

# Vermont Phosphorus Innovation Challenge Final Technical Report

## Pe<sup>-</sup>Phlo

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## 1.0. INTRODUCTION

The investigation activities described herein were conducted by Civil and Environmental Engineering graduate students and the PIs from the University of Vermont, Essex Wastewater Resource Recovery Facility (WRRF), James Morris & Associates Inc., Efficiency Vermont, and Chittenden Solid Waste District.

The purpose of this investigation was to develop and test an innovative phosphorus recovery device ( $Pe^-Phlo$ ) for phosphorus reduction in wastewater streams in a cost-effective manner. The  $Pe^-Phlo$  device is composed of two units that are critical for successful recovery of dissolved phosphorus: 1) commercial particle descaling technology a.k.a. “*HydroFlow*”, and 2) a custom-built electric filtration cell. These units can be operated individually or in tandem as per treatment requirements dictated by dissolved phosphorous, ammonia, and magnesium concentrations, and the size of colloidal phosphorus-containing crystals formed during the treatment. In addition, the pulsed-electric fields generated by *HydroFlow* should avoid scale build-up in distribution pipes carrying the wastewater streams. The enhanced phosphorous recovery in the form of struvite or struvite-like minerals (i.e., magnesium ammonium phosphate (MAP) hexhydrate or  $MgNH_4PO_4 \cdot 6H_2O$ ) using  $Pe^-Phlo$  device would improve the scalability to Vermont sized water resource recovery facilities and Vermont sized farms.

The hypothesis of this study is that the *HydroFlow* coupled with oscillating electric-field assisted membrane filtration can precipitate struvite, and consequently enhance the phosphorus removal from wastewaters. In addition, the wastewaters treated with *HydroFlow* exhibit a lower tendency to generate hard scale on surfaces of the conduits (or distribution pipes and membranes). To test this hypothesis, a bench-scale  $Pe^-Phlo$  device was developed and tested in the batch as well as continuous mode treatment using dewatering centrate obtained from Essex WRRF. Additionally, the role of seed additives (e.g., magnesium ions) on struvite precipitation was examined. The seeding approach was employed to induce precipitation and thereby enhance struvite recovery efficiency. The dewatering centrate samples before and after treatments were analyzed using APHA Standard Methods (SM), Environmental Protection Agency (EPA) methods, colorimetric assays, and inductively coupled plasma-atomic emission spectroscopy (ICP-AES). The struvite crystals formed under various treatments were characterized using scanning electron microscopy (SEM), energy dispersive X-ray spectroscopy (EDS), X-ray diffraction (XRD) spectroscopy, X-ray fluorescence (XRF) spectroscopy, and brightfield microscopy.

## 2.0. LABORATORY METHODOLOGY

**2.1. Raw Source Water:** The dewatering centrate was obtained from the Essex WRRF located at Essex Junction, Essex, Vermont. 10 L of centrate was collected and transported to Dr. Badireddy’s laboratory within 1 h and stored at 4 °C until further experimentation. The centrate sample was settled and stored at room temperature prior to the experimentation. At the time of sampling, a portion of the sample was sent to Endyne Inc. laboratory (Vermont) for the chemical composition analysis. A duplicate sample was also analyzed in Dr. Badireddy’s lab at UVM. Table 1 shows the chemical composition of the centrate employed for this investigation. The results showed the presence of magnesium (21 mg/L), ammonia (990 mg/L), and phosphorus (130 mg/L, dissolved) in the centrate sample. These three components are collectively known as MAP and are responsible for struvite precipitation under appropriate conditions. The centrate has a pH of 7.54 at 22.7 °C.

**Table 1.** The characteristics of centrate sample obtained from the Essex WRRF on 03/13/2019

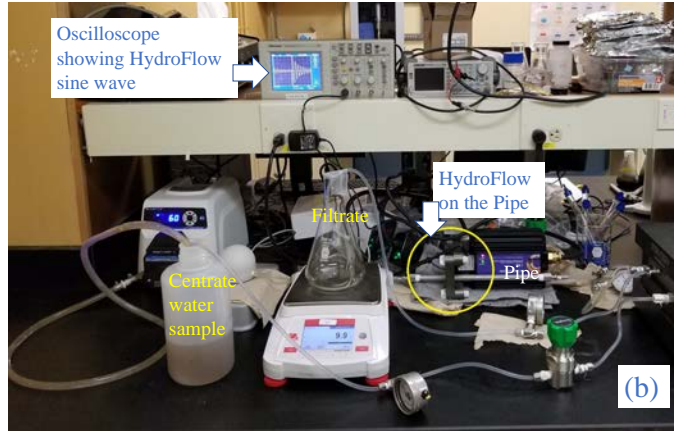
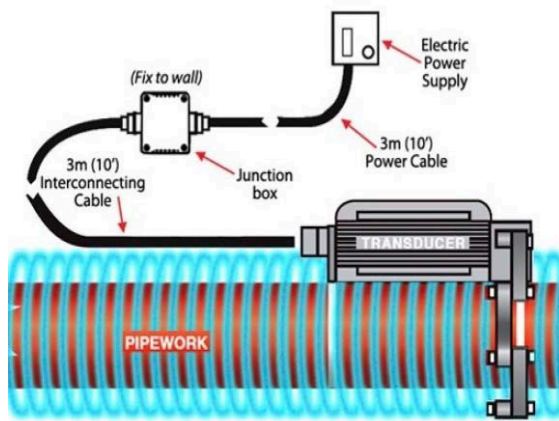
Parameter	Result	Units	Method
BOD-5 day	99,000	mg/L	SM 5210B(11)
COD	110,000	mg/L	Hach8000/EPA410.4
Conductivity at 25 °C	8,720	µmhos/cm	EPA 120.1
Ammonia as N	990	Mg/L	EPA 350.1, R.2
pH	7.54	SU at 22.7 °C	SM18 4500- H B
<b>Phosphorus, Total Dissolved</b>	<b>130</b>	mg/L	EPA 365.1, R.2
Phosphorus, Total	150	mg/L	EPA 365.1, R.2
Solids, Total Dissolved	1,690	mg/L	SM 2540C-97
Solids, Total Suspended	220	mg/L	SM 2540D-97
Metals Digestion	Digested		EPA 3015A
Calcium, Total	48	mg/L	EPA 6010C
Iron, Total	7.1	mg/L	EPA 6010C
Magnesium, Total	21	mg/L	EPA 6010C
Potassium, Total	170	mg/L	EPA 6010C
Sodium, Total	150	mg/L	EPA 6010C

### STAGE I

Pre-development stage includes the purchase of particle descaling technology (*HydroFlow Inc. USA*) and building a custom-designed electric filtration cell. These two units were assembled and developed into an innovative  $Pe^-Phlo$  technology for the VPIC project.

