Solubility of H_2S and CO_2 in N-Octyl-2-pyrrolidone and of H_2S in Methanol and Benzene

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The solubility of hydrogen sulfide and carbon dioxide in N-octyl-2-pyrrolidone (NOP) was measured up to 1.4 MPa at 303 and 324 K using the static synthetic method. Experimental results were compared to those of the predictive Soave–Redlich–Kwong (PSRK) model, wherein the group interaction parameters for the NMP-group (N-methyl-2-pyrrolidone) were applied to the NOP systems. The reliability of the apparatus used and the applied data treatment were checked by comparing new experimental data for the system hydrogen sulfide + benzene at 304 and 324 K and pressures up to 1.2 MPa, and for the system hydrogen sulfide + methanol at 298 K and up to 0.4 MPa, with published data measured with the analytical method.

Introduction

The knowledge of the solubilities of sour gases like carbon dioxide or hydrogen sulfide in suitable solvents is required for the design of absorption processes for the treatment of natural gas. Physical or chemical solvents can be used. Because of its unique physical properties, such as high polarity, low volatility, miscibility with water and organic solvents, and thermal and chemical stability, *N*-methyl-2-pyrrolidone (NMP) is a physical solvent commonly used for extractive distillation or absorption processes (GAF Corp., 1972). In a previous work (Noll et al., 1996) the binary system water − *N*-methyl-2-pyrrolidone was examined because of its importance as a mixed solvent. The concentration of water in NMP has a significant influence on both the selectivity and the capacity of the solvent mixture (Fischer and Gmehling, 2002; Krummen et al., 2000).

The replacement of the *N*-methyl group by a longer alkyl chain, for example, the ethyl or the octyl group, allows the volatility of the *N*-alkyl-2-pyrrolidone to be reduced, while

keeping the high selectivity and advantageous properties just mentioned. Carbon dioxide and hydrogen sulfide solubilities were measured in *N*-octyl-2-pyrrolidone (NOP) in this work. The data were used to check whether the PSRK group-contribution equation of state (EOS) (Holderbaum and Gmehling, 1991; Fischer and Gmehling, 1996; Gmehling et al., 1997; Horstmann et al., 2000) can be used to extrapolate the correlation of the existing data for the NMP systems in Lenoir et al. (1971), Murrieta-Guevara and Rodriguez (1984), Murrieta-Guevara et al. (1988), Rivas and Prausnitz (1979a,b) Sweeney (1984), Yarym-Agaev et al. (1980), Byeseda et al., (1985), Rivas (1974) for the H_2S systems, and in (Lenoir et al. (1971), Murrieta-Guevara and Rodriguez (1984), Murrieta-Guevara et al. (1988), Rivas and Prausnitz, (1979a, b), Sweeney (1984), Byeseda et al. (1985), Rivas (1974), Melzer et al. (1989), Wu et al. (1985), Yogish (1991), Usyukin and Shleinikov (1963), Vilcu et al. (1991), Fischer (2002), Zubchenko et al. (1985), Schroedter (1991), Schlichting (1991) for the CO_2 systems to other *N*-alkyl-2-pyrrolidone systems. Test measurements were performed for the solubility of hy-

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drogen sulfide in methanol, and in benzene to validate the indirect static synthetic method and the data treatment procedure by comparing the results to the literature data (Short et al., 1983; Schalk and Onken, private communication, 1973; Bezdel and Teodorovich, 1958; Yorizane et al., 1969; Leu et al., 1992; Preuss and Moerke, 1990) for the H_2S + methanol system, and in Bell (1931), Patyi et al. (1978), Gerrard (1972), Laugier and Richon (1995) for the H_2S + benzene system, which were partly obtained with the direct static analytical method. Except for the H_2S + methanol system, the Henry coefficients derived from the Px data obtained in this work were already published elsewhere together with the values for various other systems (Fischer et al., 1999).

Experimental Studies

Materials

Hydrogen sulfide and carbon dioxide, both with a purity 99.995 mol %, were purchased from Messer Griesheim and used without any further purification. Benzene supplied by Fluka with an initial purity of 99.7 mass %, methanol supplied by Scharlau with an initial purity of 99.99 mass %, and NOP supplied by Hoechst, were distilled and degassed after drying over a molecular sieve by vacuum distillation, as described before (Fischer and Gmehling, 1994).

