Final Abstract

Final Report Approved on September 18, 2024

M.L. 2021 Project Abstract

For the Period Ending June 30, 2024

Project Title: Novel Nutrient Recovery Process from Wastewater Treatment Plants

Project Manager: Bo Hu

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Funding Source:

Fiscal Year:

Legal Citation: M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 04b

Appropriation Amount: $200,000

Amount Spent: $200,000

Amount Remaining: -

Sound bite of Project Outcomes and Results

A novel three-stage process improves phosphorus recovery and biogas production in wastewater treatment plants by integrating thermophilic acid digestion, phosphorus precipitation and recovery, and high-rate anaerobic digestion. This method enhances P recovery, improves bioenergy generation, and reduces operational costs, offering a more efficient alternative to conventional sludge treatment.

Overall Project Outcome and Results

We have developed a novel three-stage process to enhance phosphorus (P) recovery and biogas production in wastewater treatment plants (WWTPs), addressing the limitations of conventional methods. Traditional biological P removal and anaerobic digestion (AD) often interfere with each other, leading to issues like mineral precipitation, equipment clogging, and reduced dewatering efficiency, driving up operational costs. Our innovative method integrates thermophilic acid anaerobic digestion (TAAD), P mineralization and precipitation, and mesophilic high-rate anaerobic digestion (HRAD). In the first stage, TAAD operated at 55°C solubilized over 80% of the P in thickened waste activated sludge (TWAS) within 2-5 days. The second stage involved P precipitation, recovering P as high-purity mineral precipitates like struvite and brushite, a biofertilizer, and thereby enhance the process's economic viability. Either CaCl2

or $MgCl_2$ addition recovered over 90% of dissolved P in the effluent from first-stage TAAD, while the highest phosphorus removal (>97%) was achieved at a Mg:P molar ratio of 1.5:1. The third-stage mesophilic HRAD further converted the remaining organics in the P-stripped liquid effluent into biogas within 1-3 days, resulting in a steady sCOD removal of 88% and a specific biogas yield of 0.46 L/g-sCOD/d with a methane content of 62.8%. This integrated system, with a total hydraulic retention time of 3-8 days, outperforms conventional AD processes that typically require 20-30 days. It achieves efficient sludge treatment, significantly maximizes P recovery, and improves biogas production, all while reducing operational costs. By simplifying P recovery and minimizing the need for expensive separation equipment, this process makes P recovery more accessible to a broader range of WWTPs. In conclusion, this novel three-stage process not only enhances the efficiency and effectiveness of P recovery but also increases bioenergy generation, offering a cost-effective and sustainable solution for modern WWTP operations.

Project Results Use and Dissemination

We have disseminated the results of our project, from lab-scale fermentation experiments to the pilot-scale operation of our three-stage system, at various regional and national conferences. These include the annual meetings of the Central States Water Environment Association (CSWEA), the Society for Industrial Microbiology and Biotechnology (SIMB), and the American Institute of Chemical Engineers (AIChE). Additionally, we presented our findings to our industrial collaborator, Metropolitan Council Environmental Services (MCES), which operates and maintains eight wastewater treatment plants in the Twin Cities area, including the Blue Lake Wastewater Treatment Plant, where we collected sludge samples for this project.

Environment and Natural Resources Trust Fund

M.L. 2021 Approved Final Report

General Information

Date: November 27, 2024

ID Number: 2021-115

Staff Lead: Noah Fribley

Project Title: Novel Nutrient Recovery Process from Wastewater Treatment Plants

Project Budget: $200,000

Project Manager Information

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Project Reporting

Final Report Approved: September 18, 2024

Reporting Status: Project Completed

Date of Last Action: September 18, 2024

Project Completion: June 30, 2024

Legal Information

Legal Citation: M.L. 2021, First Special Session, Chp. 6, Art. 6, Sec. 2, Subd. 04b

Appropriation Language: $200,000 the first year is from the trust fund to the Board of Regents of the University of Minnesota to conduct lab- and pilot-scale tests of a new process to promote nutrient removal and recovery at rural municipal and industrial wastewater treatment plants for water protection and renewable energy production.

