Short communication

Removal of metal ions using dead-end filtration

IOA Hodgson[1]* and RJ Wakeman[2]

[1] *Environmental Chemistry Division, Water Research Institute, CSIR, PO Box M32, Accra, Ghana*

[2] *Advanced Separation Technologies Group, Department of Chemical Engineering, Loughborough University, Loughborough, Leicestershire, LE 11 3TU, UK*

Abstract

Experimental results on a study on removal of metal ions using lecithin-enhanced dead-end filtration with 0.1 micron nylon membrane has been reported in this paper. The effects of metal-ion concentration on the pH, conductivity and zeta potential of lecithin dispersions were determined. The zeta potential of lecithin was determined to be -79 mV whilst the critical micelle concentration was 9 g·ℓ$^{-1}$. Significantly, the study showed that lecithin has the ability to adsorb metal ions. This study gives an alternate technology for metal ion removal from aqueous solutions.

Keywords: dead-end filtration, nylon, lecithin, metal ions

Introduction

The negative effects of heavy metals on the biota and environment have necessitated the need to look for suitable technologies for their removal from industrial effluent before discharging them into the water-bodies, soils and aquifers. The industries that discharge effluents with heavy metals include mining, battery, metal-finishing, semi-conductor manufacturing and mineral processing.

Quite a number of studies have been carried out on metal-ion removal in aqueous solutions and reported in the literature (Ahmadi et al., 1994; Broom et al., 1994; Huang and Batchelor, 1994; Juang and Shiau, 2000; Scamehorn et al., 1989; Wakeman and Kotzian 2000).

Surfactants due to their high selectivity properties have been used in enhancing membrane filtration for the removal of metal ions in aqueous solutions. Natural surfactants are preferred to synthetic surfactants because the synthetic surfactants have the disadvantage of introducing secondary pollutants into the filtrate. In addition, the natural surfactants are non-toxic, biodegradable and abundant.

Lecithin, a natural surfactant, which was used in this study to enhance the dead-end filtration, is primarily made from plant seed, although it can be produced from a variety of animal or vegetable sources. It is a complex mixture of phosphatides or phospholipids and is amphoteric. Commercial lecithins have been widely used in the medical, cosmetic and food industry. Lecithin is naturally occurring, cheap, non-toxic, biodegradable and forms large size micelles (Attwood and Florence, 1983)

In the present study the removal of Pb ion, mixtures of Pb and Cu, and mixtures of Pb, Cu and Cd ions using lecithin-enhanced dead-end filtration with 0.1 µm nylon membranes was investigated.

* To whom all correspondence should be addressed.
☎ +233 21 779514/5 or +233 24 3172374; fax: +233 21 777170;
e-mail: cgioah@yahoo.co.uk
Received 7 July 2004; accepted in revised form 24 January 2005.

Experimental procedures and materials

Feed characteristics

Surface tension

Surface tension measurements were carried out to determine the CMC of the lecithin dispersions with and without metal ions. A digital platinum ring tensiometer (White Electrical Instrument Co. Ltd.) was used for the surface tension measurements. The effects of Pb, mixtures of Pb and Cu, and mixtures of Pb, Cu and Cd ions on surface tension of lecithin dispersions were measured.

Metal ions

A Varian SpectrAA atomic absorption spectrophotometer (AAS) was used to determine the concentration of the metal ions present in both the feed dispersions and filtrates.

Zeta potential and particle size

The magnitude of the zeta potential gives an indication of the stability of the colloidal system. A Malvern ZetaSizer was used for the zeta potential measurements. For each sample, three readings were taken and averaged to obtain the value of the zeta potential of the sample. The Malvern Mastersizer was used to determine the particle size of the feed dispersions.

pH

A pH meter (WPA, UK) was used for pH measurements for all the feed dispersions and filtrate.

Conductivity

A conductivity meter (Philips digital, UK) was used to determine the conductivity of all the different feed dispersions and filtrate.

