# Environmental Technology

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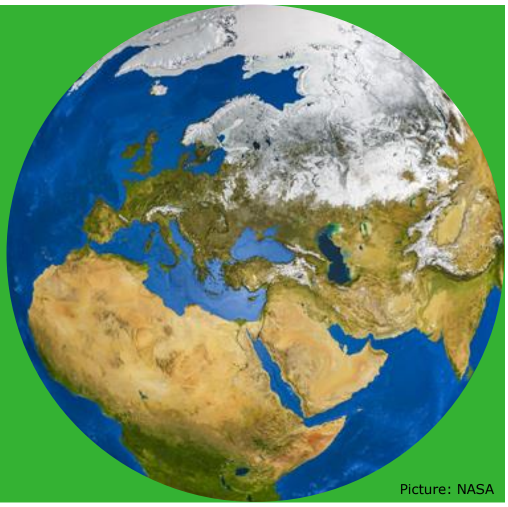


Picture: NASA

## News

### Nomination for microbial selenium crystal recovery from waste streams

Simon Hageman, former Ph.D. scientists at ETE, has been nominated, for the KNCV Piet Bennema Prize for Crystal Growth 2018. The prize is awarded every 3 years to a young scientist that has published high-level scientific research in the field of crystal growth in an industrial context. Hageman is one of 3 nominees and although he finally did not win the price, his nomination proves the relevance of his research.

#### Precious resource

Selenium is present in several waste streams from the industry, for example in emission gases from coal plants. These gases are washed before release, and as a result selenium ends up in waste water. Recovery of this precious resource is needed to save costs and prevent pollution. Hageman developed a method for the efficient removal of this compound using microorganisms. ‘There are two different oxidized forms of selenium in wastewater: selenate and selenite’, Hageman says. ‘At higher temperature, around 50 °C, or a pH above 8, microorganisms convert selenate into selenium crystals that can be recovered in a cost-effective way.’

#### Simple recovery

But Hageman also developed a procedure to recover selenium from wastewater that worked around 30 °C and neutral pH. Instead of selenate, the other form of selenium, selenite, was converted into selenium crystals in several steps. Again, microorganisms played a key role. Sulphide, formed by microorganisms in waste streams, react with selenite to form

## *Column*

### *Guest writer Arnoud de Wilt, Consultant Micropollutants and Wastewater Technology at Royal HaskoningDHV*

Improving water quality by reducing pollution and minimizing release of hazardous chemicals and materials, is a key target of the sixth Sustainable Development Goal of the United Nations. Even in developed countries with advanced wastewater management facilities, like the Netherlands, broad arrays of pollutants are still discharged into surface waters, negatively affecting the water quality and jeopardising our drinking water sources.

Impressive improvements have been made in wastewater treatment over the previous century. Significant contributions of these improvements originate from ETE and have been implemented in practice via the many alumni, spin-offs and partners of the department. No doubt ETE will continue its practice of sound scientific work with a focus on practical application.

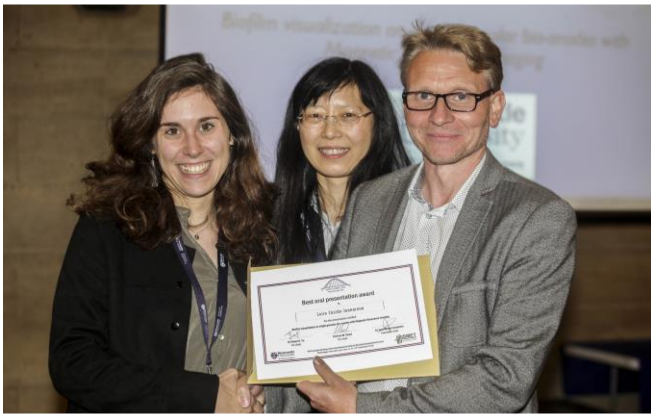
Until now only limited progress of the sixth Sustainable Development Goal has been made. Thus, there is an urgent demand for further developments in water quality improvements worldwide. In its more than 50 years history, ETE has been working according to the successful ‘Golden Triangle’ approach. This refers to collaboration between government, academia and industry. This way of working will be key in the future of the department to continue its contribution to science for impact. Looking forward for many more ‘Golden Collaborations’ of ETE!

