Annual report
2017
Section Sanitary Engineering

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For up-to-date information about education and research of the section Sanitary Engineering visit our website: www.sanitaryengineering.tudelft.nl

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Introduction

Welcome to the annual report of the Section Sanitary Engineering of the Department of Water Management, Faculty of Civil Engineering and Geosciences, Delft University of Technology. Research and education activities of the section are centred on the so-called "Urban Water Cycle" and include extraction, treatment and supply of drinking water, the collection, conveyance and treatment of used urban waters including urban drainage, and the make-up of industrial process water as well as treatment of industrial residual streams. Our current main research focus is on advanced treatment of compounds and organisms of emerging concern, recovery of valuable compounds, water and energy from used waters, monitoring and asset management of urban water infrastructures. The section consists of 10 full-time, and 5 part-time scientific staff members, about 10 (visiting) post-doctoral researchers and 50 PhD students, and 5 staff members for managerial and laboratory support.

In 2017 we consolidated our new master track Environmental Engineering that started in 2016 with 10 MSc students. We received huge (international) interest and in September 2017 40 new MSc students started their studies in this track of the Civil Engineering Master programme. This overwhelming increase demonstrates that the Netherlands in general, and the TU Delft in particular, has a great reputation in this field and that students from all over the world are motivated to benefit from our knowledge. The new master track Environmental Engineering runs parallel to the existing Water Management master track, in which we participate through the specialisation Urban Water Engineering. Also the Water Management master track had a record inflow of about 70 students in 2017. We are of course very proud that 'Water Resources' of TU Delft ranks number 1 in the several academic world-ranking lists. In 2017 we also launched our first 'ProfEd' specialised internet course on 'Membrane Technology'. We hope to launch two additional courses on 'Aerobic Granular Sludge' and 'High-rate Anaerobic Treatment' in 2018.

Our research activities resulted in the graduation of 7 PhD students in the past year, next to the publication of more than 60 peer reviewed papers in highly ranked journals. Amongst others, we developed a method to coat ceramic membranes for application in direct sewage treatment, and discovered the characteristics of arsenic removal in sand filtration. We were able to extract ammonium from liquid streams for electricity production in solid oxide fuel cells and treat saline phenolic waste streams efficiently using anaerobic membrane bioreactors. In addition, we were successful in acquiring new research funds from the Netherlands organisation for scientific research (NWO), with projects like LOTUS-HR and AdOx, and started the large EU-H2020 project "Zerobrine", while having several additional initiatives in the projects pipeline.
Regarding personnel, we are very proud that one of our talented young scientists, Merle de Kreuk, was nominated as full professor at TU Delft in 2017. Her recognition is not only for her scientific research, but also for her innovations in education that caused a great launch of our Environmental Engineering MSc track. We expect more news on personnel in 2018 as we are now in the process of recruiting a new full professor on Urban Water Infrastructures, an emerging field in both research and education, with an envisaged huge societal impact in the years to come.

We wish you a lot of pleasure reading our annual report and hope that this inspires you to start or to continue the cooperation with our section Sanitary Engineering.

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Research

Research and Education Strategy Section Sanitary Engineering

From urban water chain to urban water cycle

While more than 50% of humanity lives in urban areas, cities and water are closely linked to each other. A well-functioning water network is essential for a city. Everybody has the right to be supplied by clean and riskless drinking water, proper sanitary services, safe and reliable collection and treatment of the used urban waters, and protection of surface water and groundwater bodies. Fresh and clean water, however, is scarce and for several cities the limiting factors for economic growth.

Sanitary engineering typically takes place within the urban water cycle, which in itself is part of the greater hydrological cycle. Drinking water is obtained from groundwater or surface water. The water is treated and subsequently transported to the users, i.e. households and industries, by means of an extensive distribution network. Hereafter, the used waters, previously called wastewaters, are collected, often together with the drainage water, again via an extensive sewerage system. Subsequently, the collected sewage is conveyed to the sewage treatment plant, where the water is relieved from unwanted pollutants. After treatment, the purified water is discharged into open surface waters, after which it is again part of the natural hydrologic cycle.

Given the worldwide increasing water scarcity and/or costs involved in importing fresh waters from large distances, a growing interest exists in making shortcuts in the urban water cycle, creating possibilities for multiple water use or even partly transforming the urban water chain into an urban water cycle. As such, water is more and more regarded as a valuable commodity, whereas its polluting constituents are more and more recognized as recoverable resources. Intervening technologies are being developed for upgrading water qualities and concomitantly recovering contaminants as resources, turning negatively valued urban streams into positively valued assets. Traditional conveyance systems for sewage and urban drainage are critically evaluated and made fit for the modern urban water cycle approach, anticipating

on current societal demands and possible climate changes. Forecasted increase in flood events will put additional demands on adequate urban drainage designs. Obviously, reliability, cost-effectiveness, and resource efficiency are keywords in present research in sanitary engineering and water treatment technologies. In order to take all benefits from the used urban waters, profound knowledge is required on physical-chemical and biological treatment technologies needed to upgrade these waters to agreed standards for subsequent use or discharge.

Mission statement

The mission of the Sanitary Engineering Section programme is formulated as "Performing innovative research and (advanced) education in urban water cycles related to societal relevant themes".

Ambition in research and education

Research and education of the Sanitary Engineering Section is of high societal relevance and technical excellence. It serves the current needs of the Dutch Water sector and outlines present developments and future strategies in close cooperation with the sector. In addition, international developments and our increasing participation in the "international water arena" increasingly include research projects of global concern. Our philosophy results in a balanced combination of societal and industrial pull and scientific push. We strongly believe that this is in the best interest of our MSc and PhD students serving both science and industry. Delft University of Technology and partners not only benefit from the scientific and professional publications and PhD dissertations, but also from patents, practical applications, and knowledge transfer in open course ware lectures and massive open on-line courses (MOOCs) via the internetInternet. At present, about 50 students carry out their PhD research and yearly about 20-30 students finalise their MSc specialisation in Urban Water Engineering or Environmental Engineering.

Education

Apart from two introductory courses in the BSc, specialised courses are given in the MSc-tracks Water Management and Environmental Engineering of the Civil Engineering Programme. The education is focussed on the learning-by-doing, involving students, where possible, with practical assignments (activated learning). In addition, students are stimulated to have an internship abroad, in order to broaden their horizon. In addition, the section is active in on-line education. Current Massive Open On-line Courses (MOOCs) from our group are: "Introduction to Drinking Water Treatment", "Introduction to Urban Sewage Treatment", and "Introduction to Water and Climate". On the EdX platform these MOOCs are indicated as the WaterX-series of TU Delft. Internet based thematic ProfEd courses present detailed information in specific technologies and highlight the expertise of our group. Courses are bi-directional and charge an inscription fee. The ProfEd "Membrane Technology" is already online, whereas the courses "Aerobic Granular Sludge" and "Anaerobic High-rate Treatment" will be launched in 2018. The section Sanitary Engineering is front-runner in online education, and the MOOC "Introduction to Water Treatment" was the first one of TU Delft.

Research themes and approach

Dutch drinking water is characterized by a very high quality, owing to the high technical standards in Dutch water companies, resulting in the continuous supply of safe drinking water at an acceptable price. No chlorine is used during drinking water production, which is made possible by applying a multiple barrier treatment approach, producing biologically stable water. Moreover, the drinking water is soft, has a pleasant taste and colour and pipeline leakages are virtually zero. Water losses in our network do not go beyond 2-3%. As a result of this, the trust in the drinking water quality is high. The Dutch drink water from the tap and they do not feel the need for using bottled water or point-of-use filters. Continuation of the high quality standards in the water sector requires research on presence and fate of priority pollutants, biological growth (e.g. Legionella) and water quality deterioration in the distribution system.

Municipalities are responsible for collecting and transporting used waters and managing the rainwater and groundwater in urban areas. At present and in the near future they are facing several challenges, e.g. climate change, (de)urbanisation, more stringent legislation, required costs reduction, required drop in fossil fuels usage, maximised energy recovery, resource effectiveness, implementation of sensor networks for process control. These challenges are to be faced in the light of a more intense cooperation with other

Research and Education Strategy

stakeholders, ultimately leading to an increasing need for knowledge of the involved processes and sound engineering solutions.

Water boards, ultimately responsible for the upgrading of the used urban waters, are challenged by increasingly stringent effluent criteria and societal concerns on priority pollutants and hygienic quality of the produced effluents. Moreover, foreseen shortcuts in the water chain, creating urban water cycles, require effluent qualities meeting the demands of the subsequent user, that are often much more stringent than the emission standards. On the other hand, the proposed shortcuts may facilitate full emission control as all pollution will then be scavenged at the treatment plants for industrial water provision. The foreseen developments logically result in improved operation of sewage treatment plants, introduction of new treatment technologies, interactions between sewerage and separation of rainwater from the sewer system. In addition, the water authorities are emphasizing the potentials of recovery of resources, such as nutrients, bio-plastics, cellulose fibres, and energy from sewage streams.

To be able to address the research needs of the water sector, our MSc and PhD research is clustered in 4 thematic research themes:

1. "Water Quality: Science & Technology" includes solutions for emerging threats, increasing standards, optimized treatment, as well as for subsurface processes, where water quality relates to the geo-chemical conditions.
2. "Reclamation of Water, Energy, Resources" deals with technologies for the closing of material cycles in the urban water cycle.
3. "Distribution and Discharge Networks" investigates the water quality and hydraulic aspects in distribution and drainage systems.
4. "Global Sanitation, Safe Drinking Water & Health" focuses on health related aspects in the urban water cycle, with emphasis on improving drinking water supply and sanitation in developing countries.

Each of the staff members has its own specialisation to develop research in one or more of the above mentioned research themes. These specialisations include (anaerobic) membrane bioreactors, (ceramic) membrane filtration, metallic surfaces in water, characterisation of natural organic matter, soft sensors in water treatment, monitoring in sewer systems, emerging pathogens and technology selection in relation to water quality.

Our research agenda includes a mixture of desk-top research, laboratory experiments, pilot-plant experiments and full-scale field research. Computer modelling enables us to understand the complex reality and limit the number of experiments to achieve an optimal result. Where laboratory experiments test our initial hypothesis under defined conditions, pilot plant and field research includes the specific water quality and reactor operational aspects that cannot be simulated in the lab. Moreover, full-scale investigations at treatment plants and piped/sewerage networks are required in order to study the effects of large-scale hydraulics. As such, our research can be characterised as a mixture of water quality, process technology, hydraulics and applied mathematics. A thorough understanding of physical, chemical and biological processes is required to improve the water matrix to the required level. Combined with a thorough insight in hydraulic aspects, such as turbulence, mixing, and uneven flow patterns, this will ensure the feasibility of the technology in large-scale settings. Based on our experience, these mixtures of scales and sciences provide a total view on sound sanitary engineering that stimulates new ideas and approaches.

The professors in our group have a down-to-earth approach and practice 'management by participation'.

They stimulate discussions between PhD students, staff members and experts from science and industry. Moreover, they frequently participate in national and international meetings on the research agenda for the water sector, such as the International Water Association and KNW, providing additional stimuli to the research. The processes of improvement and innovation function primarily through the interaction with the experts from science and industry. Frequent external visitors are invited to participate in meetings and colloquia.

Our international network includes a vast number of foreign universities, such as in Leuven, Gent, Sheffield, New South Wales, Bradford, Johannesburg, Boulder, Waterloo, Trondheim, Dresden, Poitiers, Rennes, Toulouse, Zürich, Valencia, Santiago de Compostela, Cali, Sao Paulo, Belo Horizonte, Singapore, Harbin, Beijing, Shanghai, and Xiamen. Research projects are performed in cooperation with NWO, Commercial partners, TKI, AMS, and the European Union. Special agreements for research collaboration are made with Waternet, Dunea, HWL, Vewin and Rioned. Next to papers and reports, our research is communicated through a newsletter. In addition, many ideas are disseminated at our annual 'Vakantiecursus', which is acknowledged as the leading Dutch conference on Sanitary Engineering being annually first, just after New Years' eve.

