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# Phosphate adsorption by Iron Coated Sand granules as end-of-pipe solution for the purification of drainage water

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## Introduction

The main goal of this study is to demonstrate the feasibility of Iron Coated Sand (ICS) as a P sorbin material to treat nutrient-rich effluent from greenhouses. The ICS can be considered as low-cost sorbent material, because it is a by-product of a drinking water production process. The influence of granule type, initial phosphate concentration and contact time on the adsorption process were determined by identifying the adsorption equilibrium and kinetics. Secondly, rapid small-scale column tests were used to predict the breakthrough time of ICS adsorption filters.

## Material & Methods

**Batch adsorption experiments**

- Temperature: 20 ºC
- Horizontal shaker: 150 movements/min
- pH: 6.5 – 7.2
- S/X = 1/10
- Contact time: 24 – 168 hours
- $PO_4$-P conc.: 10 – 3000 mg $PO_4$-P/L
- $PO_4$-P analysis: ascorbid acid method

**Rapid small-scale column experiments**

- Influent $PO_4$-P conc.: 25 mg $PO_4$-P/L
- Contact time: 13 – 35 min
- Flow rate: 1.9 – 12.8 L/day
- Filter bed depth: 13 – 43 cm
- Continuous flow versus intermediate rest periods
- $PO_4$-P analysis: ascorbid acid method

**Mathematical modeling**

- Equilibrium: Langmuir & Freundlich
- Kinetics: pseudo-first order, pseudo-second order, Elovich & intraparticle diffusion
- Fixed-bed adsorption: Bohart-Adams model:

$$\ln\left(\frac{C_0}{C_b}-1\right) = ln\left[exp\left(\frac{k_{BA}.N_0.Z}{U}\right)-1\right] - k_{BA}.C_0.t_b$$

with $C_0$: Sorbate concentration of filter influent [mg $PO_4$-P/L]
$C_b$: Breakthrough concentration [mg $PO_4$-P/L]
$k_{BA}$: Bohart-Adams rate constant [L/(mg.d)]
$N_0$: Sorption capacity of bed per unit volume of the filter bed [mg/L]
Z: Filter bed depth [cm]
U: Flow velocity of solution through the filter bed [cm/d]
$t_b$: Service time/operating time of bed at breakthroug [d]

## Results & Discussion

**Batch adsorption experiments** *(Table 1)*

- Both Langmuir and Freundlich isotherms described the phosphate adsorption on ICS granules well, i.e., an $R^2$ of resp. 0.956 and 0.995 was observed for the ICS granules of Balen (first shipment).
- The adsorption kinetics follow the pseudo-second-order model, resulting in an $R^2$ of 0.988 and 0.970 for ICS of the 1st and 2nd shipment of Balen.
- Limited differences in adsorption capacity between the different locations were observed, caused by a difference in granule diameter.
- A mean adsorption capacity of 21 mg $PO_4$-P/g sorbent was determined at an influent concentration of 25 mg $PO_4$-P /L.

**Rapid small-scale column experiments** *(Figure 1)*

- The Bohart-Adams model was fit to the experimental data by modifying $N_0$ and $k_{AB}$.
- A quasi-linear relationship between the Empty Bed Contact Time and the filter service time to a given breakthrough concentrations was observed.
- By introducing rest periods, the effluent phosphate concentration was significantly lower compared to the continuous flow experiments:

$C_{max,restperiod}$ = 3.1 mg $PO_4$-P/L versus $C_{max,cont.flow}$ = 10 mg $PO_4$-P/L

*Table 1: Overview of the results of the evaluation of the established Langmuir and Freundlich isotherms of the granules from the different deferrization sites.*

| Location | $q_{t,max}$ $\left[\frac{mg\ PO_4-P}{g\ sorbent}\right]$ | $K_f$ [*] | $q_t$ @25mg/L $\left[\frac{mg\ PO_4-P}{g\ sorbent}\right]$ | $q_t$ @25mg/L $\left[\frac{mg\ PO_4-P}{g\ sorbent}\right]$ |
|---|---|---|---|---|
| | Langmuir | Freundlich | Langmuir | Freundlich |
| Balen (first shipment) | 17.4 | 1.011 | 5.33 | 3.94 |
| Balen (second shipment) | 23.1 | 0.432 | 3.98 | 3.20 |
| Grobbendonk | 27.6 | 0.615 | 2.67 | 2.02 |
| Herentals | 19.8 | 0.235 | 2.28 | 1.90 |
| Mol | 18.5 | 0.253 | 3.09 | 3.56 |