seleniumsulphide. That compound precipitates, where after other microorganisms present in sludge subsequently convert seleniumsulphide back into sulphide and crystalline selenium. The selenium crystals formed were relatively large, in the order of micrometers, allowing a simple recovery. ’The elegance of this method is that due to the lower temperature needed energy is saved, while sulfide is recycled during the reaction’, Hageman says. ‘Also, the relatively large selenium crystals can be recovered even more easily.’

*Ph.D. Thesis: Bio-induced solid selenium for recovery from water, 148 pages ISBN 978-94-6257-510-3*

## Best oral presentation for Leire Caizán

ETE Ph.D. scientist Leire Caizán won the award for best oral presentation on the $4^{th}$ European Meeting of the International Society for Microbial Electrochemistry and Technology (EU-ISMET) in Newcastle upon Tyne, held between September $12^{th}$-$14^{th}$ 2018.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Around 200 people attended the conference, hosting 8 plenary sessions, 62 oral presentations, and 75 poster presentations. Her winning presentation, *‘Biofilm visualization on single granular bio-anodes with Magnetic Resonance Imaging’*, was both clear and original. ‘I think the presentation drew the attention of the audience because it is an innovative topic, the story line was clear and complete, and there were appealing visual results’, says Caizán. ‘Also the use of the MRI technique, is not that common in our field; it was the first time that this technique was used in granular electrodes.’

### Electron flow

Caizán’s research focuses on improving microbial fuel cells (MFCs), where bacteria convert organic matter present in e.g. wastewater into electricity. By metabolizing organic matter, bacteria extract electrons from their food source that are subsequently transferred to the anode, resulting in an electron flow: electricity. Often these bacteria grow on the anode as a biofilm. ‘My research focuses on the growth of this biofilm on an anode made out of activated carbon granules’, Caizán explains. ‘Little is known about how biofilms are developing on this material.’ Activated carbon is a great anode material for microorganisms: it offers bacteria a 3D surface for growth, while the porous structure benefits electron storage and discharge. In her research, Caizán is specifically looking at the effect of carbon granule size, as well as pore size and distribution on biofilm growth, electron storage and charge-discharge cycles.

### Visualizing biofilm growth

Current methods to quantify biofilm growth, such as measuring total nitrogen or protein, have clear limitations: they are destructive, not all components are measured and assumptions have to be made for calculating the amount of biofilm. ‘My goal is on reliably measuring biofilm quantities, but also visualizing biofilm growth on activated carbon granules: how are the bacteria distributed on the surface and inside and outside the pores, and how is the biofilm developing over time?’, Caizán says. ‘A non-destructive way of measuring the biofilm would be a great advantage.’ The researcher decided to try to use a high-tech solution to achieve this: magnetic resonance imaging, MRI. She worked together with Julia Krug, a Ph.D. fully focused on this technology. This is a non-destructive technique, allowing to visualize biofilm growth, but also the 3D distribution of the biofilm on the carbon granules. This is a big advantage over normal microscopic biofilm evaluation, where biofilm is dead due to sample pre-treatment, only part of the granule can be observed and/or quantification is not possible. By harvesting granules from her experimental reactor, Caizán managed to visualize and quantify biofilm growth using MRI. Caizán: ‘The method is a big improvement over the conventional measurements and has shown to be able to reliably determine biofilm volume and 3D distribution on activated carbon granules. ‘Because of the non-destructive nature of the method, we can complement this method with other measurements.’