Apparatus and procedure

The apparatus used was described in detail by Fischer and Gmehling (1994). The modifications of the experimental setup as well as the raw data treatment, which is required for the indirect experimental method for determining the gas solubility in the liquid phase, are outlined by Fischer and Wilken (2001). The applied indirect experimental method provides
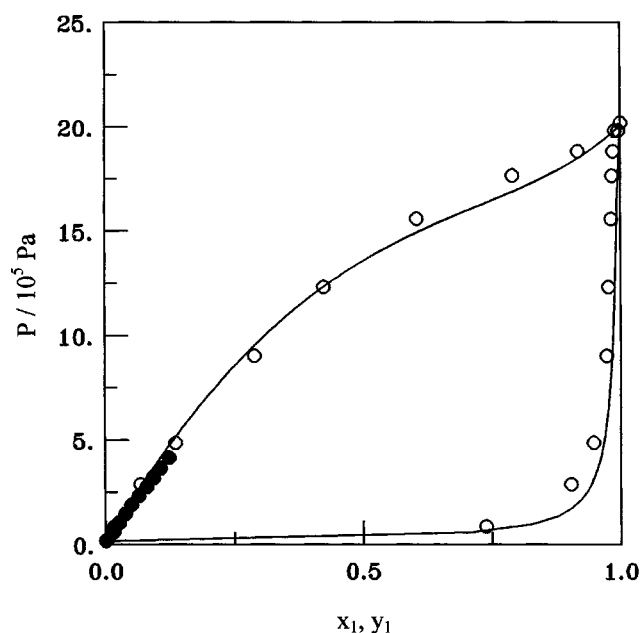

Figure 1. Experimental isothermal $Px(y)$ data for the hydrogen sulfide (1) − methanol (2) system at 298 K.

From Leu et al. (1992) (○) and from this work (●) compared to predictions using the PSRK method.

the system pressure P of a mixture with known composition charged into a thermostated equilibrium cell at temperature T. The global feed composition is known precisely, while the

Table 1. Experimental Isothermal Px Data for the Hydrogen Sulfide (1)−Methanol or Benzene (2) System

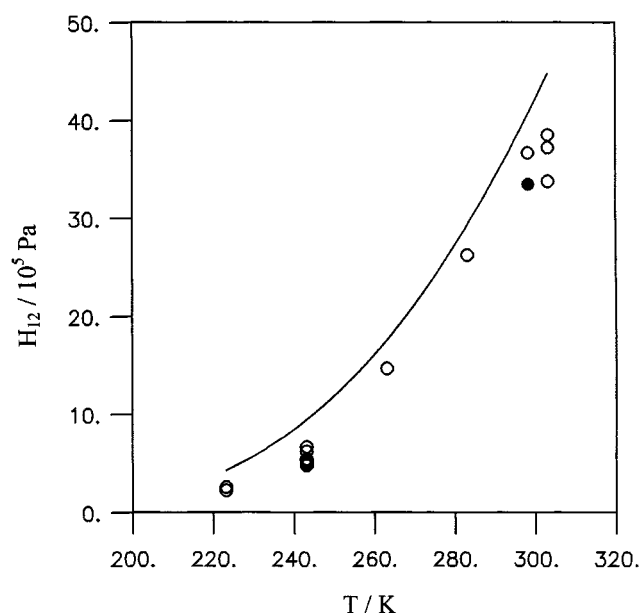| Methanol		Benzene			
298.15 K		304.30 K		323.50 K	
$P(\times 10^5$ Pa)	x_1	$P(\times 10^5$ Pa)	x_1	$P(\times 10^5$ Pa)	x_1
0.183	0.0000	1.024	0.0413	1.322	0.0339
0.230	0.0028	1.161	0.0479	2.133	0.0629
0.375	0.0078	1.696	0.0741	3.173	0.1001
0.610	0.0153	2.544	0.1159	4.271	0.1393
0.695	0.0152	3.550	0.1657	5.642	0.1881
1.035	0.0261	4.299	0.2029	6.730	0.2262
1.061	0.0260	5.914	0.2826	7.797	0.2632
1.461	0.0378	7.400	0.3548	8.924	0.3018
1.478	0.0378	8.740	0.4183	10.091	0.3409
1.903	0.0502	9.443	0.4508	11.006	0.3711
1.908	0.0502	10.260	0.4879	11.805	0.3969
2.320	0.0643				
2.328	0.0643				
2.749	0.0800				
2.766	0.0800				
3.165	0.0930				
3.173	0.0930				
3.194	0.0930				
3.249	0.0930				
3.635	0.1060				
3.652	0.1060				
4.140	0.1231				

Figure 2. Experimental Henry coefficients for hydrogen sulfide (1) in methanol (2).

From Short et al. (1983); Schalk and Onken, private communication (1973); Bezdel and Teodorovich (1958) (○); and derived from the isothermal Px data from this work (●) compared to predictions using the PSRK method.

Table 2. Pure Component Parameters for EOS-Calculations

Compound	Critical Data		Mathias−Copeman Constants			VdW Properties	
	T_c (K)	P_c (MPa)	c_1	c_2	c_3	R	Q
Carbon dioxide	304.2	7.376	0.82524	0.25155	−1.70390	1.3000	1.120
Hydrogen sulfide	373.2	8.937	0.63564	−0.45039	1.68370	1.2350	1.202
Benzene	562.1	4.894	0.83560	−0.37500	0.97150	3.1878	2.400
Methanol	512.6	8.096	1.43710	−0.79940	0.32780	1.4311	1.432
NOP	748.2	2.371	1.19778	0.00000	0.00000	8.7018	6.980
NMP	721.7	4.519	1.02050	0.00000	0.00000	3.9810	3.200

Table 3. Binary Interaction Parameters Fitted to the Isothermal Experimental Data

