2022 Report
2022 is a “recovery” year. Both people and research activities were recovering from the pandemic that (I hope) is to be ended soon. Our productivity is being restored with publishing 17 journal papers. The EBBL members have participated in several in-person conferences and professional society events. The feeling and importance of face-to-face interactions can never be replaced by Zoom.

A major activity for the lab was to help organize the 2022 AEESP conference. I was the Conference Associate Chair and many EBBL members worked as volunteers. The conference brought more than 800 attendees to WashU, the first time for many of them to be in St. Louis who were impressed by our beautiful campus. Our lab will play a similar role in next year’s the IWA Membrane Technology Conference at WashU.

We welcomed two new PhD students to the lab and said farewell to three visiting scholars. We also reunited with several alumni during the AEESP conference. I always hope that no matter how long one is with the lab, the EBBL experience will be helpful to the next stage of their career and bring them some nice memory.

As always, thank you for a wonderful year of 2022 and look forward to working with all of you in 2023!

Zhen (Jason) He, Professor and Director of EBBL
Matthew Ferby was leading EnvESA with various activities including invited lectures, conference participation, and education outreach to K-12 students. He published a 1st-author research article in Water Environment Research.

Fubin Liu has had a very productive year with three 1st-author journal papers published in Water Research, Chemosphere, and Electrochimica Acta. He gave poster presentations at both MWEA/MO AWWA and AEESP conferences.

Yue Rao delivered her first conference oral presentation at MWEA Fall Technical Conference. She also gave a poster presentation at the AEESP conference. She is working on her 1st manuscript to be submitted in Jan. 2023.

Shruti Sarjerao Kadam conducted a research rotation and then officially joined the EBBL as a PhD student. She came from Institute of Chemical Technology, Mumbai, where she received a BS in Chemical Engineering.

Yanran Xu published our 1st paper on machine learning in Journal of Cleaner Production. She led a team that won the 2nd place in the 1st Annual IWEA Intelligent Water Challenge. She also gave an oral presentation at the AEESP conference.


Yingying You completed her research visit and is now a postdoctoral scholar at the University of North Carolina - Charlotte. She published two 1st-author journal papers in Journal of Hazardous Materials and Chemosphere.

Jiasi Sun conducted a research rotation and then officially joined the EBBL as a PhD student. She completed a MS in Multi-Science at University of Tokyo and a BS in Environmental Engineering at Tianjin University.

Hau-Ming Chang completed his research visit and returned to National Taipei University of Technology. He published a 1st author journal paper on machine learning study of OMBR in Science of the Total Environment.

Rehab Hamdy Mahmoud ElSayed completed her research visit and returned to National Research Centre, Egypt. She published her work on algal growth on the nutrients extracted from wastewater in Algal Research as the 1st author.

Zixuan Wang won the 3rd place in the Fresh Ideas Student Poster Competition (MWEA) and a team member of the 2nd place in the 1st Annual IWEA Intelligent Water Challenge. His work on electrochemical P recovery was published in Water Research.

Das Bedadeep completed a research rotation in the EBBL. He worked with Matthew on TEG powering MECs for hydrogen production. He officially joined in Dr. Fuzhong Zhang’s lab as a PhD student. We wish him the best!

Daran Anand continues his undergraduate research in the EBBL. He completed a test of coagulants for P removal for American Bottoms Wastewater Treatment Facility and is now helping Zixuan with the project of electrochemical P recovery.
EBBL members attended the 2022 MWEA/MO-AWWA Joint Annual Meeting (Lake of the Ozarks). Zixuan and Fubin participated in the Fresh Ideas Student Poster Competition, and Zixuan won the 3rd Place.

WashU hosted the AEESP conference and welcomed more than 800 attendees to our beautiful campus. EBBL members presented their research and volunteered in the organization of the conference. We also had a reunion with several EBBL alumni.

Yue gave her first conference presentation at the Fall Technical Conference by MWEA (Columbia, MO).

EBBL members attended the 2022 Mid America Environmental Engineering Conference at Missouri S&T. Kaichao gave an oral presentation on his research.

Dr. He attended the 2022 WETEC in New Orleans, where he organized the editorial meeting for Water Environment Research and received the WEF Fellow plaque from the WEF President.


**Machine Learning**

Proper pH control is important to the neutralization of industrial wastewater that will facilitate downstream biological treatment and can strongly affect the utilization of chemical reagent/resource. This study aimed to apply machine learning (ML) models for both pH prediction and lime dosage control towards enhanced automated control of neutralization processes. To achieve this goal, eight ML models were employed and compared in modeling performance, and optimized by using correlation analysis, cross-validation, and grid search techniques. In the neutralizer pH prediction, the highest coefficients of determination (R²) results were obtained at 0.765 (k-nearest neighbors - KNN), 0.918 (eXtreme Gradient Boosting - XGBoost), and 0.900 (random forest - RF) for three neutralizer tanks, accompanied with the lowest root-mean-square-error (RMSE) values of 0.289, 0.100, and 0.093, respectively. The impacts of input features were quantified by sensitivity analysis using SHAP values, which demonstrated the importance of temperature, valve position, and upstream pH as high as 0.214, 0.156, and 0.118 (the mean of absolute SHAP value). For lime dosage control, the best model performance came from XGBoost (R² values of 0.605) for valve 1, RF (0.788) for valve 2, and RF (0.436) for valve 3 with the corresponding RMSE values of 8.056, 6.125, and 4.466, respectively. The recommended valve position was based on the target pH and some examples were illustrated at different upstream pH values. The results of this study have demonstrated that ML approach can be an effective tool to help conserve chemical resources via enhanced chemical dosage control in wastewater treatment.


