Environmental Technology

Newsletter | Spring 2021

Picture: NASA

News

Four million euro for new research on improving fresh water availability in coastal areas

The ETE program AquaConnect, with Prof. Huub Rijnaarts as project leader, has received 4 million euro from NWO-Perspective. Companies and other organizations add an additional 2 million euro. The program is aimed at safeguarding the fresh water supply in coastal areas with water shortage by using alternative water resources. 'Better water reuse and the use of nonconventional water resources helps us to increase fresh water reserves, that can be utilized during summer draughts', says Thomas Wagner, coordinator of the application and start-up phase.

Prof. Huub Rijnaarts

During summer draughts, The Netherlands are regularly faced with fresh water shortage. A smarter use of the available water resources could prevent this. For example, wastewater treatment plants currently discharge their treated water in rivers, while during draughts, this water could better be retained and utilized.

'In the Netherlands we are true champions in discharging water', Wagner says. 'But now we have to retain and efficiently redistribute water during dry periods to avoid water shortage.'

Flexible water treatment technologies

AquaConnect will perform multi-disciplinary research to increase fresh water reserves in coastal areas. The program aims to develop new and more flexible water treatment

Column

Rob Simm

Senior Vice President Water, at Stantec, Chandler, Arizona, USA

Selenium – The Case for Recovery

Selenium (Se) can reach the aquatic environment from several anthropogenic sources. Elevated intake of Se has resulted in teratogenic effects in fish and birds. North America has had some of the most widely publicized Se contamination events, resulting in the world's most stringent aquatic water quality guidelines.

Biological treatment has been identified by several regulators and industry organizations as the best available technology to achieve ultra-low Se effluent limits. A review completed for the NAMC-SWG suggested: *"despite numerous installations, selenium treatment technologies have not reached full maturity and should be regarded as developmental."*

Cost effective selenium recovery is a key research focus area. Active biological treatment system residuals are typically landfilled, raising the possibility of Se remobilization in landfill leachates. There is a growing need for collaboration between global industries and programs engaged in leading edge Se treatment and recovery research like the Department of ETE of Wageningen University to develop Se recovery technologies that remove and keep Se from anthropogenic sources out of the aquatic environment.

technologies, better aimed at the water quality needed by the different end users. For example, drinking water needs to be of the highest quality, while water of a lower purity can be used by industries. Such new technologies include membrane-based water treatment systems. They are more flexible and robust as compared to the traditional biological treatment methods and may as such be better suited to supply water of different qualities.

Safe water supply

To achieve a circular water system where pollutants are not accumulating, risk assessment is an important aspect of the program: what contaminants are present in the untreated water and which ones have to be removed for the specific user? 'Water treatment plants produce almost clean water, that is discharged at the surface water', Wagner explains. 'However, we know it still contains micropollutants that need to be removed if we want to use it as drinking water.'

Thomas Wagner at a discharge point of treated water from a wastewater treatment plant

Efficient distribution

In addition to risk assessments, digital, so-called, smart grids, will be designed to assess and monitor the available water as well as the different qualities by water suppliers. Water storage sites are also an important part of these smart grids. This supply will be matched with the demand of different users, enabling an efficient distribution and reuse of available water.

Negative perception

In addition to developing different technologies, also the more social aspects will be addressed. Are there any legal obstructions for water reuse and how can these be solved? For example, treated water from wastewater plants is forbidden by law to be used in agriculture, despite its relatively high cleanliness. Also, consumers may have a negative perception of treated waste water suitable for drinking, even when there is no health risk at all.

Brackish water problem

As final result of AquaConnect, there will eventually be 4 demonstration sites, that illustrate the efficient use of alternative water resources in a different context. One of the sites is planned in the Province of Zeeland, where there is a brackish water problem, while another site will be built near Amsterdam, for a completely different array of city-associated challenges.

'All this can only be realized by looking at the complete water chain. Therefore, we are closely collaborating with other universities, regional water authorities, drinking water and technology companies and governments', Wagner says. 'By combining water treatment technologies, digital technologies and knowledge about the social aspects we can effectively improve fresh water reuse and storage to avoid water shortage during the summer.'