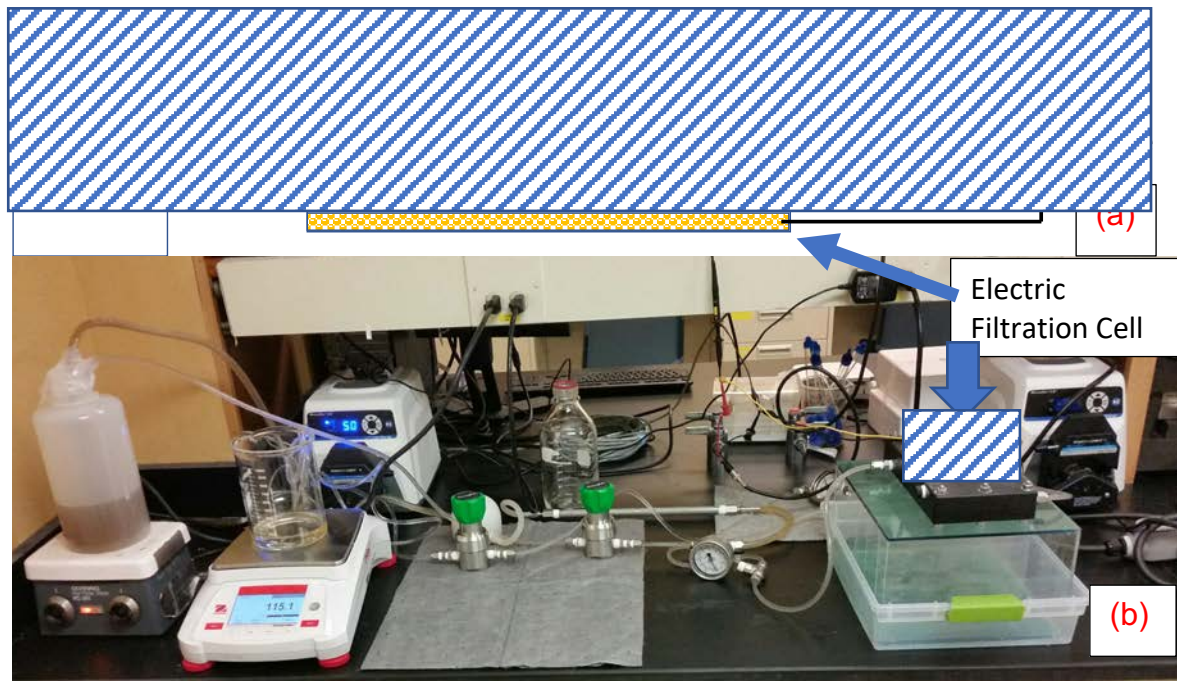
**2.2. Development and Operation of  $Pe^-Phlo$  device:** The  $Pe^-Phlo$  device is composed of two units that are critical for successful recovery of dissolved phosphorus: 1) commercial particle descaling technology (PDT) a.k.a. “*HydroFlow*”, and 2) a custom-built electric filtration cell. The description and working principle of the components is described below.

**2.2.1. Commercial particle descaling technology a.k.a. “*HydroFlow*”:** *HydroFlow* is powered by the patented *Hydropath* technology. When properly installed on any type of pipe material (Figure 1), it induces a  $\pm 150$  kHz, oscillating sine wave, alternating current (AC) signal. The electric induction is performed by a special transducer connected to a ring of ferrites. The unit attaches around an existing pipe made of any material and no plumbing or cutting of the piping system required (Figure 1a). It uses 120 V power and consumes less than \$10 of electricity per year. The pipe and the flowing fluid act as a conducting medium, which allows the signal to propagate. The induced AC signal is believed to cause the mineral ions that make up **struvite** to form **loosely held together clusters**. When certain conditions are created (e.g., pressure change, temperature change, and high mixing intensity (i.e., turbulence or shear forces)) the clusters precipitate out of solution and form stable crystals of struvite that remain in suspension. The crystals are not stable to adhere to surfaces as hard scale and are carried away with the flow. Because hard scale no longer accumulates, the shear forces created by the flowing liquid erode and soften existing scale deposits over time. **It is important to note that constant liquid flow is required to remove scale deposits from a system.** The bench scale *HydroFlow* device used in this investigation is shown in Figure 1b.



**Figure 1.** The pipe and flowing liquid act a conducting medium, which allows the electric signal generated by the *HydroFlow* device to propagate in the liquid (a); the electric signal interacts with the ionic species present in water to induce particle cluster formation. A bench-scale  $Pe^-Phlo$  device with the *HydroFlow* installed on the pipe is shown in (b).

**2.2.2. Custom-built Electric Filtration Cell:** A bench-scale electric filtration cell was developed at UVM. This filtration cell is designed to withstand transmembrane pressure up to 70 psi, which means microfiltration or ultrafiltration can be implemented depending on the treatment requirement. The filtration cell was equipped with two graphite electrodes with one on the feed side (wastewater) and the other on the permeate (filtered water or filtrate) side. A membrane is situated between the two electrodes separating the feed and permeate side (Figure 2a). The platinum wire leads connect the electrodes with the external power source (alternating or direct current) through the alligator clips. Each electrode was located at a distance of 1 cm from the membrane surface. The schematic and actual electric filtration cell set up used in this investigation is shown in Figure 2a and 2b, respectively. All crossflow microfiltration experiments were carried out using 0.22  $\mu\text{m}$  pore-size polysulfone membrane.



**Figure 2.** The schematic (a) and actual set up (b) of the custom-built electric filtration cell. Note PDT refers to particle descaling technology, a.k.a *HydroFlow*.

## STAGE II

Pe<sup>-</sup>Phlo technology development stage includes testing the technology's ability to recover dissolved phosphorus in the form of struvite or struvite-like crystals (P-product) from dewatering centrate water. In addition, develop business model and identify the market opportunities for the P-product.

### 3.0. TEST PROCEDURE AND DISCUSSION

The dewatering centrate was studied for struvite precipitation and recovery under the experimental conditions described in Table 2.

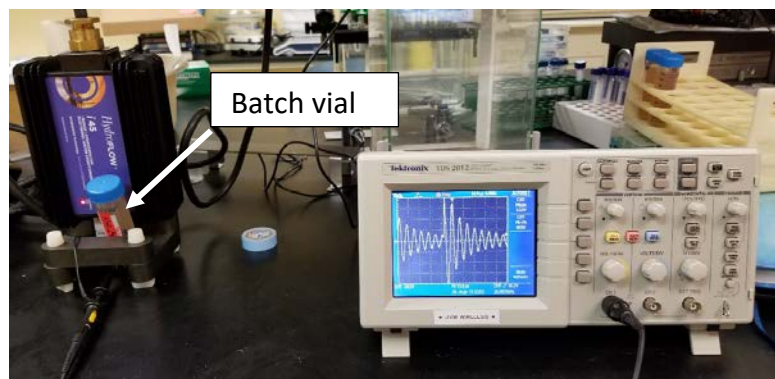
**Table 2.** The experimental test conditions investigated in this project.

