Environmental Technology

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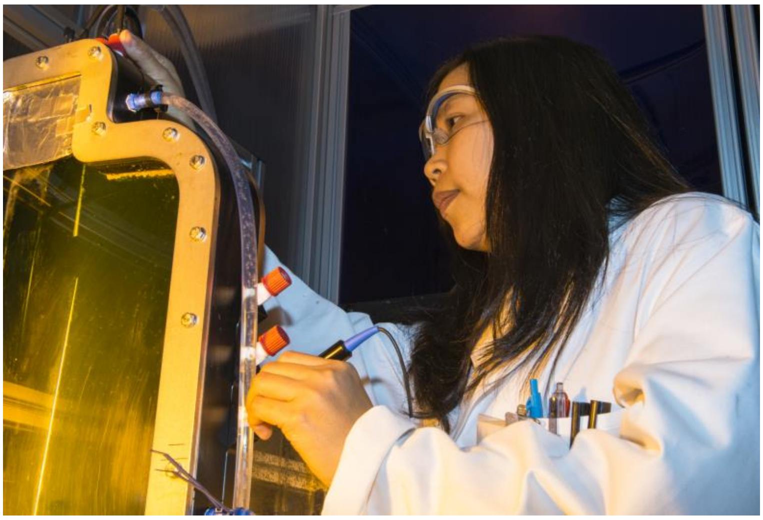
Picture: NASA

Science: From waste to resource: Toilet matters



Micro algae can grow perfectly well on human urine. Ph.D. student Kanjana Tuantet discovered that these microscopic plant-like organisms efficiently take up nutrients from urine, turning an abundant waste product into a new resource.

´This system produces more than twenty grams of algae biomass per day!´ Scientist Kanjana Tuantet points at a complicated looking piece of equipment filled with a green liquid. A maze of hoses are attached to the device, one of them bubbling CO_2 through the system. Powerful lamps illuminate the greenish algae-rich fluid in this so called ´photo-bioreactor´. Algae need light and CO_2 to grow, but they also need nutrients. In Tuantet's photo-bio reactor the algae receive concentrated urine collected from no-mix toilets and retrieve all required nutrients from this waste product.

Undesirable waste

In an average household urine accounts for about half of all phosphorous and over seventy percent of nitrogen in waste water. In total, all households in the Netherlands produce about a staggering 160.000 kg of nitrogen and 12.000 kg of phosphorous per day. These potentially useful nutrients are now flushed down

Column ***Cees Buisman***

Environmental challenges in the world are enormous today. Despite environmental policies and technological breakthroughs the ecological footprint of the world population is still increasing. Main reason is the increasing wealth and associated consumption. In recent years hundreds of millions of people have entered the 'middle class wealth', speeding up consumption and increasing environmental challenges at the same time. The number of cars will double from 1 billion to two billion the coming years. Will we ever have enough? Sometimes it seems indeed that there ís enough. In the Netherlands last year electrical power consumption has decreased for the first time ever. Of course there is the crisis, but also solar panels, led lighting, more efficient consumer electronics like led televisions are a new trend. Water consumption in households has stopped growing already decades ago and the natural gas consumption per household is already decreasing for twenty years.
If there is an ENOUGH, technical innovations can make the use of natural reserves sustainable. Our department has been working on these breakthrough innovations now for almost 48 years. Our concentrated black water approach in Sneek demonstrated a water saving of fifty percent. New ideas and solutions to groundwater pollution, industrial water recycling and resource recovery have also been shown to be effective. In the coming weeks, revolutionary technologies for nutrient recovery will be published.
We invite you to save 29&30 April 2015 in your agenda to join us in our international conference on the occasion of our 50 year celebration to discuss the innovations in Environmental Technology that the world needs.

the drain, and eventually end up in waste water treatment plants. To remove these nutrients during the water treatment process is a costly and energy consuming process. Due to stricter EU regulations regarding waste water treatment, nutrient removal has to be more efficient. Consequently, there is a need for better, cheaper and more efficient nutrient recovery processes. Algae culturing could be a key to recover nutrients effectively and relatively inexpensive. Another advantage is that nutrients from urine can possibly replace expensive fertilizers in algae culturing. These fertilizers may account for about 2-10% of total micro algal biomass production costs.