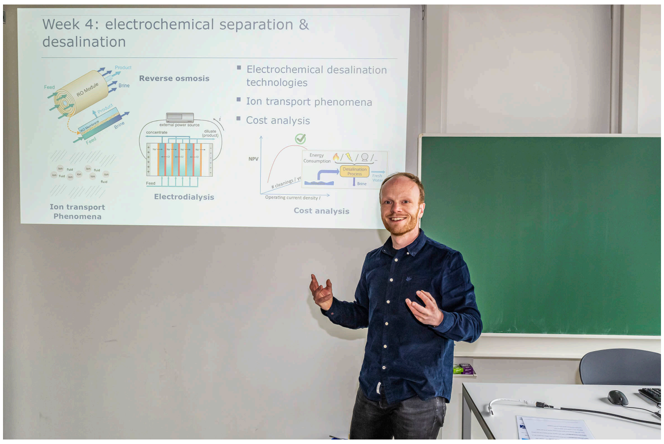
New MSc course at ETE: Environmental Electrochemical Engineering

In spring 2021 ETE has started with a new yearly course, called *Environmental Electrochemical Engineering*. The 6-week morning course is aimed at MSc students from environmental sciences, biosystems engineering, biobased- and biotechnology sciences. It combines theoretical principles of the electrochemical technology and its practical applications. This combination makes the course unique. The first lectures have started mid-March for 60 students.

Electrochemical systems use electrical energy to influence chemical reactions at the electrodes, resulting in a wide variety of applications. These systems are the basis to generate or store energy, treat water, or produce chemicals. The last ten years research on electrochemical systems has resulted in a lot of knowledge how to apply these technologies effectively in environmental sciences and the industry. 'The role of electrochemical systems in water treatment, resource recovery, and energy storage, has increased dramatically', says course coordinator Jouke Dykstra. 'This course effectively prepares students for research, and also fits in well with the demands of future employers, like knowledge institutes and the industry.'

Deep understanding

The first 3 weeks of the course focus on the theoretical and technical aspects of electrochemical cells and electrode processes. This knowledge will subsequently be applied in a case study, where the feasibility of an electrochemical-based energy storage system for an airplane will be studied. ‘It is crucial that students first get a deep understanding how the technology exactly works’, Dykstra says. ‘That knowledge helps them to evaluate concrete and feasible applications.’



Case study

The second half of the course will focus on the principles and technological applications of electrochemical systems in resource recovery, like energy recovery, (waste) water treatment, desalination, and bio-electrochemistry, where microorganisms play an additional role in treating wastewater. This knowledge will be applied in a case study, where a bio-electrochemical system will be evaluated to recover ammonia from waste water.

Unique combination

The lectures and student guidance will be provided by 6 lecturers from Wageningen UR and 3 guest lecturers. ‘The signals we get so far from students is that the course is tough, but very interesting’, Dykstra says. ‘The unique combination of theoretical principles and application in existing technologies gives an added value that is highly relevant.’

Science: A new bio-recovery method for efficient selenium retrieval from wastewater

PhD researcher Bingnan Song developed an improved biological method to remove and recover selenium from wastewater. Specialized bacteria converted more than 95 % of the selenate present into elemental selenium. In addition to this high efficiency, conversion rates were about 6 times higher than in traditional methods. Increased pH resulted in improved selenium crystal formation enabling an easier recovery and reuse.