# Science: Combining micro-organisms and ozone to effectively break down micro-pollutants

**Using a combination treatment of ozone and microorganisms, Ph.D.  scientist Koen van Gijn is developing a new cleaning technology to remove micro-pollutants, such as pharmaceutical residues, from wastewater. His research may result in a more cost-effective removal technology for these substances.**

Carefully, scientist Koen van Gijn attaches a clamping ring around a glass cylinder filled with a brownish liquid. The bottom part is filled with sand. Two neighboring cylinders contain a similar fluid, but with different solids. In the middle cylinder, little plastic pieces dance randomly in the brownish liquid as air bubbles through. ‘Bacteria have different preferences for different substrates. Therefore, we are testing activated carbon, plastic pieces with a large surface area, and just sand as growth surface’, says van Gijn, while pointing at the three glass cylinders. Van Gijn’s research to find more effective ways of cleaning micro-pollutants from wastewater has just started. In this first experiment, he is evaluating the most effective way to reduce the amount of background organic compounds in wastewater using microorganisms. This cleaning step precedes the ozone treatment and reduces the amount of ozone needed.

## Complex mixtures

Many chemical compounds used in cosmetics, medication, and also agriculture may end up in wastewater in low concentrations. These micro-pollutants consist of complex mixtures of micro plastics, breakdown products from medicine, cosmetics, as well as pesticides. Due to improved analytical methods, their presence in wastewater has become clear. In The Netherlands alone, about 1250 tons of medication was used in 2007; that is roughly 160 pills per person per year. In the future, medicine use will only grow, with an expected increase of more than a third by 2050. This will inevitably result in increased exposure to the environment and also our drinking water. ‘To determine effects of these mixtures on the environment is complex and expensive, while removal of these compounds could be cheaper than monitoring’, states van Gijn. ‘It is therefore important to develop technology to remove these compounds from wastewater before they are discharged into surface waters.’

## New cleaning technology

Current methods to remove micro-pollutants from wastewater include treatment with activated carbon or ozone. Activated carbon and ozone treatment both have the disadvantage that they require quite some energy to be produced. Reducing the amount of ozone needed could make this method more cost-effective and sustainable.  Therefore, van Gijn is developing a new, more efficient cleaning technology.
Microorganisms play a key role in this new method. ‘I think ozone and microorganisms fit well together’, van Gijn explains. ‘Ozone can be used to break down the most recalcitrant micro-pollutants into smaller pieces, where after microorganisms take care of these smaller pieces.’ But that’s only half of the method. ‘When the ozone treatment starts, a lot of this reactive compound is used to break down background organic material, making the treatment less efficient’, van Gijn explains. ‘By including an extra bacteriological cleaning step before the ozone treatment, we try to effectively

get rid of this organic material and save on ozone.' To make this first bacteriological step as efficient as possible, the scientist is optimizing reactor conditions for the microorganisms involved, for example by comparing different growth surfaces for the bacteria. In separate experiments, van Gijn is also trying to find out which groups of these organic compounds are responsible for the unwanted ozone consumption. Van Gijn: 'With this knowledge we can start investigating how to breakdown these specific compounds and really increase the efficiency of ozonation.'

### Safe effluent

After reducing the amount of background organic material, the next cleaning step exposes wastewater to ozone by simply bubbling ozone gas through it. This results in breakdown of the more biologically persistent micro-pollutants such as painkiller diclofenac. 'Finally, during the third step, different microorganisms play a main role in degrading the resulting breakdown products. Together with the department of Aquatic Ecology and Water Quality, van Gijn will also assess the toxicity of the cleaned effluent on different layers of the ecosystem to check the effectivity of our cleaning method. Van Gijn: 'When we have developed the most effective cleaning method, resulting in a safe effluent, we will test our method in a scaled-up pilot plant.'

