Distributed wastewater treatment plants – A sustainable and economical phosphorus source through struvite recovery

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Problem

The global human demand for phosphorus (P) derived from phosphate rock, is estimated at 43.7 million metric tons (MT) in 2015, and is projected to increase 1% annually. [1] An estimated seventy billion MT of P_2O_5 remain in reserves that can be economically mined. Therefore, economically available P_2O_5 may be exhausted within this century. [2] A renewable fertilizer P source must be identified in order to feed the world's growing population, which is expected to reach 9.7 billion by 2050. [3] Municipal wastewater treatment plants (WWTPs) can be an attractive source of renewable P. Total P loads to WWTPs can range from 2.1 to 4.1 g/capita/day with a concentration range of 3.7 to 11 mg/L.

Hypothesis

The formation of struvite ($MgNH_4PO_4 \cdot 6H_2O$) is thermodynamically favorable in some wastewater streams and is relatively easy to harvest using crystallizers. Struvite may be used as a slow-release fertilizer to supply a renewable source of nitrogen (N), P, and magnesium (Mg). The intentional formation of struvite from wastewater has focused on large centralized WWTPs with anaerobic biosolids stabilization. Smaller, distributed WWTPs collect, treat, dispose and/or reuse wastewater at or near its source. For economic reasons, distributed WWTPs typically use aerobic processes to stabilize biosolids. Struvite formation from distributed WWTP aerobically digested filtrate can be a viable means of P recovery.

Study Locations

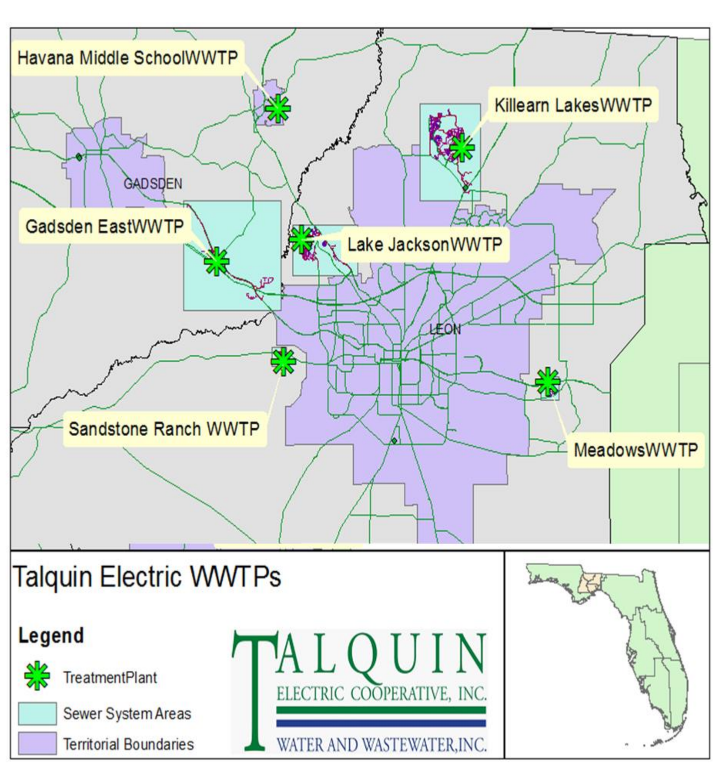

Fig. 1 Study Locations

Four distributed WWTPs in North Florida with treatment capacities from 371 to 2650 m^3/day and incoming P loads from 2 to 14 kg/day were investigated (Fig 1). The locations selected were to represent two of the three most common variations of wastewater treatment processes (Fig 2).[4] These locations treat wastewater solids by an aerobic digestion process, which is a biochemical oxidative stabilization of wastewater sludge

