

2021 Research at SERL

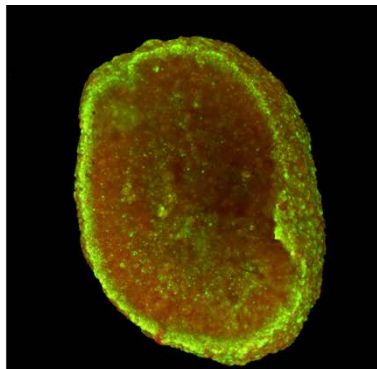
The Charles E. Via, Jr. Department of Civil and Environmental Engineering
National Capital Region (NCR) Campus



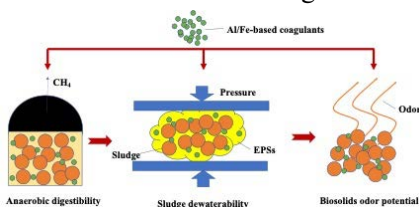
My 2021 selfie

2021 Highlights:

- Grants
- Awards
- Graduation
- Enrollment
- Projects
- Publications
- Equipment
- Fun times



Cross-section of aerobic granules



Advanced anaerobic digestion

Dear Friends,

In continuation of last year's momentum, 2021 turned out to be another fruitful year for the Sustainable Environment Research Laboratory (SERL) despite the lingering pandemic. With your blessing, our annual research fundraising was upheld at a historically high level with a healthy balance between federal and industrial supports. Such a solid financial foundation enabled us to educate more graduate students, publish more technical papers, and procure \$250,000 worth of new equipment for our stronger in-house analytical capacity down the road.

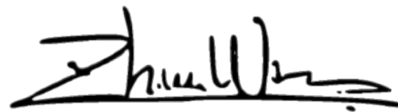
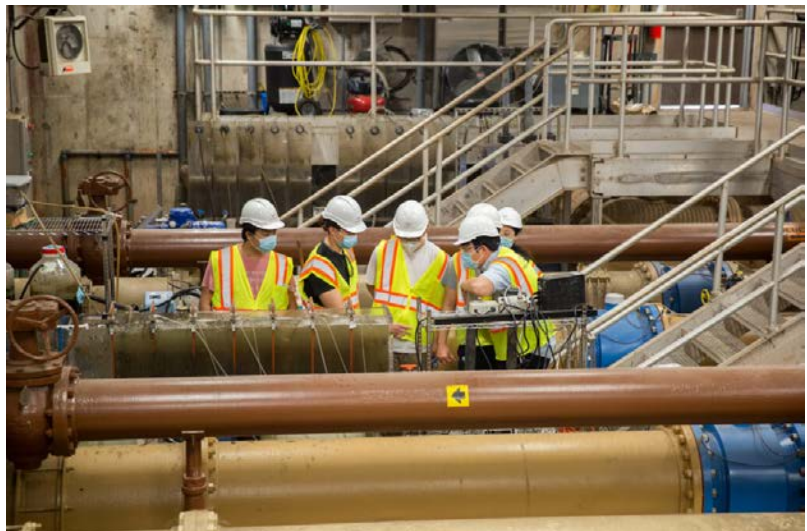
Unlike the previous year, we gradually resumed in-person communication and onsite experiments as soon as the travel ban was lifted. In 2021, we had six pilot systems running onsite within the premises of utilities spread across Virginia, Maryland, and Washington State. The success we achieved through these face-to-face interactions and hands-on research could not necessarily occur virtually. With collective efforts, this team has won several professional awards and disseminated cutting-edge research outcomes through many public presentations as detailed in this report.

2021 was also a harvest year. Kyle has successfully defended his M.S. thesis and joined HDR as a Water/Wastewater Engineer. Zhaohui and Rocky have accepted two very attractive job offers even though they are still a semester ahead of their graduation. Very importantly, Zhaohui got married after his long journey with his beloved wife, Ms. Jing Yuan. I wish these students all the best in their future lives and career endeavors.

For more detailed summary of our 2021, please refer to the content of this annual report. Since we have not only survived but also prospered over the hardest times of the past two pandemic years, I truly believe in this resolute team. With that, we are looking forward to taking on new initiatives and challenges in 2022!