Theme 1: Water Quality: Science & Technology

Theme leaders: Bas Heijman, Boris van Breukelen, Jan Peter van der Hoek & Henri Spanjers

Water resources are increasingly threatened by the presence of micro-pollutants coming from household, industrial and/or agricultural activities. Traces of these compounds, such as endocrine disrupters, polar pesticides and pharmaceuticals, are even found in Dutch drinking water. Only a few of these emerging substances are known and measured in (standardized) routine analyses in our drinking water. Since conventional treatment systems have a (very) limited capacity to eliminate these compounds, advanced water treatment is required. Similar concerns have risen towards the presence of different kinds of (resistant) pathogenic organisms in surface waters, which may find their way to the drinking water supply if not properly dealt with. Improvement of wastewater treatment effluents is well articulated in the European Water Framework Directive (WFD), which is adopted by its member states. Fortunately, in recent years we have seen major breakthroughs in new technologies such as membrane filtration and disinfection/oxidation with ozone/UV/H2O2. These technologies are investigated and currently being implemented in both the drinking water sector and the wastewater sector. In fact, an integrated approach needs to be developed.

Our research in Theme 1 is focused on optimal water quality control by developing new treatment techniques to upgrade wastewater treatment plant effluents, source water for drinking water preparation, and pre-treated industrial water prior to discharge. In addition, the subsurface water quality is monitored and assessed using geo-chemical models. In technology development, the determination of the practical feasibility is of high importance and aspects such as efficiency, costs, and operational complexity are addressed. In addition, sustainability issues such as fossil fuel consumption, use of chemicals, formation of by-products, and the possibilities for re-use of liquid/solid side streams (see Theme 2) are of increasing importance. Several PhD projects address the effectiveness of the different treatment techniques/treatment combinations in removing both common and emerging polluting substances. In addition, a modelling approach is developed to predict the removal of new emerging substances and to assess the plant performance towards organic micro pollutants. Computer models are also used to control the water quality leaving the treatment plant, while delivering the required flow and quality.

Research projects

Understanding Iron and arsenic removal	David de Ridder
Ceramic nanofiltration as the key step for sustainable wastewater treatment with reclamation of water, energy and nutrients	Ran Shang
Biostability in Drinking water distribution networks (DWDN) during and after Thermal Energy Recovery	Jawairia Imtiaz Ahmad
Online fouling control in Anaerobic Membrane Bioreactors	Magela Arbiza
Physical removal mechanisms of suspended solids from wastewater in Aerobic Granular Sludge installations	Lenno van den Berg
Natural Organic Matter removal from surface waters: Separation of Dissolved Organic Carbon and ions from Ion Exchange brine using Ceramic Nano Filtration	Irene Caltran
Managing chemicals of emerging concern in the water cycle	Astrid Fischer
Phenolic compounds degradation in AnMBR under mesophilic and thermophilic operation: BioXtreme-following up	Victor Garcia Rea
Broadening and renewal of the Dutch drinking water benchmark	Marieke de Goede
Understanding arsenic mobility for smart fixation during drinking water treatment	Jink Gude
Zeolites as novel adsorbent in water treatment	Nan Jiang
DIPool: Dutch Innovative Pool Advanced UV-based technology for pool water treatment	Maarten Keuten

Theme 1: Water Quality: Science & Technology

Theme leaders: Bas Heijman, Boris van Breukelen, Jan Peter van der Hoek & Henri Spanjers

Research projects

Improving the effectiveness of assetmanagement of the drinking water process	Rian Kloosterman
Application of flocculants in todays sewage treatment plant	Guido Kooijman
Ceramic nanofiltration as the key step for sustainable wastewater treatment with reclamation of water, energy and nutrients	Franca Kramer
Hydraulic modelling of liquid-solid fluidisation in drinking water treatment processes	Onno Kramer
BioXtreme – Anaerobic wastewater treatment under extreme conditions	Julian Munoz Sierra
Safer monitored natural attenuation of chlorinated ethenes through stable isotopes study and modeling	Héloïse Thouement
Removal of suspended solids using Aerobic Granular Sludge	Sara Toja Ortega
The Fate of hydrogen peroxide and bromate as by-products of AOP within MAR	Feifei Wang
Fluoride removal from groundwater by low-cost mineral-based adsorbents	Liangfu Wei
Bioremediation of Humic compounds from water using fungi	Mostafa Zahmatkesh

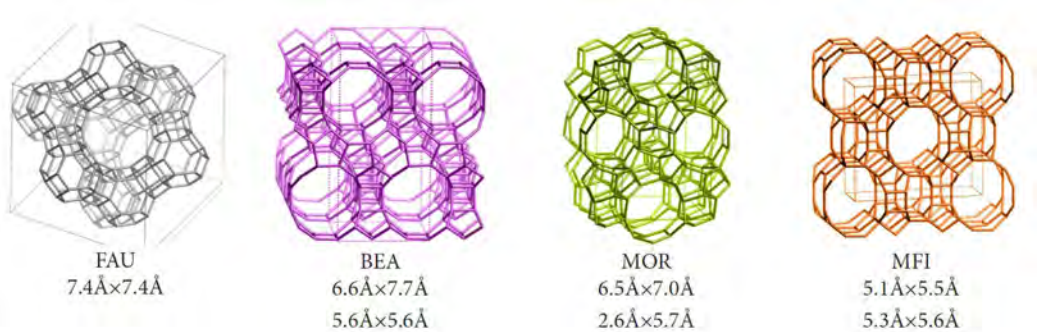


Figure 1. The name and pore opening size of 4 tested zeolite frameworks (From the database of International Zeolite Association)

Figure 2. Zeolite powders

Theme 2: Reclamation of Water, Energy, Resources

Theme leaders: Jules van Lier, Merle de Kreuk, Ralph Lindeboom & Luuk Rietveld

Our current and future legislation sets the boundary conditions for the functionalities and efficiencies of our (waste)water treatment systems. However, increasing attention is paid to the fact that wastewater treatment effluents and (waste)water treatment (side)products are also potential resources for domestic, industrial and agricultural processes. Valorisation and (re)use of these resources contribute to an increased sustainability of the water sector as well as to the foreseen future circular economy as opposed to our current consumptive linear economy. In Theme 2, research projects are being formulated that are focused on the recovery of both substances, such as water, nutrients, metals, and energy in the form of biogas, heat, electricity from waste streams and drinking water production. In this development, efficient treatment at acceptable costs plays a crucial role. Overarching institutes, such as the union of the water authorities and the association of drinking water companies have come to several agreements with the government to actually start implementing technologies focussed on the recovery and reuse of these resources. Examples are the 'Green Deal' and the reduction in 'Fossil Fuel Consumption' at municipal sewage treatment plants. At present, energy recovery in the from of biogas is being maximised, after which the energy is used in the treatment plant it self heading to energy neutrality, or biogas is being upgraded to 'green gas' for gas grid injection or production of automotive fuel. In addition to the conventional approach, novel decentralised sanitation systems are being scrutinised in which waste streams are separated in black water (faeces), yellow water (urine), grey water (bathing and kitchen) and rainwater. The feasibility of these systems is not fully clear, but the separated streams may facilitate the recovery of specific resources in an economic manner. For instance, in the past 10 years it became clear that the depleting phosphorus mines would force us to develop technologies that are specifically targeted to extract phosphorus from the waste streams. Finally, the water of the effluent of a wastewater treatment plant is increasingly regarded as a valuable resource for industry and agriculture. In the Netherlands, the largest share of our fresh water consumption is directed to the industry. Realising that sewage treatment plant effluents are a reliable water source, the production of industry water from sewage is receiving increasing interest. Moreover, sewage water reclamation for reuse will prevent the diffuse pollution of our surface waters, whereas competitive claims on fresh water sources are dealt with. Next to sewage treatment plant effluents, the direct extraction of fresh water from sewage in the so-called 'sewer mining approach' is being researched. Our current research is focused on technology development to make reclamation and recovery feasible, not only in the Dutch/Western context but also in the context of developing countries.

Research projects

Enhanced Enzymatic Anaerobic Fermentation of Organic Residues (EnzyFOR)	Steef de Valk
Mixing Characterisation for Enhanced Biomass Conversion Using CFD Modelling in Gas-mixed Anaerobic Digester	Peng Wei
Maximisation of energy recovery from sewage sludge with an innovative digestion process	Adrian Gonzalez
Re-designing the value and supply chain of water/minerals: a circular economy approach for the recovery of resources from saline impaired effluent (brine) generated by process industries - ZEROBRINE	Yasmina Bennani
Bio-methane production from urban organic matter (BeWaMet)	Maria Lousada Ferreira
Microbial community analysis of anaerobic bioreactors treating extreme wastewater	Marjet Oosterkamp
Steering Product Formation in High-Pressure Digestion Systems	Pamela Ceron Chafla
High-rate VFA production from industrial waste using the granular sludge process	Alexander Hendriks
Agriculture & Managed Aquifer Recharge (AGRIMAR): Drainage Water Recycling for Irrigation and Surface Water Quality Protection	Emiel Kruisdijk
From pollutant to power	Niels van Linden

Theme 3: Distribution & Discharge Networks

Theme leaders: Francois Clemens, Jeroen Langeveld & Jan Peter van der Hoek

Water infrastructures are a vital support of urban societal development: they supply clean drinking water and evacuate polluted wastewaters to protect public health and they drain storm waters to prevent flood damage and economic and societal disruption. Quality of service provided by water infrastructures is under threat as ageing processes degrade structural and hydraulic conditions. Leakages, blockage, pipe blockage and water quality deterioration are but a few of the detrimental effects ageing processes can generate. Developing better understanding of ageing processes is a prerequisite to be able to predict and prevent harmful effects. Early detection and warning is another essential strategy to cope with failures and to increase understanding of failure conditions. The focus of this research theme is on monitoring, detection and prediction of failures in water infrastructures by a combination of experimental research and probabilistic methods in support of quantitative risk analysis. We use urban labs to collect experimental data from real-life conditions and use data mining techniques linking multiple data sources to predict failures in support of risk analysis and prevention. Our aim is to provide society with effective techniques and strategies to use ageing water infrastructures while maintaining optimal functionality. In addition to the existing infrastructure, the group also researches novel sanitary systems to collect concentrated wastes with vacuum or pressurised systems, using small bore piping networks.

Research projects

Sewer Leak Detection, Quantification and Location	Bram Stegeman
Research on the mechanisms to prevent FOG layer formation in wastewater pump sumps	Alex Duinmeijer
Uncertainty propagation in water quality integrated catchment modeling	Antonio Manuel Moreno Rodenas
Performance evaluation of real time control in urban wastewater systems	Petra van Daal-Rombouts
Dutch urban drainage systems in transition: dealing with the uncertainties of a multi-actor context	Eva Nieuwenhuis
Sewer maintenance and hydraulic performance	Marco van Bijnen
FOULC: Fast Over-all scanning of Underground and Linear Constructions	Mathieu Lepot
Computational studies on the flow of domestic slurry	Dhruv Mehta
Effects of high spatial and temporal resolution of rainfall data on hydrological response	Elena Cristiano
Household water safety plan : A comprehensive approach in improving water quality at household level	Daniel Daniel
How to close the gap between the outcomes of the asset management analyses and the decision-making process in Waternet's drinking water section?	Geert-Jan van Heck
Use of multi-sensor condition assessment to support performance – based decision making in sewer asset management	Danai Konti
Formation and impact of recalcitrant and/or toxic compounds generated in Thermal Pressure Hydrolysis (TPH) of waste activate sludge	Javier Pavez Jara
Solids in sewer systems	Matthijs Rietveld
D-SHiT: Domestic Slurry Hydraulics in Transport systems	Adithya Thota Radhakrishnan
Quantifying Uncertainty in Integrated Catchment Studies (QUICS)	Franz Tscheikner
The urban water cycle as enabler for circular cities: New Urban Water Transport Systems	Ljiljana Zlatanovic

Theme 4: Global Sanitation, Safe Drinking Water & Health

Theme leaders: Doris van Halem, Ralph Lindeboom, Gertjan Medema

Safe water is essential to our society. Water systems should be designed, operated and maintained so they protect society against the spread of infectious disease agents, antimicrobial resistance and toxic chemicals. New issues emerge (antimicrobial resistance) and old issues continue to re-emerge in emergency settings (cholera). They emphasize the vulnerability of our densely populated society to infectious diseases and highlight the importance of knowledge about pathogens and antimicrobial resistance, their sources, fate and transport in water and effective treatment and management. In our rapidly urbanizing society, the water system is loaded with pathogens and resistant bacteria and we are need the water system for food production, supply of drinking water and recreation, so the pathways of exposure are many. The conventional exposure through drinking water is well under control, but other water uses (such as bathing or irrigation) are not. Moreover, we are inventing new concepts for dealing with water in our society (wastewater reuse, water in cities, etc.). These provide new niches for pathogens and new routes of exposure to pathogens.

