

## Techno-economical assessment of desorption

### Introduction

Within the NuReDrain project, a process was developed to regenerate P-loaded sorbents. This regeneration process allows for the reuse of the sorbents after saturation. The regeneration process is developed for iron-coated sand (ICS), but could be used for most sorbents for which the active components are iron or aluminum (hydr)oxides. These sorbents show a pH-dependent adsorption behavior. At high pH, both the sorbent and phosphate species in solution are negatively charged (e.g.  $\text{HPO}_4^{2-}$ ), providing an unfavorable condition for sorption. Furthermore, the increased number of  $\text{OH}^-$  ions competes with phosphate for sorption, thereby replacing phosphate ions on the sorbent<sup>1</sup>.

After the desorption step, a neutralization step is performed. This step ensures that the effluent during the sorption step will have a pH that allows direct discharge in soil and surface water. Furthermore, some potential precipitation products (e.g., calcium carbonates and calcium phosphates) that were formed during the desorption step could be removed with this neutralization solution<sup>2,3,4</sup>.

To avoid the need to discharge the regeneration solution, KOH and  $\text{H}_2\text{SO}_4$  are used as the desorption and neutralization agents respectively. The produced solution, mainly containing phosphate, potassium, iron and sulfate, can be used as a nutrient solution in agriculture. To increase the bioavailability of the present iron, the addition of chelating agents might be needed<sup>5</sup>.

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<sup>1</sup> Loganathan P., Vigneswaran S., Kandasamy K., & Bolan N.S. (2014). Removal and recovery of phosphate from water using sorption. *Critical Reviews in Environmental Science and Technology*, 44(8), 847-907.

<sup>2</sup> Song Y., Hahn H.H., & Hoffmann E. (2002). The Effect of Carbonate on the Precipitation of Calcium Phosphate. *Environmental Technology*, 23, 207-215.

<sup>3</sup> Sonoda A., Makita Y., Sugiura Y., Ogata A., Suh C., Lee J.-H., & Ooi K. (2020). Influence of coexisting calcium ions during on-column phosphate adsorption and desorption with granular ferric oxide. *Separation and Purification Technology*, 249.

<sup>4</sup> Kumar P.S., Eijssers W.W., Carita Clarissa K., Korving L., Dugulan A.I., Temmink H., van Loosdrecht M.C.M., & Witkamp G.-J. (2018). Understanding and improving the reusability of phosphate adsorbents for wastewater effluent polishing. *Water Research*.

<sup>5</sup> Ronen E. (2007). Micro-elements in agriculture. *Practical Hydroponics & Greenhouses*.

#### DISCLAIMER

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## Techno-economic assessment (in support of the Excel tool)

Background to the Excel tool on the techno-economic assessment is given here. The numbers in the Excel tool are based on the data of a greenhouse grower in Flanders treating its greenhouse effluent. All numbers in yellow can be adapted to represent your own case.

### Sorbent cost

The cost that the owner of the P filter installation has to pay for the purchase and disposal of the filter material depends strongly on the size of the installation. The current price for purchasing and disposal of 1 ton of sorbents in the Excel tool is derived from ICS purchase costs and landfill costs in Flanders, Belgium (2023). The amount of sorbents that has to be inserted in the Excel tool is the mass of sorbents necessary to fill the sorption installation (in metric tons).

### Lifetime sorbents

The lifetime of the sorbents is defined as the time the sorbents can be used for P sorption. Upon saturation, the sorbents will need to be regenerated or disposed. The lifetime of the sorbents depends on the sorption capacity, the amount, the phosphate load of the treated water, the flow of the treated water and the targeted phosphate concentration in the effluent. Furthermore, kinetics play a role, since sorbents might still have sorption capacity after a certain period of use, but this sorption might occur significantly slower as compared to fresh sorbents. For instance, when the sorption sites on the surface of the sorbents are loaded, the phosphate must migrate inside the sorbent for sorption to occur (intra-particle diffusion<sup>6</sup>). Keep in mind that the kinetics can change with changing conditions (e.g., changing water temperature<sup>7</sup>). The current sorbent lifetime in the excel is derived from field experiments with ICS at greenhouse cultivators and at the PCS Ornamental Plant Research (PCS) in Belgium that were performed in the NuReDrain project.

### Amount of desorption cycles possible

During each desorption cycle, the sorbents can corrode and some of the active metal (hydr)oxides will dissolve in the desorption solution. Furthermore, during sorption, phosphate may be sorbed very strongly and deep inside the sorbent particles, leading to a significant proportion of non-extractable phosphate<sup>8</sup>. This will lead to a decline in regenerability with continuing adsorption-desorption cycles.

### Lifetime desorbed sorbents

Because of the reasons mentioned in the paragraph above, the capacity of the regenerated sorbents can decrease with every adsorption-desorption cycle, leading to a decrease in time until the sorbents

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<sup>6</sup> Lalley J., Han C., Li X., Dionysiou D.D., & Nadagouda M.N. (2016). Phosphate adsorption using modified iron oxide-based sorbents in lake water: Kinetics, equilibrium, and column tests. Chemical Engineering journal, 284, 1386-1396.

<sup>7</sup> Zeng L., Li X., & Liu J. (2004). Adsorptive removal of phosphate from aqueous solutions using iron oxide tailings. Water Research, 38(5), 1318-1326.

<sup>8</sup> Genz, A., Kornmüller, A., & Jekel, M. (2004). Advanced phosphorus removal from membrane filtrates by adsorption on activated aluminium oxide and granulated ferric hydroxide. Water Research, 38, 3523-3530.

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are saturated and must undergo a new desorption step. The average time before a new desorption step is needed, must be completed in the Excel tool.

### **Cost for chemicals**

For the regeneration of the loaded sorbents, KOH and H<sub>2</sub>SO<sub>4</sub> are needed. In the Excel tool, the commodity prices of KOH and H<sub>2</sub>SO<sub>4</sub> (March 2023) are given. The amount of KOH and H<sub>2</sub>SO<sub>4</sub> used during 1 desorption and neutralization step, were obtained from desorption tests on P-loaded ICS from PCS in the NuReDrain project (loaded with 11 g P/kg sorbent).

### **CAPEX costs for desorption equipment**

In case desorption is targeted, the P filter system will need to be constructed with materials that can withstand pH values up to 12.5 (e.g., PP, PTFE, HDPE, FKM). Furthermore, the alkaline and acidic solutions will need to be added by a chemical pump (e.g., in PP or PVDF).

To steer the desorption and neutralization process at a certain pH, an electrical steering system must be added, including a pH probe and two small dosing pumps. Depending on the measured pH, less or more KOH or H<sub>2</sub>SO<sub>4</sub> will have to be added to the circulated desorption or neutralization solution. In case there is no automatic steering, the KOH and H<sub>2</sub>SO<sub>4</sub> will have to be added manually. This will slow down the desorption process and will lead to a risk for an “overshoot” (a too big increase or decrease in pH), leading to an accelerated corrosion of the sorbents.

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