

University of Groningen

Diffusivities in aqueous solutions of the potassium salt of amino acids

Hamborg, E. S.; Van Swaaij, W. P. M.; Versteeg, G. F.

Published in:
Journal of Chemical and Engineering Data

DOI:
[10.1021/je700736x](https://doi.org/10.1021/je700736x)

IMPORTANT NOTE: You are advised to consult the publisher's version (publisher's PDF) if you wish to cite from it. Please check the document version below.

Document Version
Publisher's PDF, also known as Version of record

Publication date:
2008

[Link to publication in University of Groningen/UMCG research database](#)

Citation for published version (APA):

Hamborg, E. S., Van Swaaij, W. P. M., & Versteeg, G. F. (2008). Diffusivities in aqueous solutions of the potassium salt of amino acids. *Journal of Chemical and Engineering Data*, 53(5), 1141-1145.
<https://doi.org/10.1021/je700736x>

Copyright

Other than for strictly personal use, it is not permitted to download or to forward/distribute the text or part of it without the consent of the author(s) and/or copyright holder(s), unless the work is under an open content license (like Creative Commons).

The publication may also be distributed here under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license. More information can be found on the University of Groningen website: <https://www.rug.nl/library/open-access/self-archiving-pure/taverne-amendment>.

Take-down policy

If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

Downloaded from the University of Groningen/UMCG research database (Pure): <http://www.rug.nl/research/portal>. For technical reasons the number of authors shown on this cover page is limited to 10 maximum.

Diffusivities in Aqueous Solutions of the Potassium Salt of Amino Acids

Espen S. Hamborg,^{*,†,§} Wim P. M. van Swaij,[†] and Geert F. Versteeg[‡]

University of Twente, Department of Science and Technology, P.O. Box 217, 7500 AE Enschede, The Netherlands, and Procede Group BV, P.O. Box 328, 7500 AH Enschede, The Netherlands

Diffusion coefficients of the potassium salt of taurine, sarcosine, L-proline, and glycine have been determined in aqueous solutions using the Taylor dispersion technique over a temperature range from (293 to 368) K and salt concentrations ranging from (0 to 3.0) mol·dm⁻³. The diffusion coefficients of absorbed N₂O in aqueous solutions of the potassium salt of taurine, sarcosine, L-proline, and glycine have been determined over a temperature range from (293 to 333) K and salt concentrations ranging from (1.0 to 3.0) mol·dm⁻³. The experimental results have been compared to estimated values from a modified Stokes–Einstein relation and available literature data. The diffusivities can be estimated with sufficient accuracy using a modified Stokes–Einstein relation. The diffusion coefficients of CO₂ in the aqueous amino acid salt solutions can be estimated by means of the N₂O analogy.

Introduction

Aqueous solutions of amines are frequently used for the removal of acid gases, such as CO₂ and H₂S, from a variety of gas streams. In particular, aqueous solutions of alkanolamines and blends of alkanolamines are widely applied in gas treating. Alkanolamines can undergo degradation in oxygen atmosphere, usually encountered in the treatment of flue gases. The relative high volatility of alkanolamines also leads to losses of the compound during commercial operation of CO₂ capture plants. Aqueous solutions of salts of amino acids might be an attractive alternative to alkanolamines. They have been found to have better resistance to oxidative degradation, and their reactivity with CO₂ is comparable to aqueous alkanolamines of related classes. The ionic nature of the aqueous solutions of salts of amino acids results in a negligible volatility.^{1–5}

Knowledge of diffusion coefficients is needed for the design of absorbers and desorbers in a commercial CO₂ capture plant, as they are related to the mass transfer coefficients. They are also essential for a correct and accurate interpretation of many (laboratory scale) absorption rate experiments, e.g., experiments aimed to determine the intrinsic kinetics in a gas–liquid process. Diffusivities of the potassium salt of taurine, sarcosine, L-proline, and glycine in aqueous solutions determined by the Taylor dispersion technique at temperatures from (293 to 368) K and salt concentrations ranging from (0 to 3.0) mol·dm⁻³ are presented in this work. Diffusivities of N₂O in the same solutions determined with the same technique at temperatures from (293 to 333) K and salt concentrations ranging from (1.0 to 3.0) mol·dm⁻³ are also presented. The results are correlated and compared to literature values.

