Vertmont's Phosphorus Innovation Challenge

Submitted by:

The Village of Essex Junction, The Chittenden Solid Waste District, The University of Vermont

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Project overview

A proprietary pipe descaling technology (PDT) is widely used throughout the United States in thousands of successful scale formation control applications. This technology could prove effective for phosphorus removal in Vermont sized wastewater applications. The technology uses an induced electric field of variable amplitude and frequency that can promote precipitation of crystalline minerals (struvite) without the dangerous and damaging adhesion to pipes, pumps or in tanks. The PDT coupled with electric-filtration cell will be employed to enhance phosphorus capture. This pilot application seeks to prove effective removal and capture of phosphorus from wastestreams treated throughout the Lake Champlain Basin.

Description of Project

Struvite (magnesium ammonium phosphate hexahydrate or $MgNH_4PO_4 \cdot 6H_2O$) is a crystalline compound formed when magnesium ammonium phosphate ions are dissolved in a wastestream's liquid water phase above saturation concentrations. In many instances another compound containing phosphorus may also be present, vivianite or hydrated ferrous phosphate; $Fe_3(PO_4)_2 \cdot 8H_2O$. Both of these compounds may be present in a wastewater treatment system's treatment processes and can lead to problematic scale formation on treatment plant surfaces clogging pipes, fouling valves and otherwise creating severe maintenance problems.

Struvite generation can also be employed to remove phosphorus from waste streams. There are several commercial scale proprietary struvite generation systems on the market that are geared towards farm and municipal wastewater systems that are on a scale 10 times larger than applicable to facilities in Vermont. The purpose of this proposal is to test the innovative application of pipeline descaling technology (PDT) as a means of enhancing struvite generation and phosphorus removal in a cost effective manner. Additionally, this proposal will explore an innovative oscillating electric-field assisted membrane filtration approach (or technology) to capture and recover struvite and/or vivianite from the stream exposed to PDT. Enhanced struvite generation and capture would improve the scalability to Vermont sized water resource recovery facilities and Vermont sized farms. *The hypothesis of this pilot research is that the pipe descaling technology coupled with oscillating electric-field assisted membrane filtration will prevent scaling, increase the amount particulate crystalline struvite and/or vivianite in suspension, and enhance the recovery of these phosphorus containing minerals from wastewater streams.*

Process and Technology Applied

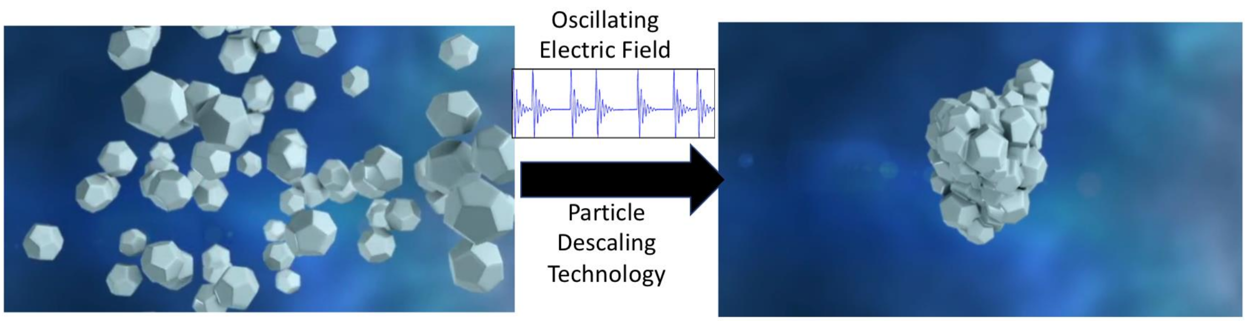
The Lake Champlain Phosphorus Total Maximum Daily Load (TMDL) has lowered phosphorus (P) discharge requirements on larger wastewater treatment and agricultural facilities. This stringent P control requirement necessitates the capture and removal of nearly all phosphorus present by additional process control means in order to achieve compliance. With conventional wastewater infrastructure currently in place, phosphorus is captured biologically or chemically and often released and recirculated through treatment processes by means of dewatering centrate (or filtrate), sludge storage decant and other forms of internal wastewater process recycle. Additional P is imported to facilities from waste generated outside of the facility service area. These wastes include but are not limited to septage, food process waste and brewers waste.