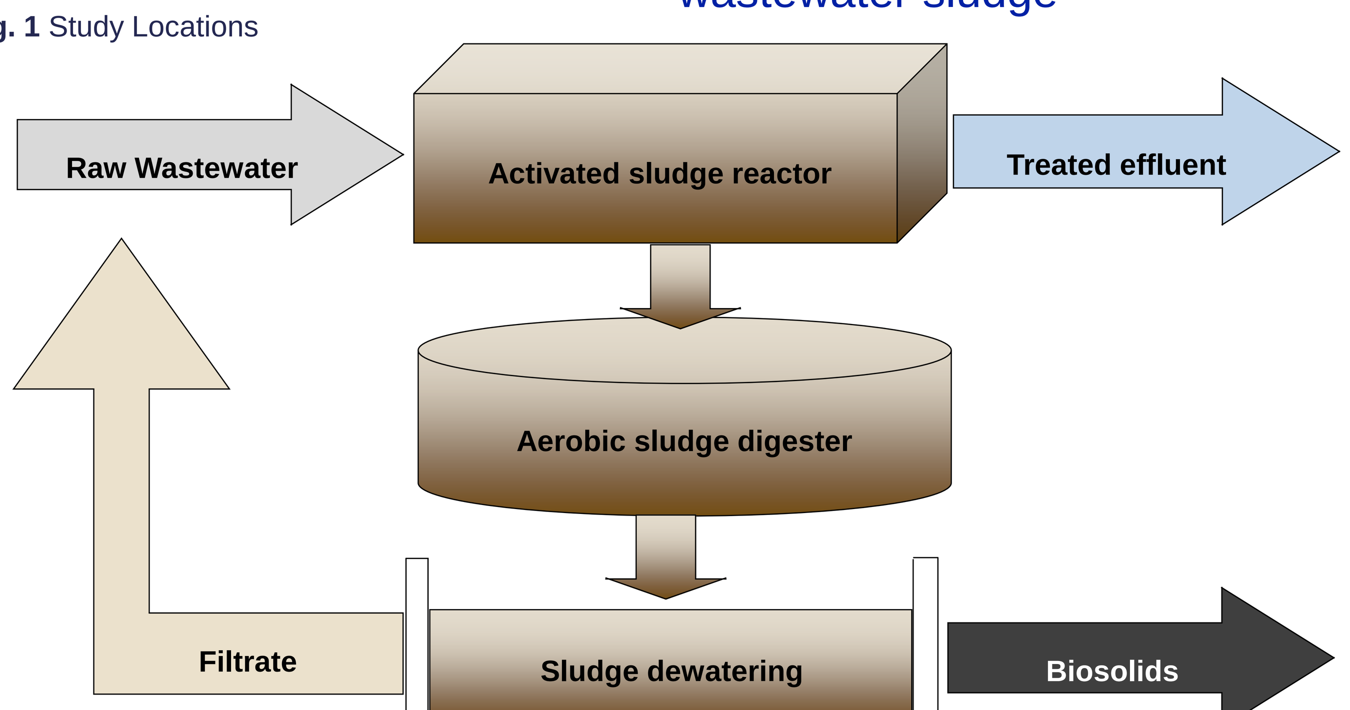

Fig. 2 Schematic representing the essential components of a small waste water treatment plant.

Project Overview

- The aerobic digester filtrate from each location was sampled six times from August 2014 to September 2015.
- A chemical equilibrium model was developed with Visual MINTEQ Version 3.0 to predict the feasibility of struvite production.
- The aerobically digested sludge digestates were measured for struvite constituents and cations known to interfere with struvite formation (Table 1).
- Struvite was formed by adjusting the pH of wastewater filtrate from an average of 7.0 to 8.5 using a base (NaOH) (Fig 3).
- Air sparging was investigated as an efficient and economical alternative to using base (Fig 4).
- Beaker experiments were used to compare struvite recovery using base additions with stirring versus air sparging.

Table 1. Aerobic filtrate chemical properties.