Theory and Experimental Procedures

General Theory of the Taylor Dispersion Technique. The diffusivities were determined using the Taylor dispersion

technique. A square pulse of a solute solution was injected into a solvent solution showing laminar flow through a capillary tube. The solute solution contained the same components as the solvent solution but with a slightly higher concentration of the compound of which diffusivities were to be determined (an addition of approximately 0.05 mol·dm⁻³). In the case of absorbed gas measurements, the solute solution contained the same amounts of liquid components as the solvent solution, but with additional N₂O gas absorbed. As an example of liquid measurements, for measurements of diffusivities in an approximately 1.00 mol·dm⁻³ solution of potassium taurate, the solvent solution contained 1.00 mol·dm⁻³ potassium taurate. The solute solution contained 1.05 mol·dm⁻³ potassium taurate, and a square pulse of this solution was injected into the flowing solvent solution. For gas measurements in aqueous solutions of potassium taurate at 1.00 mol·dm⁻³, both the solvent and solute solution contained 1.00 mol·dm⁻³ potassium taurate. The solute solution contained additional absorbed N₂O, and a square pulse of this solution was injected into the flowing solvent solution. The combined action of axial convection and radial and axial molecular diffusion eventually changed the pulse into a Gaussian curve. The theory, mathematical description, and procedure of such diffusivity measurements have been described in detail by Taylor,^{6,7} Aris,⁸ and Hamborg et al.⁹

The experimental setup used is shown schematically in Figure 1. Two vessels containing the solute solution and the solvent solution were kept under a constant 5·10² kPa pressure of saturated helium to create a constant flow of the solute and the solvent. Saturated helium was used to prevent any concentration changes in the solute and solvent solution as the liquid level in the two closed vessels decreased during a measurement due to the solution outflow. Introduction of a solute pulse was done by switching an air actuated six-way valve back and forth within a few seconds. The capillary tube was elliptical coiled and placed in a water bath for temperature control of ± 0.1 K. The flow velocity was controlled with mass flow controllers (Rosemount Flowmega 5881), located behind the refractive index (RI) detector (Varian 350 RI) and the six-way pulse valve to obtain a constant pulsation-free solute and solvent solution flow throughout the measurement. To avoid bubble formation inside

* Corresponding author. E-mail: espen.hamborg@procede.nl. Tel.: +31 53 489 2323. Fax: +31 53 489 5399.

† University of Twente.

‡ Procede Group BV.

§ Current address: Procede Group BV, P.O. Box 328, 7500 AH Enschede, The Netherlands.

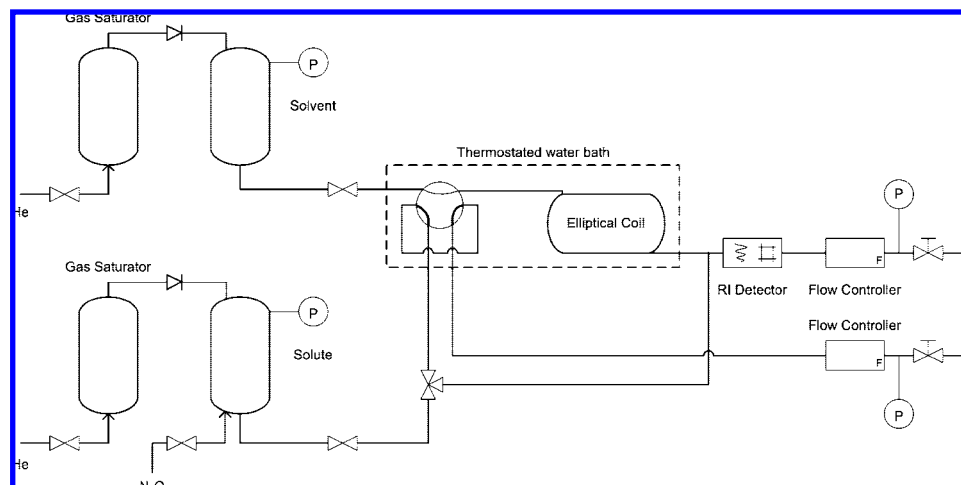


Figure 1. Schematic representation of the Taylor dispersion setup.

Table 1. Dimensions of the Experimental Setup and Flow Conditions

length of the capillary tube	L	14.92 m
inner radius of the capillary tube	R	$5.14 \cdot 10^{-4}$ m
radius of the helical coil	R_C	0.1 m
injection volume	V_{inj}	$(2.5 \text{ to } 4.1) \cdot 10^{-8}$ m ³
liquid flow velocity	u	$(2 \text{ to } 6) \cdot 10^{-3}$ m·s ⁻¹

the tubing and a disturbance of the laminar fluid flow profile, especially at higher temperatures and/or during absorbed gas diffusion measurements, pressure reducers were located behind the RI detector and the six-way pulse valve. These reducers pressurized the fluids inside the tubing to $4 \cdot 10^2$ kPa. The influence of the pressure on the diffusion coefficients can be neglected for the pressure applied.^{10,11} Prior to each experiment, both the solute and solvent solution were degassed by applying a vacuum for a while, and further the RI detector was calibrated. For absorbed gas diffusion measurements, N₂O was absorbed into the solute solution by bubbling the gas up to $1.5 \cdot 10^2$ kPa into the closed vessel containing the solution. A computer was connected to the setup for control and data acquisition. The output signal from the RI detector was recorded as a function of time and used to determine the diffusion coefficients. The RI detector showed a linear response to concentration changes of the potassium salt of amino acids and absorbed N₂O in the solutions investigated. The dimensions of the experimental setup and the flow conditions are given in Table 1.

