



Enrichment and isolation of phenol from its aqueous solution using foam fractionation



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ABSTRACT

In this work, the feasibility of foam fractionation for the enrichment and isolation of phenol from its aqueous solution was studied by using cetyltrimethyl ammonium bromide (CTAB) as the collector. A two-stage foam fractionation technology was developed for simultaneously obtaining a high enrichment ratio and a high recovery percentage. Under the suitable operating conditions, the enrichment ratio and recovery percentage of phenol reached as high as 84.46 and 93.43%, respectively. Subsequently, foam fractionation was also used to isolate phenol from CTAB in the first stage foamate, in which the interaction between phenol and CTAB could be weakened by adjusting pH. The concentration of CTAB significantly decreased from 11.230 g/L in the feeding solution to 0.620 g/L in the residual solution by using the foam fractionation, while the concentration of phenol slightly decreased from 2.533 g/L to 2.450 g/L. The results indicated that it was practicable to successively enrich and isolate phenol from its aqueous solution by using foam fractionation.

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Phenol is an important industrial chemical but also a hazardous environmental pollution, which has posed a serious threat to natural water body and soil environment [1]. Phenol is easy to be accumulated in living organisms, resulting in the damage of respiratory, immune and genital systems. Some physicochemical methods, involving membrane separation, extraction and distillation, have been used to remove phenol from its aqueous solutions [2–4]. However, these methods have been shown to be inefficient or costly when phenol was present at a low concentration.

Foam fractionation is an adsorption separation technology and it has a history of almost one hundred years [5]. Based on the principle of interfacial adsorption, foam fractionation can effectively enrich a surfactant from its diluted aqueous solution by using bubbles as the media [6]. Moreover, the material without surface activity can also be attached on the gas–liquid interface by the complexation or chelation with a surfactant, which plays a role of collector [7]. In comparison with other separation techniques, foam fractionation exhibits distinct advantages for the treatment of industrial wastewaters, including simple equipment, low energy consumption, easy scale-up and environmental compatibility [8,9]. Currently, the high efficiency of foam fractionation for the

separation of various organic compounds from their wastewaters has received increasing attention from environmentalists and researchers [10–12].

After foam fractionation, the desired material without surface activity was enriched in the foamate as the form of complex with the surfactant, where the foamate was the solution of the collected foam in a container by defoaming [12]. The isolation of the desired material from the surfactant was not only advantageous to the further purification of the desired material, but also conducive to the reuse of the surfactant.

In this work, the recovery of phenol from a simulated system (the concentration of phenol 30 mg/L) was investigated by using a column with a vertical ellipsoid-shaped foam channel (VEC) as the experimental column for strengthening foam drainage (as shown in Fig. 1). Cetyltrimethyl ammonium bromide (CTAB) was used as the collector for achieving the adsorption of phenol on the gas–liquid interface. A two-stage foam fractionation technology was developed based on the studies on the effects of column shape, CTAB concentration, pH, volumetric airflow rate and temperature on the separation efficiency of phenol. Then, the feasibility of foam fractionation for the isolation of phenol from CTAB was investigated by adjusting the pH of the foamate.

As shown in Fig. 2, when the concentration of CTAB was small, CTAB per unit mass could be complexed with more molecules of phenol and then the enrichment ratio of phenol was high but its

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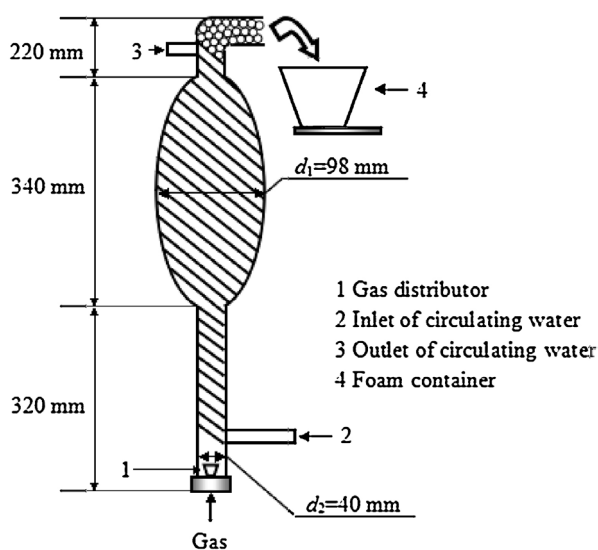
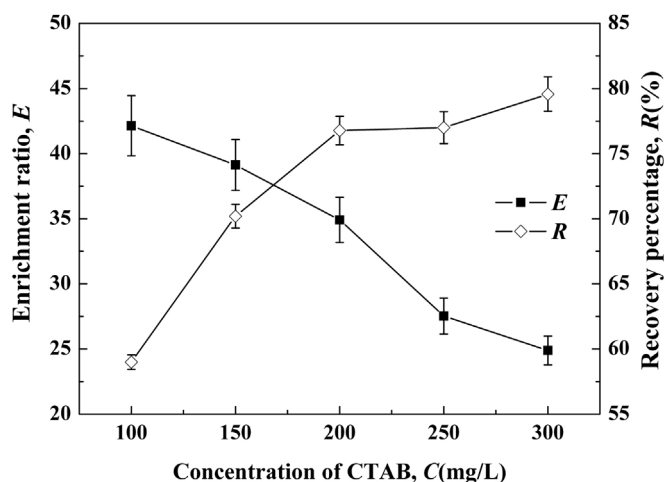


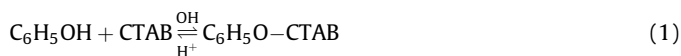
Fig. 1. Schematic diagram of the experimental setup.

