Environmental Technology

Newsletter | Fall 2012

Picture: NASA

Science: Detoxifying Arsenic

Ph. D. student Paula Gonzalez-Contreras has developed a new method to transform poisonous arsenic into a harmless compound. She successfully used microorganisms to control arsenic precipitation into stable, non-toxic iron-arsenate crystals. Her finding may have large implications to solve the problem of increasing quantities of arsenic waste.

Arsenic is a notorious substance. Throughout history it became the weapon of choice to poison political adversaries and enemies. Often, the murder remained undiscovered since the symptoms of arsenic poisoning resemble cholera, a common disease at that time. Nowadays, the use of arsenic as a murder weapon has become rare and even peaceful uses of this highly toxic substance are banned worldwide since 2003. But in spite of restrictions, arsenic still poses a problem in many parts of the world. Natural arsenic may poison drinking water through weathering from arsenic-containing rock. A recent study showed that more than 135 million people in over 70 countries are exposed to arsenic through naturally contaminated drinking water.

Welcome

Welcome to the first newsletter of the Sub-department of Environmental Technology (ETE) of Wageningen University and Research Centre. This newsletter will give you an overview of our latest research that aims at providing technologies and methods for a sustainable use of our planet's natural reserves.
The world population is expected to grow to 9 billion people in 2050. This will lead to an increasing demand on the earth's supplies and to pollution of water, air, and soil. To assure that future generations will have access to enough natural resources in clean surroundings, novel production and recycling concepts and technologies are needed for fresh water, nutrients, metals, and energy.
In our approach, chemical, microbiological, electrochemical and physical-chemical principles are combined with modelling and design. This leads to innovative and new technologies for recovery and reuse of the earth's natural reserves.

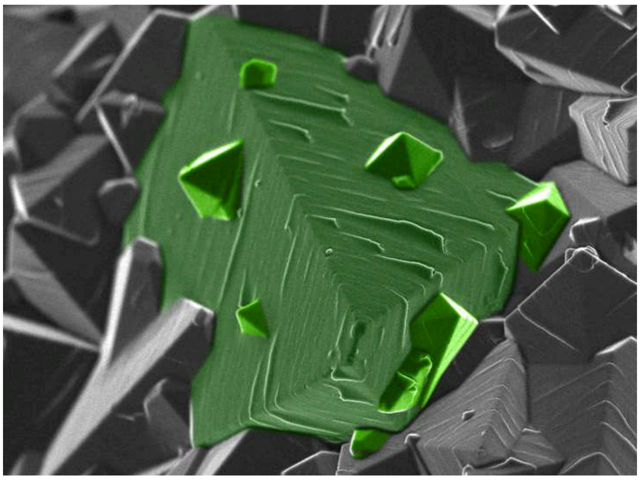
Cees Buisman and Huub Rijnaarts

Affordable solution

People may also be exposed to arsenic that becomes available through mining. For example, copper mining leads to large quantities of arsenic trioxide as a by product. The powdery substance poses a large health risk because it can easily be inhaled and readily dissolves in water. Since 2003 the annual production and release of arsenic through mining equals about 50 metric tons. ‘Only about 4 metric tons per year are used, for example as semi-conductors in cell phones and solar cells’, explains Gonzalez. ‘So we have to deal with an excess of large quantities every year´. An affordable solution to the growing problem of arsenic was really needed.

Cheaper

Gonzalez aimed at developing a bacteria-controlled process that would transform the highly toxic arsenic trioxide into a harmless compound. Iron-arsenate crystals, or scorodite, is an excellent candidate. It is stable and insoluble in water. When temperatures are high and pH is low arsenic trioxide and oxidized iron may form scorodite. This can be done through a complicated chemical process, but this method involves many steps and requires high temperature and pressure, making it too expensive. `We thought that microorganisms could do the job cheaper and more efficiently´, says Gonzalez. She started with a mixed culture of bacteria from the genus Thermoacidophiles. These microbes oxidize iron at high temperatures and low pH. In the presence of dissolved arsenic (As^{5+}) and oxidized iron (Fe^{3+}), and if conditions are right, these compounds may crystallize to scorodite. The researcher's biggest challenge was to find the conditions where the microorganisms grow, but also where scorodite crystals are formed.



Ideal conditions

When Gonzalez started her research, her supervisor pointed out it would be a very tough job. She took it as a challenge however, and locked herself up in the lab.

Short news

Grietje Zeeman has been appointed as personal professor New Sanitation, and Bert van der Wal (Voltea) has been appointed as personal professor Advanced Water Treatment Technologies at our department.

Prof. Huub Rijnaarts has been appointed as director of the research school Wageningen Institute for Environment and Climate Research (WIMEK) from September 1st 2012.