A disturbance of the laminar fluid flow profile can occur due to the elliptic coiling of the tube. The varying path lengths traversed by the fluid at different radial positions in the tube and the secondary flows present in the flow can contribute additionally to the dispersion process. This topic has been extensively discussed by Alizadeh et al.¹² and Snijder et al.¹³ To avoid this disturbance, the critical $(De)^2Sc$ was determined for each system. The dimensionless $(De)^2Sc$ number is defined as

$$De = Re \left(\frac{R_C}{R} \right)^{-1/2} \quad (1)$$

$$Sc = \frac{\mu}{\rho D} \quad (2)$$

where Re is the well-known Reynolds number and μ and ρ are the solvent viscosity and density. The other parameters are defined in Table 1. The measurements had to be carried out at a value of $(De)^2Sc$ lower than the critical one.

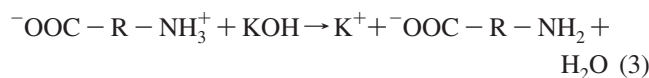
Table 2. Limiting Ionic Conductivities, λ_{∞}^0 , Estimated and Measured Diffusivities, D_{est} and D , and Relative Deviation^a

	λ_{∞}^0 cm ² ·S·mol ⁻¹	$D_{est, PG}$ 10 ⁻⁹ ·m ² ·s ⁻¹	D_{PG} 10 ⁻⁹ ·m ² ·s ⁻¹	rel. dev. %
D'yachkova et al. ¹⁵	24.5	0.979	1.11	-11.8
Miyamoto & Schmidt ¹⁶	30.0	1.13	1.11	-1.8
Mehl & Schmidt ¹⁷	39.2	1.36	1.11	22.5

^a Subscripts: PG = potassium glycinate.

Chemicals. Taurine [107-35-7], sarcosine [107-97-1], glycine [56-40-6], L-proline [147-85-3], KOH [1310-58-3] (Sigma-Aldrich), N₂O [10024-97-2], and helium [7440-59-7] (Linde Gas) were used as supplied. Water was demineralized and further purified by vacuum distillation.

Salt Preparation. The respective aqueous solutions of the potassium salt of the amino acids were prepared by adding equimolar amounts of KOH and amino acid based on weight. The aqueous amino acid zwitterion will be deprotonated according to



and form a potassium salt of the amino acid. The salt concentration was checked by means of titration.

Salt Diffusivity Measurements. The results of salt diffusivity measurements can be described by⁶⁻⁸

$$c_m = \frac{N_{inj, SAA}}{2\pi R^2 \sqrt{\pi K_{SAA} t}} \exp\left(-\frac{(L-ut)^2}{4K_{SAA} t}\right) \quad (4)$$

$$K_{SAA} = \frac{u^2 R^2}{48 D_{SAA}} + D_{SAA} \quad (5)$$

where c_m is the measured excess concentration profile at the end of the capillary tube; $N_{inj, SAA}$ is the excess number of moles of the salt of amino acid injected; t is the time; and D_{SAA} is the binary diffusion coefficient. The subscript SAA refers to the salt of the amino acid. The other parameters are defined in Table 1. $N_{inj, SAA}$, u , and D_{SAA} are the independent parameters used to fit eqs 4 and 5 to the experimentally recorded results. Since the concentration of the solute pulse decreases because of

Table 3. Diffusion Coefficients, D , of Salts of Amino Acids in Aqueous Solutions at Various Temperatures, T , and Reference Concentrations, c_{ref}^a