Phosphorus can be managed and exported from water resource recovery facilities and farms through the generation of and subsequent removal of struvite or vivianite. Often, wastewater facilities strive to control the chemical reaction that generates struvite/vivianite to prevent pipe clogging and other mechanical issues that crystalline scale can present. However, there are emerging technologies that form struvite and capture it as part of several proprietary processes. These full-scale commercial technologies are particularly effective in dealing with soluble phosphorus as it can be chemically manipulated to form a precipitate that is sold as a fertilizer component. Unfortunately for Vermont, applications of these technologies have definite negative economies of scale constraints. Our facilities are a fraction of the size required to be cost effective for these proprietary process companies' technologies.

Struvite and / or vivianite generation for control of these various process phosphorus sources will result in increased wastewater treatment operational efficiencies, lower the amount of phosphorus recirculated throughout the treatment system and will add the benefit of more reliable final effluent compliance as well as lower P in treatment process residuals. The phosphorus removed could potentially be captured in a phosphorus rich byproduct stream that could be a valuable resource and be exported out of the Lake Champlain Basin. The application of this pilot technology poses the potential to meet much needed P removal technology at a scale that is appropriate for Vermont based installations.

Proposed Approach to Control Struvite and/or Vivianite Scaling

Pipe descaling technology (PDT) developed in the United Kingdom is now widely used throughout the United States. There are over a thousand successful scale formation control installations for industrial and commercial applications across America plus a dozen or more recent applications at wastewater treatment facilities. Third-party evaluations reported that this technology is easy to install and consumes less than $10 of electricity per year. This technology may prove very effective for enhanced P removal in Vermont sized wastewater applications for struvite and / or vivianite production (depending on the chemical characteristics of the wastestream being addressed) and removal from wastewater treatment facility side streams. The technology uses an induced electric field of variable amplitude and frequency that can promote precipitation and stabilization of crystalline minerals in suspension that can be carried away with the flow without the dangerous and damaging adhesion to pipes, pumps or in tanks (Fig 1).



BEFORE **AFTER**

Figure 1. Minerals in wastewater streams without treatment (left) and with treatment with particle descaling technology (PDT). The PDT increases the crystallization and stabilization of minerals that are carried away by the flowing stream. In the absence of PDT the minerals are highly prone to precipitation and scaling.

There are several industrial and commercial-level success stories associated with PDT in scale control at wastewater treatment facilities. For example, a 90-day test conducted by Tulsa Southside Wastewater Treatment Plant, Tulsa, Oklahoma revealed that the proposed pipe descaling technology could be used to release any heavy encrustation of struvite from the distribution pipes and Belt Filter Press (BFP) back into the stream, in addition to preventing any struvite build up in the systems (Fig 2). Using this application for highly concentrated liquid waste may prove to safely remove phosphorus in many forms from waste that are treated throughout the Lake Champlain Basin.

Figure 2. Baseline condition of Belt Filter Press (BFP) before applying proposed pipe descaling technology (left). Condition of BFP Drum Surface at the end of 90-day test period.

Proposed Approach to Struvite and/or Vivianite Capture

PDT has been proven to be very successful in controlling scaling on many technically important surfaces and systems. Since the PDT appears to produce P rich particles in the wastestream's liquid phase, it has been suggested that P removal may be realized by removing these crystalline solids by innovative filtration techniques. To our knowledge, this proposed investigation uniquely combines the proven scale controlling PDT with an innovative oscillating electric-field assisted membrane filtration to potentially capture the PDT-induced stabilized minerals. Various forms of filtration can be tested to capture and assess the struvite / vivianite generated to ensure a viable product for removal and distribution out of the Lake Champlain Basin as a resource. If the material is not of sufficient quantity and quality, other means of management would be considered. Below we describe the two filtration approaches that we will evaluate in this pilot research. The first approach will (a) employ simple dead-end filtration to capture and recover PDT-stabilized minerals, and (b) assess the reusability of the membranes for continued use. The second approach will (a) employ oscillating electric-field cross flow membrane filtration to concentrate and recover PDT-stabilized minerals, and (b) assess the reusability of the membranes. In all experiments, the nature of the minerals will be evaluated using scanning electron microscopy (SEM: visual crystal morphology and dry size) and X-ray diffraction (XRD: crystalline structure).