Appropriation End Date: June 30, 2024

Narrative

Project Summary: This proposal requests funding for a new integrated process with potential to promote nutrient removal/recovery and renewable energy production at rural municipal and industrial wastewater treatment plants (WWTP).

Describe the opportunity or problem your proposal seeks to address. Include any relevant background information.

Many WWTPs typically have biological phosphorus (P) removal and anaerobic digestion (AD) to reduce sludge volume. These two processes affect each other, causing issues that impact performance and increase operating costs. The bio-P removal impacts AD by mineral precipitation and decreasing solids dewaterability. P mineral precipitation clogs piping and accumulates on mixers and in reactors, requiring costly maintenance. Dewatering performance can be reduced by 3 – 6% after bio-P is initiated, significantly increasing solids management costs. The cause of dewatering issues has been linked to the ratio of mono/divalent cations, ortho-P concentration and extracellular polymeric substances, however, the complete mechanism has not been defined. AD impacts bio-P removal by converting P bound in cell mass to a soluble form. The recycled P load may be greater than 50% of the total plant load, often requiring addition of expensive reduced organics such as methanol or metal salts to achieve the required treatment. Also, with existing processes, P recovery is more difficult by its mixture with a high concentration of biological solids. This requires use of expensive separation equipment such as fluidized bed reactors for P recovery, limiting its application only to a few large metro WWTPs; disproportionally affecting rural plants.

What is your proposed solution to the problem or opportunity discussed above? Introduce us to the work you are seeking funding to do. You will be asked to expand on this proposed solution in Activities & Milestones.

We are proposing a new integrated process, including thermophilic acid AD (TAAD) followed by dewatering, P recovery and high rate AD (HRAD) that address above issues (see attached process flow diagrams of conventional/new systems). The first step is the TAAD operated at 55°C for 2–4 days hydraulic retention time (HRT) in order to hydrolyze organics to volatile fatty acids (VFA), and P to soluble phosphate. The second step is dewatering and P recovery. TAAD effluent contains higher concentration phosphate than conventional AD, exceeding 500 mg-P/L. Dewatering of this effluent has been tested by Centrysis, documenting high cake solids concentrations and P recovery (up to 84%). Via lime/magnesium hydroxide dosing, valuable P minerals including brushite ($CaHPO_4$) and struvite ($MgNH_4PO_4$) can be recovered from the liquid effluent. These P minerals can be used as P fertilizer, readily available for crop uptake. Finally, the effluent after P recovery contains high concentration of VFAs that can be recycled as a source of reduced organics for bio-P treatment, or sent to HRAD for conversion to renewable biogas energy. HRAD is able to operate at short HRTs of below 2 days as compared to over 20 days in conventional AD.

What are the specific project outcomes as they relate to the public purpose of protection, conservation, preservation, and enhancement of the state's natural resources?

This new, integrated process has potential to improve the efficiency and effectiveness and reduce the operation costs of bio-P and AD in rural WWTPs, thus promoting their use. Specific advantages include:

- Higher P recovery than current systems, better integrated at lower costs.
- Recovery of more valuable P minerals, increasing the application and protecting rivers and lakes.
- Reducing maintenance costs at WWTPs, improving dewaterability, allowing land application of biosolids in areas with P load limitations, and reducing transportation costs.
- More stable AD, less potential for foaming, significant reduction in time/tank volume and promoting AD as means of generating renewable bioenergy.

Project Location

What is the best scale for describing where your work will take place?

Statewide

What is the best scale to describe the area impacted by your work?

Statewide

When will the work impact occur?