Experimental set-up

The experimental set-up for the dead-end filtration is shown in Fig. 1. It consists of a compressor, pressure gauge, filtration kit with a nylon membrane having a pore size of 0.1 µm and a measuring cylinder. Compressed air at a pressure of 2.068x10^5 N·m^{-2} (30 psi), measured using a pressure gauge, acted as the driving

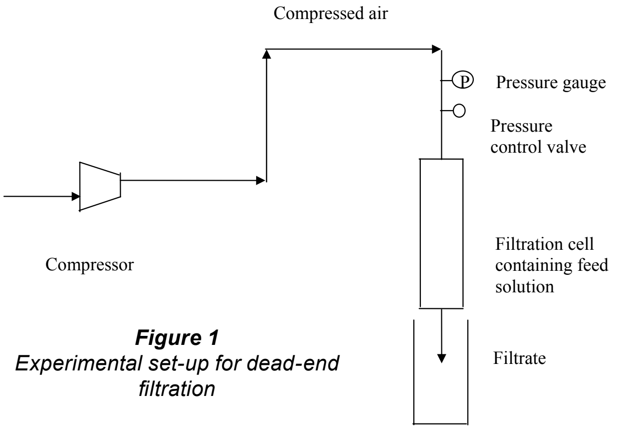

Figure 1
Experimental set-up for dead-end filtration

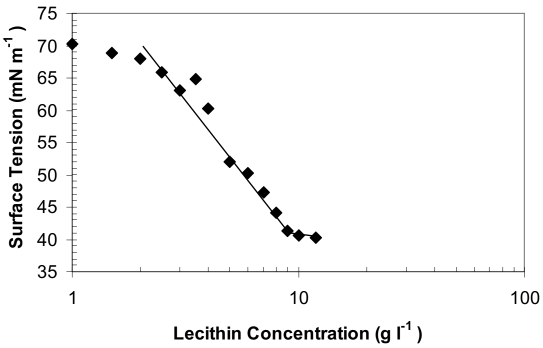

Figure 2
Determination of CMC of lecithin

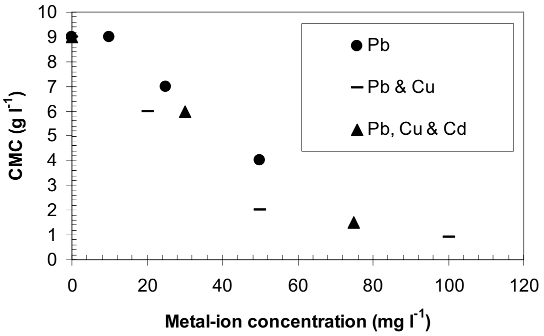

Figure 3
Effect of metal ions on CMC of lecithin

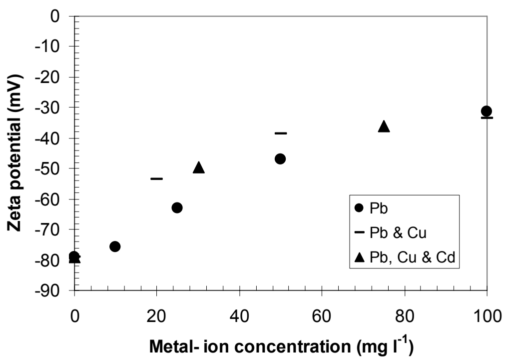

Figure 4
Effect of metal-ion concentration on zeta potential of lecithin

force for the dead-end filtration process. 100 mℓ each of feed dispersions, which contained various known concentrations of lecithin and metal-ion, were filtered. The metal-ion concentrations in the feed and filtrate, collected with the measuring cylinder over a period of about 3 to 4 h, were analysed using AAS.

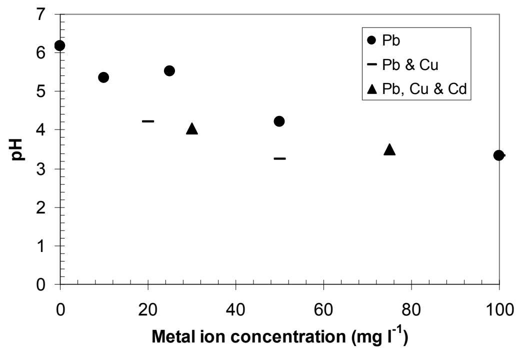

Figure 5
Effect of metal-ion concentration on the pH of lecithin

Materials

Lecithin in the form of yellow granules was purchased from Fisher Scientific, UK.

The $PbCl_2$ (Fisher Scientific, UK), $CuCl_2$ (Fisher Scientific, UK) and $CdCl_2$ (Fisher Scientific, UK) were purchased in powder form. Stock solutions of 1 000 mg·ℓ$^{-1}$ of Pb, 1 000 mg·ℓ$^{-1}$ each of Pb and Cu, and 1 000 mg·ℓ$^{-1}$ each of Pb, Cu and Cd ions were prepared and required concentrations were made for the various experiments.

Results and discussion

Feed characteristics

The effect of different concentrations of a single species of Pb ions, mixtures of Pb and Cu, and mixtures of Pb, Cu and Cd ions on various concentrations of lecithin were determined.