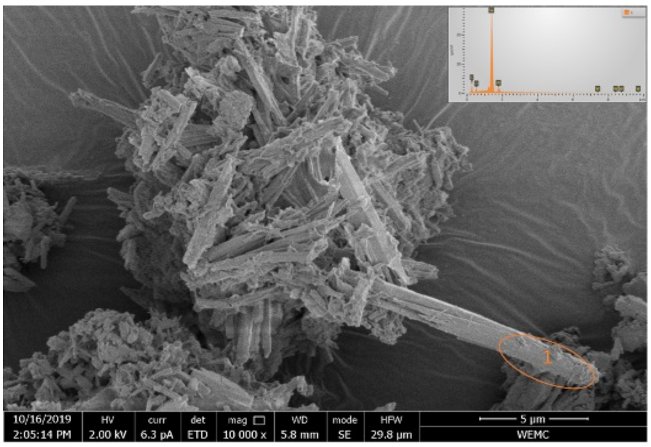
Selenate, (SeO_4^{2-}), is common in wastewater from many different industries, for example, in waste streams from copper mining and the subsequent refining process. In small quantities, selenium is an essential micronutrient for animals and humans, but at higher levels it is toxic and bioaccumulates in tissues. Improper disposal may also result in accumulation in the environment, resulting in toxic effects in aquatic wildlife. Therefore, the selenate present in wastewater has to be removed. A variety of methods can be used to achieve this, like precipitation by adding chemicals or removal using membranes. However, these methods are costly and require chemicals or tedious membrane cleaning procedures. Selenium retrieval using bacteria could be a better solution. Currently, some cleaning and recovery methods utilize bacteria that convert the selenate present into elemental selenium under anaerobic reactor conditions.

Recycling problems

But these biological treatment methods have some serious limitations. Most of the selenate present is converted into an intermediate product, selenite (SeO_3^{2-}). This substance stays in the solution and can therefore not be removed. In addition, the bacterial conversion rate from selenate into to elemental selenium is rather low: it is only about 1 % of the biological sulfate removal rate from wastewater, a commonly used cleaning technology. ‘Clearly, biological selenium recovery is still in its infancy’, Song explains. ‘Besides being a very slow conversion rate, these methods result in the formation of small, amorphous selenium particles about only 250 nanometers in size, i.e. 500 times smaller than the thickness of a human hair.’ These tiny selenium particles are mixed with bacterial biomass, making it hard to separate and recover for reuse. Storage of this selenium-containing waste is no great option either, since it may pose environmental hazards due to the possibility of selenium leakage. Therefore, a more efficient and fast method to clean selenium-containing wastewater while recovering and recycling this resource is desperately needed.

Crystal formation

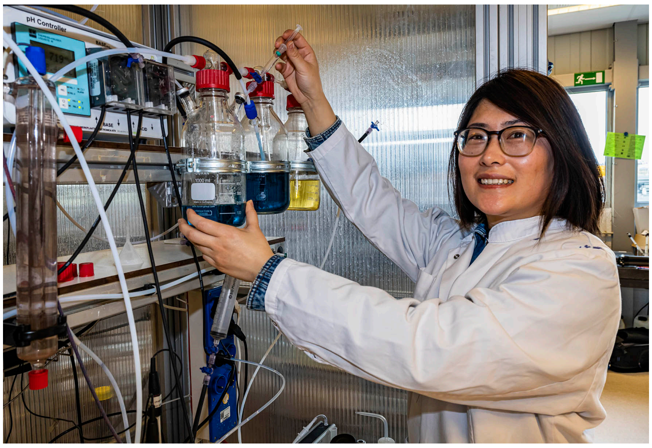
Song aimed for a better biological recovery method, that included a fast and highly selective conversion of selenate into elemental selenium, resulting in a high-purity and reusable end product. In addition, the conversion should result in a solid selenium product that was easily separated from the aqueous phase in the reactor. To meet this condition, the scientist targeted the formation of selenium crystals. As a first step, Song used bacteria-loaded sludge from the wastewater treatment site at Eerbeek. This sludge contains many bacteria species, especially those converting sulfate (SO_4^{2-}). By using a so-called 'sequencing batch reactor' she fed the reactor with an influent containing plenty of selenate. This way, she created a reactor environment favoring and selecting the bacteria that were converting selenate into elemental selenium. During the selection process, the suitable bacteria able to transform selenate into elemental selenium tend to settle at the bottom of the reactor, together with the selenium formed. The others stayed in the solution and could easily be flushed out. Song: 'This way, we selected the right bacteria for the selenium conversion step by step.' In addition, the scientists increased the pH from 7.0 to 7.5, enhancing crystal formation.