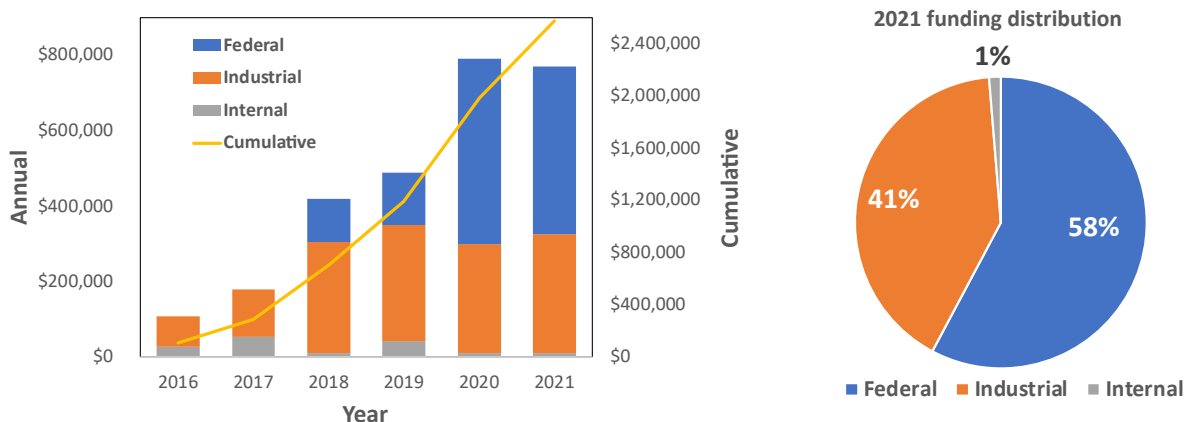
Regards,

Zhiwu (Drew) Wang

2021 Research Grants

In 2021, a total of \$771,194 in external grants had been successfully solicited by SERL in support of urgent research needs in the waste management industry, maintaining an exponential growth trend carried over the past six years, reflecting our funding sustainability. Out of these 2021 funds, 58% were from federal government and 41% were from industrial sponsors. Such a diverse and balanced funding distribution also reflects our funding security. Building on our previous year's success, we won a second Department of Energy (DOE) grant for the development of technology that enables the conversion of municipal solid wastes to drop-in fuels. This is a national collaborative effort with University of Maryland, Idaho National Laboratory, Quasar Energy Group, Ohio State University, Mississippi State University, and SCS Engineers. We were also very honored to receive funding support from the Water Research Foundation (WRF) and Fairfax County to explore the applicability of partial denitrification anammox in the secondary and tertiary wastewater treatment processes for chemical and energy saving biological nitrogen removal. Continued funding support from the National Science Foundation (NSF), Hampton Roads Sanitation District (HRSD), and Upper Occoquan Service Authority (UOSA) enabled us to solve the engineering problems impeding the full-scale application of continuous flow aerobic granulation technology. With the joint funding support from Loudoun Water, Arlington County, and WSSC Water, we were able to secure a 5-liter thermal hydrolysis pretreatment (THP) system manufactured by Cambi™ for understanding the real-world benefits and challenges those utilities may face upon the installation of this game-changing technology. We are also blessed with an internal funding support from collaborators in the College of Agriculture and Life Sciences to develop a genetically engineered plant for phosphorus pollution valorization, which was formally patented in 2021.



New Grants in 2021 (\$771,194)