		SRK + PSRK Mixing Rule + UNIQUAC		SRK + Classic Mixing Rules
	T (K)	A_{12} (kJ·mol^{-1})	A_{21} (kJ·mol^{-1})	k_{12}
Hydrogen sulfide (1) + methanol (2)	298.15	27.590	−1.6170	0.039466
Hydrogen sulfide (1) + benzene (2)	304.30	−2.0858	3.1927	0.003946
Hydrogen sulfide (1) + benzene (2)	323.50	−2.3597	3.5870	−0.003416
Hydrogen sulfide (1) + NOP (2)	306.70	−2.5107	2.5107	−0.146710
Hydrogen sulfide (1) + NOP (2)	323.60	−2.4056	2.4055	−0.138160
Carbon dioxide (1) + NOP (2)	303.40	15.837	−2.4534	0.010196
Carbon dioxide (1) + NOP (2)	323.60	7.2570	−2.5357	0.006809

composition of the liquid phase is obtained by subtracting the molar amount of all compounds in the vapor phase from the total molar amount loaded in the equilibrium cell. Further details about the data treatment method are described by Fischer and Wilken (2001). The uncertainty the raw data treatment introduced depends mainly on the relative molar amount of the gaseous compound in the vapor phase. Therefore the equilibrium cell was charged almost completely full with the solvent, leaving a relatively small vapor space. The overall uncertainty of the liquid-phase composition was estimated to be $x_1 = \pm 0.0001$, taking into account the accuracy of the feed composition and the accuracy limited by the raw data treatment method. The DIPPR density correlation (Daubert et al., 1998), or experimental values in the case of NOP (914.7 kg/m^3 at 303.15 K, and 899.7 kg/m^3 at 323.15 K), were used to calculate the amounts of the liquid solvent and of the gas loaded in the equilibrium cell. The temperature was measured with an uncertainty of ± 0.02 K, and the pressure with an uncertainty of ± 0.05 %, or ± 0.2 kPa.

Experimental results and discussion

The results for the solubility of hydrogen sulfide in methanol at 298 K and in benzene at 304 K and at 324 K are listed in Table 1. Since experimental data for the solubility of hydrogen sulfide in methanol at 298 K are available (Leu et al., 1992), they were used for comparison (Figure 1). The solid line represents the calculation using PSRK. The experimental data agree quite well with each other and with the PSRK prediction. The Px data from this work were also correlated with the SRK EOS, where classical mixing rules and also the PSRK mixing rule combined with the UNIQUAC model were used. The pure-component parameters used for the EOS calculations data are listed in Table 2. The fitted binary interaction parameters are given in Table 3. The PSRK group interaction parameters are published elsewhere (Holderbaum and Gmehling, 1991; Fischer and Gmehling, 1996; Gmehling et al., 1997; Horstmann et al., 2000).

Table 4. Henry Coefficients for Solubility of Hydrogen Sulfide or Carbon Dioxide (1) in NOP or Methanol or Benzene (2)*

	T (K)	H_{12} (MPa)
Hydrogen sulfide (1) in menthanol (2)	298.15	3.35
Hydrogen sulfide (1) in benzene (2)	304.30	1.96
Hydrogen sulfide (1) in benzene (2)	323.50	2.69
hydrogen sulfide (1) in NOP (2)	306.70	0.70
Hydrogen sulfide (1) in NOP (2)	323.60	1.15
Carbon dioxide (1) in NOP (2)	303.40	5.00
Carbon dioxide (1) in NOP (2)	323.60	6.67

*Derived from Experimental Isothermal Px Data by Correlation with the SRK EOS and the UNIQUAC G^E Model with the PSRK Mixing Rule.

The fugacity coefficient of H$_2$S at infinite dilution and the Henry coefficient were calculated from this zero partial pressure correlation of H$_2$S. This value is given in Table 4, along with the Henry coefficients for all the other systems measured, and plotted in Figure 2 together with several literature data, and with the predicted temperature dependence of the Henry coefficient by PSRK. Again, all the data agree quite well with each other. The predicted Henry coefficients are slightly larger than the experimental ones. Also VLE data for the H$_2$S + benzene system are available in the literature (Laugier and Richon, 1995), and are compared with our values at ca. 323 K in Figure 3. The data agree very well with each other and with the predicted results of the PSRK model. The results from the literature (Leu et al., 1992; Laugier and Richon, 1995) shown in Figures 1 and 3 were obtained with the direct static analytical method. As for the previous system, the Henry coefficients from the literature and from our data correlation are plotted vs. the temperature and compared with the results of the PSRK model in Figure 4. Except for one value at 298 K (Patyi et al., 1978), the experimental data are in good agreement. The Henry coefficients predicted with PSRK are lower than the experimental values, but its temperature dependence is correct. From the preced-
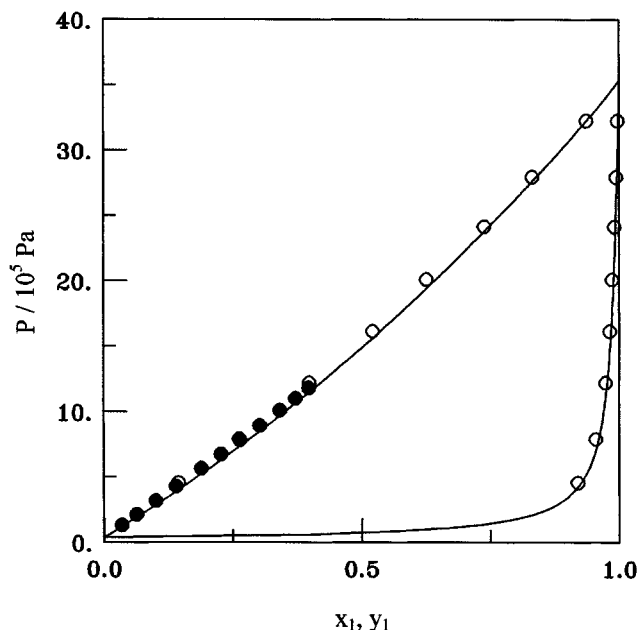
Figure 3. Experimental isothermal $Px(y)$ **data for the hydrogen sulfide (1) – benzene (2) system at 323 K.**