Critical micelle concentration (CMC)

Surface tension measurements were carried out to determine the critical micelle concentration of lecithin. The variation of surface tension with changes in the concentration of lecithin is shown in Fig. 2. The concentration at which there is a break in the plot of surface tension vs. concentration of lecithin is the critical micelle concentration which is the concentration at which its molecules start to aggregate. A negatively charged surfactant is required for the binding of the positively charged metal ions in aqueous solution.

The CMC of lecithin dispersion without any metal ions was found to be 9 g·ℓ$^{-1}$. This value is in good agreement with the value (10 g·ℓ$^{-1}$) obtained by Wakeman and Kotzian (2000). Figure 3 shows the effect of metal-ion concentrations on CMC of lecithin. An increase in metal-ion concentration caused a decrease in the CMC of lecithin. This may be due to the binding of the metal ions by lecithin, which resulted in the reduction of the repulsive head group forces between the surfactant molecules thus causing the lecithin molecules to aggregate at a lower concentration.

Zeta potential

The zeta potential of lecithin in aqueous solution was found to be about –79 mV. Lecithin is therefore negatively charged and has an attraction for positive ions, i.e. metal ions. The effect of metal-ion concentration on the zeta potential of lecithin is shown in Fig. 4. An increase in metal-ion concentration caused an increase in the zeta potential of lecithin, which suggests the binding of the metal ions to the surfactant molecules, which confirms the CMC results, discussed above.

pH

The effect of metal ions on the pH of lecithin dispersions is shown in Fig. 5. In the determination of the effect of metal-ion concentrations on lecithin dispersion, 2 g·ℓ$^{-1}$ of lecithin dispersion was used with various metal-ion concentrations ranging from 10 mg·ℓ$^{-1}$ to 100 mg·ℓ$^{-1}$. The pH of the lecithin dispersion without any metal ions is 6.2. Generally metal ions increase the acidity of solutions by reacting with the hydroxide ions present leaving the hydrogen ions thus causing the lowering of the pH of solutions. The increase in metal-ion concentration caused a decrease in the pH of the feed dispersion. For Pb ion concentrations, ranging from 10 mg·ℓ$^{-1}$ to 100 mg·ℓ$^{-1}$ the lecithin pH was between 6.2 and 3.3. It was observed that for the mixture of metal ions, Pb and Cu, and Pb, Cu and Cd, the pH of lecithin dispersion decreased with increasing metal-ion concentration from 0 to 80 mg·ℓ$^{-1}$ of each metal.

Conductivity

Figures 6, 7 and 8 show the effect of lecithin concentration on conductivity for feed dispersions with single species and mixtures of metal ions. The increase in lecithin concentration caused an increase in the conductivity. Also, an increase in metal-ion concentration in the feed dispersion caused a greater increase in conductivity which might be due to the mobility of metal ions being greater than the mobility of organic molecules.

Dead-end filtration

Without lecithin the Pb rejection was 22% which indicates some interaction between the nylon membrane and the Pb ions. Figure 9 shows the effect of Pb ion concentration on its rejection for different concentrations of lecithin. Pb rejections as high as 97% are achievable when lecithin is used to enhance the rejection. To a large extent, the study showed that the increase in Pb ion concentration did not seem to influence the Pb ion rejection for 2 g·ℓ$^{-1}$ lecithin dispersion. For lecithin concentration^{-1} of 10 g·ℓ$^{-1}$ and 20 g·ℓ$^{-1}$ the increase in Pb ion concentration caused an increase in rejection. The increase in rejection with increase in Pb ion concentrations at lecithin concentrations of 10 g·ℓ$^{-1}$and 20 g·ℓ$^{-1}$may be due to the change in the shape of the lecithin structure enabling it to bind more easily to the Pb ion. It is known that a change in the pH of lecithin dispersions can cause a change in the shape of lecithin (Wakeman and Kotzian, 2000). An increase in metal-ion concentration causes a decrease in pH of lecithin dispersion as discussed earlier.

Figure 10 shows the effect of Pb and Cu ion mixtures on their rejection in 2 g·ℓ$^{-1}$ lecithin dispersions. The increase in metal-ion concentration caused a decrease in rejection that indicates a decrease in the available binding sites with the increase in metal ions. However, for a lecithin concentration of 9 g·ℓ$^{-1}$ the increase in metal-ion concentration caused an increase in rejection as shown in Fig. 11. This observed behaviour suggests that an increase in the lecithin concentration increases the available binding sites on lecithin making it possible for higher metal-ion rejections to be achieved. Lecithin seems to have a preference for Pb ion over Cu ion.

