SELECTIVE TWO-PHASE MINERAL SEPARATION ON A MICROFLUIDIC CHIP

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ABSTRACT

We have explored microfluidic solvent extraction as a tool for high-throughput mineral separation. The microfluidic extraction efficiency for chromium, compared with bulk extraction, is shown for a range of concentrations and extraction (or contact) times. We also demonstrate selectivity for chromium from a model chromite leach solution and discuss throughput considerations.

KEYWORDS: Solvent Extraction, Mineral, Industrial, Separation

INTRODUCTION

The separation of minerals by selective dissolution or by the treatment of particulates, in the form of slurries, emulsions or foams, is of acute interest. Mineral ores are complex materials and require comprehensive separation procedures with strict control of properties, e.g. pH, ionic strength, and surface chemistry, at economically viable throughput.[1] Microfluidics can be applied to high throughput processes[2]; however, the potential for microfluidics to enhance mineral processing unit operations has not been explored. Solvent extraction is a major processing step in mineral processing[3] and the treatment of effluent and contaminated sites[4]. In this study, we demonstrate microfluidic solvent extraction as an alternative to bulk extraction for model leach solutions.

EXPERIMENTAL

Microfluidic chips (IMT, Japan) were fabricated in Pyrex glass using UV-photolithography, wet-etching, and thermal compression bonding. The microchannel design and dimensions are shown in Fig. 1. Two-phase flow was achieved using parallel microchannels, partially separated by a guide structure[5]. Partitioning takes place at the liquid-liquid interface until phase separation occurs at the second y-junction, Fig. 1(b). The organic phase was analyzed by UV-vis spectrophotometry.

Chromium(III) acetylacetonate, Cr(acac)₃, was synthesized according to Fernelius et al.[6] and the other complexes, Mⁿ⁺(acac)ₙ, were obtained from Sigma-Aldrich. The aqueous (water) and organic (chloroform) flow rate (or volumetric) ratio was 1:2 for all experiments. Aqueous and organic phase flow rates were 0.2 and 0.4 mL/h, respectively, unless otherwise specified.
RESULTS AND DISCUSSION

Microfluidic solvent extraction is achieved by partitioning the Cr complex at the liquid-liquid interface of co-flowing streams. The contact time is defined by the flow velocity and the microchannel length. Phase separation occurs at the second y-junction where the two phases diverge, Fig. 1(b). This process is fundamentally different to that for bulk extractions, where the two phases are mutually dispersed as droplets [7] and phase separation is spontaneous (via droplet coalescence) and potentially slow.

Fig. 2 (Left) shows our results from bulk and microchip extractions of Cr(acac)$_3$ at industry-relevant concentrations. All data are normalized to the bulk extraction results for $500 \mu$M. For the concentrations studied, bulk and microfluidic extractions gave equivalent results, within the uncertainty, despite the significant difference in contact time, $t_{bulk} = 5$ min, $t_{micro} = 8$ s.

The complexity of industrial solutions demands highly selective separation of valuable species. To study the selectivity for chromium, we prepared a model leach solution based on chromite ore. The aqueous (1% ethanol) matrix contained $500 \mu$M Fe(acac)$_3$, and $500 \mu$M Mg(acac)$_2$, and excess acetylacetone (5 mM), with various concentrations of Cr(acac)$_3$. Bulk and microfluidic extractions were carried out as described, with the exception that the organic phase was stripped with 0.1M NaOH.

Figure 1. Left: Schematic of the microchip. Middle: Images of the (a) inlet and (b) outlet y-junctions; black dots represent the extracted species. Right: The microchannel cross-section, showing the dimensions of the microchannel.
to selectively remove Fe(acac)₃, Mg(acac)₂, and acetylacetone. The results for model leach solutions are in good agreement with our results for the Cr(acac)₃ only extractions, Fig. 2 (Left). This demonstrates a high selectivity for Cr(acac)₃ from the leach solution.

The transfer efficiency of Cr(acac)₃ as a function of contact time was determined by varying the flow rate in the microfluidic channel, Fig. 2 (Right). The transfer efficiency reduced sharply towards zero as the contact time was reduced, while for extended contact times (> 4 s) the efficiency approached that for the bulk extractions, i.e. 100%. Based on these results, 90% of the complex can be recovered in a three stage microfluidic extraction at 7.5 mL/h ($t_{micro}$ = 0.22 s) using a single microchannel. Now consider a high-throughput processing unit consisting of 30 000 stacked microchips (each chip containing 20 channels). Throughputs of 4500 L/h could be achieved, while maintaining 90% transfer efficiency. To realize this throughput in practice, engineering challenges relating to fluid connections and pumping would need to be overcome; however, these challenges exist for the implementation of all new technologies.

CONCLUSIONS

Microfluidic solvent extraction is well-suited to mineral separation. The microfluidic extraction efficiency for chromium from a model leach solution is equivalent to that achieved in bulk extractions; however, the extraction times are significantly reduced. The rate at which microfluidic extraction occurs suggests that microchip technology could handle industrial-scale throughput, provided the engineering challenges are overcome.

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