Struvite precipitation from full-scale blackwater anaerobic digestion following different blackwater pre-treatment methods

Saida Kaykhaii*, Hamse Kjerstadius**, Annelie Hedström*, Elisabeth Kvarnström* and Inga Herrmann*

*Luleå University of Technology, Luleå, Sweden
**Nordvästra Skånes Vatten och Avlopp, Helsingborg, Sweden

Highlights:

- Phosphate bearing rock is a non-renewable resource and struvite which contains phosphorus, magnesium and nitrogen and can be used as a fertilizer.
- Three different qualities of blackwater were examined to determine how the quality of blackwater can affect the quality and efficiency of struvite precipitation.
- Application of pretreatment before struvite precipitation may improve the quality and efficiency of produced struvite.

Keywords: drum filter; microfiltration; phosphorus recovery; struvite purity

INTRODUCTION

Phosphate bearing rock is a non-renewable resource, which has been predicted to be depleted in the next 100 years (Huang et al., 2019). Therefore, it is important to draw our attention to the reuse of phosphorus derived from human waste and to prioritize its reuse over further extraction from mines. Studies have shown that struvite precipitation ($MgNH_4PO_4*6H_2O$) from wastewater (e.g. blackwater) streams can be a promising method to take a step towards phosphorus recovery and sustainable agriculture (Kim et al., 2009; Sathiasivan et al., 2019; Thant Zin & Kim, 2019).

Various parameters influence the efficiency of struvite precipitation in blackwater, including pH and magnesium (Mg): phosphate (PO4) ratio. If the waste stream is rich in PO_4 and ammonium (NH_4), the addition of Mg^{2+} can improve the struvite precipitation. However, impurities in the blackwater can precipitate with the struvite for example heavy metals (Ronteltap et al., 2007). Therefore, the quality of blackwater for which struvite precipitation is performed is important for struvite precipitation and needs further investigations.

In this study, the precipitation of struvite from blackwater obtained from three different processes (anaerobic digestion, anaerobic digestion followed by drum filtration and anaerobic digestion followed by membrane treatment) was investigated in terms of optimal molar ratio and pH. The quality and purity of the struvite from the individual pre-treatments were then compared with each other and also with the struvite produced at an industrial-scale facility in Helsingborg, Sweden.

METHODOLOGY

Blackwater used for the precipitation experiments

The pre-treated blackwater used for the experiments was provided by the wastewater treatment facility RecoLab(WWW.recolab.se) in Helsingborg, Sweden. Three different qualities of blackwater were used (Figure 1). The First quality investigated was the digestate decantate from the anaerobic digestion tank. The digestate was decanted from 6 m height of the anaerobic digestor. The second quality investigated was the same decantate as above, further treated by filtration in a drum filter. The third quality investigated was the digestated blackwater decantate as above further treated by a microfiltration membrane.

Figure 1. Different qualities of the blackwater investigated, from left to right: raw, digestate decantate, Drumfiltered digestate decantate, membrane-treated digestate decantate.

Study design

Jar tests were carried out to find the optimum pH and Mg:PO_4 molar ratio at which the highest struvite precipitation occurred. pH levels of 7.5(no pH adjustment), 8.1, 9 and molar ratio of Mg:PO_4 of 0.5:1, 0.8:1, 1.2:1, 2:1 and 4:1 was tested. Each jar test included a control sample to which no Mg salt was added. The experiment was designed as a full factorial design and randomized. A total of 16 experiments were performed. Finally, the optimal molar ratios and pH values were repeated to collect a sufficient amount of struvite for further analysis.

Struvite precipitation jar tests

The pH was adjusted using NaOH 2M. The jar test apparatus consisted of 6 one-liter jars to which different molar ratios of Mg:PO_4 were added to the blackwater. The mixing method used for the test was to subject the jars to 200 rpm for 5 min before slowing down to 60 rpm for 30 min after which it was allowed to settle for 30 min for the struvite to settle in the jars. Then, liquid phase was decanted, filtered through a 0.45 µm filter and analyzed for pH, dissolved phosphorus and metals. The struvite was collected then and left under a fume hood to dry. The struvite obtained under optimum condition was further assessed using SEM-EDS and their quality and purity was compared to industrial scale struvite.