In developing countries, the occurrence of water-borne diseases is still a major cause for the high mortality of infants. In fact, safe drinking water and improved sanitation are at present not available for every human being on earth. The Sustainable Development Agenda of the United Nations includes a goal (#6) to ensure access to water and sanitation for all. However, current knowledge on low-cost drinking water treatment and sanitation is often insufficient to provide safe water in remote or densely populated areas; either, because solutions do not fit within the targeted environment, or a scientific approach is not at hand. Therefore, the research focus lies on the development of novel treatment technologies for the rural and urban poor, explicitly taking into account the socio-economic conditions of the targeted environments. Specific topics of interest include stand-alone NF/RO membranes, arsenic removal, improved sanitation, multiple water use in mega-cities and energy/resource recovery coupled to sanitary service provision. Research projects with developing countries are designed and executed in close collaboration with local partners, such as the University of South Africa, Dhaka University (Bangladesh), Indian Institute of Technology (India), Ndejje University (Uganda) to stimulate co-creation and uptake of research output. This research theme has attracted a wide range of funders, including NUFFIC (NICHE, NFP), NWO WOTRO and Delft Global | Initiative, leading to an active group of PhD and postdoctoral researchers. In addition, a large number of BSc and MSc students travel abroad each year to support this research theme with their thesis work.

Research projects

Enhanced low-cost ceramic membrane filters for drinking water treatment	Mona Soliman & Katie Friedman
Small-scale piped water supply for ensuring safe water quality in arsenic-affected areas	Md. (Kajol) Annaduzzaman
Mobile crowd participation for water research (DELTAP)	Annemarie Mink
Removal of plant pathogens in agricultural tile drainage water by managed aquifer recharge for reuse in irrigation	Carina Eisfeld
Water quality assessment of small-scale managed aquifer recharge systems for drinking water provision in coastal Bangladesh	Muhammad Risalat Rafiq
Cellular slime moulds as regulators of bacterial numbers in faecal droppings and soil	Maja Taucer-Kapteijn
Sustainable freshwater supply in urbanizing Maputo, Mozambique	Andre Marques Arsenio
Mobile crowd participation as innovative methodology for water research	Annemarie Mink
Arsenic Removal for Drinking Water Treatment in Nicaraguan Rural Communities	Bayardo Jose Gonzalez Rodriguez
Potentials of sewage water reclamation for industrial use in Maputo, Mozambique	Noor Galamussen
Suspended sediments in a highly turbid river: implications for infiltration capacity in simulated bank filtration	Juan Pablo Guitierrez

Theme 4: Global Sanitation, Safe Drinking Water & Health

Theme leaders: Doris van Halem, Ralph Lindeboom, Gert-Jan Medema

Water reclamation for irrigation in Maputo, Mozambique	Celma Niquice Almerinda
Use of (an)aerobic DAF systems for efficient biomass retention in anaerobic sewage treatment reactors	Antonella Piaggio
Development and application of Multiplex qPCR for Antibiotic Resistance Genes in the Water Cycle	Gabriela Paulus

AdOx – a next generation adsorption-oxidation process for removal of CECs from municipal wastewater

Current wastewater treatment plants are designed to remove macro pollutants and nutrients, and are not equipped for removal of contaminants of emerging concern (CECs). Over the last years, posttreatment to remove CECs from treated wastewater has gained much attention. Especially adsorption by activated carbon, oxidation by ozonation, biodegradation and the combination of these technologies have been investigated. However, the costs and the environmental impact of the combined use of ozonation – activated carbon adsorption are high caused by the use of activated carbon and the thermal reactivation of exhausted carbon. In addition, these technologies are not selective for the removal of CECs, as also background organic matter, present in high concentrations in treated wastewater, is removed and reduces the efficiency of CECs' removal. The objective of this project is to realize an innovative adsorption-oxidation process for CECs' removal from municipal wastewater based on the use of zeolites as adsorbent and the chemical regeneration of exhausted zeolites with ozone.

In this research two break-through innovations are introduced:

- Zeolites will be tailor-made to be effective and efficient for non-selective CEC removal from wastewater treatment plant effluent, avoiding the adsorption of background organic matter;
- Chemical regeneration of the exhausted adsorbent (zeolites) with the use of ozone will result in cost savings and a lower environmental impact compared to the thermal reactivation of activated carbon. As ozone can be made available at the wastewater treatment facility applying the AdOx process, regeneration may be carried out on-site, minimizing transportation costs and minimizing CO2 emissions. With chemical regeneration of zeolites the oxidant only reacts with the adsorbed organic substances. As the background organic matter is not adsorbed by the zeolites, this potentially results in a low chemical use.

The combination of these two innovations will lead to an innovative treatment concept that is small in size, because of the short contact times; can be regenerated frequently, because of on-site generation of ozone; and does not require continuous dosage of ozone, thus not reacting with background organic matter and CECs in the full stream, avoiding the formation of by-products and metabolites.

The project will thus result in a next generation adsorption-oxidation process for CECs removal from municipal wastewater, characterized by high removal efficiencies for CECs, low costs and a low environmental impact.

Project partners:	Waternet, Waterschap De Dommel, Hoogheemraadschap Rijnland, Hoogheemraadschap Delfland, Witteveen + Bos, Xylem Water Sollutions Nederland BV
Funded by:	Stowa, KWR, Topsector Water, STW Partnership
Project coordinator:	Luuk Rietveld, Jan Peter van der Hoek, Bas Heijman
Period:	2018-2021

Local Treatment of Urban Sewage Streams for Healthy Reuse (LOTUSHR)

India's and the Global rapid urbanization keeps on putting more stress on fresh water supply, while simultaneously water resources are polluted by untreated wastewater discharge. Competitive claims on water lead to shortages in many sectors and increased health risks for the poor.

The final goal of the LOTUS-HR programme is to demonstrate a local modular technological approach to recover resources from domestic wastewater in a Megacity urban setting, while at the same time doing fundamental research. In this way, it will turn this, and possibly other Indian cities and their drains into profitable "mines" that produce clean water for households, irrigation and industry, as well as energy from the organic fraction of the drain, and nutrients for fertilizing (urban) agriculture. Eventually it will lead to a reduction in costly drinking water use for activities requiring lower quality water and is a showcase on how to reduce on-going degradation of the Yamuna river (Teri, 2016), by uncoupling this, and in the future, other heavily polluted drains.

Developing location-specific water reuse strategies does, however, require profound understanding of water quality and hydraulic fluctuations and available treatment technologies to be able to deliver cost-effectively safe, water for reuse for a variety of end-users. By combining technologies, that are cost-effective and generate water quality suitable for the specific end-users needs, rapid progress can be made. The rapid urbanization furthermore demands a scalable compact and modular design, such that future population growth is anticipated. This requires a broad consortium of government agencies, university research institutes, companies and end-users in both India and The Netherlands. In this project, 3 research lines are defined to bring all the required knowledge together and design a holistic water reuse approach together with industrial partners:

1. Reducing health risks of water reuse
2. Sewage pretreatment & energy recovery and
3. Sewage post-treatment and water & nutrients recovery

Technology has been chosen that is mature enough for rapid straightforward implementation, but has sufficient scope for fundamental water research.

Project partners:	Delft University of technology, UNESCO-IHE, NIOO-KNAW, Wageningen University, NEERI, TERI and IIT-Delhi, Nijhuis Industries, HWL, Drainblock, IPstar, Alterrra, RIKILT, Scholte holding B.V., JCI Industries, STOWA, LEAF, Kilian Water, Waste, Greenyard Horticulture Belgium NV and Saxion Hogescholen
Funded by:	NWO and DBT are supporting this programme with ~1.5 Meuro each, complemented with private co-funding
Project coordinator:	Steef de Valk, Ralph Lindeboom and Merle de Kreuk
Period:	2017-2022

Research grants 2017

Re-designing the value and supply chain of water and minerals: a circular economy approach for the recovery of resources from saline impaired effluent (brine) generated by process industries - ZEROBRINE

Project objectives

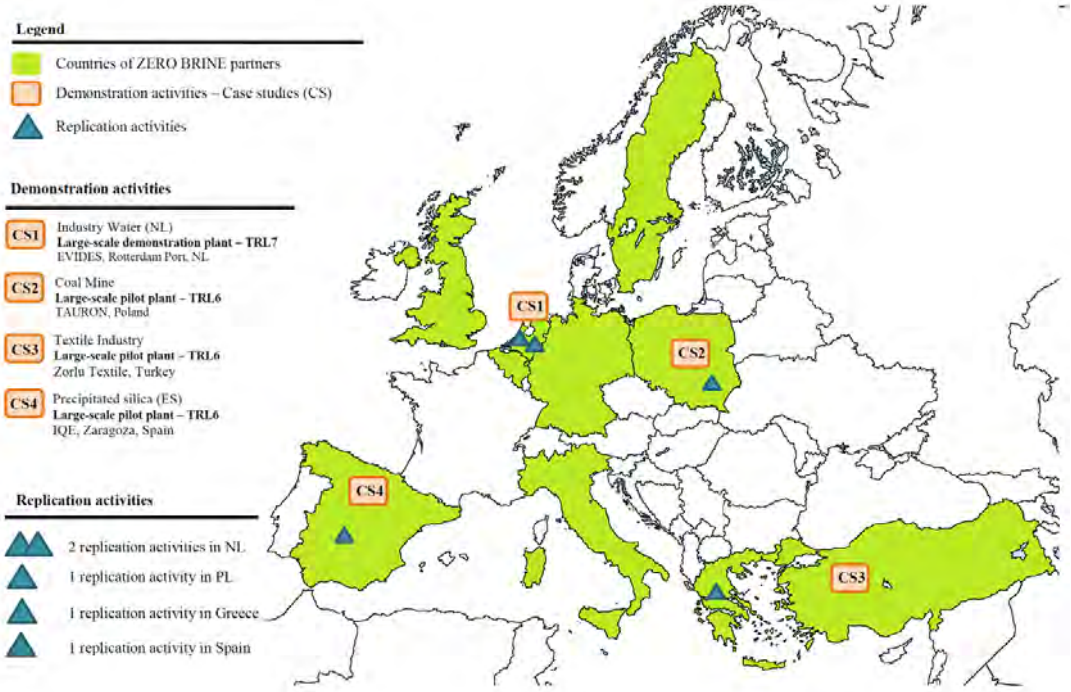
This project aims to facilitate the implementation of the Circular Economy package and the SPIRE Roadmap in various process industries by developing the necessary concepts, technological solutions and business models to re-design the value and supply chains of minerals (including magnesium) and water, while dealing with present organic compounds in a way that allows their subsequent recovery. This is achieved by demonstrating new configurations to recover these resources from saline impaired effluents (brines) generated by process industry, while eliminating wastewater discharge and minimizing environmental impact of industrial operations through brines.

Project outline

The project will bring together and integrate several existing and innovative technologies aiming to recover end-products of high quality and sufficient purity with good market value. It will be carried out by large Process Industries, SMEs with disruptive technologies and a Brine Consortium of technology suppliers across EU, while world-class research centers ensure strong scientific capacity and inter-disciplinary coordination to account for social, economic and environmental considerations, including LCA. A large scale demonstration plant will be developed in the Energy Port and Petrochemical cluster of Rotterdam Port, involving local large industries. The demo plant will be treat part of the brine effluents generated by the industry water supplier (EVIDES), while waste heat will be sourced by neighboring factories. The quality of the recovered end-products will be aimed to meet local market specifications. The involvement of representatives covering the whole supply chain will provide an excellent opportunity to showcase Circular Economy in Rotterdam Port, at large scale. Finally, three large-scale pilot plants will be developed in other process industries, providing the potential for immediate replication and uptake of the project results after its successful completion.

http://cordis.europa.eu/project/rcn/210177_en.html

Project partners:	TU Delft, NTUA, CTM, Witteveen & Bosch, UNIPA, SUT, FACSA, SEALEAU, WssTP, Revolve Media, UNIABDN, Lenntech, IVL, TYPSA, IQE, Evides Industriewater, TUBITAK, Huntsman, DLR, Europiren, ARVIA, ISPT
Funded by:	NWO Topsector Water (Delta and Water Technology)
Funded by:	Horizon H2020 Programme of the European Union
Project coordinator:	TU Delft
Period:	2017-2021



Project partners:	TU Delft, NTUA, CTM, Witteveen & Bosch, UNIPA, SUT, FACSA, SEALEAU, WssTP, Revolve Media, UNIABDN, Lenntech, IVL, TYPSA, IQE, Evides Industriewater, TUBITAK, Huntsman, DLR, Europiren, ARVIA, ISPT
Funded by:	NWO Topsector Water (Delta and Water Technology)
Funded by:	Horizon H2020 Programme of the European Union
Project coordinator:	TU Delft
Period:	2017-2021

Research grants 2017

Agriculture & Managed Aquifer Recharge (AGRIMAR): Drainage Water Recycling for Irrigation and Surface Water Quality Protection

Problem statement

Flourishing agricultural areas are essential for food security and economic growth of the cities they sustain. AGRIMAR presents an innovative and interdisciplinary approach to achieve sustainable agriculture under climate change in saline deltas of the Netherlands and elsewhere. AGRIMAR aims to provide solutions for two major agricultural water problems: (i) surface water carries plant pathogens causing diseases such as brown rot to (seed) potatoes and flower bulbs; its use for irrigation is prohibited or unwanted, and (ii) brackish groundwater and climate change further deteriorate fresh water availability.

