Phosphorus Recovery from Source-Separated Urine under Hydrothermal Conditions

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Background

- **Phosphorus** needs to be removed from wastewater to decrease harmful environmental impacts such as eutrophication.
- The price of phosphate (PO_4^{3-}) fertilizers is increasing due to dwindling resources and high energy costs required for extraction[1].
- **Source-separated urine** is the separation of urine from feces at the source.
- From urine, PO_4^{3-} can be precipitated as **struvite** ($MgNH_4PO_4 \cdot 6H_2O$), which can be used as a fertilizer[1].
- **Hydrothermal (HT) treatment** is the simulation of high temperature and pressure conditions present under the Earth's crust for the formation of minerals.

Research Objective

Recover phosphorus in the form of struvite from source-separated urine at both ambient (AMB) and HT conditions. Determine if HT treatment increases struvite precipitation.

Materials and Methods

- A summary of the synthetic fresh urine (SFU) and synthetic hydrolyzed urine (SHU) used in this project is given in Table 1.
- Visual MINTEQ (VM) was used to computationally model mineral speciation at equilibrium for SFU and SHU.
- Table 2 summarizes the parameters varied for both AMB and HT condition tests.
- Samples from AMB and HT tests were submitted for inductively coupled plasma optical emission spectrometry (ICP-OES) to measure phosphorus and magnesium concentrations after precipitation.

Table 1[2] – Synthetic Urine Summary

SFU	SHU
Nitrogen in urea	Nitrogen in NH_4^+
Trace Mg^{2+} & Ca^{2+}	No Mg^{2+} or Ca^{2+}
pH ~6	pH ~9
Ionic strength ~0.15	Ionic strength ~0.47

Table 2 – Ambient and Hydrothermal Condition Variation Summary

Parameter	Values
pH	6, 9, &11
Added $MgCl_2$	0M, 0.007M, 0.014M, & 0.028M
% Hydrolysis	0% (SFU) & 100% (SHU)
Temperature*	75°C, 150°C, 225°C, & 300°C

*Hydrothermal conditions only

Results and Discussion

- VM predicted phosphorus removal would be greatest at higher pH for SFU (Figure 1). For SHU, VM predicted phosphorus removal would be best between pH ~7 to ~9 (Figure 2). Both SFU and SHU had increased phosphorus removal at higher Mg^{2+} concentrations.
- VM predicted several phosphate containing minerals would precipitate for SFU. Struvite cannot form in SFU because there is no ammonium present, and urea does not hydrolyze quickly. PO_4^{3-} would still be removed from SFU. In SHU, struvite was predicted to form.
- ICP-OES results for AMB and HT tests have not been completed. It cannot be determined at this time if HT treatment increases struvite precipitation from source-separated urine.
- The pH of SFU changed significantly after HT treatment. This indicated that HT conditions caused the rapid hydrolysis of urea. If true, struvite would be able to form from fresh urine, and waiting for natural hydrolysis would not be necessary.

Figure 1: VM predicted phosphate concentrations at equilibrium for SFU.

