SUMMER 2021

The Official Publication of the Water Environment Association of Utah

DIGESTED news

Celebrating 50 Years of Clean Water

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INSIDE:

2021 WEAU Virtual Annual Conference Summary | Nitrogen in Municipal Wastewater, No Problem

Discover the Cost-Effective Difference ACO Stormbrixx Makes For You.

Schoonover Case Study

The Schoonover Plumbing ACO Stormbrixx project was brought to Mountain Supply out of a need to find a cost-effective way to eliminate an on-site drainage pond, while staying in compliance with the current State of Utah Stormwater Requirements. In order to eliminate the pond, it was determined that an underground stormwater detention system would be necessary. Working with Mustang Design and ACO an appropriately sized below ground retention system was designed for the site that included two access and maintenance points. Once approved, the system was installed with on-site assistance from Mountainland Supply.

By using Stormbrixx the owner was able eliminate the pond by detaining the stormwater under their parking lot in a Stormbrixx system. This system not only saved the owner from wasting land but created a structurally sound "modular vault" that will be able to be maintained for years to come. By retaining and infiltrating the storm water 100% on site the owner was able to eliminate the extra cost incurred by connecting to the city's storm sewer system.

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Contents

FEATURES

Departments

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Keeping It Simple

Trevor Lindley

All the WEAU board members and annual conference volunteers want to give a huge thanks to the attendees and sponsors of our first ever, fully virtual WEAU Annual Conference. We want to recognize the effort of the organizers, the quality presentations, and the election of new WEAU officers. We can call it a success! At the end of the conference, I took the 'golden shovel' from Chris Reilley as I became the President of WEAU. Under Chris' capable leadership, the organization continued to be financially stable and implemented virtual trainings throughout much of 2020, culminating in the 2021 Virtual Annual Conference. If you see Chris, make sure you thank him for his service.

If you heard my 'acceptance' speech, you'll recall I tried to keep it short, simple, and focused on three basic messages:

1. WEAU and this profession is where I want to be!

It's great to associated with smart, innovative, and hard-working people that make up WEAU. Our industry might be called 'blue collar', which to me means people who are in the trenches, hard workers, and provide vital service with little fanfare. I want to be like many of you and just go about my profession and get the job done!

2. Resilience and grace.

The year 2020 and the pandemic were tough. We have all had to be more patient and understanding with family members, friends, and co-workers. However, the resilience of our industry has shown through. I would encourage you all to keep moving forward as you contribute so much and have many opportunities in front of you.

3. Find somebody to mentor!

I can still remember one of my early mentors who took me through wastewater treatment design and showed me, for example, when to use a progressive cavity pump to feed a belt press and how there had to be adequate room to do maintenance on the pumps. Much of what I internalized in laying out a typical wastewater treatment system took root in the first few years of my career doing design with one or two key mentors. Our industry here in Utah has many senior leaders with many years of experience. Eventually those with all this experience will move to other responsibilities or retire and it's imperative that we train the next generation. We have many bright young engineers and operators that are eager to learn from those with more experience. Reach out when you can and find someone to mentor.

The WEAU board is looking forward to a great 2021-2022. We always need volunteers. So, if one of the board members or committee chairs reaches out, raise your hand and be part of WEAU!

Trevor Lindley, WEAU President DN

Graphic Content!

Bryan Mansell

Recently, my wife was working on a birthday invitation on the computer and needed my help getting it to look just the way she wanted it (husbands everywhere grin and sigh). It's always a chore to get it just so, but what caught my attention was her question about what format to save an image in so that it would show up best in the finished product. That got my wheel turning and I figured I would like to understand the different graphic formats better. Surely, they must each have different strengths and best applications. Below is a quick summary of what I learned. Hopefully, as you digest it, the enhanced understanding will benefit future presentations, reports, proposals, field documentation, diagrams, etc.

JPEG (Joint Photographic Experts Group)

- Most common, good compression allows for fast loading, used in digital photography and websites.
- Strengths: good compression minimizes file sizes widely supported by websites, cameras, phones, etc.
- Best uses: viewing and sharing photos/images on multiple devices or web applications.

TIFF (Tagged Image File Format)

- Non-compressed, large file size, typically used by professionals in the publishing, graphics, and printing industry, but not supported by all web browsers due to large file size and slow loading.
- Strengths: very high quality.
- Best uses: high-quality or large-scale printing.

PNG (Portable Network Graphics)

- More compressible format than TIFF, but with less quality loss than JPEG.
- Strengths: high quality, retains image details and complexity, supports transparent backgrounds.
- Best uses: complex or detailed imagery, images with transparent backgrounds.

SVG (Scalable Vector Graphics)

- Similar to PNG but with faster loading, saves text as separate layer for searchability.
- Strengths: high quality, good for interactive content, and searchable image text.
- Best uses: web development, searchable content.

