CONTINUOUS FOAM SEPARATION OF METALS ENHANCED BY DOWN-FLOWING SURFACTANT SOLUTION FROM COLUMN TOP

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Abstract: A novel operational mode of foam separation was suggested in this study. In a conventional operation, the separation of a target solute has its own limit because non-target ones exist in the interstitial water between foam and get mixed in the recovered foamate solution. As a countermeasure for this inherent drawback in foam separation, an aqueous surfactant solution was injected into the rising foam bed to enhance a downflow of the interstitial water containing unfavourable solutes. The flow characteristics of the system with and without the injection of a washing solution were investigated in terms of the liquid holdup, ϕ, and the drainage velocity, U_{LD}, under various operating conditions. Their correlation was obtained as U_{LD} (cm s $^{-1}$) $= 1.85\phi^2 + 0.0005$. The application to metal separation was also performed using a nonionic surfactant, polyoxyethylene nonylphenyl ether (PONPE 20), with an affinity to Au(III). The non-specific metal, Cu(II), was effectively washed out from the foam bed, and satisfactory separation of Au(III) was attained.

Keywords: foam separation; gold recovery; foam bed washing; liquid holdup; drainage velocity.

INTRODUCTION

Foam separation has been widely used for recovering valuable solutes and rejecting impurities such as mineral ore (Thomas *et al.*, 1992; Maurice *et al.*, 1995; Rubio *et al.*, 2002), surfactants (Tharapiwattananon *et al.*, 1996), proteins (Bhattacharya *et al.*, 1991; Maruyama *et al.*, 2000) and metal ions (Galvin *et al.*, 1992; Thomas *et al.*, 1992; Maurice *et al.*, 1995; Doyle, 2003; Kinoshita *et al.*, 2003, 2004). The most prominent advantage of this technique is efficient enrichment of solutes from dilute solutions, along with its low operational cost, e.g., power is only required for running liquid and air pumps.

In foam separation, a surfactant plays a role to produce and stabilize foam, and some additives are often added to enhance the collection of target solutes. A series of polyoxyethylene nonyl phenyl ethers (PONPEs), which are typical nonionic surfactants for industries, shows a strong interaction with tetrachloro auric acid ($HAuCl_4$) (Akita and Takeuchi, 1996; Akita *et al.*, 1996, 1997).

The auric complex in hydrochloric acid solutions would be attracted by electron-donating oxygen atoms in ethylene oxide units in PONPEs. On applying to foam separation, therefore, the surfactants show bi-functional properties of foam stabilizer and solute collector, and the saving of a reagent inventory is expected. We have carried out the foam separation of gold using PONPEs from hydrochloric acid solutions in both batch and continuous flow modes (Kinoshita *et al.*, 2003, 2004), and attained good but not-fully-satisfying separation of gold from multi-metals solutions.

In the process, a foam bed consists of both foam and interstitial water between the adjacent foam, as shown in Figure 1. A solute with affinity to the surfactant (i.e., target solute) is preferentially adsorbed on the foam surface, whereas a solute without affinity (i.e., non-target solute) exists only in the interstitial water. As the foam bed rises through a column, the interstitial water containing non-target solutes is drained out by gravity. In consequence, target one is selectively enriched in the foam bed at an upper portion of a column. However, the drain-out of the interstitial water never completes since the gravity effect attenuates with decreasing an amount of the interstitial water, resulting in the contamination in final products by accompanying non-target solutes. So far little work has been conducted on the improvement of foam separation by removing unfavourable solutes existing in the interstitial water. With an eye on this goal, we tried to enhance the selectivity in the foam separation of Au(III) by injecting a surfactant solution into the foam bed to

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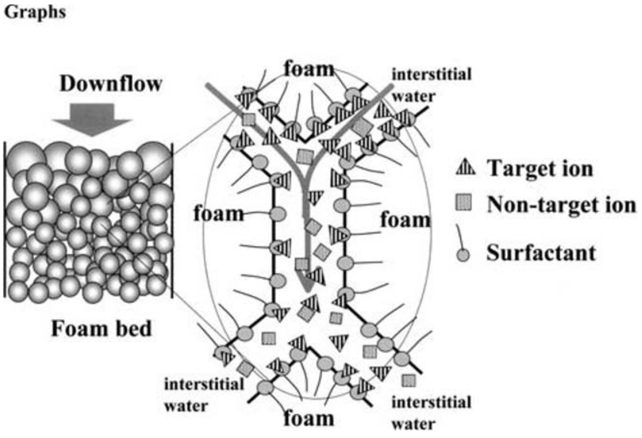

Figure 1. Schematic drawing of enhanced downflow in foam separation.

wash out a non-target solute in this study. Under various operating conditions, the liquid holdup and the drainage velocity were determined as crucial parameters for the process efficiency. This novel method was also applied to a binary metals solution of gold and copper in a continuous flow mode, and its separation performance was elucidated.

