J. Chem. Thermodynamics 40 (2008) 1654–1660

Contents lists available at ScienceDirect

J. Chem. Thermodynamics

journal homepage: www.elsevier.com/locate/jct

Solubility of carbon dioxide in 1-ethyl-3-methylimidazolium 2-(2-methoxyethoxy) ethylsulfate

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ARTICLE INFO

Article history:
Received 30 May 2008
Received in revised form 2 July 2008
Accepted 3 July 2008
Available online 17 July 2008

Keywords:
Carbon dioxide
Absorption
Equilibrium solubility
1-Ethyl-3-methylimidazolium
2-(2-methoxyethoxy) ethylsulfate

ABSTRACT

Experimental results for the solubility of carbon dioxide in the ionic liquid 1-ethyl-3-methylimidazolium 2-(2-methoxyethoxy) ethylsulfate are not reported in the literature. To this end, we present in this work new solubility data for carbon dioxide in 1-ethyl-3-methylimidazolium 2-(2-methoxyethoxy) ethylsulfate for temperatures ranging from (303.2 to 343.2) K and pressures up to 6.7 MPa using a thermogravimetric microbalance. The carbon dioxide solubility was determined from absorption saturation (equilibrium) data at each fixed temperature and pressure. The buoyancy effect was accounted in the evaluation of the carbon dioxide solubility. Highly accurate equations of states for carbon dioxide and for ionic liquids were employed to determine the effect of buoyancy on carbon dioxide solubility. The solubility measurements are presented as a function of temperature and pressure. The present experimental solubility results have been successfully correlated using an extended Henry's law equation.

1. Introduction

The use of aqueous solutions of alkanolamines (organic solvents with $-NH_2$) is one of the most widely applied technologies for removing carbon dioxide industrially via chemical absorption [1] but the use of this solutions has several setbacks such as intensive energy consumption, cost increases, and corrosion problems. In this regard, it is necessary to find a new kind of sequestering agent and to this end, a new class of solvents, known as ionic liquids (ILs) may offer at least a partial solution to these problems. In the past years, ILs had been the focus of many researchers [2–14] because of the very good potential to replace these conventional organic solvents (aqueous solutions of alkanolamines) due to their unique properties such as low vapour pressure, non-flammability, high thermal stability, and high solvation capacity. They are also termed green and designer solvents because the mentioned properties have lesser degrading effects on the environment and can be custom-fitted for specific applications [3,15].

Since knowledge of solvent phase behaviour helps determine the attractiveness of using these solvents for specific applications, solubility studies are essential for chemical separation processes. Different experimental methods such as the closed cell (static) method [2,10,13,16,17], chromatography [5,18], phase equilibration [7,12,19], pressure change measurement, [20–24], volumetric [25,26], and gravimetric [8,11,27–29] can be applied to measure the gas solubility in a solvent. Among the methods mentioned, the measurement of gas solubility using gravimetry seems to be the simplest technique to use. Many studies have focused on imidazolium ILs, but over a limited temperature and pressure range [2,5,7,8,10–13,16–29]. Sometimes no available data are available at all, as in the case of 1-ethyl-3-methylimidazolium 2-(2-methoxyethoxy) ethylsulfate [Emim][$MDEGSO_4$].

To this end, the equilibrium solubility data of carbon dioxide in IL [Emim][$MDEGSO_4$] over the temperature range of (303.2 to 343.2) K and pressures up to 6.7 MPa were measured using a thermogravimetric microbalance. The effect of buoyancy was accounted for in the evaluation of carbon dioxide solubility. Buoyancy correction requires high pressure density data for IL and carbon dioxide. In this regard, highly accurate equations of states for IL and carbon dioxide were employed. The modified equation proposed by Gardas and Countinho [30] was used to estimate the high pressure density of the investigated ILs. The equation developed by Huang *et al.* [31] was used to determine the density of carbon dioxide at high pressures. Since there is no available solubility data for the IL investigated, another IL (1-butyl-3-methylimidazolium hexafluorophosphate [Bmim][PF_6]) which is widely studied was used to show that the results in this work are correct. To this end, some solubility measurements for [Bmim][PF_6] at selected isotherms were also measured and compared to the available literature data. The present experimental solubility data are represented by an extended Henry's law correlation.

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doi:10.1016/j.jct.2008.07.003

2. Experimental

2.1. Chemicals

The IL samples were supplied by TCI Co. with a minimum mass fraction purity of (0.990 and 0.982) for [Bmim][PF_6] and [Emim][$MDEGSO_4$], respectively. The mass fraction of water in the IL samples was $\leqslant 0.002$. The ILs were degassed inside the vessel of the microbalance where it was heated ($T = 343$ K) in a vacuum for at least 8 h to remove any volatile impurities. High concentration of carbon dioxide with a minimum mass fraction purity of 0.999 was supplied by Liehwa Industrial Gases, (KUN Technology, Co., Ltd.).