The proposed pilot application would recirculate the liquid fraction of anaerobically digested digestate (digester supernatant or dewatered centrate) for precipitation and filtration of phosphorus in particulate crystalline form using the descaling technology. The remaining liquid stream would be returned to the wastewater process at reduced P concentrations for further treatment.

***Approach 1. Combined PDT and Dead-End Membrane Filtration*.**

The type of filtration that will be employed to capture the PDT-induced crystalline minerals depends on the particle size distribution of the mineral clusters, which will be assessed using Dynamic Light Scattering (DLS) technique (Malvern Zetasizer ZSP) in Dr. Badireddy's laboratory at the University of Vermont. The knowledge of particle size distributions (hydrodynamic size) will aid in the determination of an appropriate filtration technique (microfiltration (MF) or ultrafiltration (UF)) for capturing the particles in suspension. The MF and UF are well known for capturing particulates in water, however, they are also prone to fouling, i.e., particles deposited on the membrane surface block the membrane pores after a brief period of filtration, which decreases the separation efficiency and increases the cost of membrane filtration. The exciting aspect of the proposed PDT is that, based on the Third-Party evaluations thus far, it alters the fundamental nature of the crystalline clusters making them much softer, non-sticky, and easier to wash off from the surfaces. In the membrane filtration experiments accumulated crystalline clusters will be washed off periodically with the filtrate water. We will conduct measurements to determine appropriate filtration method and will optimize operating conditions to achieve best struvite and/or vivianite recovery, in addition to keeping the membranes from severe fouling. The positive results from these experiments could lead to efficient and enhanced capture of struvite and vivianite from the feed streams treated with PDT. The schematic of the set-up is shown in Figure 3.

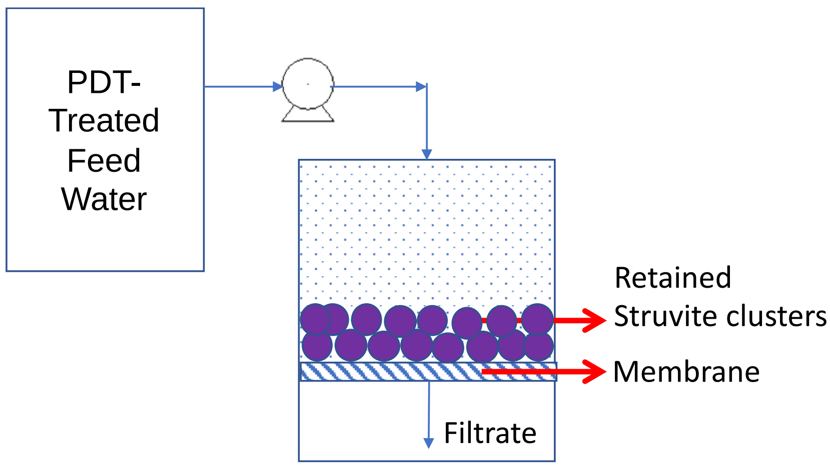


Figure 3. Conventional dead-end membrane filtration is employed to capture and recover PDT-altered struvite and/or vivianite mineral clusters.

***Approach 2. Combined PDT and Oscillating Electric Field Cross Flow Membrane Filtration*.**

The goal of this evaluation is to test a custom-built filtration unit, possibly powered by a renewable energy source. The development and testing of the filtration cell is a part of ongoing efforts in Dr. Badireddy's laboratory at UVM. We will employ this filtration unit to evaluate its efficacy to capture and recover struvite and/or vivianite from PDT treated streams.

In contrast to Approach 1 (Dead-End Filtration), the PDT treated stream will be configured in a cross-flow arrangement over a custom-designed portable filtration cell equipped with MF or UF membrane sandwiched between stainless steel electrodes. Each electrode serves as a cathode and an anode, and they can be activated with a low-frequency alternating current (AC) to deliver an oscillating-field across the membrane. In the oscillating-field the struvite and/or vivianite clusters will also attain an oscillatory motion proportional to their surface electrical charge (zeta potential). Under cross-flow conditions the oscillating clusters (particles) will not have sufficient time to deposit and form scale on the membrane surfaces, and thus be carried away by virtue of the cross flow. This technique could very efficiently concentrate and recover struvite and/or vivianite from PDT-treated streams, and it also keeps the membrane surface free of scale for a long period of time. The surface charge (zeta potential) of the clusters will be calculated from the electrophoretic mobilities (zeta potentials) of the clusters measured using Malvern Zetasizer ZSP. A conceptual schematic of the set-up is shown in Figure 4.