MAR Technology & research gaps

AGRIMAR investigates managed aquifer recharge (MAR) technology that collects fresh tile drainage water for storage in aquifers, and retrieves it in summer for crop irrigation (see Figure 1 below). This nature based solution secures water availability, recycles water and nutrients, improves surface water quality, and yields economic gain as higher crop yields become possible during droughts when prices increase. However, major research gaps are the (predictive) understanding of the conditions and processes improving both chemical and microbiological water quality in MAR; Water and agricultural legislations require this research to minimize risks of groundwater pollution and pathogen outbreaks.

Whereas insight in physical water quantity aspects of MAR has recently made progress, (predictive) understanding of the biogeochemical and (micro)biological water quality aspects is limited, especially for this novel MAR application using abundant available TDW. The following research gaps are identified and addressed:

1. What conditions/processes control subsurface water treatment of pesticides and nutrients?
2. What conditions/processes control subsurface removal of specific plant pathogens (Ralstonia solanacearum, Dickeya solina, Pectobacterium carotovorum)?
3. What computational model simulates research gaps 1-2?
4. What is the optimal MAR design and operation applying the developed model?
5. What is the (acceptable) risk on MAR-induced crop disease?
6. What is the projected variation of MAR performance at regional-scale?

Research approach

Two PhD studies on water quality treatment (PhD student Emiel Kruisdijk) and pathogen risk assessment (PhD Student Carina Eisfeld) are conducted within a well-balanced multidisciplinary consortium. Our multi-scale approach entails batch and column experiments; field characterization, experiments (push-pull tests), and MAR pilot monitoring; and regional MAR assessment; with reactive transport modelling across scales. AGRIMAR front-runs MAR research; is first in investigating subsurface plant pathogen fate; and ground-breaking in quantitative microbial risk assessment of waterborne plant diseases. The AGRIMAR consortium finally valorises knowledge to support best practices, guidelines, and new legislation for regional implementation.

Project partners:	Delft University of Technology, Utrecht University, Wageningen University & Research (DLO), CNRS (France); Acacia Water, Delphy, Broere Beregening; NVWA; STOWA; Water Boards: Hoogheemraadschap Hollands Noorderkwartier, Waterschap Hunze en Aa's, Wetterskip Fryslân, Waterschap Noorderzijl-vest; NAO (Dutch potato organisation); LTO-Noord (agricultural and horticultural organisation the Netherlands); NAV (Dutch arable farmers union); KAVB (royal general bulb growers' association)
Funded by:	NWO Topsector Water (Delta and Water Technology)
Project coordinator:	Boris van Breukelen
Period:	2017-2021

PhD students are supervised by dr. Boris van Breukelen (daily supervisor of both PhD students), prof. dr. Gertjan Medema (promotor of Eisfeld), prof. dr. Pieter Stuyfzand (promotor of Kruisdijk), prof. dr. Jack Schijven (RIVM, Utrecht University; promotor of Eisfeld), and dr. Jan van der Wolf (DLO, Wageningen; expert in plant pathogens and supervisor of Eisfeld).

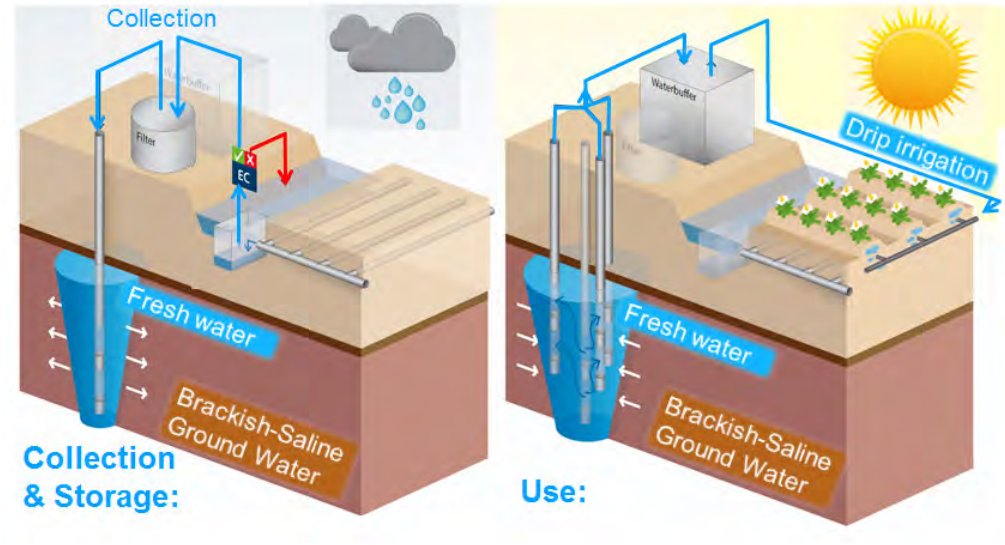


Figure 1: MAR technology: Tile drainage water (TDW) is collected and stored (left) in the underlying sandy aquifer confined by clay (the hydrogeological situation in the region). In times of water needs (summer), the stored water is used for irrigation (right). In this MAR example, one water well with two screens is used for injection, whereas three wells each with two screens are used for abstraction. Microbiological and chemical water quality is improved during aquifer passage.

Project partners:	Delft University of Technology, Utrecht University, Wageningen University & Research (DLO), CNRS (France); Acacia Water, Delphy, Broere Beregening; NVWA; STOWA; Water Boards: Hoogheemraadschap Hollands Noorderkwartier, Waterschap Hunze en Aa's, Wetterskip Fryslân, Waterschap Noorderzijl-vest; NAO (Dutch potato organisation); LTO-Noord (agricultural and horticultural organisation the Netherlands); NAV (Dutch arable farmers union); KAVB (royal general bulb growers' association)
Funded by:	NWO Topsector Water (Delta and Water Technology)
Project coordinator:	Boris van Breukelen
Period:	2017-2021

Research grants 2017

NUWTS - The new urban water transport infrastructure as enabler for resource recovery: New Urban Water Transport Systems

The urban water cycle is the carrier of water, nutrients and energy in the city and originates in its present form more than hundred years back. The carried water streams supply drinking water (production, transport and distribution), take care of sanitation (wastewater collection, treatment and disposal) and manage stormwater. Presently, the concept is linearly arranged rather focussing on protecting sources for drinking water and treating waste streams to enable discharge in the environment than on recovery and re-use of water, nutrients and energy. Historically the urban water cycle has grown into a complex infrastructure and an equally complex and scattered institutional arrangement. This essentially makes the connective infrastructure the weakest link in the cycle and hampers proper closing of the relevant cycles. A new paradigm for the urban water cycle in both technical and institutional lay-out is needed to turn it into an enabler for resource recovery and re-use. This research focuses on the technical part. The technical part holistically considers the chain of supply-use-waste of water, re-arranging it to facilitate resource recovery and re-use. Application of the research results will enable sustainable and resilient urban water cycles preserving the depleting resources while maintaining current and future high standards in comfort, public health and safety.

Project partners:	Topsector Water & Maritiem TKI Watertechnology, Amsterdam Institute of Advanced Metropolitan Solutions, Waternet, Brabant Water, Evides, Royal Haskoning DHV, Waterschap De Dommel, WML
Funded by:	all project partners
Project coordinator:	Jan Peter van der Hoek
Period:	2018-2019

AdOX

Project partners: Xylem, Witteveen + Bos, Waternet, Hoogheemraadschap Rijnland, Hoogheemraadschap Delfland
Funded by: NWO, KWR, STOWA, TKI-Water technologie
TU coordinator: Luuk Rietveld
Period: 2018-2022

Aspasia

Project partners: -
Funded by: NWO
TU coordinator: Merle de Kreuk
Period: 2016-2021

AMBR for water reclamation

Project partners: Biothane-Veolia
Funded by: Biothane-Veolia
TU coordinator: Jules van Lier
Period: 2015-2020

Biogas-SOFC for the rural poor

Project partners: 3Me, Simgas B.V.
Funded by: Delft Global Initiative
TU coordinator: Ralph Lindeboom/PV Aravind/Henri Spanjers/Jules van Lier
Period: 2018-2022

Ceramic nanofiltration as the key step for sustainable wastewater treatment with reuse of water, energy and nutrients

Project partners: TU Delft, Evides Industriewater, Logisticon
Funded by: STW-TKI
TU coordinator: Bas Heijman
Period: 2014-2018

Cracking barriers in sludge digestion

Project partners: RHDHV and STOWA
Funded by: STOWA
TU coordinator: Merle de Kreuk
Period: 2016-2021

DELTAP (an integrative approach for smart small-scale piped water supply in the Ganges-Brahmaputra-Meghna Delta)

Project partners: Studio Bereikbaar, Schlumberger, Evides, Precious Plastics, Dhaka University, AN College, EPRC, Max Foundation, UNICEF India, PRACTICA
Funded by: NWO WOTRO Urbanising Deltas of the World 2
TU coordinator: Doris van Halem
Period: 2016-2021

Current research grants

Domestic Slurry Transportability

Project partners: TU Delft, Deltares
Funded by: STW Watertech2013, Deltares, STOWA/Rioned, Waternet, Waterschap Zuiderzeeland, XYLEM BV Grontmij BV, Desah BV
TU coordinator: Ivo Pothof
Period: 2014-2018

Enhanced low-cost ceramic membrane filters for drinking water treatment

Project partners: TU Delft's ChemE and Industrial Design Engineering. Research institutes, NGOs and the Ministry of Water in Nicaragua
Funded by: Delft Global Initiative
TU coordinator: Doris van Halem
Period: 2016-2020

FixAs

Project partners: Vitens, Brabant Water, Hatenboer Water, RH-DHV, Dunea, Pidpa, Evides, RIVM, TU Delft
Funded by: STWatertechnology
TU coordinator: Doris van Halem
Period: 2014-2019

Fungi - Increasing the utilization of organic waste and low value feeds with the help of lignin degrading fungi

Project partners: Wageningen University and Research Center
Funded by: STW - Waste to Resource
TU coordinator: Henri Spanjers
Period: 2012-2017

High-rate VFA production from industrial waste using the granular sludge process

Project partners: Paques, TU Delft
Funded by: STW, Partnership program: "Partnership Paques - The VFA Platform"
TU coordinator: Merle de Kreuk
Period: 2013-2017

Hydraulic modelling of liquid-solid fluidisation in drinking water treatment processes

Project partners: TU Delft, Waternet
Funded by: Waternet
TU coordinator: Jan Peter van der Hoek
Period: 2016-2020

Integration and optimization of water, energy and material flows to achieve sustainable urban solutions

Project partners: TU Delft, Amsterdam Intitute of Advanced Metropolitan Solutions (AMS)
Funded by: TU Delft, Amsterdam Intitute of Advanced Metropolitan Solutions (AMS)
TU coordinator: Jan Peter van der Hoek
Period: 2016–2018

LOTUS-HR

Project partners: Delft University of technology, UNESCO-IHE, NIOO-KNAW, Wageningen University, NEERI, TERI and IIT-Delhi, Nijhuis Industries, HWL, Drainblock, IPstar, Alterrra, RIKILT, Scholte holding B.V., JCI Industries, STOWA, LEAF, Kilian Water, Waste, Greenyard Horticulture Belgium NV
Funded by: NWO-STW (including in-cash cofounding by companies)
TU coordinator: Merle de Kreuk/Ralph Lindeboom
Period: 2017-2022

Microbiologically safe drinking water

Project partners: RCEES (China), Oasen, TU Delft
Funded by: NWO
TU coordinator: Gertjan Medema
Period: 2014-2017

NICHE-KEN 212

Project partners: Pwani University Kenia, Q-point, K.I.Samen, DLV Dier, Egerton University
Funded by: Nuffic
TU coordinator: Bas Heijman
Period: 2015-2018