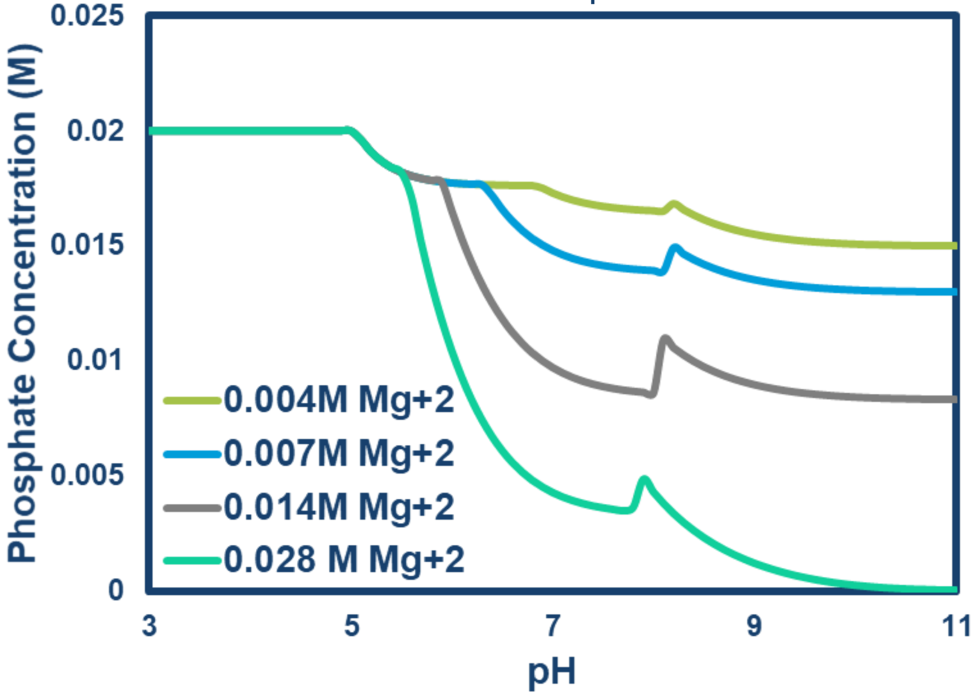
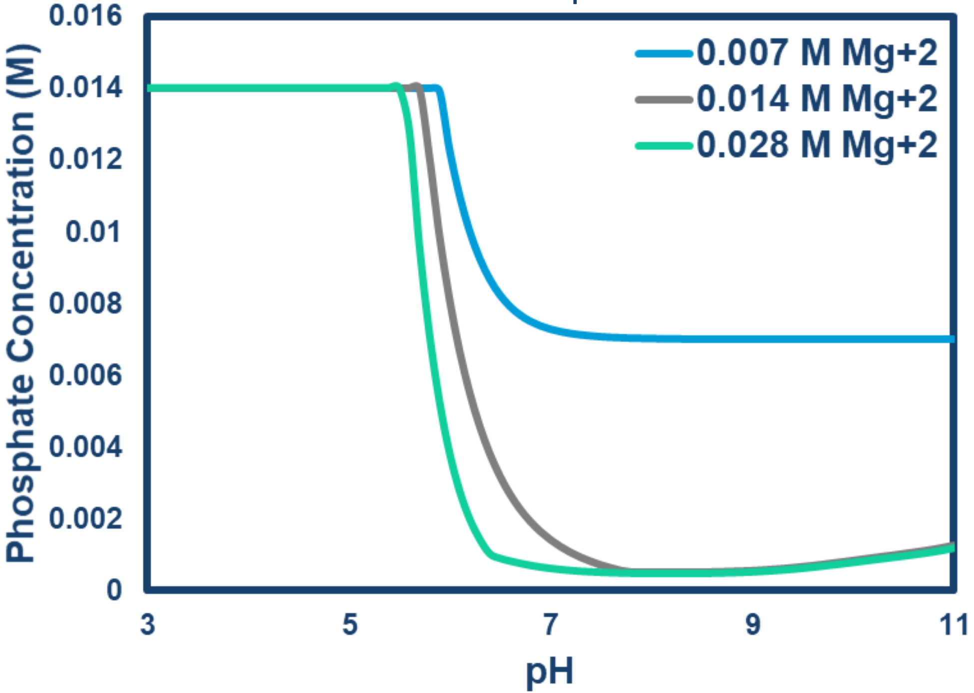


Figure 2: VM predicted phosphate concentrations at equilibrium for SHU.



Future Work

If the ICP-OES results indicate that HT treatment increases precipitation, tests will be replicated. At that time, ammonium analyses will be performed to indicate urea hydrolysis. Electron microscopy will be used to compare struvite crystals formed at AMB and HT conditions. HT crystals may make the phosphate in struvite more bioavailable to plants (i.e. HT struvite crystals may be a better fertilizer than AMB crystals).

References

(1) Mehta & Batstone (2013). Nucleation and growth kinetics of struvite crystallization. *Water Research*, 47 (8), 2890-2900.

(2) Landry, Sun, Huang, & Boyer. Ion exchange selectivity of diclofenac, ibuprofen, ketoprofen, and naproxen in ureolyzed human urine. *Water Research*, 68 (2015), 510-521.