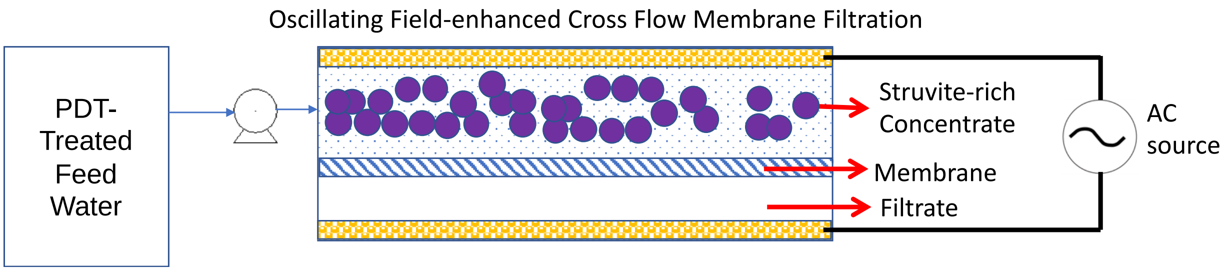


Figure 4. A novel oscillating electric field enhanced crossflow membrane filtration is employed to capture and recover struvite and/or vivianite clusters from PDT-treated streams. The oscillating AC field induces oscillatory motion into the clusters and thereby prevents the crystals from forming scale on the membrane surface. This technique concentrates the minerals to on the membrane surface by removing the water as filtrate. The crossflow on the membrane surfaces carries away the concentrate out of the filtration cell. This technique also keeps the membrane clean during operation.

The pilot would be set up to process an assortment of liquid waste streams including anaerobically digested sludge and low solids manure slurry liquid, in order to determine the potential effectiveness of this innovative application of this proven descaling device. Various coagulants and flocculants could be added to evaluate their value in enhancing struvite filtration and removal from the waste stream being treated. The low energy descaling unit has an energy consumption equivalent to that of a 100 Watt light bulb and requires minimal space. Application would be of interest to Efficiency VT and to wastewater treatment and agricultural waste management facilities. There could also be potential for broader application in the field that could be explored based on performance of this first pilot test.

Through pilot process optimization, the projected ability to remove phosphorus is considerable and at a significant saving as compared to proprietary conventional struvite generation systems.

Pilot Testing objectives and potential outcomes:

- Proven technology in new and unique applications
- Capture of finer forms of bound and un-bound phosphorus in process streams for generation of struvite / Vivianite on a Vermont size scale
- Characterize the byproduct generated in the pilot for quantification of P capture
- Evaluate various physical filtration mechanisms for capture of the slurry generated. Such methods are to include but not limited to settling, course filtration, micron filtration as well as submicron filtration
- Consider the potential for coagulants and flocculants to aid and enhance performance of the pilot system
- Explore the potential to liberate/remove phosphorus for movement out of the Lake Champlain Basin
- Evaluate the struvite byproduct for next steps of additional water removal and stabilization for shipment out of the Lake Champlain Basin
- Potential capital cost reduction for wastewater facility phosphorus control plan (PCP) implementation
- Potential energy savings over conventional biological, physical and chemical wastewater P reduction processes
- Decreased chemical use in wastewater phosphorus removal applications
- Decreased P in Biosolids land applied or exported for further processing

Project Team and Qualifications

Appala Raju Badireddy PhD.