T K	D_{PT} $10^{-9} \cdot \text{m}^2 \cdot \text{s}^{-1}$	$c_{\text{ref, PT}}$ $\text{mol} \cdot \text{dm}^{-3}$	D_{PS} $10^{-9} \cdot \text{m}^2 \cdot \text{s}^{-1}$	$c_{\text{ref, PS}}$ $\text{mol} \cdot \text{dm}^{-3}$	D_{PP} $10^{-9} \cdot \text{m}^2 \cdot \text{s}^{-1}$	$c_{\text{ref, PP}}$ $\text{mol} \cdot \text{dm}^{-3}$	D_{PG} $10^{-9} \cdot \text{m}^2 \cdot \text{s}^{-1}$	$c_{\text{ref, PG}}$ $\text{mol} \cdot \text{dm}^{-3}$
293.15	1.01	$0.3 \cdot 10^{-3}$	0.961	$0.9 \cdot 10^{-3}$	0.924	$0.4 \cdot 10^{-1}$	0.999	$0.5 \cdot 10^{-3}$
	0.975	0.937	0.945	0.970	0.840	1.03	1.05	1.07
	0.936	1.87	0.893	1.99	0.760	1.95	1.07	2.02
	0.884	2.71	0.865	2.91	0.605	2.97	1.04	3.09
298.15	1.13	$0.3 \cdot 10^{-3}$	1.10	$0.1 \cdot 10^{-2}$	1.04	$0.5 \cdot 10^{-1}$	1.11	$0.5 \cdot 10^{-3}$
	1.11	0.938	1.04	0.970	0.959	1.04	1.20	1.07
	1.07	1.87	0.993	1.99	0.870	1.96	1.25	2.02
	1.00	2.72	0.982	2.91	0.719	2.97	1.18	3.09
303.15	1.26	$0.4 \cdot 10^{-3}$	1.23	$0.1 \cdot 10^{-2}$	1.17	$0.5 \cdot 10^{-1}$	1.25	$0.6 \cdot 10^{-3}$
	1.24	0.938	1.19	0.971	1.08	1.04	1.37	1.07
	1.20	1.87	1.18	1.99	0.988	1.96	1.41	2.02
	1.14	2.72	1.11	2.91	0.819	2.97	1.37	3.09
313.15	1.56	$0.4 \cdot 10^{-3}$	1.54	$0.1 \cdot 10^{-2}$	1.48	$0.5 \cdot 10^{-1}$	1.56	$0.6 \cdot 10^{-3}$
	1.53	0.939	1.50	0.971	1.35	1.04	1.70	1.07
	1.48	1.88	1.45	1.99	1.25	1.96	1.72	2.03
	1.40	2.72	1.39	2.91	1.05	2.97	1.68	3.09
323.15	1.92	$0.4 \cdot 10^{-3}$	1.89	$0.1 \cdot 10^{-2}$	1.81	$0.6 \cdot 10^{-1}$	1.91	$0.7 \cdot 10^{-3}$
	1.89	0.939	1.85	0.972	1.68	1.04	2.11	1.07
	1.80	1.88	1.80	1.99	1.56	1.96	2.13	2.03
	1.71	2.72	1.73	2.91	1.34	2.97	2.11	3.09
333.15	2.29	$0.5 \cdot 10^{-3}$	2.34	$0.2 \cdot 10^{-2}$	2.18	$0.6 \cdot 10^{-1}$	2.28	$0.8 \cdot 10^{-3}$
	2.25	0.940	2.27	0.972	2.02	1.04	2.50	1.07
	2.16	1.88	2.18	1.99	1.88	1.96	2.53	2.03
	2.05	2.72	2.08	2.91	1.63	2.98	2.44	3.09
343.15	2.71	$0.5 \cdot 10^{-3}$	2.71	$0.2 \cdot 10^{-2}$	2.55	$0.7 \cdot 10^{-1}$	2.70	$0.9 \cdot 10^{-3}$
	2.65	0.94	2.66	0.973	2.39	1.04	2.93	1.07
	2.54	1.89	2.52	1.99	2.22	1.96	2.94	2.03
	2.41	2.73	2.44	2.92	1.94	2.98	2.88	3.09
353.15	3.17	$0.6 \cdot 10^{-3}$	3.13	$0.2 \cdot 10^{-2}$	2.93	$0.8 \cdot 10^{-1}$	3.11	$0.9 \cdot 10^{-3}$
	3.05	0.940	3.09	0.974	2.78	1.05	3.36	1.07
	2.95	1.89	2.93	1.99	2.59	1.97	3.40	2.03
	2.79	2.73	2.86	2.92	2.28	2.98	3.30	3.09
363.15	3.66	$0.6 \cdot 10^{-3}$	3.56	$0.2 \cdot 10^{-2}$	3.42	$0.8 \cdot 10^{-1}$	3.56	$0.1 \cdot 10^{-2}$
	3.48	0.942	3.53	0.974	3.18	1.05	3.88	1.07
	3.36	1.90	3.38	1.99	2.98	1.97	3.86	2.03
	3.19	2.73	3.27	2.92	2.64	2.98	3.73	3.09
368.15	3.93	$0.6 \cdot 10^{-3}$	3.85	$0.3 \cdot 10^{-2}$	3.66	$0.9 \cdot 10^{-1}$	3.82	$0.1 \cdot 10^{-2}$
	3.73	0.942	3.77	0.975	3.42	1.05	4.14	1.07
	3.59	1.90	3.64	1.99	3.19	1.97	4.11	2.03
	3.40	2.73	3.49	2.92	2.84	2.99	3.95	3.09

^a Subscripts: PT = potassium taurate; PS = potassium sarcosinate; PP = potassium proline; PG = potassium glycinate.

Table 4. Diffusivity of N_2O , $D_{\text{N}_2\text{O}}$, in Aqueous Solutions of the Potassium Salt of Amino Acids at Various Temperatures, T , and Solvent Concentrations, c^a