In the Future

Activities and Milestones

Activity 1: Set-up and test of lab-scale experimental system

Activity Budget: $101,305

Activity Description:
A lab-scale experimental system will be set up to study this new process. Thickened primary sludge (TPS) and thickened waste activated sludge (TWAS) will be collected from local WWTPs as the test substrates. TPS and TWAS will be characterized and fed into the first-stage TAAD at 55°C and an HRT of 2-4 days. The P solubilization and VFA production in the effluent will be analyzed to evaluate the substrate hydrolysis and degradation in TAAD, and the fecal coliform destruction will also be monitored. Subsequently, solid-liquid separation will be applied to assess the dewaterability of the effluent after TAAD. The dewatered cake solids will be processed as biosolids for land application, whilst lime or magnesium hydroxide will be dosed into the liquid phase to capture and recover P in the form of brushite and struvite. The effects of varied reagent dosage on P recovery will be recorded. After P recovery, the liquid effluent rich in VFA will be fed into the third-stage HRAD for biogas generation. The correlation between the VFA loading and biogas production will be graphed. The optimum operation parameters of this three-stage system will be obtained finally.

Activity Milestones:

Description	Approximate Completion Date
Lab-scale three-stage experimental system set-up.	August 31, 2021
TPS/TWAS characterization and first-stage TAAD optimization.	November 30, 2021
Maximum P recovery with minimum reagent dosage in the second stage.	March 31, 2022
Interim report on the lab-scale system performance.	June 30, 2022
Correlation between VFA loading and biogas production in the third-stage HRAD.	June 30, 2022

Activity 2: On-site demonstration of a pilot-scale system

Activity Budget: $98,695

Activity Description:
With the establishment of lab-scale three-stage system and the optimization of operation parameters obtained in Activity 1, a pilot-scale system will be built and installed at or near a local WWTP. This pilot-scale three-stage system confirm the lab-scale experimental results (i.e., P solubilization and organic hydrolysis in TAAD, P recovery through lime/magnesium hydroxide dosage, and biogas production of VFA-rich liquid effluent in HRAD) with a much larger working volume of TPS/TWAS. The full and continuous operation of this pilot-scale system will provide a new insight of this novel integrated process on future actual deployment in WWTPs. After a successful demonstration, a techno-economic assessment of the proposed system will be conducted, thus addressing the economic feasibility of the implementation of this integrated three-stage system for improved bio-P recovery and biofuel production. The expenses resulting from the on-site pilot-scale demonstration will be used for the cost analysis, including equipment purchase and construction, reagents, electricity and fuel usage, and labors in the installation and operation/maintenance. The corresponding value increase due to biosolids sale, P recovery for further utilization, biogas production, and eased discharging of effluents with lower P and organics will be monetarized in the benefit analysis.

Activity Milestones:

Description	Approximate Completion Date
On-site pilot-scale system construction and installation.	September 30, 2022
Continuous operation and optimization of pilot-scale system treating TPS/TWAS.	March 31, 2023
Techno-economic assessment of this three-stage system including expenses and monetarized benefits.	June 30, 2023

Final report on both the lab-scale system and pilot-scale demonstration performances.	June 30, 2023

Dissemination

Describe your plans for dissemination, presentation, documentation, or sharing of data, results, samples, physical collections, and other products and how they will follow ENRTF Acknowledgement Requirements and Guidelines.
The proposed research can be used by design engineers soon after the work is completed for application at new or existing WWTPs. Our team intends to present the results as they are compiled via LCCMR reporting, publishing in scientific and engineering journals and conference presentations. Our team will also present the process and research results to wastewater treatment system vendors/manufacturers. Potential vendors include Suez, Centrysis and Ovivo. If additional study is needed, funding may be pursued through the EPA Small Business Innovation Research program. Environment and Natural Resources Trust Fund will be acknowledged through use of the trust fund logo or attribution language on project print and electronic media, publications, signage, and other communications per the ENTRF Acknowledgment Guidelines.

Long-Term Implementation and Funding

Describe how the results will be implemented and how any ongoing effort will be funded. If not already addressed as part of the project, how will findings, results, and products developed be implemented after project completion? If additional work is needed, how will this work be funded?
The proposed research can be used by design engineers soon after the work is completed for application at new or existing WWTPs, especially those small ones at Greater Minnesota. Our team intends to present the results as they are compiled via LCCMR reporting, publishing in scientific and engineering journals and conference presentations. Our team will also present the process and research results to wastewater treatment system vendors/manufacturers. Potential vendors include Suez, Centrysis and Ovivo. If additional study is needed, funding may be pursued through the EPA Small Business Innovation Research program and USDA Rural Development program.