High nutrient concentrations

To test urine as an alternative nutrient source for algae Tuantet used a flat-panel photo bioreactor with a volume about a liter. These reactors are suitable to grow algae in high densities. ´We wanted to grow algae using undiluted urine, so we needed an algae species that could grow at high nutrient concentrations´, the scientist explains. After testing several algal species, *Chlorella sorokiniana* showed the highest growth under the desired conditions. Tuantet: ´This algae is commercially not the most interesting, but very well suited to test the method.´

Optimal growth

The first trials showed that the algae could deal with varying nutrient compositions in urine, but addition of micronutrients, such as iron, copper, magnesium and manganese was required for optimal growth. After running system for several months, Tuantet observed not only growing algae, but also bacterial growth. ´These bacteria were actually useful´, she says. They further cleaned the urine by removing organic compounds.´ Now, the test system works and at optimal conditions, it is capable of producing 22 grams of algae biomass per day. The algae removed 2.5 grams of nitrogen and 300 milligrams of phosphorus from urine. Experiments with real urine showed the highest removal of nitrogen up to 75 percent with around 100 percent removal of phosphorus. From the algae biomass useful components, like lipids or proteins, can be extracted. They can also be used as a fertilizer that slowly releases the nutrients. An additional benefit is that by using micro algae cultures to recover nitrogen and phosphorous from urine, nutrient loads to existing treatment facilities as well as water use are substantially reduced. This option is especially promising for areas with water scarcity.

Investments

´We now have a running and productive system where nutrients can be recovered from concentrated urine´, Tuantet says. ´This system uses ´waste´ and turns it into a resource.´ The next step is to apply the principles to bigger reactors, and test if it also works on a large scale. However, to commercially cultivate microalgae on urine, several factors must be considered and balanced and some major obstacles have to be overcome. The infrastructure of waste collecting and treating has to change. Houses have to be equipped with special toilets, that collect urine separately (Fig. 2). Also substantial investments for suitable algae culturing systems have to be made. ´I think this system can work starting with small communities having urine separation systems', Tuantet says. 'The urine might either be treated at the location or transported to another treatment location close by.'

Fig. 2 Toilet that collects urine separately

Agenda

22&23 April: Workshop Reservoir Restoration, Wageningen, Forum building

26 April, 13:30 (Leeuwarden): PhD defense Philipp Kuntke, "Nutrient and energy recovery from urine"

July 1-5: Masterclass Biobased Innovation, Wageningen (http://www.sense.nl/courses/597.html)

4 September, 13:30: PhD defense Fredrick Salukele, "Energy production from bioreactor landfills in East Africa"

10 September, 13:30: PhD defense Ran Zhao, "Theory and operation of capacitive deionization systems"

20 September, 11:00: PhD defense Nadine Boelee, "Microalgal biofilms for wastewater treatment"

20 September, 13:30: PhD defense Justina Racyte, "Alternating electric fields in an activated carbon fluidized bed electrode for wastewater disinfection"

Science: Urine as nutrient and energy supplier

Environmental Technology and Wetsus researcher Philipp Kuntke developed a revolutionary method to recover nutrients from urine, while producing energy at the same time. A breakthrough. On April 26, 2013 Kuntke will defend his Ph.D. thesis in Leeuwarden.

Urine is a major contributor of nutrients to waste water. On average, a person produces about 1.5 liter of urine per day, corresponding to roughly one percent urine in domestic waste water. But this one percent is responsible for about 80 percent of all nitrogen and 50 percent of all phosphorous in waste water. Separate collection and treatment of urine will substantially reduce the nutrient load to waste water treatment plants. Retrieving these chemicals from urine not only cleans it, but may also result in nutrient recycling since these components can be used as fertilizers in the agricultural industry. However, state of the art methods to clean waste water, while recovering nutrients are costly and require a lot of energy and chemicals. Kuntke developed an alternative two-step method to clean undiluted urine. First, phosphorus is recovered. Then, remaining compounds are converted into electricity using a microbiological fuel cell, while ammonium is recovered at the same time. The project was not easy to accomplish. 'The biggest challenge was the transition from idea to final concept', Kuntke says. 'We had to redesign and assemble several individual working methods into one single functioning technology.'