OLO-Micro

Project partners: VU, Deltares, STOWA
Funded by: STOWA, TKI-Watertechnologie
TU coordinator: Merle de Kreuk
Period: 2016-2021

PEOPLE

Project partners: Universiti Terengganu Malaysia
Funded by: Delft Global Initiative
TU coordinator: Ralph Lindeboom/Henri Spanjers/Jules van Lier
Period: 2018-2022

Pilot Research Themista-Ephyra combination at WWTP Nieuwgraaf

Project partners: RHDHV (penvoerder), Logisticon Water Treatment B.V., Waterschap Rijn en IJsel
Funded by: RVO - Hernieuwbare Energie
TU coordinator: Merle de Kreuk
Period: 2017-2019

Propopi - Towards Pro-Poor Private Investments in water supply in Kota Bandung

Project partners: Vitens-Evides-International (VEI), Simavi, PDAM-Bandung
Funded by: RVO
TU coordinator: Bas Heijman
Period: 2014-2019

Current research grants

PS Drink – Priority-setting System to assess emerging risks for safe Drinking water supply

Project partners: TU Delft, Universiteit Utrecht – Institute for Risk Assessment Sciences, RIVM – National Institute for Public Health and the Environment
Funded by: RIVM – National Institute for Public Health and the Environment
TU coordinator: Jan Peter van der Hoek
Period: 2016 - 2020

Quantifying Uncertainty in Integrated Catchment Studies (QUICS)

Project partners: University of Sheffield, University of Bristol, TU Delft, CH2M Hill, Wageningen University, Justus-Liebig-University of Giessen, University of Coimbra, Public Research Centre Henri Tudor, Eawag, Aquafin, Waterways srl, Ruhr-Universitat Bochum, Witteveen+Bos, Universite Laval, CTGA
Funded by: EU funded FP7 Marie Curie Initial Training Network (ITN)
TU coordinator: Jeroen Langeveld/Marie-Claire ten Veldhuis
Period: 2014-2018

SewerSense - Multi-sensor condition assessment for sewer asset management

Project partners: TU Delft, Leiden University
Funded by: Technologiestichting STW
TU coordinator: Lisa Scholten
Period: 2016-2020

Side reactions during Thermal Pressure Hydrolysis

Project partners: STOWA, Paques BV, Waterschappen De Dommel, Vechtstromen, Vallei & Veluwe, Waterbedrijf Limburg
Funded by: STOWA
TU coordinator: Merle de Kreuk
Period: 2017-2021

Super-W

Project partners: UGent, UPC (Barcelona), RWTH Aachen, UCT (Prague)
Funded by: Horizon 2020
TU coordinator: Jules van Lier/Ralph Lindeboom
Period: 2016-2019

Sustainable fresh water and energy production for the Island of Johnny Cay (Colombia)

Project partners: Solteq Energy, Lenntech, Coralina, TU Delft
Funded by: Transition Facility 2014, ODA subsidy, Education & Capacity building
TU coordinator: Bas Heijman
Period: 2014-2018

Sustainable fresh water supply in urbanizing Maputo, Mozambique

Project partners: TU Delft, UNESCO-IHE, Universidade Eduardo Mondlane, Vitens-Evides-International, FIPAG, Royal HaskoningDHV, Waterbedrijf Limburg, IRC
Funded by: NWO - WOTRO
TU coordinator: Luuk Rietveld
Period: 2014-2018

TAPES - Transnational Action Program on Emerging Substances

Project partners: TU Delft, Waternet, Waterschap De Dommel, KWR, DVGW, Erftverband, VMW, University of Edinburgh FNHW, VITO
Funded by: Interreg IVB NWE
TU coordinator: Jan Peter van der Hoek
Period: 2013-2018

Thermal Energy Recovery from Drinking Water

Project partners: TU Delft, Waternet
Funded by: Waternet, Topsector Water TKI Watertechnology
TU coordinator: Jan Peter van der Hoek
Period: 2015-2019

VEWIN - Improving and broadening of the Dutch drinking water benchmark

Project partners: Vewin, TU Delft (Faculty TBM), Dutch drinking water companies
Funded by: Vewin (Association of Dutch water companies), PWN, Oasen, Waternet
TU coordinator: Jan Peter van der Hoek
Period: 2013-2018

VIDI - Unravelling mechanisms underlying negative effects from complex contaminations in granular sludge

Project partners: RHDHV, TU Delft (AS-EBT)
Funded by: NWO
TU coordinator: Merle de Kreuk
Period: 2016-2021

Virus removal with low-cost ceramic membranes

Project partners: DGI
Funded by: Delft Global Initiative
TU coordinator: Doris van Halem
Period: 2016-2020

Zeolites as novel adsorbent in water treatment (Zeotreat)

Project partners: Oasen, Evides, PWN, HWL, TU Delft
Funded by: TKI Watertechnolgie
TU coordinator: Bas Heijman
Period: 2015-2018

ZERO BRINE – Recovery of resources from saline impaired effluent (brine) generated by process industries

Project partners: NTUA, CTM, Witteveen & Bos, UNIPA, SUT, FACSA, SEALEAU, WssTP, Revolve Media, UNIABDN, LENNECH, IVL, TYPSA, IQE, EVIDES, TUBITAK, HUNTSMAN, DLR, Europiren, ARVIA, ISPT
Funded by: Horizon H2020
TU coordinator: Henri Spanjers, Luuk Rietveld
Period: 2017-2021

Sewerage and urban drainage research program

The Dutch urban drainage sector will be facing a number of significant challenges in the next decade. The sector has to deal with new issues such as climate change and priority pollutants, whilst at the same time there is a societal pressure on cutting cost levels, reducing CO2 emissions and nutrient recovery. In addition, there is an increasing lack of highly qualified personnel. This urged the sector to decide to support the sewerage chair at Delft University of Technology, with the following objectives:

- an increase in the number of MSc students;
- an increase in the number of PhD students;
- fundamental research addressing the observe challenges.

Research program

The research program comprises 4 themes, therewith covering the main challenges of the sewerage and urban drainage sector.

Theme 1 Asset management

In the Netherlands, each year € 600 million is spent on asset management or, more specifically, on sewer renovation and rehabilitation. Recent research has demonstrated that visual sewer inspections are associated with significant uncertainties and limited reproducibility. As these inspections are the main source of information used in sewer rehabilitation projects, these annual investments lack a profound basis. The research within this theme focuses on alternative sources of information (or ways of working) in order to organize the asset management in such a way that sewer system performance (serviceability) will be maintained at the desired level. Laser scanning and core sampling have been tested as alternative technology, verified by full scale testing of pipe strength. In addition, a serious game has been developed to analyse the role of information quality and the influence of interactions between stakeholders. Nikola Stanic M.Sc and ir. Wouter van Riel both successfully defended their PhD thesis in 2016. Their work is now succeeded by Eva Nieuwenhuis who started at the beginning of 2017. In addition, a vacancy has been opened for a PhD student working on ageing of plastic pipes.

Theme 2. Operation and maintenance

Operation and maintenance in sewer systems is driven by local criteria, e.g. gully pots are typically cleaned once a year, irrespective of the type of sewer system (combined or storm sewer) and irrespective of the impact on sewer system performance. The research projects within this theme will provide knowledge on the relation between the operation and maintenance strategy applied and overall system performance. The main focus will be on the front end of sewerage, being house connections and gully pots. This topic was dealt with by ir. Johan Post, who defended his PhD thesis in 2016. Matthijs Rietveld started November 1st, 2016 with follow up research on gully pot performance. In addition, Marco van Bijnen is doing research on the relation between the condition of the sewer system in terms of root intrusion and sediment beds and hydraulic performance.

Theme 3. Dynamics of sewer systems

Continuous monitoring of hydraulics and wastewater quality is applied at a number of locations in the Netherlands. These data open an enormous opportunity to study the dynamics of sewer systems itself and in relation with wwtps and receiving waters and to enhance the knowledge on in sewer processes. dr.ir. Petra van Daal-Rombouts successfully defended her PhD thesis in 2017 on this topic, using the extensive database of Waterboard De Dommel and closely cooperating with the Waterboard. A vacancy has been opened to continue this work. Antonio Moreno Rodenas is working on the uncertainties in integrated modelling.

Theme 4. Sustainable urban water cycle

Theme 4 focuses on research on new concepts for the urban water cycle enabling energy recovery and reuse of materials. The main issue left to be dealt with is the conveyance of black water. Adithya Thota Radhakrishnan, M.Sc is the Phd student working on this theme within the STW funded project Domestic Slurry Transport.The project is strengthened with the postdoc Dr. Ir. Dhruv Mehta, specialised in CFD modeling.

Organization

The research program is funded by partners from the Dutch urban drainage sector. Each contributor to the research program participates in this Program Committee. The Program Committee advises the sewerage chair on the composition of the research program. In addition, the members have the privilege to actively participate in the supervisory committees of the research projects within the program and to provide case studies.

The partners of the research program are (in alphabetical

order): ARCADIS, Deltares, Gemeente Almere, Gemeente Arnhem, Gemeente Breda, Gemeente 's-Gravenhage, Gemeentewerken Rotterdam, Gemeente Utrecht, GMB Rioleringstechnieken, KWR, Royal HaskoningDHV, Stichting RIONED, STOWA, Sweco, Tauw, Vandervalk & De Groot, Vitens, Waterboard De Dommel, Waternet en Witteveen+Bos.

The urban drainage research program started in 2010 with a 5-year budget. Given the success of the program, in 2015 all partners decided to prolonged their participation until 2020, thus creating a solid base for the further development of this challenging research field.

dr.ir. J.G. Langeveld (Jeroen)
Director Kennisprogramma Urban Drainage
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Evides IW and TU Delft: Update on cooperation on "Innovations in the Industrial Waterloop"

Evides IW

Next to drinking water, Evides water company is one of the largest suppliers of water & water services to the industry in the Netherlands. Evides Industry Water (EIW) is acting as a full-service water partner to the industry, providing a utility portfolio compiling: industrial water treatment (process and demineralised water), waste water treatment and integrated treatment (water reuse). In addition EIW designs, finances and operates their custom-made water treatment plants. EIW is operating water plants for all major (petro)chemical multinational companies and makes use of both proven technology as well as innovative new process designs.

Water Reuse

One of the mayor targets of EIW is to establish water reuse and recycling. Closing the water loop has a positive effect on the environment, as it reduces the industrial use of precious water resources, such as groundwater and drinking water. Effluent water coming from waste water treatment plants is a potential feedstock and suited to apply as a source for the production of process water. EIW has excellent experiences with the recycling of treated wastewater for the production of process water in the Netherlands, for example on the Dow Chemical Terneuzen site (reusing both industrial as well as municipal effluent to serve as process & demin water). The coming years the water cycle of the site and its Terneuzen surroundings will even be further closed. This development is supported by the results of the EU FP7 E4Water project (completed 2016): "Towards a paradigm shift in the chemical industry to create a breakthrough in industrial water treatment by enhanced reuse, recycling and valorization of complex wastewater". For this case and other examples, see: www.evides.nl/en/industrial.

TUD-EIW Cooperation

In 2011 TUDelft CiTG and Evides signed a exclusive long-term cooperation aiming at a research program focused on the industrial water utility. The research program is focusing on fundamental and applied research into the water production, waste water treatment, reuse & zero discharge technologies for application in the industry to compile know-how to optimize the industrial water loop and reduce its water footprint.

The activities resulted in the establishment of indusrie water as a new focal point in our research & education activities. We are convinced that the enhancement of structural knowledge about the improvement of existing and development of new technologies will add to the attractiveness of the water technology sector for young, well-educated professionals.

The cooperation will formulate MSc and PhD research projects to develop technologies & solutions with superior performance in relation to (i) reduced energy footprint, (ii) maximized sustainable production of re-usable water and brine (concentrates) conversion (iii) operational stability over substantial periods of time at lowest operational expenses.

At present 2 PhD students are working in the framework of this cooperation. Julian Munoz is researching the potentials for bio-treatment under extreme conditions, characterized by refractory/toxic compounds, high salinity and high temperature. Franca Kramer is working on the use of ceramic nanofiltration for direct wastewater treatment and water reuse. In 2015 David Moed defended his PhD thesis “Organic Contaminants and Treatment Chemicals in Steam-Water Cycles”. In addition to the PhD students, several MSc students have performed their thesis research in the framework of this cooperation.