Fig. 2. Effects of CTAB concentration on *E* and *R*.

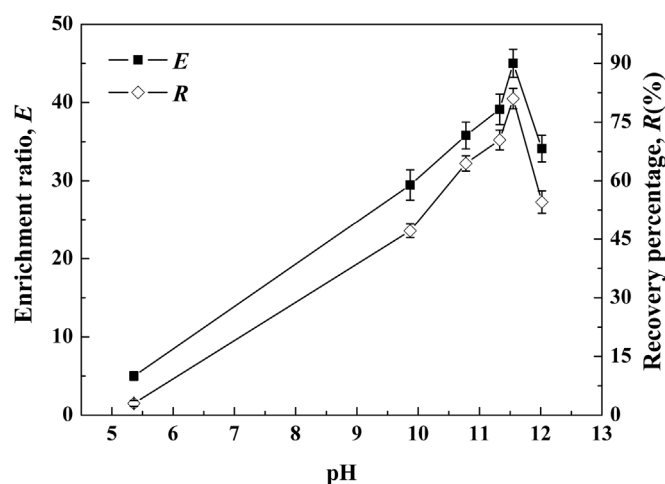
recovery percentage was low. As the concentration of CTAB increased, CTAB per unit mass could be complexed with less molecules of phenol and however, its total mass in the loading liquid volume increased resulting in increasing the total mass of the complex between CTAB and phenol. So the enrichment ratio of phenol decreased and its recovery percentage increased.

The ionization degree of a solute depends on its pH in its solution [13]. As shown in Fig. 3, pH could significantly affect the enrichment ratio and recovery percentage of phenol because the phenol-CTAB complex was formed based on the electrostatic interaction.

Phenol is a weak electrolyte and it can be partially ionized in its aqueous solution. The ionization equation of phenol is described as follows [14,15].



CTAB is a cationic surfactant and it has a typical amphipathic structure. CTAB can be dissociated out bromide ion in water, thereby having positive charge. When the introduced gas went into an aqueous solution containing CTAB, CTAB ion would rapidly

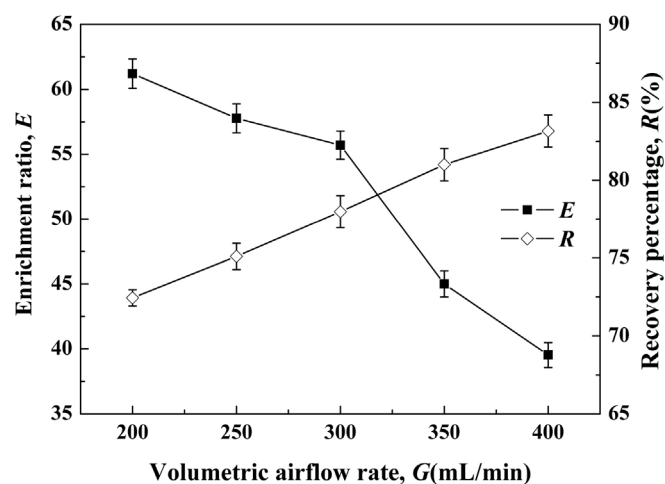
Fig. 3. Effects of pH on *E* and *R*.

adsorb on the gas–liquid interface. The stabilized bubbles left the bulk solution and a foam layer emerged. Under suitable pH conditions, phenol would be ionized and thus negatively charged. Then, phenol ion could be attached on the gas–liquid interface by CTAB based on the electrostatic interaction and then, it was enriched in the form of complex with CTAB.

Volumetric airflow rate is also one of the most important operating parameters which can affect the performance of foam fractionation [16]. When volumetric airflow rate was low, the slowly rising bubbles contributed to a higher residence time of the rising bubbles in the foam phase, resulting in strengthening foam drainage [17]. So from Fig. 4, a high enrichment ratio of phenol could be obtained at a low volumetric airflow rate. With increasing volumetric airflow rate, the residence time of the rising bubbles in the foam phase shortened, resulting in a high liquid holdup. Then, the recovery percentage of phenol was high but the enrichment ratio was low.

Temperature can significantly affect the performance of foam fractionation from the aspects of interfacial adsorption and foam drainage [18,19]. The results are shown in Fig. 5.

It is well known that the solution viscosity decreases with the increase of temperature. When the temperature is low, a high viscosity causes an enormous attraction force between the molecules in the liquid. The interstitial liquid between the bubbles

Fig. 4. Effects of volumetric airflow rate on *E* and *R*.

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