GIF (Graphics Interchange Format)

- Simple graphics format limited to 256 colors.
- Strengths: simple and small file size.
- Best uses: simple graphics, shapes, icons, diagrams, and logos.
- GIF89a format supports transparent backgrounds.

BMP (Bitmap)

- Non-compressed, large file size, low-resolution old-school format that is basically obsolete. No real benefits over TIFF, except that it's usable as Windows wallpaper.
- Best uses: windows wallpaper.

WEAU Collections College Summer 2021 Class Schedule

Date	Chapter	Tests
August 19 (Thursday)		Math Review Packet
August 25	1 & 2	Chapter 1 & 2, B Math 1, A Math 2
September 1	3 & 11	Chapter 3 & 11, B Math 2, A Math 4
September 8	4	Chapter 4 & B Math 4, A Math 5
September 16 (Thursday)	5 & 6	Chapter 5 & 6, B Math 5, A Math 6
September 22	8	Chapter 8, B Math 6, A Math 7
September 29		Fall Break No Class Turn in test application to DEQ
October 6	9	Chapter 9, B Math 7, A Math 8
October 13	10	Chapter 10, B Math 8, Mini Review
October 21 (Thursday)	12	Chapter 12, Advance Practice Problems
October 27	13 & 14	Chapter 13 & 14, 100 Question Test
November 3		Last Minute Review
November 4 (Thursday)		Test (Good Luck!)

Schedule is subject to change.

Read the Sacramento, Ken Kerri manuals titled Operation and Maintenance of Wastewater Collection Systems, 7th or 8 Edition, Volume 1 & 7th Edition Volume 2. The manuals can be purchased at www.owp.csus.edu/courses/wastewater.php.

Do the chapter tests as you read. For example, by the August 25 class, you should have read chapters 1 and 2 and finished the test. Classes start at 12:30 pm and go until 3:30 pm. Along with the chapter test, you will get two sets of math sheets each week, the B (beginning) math series is for people just starting out. The A (advanced) math series is for people who have taken and passed a test before and need training for a higher test. There is no cost for the class, but a contribution of a ream of paper per student is appreciated and it will be given it back as handouts.

Taking this class does not guarantee you will pass. The more you study outside of class, the better your chances are of passing. You can call me (Lonn Rasmussen at work 801-943-7671) with questions and to sign up. DN

Don't Get Buried

1. **How much does a cubic yard of dirt weigh?**
   a) 500 to 1,000 lbs.
   b) 1,001 to 1,999 lbs.
   c) 2,000 to 3,000 lbs.
   d) 3,001 to 3,500 lbs.

2. **Trenches usually will not collapse unless disturbed.**
   a) True
   b) False

3. **It's ok to enter all trenches 5' or less deep without shoring.**
   a) True
   b) False

4. **How many different types of soil classifications are there in trenching?**
   a) 4
   b) 5
   c) 6
   d) 7

5. **Type C soil is the most cohesive.**
   a) True
   b) False

6. **In case of a cave in use the excavator to quickly uncover the victim**.
   a) True
   b) False

7. **Put a spotter in the trench to keep a look out for the victim while excavating them.**
   a) True
   b) False

8. **The weather makes a trench unsafe.**
   a) True
   b) False

9. **Who is authorized to decide whether a trench is safe to enter?**
   a) Boss
   b) Competent person
   c) Hoe operator
   d) Trench worker

10. **What protective equipment should be worn when working in or around trenches?**

___

___

ANSWERS:

1- C, 2-B, 3-B (There could be other factors that can make a trench unsafe)
4-A (Type A, B, C & Solid rock) 5-B, 6- B
(You can injure or kill the victim)
7- B (The trench can still collapse) 8- A, 9- B,
10-Hard hat, safety vest, steel toe boots, and any other equipment deemed necessary.

Provided by the WEAU Collection Committee


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A Bear of a Quiz

Test Your Knowledge On: Solids Conditioning/Handling

1. Thickening sludge from 2% to 8% will decrease the sludge volume by _______.
   a) 55%
   b) 65%
   c) 75%
   d) 85%

2. Which thickening process typically achieves the highest percent solids?
   a) Centrifuge
   b) Drum
   c) DAF
   d) GBT

3. Typically thickening occurs before _______.
   a) Conditioning
   b) Dewatering
   c) Digestion
   d) Disposal

4. A gravity thickener can thicken primary sludge only to approximately _______.
   a) 1-4%
   b) 7-10%
   c) 12-15%
   d) 17-20%

