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Vapor–Liquid Equilibria for the Binary Systems Diethyl Ether–Halothane (1,1,1-Trifluoro-2-bromo-2-chloroethane), Halothane–Methanol, and Diethyl Ether–Methanol

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Isothermal (30 °C) and isobaric (700 mmHg) vapor–liquid equilibrium data were measured for the binary systems diethyl ether–halothane, halothane–methanol, and diethyl ether–methanol by using a recirculation still proposed by Röck and Sieg. From these data liquid-phase activity coefficients were fitted by using the Margules, van Laar, Wilson, NRTL, and UNIQUAC equation. Vapor pressure measurements of the pure substances were carried out, and the data were correlated with the Antoine equation.

Introduction

Halothane is a particularly useful nonexplosive inhalation anesthetic capable of producing full-surgical anesthesia over prolonged periods. Because it has less of a depressant effect on respiratory function than halothane, the azeotropic mixture of diethyl ether–halothane is used for anesthetic purposes (*11*). The composition of the azeotrope is about 70 mol % halothane at 760 mmHg. In order to aid the design of anesthesic procedures, we performed vapor–liquid equilibrium measurements for the systems diethyl ether–halothane. Furthermore the two binary systems halothane–methanol and diethyl ether–methanol were measured.

Experimental Section

Purification of the Components. Halothane was obtained from Hoechst AG, Frankfurt/Main-Hoechst. It contained 0.01% thymol as stabilizing agent. The thymol supposedly acts by consuming the free radicals produced by light which would otherwise lead to the evolution of bromine by chain reaction (*11*). No other impurities could be determined; the purity of halothane as determined by gas chromatography was 99.99%.

Methanol of technical grade obtained from Farbenfabriken Bayer, Leverkusen, was refluxed for 3–5 h over 5 g L^{-1} magnesium and then distilled in an all-glass distillation column. After this procedure, impurities were found by gas chromatography to be less than 0.02%. Diethyl ether received from E. Merck, Darmstadt, was rectified and stored over sodium. The purity was 99.85%, using gas chromatography.

Apparatus and Procedure. Equilibrium was attained in an all-glass equilibrium still with circulation of both the vapor and the liquid phase. An apparatus of this type was first proposed by Gillespie (*3*). The measurements were performed in an equilibrium still of this type as modified by Röck and Sieg (*10*). The apparatus was manufactured by Fritz GmbH (Normag), Hofheim (West Germany) (Figure 1). In the Cottrell pump (*2*), vapor and liquid phases are intensively mixed and then separated at the thermometer well. The liquid is collected in receiver (3) from where it flows back into the boiling flask. The vapor rising from the thermometer well is condensed and then collected in receiver (4) from which the overflow returns into the distillation flask. A shield (8) prevents liquid drops from splashing into the vapor chamber. Boiling flask, Cottrell pump, and vapor chamber are thermostated. A temperature of the thermostated jacket of up to 0.1 °C higher than the equilibrium temperature prevents partial condensation in the vapor phase. After evacuating the equilibrium still and filling it with dried inert gas (N$_2$), we filled the distillation flask with the mixture to be investigated. The mixture is heated to boiling point. At the inset of vaporization, the Cottrell pump receives a stream of bubbles and liquid, and circulation in the still starts. Equilibrium will be attained when the circulation rates of both vapor and liquid are constant and no changes in pressure or temperature can be observed. For each data point, 30–45 min elapsed before samples of both phases were drawn via the sampling cocks on the collectors (3, 4).

Table I. Vapor Pressure Data of Halothane

t, °C	$P_H{}^s$, mmHg	t, °C	$P_H{}^s$, mmHg
25.60	303.70	40.88	548.59
28.95	348.70	43.35	600.00
32.90	406.88	45.53	648.00
35.25	445.70	47.65	697.82
38.28	498.50	49.90	751.60

Table II. Antoine Constants

constant	halothane	diethyl ether	methanol
A	6.53534	6.72337	7.76879
B	915.201	955.997	1408.356
C	200.229	214.432	223.599
std dev [a]	0.50	0.78	0.49

[a] mmHg.