2.2. Carbon dioxide solubility measurements

The carbon dioxide solubility was measured using a thermogravimetric microbalance (model D-110, Thermo Cahn Co.), with experimental set-up shown in figure 1. To have a fully automatic and reproducible result of gas absorption–desorption isotherms, the Thermo Cahn design integrates precise computer-control and measurement of mass change, pressure, and temperature. The microbalance consists of a highly sensitive electro-balance with sample and counterweight components inside a stainless steel pressure vessel. The balance has a weighing range of up to 100 g with a readability of 1 μg. The maximum temperature and pressure that the balance can hold were 848.2 K and 10.34 MPa, respectively. The microbalance has the following accuracy: mass $\pm 1 \cdot 10^{-6}$ g, temperature ±0.1 K, and pressure $\pm 7 \cdot 10^{-5}$ MPa. It can operate in both dynamic and static modes. Dynamic mode operation provides a continuous flow of gas past the sample, while the static mode operation introduces gas into the top of the balance and the reactor vessel is closed. In this work, all absorption measurements were performed in static mode.

Approximately 0.200 cm^3 of the sample was loaded on the microbalance pan using a micropipette, and the vessel was sealed. The sample was dried and degassed by first pulling a coarse vacuum on the sample with a diaphragm pump and then fully evacuating the reactor to a minimum of 10^{-8} kPa with a turbo-pump (model CDK 180 Turbomolecular pump, ILMVAC Co.). While under vacuum, the sample was heated to $T = 343.2$ K for a minimum of 8 h with an external heating coil surrounding the vessel connected to a remote-controlled temperature controller (model Digital Controller CB900, RKC Instrument Inc.). The CO_2 was introduced slowly into the top of the vessel up to the desired pressure and then closed the input gas valve. Upon the introduction of the gas, the desired temperature (from high T to low T) was then set and the system were allowed to reach the equilibrium state. To ensure sufficient time for (gas + liquid) equilibrium, normally the IL sample was maintained at set-point for a minimum of 3 h, if necessary to 6 h, or even longer. Upon completion at the set temperatures, the pressure was raised to the next target pressure and the procedure was repeated accordingly. The digital recording balance (DRB) of the Thermo Cahn automatically records the data after setting the next desired temperature and pressure.

2.3. Buoyancy effect calculations

The correction for buoyancy effect was calculated using a similar technique done by Shiflett and Yokozeki [11] with some simpli-

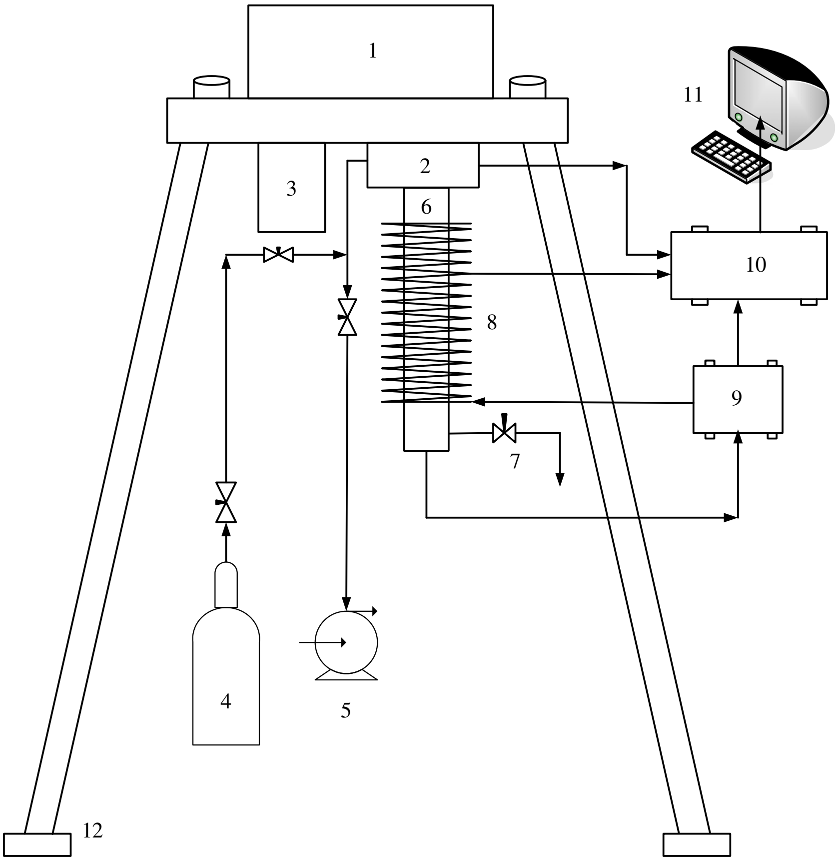

FIGURE 1. Experimental set-up for CO_2 solubility using a thermogravimetric microbalance: 1, electrobalance; 2, sample side; 3, tare side; 4, CO_2 source; 5, vacuum pump; 6, reactor vessel; 7, gas output; 8, thermostatic coil; 9, automatic temperature controller; 10, digital recording balance; 11, computer output; and 12, microbalance support base.