5. Typically DAF float is approximately ______ solids.
   a) 2%
   b) 4%
   c) 6%
   d) 8%

6. Typical DAF operating pressure.
   a) 10-40 psi
   b) 40-70 psi
   c) 70-100 psi
   d) 100-130 psi

7. On GBT the solids are windrowed by the ________.
   a) Belt weave
   b) Chicanes
   c) Doctor blade
   d) Feed pump

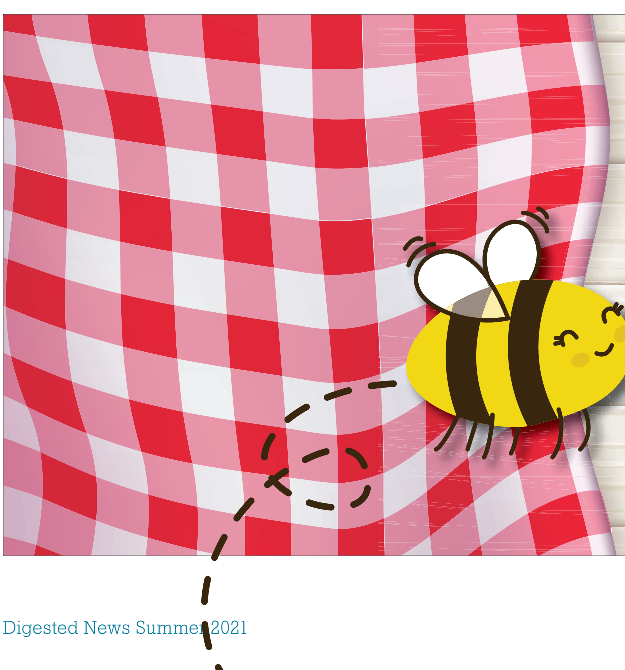
8. Typical capture rate of GBT's.
   a) 65%
   b) 75%
   c) 85%
   d) 95%

9. Increasing the speed of a drum thickener will _______.
   a) Decrease sludge concentration
   b) Increase sludge concentration
   c) Decrease sludge throughput
   d) Increase sludge throughput

10. Typical capture rate of waste activated sludge in a drum thickener.
   a) 80%-84%
   b) 85%-89%
   c) 90%-94%
   d) 95%-99%

ANSWERS:
1-C, 2-A, 3-C, 4-B, 5-B, 6-C, 7-B, 8-D, 9-A, 10-D

These questions are developed from the new WEF operations manual Wastewater Treatment Fundamentals II: Solids Handling and Support Systems Chapter Two.



Summer Bee's Game

The Summer Bee's game and picnic are back! Mark your calendars for July 24 at 6:35 pm to watch the game against the LV Aviators. Dinner will be available and the night will finish off with fireworks. Keep your eyes out for an invitation to register for tickets.

Provided by Rebecca Yoo

VIRTUAL ANNUAL CONFERENCE SUMMARY

April 13 – April 15, 2021

WELCOME TO OUR WEAU BOARD 2021-2022

Executive Committee
Trevor Lindley, President
Sarah Ward, President-Elect
Sherry Sheffield, Vice President
Chad Burrell, Secretary
Myron Bachman, Treasurer*
Chris Reilley, Past President

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Rob Jaterka, Director
Gary Vance, Director
Steve Myers, Director*
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WEF Delegates
Clint Rogers, WEF Delegate
Jeff Beckman, WEF Delegate*

PWO Representatives
Daniel Watts, PWO Rep
Dustin Lewis, PWO Rep-Elect*

*New members

WEAU Annual Conference 2021 Awards List

INDIVIDUAL AWARDS

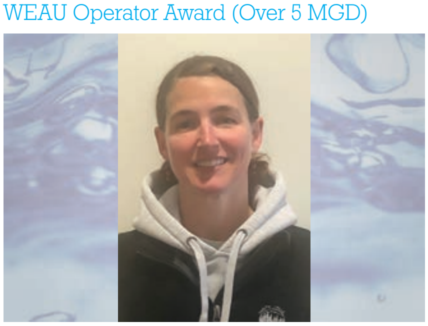
WEAU Collections Operator Award (Over 5 MGD)

Josh Surratt,
Snyderville Basin Water Reclamation District

WEAU Maintenance Specialist Award

Shaun Peters,
Timpanogos Special Service District

WEAU Operator Award (Over 5 MGD)



Sara Hopp,
Jordan Basin Water Reclamation Facility

WEAU Operator Award (Under 5 MGD)

Jim Giles,
Snyderville Basin Water Reclamation Facility

WEAU Pretreatment Specialist Award

Brad Woodhouse, *Central Valley WRF*

WEAU Laboratory Technician Award

Laurie Smith,
Cedar City Regional Wastewater Facility

WEAU Young Professional Award

Josh Donegan, *AECOM*

WEAU Supervisor Award

Ken Burgener, *North Davis Sewer District*

WEAU Supervisor Award

Marlo Davis, *Snyderville Basin Water Reclamation Facility*

FACILITY/PROGRAM AWARDS

WEAU Collections System Award (Over 5 MGD)

Snyderville Basin Water Reclamation District

WEAU Safety Program Award

Central Valley Water Reclamation Facility

WEAU Laboratory Award

Central Weber Sewer Improvement District

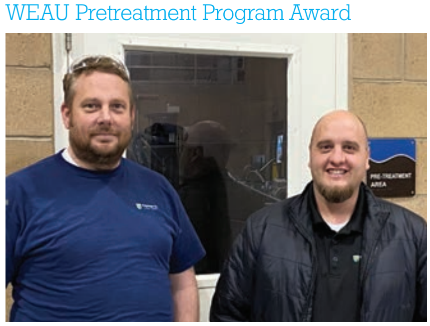
WEAU Water Reclamation Facility Award (Over 5 MGD)

