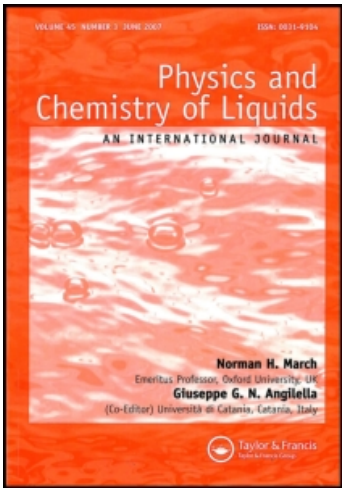
This article was downloaded by:
On: *28 January 2011*
Access details: *Access Details: Free Access*
Publisher *Taylor & Francis*
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK



Physics and Chemistry of Liquids
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713646857

Density, viscosity and refractive index for ethyl tert-butyl ether + 2-butoxyethanol mixtures

Aneta Ćwiklińska[a]; Cezary M. Kinart[a]; Wojciech J. Kinart[b]; Dorota ChĘcińska-Majak[a]
[a] Department of Chemistry, University of Łódź, Pomorska 163, Poland [b] Department of Organic Chemistry, University of Łódź, Narutowicza 68, Poland

To cite this Article Ćwiklińska, Aneta , Kinart, Cezary M. , Kinart, Wojciech J. and ChĘcińska-Majak, Dorota(2008) 'Density, viscosity and refractive index for ethyl **tert**-butyl ether + 2-butoxyethanol mixtures', Physics and Chemistry of Liquids, 46: 1, 27 — 33
To link to this Article: DOI: 10.1080/00319100600930774
URL: http://dx.doi.org/10.1080/00319100600930774

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: http://www.informaworld.com/terms-and-conditions-of-access.pdf

This article may be used for research, teaching and private study purposes. Any substantial or systematic reproduction, re-distribution, re-selling, loan or sub-licensing, systematic supply or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

Physics and Chemistry of Liquids
Vol. 46, No. 1, February 2008, 27–33

Taylor & Francis
Taylor & Francis Group

Density, viscosity and refractive index for ethyl *tert*-butyl ether + 2-butoxyethanol mixtures

ANETA ĆWIKLIŃSKA†, CEZARY M. KINART*†,
WOJCIECH J. KINART‡ and DOROTA CHĘCIŃSKA-MAJAK†

†Department of Chemistry, University of Łódź, 90-236 Łódź, Pomorska 163, Poland
‡Department of Organic Chemistry, University of Łódź, 90-136 Łódź,
Narutowicza 68, Poland

(*Received 29 July 2006; in final form 6 November 2006*)

Downloaded At: 07:34 28 January 2011

Densities (ρ) at 293.15, 298.15, 303.15, 308.15, and 313.15 K, viscosities (η) at 293.15, 298.15, and 303.15 K and refractive indexes (n) at 298.15 K of binary mixtures of ethyl *tert*-butyl ether (**1**) + 2-butoxyethanol (**2**), are reported. The excess molar volumes (V^E) and the viscosities, and refractive index deviations ($\Delta \ln \eta$ and Δn) were calculated from these experimental data. The results are discussed in terms of intermolecular interactions.

Keywords: Density; Viscosity; Refractive index; 2-Butoxyethanol; Ethyl *tert*-butyl ether; Intermolecular interactions

1. Introduction

In continuation of our program on studies of the structural properties of some mixtures of alkoxyethanols with ethyl *tert*-butyl ether (ETBE) [1–3], the present article reports densities at 293.15, 298.15, 303.15, 308.15, and 313.15 K, viscosities at 293.15, 298.15, and 303.15 K, and refractive indexes at 298.15 K for ETBE + 2-butoxyethanol (BE) binary mixtures. From these results, the excess molar volumes (V^E) and the deviations of the viscosity ($\Delta \ln \eta$) from a mole fraction (x) and refractive index (Δn) from a volume fraction (ϕ) average have been calculated. These quantities have been fitted to the Redlich–Kister equation [4], to obtain the binary coefficients and standard errors, between the calculated and the experimental parameters.

Furthermore, the experimental results are used to disclose the nature of binary interactions in the bulk of studied the binary mixtures.