From Laugier and Richon (1995) (○) and from this work (●) compared to predictions using the PSRK method.
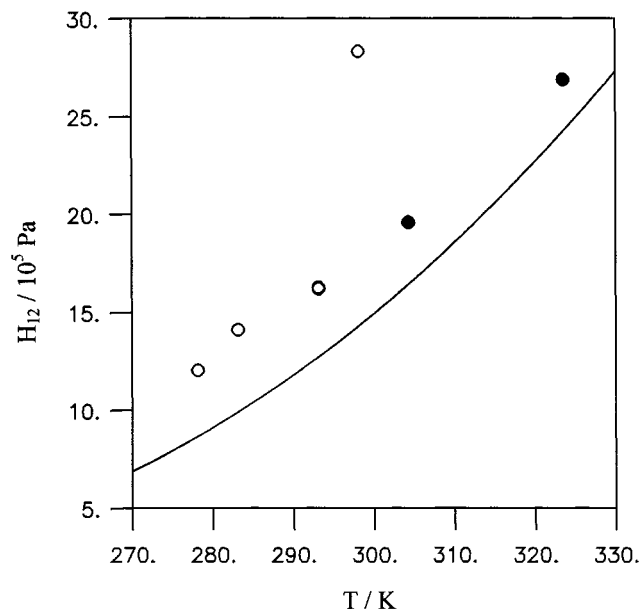

Figure 4. Experimental Henry coefficients for hydrogen sulfide (1) in benzene (2).

From Bell (1931); Patyi et al. (1978); Gerrard (1972) (○) and derived from the isothermal Px data from this work (●) compared to predictions using the PSRK method.

ing results and comparison, it can be concluded that the indirect static synthetic method and the data treatment procedure used in this work provide reliable gas solubility data.

In the next step, carbon dioxide and hydrogen sulfide solubilities were measured in NOP. The experimental data are given in Table 5. For each temperature, the experimental Px data are plotted in Figures 5 and 6 (H_2S solubilities) and Figures 7 and 8 (CO_2 solubilities). At the same time, the results of three different approaches are shown together with the experimental data: (1) solid line: correlation with the PSRK/UNIQUAC model; (2) dashed line: correlation with

the SRK EOS and classic mixing rules; (3) dotted line: prediction with the PSRK/UNIFAC model. The fitted binary interaction parameters for correlation approaches (1) and (2) are given in Table 3. In order to apply the PSRK group contribution EOS to the NOP systems, NOP was subdivided into the following groups: the NMP group and seven CH_2 groups. This allowed us to apply the already available NMP parameters for systems with NOP. The correlation with the PSRK/UNIQUAC model allows to describe all the data within experimental uncertainly. But the SRK EOS with the classic mixing rules is not flexible enough to correlate the data for the $H_2S + NOP$. The calculated bubble-point pressures are lower than the experimental values. The opposite

Table 5. Experimental Isothermal Px **data for the Hydrogen Sulfide or Carbon Dioxide (1) −** N-**Octyl-2-pyrrolidone (2) System**