	Test Condition 1		Test Condition 2		Test Condition 3		
	Control	HydroFlow	Control	HydroFlow	Control	HydroFlow + Electric field filtration OFF	HydroFlow + Electric field filtration ON
	Batch + Dead-end Filtration	Batch + Dead-end Filtration	Batch + Dead-end Filtration	Batch + Dead-end Filtration	Batch + Crossflow Filtration	Batch + Crossflow Filtration	Batch + Crossflow Filtration
	Time (h)= 4	Time (h)= 4	Time (h)= 1, 4, 24	Time (h)= 1, 4, 24	Time (h)= 0-6	Time (h)= 0-6	Time (h)= 0-6
Centrate	√	√	√	√	√	√	n/a
Centrate + Mg <sup>2+</sup> ions	n/a	n/a	n/a	n/a	√	√	√

**3.1. Centrate sample preparation:** 1 L of raw dewatering centrate sample was taken out from 4 °C storage and kept on the workbench for an hour to allow the centrate to reach ambient room temperature. Meanwhile, the settleable solids in the centrate sample settled to the bottom of the bottle and the supernatant was transferred to a clean beaker. The collected supernatant centrate sample was used for further experimentation under the test conditions described in Table 2.

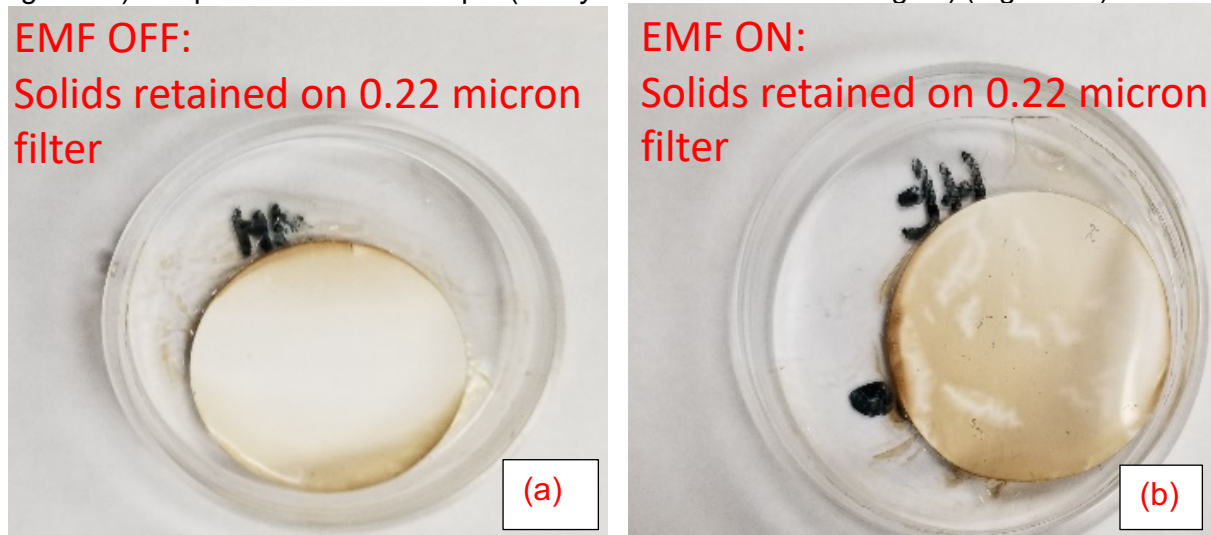
**3.1.1. Test Condition 1:** Batch mode treatment without and with *HydroFlow* for 4 h and dead-end filtration.

The experimental set up for the batch treatment with the *HydroFlow* is shown Figure 3. A 40 mL of centrate sample in a 50 mL polypropylene vial was treated under batch conditions for 4 h without (control) and with ±150 kHz *HydroFlow* electric field signal. The samples were then filtered using 0.22 μm-pore size polycarbonate filter to recovery precipitated crystals. The filters were air dried and the retained solids were analyzed for elemental composition using energy dispersive X-ray spectroscopy and X-ray fluorescence spectroscopy. The crystal morphologies were examined using the scanning electron microscopy.



**Figure 3.** Batch experiments treating centrate with *HydroFlow*.

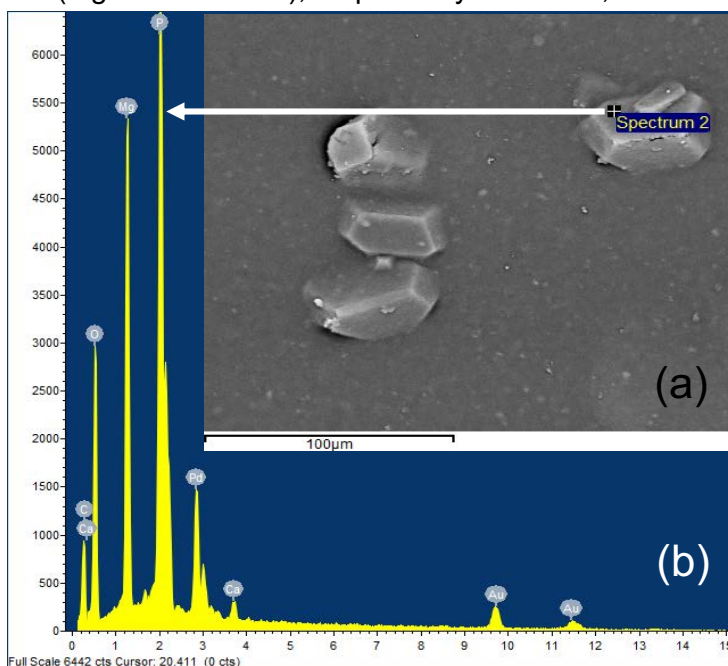
A photograph of air dried solids on the membrane filter is shown in Figure 4. The solids that were exposed to 4 h of  $\pm 150$  kHz *HydroFlow* electric field signal (EMF) appeared to be dark brown, which is likely composed of a mixture of crystals and organics at a higher concentration (Figure 4b) compared to control sample (no *HydroFlow* electric field signal) (Figure 4a).



**Figure 4.** Control centrate solids (EMF OFF) (a), and *HydroFlow* (EMF ON) treated solids (b). The exposure time was 4 h.

A high-resolution scanning electron microscopy analysis revealed crystals that resembled struvite morphology and energy dispersive X-ray spectroscopy confirmed the presence of phosphorus and magnesium in the crystals (Figure 5a and 5b), respectively. However, it appeared that the number of crystals per unit area were low while the crystal sizes were as large as 50  $\mu\text{m}$ . These 50  $\mu\text{m}$ -sized could be settled by gravity and recovered from the solution.