Dunewater in the 21th century – Strategic cooperation Dunea Duin en Water – TUD in the field of drinking water research

On 9 October 2013 Dunea drinking water company and the Faculty of Civil Engineering and Geosciences signed a 4-year contract for strategic cooperation in the field of drinking water research. The cooperation covers the focuses on four specific subjects:

- The effect of advanced oxidation processes on managed aquifer recharge during the removal of organic micro pollutants from drinking water.
- Research into the effect of dune infiltration on the arsenic concentration, and research into methods to reduce the increase during dune infiltration and methods into removal of arsenic from drinking water.
- Research into the effect of flushing the drinking water distribution system, with and without the use of chlorine, on microbiological contamination.
- Preliminary research into the extension of the lifetime of the transport system “Afgedamde Maas”.

Dunea Duin en Water produces and distributes drinking water for over 1.2 million customers in the province Zuid-Holland. The dunes near Scheveningen, Katwijk and Monster are the centre of Dunea’s treatment process, which enable the production of safe and reliable drinking water. Surface water from the Afgedamde Maas is Dunea’s main water source. After pretreatment this water is transported to the dune area and infiltrated.

TISCA: Cooperation Programme *Technology Innovation for Sewer Condition Assessment*

Sewer systems and wastewater transport systems are vital parts of the urban wastewater infrastructure. In the Netherlands, like in many other countries in Europe, over 90 % of the population is served by the urban wastewater infrastructure. Managing these assets is one of the main challenges for the municipalities and water boards that own and operate these systems. In order to further develop and optimize asset management for urban wastewater infrastructures, it is essential to have sufficiently reliable information about the current status of the assets.

During the last decades, CCTV inspection has been the main source of information for the assessment of the status of gravity sewers. For rising mains, generally having less capabilities to enable easy access during operation, the development of dedicated (non-destructive) inspection techniques is still at an early stage of development.

Recent research at Delft University has demonstrated that the information obtained by CCTV inspections is associated with high uncertainties and that this information is by definition limited to failure mechanisms accompanied by visible damage within the pipe. In order to overcome these limitations, other methods, such as core sampling, laser profiling, tilt meters, have been tested as part of the 'Kennisprogramma Urban Drainage (KPUD) at Delft University of Technology. In order to speed up the process of technology development for sewer inspection, the KPUD, RIONED and STOWA have set up the TISCA programme in cooperation with STW.

The programme budget amounts to a maximum of € 3 million. The financial resources for this programme come from Technology Foundation STW (€ 1,5 million), KPUD (€ 0,75 million), RIONED (€ 0,5 million) and STOWA (€ 0,25 million).

The researchers in TISCA will cooperate very closely with the researchers in the KPUD. Part of the programme are monthly TISCA days, which will comprise colloquia to exchange ideas and results, working sessions on specific topics, (in-)formal meetings with fellow PhD students and meetings with the user groups and user committees.

The main focus of TISCA is on solutions for a coherent methodology for the (partly in-situ) condition assessment of sewers. Or, in other words, the next generation of sewer inspection technologies. In total 5 research projects have been granted as part of the TISCA program, two of which have been granted to Jeroen Langeveld and one to Lisa Scholten.

Lisa Scholten is responsible for the project SewerSense – Multi-sensor condition assessment for sewer asset management.

This project aims at four aspects of condition assessment: 1) data acquisition, 2) validation of inspection technology, 3) a framework to assess the impacts of assessed sewer condition and 4) prediction models. TU Delft (Danai Konti) and Leiden University will develop automated defect detection and classification diagnostics for CCTV and promising novel inspection techniques, such as laser profiling and stereo vision camera's. The framework will be adjusted to make a direct relation between condition assessment and expected remaining service life.

Jeroen Langeveld is responsible for the projects FOULC: Fast Over-all scanning of Underground and Linear Constructions and Geo-Electrical Sewer Leak Detection, Quantification and Location.

The FOULC project, performed by post-Doc Matthieu Lepot, aims at obtaining information on some of the main functionalities of a sewer using non-intrusive techniques. Several sensors will be positioned on a hoovercraft drone, that can move in partly filled pipes. Information can be gathered in-situ to quantify the actual hydraulic capacity, the presence and the amount of sediments and biofilm, detailed 3D information on the actual sewer geometry and information on the locations where and the amount of infiltrating groundwater. The development of this sensor platform is dedicated to sewer systems, but the application is not limited to sewers since it can also be applied for obtaining information on hydraulic capacity of and the presence of sediments in ditches and canals.

The leak detection project addresses leakage, which is one of main causes of failures of pressure mains and the nightmare of sewer operators in areas where ground water is used as a source for drinking water production. Leaks occur due to ageing of our underground wastewater infrastructure, leakage of sewers and pressure mains and

subsequent infiltration or exfiltration (I/E) is becoming an increasingly important issue. In order to be able to deal with leakage, sewer operators need to be able to detect, quantify and locate I/E. The project focusses on exploring the potential of geo-electrical monitoring: Self Potential monitoring and Electrical Resistivity Tomography in the soil and Focused Electrode Leak Location from within the sewer to detect, quantify and locate leaks. Bram Stegeman works on this project as part of his PhD.

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Strategic research collaboration HWL

TU Delft cooperates closely with Het Waterlaboratorium (an institute for water research). A partnership agreement was signed in March 2010. Het Waterlaboratorium makes funding available for innovative research into the detection and removal of organic micro-pollutants in the urban water cycle.

Cooperation brings benefits for both parties. Het Waterlaboratorium benefits from easier access to knowledge and research at the university, while TU Delft gains access to the expertise of Het Waterlaboratorium in the field of detecting and identifying organic micro-pollutants. Research themes include the presence and behaviour of priority substances and emerging substances within the urban water cycle, the behaviour and selective removal of natural organic material, and the quality of water in distribution networks. This research is carried out both by staff at Het Waterlaboratorium and by students, PhD researchers and postdoc researchers.

Het Waterlaboratorium specialises in high-quality advice and research relating to water. The laboratory's expertise is available for all those who want to achieve perfect water quality. Its customers are companies that supply drinking water, but also include hospitals and health institutions, the off-shore sector, municipal government, businesses and sports institutions.

Waternet and TU Delft investigate innovation in water cycle

In 2008 Waternet and the faculty of Civil Engineering and Geosciences of TU Delft signed a strategic collaboration contract. The collaboration focuses on research in innovation in the water cycle, particularly on the sectors drinking water, wastewater and water systems.

Waternet is the first water cycle company in the Netherlands. Waternet takes care of the entire water cycle: from drinking water, sewerage and treatment of waste water to discharge of waste water effluent into surface water. Furthermore, maintenance of ditches, lakes and ponds, advice during high ground water levels and dike supervision are part of the tasks of Waternet. Waternet has been assigned to perform these tasks by waterboard Amstel, Gooi en Vecht and the city of Amsterdam. With Waternet's ambition to shape the innovation in the water cycle and the expertise of TU Delft in the sectors of the water cycle, this collaboration is a logical next step.

The duration of the collaboration was, in first instance, four years and still continues. The collaboration consists of MSc work of TU Delft students at Waternet, PhD research, post doc, and the use of the pilot installation at Leiduin as a "water cycle laboratory". Prof.dr.ir. J.P. van der Hoek of Waternet is appointed as a part-time professor at TU Delft.

Waternet Watercyclus Innovatie Prijs 2017

Voor de vijfde keer werd op de Vakantiecursus Delft, vrijdag 13 januari 2017, de Waternet Watercyclus Innovatieprijs uitgereikt. Dat is een tweejaarlijkse prijs voor excellent onderzoek op het gebied van de stedelijke watercyclus. Het gaat dan om afgerond promotie-onderzoek over de afgelopen twee jaar, in dit geval de periode 2015-2016.

De jury, bestaande uit Prof. Luuk Rietveld en Prof. Jan Peter van der Hoek, hanteerde drie criteria:

1. De wetenschappelijke kwaliteit van het onderzoek
2. Het praktisch nut van het resultaat
3. De doorbraak in de stedelijke watercyclus

De winnaars 2017

- De derde prijs (€ 2.000) ging naar naar Cheryl Bertelkamp voor haar proefschrift "Organic micropollutant removal during riverbank filtration": organische microverontreinigingen, en vooral medicijnen, zijn een probleem in de watercyclus. Cheryl heeft aangetoond dat oeverfiltratie, een techniek toegepast in de drinkwaterbereiding, een groot aantal van die stoffen kan verwijderen.
- De tweede prijs (€ 3.000) ging naar Evren Ersahin voor zijn proefschrift "Application of dynamic membranes in anaerobic membrane bioreactor systems": Evren heeft het concept van dynamische filtratie in een anaerobe membraanbioreactor geïntroduceerd. Uiteindelijk lijkt daarmee op kosten effectieve wijze nutriënten-rijk pathogeen vrij irrigatie water gemaakt te worden. Dat draagt bij aan hergebruik van afvalwater in de watercyclus en is een mooie cross-over tussen de watersector en de landbouwsector.
- De eerste prijs (€ 5.000) ging naar Tommaso Lotti voor zijn proefschrift "Developing Anammox for mainstream municipal wastewater treatment". Tommaso heeft aangetoond dat, door introductie van Anammox op rwzi's, rwzi' netto energie-producerend zijn te maken. Dat levert een grote bijdrage aan het energie- en klimaatneutraal maken van de watercyclus.

Prof. J.P. van der Hoek appointed as Principal Investigator at AMS -Postdoc position available for 1 year

In September 2016 the board of the Amsterdam Institute for Advanced Metropolitan Solutions (AMS) has appointed Professor Jan Peter van der Hoek as Principal Investigator for a period of two years.

AMS is the institute in Amsterdam, founded in 2014 and supported by the City of Amsterdam, in which Technische Universiteit Delft, Wageningen University Research and Massachusetts Institute of Technology, together with partners from the public and private sector, work on three specific themes: Circular City – Vital City – Connected City. As AMS Principle Investigator he received a TU Delft strategic research support grant for the project "Integration and optimization of water, energy and material flows to achieve sustainable urban solutions". The fellowship consists of the salary costs for one post-doctoral researcher for one year, starting as soon as possible, complemented with a budget for travel costs.

Vidi for Merle de Kreuk: the effects of suspended solids on granular sludge

NWO has awarded 800,000 euros to ten TU Delft researchers. They include Merle de Kreuk and her research into the effects of suspended solids on granular sludge. Vidis are awarded to experienced researchers who have conducted a number of years of successful research after receiving their PhD. Vidi grants enable researchers to conduct five years of research and develop their own, innovative research lines.

Merle on this subject: 'I want to see and comprehend what bacteria do to the colloidal fraction and decomposable particles in granular systems, in (an)aerobic processes. I want to unravel the granules and their components - cells, polymers, enzymes. If fundamental research enables you to understand exactly what is going on, the opportunity exists that you may be able to devise different, smarter processes.'

Elected Simon Stevin Fellow, finalist for the European Inventor Award, awarded the Jaap van der Graaf Prize... Before the awarding of the Vidi Merle de Kreuk had already been honoured for her prior work on the Nereda waste water treatment system. This technology enables the treatment of domestic waste water using 25% less energy and taking up 75% less space.

The fact that aerobic bacteria ('requiring oxygen') are able to convert the carbon and nitrates from sewage water into CO2 and nitrogen gas and that these bacteria can grow in granules, making it easier to separate biomass from the purified water, had already been proven in the laboratory during her PhD research, where after the road to full scale was free. Aerobic granular sludge developed during the past decade to a proven and widely applied technology.

However, there are still fundamental questions on the development and behaviour of aerobic granules, and on the conversion kinetics with aerobic granular sludge. This vidi project aims at developing scientific methods, to study fundamental mechanisms underlying possible negative effects of complex contaminants on aerobic granular sludge morphology and performance. Furthermore, we will aim to increase fundamental knowledge on these mechanisms and use that knowledge to develop models describing formation, stability and activity of granular sludge. These models can be used for both scientific research and improvements in process design.

Cees Boeter award 2017

At the end of the academic year, the Cees Boeter award is given to the student who wrote the best BSc thesis of the year.

Applying criteria of academic quality, report consistency, grade, and balance of knowledge and skills, has yielded this year, our nominees Jochem Caspers, Valerie Demetriades and Mizzi van der Ven with Magali Ponds.

This year's winner is Jochem Caspers. Jochem has worked on the Flux-Variance-DTS method, which measures spatial evaporation at the ground surface directly and is an application of distributed temperature sensing.

