Journal of Molecular Liquids 256 (2018) 1–8

Contents lists available at ScienceDirect

Journal of Molecular Liquids

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

Effect of ionic liquid based imidazolium as an additive on the formation of polymer/salt aqueous biphasic systems

Hongpeng Yang [a], Lei Zhang [a], Li Chen [b], Cunshan Zhou [a,*], Xiaojie Yu [a], Abu El-Gasim A. Yagoub [c], Haile Ma [a]

[a] School of Food and Biological Engineering, Jiangsu University, Zhenjiang 212013, China
[b] Jiangsu Marine Resources Development Research Institute, Lianyungang 222005, China
[c] Faculty of Agriculture, University of Zalingei, P.O. Box: 06, Zalingei, Sudan

ARTICLE INFO

Article history:
Received 15 March 2017
Received in revised form 20 January 2018
Accepted 31 January 2018
Available online 05 February 2018

Keywords:
Aqueous biphasic systems
Ionic liquid
Adjuvant
Polyethylene glycol
Phase diagram

ABSTRACT

Aqueous biphasic system (ABS) has been proposed as an alternative technique for the extraction, separation and/or purification of diverse biomolecules. ABS composed of polyethylene glycol (PEG) and sodium salts, using ILs ([$C_n$mim]Cl) as additives were studied. Phase diagrams of PEG 800 + sodium salts (Na_2HPO_4, $Na_3C_6H_5O_7$, Na_2CO_3, Na_2SO_4, NaH_2PO_4) + H_2O + 5 wt% [C_4mim]Cl at 298.15 K were used to study the effect of different salts on the ABS. Binodal curves for the ABS composed of PEG (molecular weights of 400, 600, 800, 1000 and 2000 $g \cdot mol^{-1}$) + Na_2SO_4 + H_2O + 5 wt% IL ([C_2mim]Cl, [C_4mim]Cl, [C_6mim]Cl, [C_8mim]Cl, [C_{10}mim]Cl) at 298.15 K were determined to study the effect of the polymer size and the IL alkyl side chain length on ABS. Ability of the various salts to form ABS follows the trend: $Na_3C_6H_5O_7$ > Na_2HPO_4 > Na_2CO_3 > Na_2SO_4 > NaH_2PO_4. The increase in the molecular weight of PEG increases the phase separation ability of the system. [C_6mim]Cl shows the best phase separation at PEG400 + Na_2SO_4. [C_8mim]Cl and [C_{10}mim]Cl improves the phase separation of PEG-Na_2SO_4. The phase diagram is not affected at 288.15–308.15 K. The phase separation increases at 318.15–328.15 K and decreases at >318.15 K. These results illustrate the ability of the IL to tune the polarity of the PEG-rich phase. PEG–Salt–IL ABS could be an interesting advance in separation processes and could lay the basis for future studies in extraction processes.

1. Introduction

In the past few decades the traditional liquid-liquid extraction has been gradually replaced by the aqueous biphasic system (ABS). ABS technique is relatively simple and inexpensive, of easy operation, allowing its scale-up, and further ensures the purification and concentration stages to be integrated in a single step procedure [1,2]. Conventional ABS typically consists of two immiscible aqueous-rich phases based on polymer/polymer, polymer/salt or salt/salt combinations dissolved in aqueous media that might be used in liquid–liquid extraction processes [1,2]. However, both phases are mostly composed of water, offering a bio-compatible medium for biologically active molecules. Due to this advantage, ABS has been successfully used for the recovery of biological products [3]. Some factors, such as the characteristics of the target material, system characteristics and the economic costs have been taken into account when deciding to choose ABS. In earlier studies, the aqueous two-phase system mainly focused on the polymer/polymer aqueous two-phase system, but the cost of this system is higher a relatively large viscosity, which limits its industrial application. ABS typically formed by polymer/inorganic salt have some advantages over conventional polymer/polymer ABS [4].

