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Physical Properties of Aqueous Sodium Glycinate Solution as an Absorbent for Carbon Dioxide Removal

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The physicochemical properties of aqueous sodium glycinate solution such as density, viscosity, surface tension, alkalinity, and pH were measured over a wide range of mass fraction (0.1 to 0.5) of sodium glycinate and at $T = (303.15 \text{ to } 353.15)$ K. The measured data were correlated with standard equations, and parameters were reported along with average absolute deviations.

Introduction

The goal of CO_2 separation and capture is to isolate CO_2 from its many sources and its utilization in many technological applications including coal conversion, organic synthesis, destructive oxidation of hazardous wastes, enhanced oil recovery, and activated carbon regeneration.[1,2] The most likely options for CO_2 separation and capture include chemical absorption, physical and chemical adsorption, gas-separation membranes, mineralization/biomineralization, and vegetation.[3−12] The CO_2 absorption process using aqueous amine solutions have been extensively used for the removal of CO_2 from gas streams in many industries. This process based on the principles of chemical absorption of CO_2 via alkanolamines like monoethanolamine, diethanolamine, or *N*-methyldiethanolamine is considered to be a potential technique for capturing greenhouse gas emission from flue gas streams. Wet chemical stripping of CO_2 involves reversible chemical reactions between CO_2 and another material such as alkanolamine solution to produce a liquid species which, upon heating, breaks down to liberate CO_2 and regenerate the original material used to react with CO_2. The amine solution has a limited lifetime due to degradation through oxidation of the amine. In addition, corrosion problems are usually observed for the aqueous amine process. In the past, sodium glycinate in glycerol was used in an immobilized liquid membrane in closed loop life support systems, such as in spacecraft or space suits, for removal of carbon dioxide from the atmosphere.[13−15] This prompted us to study the aqueous sodium glycinate solution for the absorption of CO_2. The physicochemical properties of aqueous solutions such as density, viscosity, surface tension, alkalinity, and pH are necessary for the design, operation, and optimization of acid gas treatment equipment and also for measuring other physical properties such as liquid diffusivities and gas solubility.[16−19]

The objective of this research is to study the physicochemical properties such as density, viscosity, surface tension, and alkalinity of aqueous sodium glycinate solution that will be utilized to study CO_2 absorption in our future work.

Experimental Section

The chemical absorbents (sodium glycinate and monoethanolamine) used in this study were obtained from Sigma-Aldrich Chemical Co. with a mass purity of >99 %. The aqueous solutions were prepared from doubly distilled water. All solutions were prepared by mass with a balance precision of $\pm 1 \times 10^{-4}$ g.

Density. The densities of aqueous sodium glycinate solutions were measured by a 25 mL Gay-Lussac pycnometer using the ASTM D3505 standard test method.[20] The temperature of water bath was controlled by a VTRC-620 circulator (JEIO TECH Inc., Korea) to within ± 0.05 K of the test temperature. The densities of aqueous sodium glycinate solutions were calculated by the observed mass of the sample and that of the degassed distilled water. The density of water was taken from literature.[21] The uncertainty of measurement was $\pm 0.0001 \text{ g}\cdot\text{cm}^{-3}$. Each data point reported was taken as an average of six reading with a standard deviation of $\pm 0.0001 \text{ g}\cdot\text{cm}^{-3}$.

Viscosity. The kinematic viscosities of aqueous sodium glycinate solutions were measured by RheeStress1 viscometer (HAAKE Instruments Inc.) with an uncertainty of ± 0.001 mPa·s. The temperature of water bath was controlled within ± 0.05 K of the test temperature. An electronic torque of an accuracy of 300 $\text{cycle}\cdot\text{s}^{-1}$ was used to measure the efflux times of the liquid solution. The dynamic viscosities were calculated by multiplying kinetic viscosity with the measured density. Each data point reported was taken as an average of six readings.