| Hydrogen Sulfide				Carbon Dioxide			
306.70 K		323.60 K		303.40 K		323.60 K	
$P (\times 10^5$ Pa)	x_1	$P (\times 10^5$ Pa)	x_1	$P (\times 10^5$ Pa)	x_1	$P (\times 10^5$ Pa)	x_1
1.062	0.1365	1.271	0.1050	1.068	0.0217	1.139	0.0170
1.529	0.1870	1.712	0.1376	1.531	0.0310	2.433	0.0360
1.990	0.2323	2.046	0.1611	2.176	0.0437	3.816	0.0560
2.515	0.2792	2.515	0.1925	2.962	0.0589	5.266	0.0765
3.268	0.3392	3.024	0.2247	3.892	0.0767	6.471	0.0934
4.032	0.3925	3.541	0.2554	5.149	0.1001	7.537	0.1081
5.155	0.4604	4.082	0.2858	6.358	0.1221	9.122	0.1296
5.947	0.5021	4.778	0.3223	7.900	0.1493	10.829	0.1524
6.752	0.5403	5.572	0.3609	9.179	0.1712	12.414	0.1729
7.952	0.5907	6.277	0.3926	10.342	0.1906	13.803	0.1908
9.006	0.6298	7.082	0.4263	11.374	0.2075		
9.844	0.6579	8.002	0.4618	12.472	0.2251		
10.506	0.6787	8.716	0.4874	13.223	0.2369		
11.099	0.6963	9.663	0.5191				
		10.444	0.5434				
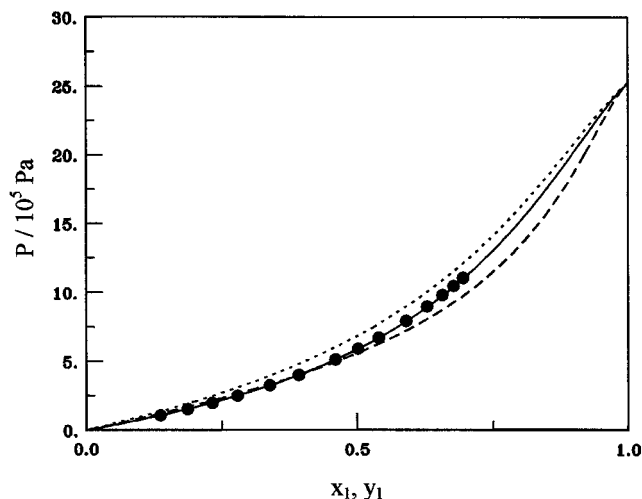
Figure 5. Experimental (● this work) and calculated (⸺ PSRK/UNIQUAC; --- SRK/quadratic mixing rule; ···· PSRK/UNIFAC) VLE behavior for the hydrogen sulfide (1) + NOP (2) system at 307 K.
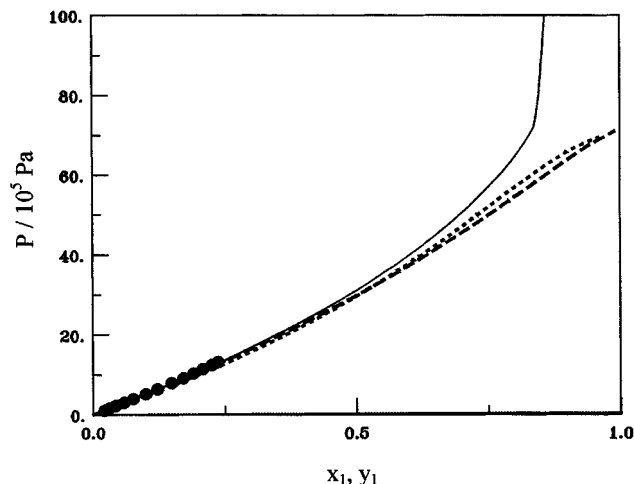

Figure 7. Experimental (● this work,) and calculated (⸺ PSRK/UNIQUAC; --- SRK/quadratic mixing rule; ···· PSRK/UNIFAC) VLE behavior for the carbon dioxide (1) + NOP (2) system at 303 K.

trend is observed when comparing the experimental data with the predicted results of the PSRK/UNIFAC model, for which the bubble-point line is slightly moved toward higher pressures. The different calculations for the CO_2 + NOP system show smaller differences, except in the critical region. Since no experimental data are available at pressures around the critical pressure of CO_2, there is no hint to which kind of calculated critical behavior meets the truth. Both correlations and the prediction allow the experimental solubility data of CO_2 to be represented very well.

The Henry coefficients for H_2S in NOP are plotted vs. the temperature in Figure 9. The solid line represents the PSRK prediction for this system. The available data from the literature for H_2S solubilities in NMP are plotted in the same diagram along with the dotted line for the PSRK prediction for the H_2S + NMP system. All the results are quite similar for this system. This is not the case for the CO_2 + (NOP or NMP) system, as can be seen in Figure 10. In this case, both the predicted line for the PSRK model and the experimental data differ for the two solvents NMP and NOP. With an increasing number of CH_2 groups in the N-alkyl chain, the solubility
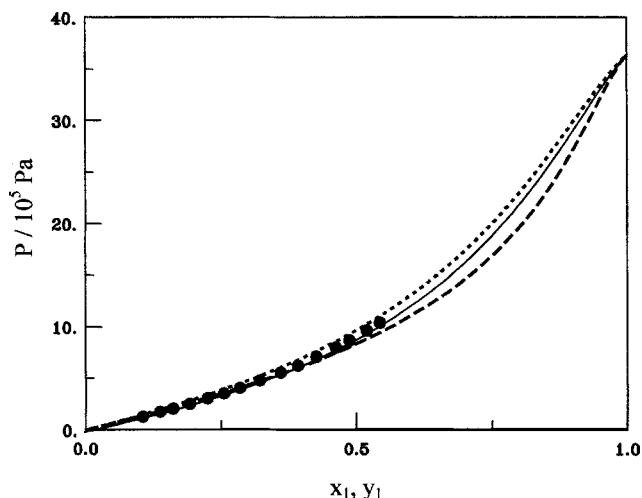