Two new European collaborative research projects between universities, research institutes and companies have started at Wetsus, Centre of Excellence for Sustainable Water Technology, with scientists from ETE:

- “Bioelectrochemical metal recovery for metal production, recycling and remediation” www.bioelectromet.eu
- “Bio-electrochemically-assisted recovery of valuable resources from urine” www.valuefromurine.eu

´I was determined to demonstrate that microorganisms could control the formation of scorodite crystals´, she says. She tested more than 200 different combinations of pressure, temperature, and oxygen and monitored bacterial Fe^{2+} uptake to find the ideal conditions for bacterial growth. For safety reasons, tests were carried out using the less toxic arsenic tetra oxide (AsO_4) to prove the principle.
Months of lab work and many test bottles later, all hard work paid off. ´One morning I saw green flakes in my test bottle!´, Gonzalez says enthusiastically. To eliminate all doubt, she visually and chemically compared the chemical composition of her green flakes with natural scorodite.

Several analysis proved they were similar. Further examinations showed that the formed scorodite was stable and insoluble in water between pH 1 and 5. Toxicity tests confirmed that they were harmless: Only between 0.01-3 mg/l arsenic went into solution after one full year, which is well below the toxicity norm. The method will further be tested on an industrial scale. Gonzalez: ‘Together with Paques, we will build a pilot-size reactor to further develop the method and make it fit to use on a large scale and reduce or even eliminate the arsenic waste problem.'

Key publication

Gonzalez-Contreras P, Weijma J, Buisman CJN (2012) Bioscorodite crystallization in an airlift reactor for arsenic removal. Crystal Growth and Design, 12(5) 2699-2706

Science: Sustainable Cities

Cities are inefficient and waste a lot of resources. However, the potential for cities to become more sustainable is huge, argues scientist Claudia Agudelo. Cities can become more self sufficient with regard to water, energy and nutrients. Agudelo: 'Reduce consumption by making people more aware and implement technologies to save, recycle and harvest local resources like solar energy and rain water.

Cities have grown bigger and bigger during the last decades, while the standard of living has increased. As a result, there is a high demand for resources like water, energy and nutrients, while waste production is huge. According to Agudelo, cities have to become more sustainable and efficient in order to accommodate the growing world population without depleting or wasting natural resources. It has to function according to the 'cradle to cradle' concept, where waste is not waste, but a valuable resource that can be re-used.
'If you look at the city as a factory or an organism, it is very inefficient', Agudelo states. 'There are substantial losses of water, food, energy, and materials. At the same time, the potential to harvest local resources, such as rainwater, is not used.' For example, an average person uses about 127 litres of water per day. More than the half is used to flush the toilet and to shower. 'You don't need water of drinking quality for all uses, rainwater or recycled water is as good and saves a lot of resources', says Agudelo. 'People should be more aware of what and how much they consume.'

Increase efficiency

To understand how to effectively improve the cities' efficiency, Agudelo quantified consumption and the effect of innovative measures aimed to increase resource efficiency. She first focused on water cycles and modelled yearly dynamics in water balances for different households. In addition, she quantified the effect of water saving and recycling, and rainwater harvest. Her study showed that water saving devices may reduce demand by more than a third, while recycling water from the shower and kitchen, 'light grey water', can supply about 20 percent of this minimized demand. In addition, rainwater harvest may provide for an extra 15-18% of required water. Light grey water and rain water are not of drinking quality, but can be (re-)used to flush the toilet or water the garden.

Customized solutions

But the positive effect of these measures is limited by differences between urban areas with respect to the feasibility to implement saving, harvesting or recycling measures. In addition, supply and demand are often unsynchronized. 'Rainwater is relatively scarce during a hot summer, just when you need more water for showering and the garden', Agudelo explains. 'In contrast, when rainwater is plentiful, demand is lower.' Large water storage tanks could be part of a solution, but are bulky and therefore not always easy to employ. Because there is a large variation in types of households, solutions have to be customized for each situation: 'A free standing house requires a different approach than an apartment flat in the centre of a big city', the scientist clarifies.

Behavioral change

Based on a study at city-scale, with Wageningen as a validation case, she concluded that this small city might be 35 percent self-sufficient with respect to water. Not much, the scientist agrees, but the limitation is that shower and kitchen and bathroom sinks require high quality water. 'To have sustainable cities in the future we need a behavioural change', Agudelo insists. 'People should be more conscious about their consumption. At the same time integrated systems to save and harvest water, energy, and nutrients should be implemented in new urban areas.'

Key publication

Agudelo-Vera CM, Leduc WRWA, Mels AR, Rijnaarts HHM (2012) Harvesting urban resources towards more resilient cities. Resources, conservation and recycling, (64) 3-12.