Surface Tension. The surface tension of the aqueous sodium glycinate solution was measured using a Sigma 70 automated tensiometer that employs the Du Noüy ring-detachment method with an uncertainty of $\pm 0.01 \text{ mN}\cdot\text{m}^{-1}$. The platinum ring was thoroughly cleaned and flame-dried before each measurement. All solutions were thermostated in a water thermostat with a precision of ± 0.05 K. Each data point reported was taken as an average of six readings with a standard deviation of $\pm 0.01 \text{ mN}\cdot\text{m}^{-1}$.

The accuracy of density, viscosity, and surface tension measurements was checked by measuring the densities,

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Table 1. Densities (ρ), Viscosities (η), and Surface Tension (σ) of Pure Monoethanolamine

	ρ/g·cm^{-3}		η/mPa·s		σ/mN·m^{-1}	
T/K	this study	ref 22	this study	ref 23	this study	ref 24
303.15	1.0095	1.0098	15.109	15.1088	48.12	48.14
313.15	1.0013	1.0009	10.021	10.0209	46.42	46.46
323.15	0.9924	0.9929	6.970	6.9715	44.78	44.81

Table 2. Densities (ρ, in g·cm^{-3}) of Aqueous Sodium Glycinate Solutions (Mass Fraction)

	w_{SG}				
T/K	0.1	0.2	0.3	0.4	0.5
303.15	1.0332	1.0800	1.1214	1.1598	1.2066
313.15	1.0296	1.0763	1.1176	1.1558	1.2026
323.15	1.0252	1.0718	1.1129	1.1510	1.1975
333.15	1.0201	1.0665	1.1075	1.1455	1.1918
343.15	1.0145	1.0607	1.1015	1.1393	1.1854
353.15	1.0082	1.0542	1.0947	1.1324	1.1782

Table 3. Viscosities (η, in mPa·s) of Aqueous Sodium Glycinate Solutions (Mass Fraction)

	w_{SG}				
T/K	0.1	0.2	0.3	0.4	0.5
303.15	1.261	1.331	1.746	2.588	4.413
313.15	1.184	1.248	1.408	2.152	3.338
323.15	1.137	1.207	1.348	1.594	2.252
333.15	0.957	1.165	1.257	1.413	2.165
343.15	0.687	0.990	1.215	1.344	1.167
353.15	0.630	0.867	1.120	1.192	1.549

Table 4. Parameters of Eq 1 and AADs for Density Correlations of Aqueous Sodium Glycinate Solution (Mass Fraction)

w_{SG}	A_1	$10^3 \cdot A_2$	$10^6 \cdot A_3$	AAD %
0.1	0.8353	1.644	−3.268	0.032
0.2	0.8698	1.733	−3.429	0.079
0.3	0.8974	1.833	−3.607	0.120
0.4	0.9419	1.807	−3.589	0.158
0.5	0.9740	1.915	−3.786	0.077

Table 5. Parameters of Eq 2 and AADs for Viscosity Correlations of Aqueous Sodium Glycinate Solution (Mass Fraction)

w_{SG}	A_1	A_2	A_3	AAD %
0.1	−8.1020	5043.5682	298.0741	0.197
0.2	−4.402	2875.9320	307.3280	0.198
0.3	0.0272	9.8635	−284.4601	1.067
0.4	−0.7336	100.5007	−243.8311	0.013
0.5	−1.5975	296.4958	−207.0051	0.085

Table 6. Surface Tension (σ, in mN·m^{-1}) of Aqueous Sodium Glycinate Solution (Mass Fraction)

	w_{SG}				
T/K	0.1	0.2	0.3	0.4	0.5
293.15	40.12	42.96	44.95	49.07	51.93
303.15	36.89	39.82	41.79	45.42	48.30
313.15	33.93	36.45	38.43	42.05	44.55
323.15	30.07	33.31	35.34	38.56	40.76
333.15	28.14	29.94	31.90	34.89	37.00

viscosity, and surface tension of pure monoethanolamine at different temperatures. The results were found to compare well with their literature values (Table 1).[22–24] The uncertainties of the measured densities, viscosity, and surface tension were estimated to be ± 0.0005 g·cm^{-3}, ± 0.001 mPa·s, and ± 0.04 mN·m^{-1}, respectively, on the basis of comparisons with literature data. [22–24]

Alkalinity and pH. Alkalinity is the capacity of a system to neutralize acid. The experimental method was in accordance with the ASTM D501 standard test method.[20] The alkalinity measurements were made at T = (293.15 to 333.15) K. The mass fraction (w_{SG}) of aqueous sodium glycinate solution was varied from (0.1 to 0.5). The pH of aqueous sodium glycinate solutions was measured at T = 298.15 K by using a pH meter (model 290A$^+$, Orion Inc). The experimental method was in accordance with the ASTM D70 standard test method.[20] The mass fraction of aqueous sodium glycinate solutions was varied from (0.1 to 0.5).