- Title: **Quantifying the Impact of the Recalcitrant Dissolved Organic Nutrient Formation from Thermal Hydrolysis at the Loudoun Water Broad Run Water Reclamation Facility.** Sponsor: Loudoun Water. Duration: 1/1/22-5/31/2022
- Title: **Systematic Characterization of Variability in MSW Streams to Identify Critical Material Attributes for Fuel Production.** Sponsor: Department of Energy (DE-EE0009667). Duration: 10/01/21-9/30/2025
- Title: **Nitrogen Reduction Technology Solutions for Ocean Discharges.** Sponsor: Water Research Foundation (WRF 5133). Duration: 06/01/21-05/31/22
- Title: **Internship Complementary Support for Collaborative Research: A Novel Biological Valorization of Hydrothermal Liquefaction Wastewater with Marine Protist and its Granulated Phenotype.** Sponsor: National Science Foundation (2001568). Duration: 07/01/21-12/31/21
- Title: **Continuous Upflow Selector for Continuous Flow Aerobic Granulation.** Sponsor: Hampton Roads Sanitation District. Duration: 4/1/21-12/31/21
- Title: **Continuous Flow Aerobic Granulation Phase IV study.** Sponsor: Upper Occoquan Service Authority: 1/1/2021-6/30/2021
- Title: **A Transdisciplinary Approach to Mediate the Phosphorus Crisis.** Sponsor: Virginia Tech College of Agriculture and Life Sciences: 3/1/2021-6/30/2022
- Title: **The benefits and pitfalls of using biosolids and treated wastewater for apple production.** Sponsor: Alexandria Renew Enterprises: 1/1/2021-12/31/2021
- Title: **Effect of solids retention time on thermal hydrolysis pretreatment-enhanced mesophilic anaerobic digestion.** Sponsor: Arlington County: 1/1/2021-12/31/2021
- Title: **Effect of alum addition on thermal hydrolysis pretreatment-enhanced mesophilic anaerobic digestion.** Sponsor: WSSC Water: 1/1/2021-12/31/2021

2021 Awards, Graduation, and Employment



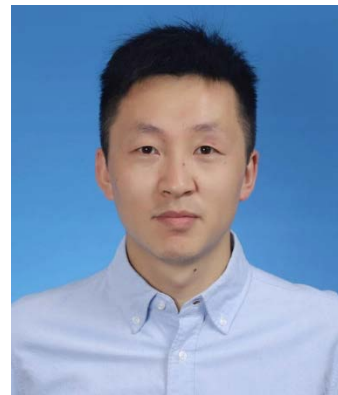
Zhaohui receiving his 1st place award in WaterJam conference



Rafael's 2nd place AWWA award



Kyle graduated with a M.S. degree



Yuepeng joined us as a Postdoctor

2021 was a fruitful year for our team members. **Mr. Zhaohui An** was the recipient of the 1st place award in the WaterJam 2021 poster competition and the NSF Internship Complementary Award for his outstanding field work in UOSA on continuous flow aerobic granulation research. With his strong publication record, I feel positive about his Ph.D. dissertation defense scheduled in Spring. Zhaohui plans to return to China to continue his wastewater R&D and has already accepted a job offer from SUS Environment in Shanghai. Likewise, **Mr. Rafael (Rocky) Iboleon** was also a two-time 2021 award recipient (a 2nd place AWWA 2021 virtual poster competition award and a 2021 Edna Bailey Sussman Internship Award). Although he also still has one more semester to wrap up his M.S. study, Rocky has accepted a very good offer from Stantec (I hope I could have earned his salary at his age). Stantec is a famous consulting firm developing similar thermal hydrolysis-enhanced anaerobic digestion technologies that Rocky has been working on during his M.S. study. Apparently, Stantec has been very impressed by Rocky's professionalism and strong communication skills. My congratulation also goes to **Mr. Kyle Malin** for his successful thesis defense on the topic of "*Development of Kinetic Parameterization Methods for Nitrifying Bacteria using Respirometry*". Kyle was co-advised by Dr. Charles Bott and me. His research was aimed to understand how nitrifiers react when exposed to low DO conditions for developing advanced technologies for saving energy and chemicals during biological nitrogen removal. Kyle has joined HDR, Inc. in Minnesota as a Water/Wastewater Engineer. I am sure his career will prosper down the road in the field of process engineering. **Ms. Xueyao Zhang** has only joined us for one year as a Ph.D. candidate, already co-authored three peer-reviewed journal papers, and given one oral and two poster presentations in national and state conferences. She is also the recipient of a 2021 Edna Bailey Sussman Internship Award and is currently spearheading our DOE project on the topic of food waste-to-bioplastics conversion. **Dr. Yuepeng Sun** joined us in the middle of 2021 as a postdoctoral research associate and brought over the molecular biology strength urgently needed by the team. Dr. Sun has already put the new qPCR system in operation and performed shotgun sequencing of multiple wastewater samples produced by the team.