	T/K					
	293.15	298.15	303.15	313.15	323.15	333.15
$c_{\text{PT}}/\text{mol} \cdot \text{dm}^{-3}$	$D_{\text{N}_2\text{O}}/10^{-9} \cdot \text{m}^2 \cdot \text{s}^{-1}$					
0.920	1.49	1.65	1.80	2.21	2.73	3.43
1.87	1.24	1.35	1.51	1.87	2.38	2.73
2.78	1.01	1.10	1.23	1.54	1.87	2.24
$c_{\text{PS}}/\text{mol} \cdot \text{dm}^{-3}$	$D_{\text{N}_2\text{O}}/10^{-9} \cdot \text{m}^2 \cdot \text{s}^{-1}$					
0.953	1.42	1.57	1.76	2.20	2.59	3.13
1.94	1.18	1.28	1.40	1.73	2.14	2.57
2.98	0.889	1.02	1.21	1.51	1.81	2.25
$c_{\text{PP}}/\text{mol} \cdot \text{dm}^{-3}$	$D_{\text{N}_2\text{O}}/10^{-9} \cdot \text{m}^2 \cdot \text{s}^{-1}$					
1.05	1.22	1.35	1.56	1.93	2.47	2.92
2.05	0.896	0.999	1.16	1.45	1.76	2.23
3.03	0.689	0.792	0.907	1.14	1.49	1.75
$c_{\text{PG}}/\text{mol} \cdot \text{dm}^{-3}$	$D_{\text{N}_2\text{O}}/10^{-9} \cdot \text{m}^2 \cdot \text{s}^{-1}$					
1.08	1.49	1.62	1.79	2.19	2.66	3.19
2.09	1.32	1.44	1.56	1.92	2.30	2.83
3.10	1.13	1.25	1.44	1.77	2.22	2.57

^a Subscripts: PT = potassium taurate; PS = potassium sarcosinate; PP = potassium proline; PG = potassium glycinate.

dispersion while the solute pulse is traversing with the solvent through the tubing, an average concentration value has to be

determined. Alizadeh et al.¹² referred to this as the reference concentration c_{ref} given by

$$c_{\text{ref}} = c_{\text{solv}} + \frac{N_{\text{inj, SAA}} \left(\frac{5}{16} - \frac{1}{8\sqrt{\pi}} \right)}{\pi R^2 \sqrt{2K_{\text{SAA}} t'}} \quad (6)$$

where c_{solv} is the solvent concentration and t' is the time at which the measurement ends.

Absorbed Gas Diffusivity Measurements. The experimental procedure used to determine diffusivities of absorbed N_2O in aqueous solutions by the Taylor dispersion technique has been given in detail by Hamborg et al.⁹ The recorded pulses are described by eqs 7 to 9

$$c_{\text{m}} = \frac{N_{\text{inj, N}_2\text{O}}}{2\pi R^2 \sqrt{\pi K_{\text{N}_2\text{O}} t}} \exp\left(-\frac{(L-ut)^2}{4K_{\text{N}_2\text{O}} t}\right) + \frac{N_{\text{inj, SAA}}}{2\pi R^2 \sqrt{\pi K_{\text{SAA}} t}} \exp\left(-\frac{(L-ut)^2}{4K_{\text{SAA}} t}\right) \quad (7)$$

$$K_{\text{N}_2\text{O}} = \frac{u^2 R^2}{48D_{\text{N}_2\text{O}}} + D_{\text{N}_2\text{O}} \quad (8)$$

$$K_{\text{SAA}} = \frac{u^2 R^2}{48 D_{\text{SAA}}} + D_{\text{SAA}} \quad (9)$$

where c_m is the measured concentration profile; $N_{\text{inj}, \text{N}_2\text{O}}$ and $N_{\text{inj}, \text{SAA}}$ are the respective numbers of moles of absorbed N_2O and excess number of moles of salt of amino acid injected; t is the time; and $D_{\text{N}_2\text{O}}$ and D_{SAA} are the respective diffusion coefficients of absorbed N_2O and the potassium salt of amino acid. The other parameters are defined in Table 1. The parameters $N_{\text{inj}, \text{N}_2\text{O}}$, $N_{\text{inj}, \text{SAA}}$, u , and $D_{\text{N}_2\text{O}}$ are the independent variables used to fit the equations to the experimental data. The value of D_{SAA} is from the previous measurement as aforementioned, and the influence of absorbed N_2O present in the current measurement on this value is neglected.

Results and Discussion

Diffusivity of the Potassium Salt of Amino Acids in Aqueous Solutions. Values of the diffusivities of the potassium salt of taurine, sarcosine, L-proline, and glycine in aqueous solutions were measured and averaged over at least three measurements at temperatures from (293 to 368) K and salt concentrations ranging from (0 to 3.0) $\text{mol} \cdot \text{dm}^{-3}$. The results are presented in Table 3. The experimental uncertainty is estimated to be 5 % at temperatures less than 333 K and 10 % at higher temperatures. The reproducibility is within 2 %. The critical $(\text{De})^2 \text{Sc}$ number was found to be about 100 for these systems.