WWTP	pH	ORP (mV)	Alkalinity (as $CaCO_3$) (mM)	NH^{4+} (mM)	PO_4^{3-} (mM)	Mg^{2+} (mM)	Ca^{2+} (mM)	Fe^{3+} (mM)	Al^{3+} (mM)
Gadsden East	7.8 ± 0.4	269 ± 42	4.19 ± 1.4	8.18 ± 2.1	1.64 ± 0.5	1.12 ± 0.1	1.26 ± 0.3	0.02 ± 0.01	0.04 ± 0.03
Killearn	8.0 ± 0.4	225 ± 37	12.48 ± 2.3	30.02 ± 6.8	4.66 ± 1.3	1.17 ± 0.2	1.15 ± 0.4	0.02 ± 0.01	0.03 ± 0.02
Lake Jackson	7.8 ± 0.4	271 ± 32	3.47 ± 0.5	7.07 ± 1.3	1.27 ± 0.3	0.74 ± 0.1	1.02 ± 0.1	0.01 ± 0.004	0.03 ± 0.02
Meadows	8.1 ± 0.3	227 ± 33	6.06 ± 2.1	9.59 ± 2.9	0.34 ± 0.1	0.41 ± 0.1	0.93 ± 0.4	0.04 ± 0.04	0.05 ± 0.05

Values represent mean ±standard deviation (n = 6).