Recipients	Awards	Amount
Zhaohui An	1st place in WaterJam 2021 poster competition	\$1,000
Rafael Iboleon	2nd place in CSAWWA 2021 virtual poster competition	\$150
Zhaohui An	NSF Internship Complementary Award	\$33,641
Xueyao Zhang	2021 Edna Bailey Sussman Internship Award	\$6,825
Rafael Iboleon	2021 Edna Bailey Sussman Internship Award	\$6,825



Xueyao joined us as a Ph.D. student



Rafael accepted an offer from Stantec at the DC/Fairfax, VA office



Zhaohui accepted an offer from SUS Environment in Shanghai, China

2021 Project Highlights



Full-scale (*Left*) and pilot-scale (*right*) continuous flow aerobic granulation research funded by NSF and UOSA



While most aerobic granular sludge has been cultivated in sequential batch reactors that are rarely used in the wastewater industry, the **continuous flow aerobic granulation** research funded by NSF (2001568) and UOSA has been successfully demonstrated in both pilot- and full-scale application in Millard H.

Robbins, Jr. Water Reclamation Plant. The major progress made in 2021 was the provision of solutions to the performance loss during the system startup through the manipulation of feast and famine as an in-situ biological selector and the surface overflow rate (SOR) as an economical physical selector for driving successful continuous flow aerobic granulation in the existing secondary tankage of wastewater treatment plants.

Partial Denitrification Anammox (PdNA)

was a new research direction explored in 2021. It is an alternative to the partial nitrification pathway that has been successful only in sidestream but not in mainstream wastewater treatment for the low strength and temperature of the latter. The WRF (5133) and Fairfax County projects explore the placement of PdNA in the secondary and tertiary processes, respectively. In collaboration with Hazen & Sawyer, a suite of feed-forward and feed-backward smart control strategies has been developed in concert with the optimum carbon source selection and retention time optimization for the best economic gain in terms of chemical and energy savings along with the greenhouse



PdNA projects funded by WRF (*left*) and Fairfax County (*right*), respectively

gas reduction for biological nitrogen removal. What is interesting is that the design has become so smart that the project team can remotely control and troubleshoot our pilot system installed in the Seattle from Northern Virginia. Smart infrastructure like this is the future of modern wastewater treatment plants.



Left: A 5 liter Cambi THP system precured with funding provided by Loudoun Water, WSSC Water, and Arlington County; *Right:* high-solid AD system for high-rate solid reduction and methane/VFA production



Anaerobic Digestion (AD) has been used for a century and is still the most applicable process for solid waste reduction and many valuable downstream bioproduct productions. The bottleneck of AD lies in its slow hydrolysis rate. The application of **Thermal Hydrolysis Pretreatment (THP)** has unblocked this rate-limiting step and accelerated AD to the limits constrained by other factors. The ongoing **THP-AD** projects are aimed to address the recalcitrant substance formation problem, the free ammonia inhibition issue,

as well as the odor nuisance along with the digestability maximization via THP. Spinning off these THP-AD research we have been focused on in the past two years, two DOE projects (DE-EE0009667 and DE-EE0009268) have been awarded to explore the potential of THP-AD in biofuel and value-added bioproduct generation from waste feedstocks.