Other ENRTF Appropriations Awarded in the Last Six Years

Name	Appropriation	Amount Awarded
Next Generation Large-Scale Septic Tank Systems	M.L. 2014, Chp. 226, Sec. 2, Subd. 08g	$258,000
Extracting Deicing Salt from Roadside Soils with Plants	M.L. 2019, First Special Session, Chp. 4, Art. 2, Sec. 2, Subd. 04i	$360,000

Budget Summary

Category / Name	Subcategory or Type	Description	Purpose	Gen. Ineligible	% Benefits	# FTE	Classified Staff?	$ Amount	$ Amount Spent	$ Amount Remaining
Personnel										
Researcher		scientific staff, working on experimental design and data collection			36.5%	2		$164,916	-	-
Professor		Principal Investigator, coordinate the research efforts, design experiments and write project reports			36.5%	0.08		$13,855	-	-
							Sub Total	**$178,771**	**$178,771**	**-**
Contracts and Services										
							Sub Total	**-**	**-**	**-**
Equipment, Tools, and Supplies										
	Equipment	A pilot scale bioreactor for phosphorus removal will be built in the first year and operated at a local wastewater treatment in the second project year to scale up the lab developed process. The components of this pilot scale reactor includes carboy, pumps, air compressor, insulation, filter device etc	This pilot scale reactor will enable us to test our proposed process in the real wastewater treatment plant					$10,721	$10,721	-
	Tools and Supplies	Chemicals, analysis kits, and personal protection supplies	materials for lab experiments					$9,322	$9,322	-
							Sub Total	**$20,043**	**$20,043**	**-**
Capital Expenditures										
							Sub Total	**-**	**-**	**-**
Acquisitions and Stewardship										
							Sub Total	**-**	**-**	**-**

Travel In Minnesota										
	Miles/ Meals/ Lodging	Within-state travel using university vehicles, standard rate applies	Trips to go to site for collection of waste samples					$1,136	$1,136	-
							Sub Total	**$1,136**	**$1,136**	**-**
Travel Outside Minnesota										
							Sub Total	**-**	**-**	**-**
Printing and Publication										
	Publication	Publication cost for two journal articles	To disseminate our research in scientific journals					$50	$50	-
							Sub Total	**$50**	**$50**	**-**
Other Expenses										
							Sub Total	**-**	**-**	**-**
							Grand Total	**$200,000**	**$200,000**	**-**

Classified Staff or Generally Ineligible Expenses

Category/Name	Subcategory or Type	Description	Justification Ineligible Expense or Classified Staff Request

Non ENRTF Funds

Category	Specific Source	Use	Status	$ Amount	$ Amount Spent	$ Amount Remaining
State						
In-Kind	Since this project does not charge any indirect cost, therefore University of Minnesota matches the in kind service F&A. The current indirect cost rate is 54% of the direct total project cost without capital equipment.	UM F&A	Secured	$95,112	$80,942	$14,170
			State Sub Total	**$95,112**	**$80,942**	**$14,170**
Non-State						
			Non State Sub Total	**-**	**-**	**-**
			Funds Total	**$95,112**	**$80,942**	**$14,170**

Attachments

Required Attachments

Visual Component

File: 4a7a9870-3f9.pdf

Alternate Text for Visual Component

This visual shows the differences between the current process and what we propose to develop....

Supplemental Attachments

Capital Project Questionnaire, Budget Supplements, Support Letter, Photos, Media, Other

Title	File
SPA approval to submit	20db0704-3ad.pdf
Approved research addendum	aafe232b-78b.docx
Background check certification form	0cdcc562-a86.pdf

Difference between Proposal and Work Plan

Describe changes from Proposal to Work Plan Stage

We added the dissemination plan for our research results and also the acknowledgement policy. We deleted the collaboration partner because Jim Postiglione no longer works at HR Green and will be hired as researcher to work on the project. So he is no longer identified as collaboration partner anymore. The other items are same as the proposal.