Agenda

22&23 November 2012: 2nd international PlantPower Symposium, Wageningen, www.plantpower.eu

23 November 2012, 16:00: PhD defense
Marjolein Helder, "Design criteria for the Plant Microbial Fuel Cell"

3 December 2012, 16:00: PhD defense
Le Thi KimOanh, "SURMAT: decision support tool to select municipal solid waste treatment technologies"

18 December 2013 11:00: PhD defense
Marco de Graaff, "Biological treatment of halo-alkaline wastewater using soda lake bacteria"

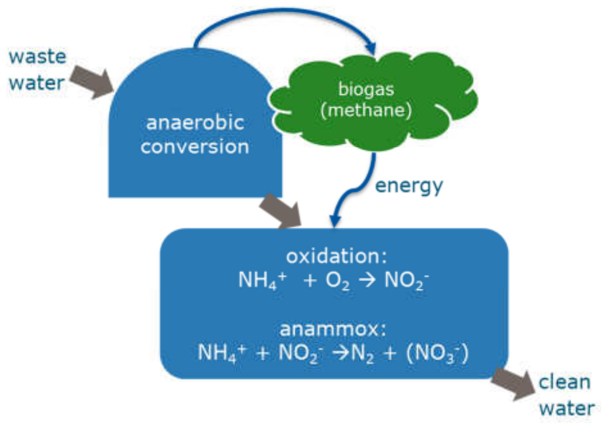
Science: Energy Neutral Wastewater Treatment

New methods to make waste water treatment more energy-efficient are currently being developed. Project leader Tim Hendrickx aims at extracting more biogas and remove nitrogen by a different pathway, using microorganisms that need less oxygen. As a result, energy use by aeration is significantly reduced.

Conventional waste water treatment is an energy consuming process. In the Netherlands this industry uses as much energy as 1.3 million people. More than half of all energy used is to aerate the system to supply it with enough oxygen for nitrification: the process where microorganisms transfer ammonium (NH_4^+) into nitrite (NO_2^-) and consequently into nitrate (NO_3^-). Together with organic matter, nitrate is converted into nitrogen gas (N_2). The remaining organic matter, 'sludge', is partly fermented into biogas, mainly methane (CH_4) at high temperatures (30-35℃). In addition to biogas, also high amounts of ammonium are formed. Together with residual organic material, the ammonium is returned back to the first treatment reactor, where the cycle starts again.

Energy saving

According to Tim Hendrickx, scientist at Environmental Technology, waste water treatment could become a lot more energy-efficient by changing this conventional pathway. 'We are currently developing a method where we produce biogas during the first steps of the treatment process', explains Hendrickx. 'By altering the biological cascade and start the process with anaerobic treatment of waste water, we can potentially reduce oxygen use, and therefore energy use, through reduced aeration.' The theory is straightforward (see figure).



In a first reactor organic matter in waste water is directly converted into biogas and ammonium through anaerobic fermentation. In a second reactor, ammonium is oxidized to nitrite by nitrification bacteria. A relatively newly discovered bacteria, Anammox, subsequently transforms ammonium and nitrite directly into nitrogen gas. Anammox thus replaces the aerobic conversion from nitrite to nitrate and partly from ammonium to nitrate. This alternative route produces nitrogen gas directly from nitrogen-containing compounds. These conversions use less oxygen and no organic material when compared to conventional methods. Overall it results in about 60 percent energy saving due to reduced aeration. Because more organic material is available for anaerobic fermentation, also more biogas is formed.

Fine tuning

In theory this works great, but there are a few obstacles to overcome. Anammox preferably grows at temperatures between 30 and 35℃, while waste water usually has lower temperatures, between 10 and 20℃. At these low temperatures Anammox grows slowly and nitrite is relatively quickly transformed into nitrate. Consequently, the amount of nitrite becomes limiting for Anammox, while nitrate accumulates. Overall, less nitrogen will eventually be converted into nitrogen gas, resulting in less efficient waste water treatment. Hendrickx solved this problem by limiting the amount of oxygen, resulting in reduced nitrate formation. Hendrickx: 'This requires quite some fine-tuning, but is very well possible.'

Energy neutral

Hendrickx calculated that through the new 'Anammox pathway' waste water treatment could eventually become energy neutral. 'Saving on aeration energy and producing more biogas more or less compensates for the energy used during waste water treatment', he says. 'We are currently working to check our calculations in the real world by testing this pathway in a pilot facility treating waste water from an actual treatment facility.'

Key publication

Hendrickx TLG, Wang Y, Kampman C, Zeeman G, Temmink H, Buisman CJN (2012) Autotrophic nitrogen removal from low strength waste water at low temperature. Water Research, 46(7) 2187-2193

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