2021 Publications

Journal papers

1. Luo H., Sun Y., Taylor M., Nguyen C., Strawn M., Broderick T., Wang Z.W. (2021) Impacts of aluminum- and iron-based coagulants on municipal sludge anaerobic digestibility, dewaterability, and odor emission, *Water Environment Research*, DOI: <https://doi.org/10.1002/wer.1684>
2. Chen Y.Z., Zhang J.L., Ding L.Y., Zhang Y.Y., Wang X.S., Qiao X.J., Pan B.Z., Wang Z.W., Xu N., Tao H.C. (2021) Sustainable treatment of nitrate-containing wastewater by a new autotrophic hydrogen-oxidizing bacterium, *Environmental Science & Ecotechnology* (Accepted)
3. Zhang K., Adams J.K., Kumar S., Wang Z.W., Zheng Y. (2021) A novel biological treatment of hydrothermal carbonization wastewater by using *Thraustochytrium striatum*, *Process Biochemistry*, 112, 217-222 DOI: <https://doi.org/10.1016/j.procbio.2021.12.005>
4. An Z.H., Jin Q., Zhang X.Y., Huang H.B., Wang Z.W. (2021) Anaerobic granulation of single culture *Clostridium beijerinckii*, *Food and Bioprocess Technology*, 130, 164-170, DOI: <https://doi.org/10.1016/j.fbp.2021.09.012>
5. An Z.H., Zhang X.Y., Zheng Y., Wang Z.W. (2021) Aerobic granulation of single culture protist, *Process Biochemistry*, 110, 163-167 DOI: <https://doi.org/10.1016/j.procbio.2021.08.014>
6. An Z.H., Bot C.B., Angelotti B., Brooks M., Wang Z.W. (2021) Leveraging feast and famine selection pressure during startup of continuous flow aerobic granulation systems to manage treatment performance, *Environmental Science: Water Research & Technology*, 7, 1622-1629, DOI: <https://doi.org/10.1039/D1EW00314C>
7. An Z.H., Zhang X.Y., Bot C.B., Wang Z.W. (2021) Long-term stability of nitrifying granules in a membrane bioreactor without hydraulic selection pressure, *Processes*, 9(6), 1024, DOI: <https://doi.org/10.3390/pr9061024>
8. Luo H., Zhang D., Taylor M., Nguyen C., Wang Z.W. (2021) Aeration in sludge holding tanks as an economical means for biosolids odor control – A case study, *Water Environment Research*, 2021;00:1-11, DOI: <https://doi.org/10.1002/wer.1582>
9. Wang S., Liu Q.X., Li J., Wang Z.W. (2021) Methane in wastewater treatment plants: status, characteristics, and bioconversion feasibility by methane oxidizing bacteria for high value-added chemicals production and wastewater treatment, *Water Research*, 198, 117122, DOI: <https://doi.org/10.1016/j.watres.2021.117122>
10. Zhang D., An Z.H., Strawn M., Broderick T., Khunjar W., Wang Z.W. (2021) Understanding the Formation of Recalcitrant Dissolved Organic Nitrogen as A Result of Thermal Hydrolysis Pretreatment and Anaerobic Digestion of Municipal Sludge, *Environmental Science: Water Research & Technology*, 7, 335-345, DOI: <https://doi.org/10.1039/D0EW00944J>
11. Sun Y.W., Gomeiz A.T., Aken B.V., Angelotti B., Brooks M., Wang Z.W. (2021) Dynamic response of aerobic

granular sludge to feast and famine conditions in plug flow reactors fed with real domestic wastewater, *Science of the Total Environment*, 758, 144155,

DOI: <https://doi.org/10.1016/j.scitotenv.2020.144155>

Patent

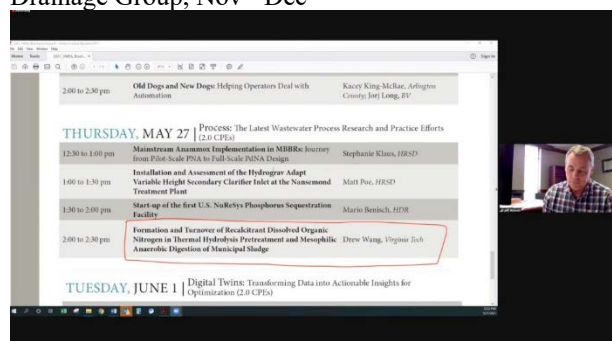
1. Gillapsy G., Freed C., Williams S.P., Wang Z.W. (2021) Heterologous ddp1 expressing plants and uses thereof. Serial No.: PCT/US2021/033799. Filing Date: May 22, 2021

