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Removal of Cadmium, Copper, Lead and Nickel from Aqueous Solution by White, Yellow and Red United Arab Emirates Sand

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Abstract: Problem statement: To remove toxic heavy metal ions from wastewater using local sand as a low cost adsorbent. **Approach:** Removal efficiency of Cd(II), Cu(II), Pb(II) and Ni(II) from aqueous solution by white, yellow and red UAE sand was investigated at 25.0°C using the methods of batch equilibrium adsorption and column filtration. In each case, a mixture containing 20 ppm of each ion was employed. In the equilibrium study, the effect of sand dosage was measured for mixtures containing 20 ppm of each ion. In the column filtration study, the mixture was added to a column packed with yellow sand and the composition of the effluent was measured for each 0.050 dm^3 portion. Concentrations were measured on an inductively coupled plasma-atomic emission spectrometer "ICP-AES". **Results:** Removal efficiency by sand type was found to follow the order yellow>white>red. At low sand dosages, removal efficiencies of Pb(II) and Cu(II) were much higher than those for Ni(II) and Cd(II). For example, at a sand dosage of 0.02 kg dm^{-3}, removal efficiencies of Pb(II), Cu(II), Cd(II) and Ni(II) were, respectively, 95, 86, 33 and 23% for yellow sand; 89, 86, 30 and 18% for white sand; and 75, 63, 12 and 13% for red sand. Column filtration using yellow sand confirmed that removal efficiency followed the order Pb(II)>Cu(II)>Cd(II)>Ni(II), with all four ions completely removed at mass ratios (metal/sand) lower than 3.0×10^{-4}. **Conclusion:** Equilibration on sand and sand filtration are most efficient for the removal Pb(II) and Cu(II). Sand filtration can be effectively utilized to separate Pb(II) and Cu(II) from a mixture containing all four ions.

Key words: UAE sand, heavy metal removal, cadmium, copper, lead, nickel

INTRODUCTION

Many industrial processes such as electroplating, galvanization, dyeing and tanning, release heavy metals into the environment. Heavy metals in industrial wastewater are particularly hazardous and are often detrimental to health. The search for low cost methods to remove them is thus of particular significance.

In a previous communication from this laboratory (Khamis *et al*., 2009), we reported on the removal and speciation of Cr(III) and Cr(VI) from wastewater using white, red and yellow United Arab Emirates (UAE) sand. The positive outcome of that study has prompted us to extend this study to other heavy metals. This study deals with the removal of Cd(II), Cu(II), Pb(II) and Ni(II) from a mixture by batch equilibration with sand and by sand column filtration.

Some of the methods cited in the literature for removal of heavy metals include precipitation, ion exchange, adsorption, solvent extraction and biosorption. Recently, adsorption studies were conducted using low cost adsorbents such as wool (Balkaya, 2002), sawdust (Dakiky *et al*., 2002), cocoa shell (Meunier *et al*., 2003) and zeolite (Babel and Kumiawan, 2004). Several reports deal with the use of sand as an inexpensive and efficient adsorbent of heavy metal from industrial effluents (Aslam *et al*., 2004; Baig *et al*., 2003; Muhammad *et al*., 1998; Awan *et al*., 2003) but there is only a single report (Khamis *et al*., 2009) on the effect of sand type on the extent of heavy metal removal. This study aims at comparing the efficiency of the various types of UAE sand in removing cadmium, copper, lead and nickel from industrial wastewater, using equilibrium and dynamic methods.

MATERIALS AND METHODS

All primary chemicals used were of analytical reagent grade. $Cu(NO_3)_2$ was purchased from Riedel De-Haen (Germany). $CdCl_2$ was purchased from BDH (UK). $Pb(NO_3)_2$, $Ni(NO_3)_2$, NaOH and HNO_3 were purchased from Panreac (Spain). White, yellow and red

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sand grab samples were obtained from several locations within the UAE and randomized.

Metal ion concentrations were determined using a Varian Liberty axial sequential inductively coupled plasma-atomic emission spectrometer "ICP-AES" (Australia). pH was measured on a 550A Thermo Orion pH meter (USA) fitted with a combined glass electrode. Solutions were shaken at 25.0±0.1°C using an Edmund Buhler KS-15/TH-15 shaker (Germany). Sand samples were sieved using impact test sieves from Standard Sieve (USA), mesh model BS410, 1986 ST. Three stainless steel frames with sieve sizes 300, 150 and 75 μm. The selected fractions used in experiments were less than 300 μm in diameter. Each sand sample was washed repeatedly with deionized distilled water and dried to a constant weight at 110°C.