Timpanogos Special Service District

WEAU Water Reclamation Facility Award (Under 5 MGD)

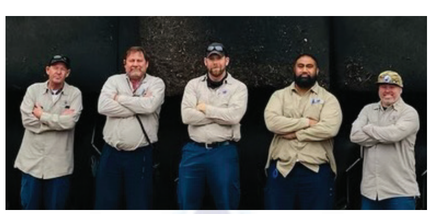
Salem City

WEAU Pretreatment Program Award



Timpanogos Special Service District

WEAU Biosolids Program Award



Central Valley Water Reclamation Facility

WEAU Excellence Award

Snyderville Basin Water Reclamation District

WEAU Excellence Award

Central Valley Water Reclamation Facility

WEAU Excellence Award

Timpanogos Special Service District

EVENT HIGHLIGHTS

The Passing of the Shovel

WEAU 2020-21 President Chris Reilley passes the ceremonial shovel to 2021-22 President Trevor Lindley.

New Sheriff in Town

Trevor Lindley addresses WEAU members for the first time as 2021-22 President.

We Learned So Much

Professionals from across Utah presented their knowledge virtually including:
Erin Andersen, Jason Broome, Ryan Bench, Dr. Ramesh Goel, and Soklida Hong.

B. Y. O. Lunch

Past-president Chris Reilley and Incoming President Trevor Lindley brought their own lunches as they attended the conference, together but apart.

Young Professionals Network Like Bosses

The YPs hosted a successful networking event at the annual conference. Attendees from various member entities and experience levels were able to meet and make valuable connections through sharing stories, common challenges, and lessons learned. Join the YPs for the next Trivia Lunch in late July! Please email *ypweau@gmail.com* to join the mail list or suggest a YP from your organization to join.

Thanks to THE ANNUAL CONFERENCE COMMITTEE

Brandon Wyatt
Korey Walsh
Ben Skousen
Rob Jaterka
Cory Christiansen
Bryan Mansell
Chris Reilley

Chad Burrell
John Richardson
Mike Chambers
Tom Anderson
Rebecca Yoo
Mike Kobe
Marianka Sochanska

Shania Lynch
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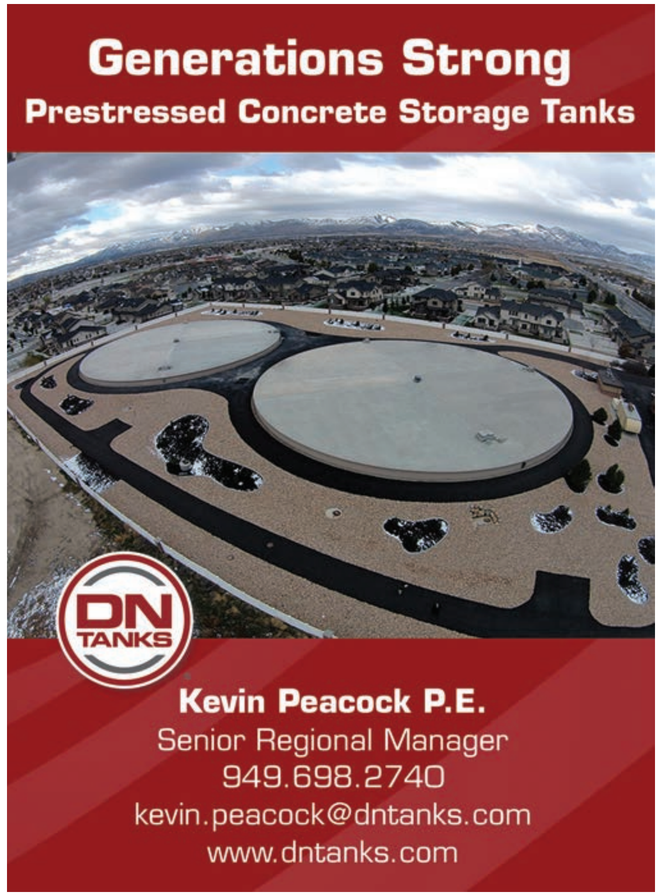
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Per and Poly-Fluorinated Alkyl Compounds

The Current State of Knowledge, Existing Regulations, Industrial Pretreatment and Concerns in POTWS