Thesis

1. Malin K. (2021) Development of Kinetic Parameterization Methods for Nitrifying Bacteria using Respirometry, M.S. Thesis, Blacksburg, Virginia Tech, USA

Invited talks

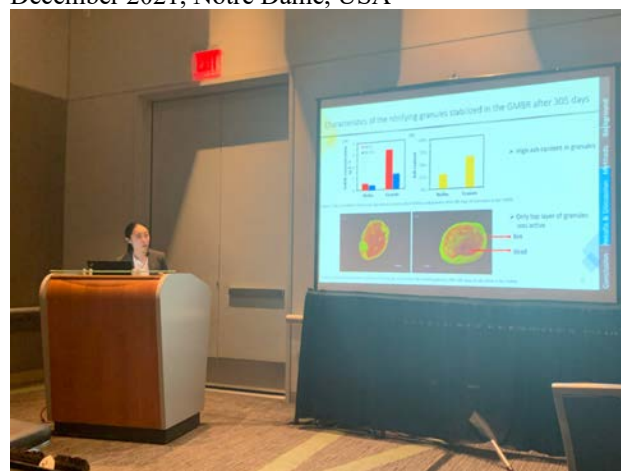
1. Wang Z.W. (2021) Formation and turnover of recalcitrant dissolved organic nitrogen in thermal hydrolysis pretreatment and mesophilic anaerobic digestion of municipal sludge, Webinar Talk invited by VWEA, May 27th
2. Wang Z.W. (2021) Technical discussion series about continuous flow aerobic granulation and partial denitrification anammox. Webinar Talk invited by Beijing Drainage Group, Nov - Dec



Dr. Zhiwu Wang's Webinar Talk invited by VWEA

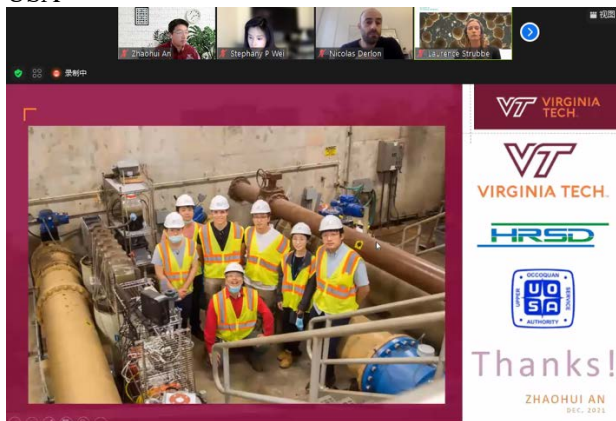
Conference Oral Presentation

1. An Z., Angelotti B., Bott C.B., Brooks M., and Wang Z.W. (2021) Coupling a continuous upflow selector with feast/famine selection for a smooth startup of continuous flow aerobic granulation reactors without performance interruption, IWA Biofilm Reactors Conference, 6 – 8 December 2021, Notre Dame, USA



Ms. Xueyao's in-person oral presentation in 2021 WaterJam conference

2. Wang J., Sun Y., Khunjar W., Pace G., Pathak A., McGrath M., Ali M., Wang Z.W. (2021) Low concentration nitrogen polishing via the synergy between partial denitrification and anaerobic ammonia oxidation in moving bed biofilm reactors under real-time feed forward control at Noman M. Cole Jr., Pollution Control Plant, IWA Biofilm Reactors Conference, 6 – 8 December 2021, Notre Dame, USA



Mr. Zhaohui An's virtual oral presentation in 2021 IWA Biofilm Reactors Conference

3. Patel H., Brazil B., Xia K., Wang Z.W., Hamoush S., Zhao R.Z. (2021) Removal of Perfluoro-alkyl Substances (PFAS) and Recalcitrant Organic Matter in Landfill Leachate using Coal Fly-Ash, WEFTEC 2021, Chicago, October 18-20
4. Iboleon R., Zhang D., An Z., Strawn M., Broderick T., Khunjar W., Wang Z.W. (2021) Fate and Formation of Recalcitrant Dissolved Organic Nitrogen During Thermal Hydrolysis and Anaerobic Digestion of Municipal Biosolids, WaterJAM 2021, Virginia Beach, VA, September 13-16
5. Zhang X., An Z., Bott C.B., Wang Z.W. (2021) Long-Term Stabilization of Nitrifying Granular Sludge Without Hydraulic Selection Pressure, WaterJAM 2021, Virginia Beach, VA, September 13-16
6. An Z., Bott C.B., Angelotti B., Brooks M., Wang Z.W. (2021) Application of a continuous upflow selector for enabling continuous flow aerobic granulation in real domestic wastewater, WaterJAM 2021, Virginia Beach, VA, September 13-16