*Corresponding author. Email: ckinart@uni.lodz.pl

Physics and Chemistry of Liquids
ISSN 0031-9104 print/ISSN 1029-0451 online © 2008 Taylor & Francis
DOI: 10.1080/00319100600930774

Table 1. Reference density, viscosity and refractive index values of ethyl *tert*-butyl ether (ETBE) and 2-butoxyethanol (BE), at 298.15 K.

	ρ (g cm^{-3})		η (mPa s)		n	
Solvent	This work	Literature	This work	Literature	This work	Literature
ETBE	0.73559	0.73557 [10] 0.7353 [11]	0.504	–	1.37322	1.3731 [16]
BE	0.89629	0.89580 [12] 0.89581 [13] 0.89621 [14]	2.825	2.836 [15]	1.41753	1.4175 [17]

2. Experimental section

2.1. *Materials*

2-Butoxyethanol and ETBE, Merck, pro-analysis, containing $<0.05\%$ (w/w) of water, respectively (determined by Karl–Fischer method), were used.

Ethyl *tert*-butyl ether and BE were further purified by the methods described by Riddick [5]. The mixtures were prepared by mass, with weightings accuracy to $\pm 1 \times 10^{-4}$ g. Conversion to molar quantities was based on the relative atomic mass table of 1985 issued by IUPAC in 1986. The uncertainty in the mole fractions is less than 1×10^{-4}. Liquids were stored in dry box over phosphoric pentoxide and degassed by ultrasound just before the experiment.

Experimental data of densities, viscosities and refractive indexes for the pure solvents, at 298.15 K, are compared with values available in the literature and listed in table 1.

Downloaded At: 07:34 28 January 2011

2.2. *Measurements*

Solvent densities were measured with a bicapillary type Lipkin pycnometer, with a capacity of ca 90 cm^3. The maximum error in the density measurements was 3×10^{-5} g cm^{-3}.

The flow times of the mixtures and pure liquids were measured in a ViscoClock (made by Schott), equipped with an Ubbelohde capillary viscometer. The double distilled, deionized and degassed water with a specific conductance of $1 \times 10^{-7}\,\Omega^{-1}\,\mathrm{cm}^{-1}$ was used for the calibration. The time measurement tolerance was $\pm 0.005\%$, and the display accuracy was ± 0.01 s. The accuracy in the viscosity measurements was ± 0.001 mPa s.

The refractive indexes n_D (Na-D line, at $\lambda = 589$ nm) were measured by an automatic refractometer DR 5000 Krűss, with a resolution 1×10^{-5} and an accuracy of 2×10^{-5}.

In all the physicochemical properties measurements, an Haake model DC-30 thermostat was used at a constant digital temperature control of ± 0.01 K.

3. Results and discussion

The experimental values of density (ρ), viscosity (η) and refractive index (n) at all measured temperatures are given in tables 2 and 3. From the measured densities the

Table 2. Experimental density (ρ) and excess molar volume (V^E) for ethyl *tert*-butyl ether (**1**) + 2-butoxyethanol (**2**) binary mixtures.

