation parameters of viscous flow

Thermodynamic parameters of the viscous flow can be obtained from the viscosity B-coefficients [53]: the Gibbs free energy of activation for viscous flow per mole of solvent, $\Delta\mu_1^{0\neq}$; the Gibbs free energy of activation per mole of solute, $\Delta\mu_2^{0\neq}$; the standard partial molar entropy of activation for viscous flow, $\Delta S_2^{0\neq}$; and the standard partial molar

enthalpy of activation for viscous flow, $\Delta H_2^{0\neq}$. These parameters are given in Table 4 and the equations used are the following:

$$\Delta\mu_1^{\neq} = RT \ln (\eta_1 V_1 / hN_A) \quad (5)$$

$$\Delta\mu_2^{\neq} = \Delta\mu_1^{\neq} + \frac{RT}{V_1}(B + V_2^0 - V_1) \quad (6)$$

$$\Delta S_2^{\neq} = -\, d(\Delta\mu_2^{\neq})/dT \quad (7)$$

$$\Delta H_2^{\neq} = \Delta\mu_2^{\neq} + T\Delta S_2^{\neq} \quad (8)$$

where η_1 is the solvent (water or DES+water) viscosity; V_2^0 and V_1 are the standard partial molar volume of the solute and the solvent molar volume [35], respectively; h is the Planck constant; N_A is the Avogadro number; R is the gas constant; and T is the temperature.

$\Delta\mu_1^{\neq}$ and $\Delta\mu_2^{\neq}$ calculated data are positive and decrease with increasing temperature. Regarding the effect of the DES concentration, $\Delta\mu_1^{\neq}$ increases slightly and $\Delta\mu_2^{\neq}$ decreases when m_{A} increases. According to the transition state theory of relative viscosity [53], $(\Delta\mu_2^{\neq} - \Delta\mu_1^{\neq})$ values indicate the change in the activation energy when one mole of solvent is replaced by on mole of solute at infinity dilution. Then, if $\Delta\mu_2^{\neq} > \Delta\mu_1^{\neq}$, as this work, the ground state is the favoured status from the free energy point of view; i.e. solute-solvent interactions are stronger than in the transition state. Furthermore, the higher $\Delta\mu_2^{\neq}$ value the higher structure-making tendency of the solute. Again, our results indicate that the *myo*-inositol in ([Ch]Cl:U+water) solvent is the best structure-making. Finally, it is observed that the formation of the transition state is a process that involves a bond breaking and increased disorder as indicated by the positives values of $\Delta S_2^{\neq}$ and $\Delta H_2^{\neq}$. These parameters are higher in the mixtures with [Ch]Cl:U.

Table 4

Activation parameters of viscous flow (free energy of activation per mole of solvent, $\Delta\mu_1^{\neq}$, free energy of activation per mole of solute, $\Delta\mu_2^{\neq}$, enthalpy of activation, $\Delta H_2^{\neq}$, and entropy of activation, $T\Delta S_2^{\neq}$) for *myo*-inositol in pure water or DES ([Ch]Cl:U or [Ch]Cl:Gly) aqueous solutions at p = 99.0 kPa, at several temperatures, T, and DES molality, m_A.

T / K	m_A / mol·kg^{-1}	$\Delta\mu_1^{0\neq}$/ kJ·mol^{-1}	$\Delta\mu_2^{\neq}$/ kJ·mol^{-1}	$\Delta H_2^{\neq}$/ kJ·mol^{-1}	$T\Delta S_2^{\neq}$/ kJ·mol^{-1}
Myo-inositol in aqueous solution					
293.15	0	9.29	86.46	120.73	34.27
298.15		9.16	85.29	120.14	34.85
303.15		9.04	84.90	120.34	35.44
308.15		8.94	84.13	120.15	36.02
313.15		8.84	84.42	121.03	36.61
318.15		8.75	83.05	120.24	37.19
Myo-inositol in aqueous [Ch]Cl:U solutions					
293.15	0.1109	9.32	89.75	136.51	46.76
298.15		9.20	88.44	136.00	47.55
303.15		9.09	87.21	135.56	48.35
308.15		8.98	86.63	135.78	49.15
313.15		8.87	86.53	136.48	49.95
318.15		8.80	85.43	136.17	50.74
293.15	0.2219	9.36	88.76	155.39	66.63
298.15		9.24	87.38	155.15	67.77
303.15		9.13	86.14	155.05	68.91
308.15		9.02	83.93	153.97	70.04
313.15		8.92	84.79	155.97	71.18
318.15		8.84	82.80	155.12	72.32
293.15	0.3833	9.41	87.02	134.33	47.31
298.15		9.30	86.82	134.94	48.12
303.15		9.18	85.26	134.18	48.93
308.15		9.07	84.66	134.39	49.74
313.15		8.98	84.76	135.30	50.54
318.15		8.91	82.73	134.08	51.35