Scanning Electronic Microscopic (SEM) image of pure selenium crystal needles

Large crystal clusters

Song's research eventually resulted in an efficient selection of selenium-converting bacteria, that were no less than 1000 times faster in forming elemental selenium than the bacteria present in the original sludge sample. Compared to the traditional biological selenium recovery methods, the new bacteria performed much better with conversion rates over 6 times faster, while removing more than 95 % of all selenate present. Another important result was that the selenium was effectively formed as relatively large crystal clusters, the biggest ones measuring 200 micrometers in size, almost 1000 times bigger than the amorphous particles formed in the traditional methods.



The newly developed process may serve as an alternative efficient, quick and effective method to remove and recover selenium from wastewater with high selectivity. Due to the formation of large crystal clusters, recovery and reuse are relatively easy.

Reference

Song, B., Tian, Z., van der Weijden R.D., Buisman C.J.N., and Weijma J. 2021. High-rate biological selenate reduction in a sequencing batch reactor for recovery of hexagonal selenium. Water Research 193, 116855

Science: Treatment versus transport: smart use of local and distant water sources in coastal areas

Within the framework of ETE's Water Nexus program, PhD scientists Alessio Belmondo Bianchi studied smart ways to match the increasing water demands by the chemical industry DowDuPont in Terneuzen. By combining previously developed simulation models, he concluded that a combination of treating local brackish water and transporting fresh water from distant sources was the most cost-effective and sustainable way to balance the companies water demands.

Due to climate change and increased water demand by the industry, agriculture and households, water scarcity will be an increasing problem in the future.

Especially in coastal areas of The Netherlands, where a lot of industry is located, saltwater intrusion affects groundwater quality up to several kilometers inland, which may increase the scarcity of fresh water. This water stress can be diminished though by promoting freshwater use only when absolutely necessary, while using local brackish water resources as much as possible. 'Different users have different requirements for their water', Belmondo Bianchi explains. 'Cooling water in powerplants and the chemical industry could as well use brackish instead of fresh water. Besides, brackish water can be treated to meet the quality requirements of the user.' Not without reasons Water Nexus' slogan is '*Use fresh water where needed, salt water when possible'*.

Best Trade-off

However, treating brackish water on-site is not necessarily a better option than transporting fresh water to the user. There is a trade-off in environmental consequences and expenses between treatment and transport, depending on the water quality needed and the amount of water available. For the industry, the big question is whether to transport fresh water from tens of kilometers away, or treat brackish water on site. 'Each trade-off is case-specific and can't be generalized', Belmondo Bianchi says. 'In our case study, we modelled the best trade-off for DowDuPont in Terneuzen: should they use treatment or transport, or maybe a combination of the two to operate cost-effectively and as sustainably as possible?'

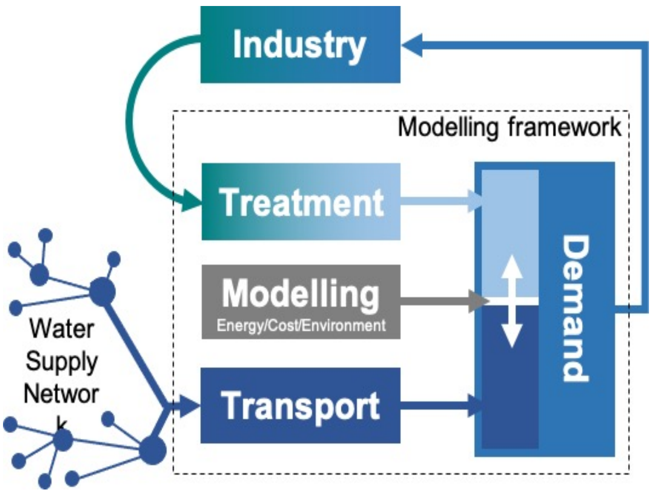
Existing digital models

To decide the best balance between treatment and transport of available water for DowDuPont, the scientists combined two existing digital models. The first model, developed by ETE scientists Jessica Wreyford, calculated costs and impacts of the treatment (desalination) process, while the second model, made by Joeri Willett, did the same for water transport through a pipeline.