The centrate and settled solids from the control sample (no *HydroFlow*) as well as the settled solids after treatment with  $\pm 150$  kHz *HydroFlow* were centrifuged and filtered using 0.22  $\mu\text{m}$  polycarbonate filter. The solids were air-dried for X-ray fluorescence analysis. It was anticipated that the phosphorus-containing crystals will increase in the solids due to interactions with the *HydroFlow* electric field. The elemental composition of the solids was analyzed using a semi-quantitative X-ray fluorescence technique. The results from X-ray fluorescence analysis are summarized in Table 3.



**Figure 5.** Scanning electron microscopy image of solids on the filter (a). The energy dispersive X-ray spectroscopy analysis of the solids (b). The exposure time was 4 h.

**Table 3.** X-ray fluorescence analysis of solids.

**X-ray fluorescence (XRF) Analysis of settled and centrifuged**

	%P	%S	%K	%Fe	%Cu	%Ca
Settled solids	8.14 ± 0.08	3.09 ± 0.04	13.36 ± 0.05	<b>3.36 ± 0.07</b>	0.03 ± 0.01	12.71 ± 0.05
Solids w/o EMF exp. (centrifuged)	9.23 ± 0.07	5.31 ± 0.05	<b>17.97 ± 0.06</b>	0.92 ± 0.05	0.03 ± 0.01	11.15 ± 0.05
Solids after EMF exp. (centrifuged)	<b>13.13 ± 0.07</b>	<b>12.16 ± 0.05</b>	11.84 ± 0.04	0.71 ± 0.03	<b>0.32 ± 0.01</b>	<b>12.34 ± 0.04</b>
EMF effect On Solids composition	<b>Increase</b>	<b>Increase</b>	Decrease	Decrease	<b>Increase</b>	Slight Increase

Based on the Table 3 results, the changes in the elemental composition of the settled solids exposed to ±150 kHz *HydroFlow* for 4 h are as follows:

- 1) the percent **phosphorus** in the settled solids increased from 9% to **13%**
- 2) the percent sulfur in the settled solids increased from 5% to **12%**
- 3) the percent calcium in the settled solids slightly increased from 11% to **12%**
- 4) the percent copper in the settled solids increased from 0.03% to **0.32%**

Above results suggest that 4 h treatment with ±150 kHz *Hydroflow* electric signal was likely responsible for the observed increases shown in Table 3.

Furthermore, analysis of filter weights with retained solids on the control and *Hydroflow* treated indicated the following:

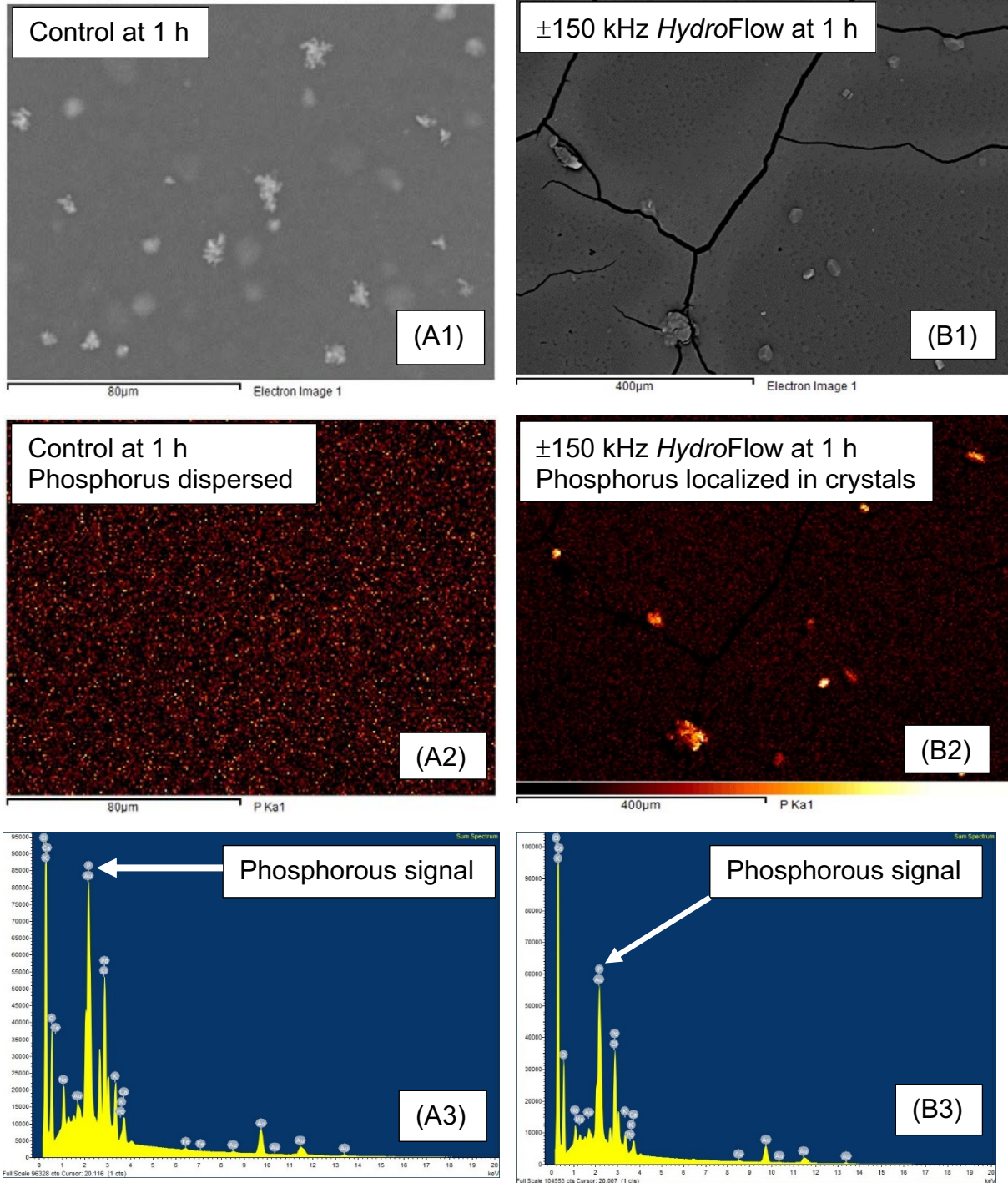
- 1) Control sample: weight of solids retained on the membrane surface was **0.1722 g/80 mL** filtered
- 2) *HydroFlow*-treated sample: weight of solids retained on the membrane surface was **0.4576 g/80 ml** filtered

These results confirm that *HydroFlow* treatment likely increased the concentration of settleable solids and possibly a fraction of them are phosphorus-containing struvite crystals. After the *HydroFlow* treatment, **the total solids recovered on the filter were remarkably increased by 165% compared to the control samples.**

3.1.2 Test Condition 2. Batch mode treatment without and with *HydroFlow* for time 1 h, 4 h, and 24 h.

The effect of exposure time on the formation and growth of crystalline solids and the phosphorus-containing crystals was investigated in the Test Condition 2. The samples were filtered and the solids were analyzed using scanning electron microscopy, and energy dispersive X-ray spectrometer. The results are shown in Figure 5 (1 h time) and Figure 6 (4 h time). The