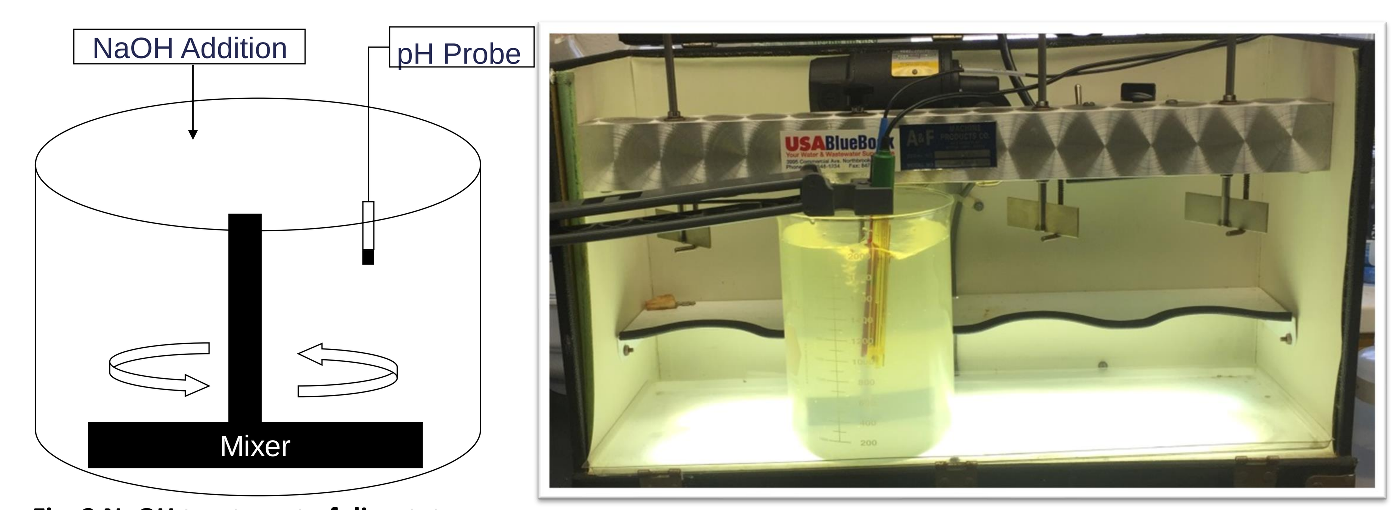

Fig. 3 NaOH treatment of digestates

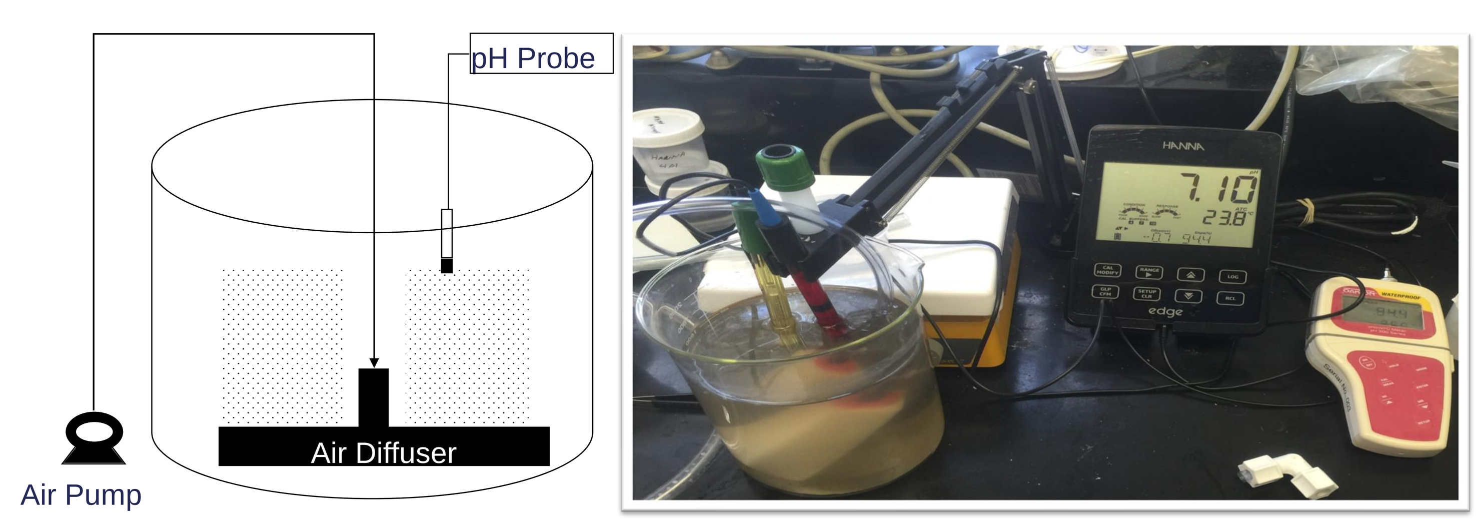

Fig. 4 Air sparged treatment of digestates

Formation

The NaOH and Air sparged experiments on digestates from all the WWTPs formed struvite (Table 2) with in 93-100% of the amount predicted by the model.

Table 2. NaOH versus Air sparging struvite formation.

WWTP	NaOH	Air Sparge
	(g/m^3)	
Gadsden East	88.2 ± 1	107.8 ± 4.25
Killearn	352.1 ± 5.05	353.1 ± 2.8
Lake Jackson	71.6 ± 0.2	74.9 ± 0.8
Meadows	27.1 ± 0.12	30.9 ± 0.21

Struvite Yield

Struvite formation in the air-sparged treatment showed a 1-22% increase in yield from the wastewater digestate in the NaOH beaker treatment (Fig. 3).