For equilibration experiments stock solutions containing 1000 ppm of Cd(II), Cu(II), Pb(II) and Ni(II) were prepared. These were then used to prepare mixtures containing 20 ppm of each ion. The pH of all mixtures was adjusted to 4.0 using 50% HNO_3. Experiments were conducted using a batch reaction process in triplicates. A known mass of sand was added to 0.100 dm^3 of the mixture in a 0.250 dm^3 flask and shaken at 25.0°C for 2 h at 200 rpm. Ion concentrations were determined using ICP. Data were collected for sand dosages in the range 0-0.180 kg sand dm^{-3} solution. Prolonging the contact time between sand and solution beyond 2 h did not result in additional removal of heavy metal ions, from which it was concluded that 2 h was sufficient to attain equilibrium.

Removal of the four heavy metal ions was also investigated using a dynamic approach. A column, 0.225 m in height and 0.025 m in diameter, was packed with yellow sand to a height in the range 0.050-0.100 m. Yellow sand was selected because equilibration data showed that it had the highest heavy metal removal efficiency. Prior to each run, the column was washed with 1.5 dm^3 of distilled deionized water. 9.0 dm^3 of the heavy metal mixture, containing 20 ppm of each ion, was added to the column and the flow rate adjusted in the range 0.3-0.6 dm^3 h^{-1}. Concentrations of heavy metals in the effluent were measured at 0.050 dm^3 intervals.

The removal efficiency is defined as follows:

$$\text{Removal efficiency} = \left[\frac{C_I - C_F}{C_I}\right] \times 100 \tag{1}$$

where, C_I and C_F are the initial concentration and the concentration after treatment.

RESULTS

Batch equilibration: Heavy metal ion removal efficiencies from mixtures containing 20 ppm Cd(II), Cu(II), Pb(II) and Ni(II), after equilibration on sand, are shown in Fig. 1. These efficiencies are plotted as a function of sand type and dosage.

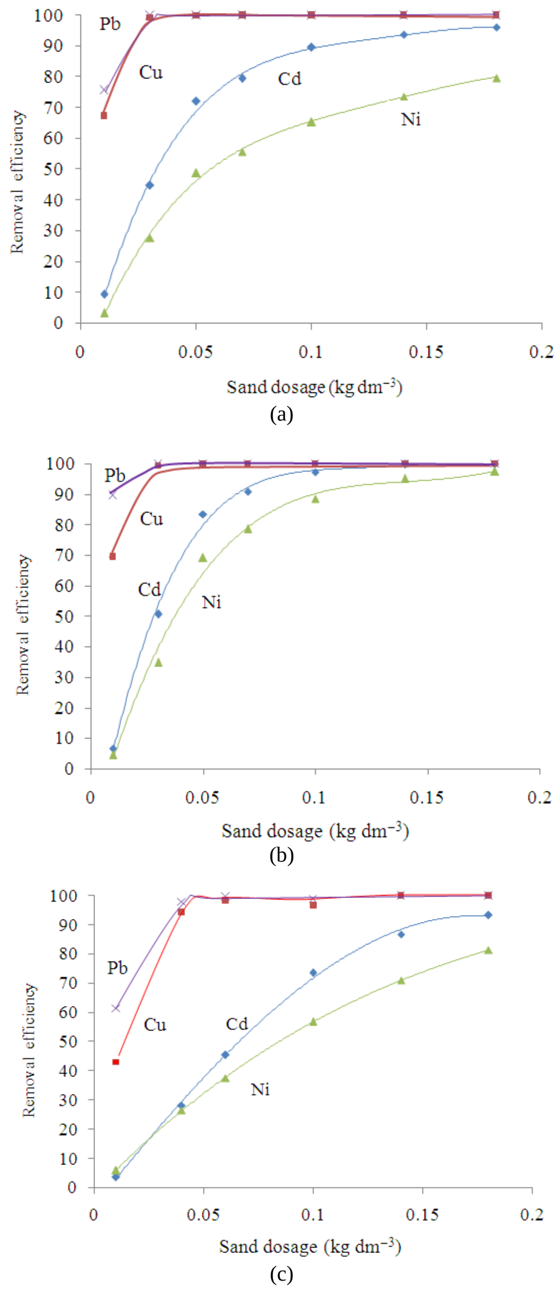

Fig. 1: Effect of sand dosage on heavy metal removal efficiency. (a) White sand; (b) yellow sand; (c) red sand. Contact time: 2 h, T = 25.0°C