(*) = $\left(mg_{PO_4-P}^{\left(1-\frac{1}{n}\right)} \cdot L^{\left(\frac{1}{n}\right)}\right)/g\ sorbent$

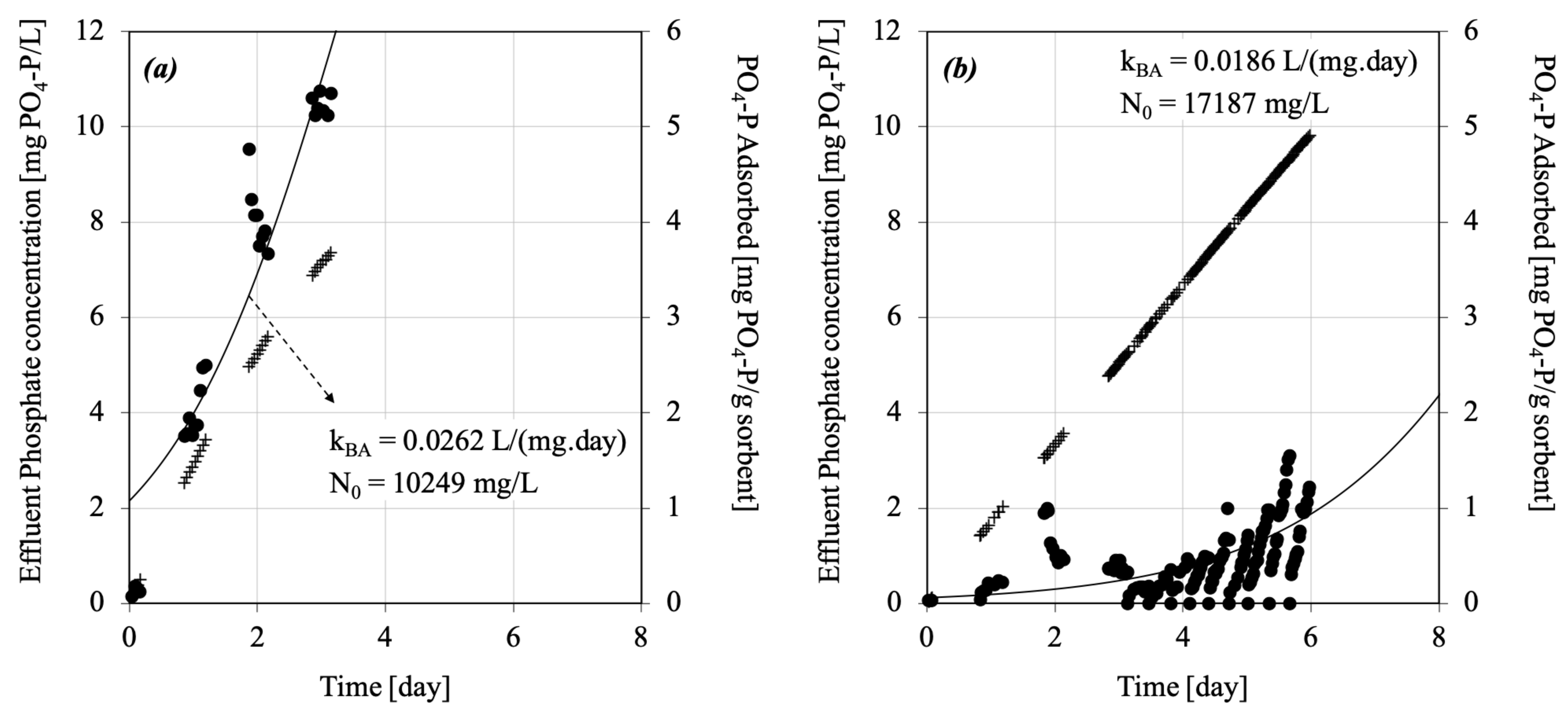


*Figure 1: Adsorption column experiments on lab-scale (influent P concentration = 25 mg $PO_4$-P/L) at different flow rates and operating conditions (a: continuous flow at 12.8 l/day, $\tau$ = 13 min & Z = 33 cm; b: intermediate rest periods at 6.9 L/day, $\tau$ = 24 min & Z = 33 cm)*

## Conclusions

- The low-cost adsorbent Iron Coated Sand was succesfully applied to remove phosphate from greenhouse effluent.
- The adsorption capacity, and consequently the service time of the adsorption column, increased by introducing intermediate rest periods.
- The rest periods create fresh and free adsorption sites at the outsite of the granules by diffusion of phosphate towards the core of the granule.