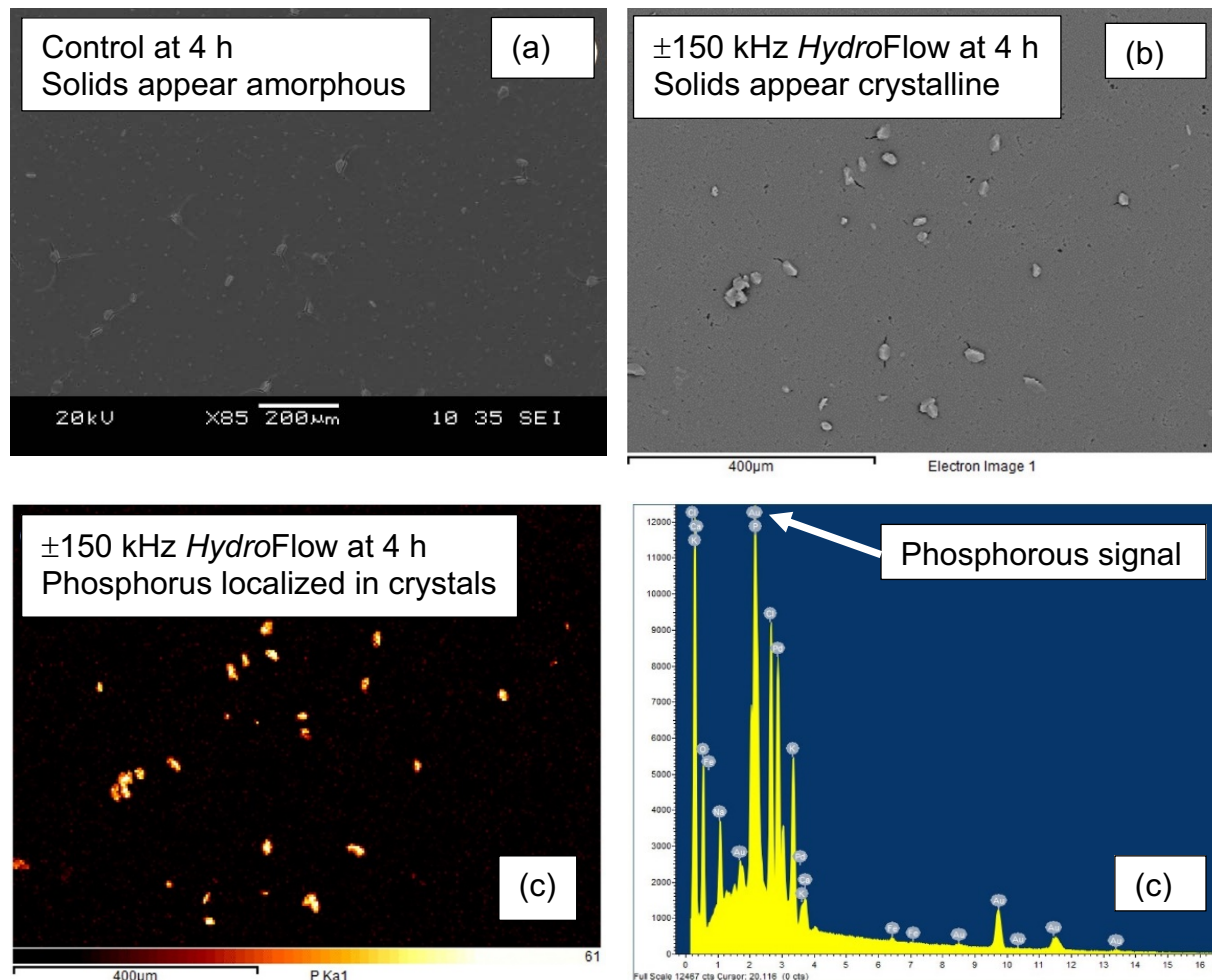
compositional differences between 4 h and 24 h samples were insignificant so data corresponding to 24 h are not shown in Figures 5 and 6.



**Figure 5.** Scanning electron micrographs (A1 and B1), phosphorous elemental maps (A2 and B2), and energy dispersive X-ray spectra of control and  $\pm 150$  kHz HydroFlow treated samples (A3 and B3). Time: 1h.



Phosphorous-containing solids appeared amorphous and dispersed across all solids retained on the membrane surface (Figure 5: A1 and A2 (1 h); Figure 6a (4 h)), as revealed by the scanning electron microscopy and energy dispersive X-ray spectrometer analysis. On the contrary, solids retained on the filter appeared crystalline and the phosphorus was remarkably localized in the crystalline solids just after 1 h as well as 4 h of treatment with  $\pm 150$  kHz *HydroFlow* treatment (Figure 5: B1 and B2, and Figure 6b and 6c).



**Figure 6.** Scanning electron micrographs of the control (a) and  $\pm 150$  kHz *HydroFlow* solids (b), phosphorous elemental map of the *HydroFlow* solids (c), and energy dispersive X-ray spectrum of the *HydroFlow* solids (d). Time: 4h.

### 3.1.3 Test Condition 3. Batch treatment with *HydroFlow* for 6 h followed by crossflow electric microfiltration.

The effect of magnesium ions ( $Mg^{2+}$ ) as seed species and the *HydroFlow* field on struvite formation was investigated. The hypothesis was that the  $Mg^{2+}$  ions can increase the struvite formation and  $\pm 150$  kHz *HydroFlow* treatment will decrease the nucleation time required for struvite formation. Furthermore, the struvite exposed to  $\pm 150$  kHz *HydroFlow* electric field will result in soft scale, which can be easily removed and recovered from the surfaces. The suspensions containing struvite crystals were captured and recovered using crossflow microfiltration in the presence and absence of electric fields across the membranes.

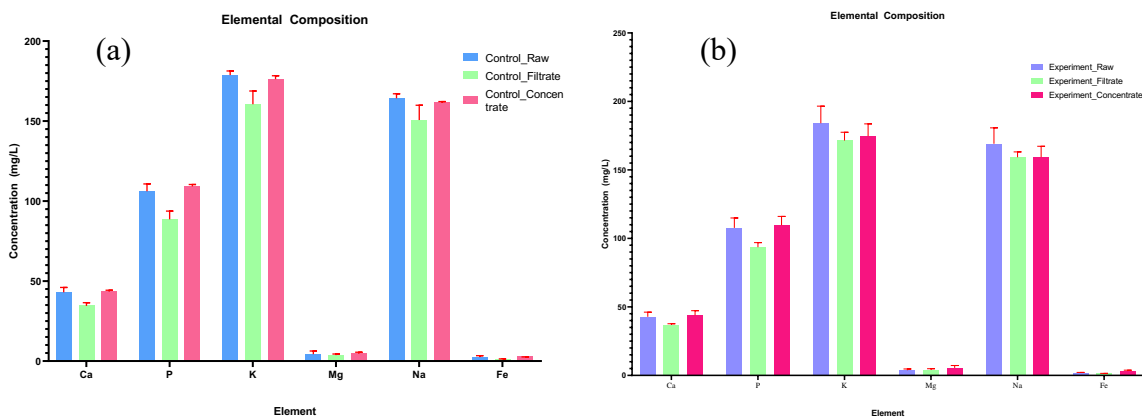
The centrate samples were treated for a maximum of 6 h, to mimic the residence time at Essex WRRF, and the struvite crystal formation was monitored and analyzed during that period. Two centrate samples, one obtained in March and the other in June, were exposed to Test Condition 3. The parameters including pH, conductivity, crystal nucleation time, and phosphorus concentration and recovery were measured. The phosphorus concentrations in the filtrate and concentrate from crossflow electric microfiltration were also measured.