**Electrochemical P Recovery**

With the rising concern over the depletion of phosphorus rock, phosphorus recovery from wastewater has become a key step for sustainable economy. Herein, simultaneous phosphorus leaching and nutrient recovery were accomplished in an electrochemical nutrient recovery cell (ENRC) treating digested anaerobic sludge. The anode reaction of water electrolysis lowered the sludge pH from 8.0 to 2.0 at a current density of 25 A m−2, elevating the PO₄³⁻-P concentration from 27.72 to 253.47 mg L⁻¹, comparable to that from direct acid leaching. The released PO₄³⁻-P was transferred to the cathode chamber for recovery, where PO₄³⁻-P recovery efficiency was enhanced from 42.0% to 90.3% by 0.26 M HCl catholyte acidification. The ENRC recovered 90-98% of the coexisting NH₄⁺-N in the sludge. Increasing current density accelerated both phosphorus leaching and PO₄³⁻-P & NH₄⁺-N recovery, but at the expense of a higher energy consumption. After five consecutive cycles of operation, the PO₄³⁻-P and NH₄⁺-N concentrations reached 404.56 and 3493.56 mg L⁻¹, respectively, at a normalized energy consumption of 229.20 ± 30.13 kWh kg⁻¹ P or 25.67 ± 3.07 kWh kg⁻¹ N. At pH 8.5, 99% of the recovered aqueous PO₄³⁻-P in the recovery solution precipitated, mainly as calcium phosphate that can have a good soil phosphorus availability. The results of this study have provided a foundation for further exploration of electrochemically leaching P from waste sludge with simultaneous nutrient recovery.


**Advanced Oxidation Processes**

Regeneration of Fe(II) is a key issue for heterogeneous advanced oxidation processes (AOPs) using iron-based catalysts. Herein, a hybrid catalyst was developed from α-Fe2O3 and SeS2 to enhance the Fe(III)/Fe(II) redox cycling in both hydrogen peroxide (H2O2) system and persulfate (PS) system. The regeneration of Fe(II) was evidenced by the increased Fe(II)/Fe(III) ratio in the used catalyst (205.8% in the H2O2 system or 125.4% in the PS system), compared to 68.4% in the fresh hybrid catalyst Fe/Se-3. Methyl orange was used as a model pollutant to evaluate the degradation performance of the hybrid catalyst. Owing to the promotion of Fe(II) regeneration, Fe/Se-3 achieved a pollutant removal efficiency of 100.0% in 12 min in both systems, significantly higher than that with pure α-Fe2O3 (33.9 ± 3.6% in the H2O2 system or 30.7 ± 2.8% in the PS system). The dominant active species were identified as hydroxyl radicals in the H2O2 system and sulfate radicals in the PS system. In the proposed mechanism, soluble and surface-bound Fe species are provided by α-Fe2O3 to activate H2O2 or PS to radicals, and SeS2 participates in the reactions via Se(IV) reducing Fe(III) to Fe(II) and S atoms being released through protonation to expose more active Se sites.

Matthew led EnvESA to collaborate with the School District of University City and St. Louis Aquarium Foundation to provide fifth-grade students with a hands-on water education program. EnvESA members taught more than 200 fifth-grade students at four district elementary schools. As part of the program's curriculum, students learned about the water cycle and wastewater treatment processes and participated in an activity in which they treated wastewater using different filtering materials.

Dr. He was named the Editor in Chief of *Journal of Hazardous Materials*. He continues to be listed among the top 2% most cited researchers globally with a total number of Google Scholar citations reaching 20,000.

Fubin’s paper ‘Enhancing the Performance of a Microbial Electrochemical System with Carbon-based Dynamic Membrane as both Anode Electrode and Filtration Media’ was selected as the 2021 Runner-Up Best Paper in *Environmental Science: Water Research & Technology*.

Zixuan has successfully defended his PhD proposal and became EBBL’s first PhD candidate at WashU.

Dr. He gave an invited seminar to the Department of Civil and Environmental Engineering at Rice University.

Dr. Ibrahim Md Abu-Reesh visited us from Qatar University. We are currently collaborating with Dr. Abu-Reesh on a project funded by Qatar National Research Fund that has generated two journal papers (Kaichao as the 1st author). Dr. Abu-Reesh received his PhD in Chemical Engineering from WashU.

A team led by Dr. He was selected for funding ($2.5 M) by the U.S. Department of Energy. The team, including WashU, Lincoln U., Virginia Tech, Argonne National Lab, and CLEARAS, will grow algae on wastewater nutrient and CO2. Patrick Kelly, an EBBL MS graduate, will participate in the project as an industrial partner.

We received a new grant from National Science Foundation ($390K) to produce volatile fatty acids from wastewater through inhibiting methanogens using microbial electrochemical generated hydrogen peroxide.

Yanran and Zixuan teamed with Shaker Nairat (Southern Illinois University Edwardsville) in the 1st Intelligent Water Challenge by Illinois Water Environment Association. Their team won the 2nd place with a strong support from Dr. Jim Zhou, Shaker’s MS adviser. This effort has led to a collaborative paper that was just accepted for publication in *ACS ES&T Water* and another manuscript that is under preparation.
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