Analysis. Liquid and vapor compositions were determined by using a Pye Unicam gas chromatograph (Series 104) equipped with a thermal conductivity detector. The column used was a 15-m glass tube of 4-mm diameter with diatomite (Embacel) packing coated with polypropylene glycol (15%). Hydrogen was used as the carrier gas with a flow rate of 40 mL/min. The column was kept at 80 °C. Samples of both vapor and liquid phases were taken, and triplicate analyses were run on each sample. These analyses were representable to ±0.001 mole fraction.

Vapor Pressure Measurements of the Pure Substances. For the three pure components (diethyl ether, halothane, methanol), vapor pressure measurements were carried out by using the still (Figure 1). Pressures were measured to ±0.02 mmHg with a precision mercury manometer. Temperature in the equilibrium still was measured with the aid of mercury-in-glass thermometers within ±0.02 °C. The experimental vapor pressure data for halothane are given in Table I.

The results for all components were fitted to the Antoine equation

$$\log P_i{}^s \text{ (mmHg)} = A - B/(t\,(^\circ\text{C}) + C)$$

and the parameters are listed in Table II together with the standard deviation between experimental and calculated values.

Treatment of VLE Data. Vapor-liquid equilibrium measurements were performed for three binary systems. The measurements were carried out at both isobaric conditions (700 mmHg) and isothermal conditions (30 °C). Before the data are

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Table III. Experimental Data and Parameters for Halothane (1)-Methanol (2)

	temp 30.00 °C method 1 + consistency method 2 + consistency				pressure 700.00 mmHg (0.933 bar) method 1 + consistency method 2 + consistency			
	A_{12}	A_{21}	α_{12}	mean dev in y	A_{12}	A_{21}	α_{12}	mean dev in y
Margules	0.2948	1.8341		0.0118	0.6663	1.6851		0.0034
van Laar	0.6688	2.6682		0.0204	0.8127	2.1545		0.0086
Wilson	−725.7437	2468.6590		0.0252	−645.0476	2215.2292		0.0129
NRTL	32005.1886	−26567.2614	0.0033	0.0139	1592.6350	−272.0496	0.2906	0.0076
UNIQUAC	1752.6233	−396.7372		0.0165	1463.1328	−340.4383		0.0059

P, mmHg	x_1	y_1	t, °C	x_1	y_1
196.75	0.0753	0.1946	57.94	0.0822	0.2284
271.60	0.2054	0.5263	52.25	0.2036	0.4745
310.10	0.2784	0.6206	49.63	0.2773	0.5698
341.80	0.3602	0.6836	47.68	0.3588	0.6359
362.00	0.4325	0.7194	46.37	0.4357	0.6781
369.00	0.4652	0.7326	45.64	0.4992	0.7035
375.50	0.5009	0.7434	44.35	0.7684	0.7806
399.30	0.7672	0.8098	44.45	0.8475	0.8096
400.00	0.8315	0.8279			
400.45	0.8465	0.8322			