	ρ (g cm^{-3})					V^E (cm^3 mol^{-1})				
x_1	293.15 K	298.15 K	303.15 K	308.15 K	313.15 K	293.15 K	298.15 K	303.15 K	308.15 K	313.15 K
0.0000	0.90119	0.89629	0.89235	0.88818	0.88349	0.000	0.000	0.000	0.000	0.000
0.0499	0.89430	0.88909	0.88487	0.88043	0.87548	−0.218	−0.182	−0.150	−0.119	−0.088
0.1000	0.88702	0.88170	0.87732	0.87271	0.86760	−0.382	−0.338	−0.292	−0.244	−0.195
0.1511	0.87951	0.87413	0.86966	0.86494	0.85967	−0.534	−0.489	−0.438	−0.381	−0.317
0.2007	0.87220	0.86676	0.86223	0.85742	0.85207	−0.675	−0.628	−0.577	−0.515	−0.445
0.2489	0.86507	0.85960	0.85499	0.85014	0.84475	−0.805	−0.760	−0.706	−0.645	−0.575
0.2999	0.85749	0.85196	0.84731	0.84241	0.83700	−0.933	−0.887	−0.834	−0.772	−0.706
0.3421	0.85116	0.84559	0.84088	0.83597	0.83054	−1.027	−0.980	−0.925	−0.868	−0.804
0.4018	0.84209	0.83644	0.83167	0.82674	0.82131	−1.138	−1.085	−1.030	−0.977	−0.920
0.4500	0.83463	0.82893	0.82412	0.81916	0.81373	−1.200	−1.145	−1.090	−1.038	−0.988
0.5002	0.82671	0.82096	0.81612	0.81115	0.80872	−1.236	−1.179	−1.124	−1.076	−1.031
0.5521	0.81840	0.81261	0.80775	0.80274	0.79730	−1.247	−1.187	−1.135	−1.087	−1.044
0.5998	0.81066	0.80485	0.79994	0.79490	0.78943	−1.234	−1.175	−1.119	−1.071	−1.026
0.6538	0.80194	0.79599	0.79103	0.78594	0.78039	−1.219	−1.139	−1.081	−1.027	−0.973
0.6987	0.79446	0.78858	0.78356	0.77840	0.77281	−1.161	−1.096	−1.030	−0.969	−0.908
0.7501	0.78600	0.78007	0.77497	0.76974	0.76404	−1.104	−1.032	−0.957	−0.885	−0.808
0.8000	0.77775	0.77174	0.76657	0.76125	0.75550	−1.033	−0.950	−0.866	−0.780	−0.693
0.8492	0.76947	0.76343	0.75819	0.75283	0.74702	−0.930	−0.841	−0.747	−0.655	−0.559
0.8997	0.76068	0.75464	0.74941	0.74406	0.73830	−0.761	−0.672	−0.581	−0.492	−0.404
0.9493	0.75149	0.74558	0.74048	0.73528	0.72966	−0.484	−0.416	−0.349	−0.286	−0.224
1.0000	0.74111	0.73559	0.73085	0.72598	0.72069	0.000	0.000	0.000	0.000	0.000

Downloaded At: 07:34 28 January 2011

excess values of molar volumes V^E of the mixtures, at the each investigated temperature, were fitted to the equation:

$$V^E = x_1 M_1\left(\rho^{-1} - \rho_1^{-1}\right) + x_2 M_2\left(\rho^{-1} - \rho_2^{-1}\right) \quad (1)$$

where M_1 and M_2 are the molar masses of the pure components and ρ_1, ρ_2, and ρ are the densities of the pure species (1) and (2) and that of the mixtures at different temperatures, respectively.

The deviations of the viscosity from a mole fraction (x) and refractive index from a volume fraction (ϕ) average were calculated from the equations:

$$\Delta \ln \eta = \ln \eta - (x_1 \ln \eta_1 + x_2 \ln \eta_2) \quad (2)$$

$$\Delta n = n - (\phi_1 n_1 + \phi_2 n_2) \quad (3)$$

where η_1, η_2, n_1, n_2, and η, and n are the viscosities and refractive indexes of the ETBE, BE and the mixtures, respectively.

The values of V^E, $\Delta\eta$ and Δn of the studied binary mixtures, at all measured temperatures, are given in tables 2 and 3.

The variations of V^E and $\Delta \ln \eta$ *versus* the mole fraction of 2-methoxyethanol (x_1), and Δn *versus* the volume fraction of 2-methoxyethanol (ϕ_1), at all measured temperatures, are presented in Figures 1–3, respectively. The curves have been obtained by fitting the V^E, $\Delta \ln \eta$ and Δn with Redlich–Kister equations of the type [4]:

$$V^E \left(\text{cm}^3 \text{ mol}^{-1}\right) \quad \text{or} \quad \Delta \ln \eta = x_1(1 - x_1) \sum_{j=0}^{4} a_j (2x_1 - 1)^j \quad (4)$$

Table 3. Experimental viscosity (η), refractive index (n) and deviations viscosity ($\Delta\ln\eta$), and refractive index (Δn) for ethyl *tert*-butyl ether (**1**) + 2-Butoxyethanol (**2**) binary mixtures.