Jaap van der Graaf award 2017

The Jaap van der Graaf Award was presented to Heleen de Fooij MSc on 13 January 2017, during the 69th Drinking Water and Waste water Symposium ('Vakantiecursus') at Delft University of Technology. This annual prize is given in recognition of the best English-language article about waste water treatment, written by a student or researcher and published during the preceding year. The winning article, by De Fooij and co-authors, was published in the journal 'Resources, Conservation and Recycling' under the title 'Wastewater as a resource: Strategies to recover resources from Amsterdam's wastewater'.
An independent jury considered 39 entries, all of high quality. The names of the three finalists and the overall winner were announced during the Symposium. The jury members based their deliberations on five key criteria: societal relevance, innovation, practicality (with a view to implementation in the short to medium term), scientific content and language. Based on these criteria, a shortlist of 7 names was composed. The jury chose the article by Heleen de Fooij as overall winner by virtue of the suggested adaptive policy measures it contained. In the words of De Fooij: 'In a world where resources are becoming increasingly rare, recovery and reuse is becoming more profitable. Adaptive measures, including the interaction between them, are suitable for dealing with an array of uncertainties and possibilities.'

Heleen de Fooij obtained her Master's degree at the University of Twente in Civil Engineering and Management, with a specialization in Water Engineering and Management, which focuses on the behavior and control of water systems. De Fooij currently follows a traineeship in secondary education, working as a math teacher.

The Jaap van der Graaf Award is sponsored by consultancy and engineering firm Witteveen+Bos, which created the award in 2009 to mark the retirement of Jaap van der Graaf as Professor of Waste water treatment at the Faculty of Civil Engineering at TU Delft. Prof. van der Graaf has close ties with the Deventer-based company, having been its managing director from 1988 to 2003. The prize is awarded annually and the winner receives five thousand euros and a glass trophy.

Research exchange

Guest researchers

Hongbo Liu

I am Hongbo Liu, a teacher of Jiangnan University in China. Very lucky, I could come to the TUDelft and participate in some research work as a visiting scholar.
In the following days, in the section of Sanitary Engineering, I will start my work under the supervision of Prof. Jules van Lier and Prof. Merle de Kreuk. Although the specific subject for my research has not yet been confirmed, but should be confirmed soon, the research direction will focus on urban sludge anaerobic fermentation for fatty acids and biogas productions.

Bensheng Su

I am Bensheng Su, I come from Beijing University of Chemical Technology, China. Main research: biological treatment technologies mainly including advance anaerobic technology and aerobic granular sludge in industrial sewage and municipal sewage.
Currently, I am working at TUDelft as a visiting scholar from 9/12/2016 to 1/10/2018. My current project is focussing on anaerobic digestion of sludge, how to improve the hydrolysis rate and get more methane.

Paula Paulo

Paula comes from Brazil where she is associate professor at the Federal University of Mato Grosso do Sul (UFMS), located in Campo Grande-MS. Her project deals with risk assessment for the safe reuse of greywater, where she is proposing a semi-quantitative approach inspired by the WHO safety sanitation planning for both microbial and chemical risk assessment. The main objective is to build a conceptual a model, serving as a tool to assist in the decision making process for household/decentralised sanitation systems aiming at reuse.

Guest researchers

Karoline Richter

My name is Karoline Richter. I graduated in Civil Engineering from Federal University of Paraná (UFPR) in 2010 in Brazil. I started working as a Civil Engineering also at UFPR. Dissatisfied with the waste of materials in the construction, in 2012, I started my master's degree in the sustainability process area and it contributed with my engineering work. I completed my masters degree in 2014, yes, in Brazil we stay 5 years in under graduation and more 2 years in masters graduation. In 2015, I realized that I could contribute even more to the Brazilian society if I could help them to have access to water and sanitation supply systems through a scientific contribution. So, in 2016, I started my PhD studies in UFPR at the Postgraduate Program of Water Resources and Environmental Engineering where I am researching on design a model of decision-making process for alternatives of integrated drainage and sanitation systems in urban areas (peri-urban areas; areas with lack of drainage and sanitation). My supervisor here at TU Delft is Professor Francois Clemens and I am also thankful for the Assistant Professor Lisa Scholten support. I'm very happy for being received as a guest researcher here at the university.

Marc Arpad Boncz

Graduated as a chemist (VU, Amsterdam), I obtained a PhD in Environmental Technology (Wageningen) and am now working as assistant professor at the UFMS in Campo Grande (Brazil). My main research interest is processing of wastewater for materials recovery and bioenergy production, and I work with anaerobic and algae-based processes, as well as some physical-chemical methods.

Objective of my one-year stay here in Delft is modeling the processes studied in Brazil and writing papers, but a significant part of the time I will be contributing to the AnMBR and ZeroBrine projects coordinated by Henri Spanjers, where chemical precipitation of inorganic materials and filter clogging will be studied.

Individual Projects

Jawairia Imtiaz Ahmad

Biostability in Drinking water distribution networks (DWDN) during and after Thermal Energy Recovery

Research objectives

The aim of the current research is to determine the impacts of thermal energy recovery on microbiological quality and biostability of drinking water in distribution network. The study will also focus on determining the maximum allowable temperature change without compromising the biostability and microbiological quality after thermal energy recovery (TER).

Project outline

Introduction

Climate Change is happening and it results into temperature changes globally and also at regional and local levels. It is also impacting the water bodies, as reported in the IPCC AR5. It is strongly agreed that fresh water resources will be negatively impacted by climate change, resulting in reduced water quality. These risks will occur due to increased temperature, sediment and nutrient load due to heavy rainfalls, which cause malfunctioning of treatment plants (Cisneros et al. 2014). But every threat comes with an opportunity. In the same manner the water sector has a huge potential to contribute in lessening the impacts of climate change by reducing CO_2 emissions from its processes. Because water contains a lot of energy, both thermal and chemical energy, recovery of this energy and using it as an alternative for fossil fuel will reduce CO_2 emissions (Van der Hoek 2012). But the changes in water temperature may effect the microbiological, physical and chemical properties of water during distribution (McNeill & Edward, 2002). It was highly observed that frequency abundance of many dominant phyla in DWDN increased in summer and in extreme winter conditions. Apart from this some opportunistic pathogens do exist in DWDN under favourable temperature conditions above 25°C (Pinto et al. 2014; Chakhtoura et al. 2015; Hammes et al. 2010).

Approach

The current study is carried out both at bench scale and full scale distribution networks with a thermal energy recovery system to evaluate the impacts of TER on biostability and microbiological water quality under different process regimes.

Scientific relevance

The thermal energy recovery might make the distribution network vulnerable for growth of some bacterial communities. Theimpact may also be the opposite for some microbes which cannot compete at high temperatures. This is one of the questions to be solved: TER either will enhance the growth of microbial communities in the system or it will increase the microbial quality of drinking water in DWDN. The current study is trying to fill this knowledge gap in field of drinking water supplies and biostability of water.

Social relevance

Reducing carbon emissions is the human responsibility to save earth from climate change. The supply of safe and wholesome drinking water to masses of population is also the core responsibility of drinking water utilities. This research is trying to correlate/link both goals by extracting the TER from DWDN under the condition which cannot compromise biostability and microbiological quality of the drinking water.

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Start date project: May 2015
Expected end date: May 2019

Key words:
Thermal energy recovery, Drinking water distribution network, Biostability, Microbial water quality

Cooperation with other institutes:
Waternet, TKI

Md Annaduzzaman Kajol

Small-scale piped water supply for ensuring safe water quality in arsenic-affected areas

Research objectives

To develop a series of blueprints for SPWS of the future for dynamic urbanizing settlements in arsenic-affected areas, where the microbial water quality is maintained from source to the consumer's mouth.

Project outline

Introduction

Large parts of the Ganges-Brahmaputra-Meghna Delta (GBM Delta) are densely populated, with megacities Dhaka and Patna as pillars of the region. Urbanization of deltas puts a severe stress on the availability of clean, safe drinking water and therefore threatens the lives of millions, mostly affecting the poorest. Arsenic-contaminated groundwater causes a widespread, serious health risk exposing millions of people worldwide (Smith et al., 2002; Chowdhury, 2010). In the GBM Delta in India and Bangladesh this contamination was recognized over twenty years ago (Acharyya and Shah, 2006); however, to date, arsenic mitigation strategies have collectively disappointed, due to the financial, institutional, environmental, technical and social (FIETS) complexity of the arsenic problem.

Water supply in the GBM Delta is predominantly organized through the use of scattered household hand-pumps, where the water safety is un-controlled, leading to contaminant exposure, particularly for the poorest.

Drinking water interventions have so far predominantly focussed on treatment, whereas SPWS combines source selection, abstraction, treatment and distribution (full water supply chain: from source-to-mouth; (Mara and Alabaster, 2008). For instance, once water is abstracted and treated, the water is repeatedly exposed to microbial re-contamination hazards, particularly through infiltration of the contaminated water in the system, back siphonage during backwashing of the distribution system, open water storage reservoirs, line construction and repairs and also unregulated storage to overcome intermittent water supply periods (Labite et al., 2010). Microbial water quality changes caused by temperature shifts, flooding events, and unhygienic practices are frequently reported by end-users, but has as yet not resulted in smarter SPWS designs.

Approach

- Field study in Bihar (India) to assess microbial contamination of household water in arsenic-affected areas (April 2017)
- Evaluation of best practices of SPWS in Bangladesh (UNICEF-Worldbank-DPHE documents)
- Laboratory and field investigations of novel materials and designs for their sensitivity to microbial (re-) contamination considering extreme flooding events, temperature shifts, and unhygienic practices.
- Formulate design, implementation and monitoring boundary conditions for SPWS blueprint for a source of mouth in rapidly changing urbanizing conditions in the GBM Delta.

Figure 1. Drinking water practice in rural Bangladesh.

Scientific relevance

At present, SPWS are being constructed in arsenic-affected areas. However, supplies are most often intermittent, leading to unregulated storage practices at communal of the household level. So far, little attention has been given to the clever design of storage containers, resulting in microbial recontamination hazards. The coming year, we will investigate the effect of different container materials,

designs, and usage on the microbial safety of the water; with specific attention to the DIY practices of end-users.

Social relevance

This study is of direct interest to NGOs and governmental agencies in Bangladesh and Bihar (India), as it will develop solutions for the design and sustainable operation of piped water supply in these arsenic-affected areas. The solutions are developed in close collaboration with Industrial Design engineers, aiming at a close link to end-user desires and needs for improved health through safer drinking water.

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Expected end date: Dec 2020

Key words:
Drinking-water, Water quality, Arsenic, Microbial pollution, GBM delta

Cooperation with other institutes:
Dhaka University, EPRC-Bangladesh, Patna College-India, IDE-TU Delft

Magela Odriozola Arbiza

Online fouling control in Anaerobic Membrane Bioreactors

Research objectives

The purpose of this project is to develop a control system based on online filterability measurement coupled with chemical dosage to stabilize and enhance flux in Anaerobic Membrane Bioreactors (AnMBRs).

Project outline

Introduction

AnMBR is an innovative technology for municipal wastewater treatment and an established technology for industrial wastewater. However, the main bottleneck of the AnMBR is the much lower fluxes than those reported for aerobic membrane bioreactor technology [1]. The decline in permeate flux is caused by 'fouling', this is the deposition and accumulation of particles on the surface and in the membrane.

The causes and mitigation of membrane fouling have been widely studied in both aerobic and anaerobic membrane bioreactors. Research on membrane fouling mitigation strategies focuses on optimization of operational conditions, mechanical cleaning and chemical cleaning. Although fouling mitigation actions are usually suitable in a stable operation of the membrane system, they may not be adequate or enough when the fouling problems are caused by sludge with high fouling potential [2]. The application of flux enhancers (FEs) for fouling control has been extensively researched. However, research has focused in short-term lab scale tests. Feasibility of continuous addition of FEs during long-term operation in pilot AnMBRs is still uncertain therefore it should be further studied [3]. Quantifying the sludge fouling potential, independently of membrane operational conditions, is crucial for allowing successful control actions on the sludge. Different indicators, such as critical flux and filterability, were defined aiming at quantifying fouling potential of activated sludge. These were mainly applied to characterize and monitor fouling and not for control purposes.

This research project will focus on developing an advanced control strategy based on online sludge filterability measurements coupled with FEs addition to optimize the membrane filtration process in a pilot AnMBR allowing to stabilize and enhance the operational flux.

