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Analysis of Physicochemical Properties of Aqueous Sodium Glycinate (SG) Solutions at Low Concentrations from 0.1-2.0 M

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Abstract: Sodium glycinate, a type of amino acid salt, is one of the potential solvent for carbon dioxide removal from various gas streams. In this study, physicochemical properties such as density, viscosity and refractive index of aqueous sodium glycinate at low concentrations were measured from 303.15 to 333.15 K. It was found that, the densities, viscosities and refractive indices of low concentrated sodium glycinate decrease with an increase in temperature, whereas with increasing the concentration in the solution, all three properties increase. The experimental data were correlated with respect to temperature and concentration by establishing the proper correlations.

Key words: Sodium glycinate, physicochemical property, density, viscosity, refractive index

INTRODUCTION

A well-known issue of the worldwide concern is the global warming which results from excessive increase in carbon dioxide level. The global temperature is rising to a certain degrees due to the rising effect of CO_2 on the climate. Coal fired power plants, refineries, gas processing plants and transportation are the main sources emitting CO_2 (Wang *et al.*, 2011; Simons *et al.*, 2010; Lee *et al.*, 2007; Kumar *et al.*, 2003). Global warming poses various negative effects such as ice caps melting, sea level rise, floods and other climatic disturbances (Rao and Rubin, 2002; NOAA, 2012; IPCC, 2007). There are so many techniques to capture CO_2 from different gas streams such as chemical solvent absorption, physical absorption, membrane separation and separation by cryogenic process (Rao and Rubin, 2002). The largely used techniques is chemical absorption. In this technique, the solvents which are extensively used are monoethanolamine (MEA), diethanolamine (DEA) and methyldiethanolamine (MDEA) (Nuchitprasittichai and Cremaschi, 2011; Kadiwala *et al.*, 2010). These conventional solvents have been favored owing to their number of benefits in CO_2 capture process (Hartono *et al.*, 2011). After the extensive use of these solvents, it was found that these solvents are corrosive, volatile and oxidative degradable (Portugal *et al.*, 2009; Ahn *et al.*, 2010). In addition to this, high regeneration cost has also been reported (Kumagai *et al.*, 2011; Aronu *et al.*, 2010, 2011). In recent times, amino acid salt solutions in an aqueous form have been suggested as a potential alternative to previously used amines. The researchers' focus is increasing towards the use of amino acids because of several useful features. High resistance to degradability, negligible volatility and environmental friendly characteristics are among the useful features (Shariff *et al.*, 2011; Portugal *et al.*, 2009; Ahn *et al.*, 2010). The prospective benefits of the amino acids have increased our interest to investigate further the amino acids' properties for removal of CO_2 from various streams of gas.

For commercial implementation of the solvent, physicochemical properties data such as density and viscosity data are required for the acid gas contactor design and optimization (Paul *et al.*, 2008; Yunus *et al.*, 2010). The refractive index data is supportive to determine the composition of solvents. Detailed molecular interactions of the solvent mixtures can be studied by obtaining molar refractions calculated from refractive index data (Tseng and Thompson, 1964). Density, viscosity and surface tension data of sodium glycinate in aqueous form have been already reported (Harris *et al.*, 2009; Lee *et al.*, 2005). These studies were conducted at high solvent concentrations owing to achieve high CO_2 removal. However, this solvent precipitate at concentrations higher than 2 M (Holst *et al.*, 2009), which can cause operational problems in the absorption system such as an obstruction of equipment, pipe lines, etc. They have also identified that the concentration range below 2.0 M is a non-precipitating region. Therefore, for detailed

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study of potential CO_2 removal process without precipitation, study of physicochemical properties of aqueous sodium glycinate at lower concentrations is required. In this study, density, viscosity and refractive index sodium glycinate aqueous solutions up to the concentration of 2.0 M have been studied.

MATERIALS AND METHODS

The materials such as glycine (purity≥99%) and sodium hydroxide (purity≥99%) were purchased from Merck Sdn. Bhd, Malaysia. Sodium glycinate was prepared in an aqueous form by taking an equimolar quantity of glycine and sodium hydroxide thereby neutralizing the glycine with 3 sodium hydroxide. The distilled water (double distilled) was used for the preparation of solutions. The different concentrations of sodium glycinate for this study were taken in molarity as 0.1, 0.5, 1.0, 1.5 and 2.0 M. The concentration values were accurate with the accuracy of 0.001 M. The properties were measured at temperatures (303.15, 313.15, 323.15 and 333.15) K. Before the analysis of samples, all equipments were calibrated with the water of Millipore quality. The sodium glycinate aqueous solutions of the same concentration as published in literature (Harris *et al.*, 2009; Lee *et al.*, 2005) were also prepared and analyzed for validation of the methods and results.