Microbiological fuel cell

The first step to recover nutrients from urine involves simple precipitation. 'Adding magnesium binds some nitrogen and most phosphate, resulting in the formation of the crystal struvite', Kuntke explains. By letting urine settle, struvite will sink to the bottom.' Struvite is a valuable slow-release fertilizer. The remaining urine still contains some nitrogen (ammonium, NH_4^+) and organic compounds like proteins, fatty acids and sugars. These fractions go straight into the microbiological fuel cell. At the anode microorganisms catalyze the conversion of chemical energy into electrical energy (electrons), while at the cathode nitrogen (ammonium) is recovered (Fig. 1). Electrons generated at the anode flow through the electrical circuit to the cathode that becomes negatively charged. To keep electron neutrality, positively charged ammonium ions (NH_4^+) in the solution flow to the cathode, where they are converted into ammonia gas. This gas can be collected and used for a variety of purposes. 'This conversion saves energy compared to other methods to clean waste water from nutrients and organic material', says Kuntke. 'To be the most effective, you need undiluted urine. This can be collected using special separation toilets'.

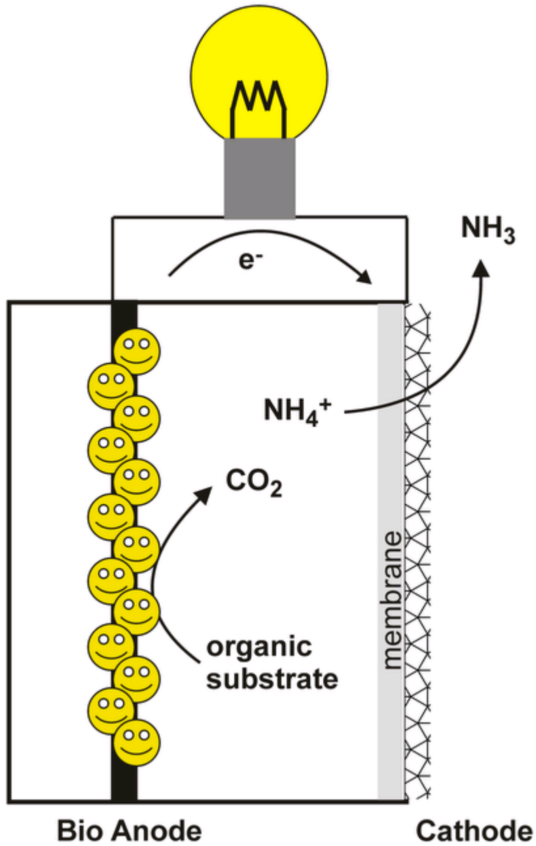


Fig. 1 Organic compounds present in urine are converted by microorganisms into electricity, while nitrogen is recovered in the form of ammonium at the cathode.

Full-size pilot plant

In the near future Kuntke and his colleagues will test if this revolutionary method works not only at lab scale, but also at larger scale. ‘Quite a challenge’, he says. ‘We need to design and build a microbiological fuel cell 50 to 100 times the size of the lab model. That requires many adaptations.’ The team needs to look into new materials and design, and improve the robustness of the process. Also the precipitation step and the microbiological fuel cell step have to be made compatible with each other to assure a smooth running process. Currently the team is building a larger pilot plant to test the method (Fig. 2). Special infrastructure was needed, including a separation toilet or urinal for separate collection of urine.
‘We aim for three main goals: struvite production, energy production and ammonium recovery’, Kuntke says. ‘In theory it is possible to recover more than 90 percent of nutrients from urine.’ The scaled-up pilot plant will show if these expectations are realistic. If tests are successful, urine can become an important source of valuable products and energy, instead of just a waste product.

Fig. 2 The first pilot study on the recovery of energy and nutrients from urine at the Wetterskip Fryslân.

Key publication

Kuntke P, Smiech KM, Bruning H, Zeeman G, Saakes M, Sleutels THJA, Hamelers HVM, Buisman CJN (2012). Ammonium recovery and energy production from urine by a microbial fuel cell. Water Research, (46) 2627-2636.

Short news

A new PhD project will be started soon in cooperation with Climate KIC on **modelling resource cycles**, together with the Biomass Refinery and Process Dynamics group of WUR (Karel Keesman and Ingo Leusbrock).