PRELIMINARY RESULTS

The preliminary result of this experiment showed that for a membrane treated decantated blackwater, a Mg:PO4 ratio of 1:1, the precipitation rate was increasing by increasing the molar ratio and further increase in the molar ratio did not have a significant effect on struvite precipitation. It should be mentioned that the optimal ratio was determined based on phosphorus recovery and chemical consumption and whether it is economical to add more chemical. For digestate decantate and drumfiltered digestate decantate also the molar ratio of 1:1 was optimum. This molar ratio has already been used in several practical applications(Aguilar-Pozo et al., 2023; Pavez-Jara et al., 2024). In addition, increasing pH had a positive effect on the amount of phosphorus precipitated in the struvite.

The molar ratio of 4:1 at pH 9 exhibited the highest precipitation efficiency for the blackwater from three different pre-treatment processes. The average precipitation percentage for membrane treated decantate, drumfiltered decantate and digested decantate blackwater was 96% each. Figure 2 clearly represents the effect of blackwater quality on the quality of precipitated struvite. The digestate decantate included organics and suspended solids which settle in the struvite. Further treatment of the digestate decantate blackwater prior to struvite precipitation improves the quality of struvite.

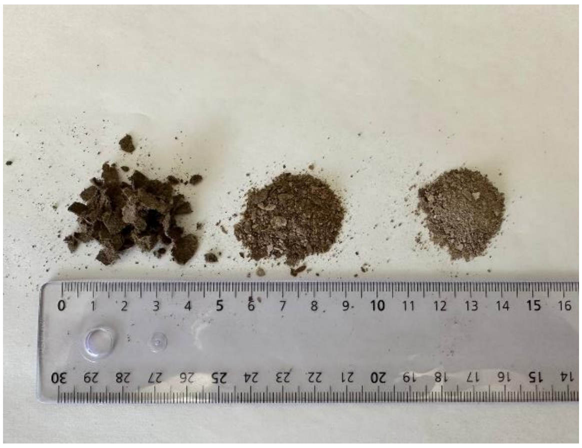

Figure 2. Struvite produced from blackwater with various pre-treatments. From left to right, struvite from blackwater digestate, digestate drum-filtered and membrane-filtered digestate.

ACKNOWLEDGMENT

This research was jointly financed by Stormwater & Sewers and NSVA (Nordvästra Skånes Vatten och Avlopp). The authors would like to thank Maria Gelfgren, Peter Rosander, Paul Lindh and Andreas Arcen for their cooperation in the installation of the equipment. In addition, the authors would like to thank Stephanie Rusch Fehrmann and Letty Mora for their help with the sampling.

REFERENCES

Aguilar-Pozo, V. B., Chimenos, J. M., Elduayen-Echave, B., Olaciregui-Arizmendi, K., López, A., Gómez, J., Guembe, M., García, I., Ayesa, E., & Astals, S. (2023). Struvite precipitation in wastewater treatment plants anaerobic digestion supernatants using a magnesium oxide by-product. *Science of the Total Environment*, *890*. https://doi.org/10.1016/j.scitotenv.2023.164084

Huang, H., Li, B., Li, J., Zhang, P., Yu, W., Zhao, N., Guo, G., & Young, B. (2019). Influence of process parameters on the heavy metal (Zn2+, Cu2+ and Cr3+) content of struvite obtained from synthetic swine wastewater. *Environmental Pollution*, *245*, 658–665. https://doi.org/10.1016/j.envpol.2018.11.046

Kim, D., Kim, J., Ryu, H. D., & Lee, S. I. (2009). Effect of mixing on spontaneous struvite precipitation from semiconductor wastewater. *Bioresource Technology*, *100*(1), 74–78. https://doi.org/10.1016/j.biortech.2008.05.024

Pavez-Jara, J., Iswarani, W. P., van Lier, J. B., & de Kreuk, M. K. (2024). Role of the composition of humic substances formed during thermal hydrolysis process on struvite precipitation in reject water from anaerobic digestion. *Journal of Water Process Engineering*, *59*. https://doi.org/10.1016/j.jwpe.2024.104932

Ronteltap, M., Maurer, M., & Gujer, W. (2007). The behaviour of pharmaceuticals and heavy metals during struvite precipitation in urine. *Water Research*, *41*(9), 1859–1868. https://doi.org/10.1016/j.watres.2007.01.026

Sathiasivan, K., Ramaswamy, J., & Rajesh, M. (2019). Optimization studies on the production of struvite from human urine – waste into value. *Desalination and Water Treatment*, *155*, 134–144. https://doi.org/10.5004/dwt.2019.24063

Thant Zin, M. M., & Kim, D. J. (2019). Struvite production from food processing wastewater and incinerated sewage sludge ash as an alternative N and P source: Optimization of multiple resources recovery by response surface methodology. *Process Safety and Environmental Protection*, *126*, 242–249. https://doi.org/10.1016/j.psep.2019.04.018