Density was measured using digital Anton Par density meter (DMA-4500 M). The accuracy of data was ±0.00003 g cm^{-3} and ±0.01 K, respectively. The apparatus was calibrated continually after finishing every experiment by Millipore quality water. The data reported is average of triplicate readings. For measuring viscosity in mPa.s, digital Anton Par micro viscometer (Lovis-2000 M) was used. The equipment calibration was carried out repetitively with millipore quality water after the end of each experiment. The sample was kept inside the viscometer before the measurement, until the desired equilibrium state of temperature is achieved. All experiments were conducted in triplicate to report the data

in average. The accuracy of data was 0.002 mPa.s and ±0.02 K, respectively. Digital Anton Par refractometer (Abbemet) was used for measuring the R.I (nD) of aqueous sodium glycinate solutions. The refractometer was calibrated with Millipore quality water each time after completing the experiment in order to avoid the error in reading. The presented data is taken as average of three measurements. The accuracy was 0.00005 nD and ±0.05 K, respectively.

RESULTS AND DISCUSSION

For the validation of methods and results, the experimental data on sodium glycinate of the same concentration as published in literature (Harris *et al.*, 2009; Lee *et al.*, 2005) was carried out as reported in Table 1. Average absolute deviation percent (%AAD) calculated by the 'Eq. 1' as also mentioned in Paul *et al.* (2008) is also reported:

$$AAD\ (\%) = \frac{1}{n} \left| \frac{X_{exptl} - Y_{lit}}{Y_{lit}} \right| \times 100 \qquad (1)$$

The Refractive Index (RI) data on aqueous sodium glycinate is not reported in open literature, therefore, for the validation of R.I data, the experiments was carried out using Millipore water and results were compared with those published in the literature. The deviation of the results shows the proper calibration of the equipment and validation of the data.

The experimental data of the physicochemical properties, such as densities, viscosities and refractive indices of sodium glycinate solutions at low concentrations are presented in Table 2, respectively. The dependence of density, viscosity and refractive index on temperature and concentration is shown in Fig. 1-6 correspondingly.

The experimental results of the density and refractive index show that with increasing the temperature, the density and R.I values decrease while with increasing the

Table 1: Experimental and literature data comparison

T (K)	Density (ρ) (g cm^{-3})			Viscosity (η) (mPa sec^{-1})		
	Exp.	Hariss *et al.* (2009)	AAD (%)	Exp.	Lee *et al.* (2007)	AAD (%)
10 wt% sodium glycinate (SG)						
313.15	1.0299	1.02968	0.07455	1.1839	1.184	0.00646
323.15	1.0254	1.02256		1.1374	1.137	
20 wt% sodium glycinate (SG)						
313.15	1.0765	1.07644	0.02235	1.2482	1.248	0.00814
323.15	1.0719	1.071		1.2072	1.207	
T (K)		Exp.		Murshid *et al.* (2011)		AAD (%)
Refractive index n$_D$ (water of millipore quality)						
303.15		1.33229		1.33221		0.00090
313.15		1.33045		1.33048		

Table 2: Densities, viscosities and refractive indices of different concentrations of aqueous sodium glycinate solutions