	η (mPa s)			n	$\Delta\ln\eta$			Δn
x_1	293.15 K	298.15 K	303.15 K	298.15 K	293.15 K	298.15 K	303.15 K	298.15 K
0.0000	3.239	2.825	2.449	1.41753	0.0000	0.0000	0.0000	0.00000
0.0499	2.901	2.558	2.239	1.41572	−0.0202	−0.0134	−0.0083	0.00051
0.1000	2.603	2.314	2.038	1.25808	−0.0381	−0.0270	−0.0205	0.00102
0.1511	2.336	2.092	1.850	1.41215	−0.0541	−0.0400	−0.0335	0.00153
0.2007	2.107	1.899	1.687	1.40968	−0.0676	−0.0512	−0.0448	0.00218
0.2489	1.910	1.731	1.545	1.40844	−0.0787	−0.0605	−0.0537	0.00246
0.2999	1.725	1.573	1.412	1.40653	−0.0883	−0.0686	−0.0608	0.00284
0.3421	1.589	1.455	1.312	1.40464	−0.0945	−0.0739	−0.0650	0.00312
0.4018	1.417	1.305	1.186	1.40244	−0.1007	−0.0794	−0.0689	0.00335
0.4500	1.296	1.198	1.094	1.40037	−0.1034	−0.0821	−0.0706	0.00347
0.5002	1.183	1.097	1.007	1.39832	−0.1040	−0.0834	−0.0715	0.00354
0.5521	1.079	1.004	0.925	1.39614	−0.1024	−0.0830	−0.0715	0.00353
0.5998	0.993	0.926	0.857	1.39390	−0.0991	−0.0811	−0.0704	0.00347
0.6538	0.906	0.847	0.786	1.39151	−0.0934	−0.0771	−0.0677	0.00335
0.6987	0.840	0.788	0.734	1.38920	−0.0870	−0.0720	−0.0638	0.00317
0.7501	0.773	0.727	0.679	1.38686	−0.0781	−0.0644	−0.0571	0.00295
0.8000	0.714	0.673	0.632	1.38442	−0.0677	−0.0549	−0.0480	0.00267
0.8492	0.661	0.626	0.590	1.38176	−0.0555	−0.0436	−0.0366	0.00225
0.8997	0.612	0.581	0.550	1.37921	−0.0406	−0.0303	−0.0232	0.00174
0.9493	0.570	0.541	0.514	1.37640	−0.0228	−0.0159	−0.0101	0.00104
1.0000	0.532	0.504	0.478	1.37322	0.0000	0.0000	0.0000	0.00000

Downloaded At: 07:34 28 January 2011

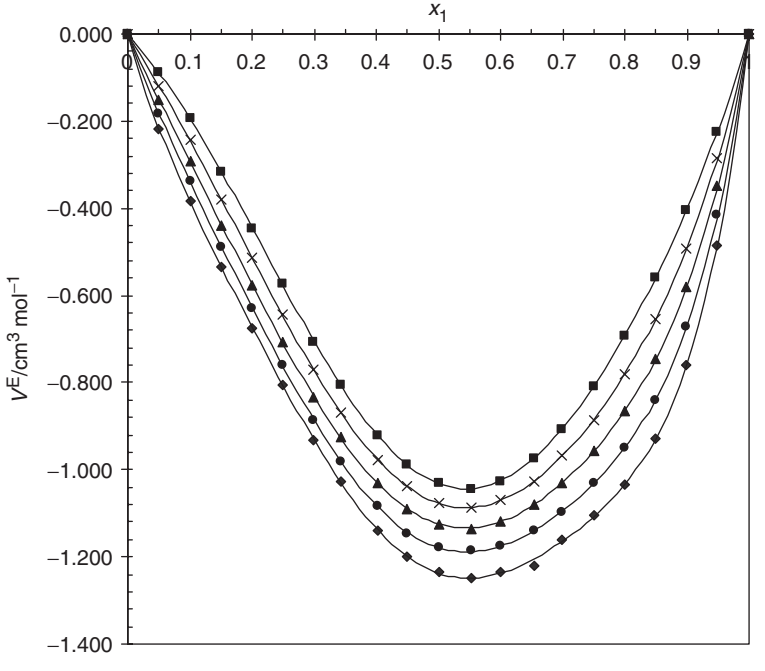


Figure 1. Plot of excess molar volume (V^E) as a function of composition for ETBE (**1**) + BE (**2**) binary liquid mixtures, at 293.15, 298.15, 303.15, 308.15, and 313.15 K.