Polyethylene glycol (PEG) is commonly used as one of the phase-forming polymers in ABS because it presents high biodegradability, low toxicity, low volatility, low melting temperature, large water miscibility and low cost [5]. Polymer-Salt ABS provides advantages over systems formed by polymer–polymer combinations, such as a low interfacial tension, low viscosity, good biocompatibility, fast and high phase separation rates and low cost, which makes them practical for downstream processing [4,5]. Despite all these advantages, the narrow tailoring nature of PEG, which can be achieved only by changes in the molecular weight or by the polymer structural modification, limits its applicability through the complete extraction of several biomolecules to the polymer-rich phase [5]. To overcome this limitation, recent works have introduced ionic liquids (ILs) to tune the physicochemical properties of the PEG-rich phase, either by using them as adjuvants or as an agent to improve functionality of PEG, aiming at getting high extraction yields [6]. Rosa et al. [7] and Azevedo et al. [1] used functionalized PEG for purification of the human immunoglobulin. Jiang et al. [6] have used an ionic liquid to functionalize PEG for extraction of penicillin. Moreover, Wu et al. [8] have shown that PEG could be functionalized with ionic liquids, to enhance the extraction process and polymer recovery. The former studies [6–8] prove that the properties of polyethylene

* Corresponding author.
E-mail address: zhcs@ujs.edu.cn (C. Zhou).

https://doi.org/10.1016/j.molliq.2018.01.182
0167-7322/

glycol could be changed by modifying the chemical structure of polyethylene glycol.

Ionic liquids (IL) are salts composed of asymmetric organic cation and organic or inorganic anions and liquefy below a temperature of 373.15 K [9]. ILs have remarkable characteristics, such as a negligible vapor pressure, non-flammability under ambient conditions, which contribute to their "green solvents" characterization, good solubility, high ionic conductivity, high thermal stability, large liquid temperature range and good chemical stability [10–16]. Moreover, there are large variations in the cation and anion chemical structures which further allow the fine-tuning of their physicochemical properties [10]. One of the main advantages of ABS composed of ionic liquid relays on possibility of controlling its phase polarity by an appropriate choice of the ions that combined to form a given ionic fluid [5]. Due to these advantages, some researchers have studied application of the IL-based ABS in extraction of variety of compounds such as proteins [17–22], amino acids [23–25], enzymes [26,27], alkaloids [28–33], metals [34–36], aromatic and phenolic compounds [37–40], natural colorants [41] and pharmaceuticals [42–48]. In addition to their use as phase-forming components in IL-salt ABS, ILs can be used as adjuvants to tailor the systems' selectivity for target biomolecules [5]. Furthermore, several researchers have reported that enzymes and proteins remain stable and active in IL aqueous solutions [49,50]. The use of ILs as adjuvants in typical polymer-salt ABS for the extraction and purification of high-value biomolecules have been reported in the literature. Pereira et al. [5] were the first to propose the use of ILs as adjuvants in conventional PEG-salt ABS for extraction of biomolecules. de Souza et al. [51] have also investigated the partition behavior of two dyes with ILs as adjuvants on PEG-based ABS. Ferreira et al. [3] improved the extraction and purification of immunoglobulin G by the use of ionic liquids as adjuvants in aqueous biphasic systems. Souza et al. [52] used polyethylene glycol systems (1500, 4000, 6000 and 8000 $g \cdot mol^{-1}$) with potassium phosphate buffer at pH 7, in the extraction and purification of a lipase produced by submerged fermentation by *Bacillus* sp. Almeida et al. [2] used ionic liquids as additives to enhance extraction of the phenolic antioxidants in aqueous two-phase systems.

In this study, ILs were investigated as adjuvants (at 5 wt%) in polymer-salt ABS to allow the tailoring of the polarities of the phases. Accordingly, phase diagrams of ABS composed of PEG, sodium salts and imidazolium chloride salts, were fitted by using the empirical equations. The molecular weight of the polymer, the type of the salt, and the length of the ionic liquid cationic carbon chain and the role of temperature on the phase diagram were studied.

2. Experimental section

2.1. Materials

The present study was carried out using different polyethylene glycol polymers of molecular weights of 400, 600, 800, 1000, 2000 $g \cdot mol^{-1}$ (abbreviated as PEG400, PEG600, PEG800, PEG1000, and PEG2000, respectively). These polymers were supplied by Aladdin Industrial Corporation and were used as received. The salts used in formation of the phase diagrams were anhydrous sodium sulfate (Na_2SO_4), anhydrous sodium carbonate (Na_2CO_3), sodium dihydrogen phosphate dihydrate ($NaH_2PO_4 \cdot 2H_2O$), trisodium citrate dihydrate ($Na_3C_6H_5O_7 \cdot 2H_2O$), disodium hydrogen phosphate dodecahydrate ($Na_2HPO_4 \cdot 12H_2O$). The salts were purchased from Sinopharm Chemical Reagent Co., Ltd., with purities higher than 99 wt%. The ionic liquids used in this work were 1-ethyl-3-methylimidazolium chloride, [C_2mim]Cl; 1-butyl-3-methylimidazolium chloride, [C_4mim]Cl; 1-hexyl-3-methylimidazolium chloride, [C_6mim]Cl; 1-octyl-3-methylimidazolium chloride, [C_8mim]Cl; 1-decyl-3-methylimdazolium chloride, [C_{10}mim]Cl. The ionic liquids were supplied by Chenjie Chemical Co., Ltd. (Shanghai, China) with quoted purities of above 0.99 mass fraction and were used without further purification. Double distilled water was used for preparation of the solutions.