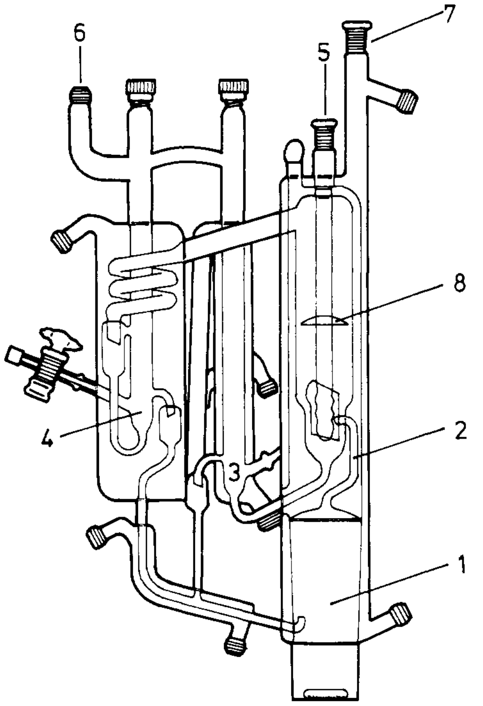

Figure 1. Equilibrium still: 1, boiling flask; 2, Cottrell pump; 3, liquid-phase collector; 4, condensed-vapor-phase collector; 5, thermometer well; 6, joining flange to manostat; 7, thermometer mounting; 8, shield.

fitted to models for the excess Gibbs energy, e.g., Margules (*6*), van Laar (*12*), Wilson (*14*), NRTL (*9*), UNIQUAC (*1*), the data should be checked for thermodynamic consistency. We used two different methods for this purpose: the integral test described by Redlich and Kister (*8*) and Herington (*5*) and a point-to-point test developed by van Ness, Byer, and Gibbs (*13*) and modified by Fredenslund (*2*). Unlike the integral test, in which all experimental data are reduced to one result, the essential feature of the second type of consistency test is the checking of individual data points (*2*, *13*). The difference between experimental (exptl) and calculated (calcd) values of vapor-phase mole fraction

$$\Delta y = y_{\text{exptl}} - y_{\text{calcd}}$$

is a direct criterion for the consistency of data. For fitting activity coefficients γ_i to VLE data, we chose the nonlinear simplex method modified by Nelder and Mead (*7*), where the following objective function was minimized

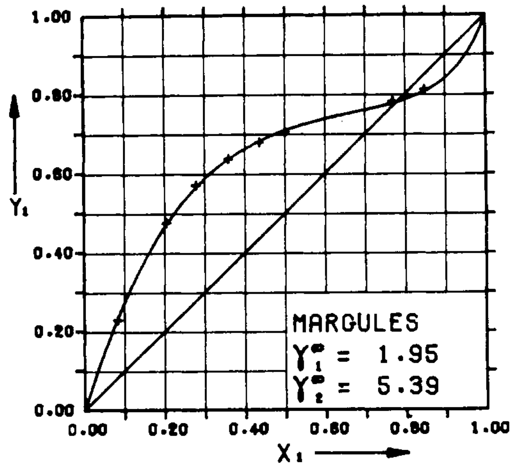

Figure 2. y–x diagram of the binary system halothane (1)–methanol (2) at 700 mmHg.

$$\sum_n \sum_i (\Delta\gamma_{i,n})^2_{\text{rel}} = \sum_n \sum_i \left(\frac{\gamma_{\text{exptl}} - \gamma_{\text{calcd}}}{\gamma_{\text{exptl}}} \right)^2_{i,n} \qquad (1)$$

where subscripts i = component and n = data point.

Results

The experimental data and the fitted parameters are given in Tables III–V together with the mean deviation in y. The parameters of the different expressions for the excess Gibbs energy were determined by using the pure component properties given in Table II and Table VI and by assuming vapor-phase ideality. For the equations based on the concept of local compositions A_{ij} has the following meanings: Wilson $A_{ij} = (\lambda_{ij} - \lambda_{ii})$ cal/mol; NRTL, $A_{ij} = (g_{ij} - g_{jj})$ cal/mol; UNIQUAC, $A_{ij} = (u_{ij} - u_{jj})$ cal/mol. Furthermore, the tables contain information on the consistency of data. In Table VII the meaning of the characters is interpreted.

