Model Validation of Nutrient Precipitation Using a Bench-scale Reactor

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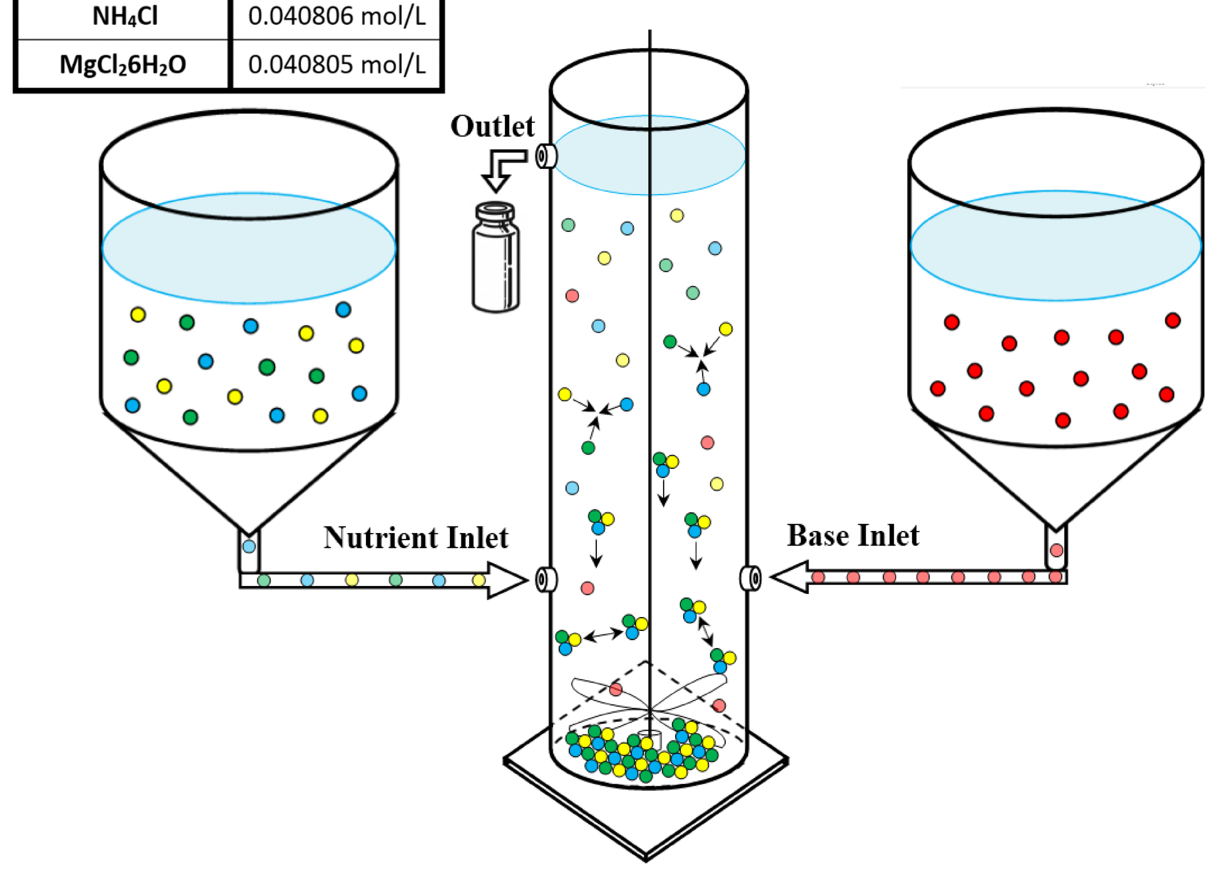
Summary of key findings

- A model for nutrient recovery by the precipitation of struvite is compared to the operation of a 12-litre bench precipitation reactor
- The reactor was operated for durations up to 125 hours
- Recovery rates of 75% and 90% were observed at residence times of 2.5 and 4 hours, respectively.
- This model may be of utility to practitioners wishing to assess process designs and operating policies for their nutrient recovery systems.

$$Mg^{2+}{}_{(aq)} + NH_4^+{}_{(aq)} + PO_4^{3-}{}_{(aq)} + 6H_2O \rightleftharpoons MgNH_4PO_4 \cdot 6H_2O_{(s)}$$

NUTRIENT FEED	VALUE
KH_2PO_4	0.040803 mol/L
NH_4Cl	0.040806 mol/L
$MgCl_2 6H_2O$	0.040805 mol/L

BASE FEED	VALUE
NaOH	0.078455 mol/L



$$Rate = 3\left\{\frac{\rho}{MW}\frac{\pi}{6}\right\}^{1/3} N^{1/3}(Mol)^{2/3}\frac{d\bar{L}}{dt} = k_{app}(Mol)^{2/3}\ SI^n$$

Figure 1: Schematic diagram of mixed-mode nutrient recovery reactor showing struvite stoichiometry and molar rate of formation

Methodology

A 12-litre laboratory reactor (Figure 1) treats a constant inflow of nutrient-rich feed. A caustic solution is fed to the reactor to affect changes in the saturation index (*SI*) of struvite. Struvite seeds crystals grow and are retained in the reactor.