The theory of diffusion of aqueous salts at low concentration is well developed.¹⁴ For dilute solutions of a single salt, the diffusion coefficient can be estimated by the Nernst–Haskell equation

$$D^0 = \frac{RT[(1/z_+) + (1/z_-)]}{F^2[(1/\lambda_+^0) + (1/\lambda_-^0)]} \quad (10)$$

where D^0 is the diffusion coefficient at infinite dilution; R is the gas constant; T is the temperature; F is the faraday constant; λ_+^0 and λ_-^0 are the limiting ionic conductivities; and z_+ and z_- are the respective valences of the cation and anion. In the case of the potassium salt of glycine at 298.15 K, limiting ionic conductivities have been reported by D'yachkova et al.,¹⁵ Miyamoto & Schmidt,¹⁶ and Mehl & Schmidt¹⁷ for glycinate. These values are listed in Table 2. The limiting ionic conductivity of the potassium ion is reported by Poling et al.¹⁴ to be 73.5 $\text{cm}^2 \cdot \text{S} \cdot \text{mol}^{-1}$. By the use of these values and eq 10, the respective estimated diffusivities at infinite dilution, $D_{\text{est, potassium glycinate}}$, are calculated and listed in Table 2. From Table 3, the experimentally determined value at low salt concentrations, $D_{\text{potassium glycinate}}$, is $1.11 \cdot 10^{-9} \text{ m}^2 \cdot \text{s}^{-1}$ at 298.15 K. The relative deviation between the estimated and the experimental values is listed in Table 2. The limiting ionic conductivity of 39.2 $\text{cm}^2 \cdot \text{S} \cdot \text{mol}^{-1}$ from Mehl & Schmidt¹⁷ is most likely too high¹⁸ for an ion of the size of glycinate. This can explain the relative deviation of 22.5 %. In the absence of information on limiting ionic conductivities of taurate, sarcosinate, and proline, diffusivities at infinite dilution are not estimated for salts of these ions. At higher concentrations, salt diffusivities can be estimated¹⁴ by the additional use of viscosities, solvent partial molar volume, and molar density and mean ionic activity coefficients. As some of these properties are not readily available for the considered salts, such estimations are not further investigated in the present work.

Diffusivity of N_2O in Aqueous Solutions of the Potassium Salt of Amino Acids. The experimental determined diffusivities of N_2O in aqueous solutions of the potassium salt of taurine, sarcosine, L-proline, and glycine were measured and

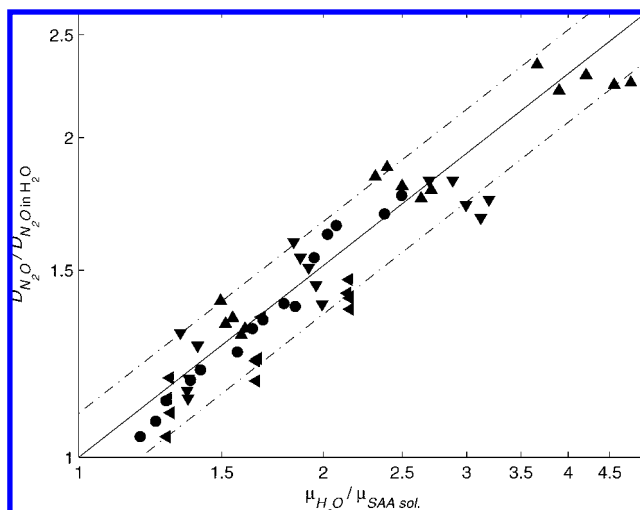


Figure 2. Logarithmic Stokes–Einstein plot relating diffusivities, D , and viscosities, μ , in aqueous solutions of the potassium salt of amino acids: ●, potassium taurate; ▼, potassium sarcosinate; ▲, potassium proline; solid triangle pointing left, potassium glycinate. The solid line represents eq 11, and the dashed lines represent $\pm 10\%$.

averaged over at least three measurements at temperatures from (293 to 333) K and salt concentrations ranging from (1.0 to 3.0) $\text{mol} \cdot \text{dm}^{-3}$. The results are presented in Table 4. The experimental uncertainty is estimated to be 10 %, and the reproducibility is within 2 %. The critical $(\text{De})^2 \text{Sc}$ number was found to be about 80 for these systems.

Several investigators have correlated the diffusivity of an absorbed gas in an aqueous salt solution to the viscosity or the salt concentration.^{19–23} Ratcliff & Holdcroft,¹⁹ Brillman et al.,²² and Kumar et al.²³ correlated the diffusivities to the viscosities by a modified Stokes–Einstein relation

$$\frac{D_{\text{N}_2\text{O}}}{D_{\text{N}_2\text{O in H}_2\text{O}}} = \left(\frac{\mu_{\text{H}_2\text{O}}}{\mu_{\text{SAA}}} \right)^\alpha = \text{constant} \quad (11)$$

where α is a constant. Ratcliff & Holdcroft¹⁹ found this value to be 0.637, whereas Brillman et al.²² found it to be 0.6. Kumar et al.²³ found the value to be 0.74. An α value of 0.6 was found to predict the diffusivities within an average and maximum absolute relative deviation of 5.6 % and 15.1 %, respectively. The viscosities were taken from Kumar et al.,²³ van Holst et al.,²⁴ Portugal et al.,²⁵ and Lide.²⁶ The diffusivity of N_2O in H_2O was taken from Versteeg & van Swaaij.²⁷ The correlation is presented in Figure 2 for the aqueous solutions of the potassium salt of the amino acids considered. Diffusivities of CO_2 in aqueous solutions of the potassium salt of amino acids can be estimated by the N_2O analogy.²⁷

Kumar et al.²³ reported diffusivities of N_2O in aqueous solutions of the potassium salt of taurine at 293 K using a diaphragm cell technique. The results²³ are compared to the results from the present work at 293.15 K in Figure 3 and the estimated values from the modified Stokes–Einstein relation at 293.15 K. The values from the present work have an absolute average and maximum deviation of 4.6 % and 6.1 % from the estimated values at 293.15 K, respectively. The results of Kumar et al.²³ deviate by 4.8 % and 10.5 % from the estimated values.