By Divyam Goel, University of Utah

PFAS is used to describe a broad group of perfluoroalkyl and polyfluoroalkyl chemical substances. Per and polyfluoroalkyl substances (PFAS) are highly fluorinated aliphatic substances that contain one or more carbon atoms on which all hydrogen substituents have been replaced by fluorine atoms. Consequently, they contain the perfluoroalkyl moiety. PFAS substances have been used since the 1950's in various capacities due to their resistance properties against oils, water, temperature, chemicals, and heat. Commercial production of PFAS chemicals began over half a century ago. The US is one of the largest producers of PFAS compounds. The per fluorinated or polyfluorinated compounds are anthropogenic in nature and released into the environment due to human and industrial activities. Due to their unique chemical structures and stability, several PFASs have been proven to be bio-accumulative and toxic in many animals, also including humans. Their characteristic carbon backbone surrounded by fluorine atoms makes them one of the most resistant molecules to various degradation processes and, thus, a pain to treat. Due to this unique characteristic, these stubborn chemicals have been used in non-stick cookware, waterproofing treatments, furniture, carpets, waterproof coatings and carboard, mist suppressants in the metal industry, and firefighting foam. PFAS compounds are found worldwide in the environment, wildlife, and humans. The

"The half-lives of many PFAS compounds have been measured to be hours to days in rats and in years in humans.

half-lives of many PFAS compounds have been measured to be hours to days in rats and in years in humans. Due to the bio-accumulative nature of most of PFAS compounds, PFAS compounds were added to the "most persistent" chemical list by the United States Protection Agency.

Quite recently, the State of Michigan's Department of Environment, Great Lakes and Energy announced a new set of regulations limiting PFAS contaminants in drinking water. The regulations establish strict Maximum Contaminant Levels (MCLs) on various types of PFAS and the accepted amount in parts per trillion (ppt). For example, PFAS PFNA is permissible at a mere 6 ppt while PFBS is allowed at 420 ppt. The regulations brought a wave of reform as public water supplies in the state have started to modify and evolve their operations to better treat PFAS. The State of Michigan wrote, "MPART agencies like EGLE and MDHHS will assist public water systems to bring their water into compliance over the next several months." The announcement was released in late July, 2020 (EGLE Media Office, 2020).

1 Sources of PFAS in POTW

PFAS can enter the sewage system through a variety of industrial sources that include PFAS manufacturing, fluoropolymer manufacturing, and AFFF manufacturing. PFAS can get into municipal wastewater through a variety of sources including sloughing of the film from non-stick cooking utensils, industrial disposals (plastic manufacturing, textiles and leather industries, surfactants preparation, and even medical applications), landfill seepage and stormwater runoffs (for combined sewer systems). The number one contributing source for PFAS contaminants entering sewage systems is food packaging material.

Due to their widespread use in industries and daily-life products, PFAS have entered the soil and water environments and are now found in microorganisms, plants, various different animals, and humans globally. PFAS are even being found in extreme environments including in the Arctic and Antarctic ecosystems.

2 Concerns about the presence of PFAS in POTWs

Exposure to PFAS threatens human health and aquatic habitats when the treated effluent from the wastewater treatment plants is discharged into the environment (WWTPs), and thus, WWTPs act as secondary sources of PFAS (Yiping et al., 2008). While PFAS might be released into the environment during production, usage, or disposal, there are several PFAS precursors, that can be transformed abiotically or biologically into PFASs. Some of the PFAS precursors such as fluorotelomer alcohols can be transformed in the environment and form many intermediate transformation products. The concentrations of these pollutants are typically negligible (µg/L to ng/L) as compared to COD or BOD in wastewater, however, there has been a growing concern on their occurrences as long-term exposure to these substances can be carcinogenic (Wielsøe et al., 2015). Due to persistent and recalcitrant nature of PFAS, most of the PFAS remain unaffected through conventional water treatment processes. As a result, PFAS originating from domestic and industrial sources as well as PFAS originating from their precursor compounds in the treatment train, are typically present in the final effluent in wastewater treatment plants. Hence, established practices towards water sustainability such as recycling and environmental discharges are currently being questioned.

> "Due to their widespread use in industries and daily-life products, PFAS have entered the soil and water environments and are now found in microorganisms, plants, various different animals, and humans globally.

The PFAS issue arises in sewage sludge because conventional wastewater and sewage treatment methods cannot efficiently eliminate these recalcitrant compounds from the system. The increase in concentration of some PFAS compounds such as perfluoroalkyl acid (PFAA) in sewage effluents over that in the influent is attributed to the degradation of more complex PFAA precursors during activated sludge treatment For example, wastewater treatment plants could show 9-352 % increase in PFOA concentration in effluents over influents (Schultz et al., 2006). However, PFOS often could exhibit a decrease in concentration in the effluent, attributed to high Kd values causing retention of PFOS in the sludge and lowering final PFOS concentrations in effluents (Yu et al., 2009). Becker et al. (2008) observed a 20-fold increase in PFOA concentrations from influents to effluents, and an additional 10% and 50% PFOA and PFOS, respectively, adsorbed in the sludges. As a result, land application, landfilling and other application of biosolids have been revisited recently in light of the presence of PFAS compounds in biosolids/sewage sludge.