#### Batch and Crossflow Treatment- Seeding with Mg<sup>2+</sup> ions

**Seeding solution:** 0.3525 g of magnesium chloride (MgCl<sub>2</sub>) was dissolved in 100 mL of ultrapure water by stirring at 400 rpm. The stock solution concentration of Mg<sup>2+</sup> ions was 900 mg/L.

**Procedure:** 45 g of centrate water in 50 mL polypropylene vials were exposed to ±150 kHz *HydroFlow* electric signal for 6 h. Another set of samples were set aside for 6 h but without exposure to the *HydroFlow* field, which served as the controls. At the end of 6-h period the samples were filtered using 0.22 μm polysulfone membranes (Millipore) using crossflow microfiltration. The centrate samples were spiked with Mg<sup>2+</sup> ions at 100 mg/L prior to activating the ±150 kHz *HydroFlow* electric field. The controls were also spiked with Mg<sup>2+</sup> ions at 100 mg/L. The two different centrate samples, which were obtained in March and June, were tested under these conditions.

After filtration the membrane was air dried overnight and analyzed using scanning electron microscopy and energy dispersive X-ray spectroscopy for crystal morphology and elemental composition, respectively. The raw centrate, filtrate, and concentrate samples were analyzed for phosphorus and other elemental concentrations using ICP-AES (Figure 7). All samples were measured in triplicate.



**Figure 7.** Elemental composition of centrate feedwater (raw), filtrate, and concentrate from microfiltration without (a) and with 6 h *HydroFlow* electric signal (b). The differences in elemental composition in the presence and absence of *HydroFlow* treatment were statistically insignificant ( $p > 0.05$ ).

In absence of additional Mg<sup>2+</sup> ions (i.e., spike solution), and 6-h continuous crossflow microfiltration conditions the ±150 kHz *HydroFlow* electric signal did not result in crystals that were large enough to be captured by 0.22 μm membrane, and therefore, the observed change in phosphorus concentration between the raw centrate and permeate (filtrate) was not that remarkable (Figure 7). On the contrary, the results from Test Conditions 1 and 2 suggest that although the number of struvite crystals per unit area of the membrane was small the crystal sizes

were as large as 50 µm after 4 h of *HydroFlow* treatment. At these sizes the struvite crystals can readily settle to the bottom of the vial.

Centrate samples were thoroughly investigated with Mg<sup>2+</sup> spike solutions and combination *HydroFlow* and microfiltration. The most interesting results were obtained when both Mg<sup>2+</sup> and ±150 kHz *HydroFlow* electric field was applied simultaneously. A summary of the results from these experiments with spiked Mg<sup>2+</sup> ions are shown in Table 4.

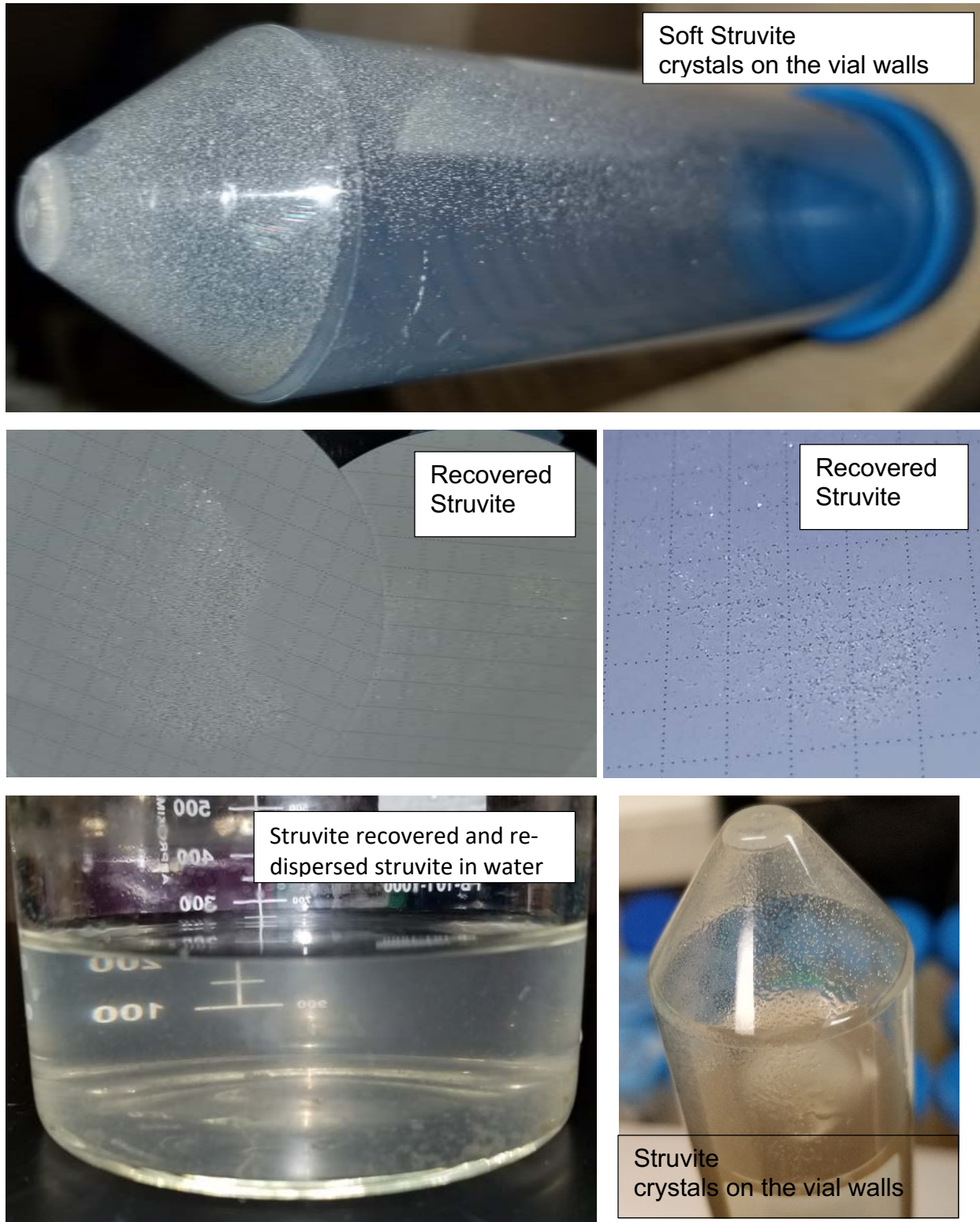
**Table 4.** *HydroFlow* treatment and crossflow microfiltration

