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Article—Supplementary Materials

Ion flotation of La^{3+}, Cd^{2+}, and Cs^{+} using monorhamnolipid collector

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The flotation columns utilized in this study were designed, constructed, and tested specifically for this work. To reduce the number of experimental variables, preliminary experiments were conducted to establish the aeration rate and frother (ethanol) concentration to be used in the primary experiments. The data and rational for selecting the values for these two parameters is outlined below.

Aeration Rate

Aeration rates ranging from 20 to 500 mL min^{-1} have been reported for ion flotation apparatus [1–8].Generally, increasing the aeration rate increases the removal or recovery of metals and decreases aeration time as a result of increased foam production. Increasing the aeration rate can also have detrimental effects: increased water entrainment (low concentrating efficiency), creation of excess foam (foam management challenges), and redispersion of sublate into the bulk solution due to solution turbulence (incomplete removals). The efficacy of the aeration rate is also dependent on other factors in the flotation system such as the porosity of the system diffuser, collector/colligend characteristics, solution volume, column head space (foam drain time), etc. [9–11]. Thus, determination of an optimal aeration rate must balance these outcomes in a given system.

The columns utilized in this study are based the design of Thalody and Warr [8]. This study recommends an aeration rate of 20-200 mL min^{-1} depending on the solution volume and nature of the colligend and collector. Previous work by Bodagh et al. [4] in a Cd^{2+} and rhamnolipid flotation system showed a moderate increase in cadmium removal from 40% at 25 mL min^{-1} to 50% at 90 mL min^{-1} followed by a decrease to about 25% removal at 150 mL min^{-1}. Based on these results, a 10-15 minute preliminary experiment was conducted to test column performance at three aeration rates: 50, 75, and 100 mL min^{-1}.

Qualitative results showed significant foam formation at all three aeration rates. Both the 75 and 100 mL min^{-1} aeration rates were observed to transfer a large amount of water (>20%) out of the column. Both rates also resulted in the formation of a homogenous froth inside the column, wherein, there was no observable delineation between the foam and the bulk solution. At the 50 mL min^{-1} aeration rate, the transference of water out of the column was greatly reduced relative to the other two aeration rates. An observable delineation between the foam and bulk solution was visible for the length of the experiment, though the level of this delineation dropped overtime. The surface drop eventually passed the height of the sampling port which was 6 cm above the glass frit. As a result, the port height was lowered to 2 cm above the frit. The slower aeration rate also had the benefit of increasing the residence time of the foam in the column, thus allowing increased drainage of entrained water from the foam. Aeration rates below 50 mL min^{1-} were not tested because this rate was the lower limit of the available rotameter, and 50 mL min^{-1} was selected as a constant for the primary experiments.

Frother Concentration

Frothers are amphiphiles added to flotation processes to improve conditions for bubble and froth formation. Frothers improve flotation efficiency by facilitating the formation of smaller bubble sizes, preventing coalescence of bubbles, decreasing bubble rise rate thereby increasing the time for sublate attachment to the bubble interface, and increasing the strength of bubbles and stability of foams [12]. Linear alcohol frothers like ethanol improve foam formation by lowering the air/water interfacial tension enabling smaller bubbles to form and increasing surface area for sublate attachment [9,13]. They reduce coalescence and stabilize foams by stabilizing the hydrated layer around the bubble through interactions of their hydrophilic moieties with the aqueous phase. By stabilizing the hydrated layer, it is more difficult to displace the water film surrounding the bubble as bubbles collide and coalescence is reduced [12,14].

To determine the concentration of ethanol utilized in the primary experiments, a preliminary experiment was conducted to test the removal efficiency of La^{3+} in the presence of 0.0, 0.5, and 1.0% (v/v) ethanol frother. Each concentration was tested in a single column ($n = 1$). Other column conditions were pH 7.0 ± 0.1, 100 μM monorhamnolipid, 1.4 μM La^{3+}, 50 mL min^{-1} aeration rate, and 500 mL of solution. Solution samples were collected from the column sampling port at 0, 10, 25, and 50 min.

The results of La^{3+} flotation under three ethanol regimes are shown in Figure S1. Flotation of La^{3+} in the presence of 1.0% showed the fastest removal and highest removal percentage that reached 95% by 50 min. Removal was slower for the 0.5% ethanol treatment, but the removal rate was increased relative to the ethanol-free treatment. The 0.5% ethanol treatment achieved a maximum removal of 90% at 25 min then decreased to 84% at 50 min. The 0.0% ethanol treatment achieved maximum La^{3+} removal of 84% by 50 min.

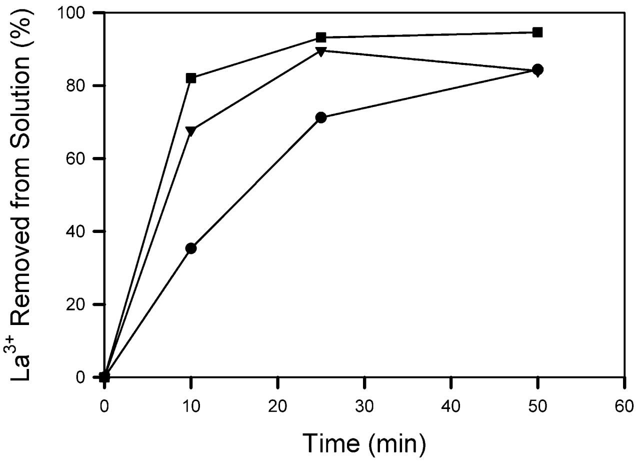

Figure S1. Percent La^{3+} removed from solution during flotation with 0.0 (●), 0.5 (▼), and 1.0% (■) (v/v) ethanol frother. Symbols represent a single measurement from an individual column ($n = 1$).

Though all three ethanol treatments achieved high levels of La^{3+} removal, the presence of ethanol affected water entrainment and removal of solution from the flotation column. The 0.0, 0.5, and 1.0% ethanol treatments removed 5, 6, and 100 mL of column solution as foam, respectively. The large volume of water removed from the 1% ethanol treatment represent 20% of the column solution. This large transfer of water is undesirable because it both reduces the volume of water which has been treated and dilutes the concentration of La^{3+} captured in the foamate. As a result, the ethanol concentration was reduced from 1.0% for the primary experiments. An ethanol concentration of 0.8% was utilized in Section 3.1 because the higher metal concentrations (10-50 μM versus 1.4 μM) were anticipated to inhibit foam production [13]; however, water transfer was still high, so an ethanol concentration of 0.5% was selected for all subsequent experiments.

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