3 Pretreatment of PFAS compounds

Because only a small subset (<30) amongst the large set (>5000) of PFAS have been detected and quantified in municipal wastewater and since they are not currently regulated under National Pollution Discharge Elimination system, there are no defined pretreatment methods for PFAS compounds. The carbon-fluorine bond is one of the strongest in chemical bonding. Hence, PFAS compounds are known to be recalcitrant to biodegradation. However, PFAS compounds could be remediated using a variety of abiotic techniques including sorption, immobilisation, stabilisation, filtration, coagulation, separation, chemical oxidation/reduction, thermal decomposition, and UV/photocatalytic degradation. However, most of these techniques have evaluated degradation efficiency of PFAS compounds in terms of removal of parent compound and very few studies included identifying degradation intermediates.

4 Existing regulations and their impacts on industrial users

Since 2000, USEPA has taken serious interest in developing strategies to study the presence, fate and transport of long chain PFAS compounds in the environment. EPA intended to implement regulatory actions under the toxic substances control act (TSCA) to address the potential risks from long chain PFAS. In terms of drinking water regulations, there are currently no minimum contaminant limits established for PFAS compounds. However, USEPA initiated the process of MCL for selected PFAS compounds under the regulatory determination process. Consequently, on February 20, 2020, EPA issued preliminary determinations to regulate PFOA and PFOS in drinking water. Nevertheless, EPA has already issued a health advisory for PFOA and PFOS compounds. Under the TSCA act, USEPA has developed three framework rules outlining path forward for future actions but these rules do not require POTWs to operate under any regulatory guidelines. The EPA identified three final Significant New Use Rules (SNURs) and one proposed SNUR that cover 24 of the 40 PFAS chemicals within the scope of this review and require manufacturers to notify the EPA through submission of a Significant New Use Notice (SNUN) at least 90 days before manufacturing, importing, or processing listed chemicals. The EPA does not currently have an approved Clean Water Act analytical method for monitoring PFAS in wastewater discharges. Consequently, state permitting authorities are using the Method 537 drinking water method, or its variations, to establish permit limits or monitoring requirements for NPDES permits as needed.

Conclusion

Presence, fate and transport of PFAS compounds in different environmental matrixes including in POTWs is still an unknown territory although research is underway. Future directions should focus on degradation intermediates and their toxicity, simple analytical tools for POTWs managers, and training to POTWs personnel about potential health effects of PFAS compounds

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About the Author

Divyam Goel is a sophomore student University of Utah studying environmental microbiology and economics. In high school, he was the recipient of Utah Stockholm Junior Water Prize and represented Utah at the National competition after completing research on the potential of recovering phosphorus and nitrogen in excess amounts from wastewater as a fertilizer for plants. He was also the recipient of Utah Governor's science medal in 2019. He plans to go to graduate school or enter industry to continue working on environmental microbiology and related fields. DN


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NITROGEN IN MUNICIPAL WASTEWATER-NO PROBLEM;
Employ Innovative Carbon and Energy Efficient Technologies

By Dr. Ramesh Goel and Soklida Hong, University of Utah

Nitrogen is a naturally occurring element and a critical component in the growth and reproduction of all living organisms. Nitrogen is a major element of DNA, RNA and proteins – the building blocks of life. However, human production of fixed nitrogen has disrupted the natural nitrogen cycle. Fixed nitrogen such as ammonium (NH_4^+), nitrite (NO_2^-), nitrate (NO_3^-), and urea have been industrially produced and widely used as fertilizers, refrigerants, food preservatives, and in the industry, such as annealing of steels. These extensive uses lead to the excess of the fixed nitrogen discharged to the surface water. Fixed nitrogen poses threats to the global environment and water sustainability by causing eutrophication, dissolved oxygen depletion, and formation of cyanotoxins threatening other aquatic organisms and contaminating the drinking water supply. Nitrate in drinking water can cause a human health condition called methemoglobinemia (blue baby syndrome). Therefore, it is crucial to remove fixed nitrogen in wastewater to a safe level before being discharged to the surface water. Managing nitrogen in the environment is one of the 14 Grand Challenges identified by the National Academy of Engineering.

The Clean Water Act established the National Pollutant Discharge Elimination System (NPDES), requiring utilities to comply with their NPDES permits. With increasing surface water eutrophication and harmful algal blooms, regulatory agencies are becoming more stringent for total inorganic N (TIN) in treated effluents. As a result, more and more utilities are considering improved TIN removal while maintaining low energy and carbon footprints. The majority of fixed nitrogen in municipal wastewater is in the form of ammonium with a typical concentration of 20 to 40 mg N/L (ppm). The primary source of ammonium is from hydrolysis of urea, found in urine and biodegradation of organic matter containing nitrogen such as protein and nucleic acid. Conventional nitrification-denitrification is the most common process to remove inorganic nitrogen in wastewater. Nitrification is carried out by two distinct groups of microorganisms – ammonium oxidizing bacteria (AOBs) and nitrite-oxidizing bacteria (NOBs). In first the step, AOBs oxidize ammonium to hydroxylamine (NH_2OH) that is mediated by an enzyme called ammonia monooxygenase (AMO) and then another enzyme called hydroxylamine oxidoreductase (HAO) converts hydroxylamine to nitrite. After this NOBs use nitrite oxidoreductase (NXR) to convert nitrite to nitrate to complete the nitrification process, as shown in the figure below.