Additional Acknowledgements and Conditions:

The following are acknowledgements and conditions beyond those already included in the above workplan:

Do you understand and acknowledge the ENRTF repayment requirements if the use of capital equipment changes?

N/A

Do you understand that travel expenses are only approved if they follow the "Commissioner's Plan" promulgated by the Commissioner of Management of Budget or, for University of Minnesota projects, the University of Minnesota plan?

Yes, I understand the UMN Policy on travel applies.

Does your project have potential for royalties, copyrights, patents, sale of products and assets, or revenue generation?

No

Do you understand and acknowledge IP and revenue-return and sharing requirements in 116P.10?

N/A

Do you wish to request reinvestment of any revenues into your project instead of returning revenue to the ENRTF?

N/A

Does your project include original, hypothesis-driven research?

Yes

Does the organization have a fiscal agent for this project?

Yes, Sponsored Projects Administration

Work Plan Amendments

Amendment ID	Request Type	Changes made on the following pages	Explanation & justification for Amendment Request (word limit 75)	Date Submitted	Approved	Date of LCCMR Action
1	Amendment Request	• Budget • Budget - Personnel • Budget - Capital, Equipment, Tools, and Supplies • Budget - Travel and Conferences	We want to move $14,931 to the staff salary and fringe benefits. We finished assembling our pilot scale equipment, and spent less than originally requested. Meanwhile we need more support for the postdoc researcher's salary due to the job code change and salary inflation required by the University	December 1, 2023	Yes	January 22, 2024
2	Amendment Request	• Budget • Other • Budget - Personnel • Budget - Capital, Equipment, Tools, and Supplies • Budget - Travel and Conferences • Budget - Printing and Publication	Move $3040 from lab supplies to personnel, move $3304 from publication cost to personnel, move $652 from travel to capital equipment, and move $252 from travel to personal. This is final adjustment before project ends. The reason for the move is the recent labor cost increase for the postdoc researcher.	May 31, 2024	Yes	June 7, 2024

Status Update Reporting

Final Status Update August 14, 2024

Date Submitted: August 13, 2024

Date Approved: August 23, 2024

Overall Update

We have finished both the lab-scale tests in Activity 1 and the pilot-scale tests in Activity 2, and also have disseminated our findings in national conferences (e.g., SIMB 2023 Annual Meeting and 2023 AIChE Annual Meeting). Through the lab-scale batch tests, we observed that thermophilic conditions aided in the phosphorus solubilization in sludge by an additional 9% over the mesophilic conditions, while pretreatments and loading rate did not significantly affect phosphorus solubilization, which confirmed with the results in the continuous test. The precipitation jar assays achieved efficient phosphorus removal (>97%) at a Mg:P molar ratio of 1.5:1, while the third-stage mesophilic anaerobic digestion of the P-stripped liquid effluent resulted in a 77% COD removal and producing biogas with a high methane content. In Activity 2, the pilot-scale system comprising a 15-L first-stage thermophilic fermenter, a second-stage precipitation reactor, and a 5-L third-stage mesophilic digester has been established and operated for over half a year. In pilot-scale tests, the three-stage system exhibited slightly reduced performances (vs lab-scale tests) due to the instability caused by upscaling, but still comparable to that of the existing wastewater treatment plant.

Activity 1

This activity was previously marked complete. More batch tests on the working conditions of first-stage thermophilic acid anaerobic digestion were conducted. The results showed that the use of pretreatments in TPS and TWAS did not increase the nutrient solubilization capabilities for phosphorus, ammonia, or COD in comparison to the untreated controls. Moreover, thermophilic conditions (55 ºC) for the process were beneficial for phosphorus solubilization, with an average 9% increase in solubilized phosphorus as compared to that in mesophilic conditions. The VS loading rate of TWAS in the digester had a linear relationship with the concentration of phosphorus and other nutrients released from the substrate, indicating that reducing the loading rate did not increase nutrient solubilization from sludge. These results also confirmed with the findings obtained in previous lab-scale continuous TAAD tests digesting TPS and TWAS. In subsequent jar tests, the potential for phosphorus recapture from the digested liquid fraction was determined with a soluble phosphorus removal of 97% at the optimum magnesium dosage molar ratio of 1.5:1 (Mg:P). Finally, the phosphorus-stripped liquid effluent was further digested in the third-stage UASB reactor, achieving a 77% COD removal and producing high biogas with a high methane content (88%).
(This activity marked as complete as of this status update)