Sample	Visual Crystal Nucleation Time (h)	Phosphorus Recovery Efficiency (%)	pH
<b>March 2019</b>			
Centrate sample	n/a	n/a	8.23
Centrate sample treated <b>with</b> ±150 kHz <i>HydroFlow</i> electric field signal	No visible crystal growth	9.53	8.19
Centrate sample treated <b>without</b> ±150 kHz <i>HydroFlow</i> electric field signal	No visible crystal growth	4.73	8.36
<b>Mg<sup>2+</sup> spiked</b> into Centrate sample and treated <b>with</b> ±150 kHz <i>HydroFlow</i> electric field signal	2.5	84.63	8.15
<b>Mg<sup>2+</sup> spiked</b> into Centrate sample and treated <b>without</b> ±150 kHz <i>HydroFlow</i> electric field signal	4	88.07	7.78
<b>June 2019</b>			
Centrate sample	n/a	n/a	7.41
Centrate sample treated <b>with</b> ±150 kHz <i>HydroFlow</i> electric field signal	No visible crystal growth	4.5	7.69
Centrate sample treated <b>without</b> ±150 kHz <i>HydroFlow</i> electric field signal	No visible crystal growth	10.97	7.97
<b>Mg<sup>2+</sup> spiked</b> into Centrate sample and treated <b>with</b> ±150 kHz <i>HydroFlow</i> electric field signal	5.5	78.61	7.81
<b>Mg<sup>2+</sup> spiked</b> into Centrate sample and treated <b>without</b> ±150 kHz <i>HydroFlow</i> electric field signal	6.5	76.26	7.94

Key findings from Table 4 are as follows:

1. Mg<sup>2+</sup> ions and ±150 kHz *HydroFlow* electric field significantly decreased the struvite nucleation time from 4 h to 2.5 h.
2. Struvite crystals were formed more rapidly in the presence of both Mg<sup>2+</sup> ions and *HydroFlow* electric field compared to Mg<sup>2+</sup> ions only.
3. **85% of dissolved phosphorous was recovered in the form of struvite within 2.5 h.**
4. Physical examination of struvite crystals revealed that **Struvite formed a soft scale (a loosely held together crystal clusters) on the surfaces.**
5. Struvite nucleation time and recovery appears to be sensitive to slight changes in pH.

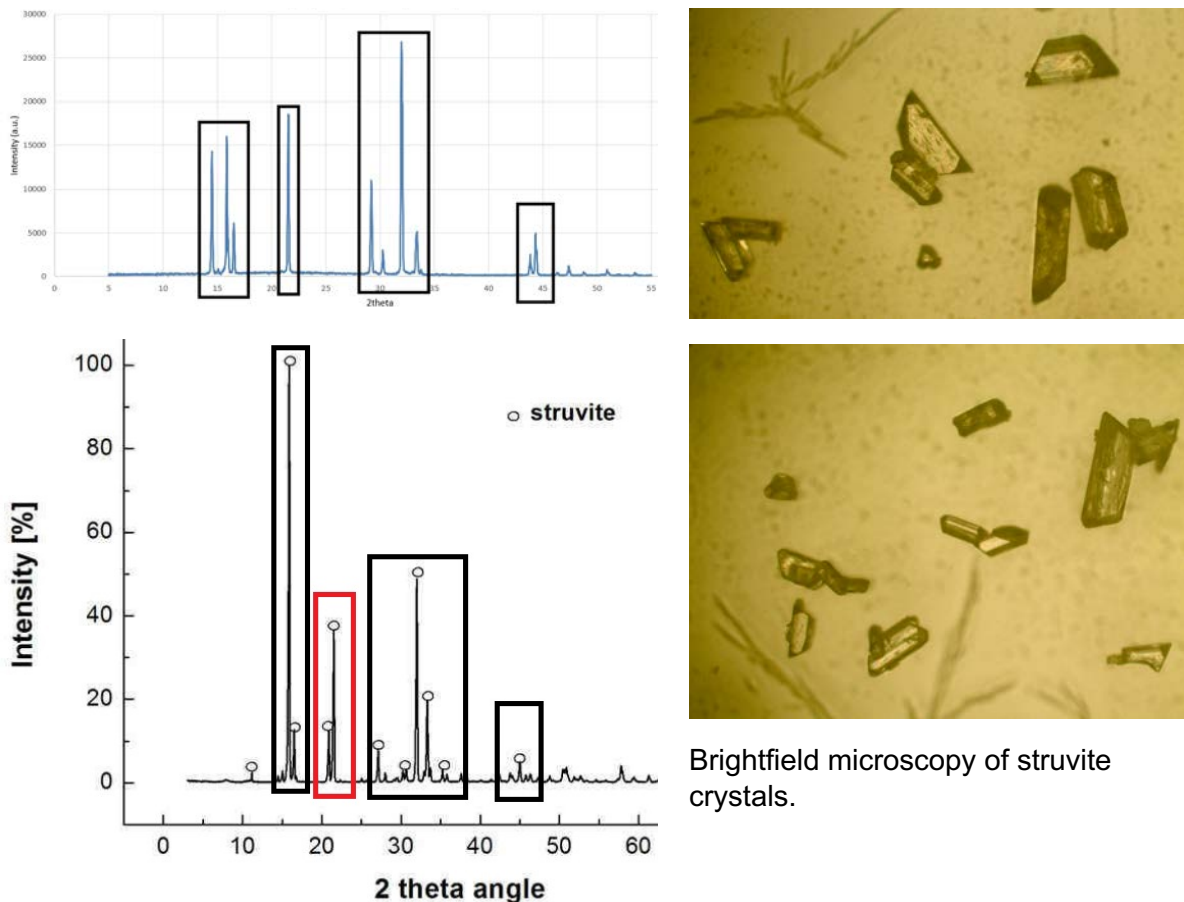
Visual and Quantitative Observations of Struvite Crystals



**Figure 8.** Struvite crystals formed by  $Mg^{2+}$  and  $\pm 150$  kHz *HydroFlow* electric field signal.

Struvite crystals were found to be a form of soft scale on vial surfaces and they were easily recovered by simple scraping or high intensity rinsing.