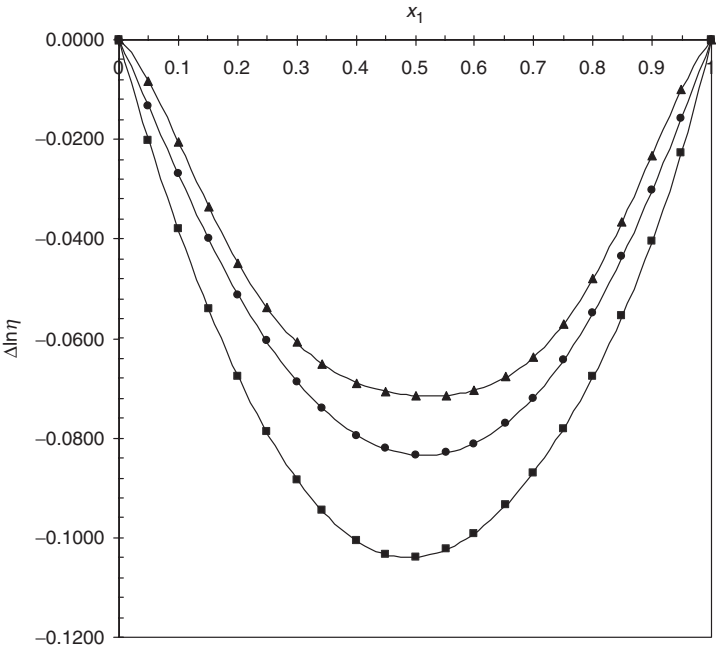


Figure 2. Plot of excess $\Delta\ln\eta$ against mole fraction of ETBE for ETBE (**1**) + BE (**2**) binary liquid mixtures, at 293.15, 298.15, and 303.15 K.

Downloaded At: 07:34 28 January 2011

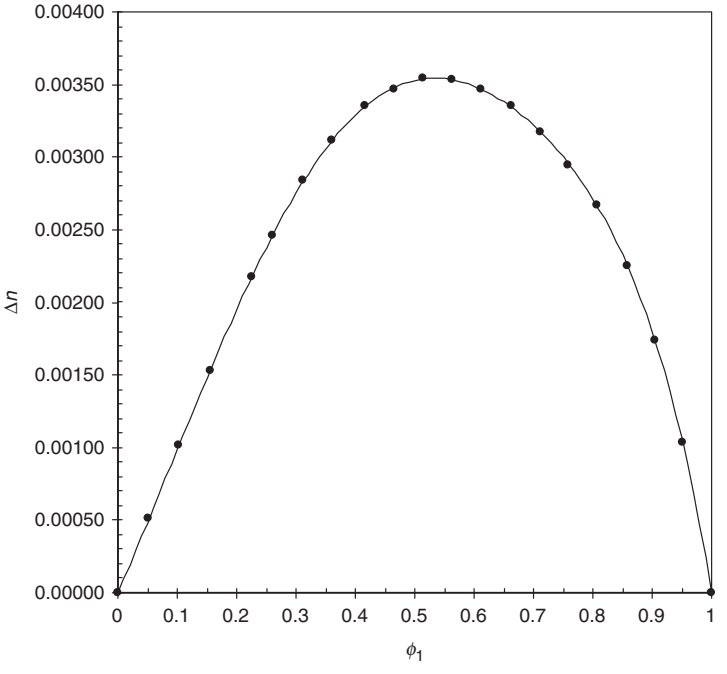


Figure 3. Plot of excess Δn against the volume fraction of ETBE for ETBE (**1**) + BE (**2**) binary liquid mixtures, at 298.15 K.

Table 4. Parameters a_j of equations (4) and (5) and SD $\sigma(V^E)$, $\sigma(\Delta\ln\eta)$ and σ (Δn) for ethyl *tert*-butyl ether (**1**) + 2-butoxyethanol (**2**) binary mixtures.

T	a_0	a_1	a_2	a_3	a_4	$\sigma(V^E)$ (cm^3 mol^{-1})
Ethyl *tert*-butyl ether (**1**) + 2-butoxyethanol (**2**)						
293.15 K	−4.9520	−0.9662	−4.0760	−2.5602	−4.0633	0.005
298.15 K	−4.7156	−0.8733	−0.4419	−2.2485	−2.8756	0.001
303.15 K	−4.4983	−0.8898	0.7016	−1.7280	−1.9541	0.001
308.15 K	−4.3059	−0.9725	1.2282	−1.1597	−1.3896	0.001
313.15 K	−4.1255	−1.1008	2.0056	−0.5394	−1.1546	0.001
						$\sigma(\Delta\ln\eta)\times10^5$
293.15 K	−0.4160	0.0176	0.0026	−0.0534	−0.0547	3.7
298.15 K	−0.3336	−0.0182	−0.0152	−0.0064	0.0615	7.5
303.15 K	−0.2860	−0.0167	−0.1096	−0.0023	0.2779	2.6
						$\sigma(\Delta n)\times10^6$
298.15 K	0.0141	0.0018	0.0001	0.0060	0.0032	7.3

$$\Delta n = \phi_1(1-\phi_1)\sum_{j=0}^{4} a_j(2\phi_1-1)^j \tag{5}$$

The values of these parameters, at each studied temperature, with SD $\sigma(V^E)$, are summarized in table 4.