Activity 2

We established the pilot-scale three-stage system, including a first-stage thermophilic acid fermenter (15L CSTR), a second-stage 2L P precipitation reactor with an agitator, and a third-stage mesophilic high-rate anaerobic digester (5L UASB). The pilot-scale system has been continuously operated for six month. We observed that P solubilization from TWAS in the large fermenter without effective pH control was about 60-70% of small-scale tests. Therefore, whey permeate at a volume ratio over 1:60 (to TWAS) was added to control pH below 6. In the second stage, either CaCl2 or MgCl2 addition recovered over 90% of dissolved P in the effluent from 1st-stage TAAD. CaCl2 addition with pH control at 7 using NaOH was more effective with less sodium dosage, resulting in the formation of brushite (CaHPO4). MgCl2 addition required higher pH at 8.4 but simultaneously reduced ammonium by the formation of struvite (NH4MgPO4). In the third-stage HRAD, the remaining organics in the effluent was consumed efficiently with an average sCOD removal of 88% in a steady state, resulting in an average specific biogas yield of 0.46 L/g-sCOD/d with a methane content of 62.8%. The results are comparable to that in a local wastewater treatment plant
(This activity marked as complete as of this status update)

Dissemination

We disseminated our results on batch tests and up-scaled continuous system on P recovery from wastewater sludge entitled “Novel Nutrient Recovery Process from Wastewater Treatment Plants” through both poster and oral presentations to the SIMB 2023 Annual Meeting held in Minneapolis, MN on July 30 - August 2, 2023. Moreover, we further organized the comprehensive results in this project from the lab-scale fermentation experiments to pilot-scale three-stage system operation, entitled “A novel three-stage process to treat sewage sludge with high phosphorus recovery and bioenergy production”, and disseminated it through an oral presentation at the 2023 AIChE Annual Meeting in Orlando, FL on November 5-10, 2023.

Status Update Reporting

Status Update June 1, 2024

Date Submitted: May 31, 2024

Date Approved: June 7, 2024

Overall Update
We have finished all the proposed research listed in the work plan and this is the final budget adjustment to reflect some lab cost increase. We will submit our final report before the deadline

Activity 1
This activity was previously marked complete.
(This activity marked as complete as of this status update)

Activity 2
This activity was previously marked complete.
(This activity marked as complete as of this status update)

Dissemination
This activity was previously marked complete.

Status Update Reporting

Status Update December 1, 2023

Date Submitted: December 1, 2023

Date Approved: January 22, 2024

Overall Update
We finished our pilot scale testing and the project moving to the final step, which is the techno-economic analysis. We made two oral presentations and one poster presentation to the national conferences to disseminate our results.

Activity 1
This activity was previously marked complete.
(This activity marked as complete as of this status update)

Activity 2
We are finishing up our pilot scale operation, and the results are similar to our lab scale testing. We are still running the continuous anaerobic fermentation reactor to collect long term operation data while also generating the fermentation broth. The fermentation broth is used to test different separation methods for the precipitated phosphorus. We will be working on the techno-economic analysis of our current process, which is the last step to be finished.

Dissemination
Daniel made an oral and a poster presentations: Daniel Jurado Pineda, Lingkan Ding, James Postiglione, Bo Hu. Novel Nutrient Recovery Process from Wastewater Treatment Plants, SIMB 2023 Annual Meeting, Minneapolis, MN, August 4-7, 2023.