## Spin-off: Implementing cost-effective technologies for removing pharmaceuticals from wastewater

**Four years ago, Ph.D. scientist Arnoud de Wilt investigated the use of microalgae, in combination with bacteria and light, for improved micro-pollutant degradation in wastewater. This photo-bioreactor was very effective in breaking down different medicine residues in wastewater. However, implementing his idea proved to be challenging due to less favorable conditions for microalgae growth in The Netherlands. Therefore, in the last stage of his research, de Wilt focused on using ozone in combination with bacteria to degrade these compounds. The extra biological treatment step demonstrated a more efficient removal of micro-pollutants compared to just ozone treatment. Hence, implementation of this new cost-effective technology in current wastewater treating plants is promising.**

Conventional wastewater treatment facilities are not designed to remove pharmaceutical residues. As a result, these components end up in surface water, threatening ecosystems as well as drinking water supplies. 'Chemical or physical treatment for the removal of pharmaceuticals in wastewater is expensive and consumes significant amounts of chemicals and/or energy', Arnoud de Wilt says. 'We wanted to make these treatment processes more sustainable by combining them with biology.' During the last year of his Ph.D., De Wilt decided to focus on ozone in combination with bacteria. Just ozone treatment to degrade micro-pollutants is not cost-effective, among others due to high amounts of background organic matter in wastewater: a lot of ozone is consumed by degrading this fraction. De Wilt's first step was therefore to add a biological treatment step to remove this organic matter, so less ozone was required for effectively degrading pharmaceuticals. This resulted in a reduced ozone demand of more than a third, offering an excellent starting point to continue the research and further improve the process. 'The combination of ozone and biological treatment is even more interesting, since EU regulations will require the removal of more phosphorous and nitrogen', says de Wilt. 'Most likely, this can also be achieved by this biological step.'

### Mature the technology

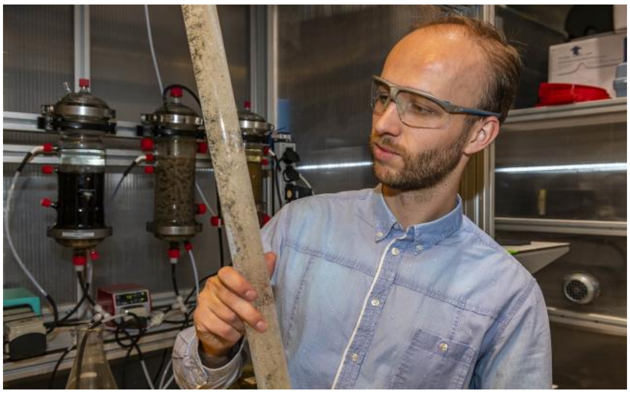
After finishing his Ph.D., De Wilt was employed at Royal HaskoningDHV. This consultancy firm was interested in continuing de Wilt's Ph.D. research. With a supplementary grant from the Minister of Economic affairs, Royal HaskoningDHV invested in an extension of his research. A new Ph.D. scientist was hired, while de Wilt was in charge as supervisor. 'The overall aim is to mature the technology and bring it into practice', says de Wilt. 'My Ph.D. research was mainly an academic exercise. Now we aim to build a pilot plant where we will bring theory and practice together.'

However, before the technology can be implemented, several key questions need to be answered: Which reduction in ozone demand can be achieved? What are additional benefits of the combined treatment? Who is going to use the technology? How can it be implemented in current wastewater treatment plants?

## Hotspots

De Wilt aims for the implementation of an additional step in existing water treatment plants to remove pharmaceuticals. However, currently, there is no legal obligation. Only in Switzerland, there is legislation enforcing the removal of these compounds. This increased the costs of wastewater treatment roughly by five to ten euro per person per year: the price of just three to four cappuccinos per year, as the Swiss state.

In The Netherlands, amounts of pharmaceuticals present vary between different locations. Several dozens out of ca. 320 wastewater treatment plants are marked as so-called 'hotspots', meaning the effluent contains concentrations of these compounds which negatively affect the receiving surface waters. These plants should be upgraded first with such an



additional cleaning technology. 'In four years time, I hope we have managed to implement an efficient and cost-effective technology to remove these micro-pollutants, together with additional nitrogen and phosphorous removal,', says de Wilt. 'The hotspots should of course be prioritized. This is important to keep our surface water clean and our drinking water safe.'

*Agenda*

**PhD defences (Aula, Wageningen):**

Yin Ye December 7th 2018, 16:00. Micropollutants removal by photochemical processes

**Conferences**

AquaConSoil conference May 20-25 2019, Antwerp, Belgium

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