X-ray diffraction analysis confirmed that the crystals were struvite (Figure 9). The crystal structure of struvite is consistent with the struvite structure that was precipitated under similar wastewater conditions. However, the crystal structure was different from pure struvite. This change in structure was likely the result of treatment with  $\pm 150$  kHz *HydroFlow* and was probably responsible for the transformation of “hard scale” nature of struvite into “soft scale”. This “soft scale” nature of struvite is important because it would allow easy recovery with minimal energy from any technical surface including holding tanks, distribution pipes, membrane surfaces, and others.



Brightfield microscopy of struvite crystals.

**Figure 9.** XRD spectrum of struvite (current work) (A); XRD spectrum of struvite (Zhang, T. et al 2014, 21 (1) Ecol Chem Eng S) (B); Brightfield images of struvite crystals that were recovered from the vial (C-D).

The experimental set up for crossflow electric filtration is shown in Figure 10. The centrate with spiked  $Mg^{2+}$  was filtered using  $0.22 \mu m$  polysulfone membrane at a transmembrane pressure of 5 psi. The oscillating electric field was applied at 100 kHz, 1 A, and 3 V peak-peak across the membrane. During the filtration the clear filtrate was collected. At the end of 6 h operation, the samples of raw centrate, filtrate, and concentrate were collected and sent to Endyne Lab for the phosphorus and other elemental analysis. We are still waiting on these results.

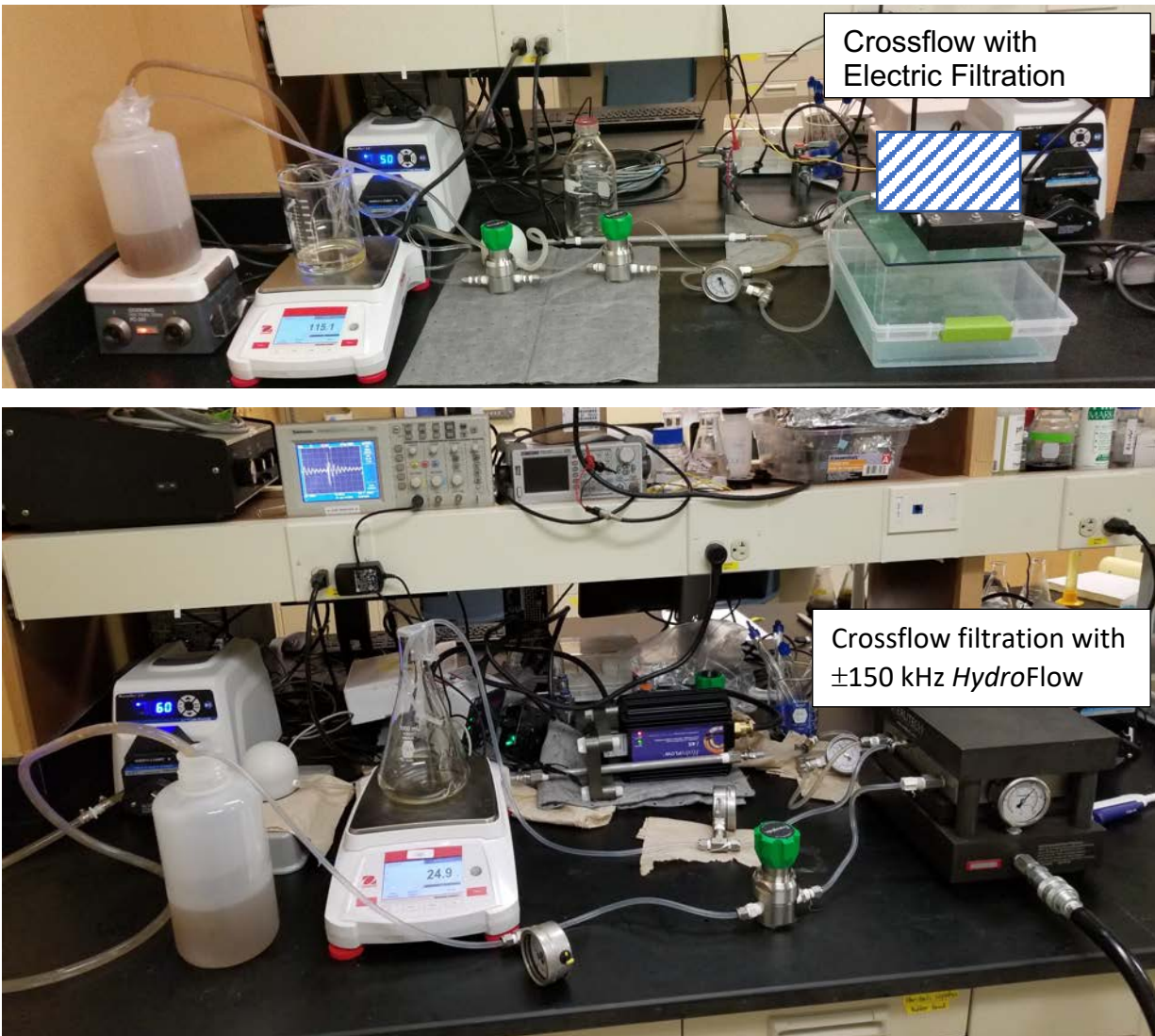


Figure 10. Test condition 3: Schematic of crossflow electric filtration without and with *HydroFlow* systems.

#### 4.0 CONCLUSIONS

- A combination of  $Mg^{2+}$  ions and  $\pm 150$  kHz *HydroFlow* electric field was found to be most effective at capturing phosphorus in the form of struvite. **The phosphorus recovery in the form of “soft scale” (i.e., loosely held together clusters) struvite was about 85% at pH 8.12.** The 7.0-8.5 pH is typical of dewatering centrates.
- Above treatment rapidly, about 38% less time, precipitated struvite in the form of “soft scale” compared to controls that were not treated with  $\pm 150$  kHz *HydroFlow* electric field. The nucleation time appears to be sensitive to slight changes in pH.
- It appears that higher pH will lead to greater and rapid precipitation. Further investigation is required to determine the effects of pH,  $Mg^{2+}$  dosage (concentration and contact time), operation conditions (batch vs continuous).
- In the absence of  $Mg^{2+}$ ,  $\pm 150$  kHz *HydroFlow* electric field alone was able to agglomerate suspended solids to a level that was easily captured by filters. When compared with controls

(no *HydroFlow*), the percentage of solids retained by the filter increased to 165% due to  $\pm 150$  kHz *HydroFlow* electric field.

- Based on the above findings, we suspect that at significantly lower nucleation time (< 2.5 h) the struvite crystal sizes may be in the range of few microns or sub-microns that can be easily retained by microfilter or ultrafilters depending on the treatment requirements.
- The X-ray diffraction analysis confirmed that struvite formed under *HydroFlow* electric signal had an altered crystal structure that might have given the “**soft scale**” nature to the struvite. This characteristic allows easy recovery of struvite as well as easy cleaning of technical surfaces including holding tanks, distribution pipes, reactors, and membrane surfaces.