Lingkan made an oral presentation: Lingkan Ding, Daniel Jurado Pineda, James Postiglione, Bo Hu. A Novel Three-Stage Process to Treat Sewage Sludge with High Phosphorus Recovery and Bioenergy Production, AICHE annual meeting, Orlando, FL, November 9th, 2023

Daniel is working on his master thesis and plan to defend it in the spring 2024.

Status Update Reporting

Status Update June 1, 2023

Date Submitted: June 1, 2023

Date Approved: June 9, 2023

Overall Update

We have already finished the activity 1 and are working on the activity 2. The finalized process is slightly different from what we originally proposed, and this new process was filed for a US patent protection. Now we are building the pilot-scale apparatus to test the whole system at a larger scale.

Activity 1

From lab experiments from activity 1, we found that TWAS is highly biodegradable as over 90% of P can be soluble after 3 days of anaerobic fermentation while TPS does not significantly contribute to the overall dissolved P. Therefore, we modify the current sludge treatment process, instead of combining TPS and TWAS together in feeding to the anaeorbic digester, we first fermented the TWAS for three days, then combining the solids from fermentation effluent together with TPS for the anerobic digestion. We also tested different methods to reduce the pH value of TWAS and recommended to use food waste to co-ferment with TWAS for better control the pH and release the P. Because TWAS and TPS will be processed separately in our new process, we decided to use less concentrated TWAS for better processibility.
(This activity marked as complete as of this status update)

Activity 2

We have finalized the small-scale study and moved on to build the pilot-scale equipment for demonstration operation, corresponding to milestone 3 and 4 on the activity 2. We toured the Blue-lake Wastewater Treatment Plant and also the Empire Station Wastewater Treatment to take samples and determine best way for the pilot-scale demonstration. We also had a meeting with George Sprouse, Adam Sealock, Elizabeth Schrandt at the Metrocouncil to tour our on-building pilot-scale system and to collect some feedback on developing this technology. We all decided that it is better to take large amount of wastewater sludge from Blue Lake WWTP every week while operate the pilot-scale demonstration in the BAE lab 320 at UMN campus. By this way, it is easier for our students to measure the water quality and have a close monitoring of our operation. The pilot scale fermentor and the UASB reactors are now finished, and we start to operate them continuously and separately; while working on the centrifugation/filteration step to separate the phosphate precipitate from fermentation effluent. We will connect all parts together when this step is finished.

Dissemination

The Office of Technology Commercialization at UMN filed a patent application of our newly developed process on May 19th, 2023: "Methods and Systems for Nutrient Recovery and Biogas Production"- Case#2023-275 [FR Ref. No. 09531-0532P01]

We have made the following oral presentations:
"Novel Nutrient Recovery Process from Wastewater Treatment Plants", Daniel Jurado Pineda 2023 CSWEA 96th Annual Meeting. St. Paul River Center, Saint Paul, MN, May 2023.
"Novel Nutrient Recovery Process from Wastewater Treatment Plants", Daniel Jurado Pineda 2023 CFANS Research Symposium-Poster. University of Minnesota, Saint Paul, MN, March 2023.

Status Update Reporting

Status Update December 1, 2022

Date Submitted: December 1, 2022

Date Approved: December 14, 2022

Overall Update
We have finished establishing the lab-scale three-stage system in Activity 1. We have extended the lab work in Activity 1 to further study the optimum conditions for solubilizing phosphorus and carbon in the fermentation step. Additional batch bottle tests and CSTR operation have been completed to study several options for fermentation of TPS, TWAS, and combined TPS and TWAS. This showed significant P release by fermentation of combined TPS and TWAS or TWAS only. After the second-stage chemical dosing, over 80% of soluble P in the effluent from TAAD was efficiently recovered in the form of P-bearing mineral precipitates. After the third-stage HRAD, the soluble organics in the TAAD effluent were efficiently degraded to methane-rich biogas, and the soluble COD reduction was found significant. With the results obtained in the lab-scale three-stage system, the corresponding pilot-scale system proposed in Activity 2 has been designed, and now it is under construction with two possible treatment scenarios.