The model on desalination took various crucial factors into account during operation, like the design of the treatment technology, the achievable water quality, energy consumption and the overall environmental impact, based on complete life-cycle analysis. For this analysis, information on materials used as well as associated CO_2 emissions were included. The model's output included the total expenses and environmental costs, expressed as CO_2 units.

The transport optimization model relied on a detailed information system (GIS), where geographical information regarding fresh and brackish groundwater sources and surface waters were stored. Water extraction limits linked to land use, like agricultural use and nature conservation, were also included. This resulted in an information map containing all possible water sources and possible pipeline routes. The subsequently built model was able to find the shortest and most efficient network to connect water sources to the end user. In a second decision-making stage, the expenses and environmental costs were calculated and compared to the outcome of the treatment model.

Belmondo Bianchi: 'My study included the integration of these two models into a decision-making framework to be able to identify the optimal trade-off between water treatment on-site and water transport.'



Graphical abstract of the treatment vs transport research

Practical limits

For DowDuPont the water sources locally available included wastewater from the cooling towers, brackish ground water and brackish water from the deltas. The decision-making framework considers three main criteria to decide between treating these sources or transport fresh water from longer distances: the cost for supplying a cubic meter of useable water, total energy consumption, and finally the environmental impact based on the equipment's life cycle. 'Our model showed that treatment and transport can be comple-

mentary in finding the optimum trade-off', Belmondo Bianchi says. 'In our case, treatment reduces energy consumption and emissions, while transport is more cost-effective.' For DowDuPont, the best configuration was a combination of 20-30% treatment and 70-80% transport.

Although, treatment on-site is usually more expensive than transport, there are practical limitations to utilize the more cost-effective transport. DowDuPont extracts water from De Biesbos, a nearby nature area, but there are limits to the amount. Belmondo Bianchi: 'Increasing the amount of water taken from De Biesbos is difficult, since this may damage the ecosystem. It's therefore important to use treatment as an additional option, to prevent this area from drying out.'

Selected publication:

Belmondo Bianchi, A., Wreyford, J.M., Willet, J., Gerdessen, J.C., Dykstra, J.E., and Rijnaarts H.H.M. 2021. Treatment vs. transport: A framework for assessing the trade-offs between on-site desalination and off-site water sourcing for an industrial case study. J. of Cleaner Prod. 285 (2021) 124901.

Agenda

PhD defences (Online):

Casper Borsje, May 28th 2021, 13.30h. Moving bed capacitive bioanodes.

Shiyang Fan, June 29th 2021, 11.00h. Sustainable heat production via biological wood oxidation.

Carlos Contreras, September 3rd 2021, 13.30h. Engineering Chain elongation Biorefineries.

Daniel Reyes Lastiri, September 7th 2021, 11.00h. Uncertainties in Aquaponics.

Rieks de Rink, October 13th 2021, 13.30h. Electron shuttling with haloalkaliphilic sulfide oxidizing bacteria to improve biological gas desulfurization.

Thu Hang Duong, October 14th, 2021, 11.00h. Anaerobic conversion of proteins under methanogenic and acidifying conditions.

Indra Firmansyah, October 15th 2021, 11.00h. Development of a planning approach for resource recovery and reuse on small islands.

Andrea Brunsch, October 18th 2021, 13.30h. Managing organic micropollutants in rivers – from monitoring to mitigation.

Conferences in planning:

ETEI2021 Alumni Day 2021 to be determined

The 8th International Congress & Exhibition on Arsenic in the Environment (As2021) will take place in Wageningen, The Netherlands, from June 7 - 10 2021. The theme of the 2021 congress is "Bridging Science to Practice for Sustainable Development". Want to know more? Visit: https://www.as2021congress.com/ or ask Jan Weijma

AquaConSoil started 19 January 2021 and will end with a focus week 2021 Online 14-18 June 2021 see: AquaConSoil 2021 goes digital - Deltares

Electrochemistry for electrification and energy transition toward a sustainable future 13-17 June 2021, Leeuwarden.

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