Figure 6. Experimental (● this work) and calculated (⸺ PSRK/UNIQUAC; --- SRK/quadratic mixing rule; ···· PSRK/UNIFAC) VLE behavior for the hydrogen sulfide (1) + NOP (2) system at 324 K.
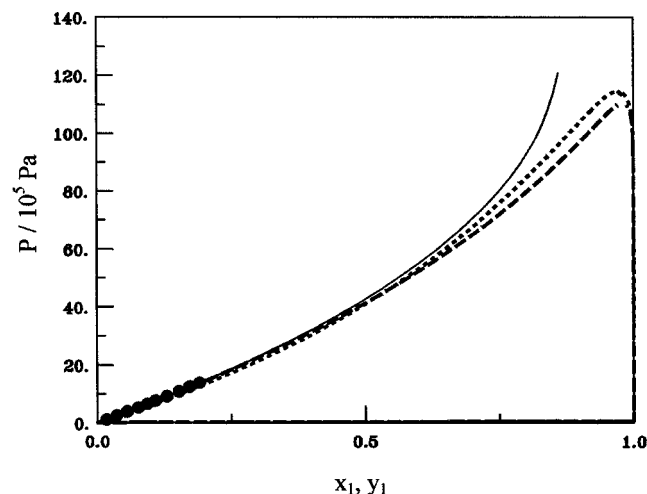

Figure 8. Experimental (● this work) and calculated (⸺ PSRK/UNIQUAC; --- SRK/quadratic mixing rule; ···· PSRK/UNIFAC) VLE behavior for the carbon dioxide (1) + NOP (2) system at 324 K.
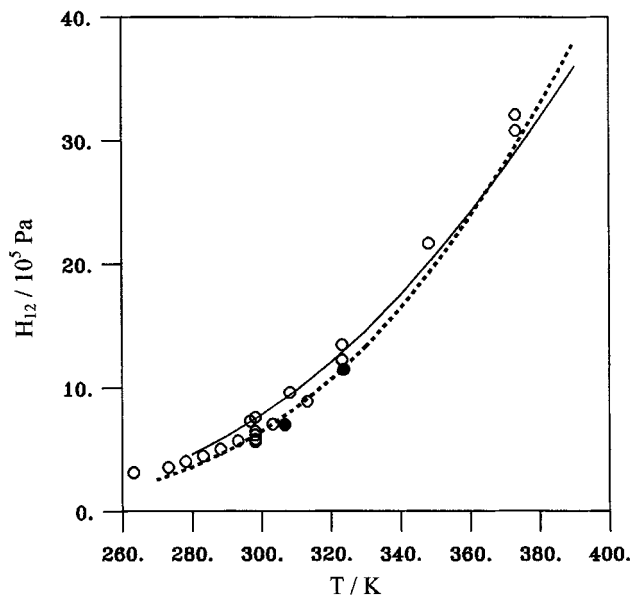
**Figure 9. Experimental (● this work) and predicted (——
PSRK/UNIFAC) Henry coefficients for hydro-
gen sulfide (1) in NOP (2).**

Experimental (Lenoir et al., 1971; Murrieta-Guevara and
Rodriguez, 1984; Murrieta-Guevara et al., 1988; Rivas and
Prausnitz, 1979a,b; Sweeney, 1984; Yarym-Agaev et al., 1980;
Byeseda et al., 1985; Rivas, 1974) (○) and predicted (····
PSRK/UNIFAC) Henry coefficients for hydrogen sulfide (1)
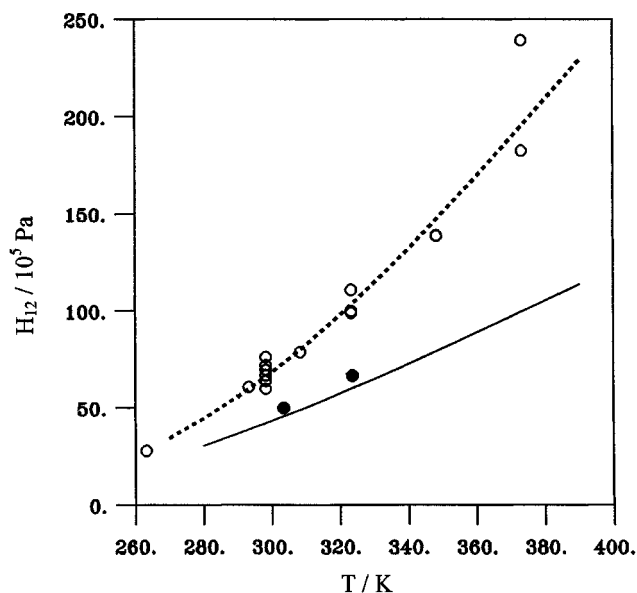in NMP (2) as a function of temperature.