The paper "Review on the Science and Technology of **Water Desalination by Capacitive Deionization**" by Ran Zhao, Maarten Biesheuvel and Bert van der Wal, in cooperation with Wetsus and the University of Saarland (Germany), has recently been accepted for publication in Progress in Materials Science (PIMS), a journal with an impact factor of 18.

On 22 and 23 April, ETE, Bioprocess Engineering and Deltares organize the **workshop Reservoir Restoration** in Wageningen (Forum building).The workshop addresses the nutrient overload in reservoirs leading to blooming of Blue Algae. The origin of the problem and new approaches to tackle this phenomenon by cultivation of green algae will be addressed.

ETE PhD students Fei Liu and Ran Zhao both received a special Marcel Mulder **prize for outstanding papers** at the annual Wetsus congress in October 2012.

The **Masterclass Biobased Innovation** will take place in Wageningen July 1-5. The Masterclass is aimed at PhD students and provides a background on biobased energy and materials. This knowledge will be validated by proposing a possible application or

Dynamic teaching at Environmental Technology

Educating students has become an increasingly demanding task. Student numbers are increasing, while they come from many different scientific backgrounds. Consequently, it is challenging to create a teaching program that suits all students. Scientist and teacher Ingo Leusbrock and his colleagues designed dynamic and challenging courses, fitting most students.

About five years ago the Urban Environmental Technology and Management joined. Leusbrock and his colleagues redesigned the teaching courses involved and adapted it to today's standards. Most importantly, teaching became more dynamic. Leusbrock's teaching program offers flexible and varied programs, and includes both theoretical and practical aspects. The application of new environmental technologies is central, while theoretical and practical aspects are well balanced. His teaching focuses on closing energy, water and waste cycles. 'Often the topics go beyond just environmental technology', Leusbrock says. 'For example, when combining quality of life with sustainability: then you also need environmental policy as well as spatial planning.' In this multi-disciplinary approach, students are actively involved in case studies, for instance the possibilities to implement 'separation toilets' and New Sanitation into households, or the large-scale application of solar energy in certain cities or urban areas.

Practical examples

Today, Leusbrock is involved in different teaching courses, like principles and basic technologies of urban environmental management. These courses include climatology, system analysis, environmental management, but also energy, water and waste cycles. 'The goal is to teach students basic concepts', Leusbrock explains. 'With this knowledge they have tools to implement technologies and close energy, waste and water cycles.' In addition to lectures, two to three excursions per course are made These are invaluable tools to illustrate the application of technologies in practical 'real life' situations. For example, the new and highly sustainable NIOO-KNAW building in Wageningen houses a variety of technologies to separate waste, including toilet waste, reduce energy use and recycle. In this way, theoretical knowledge about technologies is supported and illustrated with clear, practical examples.

Great questions

Leusbrock, a specialist in applying sustainable technologies into industrial or household situations, gets a lot of satisfaction from his work. Not seldom the teacher himself is surprised by great questions and suggestions from his students. 'Sometimes I am really surprised by a question and think: wow, that´s a great idea, why didn't we think of that?´, says Leusbrock. ´But it tells me that the teaching method works.´ He enjoys guiding M.Sc. projects the most. These are true challenges that require a complete involvement in the project. ´You really need to go for it and give some extra', he says. 'But to see students grow during their 6-months project is just a great reward!'

Fig. 1 Students in the course "Planning and Design of Urban Space" course. A touch table is used to plan an energy self-sufficient area in Almere Oosterwold. The touch table is linked to a server that enables real-time calculations of energy demand and supply, and spatial organisation of urban land use and renewable energy.

Leusbrock's most recent educational and research task of involves supervision of a Ph.D. project. Here, new methods will be tested and developed to close energy, water and bio-degradable material cycles in cities. Large datasets obtained from satellites and smart metering systems will be collected and modelled to obtain real-time information about the current status of these cycles. This will be used to efficiently control energy and waste water cycles in urban areas.

Contact

Annemiek ter Heijne (Environmental Technology)
E: Annemiek.terHeijne@wur.nl
www.wageningenur.nl/ete

Hans Wolkers (Wild Frontiers B.V.)
E: Hans.Wolkers@gmail.com
www.wildfrontiers.nl, www.science-explained.nl