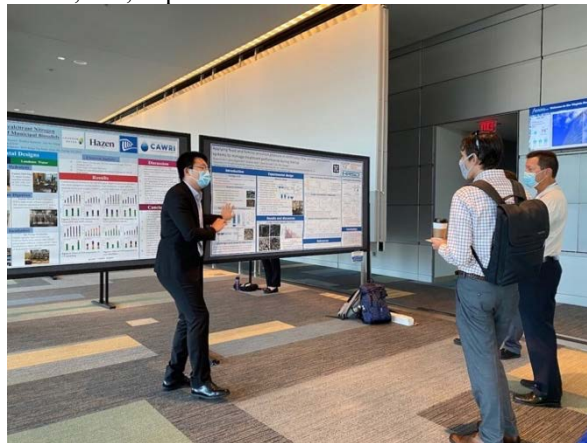


Ms. Xueyao and Mr. Hao Luo gave in-person poster presentation in 2021 WaterJam Conference

Conference Poster Presentations

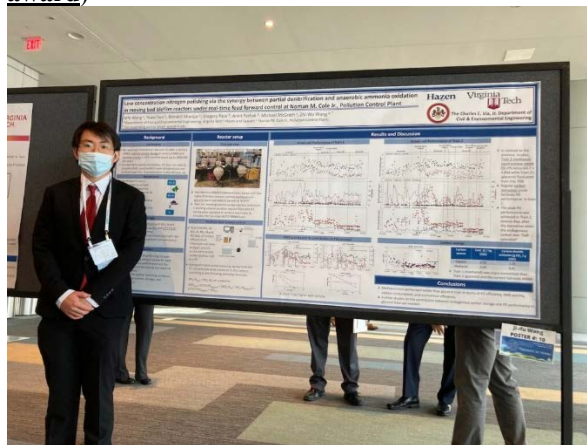
1. Luo H., Freed C., Gillaspay G., Wang Z.W. (2021) Phosphorus immobilization in biochar produced from plants genetically engineered for luxury phosphorus uptake, WaterJAM 2021, Virginia Beach, VA, September 13-16

2. Wang J.F., Sun Y.W., Khunjar W., Pace G., Pathak A., McGrath M., Wang Z.W. (2021) Low concentration nitrogen polishing via the synergy between partial denitrification and anaerobic ammonia oxidation in moving bed biofilm reactors under real-time feed forward control at Noman M. Cole Jr., Pollution Control Plant, WaterJAM 2021, Virginia Beach, VA, September 13-16
3. Zhang X.Y., Shi J., Zhang W., Wang Z.W. (2021) Volatile Fatty Acid Recovery via Deep Eutectic Solvent in Membrane Contactor System, WaterJAM 2021, Virginia Beach, VA, September 13-16



Mr. Zhaohui An's in-person oral presentation in 2021 WaterJam Conference

4. An Z., Bott C.B., Angelotti B., Brooks M., Wang Z.W. (2021) Applying feast and famine selection pressure in continuous flow aerobic granulation systems to manage treatment performance during startup, WaterJAM 2021, Virginia Beach, VA, September 13-16 (**1st place award**)
5. Iboleon R., Zhang D., An Z., Strawn M., Broderick T., Khunjar W., Sveuma K., Schmitz B., Wang Z.W. (2021) Understanding the Thermal Hydrolysis Effect on Recalcitrant Nitrogen Formation With and Without Anaerobic Digestion of Municipal Biosolids, Virginia Beach, VA, September 13-16
6. Iboleon I., Zhang D., An Z.H., Strawn M., Broderick T., Khunjar W., Wang Z.W. (2021) Recalcitrant Dissolved Organic Nitrogen Formation in Thermal Hydrolysis and Anaerobic Digestion of Municipal Sludge, CSAWWA'S 2021 second annual virtual poster competition (**2nd place award**)