293.15	0.5081	9.45	85.63	112.63	27.00
298.15		9.34	85.06	112.52	27.46
303.15		9.23	84.46	112.38	27.92
308.15		9.12	84.74	113.12	28.38
313.15		9.03	83.20	112.04	28.84
318.15		8.95	83.50	112.80	29.30
		Myo-inositol in aqueous [Ch]Cl:Gly solutions			
293.15	0.1252	9.38	84.89	120.88	36.00
298.15		9.26	84.35	120.97	36.61
303.15		9.14	83.08	120.31	37.23
308.15		9.03	82.53	120.37	37.84
313.15		8.93	81.92	120.38	38.45
318.15		8.85	82.16	121.22	39.07
293.15	0.2538	9.46	84.74	131.47	46.73
298.15		9.35	83.85	131.37	47.53
303.15		9.23	82.44	130.76	48.32
308.15		9.12	81.43	130.55	49.12
313.15		9.02	81.02	130.94	49.92
318.15		8.94	81.05	131.77	50.71
293.15	0.3742	9.54	84.68	129.24	44.56
298.15		9.42	83.32	128.64	45.32
303.15		9.31	82.50	128.58	46.08
308.15		9.19	81.51	128.35	46.84
313.15		9.09	81.06	128.66	47.60
318.15		9.02	80.91	129.27	48.36
293.15	0.4986	9.62	83.88	125.04	41.16
298.15		9.50	83.22	125.08	41.86
303.15		9.39	82.62	125.18	42.56
308.15		9.27	81.28	124.54	43.26
313.15		9.17	80.47	124.44	43.97
318.15		9.10	80.88	125.55	44.67

Standard uncertainties, u, are: $u(m_A)$=0.0001 mol·kg^{-1}; $u(T)$=0.01 K; $u(p)$=0.5 kPa.

4. Conclusions

The viscosity is an important property for the industrial processes design. In this paper, viscosity data of *myo*-inositol in pure water, and in [Ch]Cl:U and [Ch]Cl:Gly aqueous solutions are presented. The measurements were performed at p = 99.0 kPa and at six temperatures from 293.15 to 318.15 K. From experimental data, other properties were calculated and the interactions were evaluated.

The *B*-coefficient values and its variation with the temperature indicates that the *myo*-inositol is a structure-maker in all the mixtures studied. The greatest solute hydration numbers are found in the system containing [Ch]Cl:U. The mixtures with [Ch]Cl:Gly exhibits the strongest interactions. From activation parameters of viscous flow, we obtain that the ground state is the favoured status.

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Appendix A. Supplementary data

Supplementary data related to this paper can be found in version online. Kinematic viscosities, ν, and dynamic viscosities, η. Compounds chemical structures. Arrhenius plot for the hydration number.

References

[1] M. Mueckler, B. Thorens, The SLC2 (GLUT) family of membrane transporters, Mol. Aspects Med. 34 (2012) 121-138.

[2] S. Schneider, Inositol transport proteins, FEBS Lett. 589 (2015) 1049-1058.

[3] R. Valluru, W. Van den Ende, *Myo*-inositol and beyond – Emerging networks under stress, Plant Sci. 181 (2011) 387-400.