The solution *pH* was continuously monitored and discrete samples were taken from the reactor volume to quantify two key variables

- orthophosphate concentration
- weight fraction of precipitated solid

Our previously developed dynamic model[1] was simulated using the same feed flows and compositions, seed crystal amount and initial solution composition. Unknown model parameters were the apparent rate coefficient, k_{app}, and the order of the linear growth rate of crystals, n.

Results and Discussion

The reactor ran for several campaigns ranging from 30 to 125 hours. Figure 2 shows the first 70 hours of one such campaign, which indicates the reduction of the bed height.

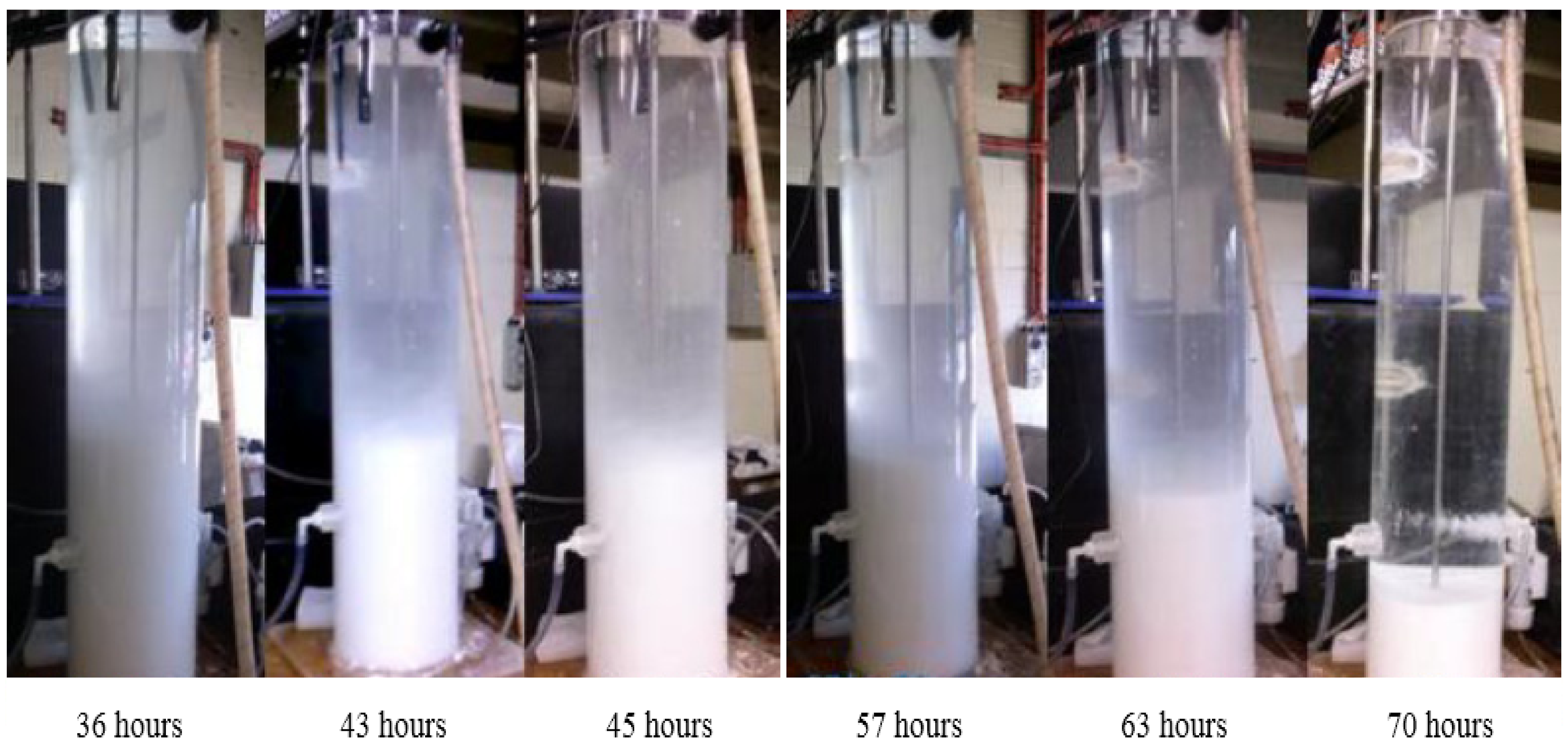


Figure 2: Operating nutrient recovery reactor showing bed height reduction throughout the recovery campaign