$$NH_4^+ \xrightarrow{\text{AMO}} NH_2OH \xrightarrow{\text{HAO}} NO_2^- \xrightarrow{\text{NXR}} NO_3^-$$

During anoxic zone, denitrifying bacteria use organic carbon to reduce NO_3^- to NO_2^-, NO (nitric oxide), N_2O (nitrous oxide), and finally back to N_2 by using a series of enzymes, as shown in the figure below.

$$NO_3^- \xrightarrow{\text{Nitrate reductase}} NO_2^- \xrightarrow{\text{Nitrate reductase}} NO \xrightarrow{\text{Nitrate oxide reductase}} 0.5N_2O \xrightarrow{\text{Nitrate oxide reductase}} N_2$$

Nitrification is an aerobic process, which means that it requires O_2 in the form of dissolved oxygen (DO). Complete nitrification is an oxygen-intensive process that requires approximately 4.6 pounds of oxygen for every pound of ammonium. Nitrifying bacteria are also sensitive to low concentrations of DO. DO should not be below 1.0 mg/L for nitrification to proceed. Nitrification also produces acids that can lower the pH of the wastewater leading to a reduction in the growth rate of nitrifying bacteria. Complete nitrification consumes about 7.14 pounds of alkalinity (as $CaCO_3$) per pound of ammonia. Nitrifying bacteria are also slow growers, thus require higher solid retention time (SRT) to complete nitrification. Typically, SRT higher than 10 days suffices.

Denitrification is an anoxic process that occurs in the absence of DO. Denitrification requires an anoxic condition and the presence of organic matter. Denitrifying bacteria are facultative anaerobes that can use either DO or nitrate as an electron acceptor. In the presence of DO, denitrifying bacteria will use DO over nitrate, thus lower the denitrification efficiency. Organic matter is needed to supply that can be as raw wastewater or chemicals such as methanol or acetate.

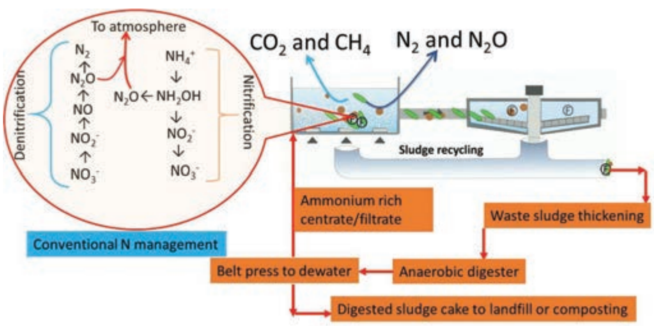

Figure 1. Conventional wastewater bioreactor employing Nitrification/Denitrification. The ammonium-rich centrate is returned to the bioreactor resulting in excess ammonium load and lost opportunity for N management in concentrated streams. These current configurations are carbon and energy intensive, emit GHG (N_2O from nitrification/denitrification, CH_4 dissolved in return flows, and fossil CO_2 from aerobic respiration and return flows).

Due to their difference in respiratory metabolism, nitrification and denitrification are separated spatially. An aerobic tank is designated for carbonaceous biological oxygen demand (CBOD) and nitrification, with an anoxic tank for denitrification. Perhaps the most common configuration for nitrification-denitrification used in wastewater treatment plants (WWPTs) is the modified Ludzack-Ettinger (MLE) process. In this configuration, the first process is a pre-anoxic tank followed by an aerobic tank. The pre-anoxic tank receives carbon-rich influent wastewater, return sludge from the clarifier, and nitrate-rich mixed liquor from the effluent end of the aerobic tanks. The advantages of the MLE process include the use of BOD from the influent for denitrification, hence no exogenous addition of organic carbon is required. It is also easily upgraded from the existing aerobic nitrification system. Alkalinity produced during denitrification can be used for the subsequent nitrification; energy can be saved from aeration by using nitrate to remove BOD. However, in this setup, a lot of energy is required for internal recycling to feed nitrate from the aeration tank to the anoxic tank.