Figures 2–4 show plots of isobaric data with crosses for experimental points and equilibrium line calculated by the

Table IV. Experimental Data and Parameters for Diethyl Ether (1)-Methanol (2)

	temp 30.00 °C method 1 + consistency method 2 + consistency				pressure 700.00 mmHg (0.933 bar) method 1 + consistency method 2 + consistency			
	A_{12}	A_{21}	α_{12}	mean dev in y	A_{12}	A_{21}	α_{12}	mean dev in y
Margules	1.1604	1.4337		0.0100	1.0878	1.4813		0.0111
van Laar	1.1669	1.4475		0.0099	1.1013	1.5207		0.0100
Wilson	−245.6867	1219.5876		0.0095	−281.1613	1286.1609		0.0084
NRTL	680.7553	219.7657	0.2964	0.0098	744.2572	189.0559	0.2966	0.0097
UNIQUAC	884.5730	−151.1839		0.0099	942.4117	−172.5094		0.0098

P, mmHg	x_1	y_1	t, °C	x_1	y_1	t, °C	x_1	y_1
187.78	0.0121	0.1296	55.98	0.0390	0.2516	38.40	0.3317	0.7172
294.35	0.0774	0.4647	51.78	0.0732	0.3858	33.40	0.6085	0.8307
394.25	0.1640	0.6235	50.00	0.0924	0.4384	32.90	0.7707	0.8659
459.80	0.2401	0.6982	49.66	0.0909	0.4418	32.48	0.8284	0.8857
527.90	0.3719	0.7539	48.95	0.1084	0.4773	32.02	0.9770	0.9766
560.70	0.4661	0.7867	46.20	0.1402	0.5404	31.10	0.7716	0.8717
581.60	0.5409	0.8089	45.70	0.1481	0.5530	30.50	0.9502	0.9458
627.70	0.7724	0.8688	42.25	0.2130	0.6351			
636.20	0.8252	0.8840	41.65	0.2174	0.6443			
649.70	0.9767	0.9764	41.15	0.2383	0.6574			
			39.90	0.3387	0.7247			
			39.45	0.2924	0.6958			

Table V. Experimental Data and Parameters for Diethyl Ether (1)-Halothane (2)

	temp 30.00 °C method 1 + consistency method 2 + consistency				pressure 700.00 mmHg (0.933 bar) method 1 + consistency method 2 + consistency			
	A_{12}	A_{21}	α_{12}	mean dev in y	A_{12}	A_{21}	α_{12}	mean dev in y
Margules	−1.4869	−1.4283		0.0079	−1.1085	−1.3300		0.0011
van Laar	−1.4835	−1.4312		0.0078	−1.1195	−1.3357		0.0012
Wilson	−337.4838	−419.7563		0.0093	−382.3328	−289.1177		0.0038
NRTL	−440.7119	−354.8868	0.3083	0.0083	−241.5812	−457.3195	0.3067	0.0031
UNIQUAC	−182.8922	−84.1341		0.0080	−77.3340	−158.1750		0.0029

P, mmHg	x_1	y_1	t, °C	x_1	y_1
337.00	0.1480	0.0990	49.15	0.1133	0.0815
323.00	0.2493	0.2121	50.20	0.2378	0.2160
318.90	0.3317	0.3334	50.25	0.3429	0.3694
329.20	0.4347	0.5148	49.33	0.4352	0.5124
339.50	0.4762	0.5875	48.65	0.4756	0.5786
387.98	0.5953	0.7790	45.61	0.5894	0.7458
459.55	0.7106	0.8887	41.60	0.7033	0.8702
534.35	0.8203	0.9570	36.75	0.8318	0.9517
586.95	0.8996	0.9787	34.60	0.9063	0.9795
631.35	0.9712	0.9955	33.10	0.9610	0.9933

Table VI. Pure Component Properties

	v_i, mL/mol	r_i	q_i
halothane	106.07	3.5682	3.1600
diethyl ether	104.75	3.3949	3.0160
methanol	40.73	1.4311	1.4320

equation yielding the lowest mean deviation in vapor-phase mole fraction y_1. The name of the "best" equation is printed on the diagram, together with the values for the activity coefficients at infinite dilution γ_1^∞, γ_2^∞.