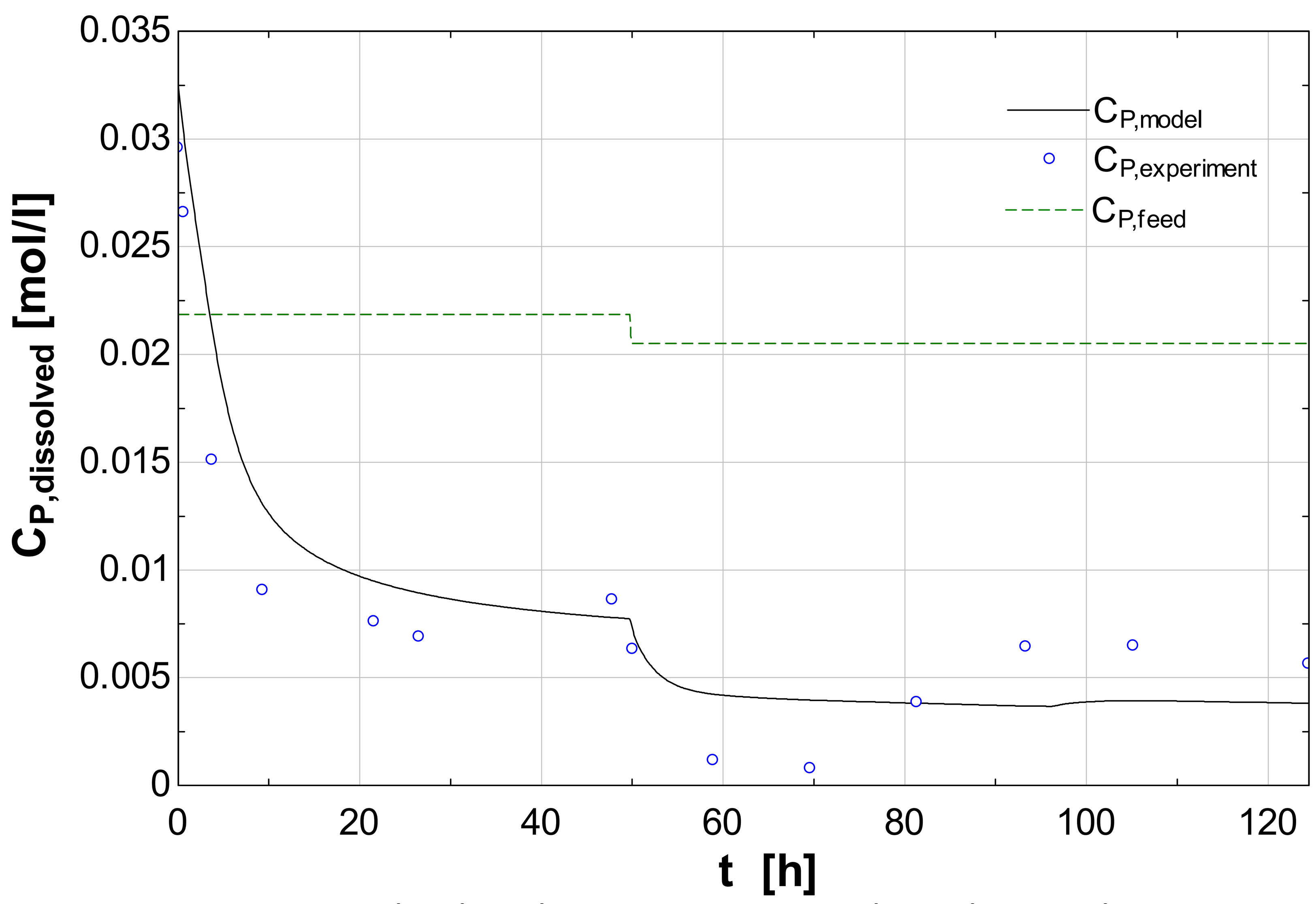


Figure 3: Orthophosphate concentration through a 125-hour campaign, showing feed, model-predicted and experimental values

Figures 3 and 4 show the time course of the orthophosphate concentration and solids mass fraction suspended in the reactor, respectively, for the experimental run and the associated model simulation. It is clear that the transient response of the process is well matched by the dynamic model.

We fit the k_{app} parameter to the orthophosphate data, given its enhanced confidence, and assuming a second order growth rate dependency. This gives a reasonable fit to the orthophosphate profile.