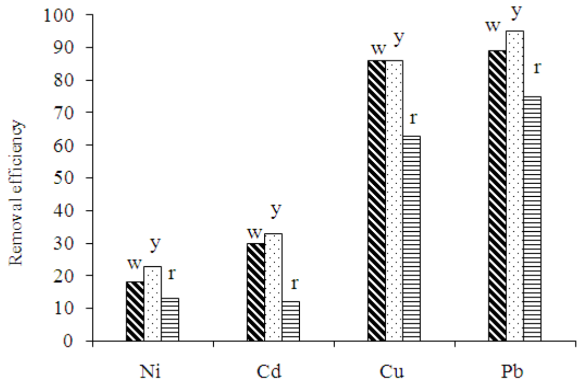

Fig. 2: Effect of sand type on heavy metal removal efficiency from a mixture containing 20.0 ppm each of Cd(II), Cu(II), Pb(II) and Ni(II). Sand dosage = 0.020 kg dm^{-3}. Contact time = 2 h, T = 25.0°C

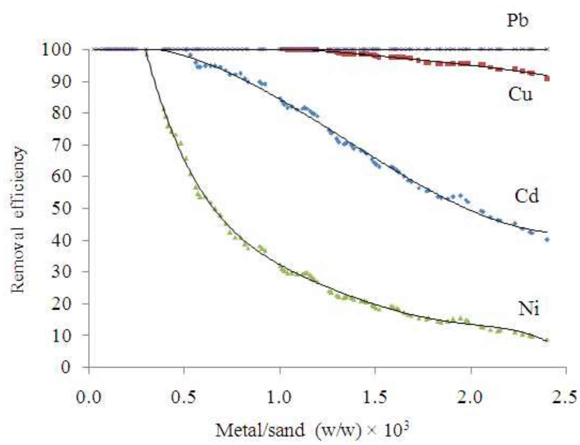

Fig. 3: Dependence of heavy metal removal efficiency on metal/sand ratio. T = 25.0°C

Figure 1 shows that the efficiency follows the order yellow>white>red for all four ions. This effect is further illustrated in Fig. 2, which summarizes data for 0.020 kg dm^{-3} sand dosages. Figure 2 also shows that such a low sand dosage could be used to separate Cd(II) and Ni(II) ions from a solution containing the four ions. For the same sand type, removal efficiency follows the order Pb(II)>Cu(II)>Cd(II)>Ni(II).

Sand column filtration: Under industrial conditions, it is practical to use columns to treat wastewater. The height of the sand column and the rate of flow of effluent could be controlled so as to achieve optimal efficiency. Figure 3 shows the dependence of removal efficiency on the mass ratio of heavy metal ion to that of yellow sand. For ratios lower than 3.0×10^{-4}, removal of all four ions was complete. As the ratio increases, Ni(II) begins to elute, followed by Cd(II). Figure 3 also shows that Cu(II) begins to elute at a significantly higher ratio, ca. 1.5×10^{-3}, whereas Pb(II) is completely removed in the region of detailed investigation. A separate experiment using a short column showed that Pb(II) is retained up to a mass ratio of 4.0×10^{-2}.

DISCUSSION

Removal of Pb(II)>Cu(II)>Cd(II)>Ni(II) via equilibration with sand and via sand filtration can be achieved with high efficiency. Equilibration at low sand dosages has shown that it would be possible to separate Pb(II) and Cu(II) from a mixture that also contains Ni(II) and Cd(II). The sand column results agree with those from batch equilibration, both demonstrating that it would be feasible to separate Ni(II) and Cd(II) from a mixture containing the four heavy metal ions. At a mass ratio of 2.0×10^{-3}, for example, Pb(II) is completely retained and Cu(II) is only ca. 5% eluted. By contrast Cd(II) and Ni(II) are ca. 50 and 88% eluted. Future research will be extended to other heavy metal ions, using sand as well as other low cost adsorbents and will involve studies on recovery of adsorbed species.

CONCLUSION

Equilibration on sand and sand filtration are most efficient for the removal Pb(II) and Cu(II). Sand filtration can be effectively utilized to separate Pb(II) and Cu(II) from a mixture containing all four ions.

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