Standard deviation values were obtained from:

$$\sigma = \left[\frac{\sum (X_{\text{exptl}} - X_{\text{calcd}})^2}{n-p}\right]^{1/2} \tag{6}$$

where n is the number of experimental points, p is the number of parameters, X_{exptl} and X_{calcd} are the experimental and calculated properties.

Figures 1 and 2 shows that the excess of molar volumes (V^E) and deviation of the viscosities ($\Delta\ln\eta$) are negative over the whole composition range, and that they become less negative when temperature increases, with the minimums lying always nearly at $x_1 \approx 0.50$.

Figure 3 shows that the deviation of refractive indices (Δn) are positive over the whole composition range, with the maximums lying nearly at $\phi_1 \approx 0.51$ (corresponding to $x_1 \approx 0.50$).

The course of changes of these structural parameters may be attributed mainly to the association through intermolecular hydrogen bonds between oxygen of the –O– group of the ETBE and hydrogen atom of the H–O– group of BE [1–3]. The addition of pure ETBE to BE would disrupt the self-associated structure in this alkoxyethanol causing the appearance in the solution of free BE molecules [6–9]. These free BE molecules may interact by dipole–dipole forces and/or intermolecular hydrogen bonds with ETBE molecules.

Obtained results seem to indicate that the stable intermolecular complexes of the ETBE–BE types are respectively formed in the studied binary mixtures.

References

[1] C.M. Kinart, K. Nowak, W.J. Kinart. *J. Chem. Thermodyn.*, **37**, 423 (2005).
[2] C.M. Kinart, A. Ćwiklińska, W.J. Kinart, A. Bald. *J. Mol. Liq.*, **126**, 135 (2006).

Downloaded At: 07:34 28 January 2011

[3] C.M. Kinart, A. Ćwiklińska, W.J. Kinart. *J. Therm. Anal. Cal.*, **84**, 535 (2006).
[4] O. Redlich, A.T. Kister. *Ing. Eng. Chem.*, **40**, 345 (1948).
[5] J.A. Riddick, W.B. Bunger, T.K. Sakano. *Organic Solvents: Physicochemical Properties and Methods of Purification*, 4th Edn, Wiley-Interscience, New York (1986).
[6] J.A. Gonzalez, S. Villa, N. Riesco, I.G. De la Fuente, J.C. Cobos. *Can. J. Chem.*, **81**, 319 (2003).
[7] P. Buckley, M. Brochu. *Can. J. Chem.*, **50**, 1149 (1972).
[8] G. Vaidyanathan, W.J. Herron, J.F. Garvey. *J. Phys. Chem.*, **97**, 7880 (1993).
[9] F.P.S.C. Gil, R. Fausto, A.M. Amorim da Costa, J.J.C. Taixeira-Dias. *J. Chem. Soc. Faraday Trans.*, **90**, 689 (1994).
[10] S. Fuangfoo, M. Kersting, D.S. Viswanth. *J. Chem. Eng. Data*, **44**, 405 (1999).
[11] A. Aucejo, S. Loras, R. Munoz, R. Reich, H. Segura. *J. Chem. Eng. Data*, **43**, 973 (1998).
[12] A. Pal, W. Singh. *J. Chem. Eng. Data*, **35**, 285 (1990).
[13] M.J. Davis. *J. Chem. Thermodyn.*, **23**, 99 (1990).
[14] D. Venkatesulu, M.V.P. Rao. *J. Chem. Eng. Data*, **37**, 479 (1992).
[15] A. Pal, W. Singh. *Fluid Phase Equlib.*, **129**, 211 (1997).
[16] T.E. Daubert, R.P. Daneer. *Physical and Thermodynamic Properties of Pure Chemicals: Data Compilation*, Library of Congress Cataloging-in Publication Data, New York (1989).
[17] F. Comelli, R. Francesconi, C. Castellri. *Thermochim. Acta*, **354**, 89 (2000).

Downloaded At: 07:34 28 January 2011