Conclusion

Diffusivities of the potassium salt of taurine, sarcosine, L-proline, and glycine have been determined in aqueous solutions at temperatures from (293 to 368) K and salt concentrations

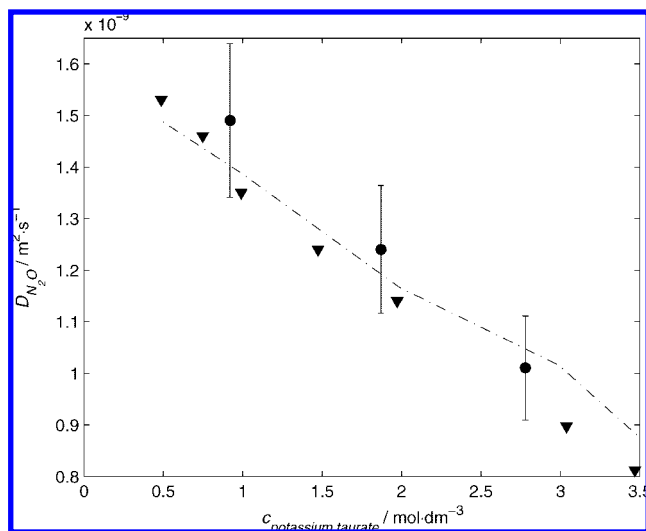


Figure 3. Comparison of the diffusivity of N_2O , D_{N_2O} , in aqueous solutions of the potassium salt of taurine to literature values as a function of concentration, c , at 293.15 K: ●, exptl results from the present work with error bars representing the uncertainty of $\pm 10\%$; ▼, Kumar et al.,²³ - - -, modified Stokes–Einstein relation.

ranging from (0 to 3.0) mol·dm⁻³. The diffusivities at infinite dilution can be estimated by the Nernst–Haskell equation if limiting ionic conductivity data are available.

Diffusivities of N_2O in aqueous solutions of the potassium salt of taurine, sarcosine, L-proline, and glycine have been determined at temperatures from (293 to 333) K and salt concentrations ranging from (1.0 to 3.0) mol·dm⁻³. The diffusivities are in agreement with available literature values. The diffusivities can be estimated using a modified Stokes–Einstein relation, and the diffusivities of CO_2 in these solutions can be further calculated.

Acknowledgment

The authors also wish to acknowledge H. F. G. Moed and B. Knaken for the construction of the experimental setup and P. H. M. Feron and F. Geuzebroek for their valuable discussions regarding the experimental technique and results.