Mr. Jiefu Wang's in-person poster presentation in 2021 WaterJam Conference

2021 Equipment Procurement

Equipment	Cost
1. Cambi 5L Thermal Hydrolysis Pretreatment (THP) System	\$ 33,000.00
2. Coy Anaerobic Chamber, Type A, Vinyl	\$ 24,226.00
3. Sartorius™ MA37 Moisture Analyzer	\$ 2,673.42
4. Brookfield Engineer Labs LVDV2T VISCOMETER	\$ 5,721.25
5. Eppendorf Mastercycler X50s 96-Well Silver Block Thermal Cycler	\$ 8,281.70
6. Eppendorf Centrifuge 5425	\$ 2,694.45
7. Thermo Scientific TSX Series High Performance -20°C Manual Defrost Freezer	\$ 6,542.36
8. NanoDrop One Microvolume UV-Vis Spectrophotometer	\$ 11,623.67
9. Labconco Purifier Logic+ Class II A2 Biosafety Cabinets	\$ 9,405.23
10. Labconco Benchtop FreeZone Legacy Freeze-Dry Systems	\$ 11,573.28
11. 1200°C Compact Split Tube Furnace w/ Vacuum Flanges & 2.36" Tube, 110V – OTF-1200X-S	\$ 3,779.60
12. Agilent 8890 Gas Chromatograph system with an autosampler and a Flame Ionization Detector (FID)	\$ 37,065.50
13. Refrigerated Thermo Scientific Sorvall Legend XF Centrifuge with a Fiberlite F15-8 x 50cy Fixed-Angle Rotor and a Fiberlite F21-48 x 2 Fixed-Angle Rotor, as well as adapters for 4X1000 ml and 15mL conical tubes	\$ 8,419.47
14. CF016 Cell Assembly, Forward Osmosis, PTFE	\$ 1,084.09
15. Volute Dewatering Press PWTech model ES-501	\$ 13,000.00
16. 2L Jacketed Glass Reactor Reaction Vessel 100w Digital 0-1200r/min Chemical Lab	\$ 726.98
17. Two (2) EXO3 Sonde with a Wiped Conductivity/Temperature Sensor, a Turbidity Sensor, a Optical DO Sensor, and a NitraLED UV Nitrate Sensor	\$ 29,887.95
18. AmmoLyt Plus Ammonium probe complete w/Reference Electrode and System 282 IQ SensorNet Controller	\$ 5,518.10
19. Shimadzu TOC Analyzer	\$ 38,813.25
Total	\$ 249,012.74



Agilent 8890 Gas Chromatograph



Labconco Class II A2 Biosafety Cabinets



Coy Anaerobic Chamber



Shimadzu TOC Analyzer



Cambi 5L Thermal Hydrolysis Pretreatment unit

2021 Fun Times

Opportunities for in-person communication has been precious commodities in 2021 as the pandemic still lingered around. A fully vaccinated SERL team started to meet collaborators as soon as the travel restrictions were lifted in mid of 2021.



Congratulations on Mr. Zhaohui's marriage with Ms. Jing Yuan from UC Berkley on March 11, 2021. This young couple were undergraduate classmates in Environmental Engineering back in Tongji University, Shanghai, China. Best wishes on their wonderful love journey as they continue to build their new lives together. They plan to move back to Shanghai after graduation early next year.



We enjoyed some fresh seafood to celebrate a productive WaterJam conference on Sep 16, 2021, in Virginia Beach



An in-person meeting between previous, outgoing, and incoming graduate students for a successful team building and culture inheritance



A re-union with collaborators that we have not met with for two years



An in-person gathering with experts in the field of partial denitrification anammox at HRSD



An in-person re-union of SERL team members in Virginia Beach



An in-person workshop with all WRF (5133) partners and sponsors in University of Washington at Seattle