As mentioned above, conventional nitrification-denitrification requires extensive aeration, addition of organic carbon and produces a significant amount of N_2O (one of the intermediates during denitrification), a potent greenhouse gas. Anaerobic ammonium oxidation (Anammox) has emerged as a powerful tool to treat nitrogen in liquid waste streams. In anammox process, nitrite functions as an electron acceptor for ammonium oxidation and as an electron donor for CO_2 reduction. As a result, N_2 with a slight amount of nitrate are produced according to stoichiometry as shown in the equation below.

$$1NH_4^+ + 1.32NO_2^- + 0.066HCO_3^- + 0.13H^+ \longrightarrow 1.02N_2 + 0.26NO_3^- + 0.066CH_2O_{0.5}N_{0.021} + 2.03H_2O$$

Compared to the conventional nitrification-denitrification process, Anammox process is as effective in the removal of nitrogen with energy-efficiency and cost-saving as it requires less aeration and without organic carbon addition. Besides, in the Anammox process, there is no production of N_2O. Integration of the N cycle into wastewater treatment has undergone successive iterations and with recent innovations. For example, studies have shown that shifting traditional nitrification/denitrification (NDN) to anaerobic ammonia oxidation (anammox) can reduce energy use and GHG emissions, directly (as N_2O) or indirectly (as energy savings). However, implementation of anammox has been slow. Despite many positive attributes of the anammox process, the applications of anammox in the US have been very limited. One of the primary reasons is the lack confidence by the WWTP community about anammox operations and the need for special operational capabilities. Except for few big utilities in the US (e.g., Hampton Road Sanitation District in VA, DC WATER, Seattle, and Denver Metro), the application of anammox is scarce. These selected utilities have in-house research programs or working relationships with researchers from the US and Europe. Another technical challenge with adoption of anammox is the sensitivity of anammox bacteria towards external perturbations (both chemical and physical). Anammox bacteria are very sensitive, for example, to sulfide or substrate inhibition (e.g., nitrite) and heavy metals. Additionally, dependency on temperature cast a negative light on anammox in the wastewater community. Anammox bacteria have significantly slow growth rate, which is further exacerbated at low temperature.

Partial nitritation-Anammox (PN-A) has been increasingly implemented to treat high-strength ammonium streams in full-scale sidestream applications. In PN-A, AOBs partially convert ammonium to nitrite, which anammox bacteria use to oxidizing the remaining ammonium to N2. Theoretically, PN/A offers a 60% saving in aeration, 100% saving in organic carbon dosing, and 90% less sludge production compared to conventional nitrification-denitrification.

Despite the success of PN-A in sidestream application, full-scale implementation of PN-A remains a challenge due to the lack of efficient strategy to suppress the growth of NOBs and maintain a stable PN. Low ammonium concentration, as well as fluctuation in temperature and loading in mainstream conditions are the recognized as the main difficulties for NOB out-selection. Moreover, effluents from PN-A systems still contain considerable amounts of total inorganic nitrogen (TIN) from residual ammonium (up to 5 mg NH_4+-N/L), maintaining to suppress NOB growth and nitrate produced from anammox reaction (about 11% of each mg NH_4+-N removed). PN-A effluents still require further treatment to reduce TIN to comply with the more stringent regulations expected in the coming years. Furthermore, the relatively slow growth rate of anammox bacteria with a doubling time of 11-20 days is also perceived as another bottleneck for the successful implementation of mainstream PN-A.

The application of anammox as a mainstream application is being seriously considered by the wastewater community but with few ongoing efforts in the US. There are bottlenecks for full-scale anammox processes. Mainstream anammox is challenging as a result of low ammonium concentrations and retention times that wash out slow growing anammox bacteria. For example, ammonium concentrations in mainstream wastewater are too low to support high rates of anammox activity and the presence of biodegradable C results in heterotrophs outcompeting anammox bacteria. Secondly, the need to meet NPDES requirements with energy efficiency typically results in limited SRTs, associated with washout of slow-growing anammox bacteria. Lastly, partial nitrification requires careful control to avoid accumulation of nitrite oxidizing bacteria (NOB). One option to apply anammox to the mainstream and circumvent these challenges is to couple it with partial heterotrophic DN in a process known as partial denitrification-anammox (called PdNA process). PdNA, in which denitrifiers anoxically reduce nitrate to nitrite, has proved as a stable supply of nitrite for anammox bacteria. Theoretically, PdN-A systems reduce the cost of aeration and external carbon by 50% and 80%, respectively, compared to conventional nitrification-denitrification. These advantages of PdN-A come without the need to suppress the growth NOB. Despite these challenges, anammox still is a welcome innovation for nitrogen management in municipal wastewater treatment plants. Anammox process shows a promising future in full deployment coupling with the conventional activated sludge process to manage nitrogen and organic carbon in WWTPs.

PdNA offers the opportunity to save significant amount of C because nitrate is partially reduced only to nitrite. Additionally, partial DN of nitrate to nitrite precludes the production of unwanted N_2O, since the production of this GHG occurs in later steps of DN. Although PdNA appears an option for C-neutral and energy-efficient N management, its implementation at full-scale could be challenging because terminating DN at nitrite would require careful process control and selection of a suitable C source.

In summary, recent advances in nitrogen cycle have enabled the wastewater community with several wonderful tools which could be used as single (e.g. nitrification only) or in combination with each other (nitrification/denitrification or anammox/partial denitrification) could enable energy and carbon efficient nitrogen management in municipal wastewater treatment plants.

About the Authors

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