Activity 1
The lab-scale three-stage system comprising of first-stage TAAD, second-stage P precipitation, and third-stage HRAD has been established. The first-stage TAAD has been conducted on a 1-L continuous stirred-tank reactor and also on serum bottles, and different combinations of feedstock, including mixed TPS and TWAS, pure TWAS, and diluted TWAS have been assessed. This showed significant P release by fermentation of combined TPS and TWAS or TWAS only. However, it also indicated that the level of carbon solubilization was not high enough to meet the solids reduction needed to avoid additional digestion after TAAD. Additional batch tests were performed on diluted TWAS with the theory that this would increase the hydrolysis rate. These tests produced promising results that need confirmation by continuous operation. In the second-stage P recovery from the supernatant of TAAD effluent, the maximum P recovery of over 80% was achieved with a molar P to Mg dosage of 1:1.9. The third-stage HRAD has been constructed and the P-removed effluent solution with a high soluble COD has been fed as the feedstock. The results confirmed that the conversion of soluble organics to methane was efficient.

Activity 2
With the results obtained in the lab-scale system, the corresponding pilot-scale system proposed in Activity 2 has been designed and equipment has been ordered. This system will be set up for study of two possible treatment scenarios:
1. The proposed concept of combined TWAS (diluted) and TPS fermentation, dewatering, P recovery and HRAD will be operated if sufficient carbon solubilization is achieved in the fermentation step and dewatering is effective.
2. If the carbon solubilization and dewatering goals are not achieved, the pilot operation will be modified to include fermentation of diluted TWAS, solids separation by ultrafilter (UF), P recovery, HRAD and separate anaerobic digestion of the UF solids stream and the TPS streams.

Dissemination
An abstract with the results obtained in this project has been submitted to the 96th Annual Meeting of the Central States Water Environment Association, Inc., which will be held May 22-24, 2022 at the Saint Paul River Center in St. Paul, MN.

Status Update Reporting

Status Update June 1, 2022

Date Submitted: May 25, 2022

Date Approved: May 26, 2022

Overall Update

We have conducted most of the lab work in Activity 1, mainly including the collection and characterization of sludge feedstock, the first stage TAAD of sludge feedstock, and the second stage chemical dosing for phosphorus recovery. Through the feedstock characterization, the properties of wastewater sludge were revealed. After the first stage TAAD, higher soluble P and COD release from the solids into the liquid were achieved. After the second stage chemical dosing, efficient P recovery in the form of P-bearing mineral precipitates was secured. The third stage HRAD of liquid effluent is now under construction and will be operated soon. With the results obtained in the lab-scale first and second stages, the corresponding pilot-scale system proposed in Activity 2 is now under design, and the document to MCES for approval is now being drafted for an on-site operation in the following year.

Activity 1

The feedstock TPS and TWAS were collected from the Blue Lake WWTP, and analyzed for the TS, VS, phosphorus, and nitrogen levels. The first and second stages of the lab-scale system have been established. The first stage of TAAD is being conducted on a 1-L continuous stirred-tank reactor. After over 150 days operation, the soluble P release significantly increased from approx.. 400 mg/L in the mixed TPS and TWAS to approx. 600-900 mg/L after TAAD (at an HRT of 3 days and with a controlled pH value below 6), and the soluble COD also increased from 8000 mg/L to over 20,000 mg/L. Subsequently, the second stage P recovery from the supernatant of the TAAD effluent was conducted through a standardized jar test, and the maximum P removal was achieved with a molar dosage of 1:1.9 (phosphate to magnesium ions) in the solution. With this dosage, up to 80% of the soluble phosphate was recovery in the form of P-bearing mineral precipitates. The third stage of high-rate AD is now under construction and will be implemented soon using the P-removed effluent solution with a high soluble COD as the feedstock.

Activity 2

Currently, we are designing the pilot-scale system based on the results obtained in Activity 1. We are also drafting a document (including the description of the proposed pilot-scale system and on-site work) to the Metropolitan Council Environmental Services so that we can get the approval to install and operate it in one of the WWTPs in the following year.

Dissemination

Nothing to report at this stage.