[4] A. Saiardi, Has inositol played any role in the origin of life? Life 7 (2017) 24.

[5] T. Taji, S. Takahashi, K. Shinozaki, Inositol and their metabolites in abiotic and biotic stress responses, in Biology of Inositols and Phosphoinositides, Springer, Berlin, 2006, pp. 239-264.

[6] J. Sarris, J. Murphy, D. Mischoulon, G.I. Papakostas, M. Fava, M. Berk, C.H. Ng, Adjunctive nutraceuticals for depression: a systematic review and meta-analyses, Am. J. Psychiatry 173 (2016) 575-587.

[7] A.D. Frej, G.P. Otto, R.S.B. Williams, Tipping the scales: lessons from simple model systems on inositol imbalance in neurological disorders, Eur. J. Cell. Biol. 96 (2017) 154-163.

[8] S. Benvenga, A. Antonelli, Inositol(s) in thyroid function, growth and autoimmunity, Rev. Endocr. Metab. Disord. 17 (2016) 471-484.

[9] 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 125 (2018) 299-308.

[10] 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.

[11] E.M. Wright, B.A. Hirayama, D.F. Loo, Active sugar transport in health and disease, J. Int. Med. 261 (2007) 32-43.

[12] 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.

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

[14] 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.

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

[16] P. Anastas, J. C. Warner, Green chemistry: theory and practice, Oxford University Press, Oxford, 2000.

[17] 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. 156 (2011) 1701-1705.

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

[19] A.P. Abbott, D. Boothby, G. Capper, D.L. Davies, R.K. Rasheed, Deep eutectic solvents formed between choline chloride and carboxylic acids: versatile alternatives to ionic liquids, J. Am. Chem. Soc. 126 (2004) 9142-9147.

[20] A. Paiva, R. Craveiro, I. Aroso, R.L. Reis, A.R. Duarte, Natural deep eutectic solvents – Solvents for the 21st century, ACS Sustain. Chem. Eng. 2 (2014) 1063-1071.

[21] 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.

[22] E. Durand, J. Lecomte, P. Villeneuve, From green chemistry to nature: the versatile role of low transition temperature mixtures, Biochimie 120 (2016) 119-123.

[23] Y. Dai, J. van Spronsen, G.J. Witkamp, R. Verpoorte, Y.H. Choi, Natural deep eutectic solvents as new potential media for green technology, Anal. Chim. Acta 766 (2013) 61-68.

[24] C. D'Agostino, L.F. Gladden, M.D. Mantle, A.P. Abbott, E.I. Ahmed, A.Y.M. Al-Murshedi, R.C. Harris, Molecular and ionic diffusion in aqueous-deep eutectic solvent mixtures: probing inter-mlecular interactions using PFG NMR, Phys. Chem. Chem. Phys. 17 (2015) 15297-15304.

[25] 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 Suf. A 487 (2015) 221-231.

[26] Y. Dai, G.J. Witkamp, R. Verpoorte, Y.H. Choi, Tailoring properties of natural deep eutectic solvents with water to facilite their applications, Food Chem. 187 (2015) 14-19.

[27] Q. Zhang, K. de Oliveira Vigier, S. Royer, F. Jérôme, Deep eutectic solvents: syntheses, properties and applications, Chem. Soc. Rev. 41 (2012) 7108-7146.

[28] M. Espino, M.A. Fernández, F.J.V. Gomez, M.F. Silva, Natural designer solvents for greening analytical chemistry, Trends Analyt. Chem. 76 (2016) 126-136.

[29] H. Lores, V. Romero, I. Costas, C. Bendicho, I. Lavilla, Natural Deep eutectic solvents in combination with ultrasonic energy as a Green approach for solubilisation

of proteins: application to glute determination by immunoassay, Talanta 162 (2017) 453-459.

[30] E. Rozema, A.D. van Dam, H.C.M. Sips, R. Verpoorte, O.C. Meijer, S. Kooijman, Y.H. Choi, Extending pharmacological dose-response curves for salsalate with natural deep eutectic solvents, RSC Adv. 5 (2015) 61398-61401.