For mixtures of Pb, Cu and Cd ions in 2 g·ℓ$^{-1}$ lecithin dispersion the increase in Pb, Cu and Cd ions caused a drop in rejection as shown in Fig. 12. The heavy fouling of the membrane made it

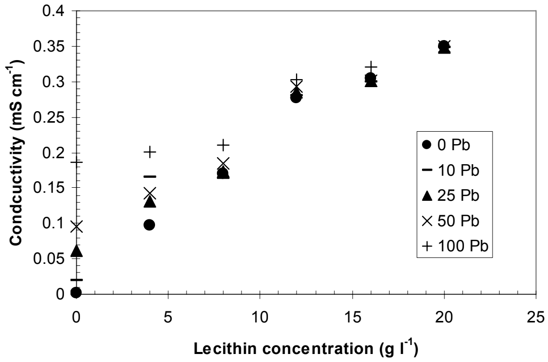

Figure 6
Effect of Pb ions on conductivity of lecithin

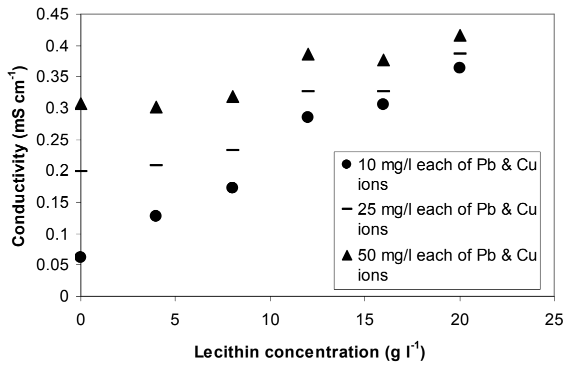

Figure 7
Effect of mixtures of Pb and copper ions on conductivity of lecithin

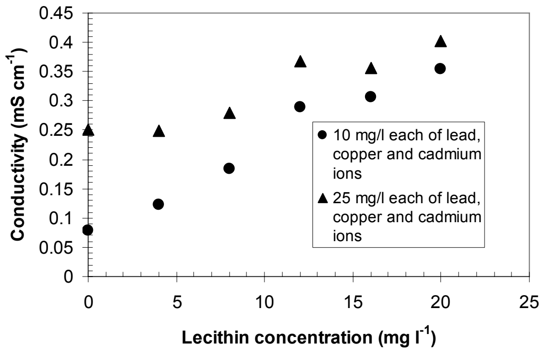

Figure 8
Effect of mixtures of Pb, Cu and Cd ions on conductivity of lecithin

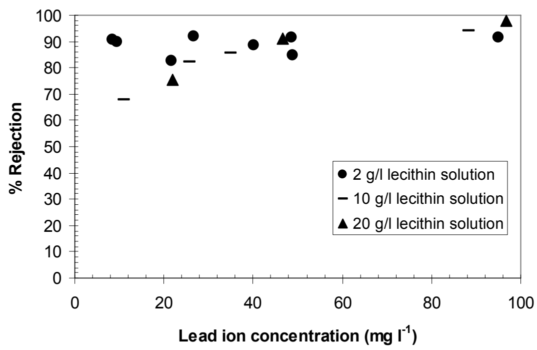

Figure 9
Effect of Pb ion concentration on its rejection

ISSN 0378-4738 = Water SA Vol. 31 No. 3 July 2005

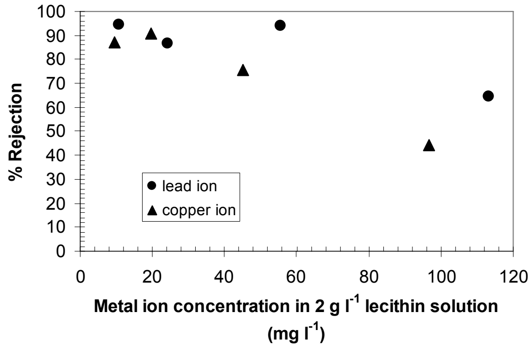

Figure 10
Effect of mixtures of Pb and Cu ion on their rejection in 2 g·ℓ-1 lecithin solution