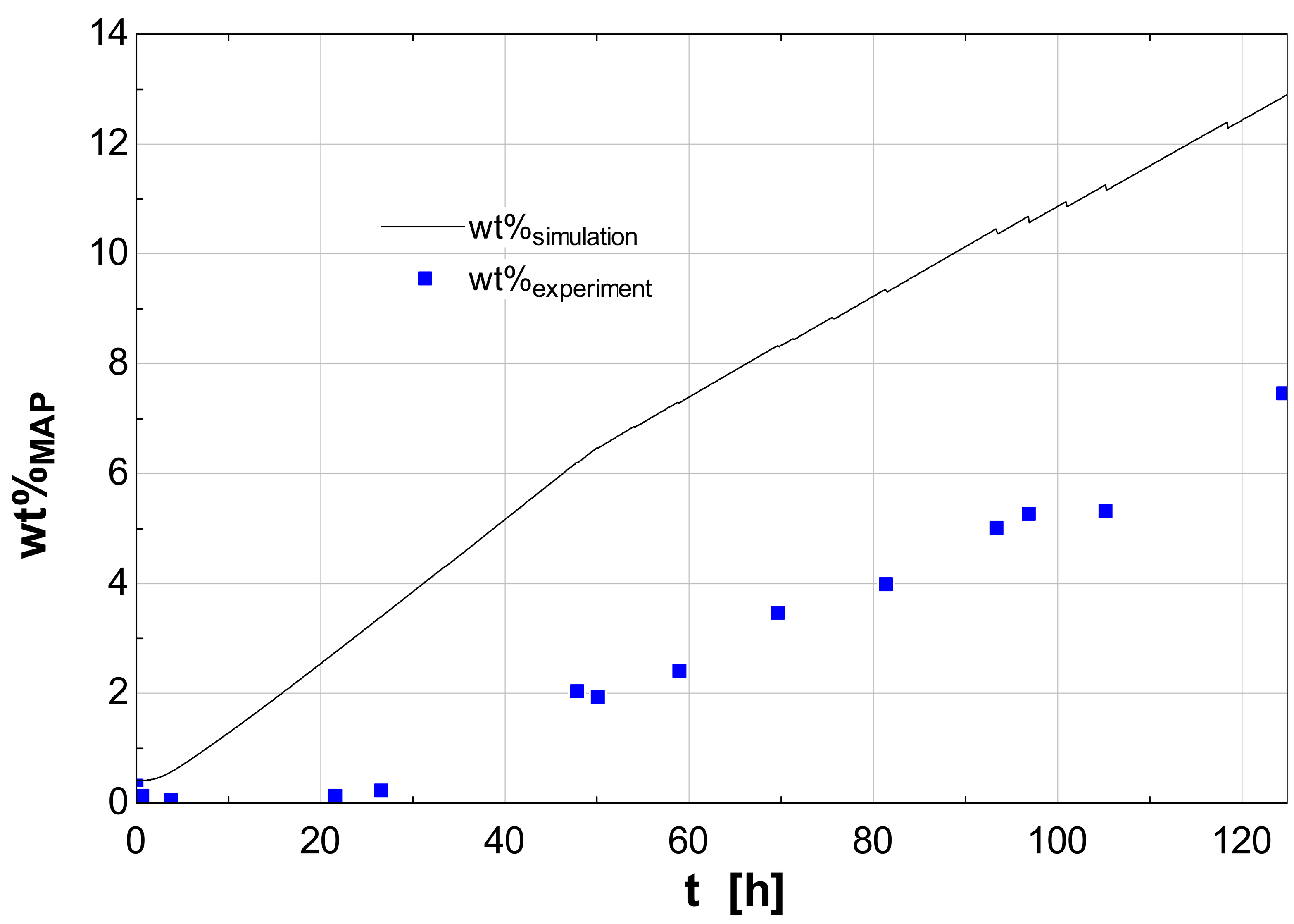


Figure 4: Solids mass fraction in reactor through nutrient recovery campaign. Solid line is model prediction and squares are data from bench scale reactor

Clearly, the model-predicted solids fraction differs substantially from the experimental results. This is likely due in part to the loss of solids in the first 24 hours of operation, when a significant amount of small struvite particulates carried over with the outlet stream.

One interesting feature of both the experimental data and the process model is the acceleration of the mass fraction of solid struvite in the reactor at the start of the campaign. In this early period the system has a lower available surface area for growth and/or secondary nucleation effects. However, with the eventual increase in surface area, the process becomes feed rate limited. It is evident from the simulation results that slowing the nutrient feed rate, gave a reduction in the rate of struvite production, but did lead to higher levels of nutrient recovery.

Recovery rates of phosphorus were in the range of 75% to 90% under the conditions evaluated.

References

[1]Schneider, P. A., Wallace, J. W., & Tickle, J. C. (2013). Modelling and dynamic simulation of struvite precipitation from source-separated urine. Water Science and Technology : A Journal of the International Association on Water Pollution Research, 67(12), 2724–32. doi:10.2166/wst.2013.184

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