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1. Introduction

Phosphorus (P) recovery (and potentially re-use) through adsorption has been identified as a promising technology as this involves low energy consumption, may provide various economic benefits, is simple to apply, and it may be highly effective even at low P concentrations (Pap, S., et al., 2020a).

Rock phosphate on Earth's surface is a dwindling resource (Fig. 1) and in 2014, P was added to the EU list of critical raw materials.

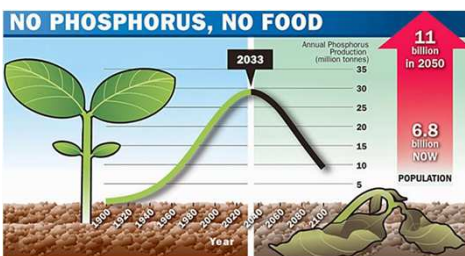


Figure 1: The main source of terrestrial P comes from rapidly dwindling terrestrial rock phosphate reserves (Cordell, et al., 2011)

2. Materials and Methods

Pilot-scale trials were conducted using a novel KOH deacetylated calcite-chitosan based adsorbent (CCM) to remove P from secondary wastewater effluent. The CCM has been characterised in detail using scanning electron microscopy with energy-dispersive X-ray analysis, X-ray powder diffraction (XRD) and Fourier-transform infrared spectrometry (FTIR) (Pap, S., et al., 2020b). Box-Behnken Design and Response Surface Methodology approaches were used to optimise CCM synthesis (Fig. 2).

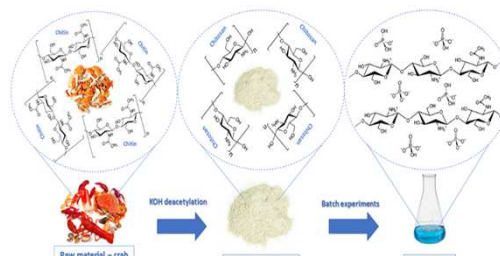


Figure 2: Schematic diagram of CCM fabrication (Pap, S., et al., 2020b)

3. Pilot Description

The Environmental Research Institute (ERI) has applied the FILTRAFLO™-P reactor (with Veolia Water Technologies) to recover P from real wastewater using CCM filtration/adsorption. This small unit employs enhanced gravitational filtration through adsorption media (waste crab carapace based CCM) with continuous self-backwashing. Trials were designed to assess how the FILTRAFLO™-P would operate under 'real' conditions (with low and high P levels), and to ascertain the effectiveness of the adsorbent to recover P. A six week trial was carried out at Scottish Water Horizons Development Centre at Bo'ness in January-February 2020.



Figure 3: FILTRAFLO™-P reactor designed by Veolia (a and c) and the obtained P-rich CCM material (b) (© Szabolcs Pap, ERI)

4. Results and Discussion

The P adsorption trials indicated two quite different options for the FILTRAFLO™-P reactor combined with the CCM adsorbent. As Figure 4a illustrates, the CCM adsorbent was capable of removing P even at very low concentrations, bringing residual P levels below 0.5 mg P/L. This shows its applicability in terms of polishing low-P effluents (i.e., potential for use in preventing eutrophication in sensitive receiving waters). Further, at high P concentrations, trials showed its P harvesting potential. From the theoretical breakthrough curves on Figure 4.b, it can be estimated that with 15 kg of CCM approximately 20 m³ of wastewater could be filtered/P harvested.

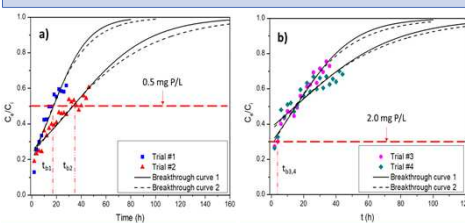


Figure 4: P theoretical breakthrough curves (Bohart-Adams with solid line and Clark with dashed line) for trials. Low P concentration influents (a) and high concentration influents (b) (© Szabolcs Pap, ERI)

Alkaline pH values (pH 8-9) favoured hydroxyapatite (Ca₅(PO₄)₃(OH)) precipitation on the CCM surface (a microprecipitation mechanism) (Fig. 5 gives SEM and XRD). Another important removal mechanism under these conditions was ligand exchange whereby H₂PO₄⁻ and HPO₄²⁻ anions replaced CO₃²⁻ on the CCM surface and formed inner-sphere surface complexes (via Lewis acid-base interactions between P and ≡Ca-CO₃ groups) (Fig. 5 gives EDX and FTIR).

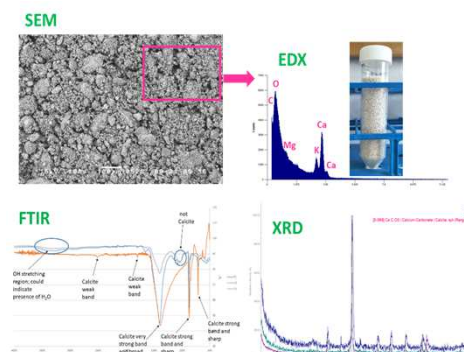


Figure 5: Characterisation of the CCM after P adsorption (© Szabolcs Pap, ERI)

5. Conclusion

High P recovery potential was achieved even at low P concentrations, bringing residual wastewater P levels below 1 mg/L (EU limit for sensitive water bodies).

Surface microprecipitation and inner-sphere complexation were postulated as key P adsorption mechanisms due to reduced concentrations of Fe, Mn and Ca. Slightly increased turbidity in treated water (e.g., from magnesium carbonates) may require integration with simple sand filtration.

Quality assessment indicated ~2.5% of P₂O₅, low heavy metal content and no detectable levels of target bacterial pathogens present.

The results show that this CCM could serve as a potential P-rich soil improvement product.