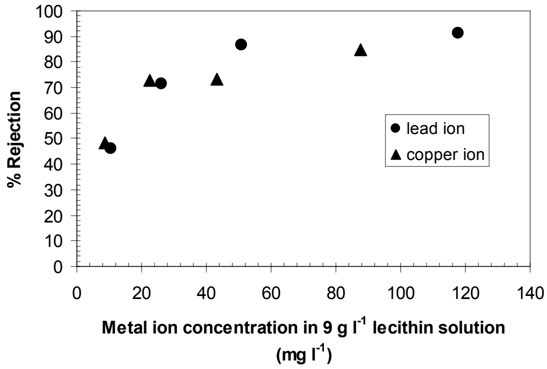

Figure 11
Effect of mixtures of Pb and Cu ions on their rejection in 9 g·ℓ-1 of lecithin solution

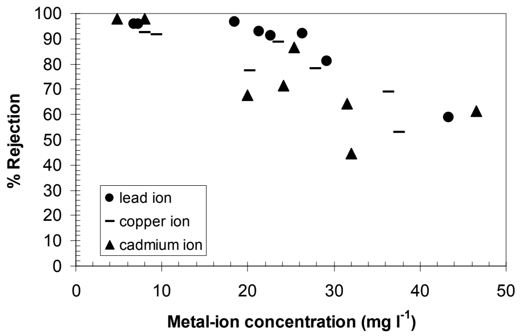

Figure 12
Effect of Pb, Cu and Cd ions on their rejection for 2 g·ℓ-1 of lecithin solution

impossible to carry out the dead-end experiments for mixtures of Pb, Cu and Cds ions for higher concentration range of lecithin.

At lecithin concentration of 2 g·ℓ$^{-1}$, an increase in Pb ion concentration caused a decrease in both pH and CMC, and an increase in zeta potential, conductivity but insignificantly affected the metal rejection. For lecithin concentrations of 10 and 20 g·ℓ$^{-1}$, an increase in Pb ion concentration caused a decrease in both pH and CMC, and an increase in zeta potential, conductivity and metal rejection. For mixtures of Pb and Cu, and mixtures of Pb, Cu and Cd in 2 g·ℓ$^{-1}$ of lecithin feed dispersion, an increase in metal concentration led to an increase in zeta potential, conductivity and metal rejection with a decrease in both pH and CMC. For mixtures of Pb and Cu in 9 g·ℓ$^{-1}$ of lecithin feed dispersion, an increase in metal concentration caused a decrease in both the pH and CMC and an increase in zeta potential, conductivity and metal rejection.

Conclusions

The study has shown that metal ions can be removed using lecithin-enhanced dead-end filtration. Lecithin is negative charged (-76 mV) thus has the ability to attract metal ions which are positively charged. Adsorption of metal ions by lecithin indicated by the zeta potential measurements was confirmed by the CMC results. The effect of metal-ion concentration on the pH, conductivity and zeta potential of lecithin dispersions and metal rejection was established. The high fouling observed for the removal of mixtures of Pb, Cu and Cd could be reduced if a crossflow filtration configuration is adopted. The study suggests an alternate technology from metal-ion removal for aqueous solutions.

References

AHMADI S, TSENG LK and BACCHELOR B (1994) Micellar enhanced ultrafiltration of heavy metals using lecithin. *Sep. Sci. Technol.* **29** (18) 2435-2450.

ATTWOOD D and FLORENCE AT (1983) *Surfactant Systems, their Chemistry, Pharmacy and Biology.* JW Arrowsmith Ltd, Bristol, UK, 203, 549 .

BROOM GP, SQUIRES RC, SIMPSON MPJ and MARTIN I (1994) Treatment of heavy metal effluents by crossflow microfiltration. *J. Membrane Sci.* **87** (1-2) 219-230.

HUANG Y and BATCHELOR B (1994) Crossflow surfactant-based ultrafiltration of heavy metals from waste streams. *Sep. Sci. Technol.* **29** (15) 1979-1998.

JUANG R-S and SHIAU R-C (2000) Metal removal from aqueous solutions using chitosan-enhanced membrane filtration. *J. Membrane Sci.* **165** 159-167.

SCAMEHORN JF, CHRISTIANS SD and ELLINGTON RT (1989) Use of micellar-enhanced ultrafiltration to remove multivalent metal ions form aqueous streams. In: Scamehorn JF and Harwell JH (eds.*) Surfactant-Based Separation Processes*, *Surfactant Science Series.* **Vol 33** Marcel Decker NY.

WAKEMAN RJ and KOTZIAN R (2000) Copper and cadmium removal of metal ions from aqueous solutions using lecithin-enhanced ultrafiltration. *Trans Filt. Soc.* **1** 8-13.