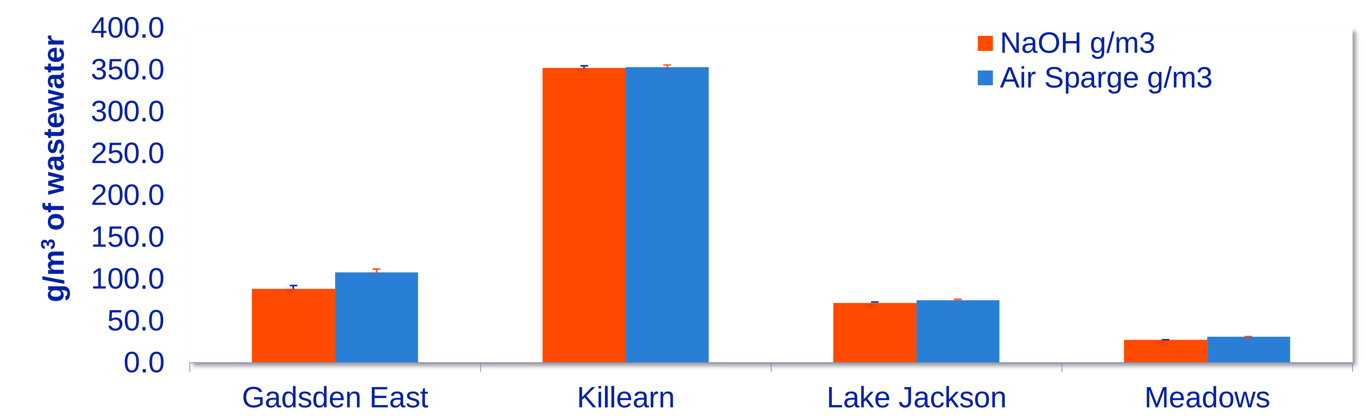

Fig. 3. Struvite yield

The purity was measured by the mass of precipitate formed minus the calculated mass of struvite. The purity increased from 12 to 45% between the NaOH treatment and the Air sparged treatment and can be seen in Figures 4a and 4b from the Killearn WWTP.

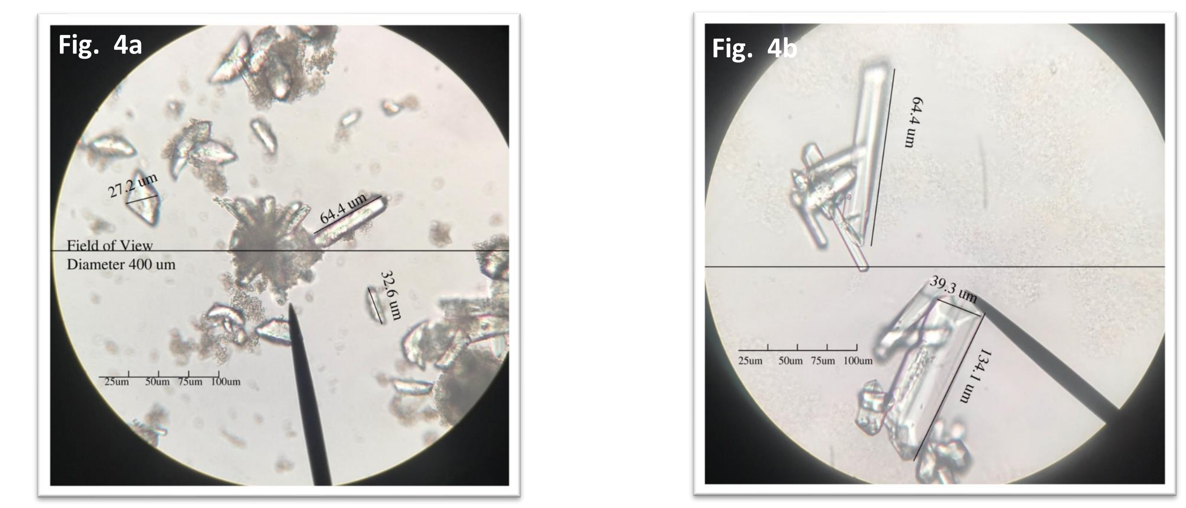

Fig. 4. Struvite crystals Killearn WTTP a) NaOH adjusted b) Air Sparged

The distributed WWTP studied could produce 277-3609 kg of struvite per year (Table 3).

Table 3. Estimated annual struvite production.

Treatment	Gadsden East	Killearn	Lake Jackson	Meadows
	(kg/year)			
NaOH	909	3,598	823	277
Air Sparge	1,111	3,609	861	316

Conclusions

- Phosphorus recovery via struvite from distributed WWTPs appears feasible based on modeling results and experiments.
- Air Sparging increased struvite yield and purity.
- Assuming an average struvite formation rate of 212 g/m^3 of wastewater, the combined distributed WWTPs in the United States are capable of producing 1.2 million metric tons of P as P_2O_5 per year.

References

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2) Cordell, D., White, S., 2014. Life's Bottleneck: Sustaining the World's Phosphorus for a Food Secure Future. Annual Review of Environment and Resources 39, 161–188. doi:10.1146/annurev-environ-010213-113300

3) Metcalf & Eddy, Tchobanoglous, G., Stensel, H.D., Tsuchihashi, R., Burton, F.L., Abu-Orf, M., Bowden, G., Pfrang, W. (Eds.), 2014. Wastewater engineering: treatment and resource recovery, Fifth edition. ed. McGraw-Hill Education, New York, NY.

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