Dr. Badireddy is an assistant professor of civil and environmental engineering at the University of Vermont. He has a background in chemical and environmental engineering with extensive research experience in water quality engineering, and solid-and liquid-waste resource recovery. He develops novel membrane filtration nanotechnologies for water and wastewater treatment, phosphorus recovery, and remediation of emerging contaminants including PFOS and PFOA. The feed water characterization and membrane filtration will take place in his laboratory (Votey Hall, *Room no*. 220) at the University of Vermont. The laboratory space includes a cell culture room and two rooms containing equipment and bench space for chemical, biochemical, and molecular assays. Designated areas are approved for biohazard and cell culture research. For chemical analysis, Dr. Badireddy laboratory space includes a six-foot chemical fume hood and a biosafety cabinet, various bench-scale membrane filtration apparatus, API3200 LC/MS/MS, CytoViva Hyperspectral Imaging Microscope, and Malvern Zetasizer Nano ZSP all dedicated to water and wastewater engineering research. He also has access to Perkin-Elmer 7000DV Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES) with CCDarray detector and a cyclonic spray chamber and concentric nebulizer for liquids, and various microscopy and spectroscopy techniques at UVM. In addition, the 900 sq. ft of Dr. Badireddy's and the ~2,000 sq. ft. Civil & Environmental Engineering Program Environmental Laboratory has a wide array of analytical instruments available for project use including an analytical balance, a Millipore water system, muffle furnace, drying ovens, and UV-VIS Spectrophotometer for sample analysis. He will serve as lead researcher and technical resource for this pilot project.

Jeffrey Hullstrung
Mr. Hullstrung is a Senior Energy Consultant with Efficiency Vermont. His primary work is with water supply and wastewater treatment facility conservation and efficiency enhancement as well as…. Jeff will provide oversight to the project from an energy efficiency and application perspective in applying the pilot to broad application in Vermont water resource recovery facilities.

James Jutras Water Quality Superintendent for the Village of Essex Junction
Mr. Jutras will serve as project coordinator and installation site host for the pilot. James has over 35 years of experience in industrial and domestic wastewater treatment using innovation to gain compliance. His industrial experience was in concentrated and complexed/chelated (water soluble) heavy metal removal using early innovative applications (1980's) with ion exchange, emerging chemical applications as well as ultra-filtration. Municipal experiences with innovation led to two installations of combined heat and power installations in Essex Junction as well as the facility serving as a regional resource for receiving and treating high strength wastes.
James has successfully applied for and managed many grants and construction projects for the Village of Essex Junction in water quality and in alternative energy. The facility is the recipient of the 2017 NEWEA Energy Management Award, the 20X EPA Facility Maintenance Award, 20XX Governors Award for Energy and the Environment and has been featured in BioCycle and Treatment Plant Operator Magazines.

Josh Tyler
Mr. Tyler will also serve to coordinate the project for applicability to the other Chittenden County Water Resource Recovery Facilities. Josh manages Chittenden County's sewage sludge solids for the District and has multiple years' experience in the environmental engineering field. Past projects include modeling p transport on small scale agricultural fields with significant topographical variability and investigating a regional sludge solids treatment facility focused on the removal of phosphorus.

James W. Morris, Ph.D., P.E.
Dr. Morris will serve as technology installer and technical support.
James Morris offers the broad capabilities, knowledge and understanding gained through more than 40 years of engineering experience (over 30 years of environmental process engineering). As an environmental engineering consultant he is responsible for study, technical evaluations, design, and operational guidance of processes to treat, handle, convey, and discharge liquid and solid wastestreams using aerobic and/or anaerobic biological and physical-chemical technologies. Dr. Morris has the in-depth experience as an engineer / scientist who has helped to foster new technologies (twelve patents total) and improved operating techniques through applied research. James is able to address the many sides of environmental issues and understand varied viewpoints as someone who has dealt directly with and taught a wide array of environmental processes and impacts; as consultant, mentor, technology provider, researcher and professor. He has the hands-on, down to earth, can-do approach of an engineering practitioner. James is a registered Professional Engineer in Vermont and Maine

Preliminary Budget
(subject to further discussion and modification)

	Budget	Match	Request
Equipment HydroFlow	$30,000	$15,000*	$15,000
Laboratory Testing	$4,500	$ 500*	$ 4,000
Equipment Rental	$5,000		$ 5,000
Filters and expendables	$2,000		$ 2,000
Outside Consulting Services	$5000		$ 5,000
UVM Grad Student Stipend (4.5 month's salary +12% fringe+ tuition)	$17,700		$17,700
UVM F & A charged at 56% for FY2018	$10,000		$10,000
Total Grant Request			$58,700

*Efficiency VT pledge plus funding from the Village of Essex Jct.

Note: other in kind dollars and time pledged by the Essex Jct. facility including but not limited to coagulants, flocculants and other operational equipment, chemical, set up, etc. Details are not defined at this time.