Conclusions

Each of the three binary systems has an azeotrope with diethyl ether (1)–halothane (2) showing negative deviation from Raoults'

Table VII

character in the table	method 1: Van Ness (*13*) and Fredenslund (*2*)	method 2: Redlich-Kister (*8*) and Herington (*5*)
+ (consistent)	mean deviation in vapor mole fraction y, $\overline{\Delta y} \leqslant 0.01$	isothermal data: $D \leqslant 10\%$ isobaric data: $D - J \leqslant 10\%$ $D = 100\,(\lvert A' - B' \rvert)/(A' + B')\,\%$ $J = 150 \Delta T_{\max}/T_{\min}$
− (inconsistent)	mean deviation in vapor mole fraction y, $\overline{\Delta y} > 0.01$	isothermal data: $D > 10\%$ isobaric data: $D - J > 10\%$

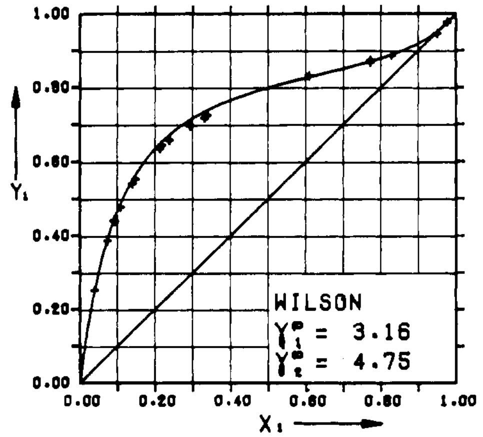

Figure 3. y-x diagram of the binary system diethyl ether (1)-methanol (2) at 700 mmHg.

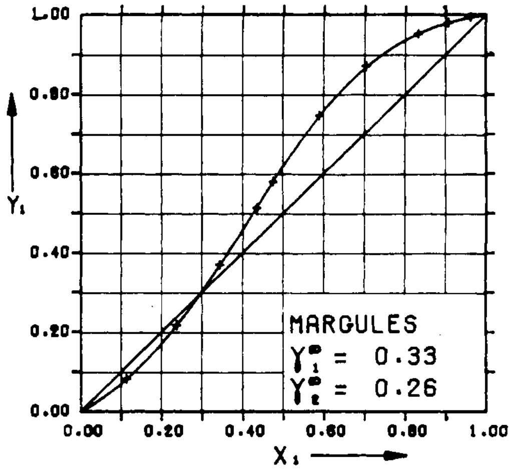

Figure 4. y-x diagram of the binary system diethyl ether (1)-halothane (2) at 700 mmHg.

law, in contrast to the other systems.

The systems diethyl ether-methanol and diethyl ether-halothane (Tables III-V) show good agreement between calculated and experimental data. In general the mean deviations in vapor-phase compositions are less than 1 mol %.

The results for the system diethyl ether-methanol are in good agreement with the data of Arm and Bankay (*15*) and Pettit (*16*).

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Glossary

A, B, C	constants of the Antoine equation
A' (B')	area above (below) x axis for area test
A_{ij}	parameter in the Margules and van Laar equation
D	consistency criterion for area test
g_{ij}	interaction energy parameter in NRTL equation
n	number of components
P_i^s	vapor pressure, mmHg
q_i	pure component area parameter of component i
r_i	pure component volume parameter of component i
T	absolute temperature, K
t	temperature, °C
u_{ij}	interaction energy parameter in UNIQUAC equation
v_i	molar liquid volume of component i, mL/mol
x_i	liquid-phase mole fraction of component i
y_i	vapor-phase mole fraction of component i
Δy	deviation between experimental and calculated vapor-phase mole fraction
$\overline{\Delta y}$	mean deviation in vapor-phase mole fraction

Greek Letters

α_{ij}	nonrandomness parameter in NRTL equation
γ_i	activity coefficient of component i
λ_{ij}	interaction energy parameter in Wilson equation

Subscripts

calcd	calculated
exptl	experimental
rel	relative
i, j, k, l, m	component i, j, k, l, m

Superscripts

∞	infinite dilution

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