Literature Cited

- (1) Kohl, A. L.; Nielsen, R. B. *Gas Purification*, 5th ed.; Gulf Publishing Company: Houston, 1997.
- (2) Hook, R. J. An Investigation of Some Sterically Hindered Amines as Potential Carbon Dioxide Scrubbing Compounds. *Ind. Eng. Chem. Res.* **1997**, *36*, 1779–1790.
- (3) Penny, D. E.; Ritter, T. J. Kinetic study of the reaction between carbon dioxide and primary amines. *J. Chem. Soc., Faraday Trans.* **1983**, *79*, 2103–2109.
- (4) Kumar, P. S.; Hogendoorn, J. A.; Feron, P. H. M.; Versteeg, G. F. Kinetics of the Reaction of CO_2 with Aqueous Potassium Salt of Taurine and Glycine. *AIChE J.* **2003**, *49*, 203–213.
- (5) van Holst, J.; Politiek, P. P.; Niederer, J. P. M.; Versteeg, G. F. CO_2 capture from flue gas using amino acid salt solutions. In *8th International Conference on Greenhouse Gas Control Technologies (GHGT-8)* Trondheim: Norway, 2006.
- (6) Taylor, G. Dispersion of soluble matter in solvent flowing slowly through a tube. *Proc. R. Soc. London A* **1953**, *219*, 186–203.
- (7) Taylor, G. Conditions under which dispersion of a solute in a stream of solvent can be used to measure molecular diffusion. *Proc. R. Soc. London A* **1954**, *225*, 473–477.
- (8) Aris, R. On the dispersion of a solute in a fluid flowing through a tube. *Proc. R. Soc. London A* **1956**, *235*, 67–77.
- (9) Hamborg, E. S.; Derks, P. W. J.; Kersten, S. R. A.; Niederer, J. P. M.; Versteeg, G. F. Diffusion Coefficients of N_2O in Aqueous Piperazine Solutions using the Taylor Dispersion Technique from (293 to 333) K and (0.3 to 1.4) mol·dm⁻³. *J. Chem. Eng. Data* **2008**, submitted. Manuscript ID: je-2007-00717w.
- (10) Eastal, A. J.; Woolf, L. A. Pressure and Temperature Dependence of Tracer Diffusion Coefficients of Methanol, Ethanol, Acetonitrile, and Formamide in Water. *J. Phys. Chem.* **1985**, *89*, 1066–1069.
- (11) Matthews, M. A.; Akgerman, A. J. High-Temperature Diffusion of Hydrogen, Carbon Monoxide, and Carbon Dioxide in Liquid n-Heptane, n-Dodecane, and n-Hexadecane. *J. Chem. Eng. Data* **1987**, *32*, 319–322.
- (12) Alizadeh, A.; Nieto de Castro, C. A.; Wakeham, W. A. The Theory of the Taylor Dispersion Technique for Liquid Diffusivity Measurements. *Int. J. Thermophys.* **1980**, *1*, 243–283.
- (13) Snijder, E. D.; te Riele, M. J. M.; Versteeg, G. F.; van Swaaij, W. P. M. Diffusion Coefficients of Several Aqueous Alkanolamine Solutions. *J. Chem. Eng. Data* **1993**, *38*, 475–480.
- (14) Poling, B. E.; Prausnitz, J. M.; O'Connell, J. P. *The Properties of Gases and Liquids*, 5th ed.; The McGraw-Hill Companies, Inc.: New York, 2001.
- (15) D'yachkova, N. G.; Zagorodnykh, L. A.; Bobreshova, O. V. Conductivity of Systems Comprising Anion-Exchange Membranes MA-41 and Alkaline Glycine Solutions. *Russ. J. Electrochem.* **2006**, *42*, 276–279.
- (16) Miyamoto, S.; Schmidt, C. L. A. Transference and conductivity studies on solutions of certain proteins and amino acids with special reference to the formation of complex ions between the alkaline earth elements and certain proteins. *J. Biol. Chem.* **1933**, *99*, 335–358.
- (17) Mehl, J. W.; Schmidt, C. L. A. The conductivities of aqueous solutions of glycine, d,l-valine, and l-asparagine. *J. Gen. Physiol.* **1935**, *18*, 467–479.
- (18) Robinson, R. A.; Stokes, R. H. *Electrolyte Solutions*, 2nd ed.; Butterworths: London, 1959.
- (19) Ratcliff, G. A.; Holdcroft, J. G. Diffusivities of gases in aqueous electrolyte solutions. *Trans. Instn. Chem. Eng.* **1963**, *41*, 315–319.
- (20) Gubbins, K. E.; Bhatia, K. K.; Walker, R. D. Diffusion of Gases in Electrolytic Solutions. *AIChE J.* **1966**, *12*, 548–552.
- (21) Hung, G. W.; Dinius, R. H. Diffusivity of Oxygen in Electrolyte Solutions. *J. Chem. Eng. Data* **1972**, *17*, 449–451.
- (22) Brilman, D. W. F.; van Swaaij, W. P. M.; Versteeg, G. F. Diffusion Coefficient and Solubility of Isobutene and trans-2-Butene in Aqueous Sulfuric Acid Solutions. *J. Chem. Eng. Data* **2001**, *46*, 1130–1135.
- (23) Kumar, P. S.; Hogendoorn, J. A.; Feron, P. H. M.; Versteeg, G. F. Density, Viscosity, Solubility, and Diffusivity of N_2O in Aqueous Amino Acid Salt Solutions. *J. Chem. Eng. Data* **2001**, *46*, 1357–1361.
- (24) van Holst, J. Physicochemical properties of Several Aqueous Potassium Amino Acid Salts. *J. Chem. Eng. Data* **2008**, submitted. Manuscript ID: je-2007-00699u.
- (25) Portugal, A. F.; Derks, P. W. J.; Versteeg, G. F.; Magalhães, F. D.; Mendes, A. Characterization of potassium glycinate for carbon dioxide absorption purposes. *Chem. Eng. Sci.* **2007**, *62*, 6534–6547.
- (26) Lide, D. R. *Handbook of chemistry and physics*, 75th ed.; CRC Press: Boca Raton, FL, 1994.
- (27) Versteeg, G. F.; van Swaaij, W. P. M. Solubility and Diffusivity of Acid Gases (CO_2 , N_2O) in Aqueous Alkanolamine Solutions. *J. Chem. Eng. Data* **1988**, *33*, 29–34.

Received for review December 12, 2007. Accepted March 10, 2008. This research is part of the CATO programme, the Dutch national research programme on CO_2 Capture and Storage. CATO is financially supported by the Dutch Ministry of Economic Affairs (EZ) and the consortium partners (www.co2-cato.nl). The authors would like to express their gratitude for their financial support.

JE700736X