EXPERIMENTAL

Reagents

A nonionic surfactant, polyoxyethylene nonyl phenyl ether, $HO(CH_2CH_2O)_{20}C_6H_4C_9C_{19}$ (PONPE20) was purchased from Tokyo Kasei Chemical Co., Ltd, and used without further purification. In all runs, the hydrochloric acid concentration was 2.0 M, and the PONPE concentration of surfactant solutions was fixed at 0.10 wt%. Aqueous metal solutions were prepared by dissolving prescribed amounts of metal chlorides in hydrochloric acid solutions. All the chemicals used were of reagent grade.

Experimental Setups and Procedure

Figure 2 shows the schematic diagrams of two experimental setups. With the setup A the flow characteristics were evaluated, while with the setup B the separation of two metals, Au(III) and Cu(II), was tried. The columns were made of a glass tube whose inner diameter was 3.3 cm and height being 80 cm. A gas distributor, a sintered glass filter with 1.5 cm diameter, was mounted at a bottom part of the column. The height of bulk solution was kept constant at 5.0 cm above the gas distributor by balancing the introduction of the base solution (7.3 ml min^{-1}) and the discharge of the effluent solution. The surfactant was contained in the base solution. Through the gas distributor air was introduced; the flow rate was 60 ml min^{-1} except for the experiments on its effect. After the column was replenished with the foam bed, the washing solution containing the surfactant was injected to the column centre at 33 cm below the column top by a peristaltic pump. For the separation of metals with the setup B, the metal solution was also injected. The foam coming out from the column top was defoamed in a foam breaker and the foamate solution was collected. The steady state was attained after several hours from the start. All experiments were carried out at 295 K in a temperature-controlled room. The average diameter of each foam was determined to be approximate 0.07 cm by photographing and scaling the foam.

In the setup A, a long glass tube with 0.3 cm of the inner diameter was inserted vertically inside the column from the top, and was used to sample a mixture of gas and liquid in the foam bed. The sampling was carried out by sucking the mixture at a predetermined flow rate using a peristaltic pump through a hemispherical shaped ending of the tube. The diameter of the hemisphere was 0.6 cm. The ending was situated at 8.5 cm above the liquid interface, except for

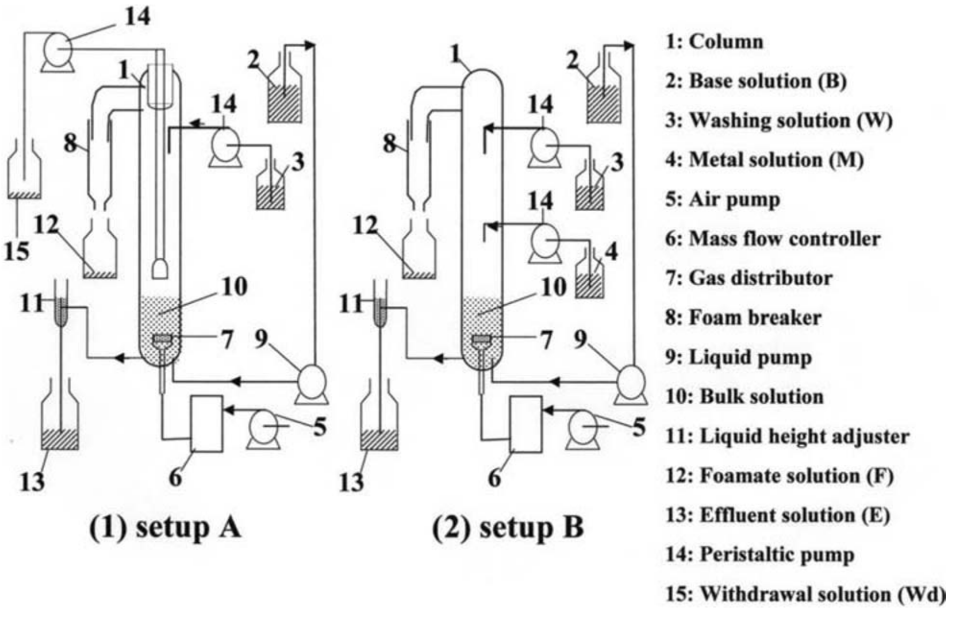

Figure 2. Schematic diagram of foam separation apparatus.