**Figure 10. Experimental (● this work) and predicted
(—— PSRK/UNIFAC) Henry coefficients for
carbon dioxide (1) in NOP (2).**

Experimental (Lenoir et al., 1971; Murrieta-Guevara and
Rodriguez, 1984; Murrieta-Guevara et al., 1988; Rivas and
Prausnitz, 1979a,b; Sweeney, 1984; Byeseda et al., 1985;
Rivas, 1974; Melzer et al., 1989; Wu et al., 1985; Yogish,
1991; Usyukin and Shleinikov, 1963; Vilcu et al., 1991;
Zubchenko et al., 1985) (○) and predicted (····
PSRK/UNIFAC) Henry coefficients for carbon dioxide (1)
in NMP (2) as a function of temperature.

of CO_2 in *N*-alkyl-2-pyrrolidone increases significantly. This
is not the case for H_2S, and thus the chain length of the
N-alkyl group has a strong impact on the selectivity differ-
ence between the two sour gases. The PSRK method is a
reliable estimation method for all the systems investigated in
this article.

Acknowledgment

Literature Cited

Bell, R. P. "CLXXXV.—The Electrical Energy of Dipole Molecules
in Solution, and the Solubilities of Ammonia, Hydrogen Chloride,
and Hydrogen Sulphide in Various Solvents," *J. Chem. Soc.*, 1371
(1931).

Bezdel, L.S., and V. P. Teodorovich, "Solubility of CO_2, H_2S, CH_4,
and C_2H_6 in Methanol at Low Temperatures," *Gaz. Prom.*, **8**, 38
(1958).

Byeseda, J. J., J. A. Deetz, and W. P. Manning, "The Optisol (TM)
Gas Sweetening Solvent," *Proc. Pacific Chemical Congr.*, p. 1 (1985).

Daubert, T. E., R. P. Danner, H. M. Sibul, and C. C. Stebbins, *Physi-
cal and Thermodynamic Properties of Pure Chemicals*, Data Compi-
lation, Taylor & Francis, New York (1998).

Fischer, K., "Solubilities of Carbon Monoxide and Carbon Dioxide
in N-Methyl-Pyrrolidone-2 and Water," *J. Chem. Eng. Data*, in press
(2002).

Fischer, K., and J. Gmehling, "Px- and γ^∞-Data for the Different
Binary Butanol - Water Systems at 50°C," *J. Chem. Eng. Data*, **39**,
309 (1994).

Fischer, K., and J. Gmehling, "Further Development, Status and Re-
sults of the PSRK Method for the Prediction of Vapor-Liquid
Equilibria and Gas Solubilities," *Fluid Phase Equilib.*, **121**, 185
(1996).

Fischer, K., and J. Gmehling, "Influence of Water on the Vapor-
Liquid Equilibria, Activity Coefficients at Infinite Dilution and
Heat of Mixing for Mixtures of N-Methyl Pyrrolidone-2 with C5 or
C6 Hydrocarbons," *Fluid Phase Equilib.*, in press (2002).

Fischer, K., and M. Wilken, "Experimental Determination of Oxy-
gen and Nitrogen Solubility in Organic Solvents up to 10 MPa at
Temperatures between 298 K and 398 K," *J. Chem. Thermodyn.*,
33, 1285 (2001).

Fischer, K., M. Wilken, and J. Gmehling, "Correlation, Prediction
and Experimental Determination of Gas Solubilities," *Proc. GVC-
Fachausschuβ High Pressure Chemical Engineering*, Karlsruhe, Ger-
many, p. 167 (1999).

GAF Corp., *M-Pyrrol (N-methyl-2-pyrrolidone) Handbook*, Chemical
Division, GAF, New York (1972).

Gerrard, W., "Solubility of Hydrogen Sulphide, Dimethyl Ether,
Methyl Chloride and Sulphur Dioxide in Liquids. The Prediction
of Solubility of all Gases," *J. Appl. Chem. Biotechnol.*, **22**, 623 (1972).

Gmehling, J., J. Li, and K. Fischer, "Further Development of the
PSRK Model for the Prediction of Gas Solubilities and Vapor-
Liquid Equilibria at Low and High Pressures II," *Fluid Phase Equi-
lib.*, **141**, 113 (1997).

Holderbaum, T., and J. Gmehling, "PSRK: A Group Contribution
Equation of State Based on UNIFAC," *Fluid Phase Equilib.*, **70**,
251 (1991).

Horstmann, S., K. Fischer, and J. Gmehling, "PSRK Group Contri-
bution Equation of State: Revision and Extension III," *Fluid Phase
Equilib.*, **167**, 173 (2000).

Krummen, M., D. Gruber, and J. Gmehling, "Measurement of Activ-
ity Coefficients at Infinite Dilution in Solvent Mixtures Using the
Dilutor Technique," *Ind. Eng. Chem. Res.*, **39**, 2114 (2000).

Laugier, S., and D. Richon, "Vapor-Liquid Equilibria for Hydrogen
Sulfide + Hexane + Cyclohexane, + Benzene, + Pentadecane,
and + (Hexane + Pentadecane)," *J. Chem. Eng. Data*, **40**, 153
(1995).

Lenoir, J.-Y., P. Renault, and H. Renon, "Gas Chromatographic De-
termination of Henry's Constants of 12 Gases in 19 Solvents," *J.
Chem. Eng. Data*, **16**, 340 (1971).