2.2. Experimental method

The phase diagrams were determined through the cloud point titration method at 298.15 (±1 K) and atmospheric pressure. To study the effect of temperature, the phase diagrams were determined at different temperatures (288.15 K, 298.15 K, 308.15 K, 318.15 K, and 328.15 K). The experimental methods were previously validated in the literature [2,5,53]. The temperature of the vessel was maintained constant by using a water thermostat (Model: KW-1000 DC, Jintan Zhongda Instrument Factory, Changzhou, China) with precision of ±1 K. Aqueous solutions of salt +5 wt% of IL, aqueous solution of PEG +5 wt% of the same IL, and aqueous solutions of 5 wt% of IL were prepared and used for determination of the binodal curves. For determination of the phase diagrams, IL was added to the solution and Kept at a constant concentration (at 5 wt%) during experiment. The aqueous inorganic salt solution (containing 5 wt% IL) was added drop-wise to the PEG aqueous solution (containing 5 wt% IL) until detection of a cloudy (biphasic) solution, followed by a drop-wise addition of water solution (containing 5 wt% IL) until formation of a clear solution (monophasic region). The weight of the added components was recorded. The drop-wise addition was carried out under constant shaking. The quaternary systems compositions were determined on an analytical balance within $\pm 10^{-4}$ g (Model: PRACTUM124-1CN, Sartorius Scientific Instruments Co., Beijing, China). The phase diagram experiments were repeated three times and average weight was obtained. The binodal data of these systems are correlated by the exponential Eq. (1) [54].

$$Y = A\exp\left(BX^{0.5} - CX^3\right) \quad (1)$$

where Y and X are the PEG and salt molality units, respectively, and A, B, and C are the fitting parameters.

3. Results and discussion

The major drawback of the conventional polymer-salt based ABS is their limited polarity of both aqueous phases. This work studies the phase behavior of different quaternary ABS formed by different combinations of PEG + salts + water + imidazolium-based ILs (applied as adjuvants). In this work several parameters were investigated, namely the type of salt, the PEG molecular weight, the temperature and the IL alkyl chain length. All phase diagrams are presented in molality units to avoid discrepancies in the phase diagrams behavior, which could be arise from the differences in the molecular weights of the PEG, IL and the salt. The data were correlated using Eq. (1) with the regression parameters reported in Tables 1–3.

3.1. Effect of salts

The effect of using [C_4mim]Cl as an additive upon the formation of ABS composed of PEG800 and salts (Na_2HPO_4, $Na_3C_6H_5O_7$, Na_2CO_3, Na_2SO_4, NaH_2PO_4) was analyzed. The results depicted in Fig. 1 show that the addition of 5 wt% of [C_4mim]Cl produces a small effect on the formation of ABS. Accordingly, the phase-forming ability mainly depends on the type of sodium salt used (Na_2HPO_4, $Na_3C_6H_5O_7$, Na_2CO_3, Na_2SO_4, NaH_2PO_4). In Fig. 1, the ternary phase system of PEG800 + salt + water indicates that the ability of the various sodium salts to form ABS follows the trend: $Na_3C_6H_5O_7 > Na_2HPO_4 > Na_2CO_3 > Na_2SO_4 > NaH_2PO_4$, describing the Hofmeister series [55] and salting-out ability of these salts. Many authors related this rank of salting-out strength of the inorganic salts to their negative Gibbs free energy of hydration [53–55]. The anion which induces the strongest salting-out effect is $C_6H_5O_7^{3-}$ as previously observed [56,57]. Moreover, the salt's ion charge plays a significant role being responsible for the formation of hydration complexes [24]. Due to its higher charge, $C_6H_5O_7^{3-}$ more strongly and readily hydrogen bonded with water than the less charged other anions.