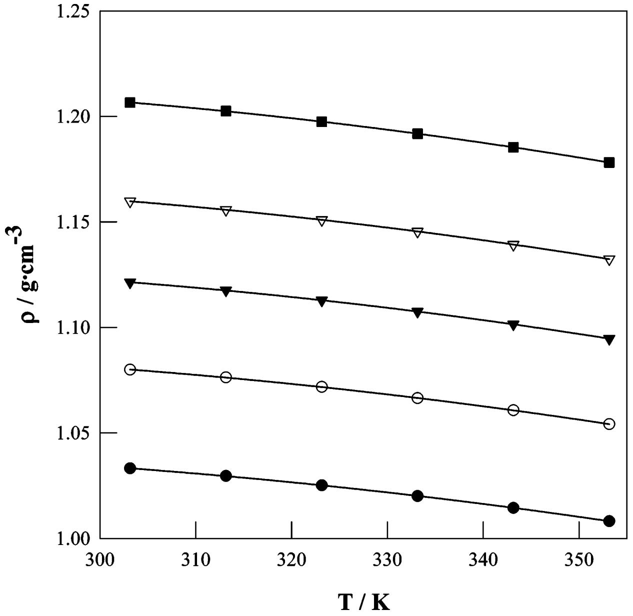

Figure 1. Values of the density as a function of temperature for aqueous sodium glycinate solution of different mass fractions; ●, 0.1; ○, 0.2 ▼, 0.3; ▽, 0.4; ■, 0.5.

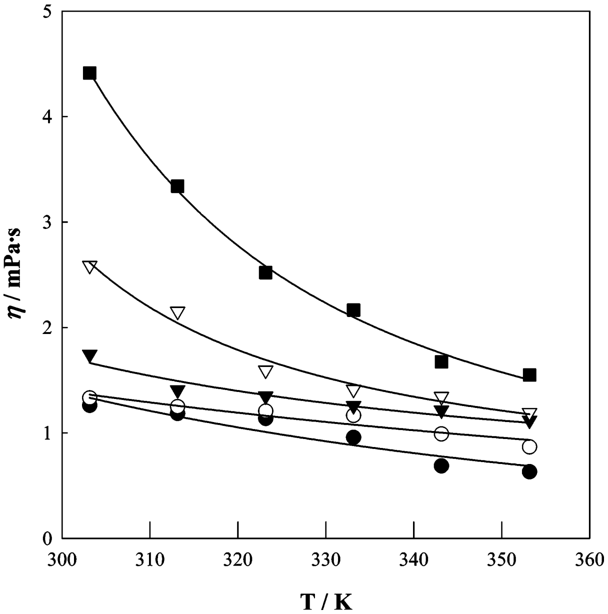

Figure 2. Values of the viscosity as a function of temperature for aqueous sodium glycinate solution of different mass fractions; ●, 0.1; ○, 0.2 ▼, 0.3; ▽, 0.4; ■, 0.5.