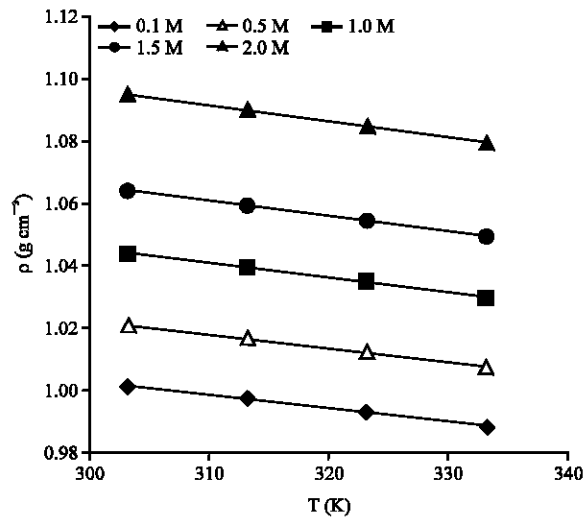| T (K)	Concentration of sodium glycinate (M)				
	0.1	0.5	1.0	1.5	2.0
303.15	1.00143	1.02112	1.04380	1.06412	1.09495
313.15	0.99793	1.01733	1.03969	1.05973	1.09019
323.15	0.99370	1.01291	1.03505	1.05489	1.08506
333.15	0.98886	1.00794	1.02995	1.04965	1.07959
303.15	0.90110	1.08500	1.18100	1.34200	1.80800
313.15	0.73570	0.89350	0.95780	1.09300	1.47000
323.15	0.61450	0.74790	0.81100	0.91510	1.20700
333.15	0.52040	0.63920	0.69090	0.78280	0.98340
303.15	1.33340	1.33930	1.34630	1.35210	1.36120
313.15	1.33200	1.33790	1.34470	1.35050	1.35960
323.15	1.33040	1.33640	1.34330	1.34930	1.35810
333.15	1.32860	1.33490	1.34200	1.34870	1.35720

Fig. 1: Densities of different concentrations of aqueous sodium glycine as a function of temperature
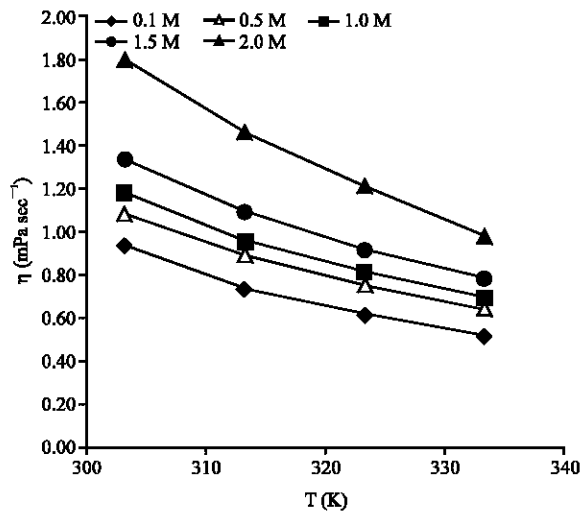

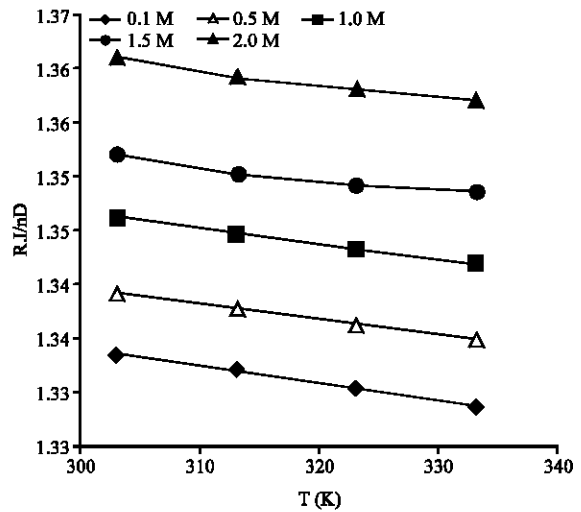Fig. 2: Viscosities of different concentration of aqueous sodium glycinate as a function of temperature

Fig. 3: Refractive indices of different concentration of aqueous sodium glycinate as a function of temperature
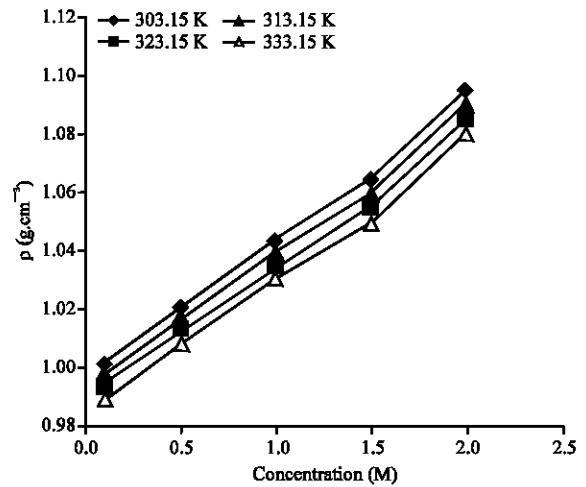