[31] Z. Li, P.I. Lee, Investigation on drug solubility enhancement using deep eutectic solvents and their derivatives, Int. J. Pharm. 505 (2016) 283-288.

[32] A.R. Duarte, A.S.D. Ferreira, S. Barreiros, E. Cabrita, R.L. Reis, A. Paiva, A comparison between pure active pharmaceutical ingredients and therapeutic deep eutectic solvents: Solubility and permeability studies, Eur. J. Pharm. Biopharm. 114 (2017) 296-304.

[33] M.H. Zainal-Abidin, M. Hayyan, A. Hayyan, N.S. Jayakumar, New horizonts in the extraction of bioactive compounds using deep eutectic solvents: A review, Anal. Chim. Acta 979 (2017) 1-23.

[34] C. Guízar-González, N.R. Mustafa, E.G. Wilson, R. Verpoorte, Y.H. Choi, Application of natural deep eutectic solvents for the “green” extraction of vanillin from vanilla pods, Flavour Fragr. J. 33 (2018) 91-96.

[35] F. Bergua, M. Nuez, J. Muñoz-Embid, C. Lafuente, M. Artal, Volumetric and acoustic behaviour of *myo*-inositol in aqueous natural deep eutectic solvent solutions, J. Mol. Liq. 258 (2018) 106-113.

[36] D. Lapeña, L. Lomba, M. Artal, C. Lafuente, B. Giner, The NADES glyceline as a potential green solvent: a comprehensive study of its physicochemical properties and effect of water content, J. Chem. Thermodyn.(submitted).

[37] 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.

[38] 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.

[39] 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.

[40] A. Yadav, S. Pandey, Densities and viscosities of (choline chloride+urea) deep eutectic solvent and its aqueous mixtures in the temperature range 293.15 K to 363.15 K, J. Chem. Eng. Data 59 (2014) 2221-2229.

[41] Y. Xie, H. Dong, S. Zhang, X. Lu, X. Ji, Effect of water on the density, viscosity and CO2 solubility in choline chloride/urea, J. Chem. Eng. Data 59 (2014) 3344-3352.

[42] H. Shekaari, M.T. Zafarani-Moattar, B. Mohammadi, Thermophysical characterization of aqueous deep eutectic solvent (choline chloride/urea) solutions in full ranges of concentration at T = (293.15-323.15) K, J. Mol. Liq. 243 (2017) 451-461.

[43] 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 293.15 K to 363.15 K, Fluid Phase Equilib. 367 (2014) 135-142.

[44] 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.

[45] T.T. Herskovits, T.M. Kelly, Viscosity studies of aqueous solutions of alcohols, ureas and amides, J. Phys. Chem. 77 (1973) 381-388.

[46] G. Jones, M. Dole. The viscosity of aqueous solutions of strong electrolytes with special reference to barium chloride, J. Am. Chem. Soc. 51 (1929) 2950–2964.

[47] H. Zhao, Viscosity B-coefficients and standard partial molar volumes of amino acids, and their roles in interpreting the protein (enzyme) stabilization, Biophys. Chem. 122 (2006) 157-183.

[48] S. Glasstone, K. Laidler, E. Eyring, The theory of rate processes. New York: Mc-Graw-Hill, 1941.

[49] A. Einstein, A new determination of molecular dimensions, Ann. Phys. (Berl) 324 (1906) 289-306.

[50] Y. Sato, O. Miyawaki, Analysis of hydration parameter for sugars determined from viscosity and its relationship with solution parameters, Food Chem. 190 (2016) 594-598.

[51] Y. Marcus, Concentration dependence of ionic hydration numbers, J. Phys. Chem. B 118 (2014) 10471-10476.

[52] A.Burakowski, J.Glinski, Hydration numbers of nonelectrolytes from acoustic methods, Chem. Rev. 112 (2012) 2059-2081.

[53] D. Feakins, D.J. Freemantle, K.G. Lawrence, Transition state treatment of the relative viscosity of electrolytic solutions, J. Chem. Soc. Faraday Trans. 70 (1974) 795-806.