Results and Discussion

We are unaware of any previously published data on aqueous sodium glycinate solutions with which to compare our results. The measured density (ρ) and viscosity (η) data of aqueous sodium glycinate solutions of various mass

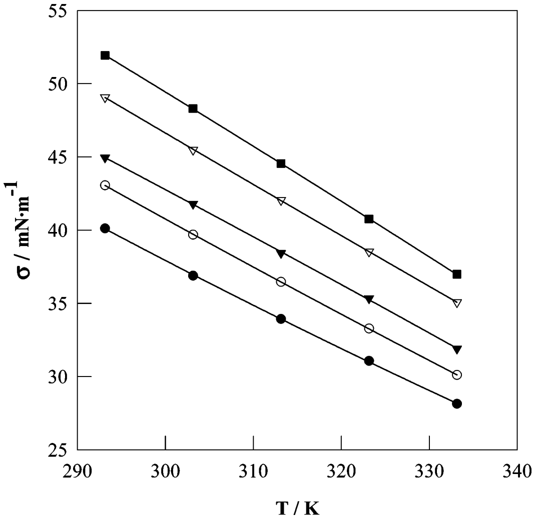

Figure 3. Values of the surface tension as a function of temperature for aqueous sodium glycinate solution of different mass fractions; ●, 0.1; ○, 0.2 ▼, 0.3; ▽, 0.4; ■, 0.5.

Table 7. Parameters of Eq 1 and AADs for Surface Tension Correlations of Aqueous Sodium Glycinate Solution (Mass Fraction)

w_{SG}	A_1	A_2	A_3	AAD %
0.1	176.2175	−0.6110	0.0005	0.1567
0.2	167.7578	−0.5155	0.0003	0.6881
0.3	120.1407	−0.1958	−0.0002	0.6913
0.4	162.6409	−0.421	0.0001	1.4000
0.5	140.6555	−0.2398	−0.0002	1.4015

fractions (0.1 to 0.5) at T = (303.15 to 353.15) K were recorded in Tables 2 and 3, respectively. The measured data were then regressed using the following equations:

$$X = A_1 + A_2(T_i/\mathrm{K}) + A_3(T_i/\mathrm{K})^2 \tag{1}$$

$$\eta/\mathrm{mPa{\cdot}s} = \exp\left[A_1 + \frac{A_2}{(T/\mathrm{K}) + A_3}\right] \tag{2}$$

$$\mathrm{AAD} = \frac{1}{N}\sum_{i=1}^{N}|\rho_{i,\mathrm{exptl}} - \rho_{i,\mathrm{calcd}}| \tag{3}$$

where X (= ρ or σ) is the density or surface tension, N is the number of data points, and A_i (i = 1 to 3) are the regression parameters calculated by least-squares method and reported in Tables 4 and 5 along with average absolute deviations (AADs) between calculated and measured values. Variation of measured densities and viscosity with temperature is shown in Figures 1 and 2. It was found that while density increases linearly with an increase in sodium glycinate mass fraction and decreases linearly with a decrease in temperature, viscosity decreases with an increase in temperature and the decrease is more sharp in case of higher mass fraction. Similar trends were reported in the literatures for MEA solution.[24]

The surface tension data of aqueous sodium glycinate solution at T = (293.15, 313.15, and 333.15) K for various mass fractions (0.1 to 0.5) were recorded in Table 6. The measured data were then regressed using eq 1, and A_i parameters together with AADs were recorded in Table 7.

It was found that surface tension increases linearly with an increase in sodium glycinate mass fraction and decreases with a decrease in temperature (Figure 3). Similar results were also reported by Matubayasi et al.[25] This behavior is opposite that of an alkanolamine solution where surface tension decreases with a decrease in the mass fraction of an alkanolamine aqueous solution.[26−28]

Table 8. Alkalinity in Terms of Mass Fraction of NaOH (w_{NaOH}) and pH of Aqueous Sodium Glycinate Solution (Mass Fraction)

	w_{SG}				
T/K	0.1	0.2	0.3	0.4	0.5
			$100w_{NaOH}$		
293.15	4.278	8.983	13.145	17.946	22.392
313.15	3.984	8.411	13.277	18.128	22.299
333.15	4.106	8.655	13.233	18.006	22.314
			pH		
298.15	11.786	11.887	12.140	12.308	12.524

Next we recorded the measured alkalinity of aqueous sodium glycinate solution in terms of mass fraction of sodium hydroxide (w_{NaOH}) at T = (293.15, 313.15, and 333.15) K for various mass fractions (0.1 to 0.5) and pH of these solutions at T = 298.15 K in Table 8. It was observed that alkalinity and pH increase with an increase in mass fraction and alkalinity was independent of temperature.

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