Fig. 4: Density of aqueous sodium glycinate as a function of concentration

concentration, the values increase. The similar trends have been observed by various researchers (Aronu *et al.*, 2011; Harris *et al.*, 2009; Lee *et al.*, 2005; Murshid *et al.*, 2011; Baragi *et al.*, 2013; Al-Ghawas *et al.*, 1989; Campos *et al.*, 2008; Muhammad *et al.*, 2009). It was observed that the viscosity of the sodium glycinate increase with increasing the concentration of sodium glycinate due to the reason that sodium glycinate is an ionic compound. It has the potential to enhance the ionic strength of the solution that can results in the viscosity increase of the solution. The effect of temperature on the viscosity shows that, with increasing temperature; the
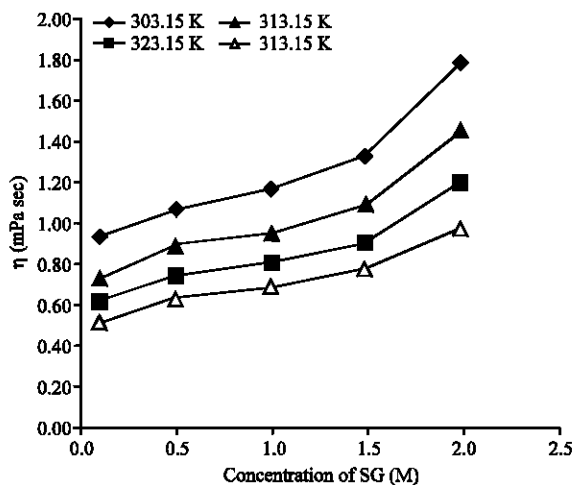
Fig. 5: Viscosities of aqueous sodium glycinate as a function of concentration
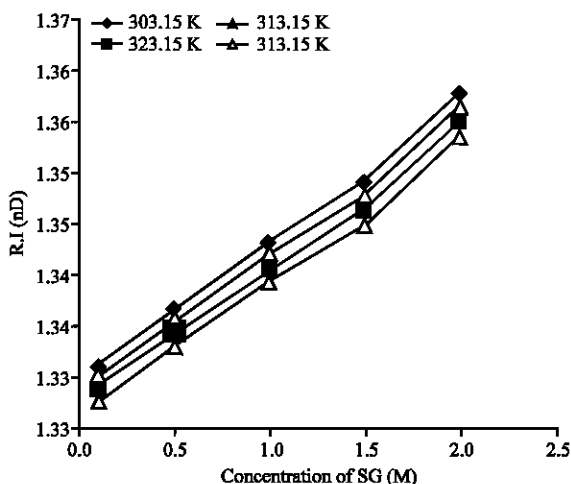

Fig. 6: Refractive indices of aqueous sodium glycinate as a function of concentration

viscosity decreases and the same behaviors have been also reported in the published work (Aronu *et al.*, 2011; Harris *et al.*, 2009; Lee *et al.*, 2005). This trend of increasing and decreasing the measured properties with change in temperature is because; increased temperature of solution mixtures causes the decrease in intermolecular forces of attraction between them. Therefore, the wider space will be occupied by molecules of liquid thus decreasing all the properties (Shaikh *et al.*, 2013).

The measured density data were correlated versus temperature and concentration by the least square method and following expressions were developed as indicated by 'Eq. 2' and '3', respectively:

$$\rho = A_0 + A_1 (T/K) + A_2 (T/K)^2 \qquad (2)$$

Table 3: Density correlation parameters A_0, A_1, A_2 in Eq. 2 and B_0, B_1 and B_2 in Eq. 3 with standard deviation

Concentration of SG (M)	A0	A1	10^6. A_2	R^2	S.D
0.1	0.79024	0.00171	-3.3	0.99999	0.00450
0.5	0.85645	0.00143	-2.9	0.99999	0.00454
1.0	0.93387	0.00111	-2.5	0.99999	0.00229
1.5	0.99577	0.00086	-2.1	0.99999	0.00219
2.0	1.07092	0.00061	-1.8	0.99999	0.00228
T (K)	B0	B1	10^3. B_2	R^2	S.D
303.15	0.99848	0.04038	3.61	0.99693	0.00180
313.15	0.99503	0.03973	6.10	0.99691	0.00550
323.15	0.99083	0.03933	3.58	0.99690	0.00177
333..15	0.98600	0.03911	3.53	0.99692	0.00175