Leu, A.-D., J. J. Carroll, and D. B. Robinson, "The Equilibrium Phase Properties of the Methanol-Hydrogen Sulfide Binary System," *Fluid Phase Equilib.*, **72**, 163 (1992).

Melzer, W. M., F. Schroedter, and H. Knapp, "Solubilities of Methane, Propane and Carbon Dioxide in Solvent Mixtures Consisting of Water, N,N-Dimethylformamide, and N-Methyl-2-Pyrrolidone," *Fluid Phase Equilib.*, **49**, 167 (1989).

Murrieta-Guevara, F., and A. T. Rodriguez, "Solubility of Carbon Dioxide, Hydrogen Sulfide, and Methane in Pure and Mixed Solvents," *J. Chem. Eng. Data*, **29**, 456 (1984).

Murrieta-Guevara, F., A. Romero-Martinez, and A. Trejo, "Solubilities of Carbon Dioxide and Hydrogen Sulfide in Propylene Carbonate, N-Methylpyrrolidone and Sulfolane," *Fluid Phase Equilib.*, **44**, 105 (1988).

Noll, O., K. Fischer, and J. Gmehling, "Vapor-Liquid Equilibria and Enthalpies of Mixing for the Binary System Water−N-Methyl-2-Pyrrolidone in the Temperature Range 80−140°C," *J. Chem. Eng. Data*, **41**, 1434 (1996).

Patyi, L., I. E. Furmer, J. Makranczy, A. S. Sadilenko, Z. G. Stepanova, and M. G. Berengarten, *Solubilities of Gases in Certain Organic Liquids*, Plenum, New York, p. 1240 (1978).

Preuss, H., and K. Moerke, "Determination of the Vapor(Gas)-Liquid Equilibrium in the System Hydrogen Sulfide-Methanol," unpublished data stored in the Dortmund Data Bank, Dortmund, Germany, 8301 (1990).

Rivas, O. R., *Solvent Selectivity for Purification of Natural Gases*, PhD Thesis, Univ. of California, Berkeley (1974).

Rivas, O. R., and J. M. Prausnitz, "Apparatus for Rapid Determination of Low-Pressure Solubilities of Gases in Liquids over a Wide Range of Temperatures. Application to Corrosive Systems," *Ind. Eng. Chem., Fundam.*, **18**, 289 (1979a).

Rivas, O. R., and J. M. Prausnitz, "Sweetening of Sour Natural Gases by Mixed-Solvent Absorption: Solubilities of Ethane, Carbon Dioxide, and Hydrogen Sulfide in Mixtures of Physical and Chemical Solvents," *AIChE J.*, **25**, 975 (1979b).

Schlichting, H., *Experimentelle Bestimmung und Korrelierung der Löslichkeit verschiedener Lösungsmittel in Hochdruckgasen*, PhD Thesis, Technical Univ. of Berlin, Berlin, Germany (1991).

Schroedter, F., *Experimentelle Untersuchung und Berechnung von Phasengleichgewichten für Gemische aus Kohlendioxid, Propan, Propen, Methanol, 1-Methyl-2-Pyrrolidon und Wasser*, PhD Thesis, Technical Univ. of Berlin, Berlin, Germany (1991).

Short, I., A. Sahgal, and W. Hayduk, "Solubility of Ammonia and Hydrogen Sulfide in Several Polar Solvents," *J. Chem. Eng. Data*, **28**, 63 (1983).

Sweeney, C. W., "Solubilities and Partial Molar Enthalpies of Solution for Polar Gas-Liquid Systems Determined by Gas Chromatography," *Chromatographia*, **18**, 663 (1984).

Usyukin, I. P., and V. M. Shleinikov, "Solubility of Carbon Dioxide in Certain Organic Solvents at Low Temperature," *Neftepererab. Neftekhim.*, **1**, 39 (1963).

Vilcu, R., I. Gainar, G. Anitescu, and S. Perisanu, "A Physical Method for Determining the Solubility of Gases in Liquids at High Pressures," *Rev. Roum. Chim.*, **36**, 421 (1991).

Wu, Z., S. Zeck, and H. Knapp, "Measurements of the Solubility of Carbon Dioxide, Ethylene and Methane in N-Methylpyrrolidone and in its Aqueous Solution," *Ber. Bunsen-Ges. Phys. Chem.*, **89**, 1009 (1985).

Yarym-Agaev, N. L., V. G. Matvienko, and N. V. Povalyaeva, *Solubility of Hydrogen Sulfide in N-Methylpyrrolidone*, Zh. Prikl. Khim. (Leningrad), **53**, 2456 (1980).

Yogish, K., "Solubility of CO_2 in Some Physical Solvents," *J. Chem. Eng. Jpn.*, **24**, 135 (1991).

Yorizane, M., S. Sadamoto, H. Masuoka, and Y. Eto, "Gas Solubilities in Methanol at High Pressures," *Kogyo Kagaku Zasshi*, **72**, 2174 (1969).

Zubchenko, Y. P., S. F. Shakhova, and O. P. Ladygina, "Solubility of Carbon Dioxide in N-Methylpyrrolidone under Pressure," *Khim. Prom.*, **17**, 535 (1985).