Table 4: Viscosity correlation parameters E_0, E_1, E_2 in Eq. 5 and F_0, F_1 and F_2 in Eq. 6 with standard deviation

Concentration of SG (M)	E_0	E_1	10^3. E_2	R^2	S.D
0.1	33.23341	-0.19088	2.783	0.99835	0.008880
0.5	26.48611	-0.14654	2.070	0.99996	0.001640
1.0	32.11206	-0.18017	2.578	0.99908	0.009250
1.5	36.43079	-0.20419	2.918	0.99981	0.007400
2.0	38.98723	-0.20934	2.860	0.99983	0.005050
T (K)	F_0	F_1	F_2	R^2	S.D
303.15	0.98088	-0.02654	0.21146	0.97142	0.050430
313.15	0.77100	0.03076	0.15155	0.96226	0.048210
323.15	0.63789	0.06258	0.10478	0.96427	0.037678
333.15	0.53224	0.10352	0.05693	0.97057	0.026620

$$\rho = B_0 + B_1 (C_{SG}/M) + B_2 (C_{SG}/M)^2 \qquad (3)$$

where, ρ is the density in g cm^{-3} and A_0, A_1, A_2, B_0, B_1 and B_2 are the correlation parameters, which are presented in the Table 3 along with standard deviation calculated by 'Eq. 4':

$$SD = \left[\frac{\sum_i^n \left(X_{exp} - X_{calc}\right)^2}{n} \right] 0.5 \qquad (4)$$

For the prediction of viscosity data, the correlations were also developed from experimental data by using least-squares method . The following expressions 'Eq. 5' and '6' were obtained for viscosity correlation:

$$\eta = E_0 + E_1 (T/K) + E_2 (T/K)^2 \qquad (5)$$

$$\eta = F_0 + F_1 (C_{SC}/M) + F_2 (C_{SC}/M)^2 \qquad (6)$$

where, η is the viscosity E_0, E_1, E_2, F_0, F_1 and F_2 are the parameters of the correlation which are listed in Table 4 along with standard deviation calculated using 'Eq. 4 '.

The correlations were also established to allow the prediction of refra ctive index data using method of least-squares and the following regression equations 'Eq. 7' and '8' were obtained:

$$\eta_D = P_0 + P_1 (T/K) + P_2 (T/K)^2 \qquad (7)$$

Table 5: Refractive index correlation parameters P_0, P_1, P_2 in Eq. 7 and Q_0, Q_1 and Q_2 in Eq. 8 with standard deviation

Concentration of SG (M)	P0	P1	P2	R^2	S.D
0.1	1.28090	4.76 e-4	-1.0 e-6	1.00000	9.58 e-6
0.5	1.35861	1.21 e-5	-2.0 e-7	0.99995	5.07 e-3
1.0	1.46539	-6.20 e-4	8.0 e-7	0.99995	5.08 e-3
1.5	1.63915	-1.70 e-3	2.5 e-6	0.99970	2.48 e-5
2.0	1.57889	-1.24 e-3	1.7 e-6	0.99864	5.07 e-3
T (K)	Q_0	Q_1	$10^4 \cdot Q_2$	R^2	S.D
303.15	1.33254	0.01250	8.30	0.99652	5.73 e-4
313.15	1.33111	0.01221	9.10	0.99638	5.79 e-4
323.15	1.32942	0.01282	6.70	0.99728	5.05 e-4
333.15	1.32700	0.01400	4.00	0.99874	5.36 e-4

$$\eta_D = Q_0 + Q_1 (C_{SG}/M) + Q_2 (C_{SG}/M)^2 \qquad (8)$$

where, η_D denotes the refractive index, P_0, P_1, P_2, Q_0, Q_1 and Q_2 are the correlation coefficients as presented in Table 5, respectively together with standard deviation calculated using 'Eq. 4'.

CONCLUSION

The study of physicochemical properties of sodium glycinate aqueous solutions at low concentrations 0.1 to 2.0 M was carried out at 303.15 to 333.15 K. It was observed that the density, viscosity and refractive index of the aqueous sodium glycinate solution increase with increasing the concentration of the sodium glycinate in the solution and decrease with increasing the temperature. The trend of temperature and concentration dependence of measured properties was consistent with the findings of other researchers. The predicted values obtained from correlation equations for all properties are in good agreement with the measured values.

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