Approach

The research will be done within the framework of a European project that proposes AnMBR as an innovative technology for municipal wastewater treatment. A pilot AnMBR for black water treatment was constructed in Spain by the project leader Aqualia. Crucial information to develop a control strategy, such as dynamics of the control elements, possible disturbances and the link between the manipulated and controlled variables, will be studied in this pilot. Additionally, the long-term effect of FEs on reactor performance and sludge characteristics will be studied, including biological activity inhibition and FEs biodegradability.

The experimental data will be used to develop an online control strategy to stabilize and enhance flux based on sludge filterability measurements coupled with FEs addition.

Results

Preliminary short-term filterability tests were performed in order to select an appropriate FE for further work. Several coagulants, adsorbents and flocculants were tested in the Anaerobic Delft Filtration Characterization (AnDFC) installation [4] using sludge samples from the anaerobic digestor of the Harnaschpolder sewage treatment plant.

Results showed that almost all FEs tested significantly improved the sludge filterability. The cationic polymer KD451 from ADIPAP was selected for this project since a smaller dosage was needed and higher membrane resistance recovery was achieved when comparing to other chemicals tested.

Then, filterability tests were performed with consecutive additions of KD451 (achieving different dosages) on industrial and municipal sludge samples, results are shown in Figure 1. It can be seen that increasing FE dosage decreases cake layer resistance (improves sludge filterability). However, a minimum cake layer resistance value was achieved and the resistance slightly increased with further additions.

Scientific relevance

Low flux caused by membrane fouling is the main factor determining the economic feasibility and applicability of AnMBR technology. Lower fluxes translate into higher membrane surface requirements and membranes

represent a significant cost in AnMBR systems. The development of an online fouling control strategies to stabilize and enhance flux will contribute to position the AnMBR as an economically feasible technology.

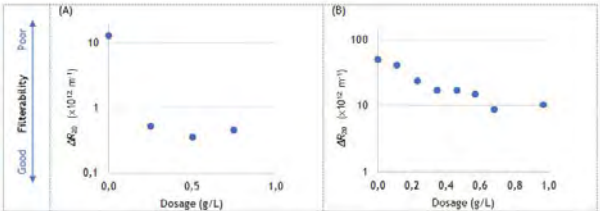

Figure 1. Cake layer resistance, expressed as ΔR_{20} after consecutive KD451 additions in the AnDFC installation to (A) municipal sludge samples from the anaerobic digester at Harnaschpolder and (B) industrial sludge samples from the AnMBR at Mars Netherlands.

Social relevance

Water scarcity is a severe worldwide problem that rises the interest in sustainable wastewater treatment to produce reclaimed water, reduce energy and environmental impacts while recovering resources. AnMBR technology couples the widely proved advantages of the anaerobic digestion process, namely biogas production and low sludge generation, with disinfection by membrane filtration. The biogas can be used to generate calorific energy and/or electric power. Additionally, anaerobic digestion does not require oxygen supply and consequently the energy consumption is significantly reduced. Therefore, AnMBR is a promising technology for sustainable wastewater treatment.

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Key words:
AnMBR, Flux enhancer, Fouling control, Sludge filterability

Cooperation with other institutes:
Aqualia Spain, University of Southampton UK

Lenno van den Berg

Physical removal mechanisms of suspended solids from wastewater in Aerobic Granular Sludge installations

Research objectives

The aim of this project is to obtain insight in the interaction between complex contaminants (e.g. suspended solids and colloids) in wastewater and aerobic granular sludge and the removal of these contaminants from the wastewater with aerobic granular sludge.

Project outline

Introduction

Aerobic granular sludge (AGS) is a recent innovation in which microorganisms are selected to grow in granules rather than flocs. The technology enables combined carbon, nitrogen and phosphorus removal, can reduce space requirements of the installations by ±80% and is cost-effective compared to activated sludge technology (De Bruin et al, 2004). The granules are a form of biofilm, in which no support or carrier material is used (so-called auto-immobilization).

Development of the AGS technology was primarily based on laboratory studies with soluble and readily biodegradable substrates. The soluble fraction of the organic matter in wastewater however, is typically less than 50% (Roeleveld and Van Loosdrecht, 2002). So-called particulate substrates or suspended solids are the majority of the organic matter in the influent of a treatment plant. These particulate substrates are often slowly biodegradable and require extracellular hydrolysis before biochemical conversion. Hydrolysis is a slow, rate-limiting process.

It has been shown in the laboratory that particulate COD can be removed effectively by granular sludge, but the granules tend to have more filamentous structures on their surface. An excess of filamentous structures can lead to a reduced settleability, scum layer formation and potentially complete process failure (De Kreuk et al, 2010; Wagner et al, 2015). Also, effluent suspended solids concentrations in full-scale granular sludge installations are slightly higher than for activated sludge installations (STOWA, 2016). If we understand the interaction mechanisms between suspended solids and granular sludge on a fundamental level, we might be able to propose control strategies that enable more efficient removal and ultimately a more stable wastewater treatment process.

Approach

1) Characterization of the suspended solids in wastewater regarding physical characteristics such as size, shape and charge
2) Analysis of the kinetics of particulate removal in AGS reactors with batch experiments
3) Analysis of the incorporation of particulates into the granule with imaging techniques, such as confocal laser scanning microscopy (CLSM) and magnetic resonance imaging (MRI)
4) Computational Fluid Dynamics (CFD) modelling of AGS reactor to simulate different removal mechanisms, preferably leading to advanced control strategies for suspended solid removal.

Scientific relevance

This research will provide a better understanding of the interaction between suspended solids and granular sludge. The obtained knowledge might be applicable to other granular sludge systems, such as anaerobic granular sludge and Anammox.

Social relevance

The development of a new control strategy for the removal of suspended solids can reduce the amount of pollutants (suspended solids and the nitrogen and phosphate associated with these solids) that are discharged to the environment. It can furthermore lead to a reduction in treatment cost by reduced aeration requirement and increased biogas production.

Literature

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Key words:
Suspended solids, granular sludge

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Montana State University, Wageningen UR, Royal Haskoning DHV, Department of Biotechnology (TU Delft)

Irene Caltran

Natural Organic Matter removal from surface waters: Separation of Dissolved Organic Carbon and ions from Ion Exchange brine using Ceramic Nano Filtration

Research objectives

This research aims to:

- Make an inventory of the state of the art for Natural Organic Matter removal from drinking water
- Test and upscale Nano Filtration ceramic membranes in order to treat Natural Organic Matter rich brine

Project outline

Introduction

Natural Organic Matter (NOM) is usually present in surface water. NOM is not only the cause of odor and color problems in drinking water. It is also responsible for the majority of the demand for coagulants and disinfectants, the competition with removal of other compounds, membrane fouling, biological instability and bacterial growth and formation of disinfection by-products (DBPs) (Matilainen and Sillanpää, 2010).

In locations where fresh ground water is scarce, the removal of NOM from surface waters is one of the main challenges of drinking water companies. Therefore, many companies are performing experimental work about this subject. DOC2C's is a joint project of different West European drinking water companies and universities and has the aim to improve the NOM removal processes with research and mutual collaboration.

One of the technologies used for NOM removal is Ion Exchange (IEX). The resin used during IEX has to be periodically regenerated. From the regeneration process, there is production of brine containing salts, NOM and other ions. The disposal and the treatment of the brine can be a limiting factor for the use of IEX at a large scale (Verdickt, 2012).

Several approaches are studied in order to reduce the amount of brine to be disposed and in order to recover resources present in the IEX brine, such as water, salt and NOM.TU Delft is developing selective Ceramic Nano Filtration membranes (CNF), coated by TiO_2 Atomic Layer Deposition (ALD).

The membranes will be studied in order to be applied to the IEX brine with the objective to:

- Separate the regeneration salt (e.g. NaCl) from NOM and the other ions (e.g. NO_3-, SO_4^{2}-), in order to reuse the recovered salty water in the regeneration process.
- Separate salts from NOM, in order to recover the NOM concentrate for other uses, for instance for agricultural purposes.

Approach

The current techniques for NOM removal and their combinations are being inventoried, with particular attention to the drinking water companies in the European Two Channels region. The inventory includes the approach used by different water companies and their experienced challenges. Both literature research and questionnaires are used for this purpose.

IEX is a promising NOM removal technique, and the disposal of the produced brine is challenging its use. To address this problem, we investigate separation between ions (Cl- , NO_3- and SO_4^{2}-) and NOM by ALD Ceramic Nano Filtration. On laboratory scale, nanofiltration tests are performed with water prepared with different concentration of salts and NOM. On a pilot scale, nanofiltration tests will include also IEX brine from drinking water treatment plants.

Scientific relevance

The work will contribute to understand the different approaches used to remove Natural Organic Matter, and can be a basis for the choice of the most suitable Natural Organic Matter treatment technique(s) in a specific situation.

Moreover, a performance study of the innovative Ceramic Nano Filtration membrane with Atomic Layer Deposition will be provided.

Social relevance

The inventory and the integration of the experimental work of different companies and institution can facilitate the optimization of the efforts for research on Natural Organic Matter.

Further, studies on brine treatment using Ceramic Nano Filtration will contribute to waste reduction and resource recovery in the drinking water sector.

Literature

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Interreg project DOC2C`s.
Partners: PWNT, South West Water, De Watergroup, University of Lille

Pamela Ceron Chafla

Steering Product Formation in High-Pressure Digestion Systems

Research objectives

This research project aims to explore the feasibility that inside the context of a biobased economy, wastewater can become an innovative source of organic "feedstocks" for the carboxylate platform. However, in order that this platform can be competitive in the market, the productivity, selectivity, and titer of the fermentation process have to be significantly improved. The use of high-pressure technology, which is widely applied in other fields of industrial biotechnology, could reveal interesting features of microbial communities which can be exploited to improve the overall performance and stability of the bioprocess

Project outline

Introduction

Anaerobic Digestion is a widely used and advantageous technology for wastewater treatment, since besides organic material degradation, biogas is produced (van Lier et al. 2008). Using conventional technology and process conditions, the methane content reaches 50-75% (IEA Bioenergy 2009). This, plus a high CO_2, NH_3, H2S and water content make the obtained biogas not suitable for natural gas grid direct injection, so upgrading systems are required. Previous proof-of-principle research work has demonstrated the feasibility of using Autogenerative High Pressure Anaerobic Digestion (AHPD) to produce biogas with improved quality (90-95% methane content) and at a pressure suitable for high grade use (Lindeboom 2014a). Furthermore, AHPD has also proved to produce other metabolites (carboxylates), that by themselves or through further conversion, could be of interest for the chemical industry (Lindeboom 2014b). New insights into waste to bioproduct conversion have been established and it has been demonstrated that interesting and economically-attractive end-products can be obtained with undefined mixed cultures dealing with complex substrates (Agler et al. 2011). In this context, High Pressure Anaerobic Digestion (Hi-PAD) offers some interesting features. Based on previous work, it is expected that specific pressure effects influence the kinetics and thermodynamics of mixed culture fermentations (e.g. role of the CO_2 partial pressure). This project aims to further address these effects and determine to what extent they can be exploited to improve the production yield or increase the selectivity once optimized conditions are achieved regarding substrate, inoculum and operational parameters.

Approach

The research will focus in the development of a process framework for selective carboxylates production in Hi-PAD systems, initially considering simple substrates and moving forward to more complex ones. Furthermore, the requirements for process design and optimization will be unveiled, as well as the alternatives for coupling these systems with sustainable downstream processing.

Results

A low-cost pressure set-up and a soft-sensor for pH monitoring in pressurized systems have been developed and used to test the effects of increased pCO_2 in anaerobic propionate oxidation activity for different inocula. From the preliminary results, it has been established that the source and characteristics of the inoculum had a significant role in the response to the stablished stress conditions, and concomitantly is a factor playing a role in the final product spectrum.

Scientific relevance

HPD has been proposed as a cost-effective technology for direct biogas upgrading. However, its possible use inside the "carboxylate platform" remains as an unexploited field of study. The forthcoming results of this research will provide insights into establishing HPD as an innovative and cost-effective resource recovery technology focused on viable bioproducts.

Social relevance

Increased waste production is a direct consequence of population growth, so alternatives to sustainably reduce/treat them are required. Wastewater treatment has traditionally been seen as an expenditure and an environmental compliance requirement. However, using an innovative technological approach focused on resource recovery, this perspective about wastewater and its treatment can be significantly changed. This research project aims that inside the context of a biobased

economy, wastewater can become an innovative source of organic "feedstocks" for the carboxylate platform.

Literature

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Key words: High Pressure, Anaerobic Digestion, Carboxylates Production, Resource Recovery, Undefined Mixed cultures

Cooperation with other institutes:
Ghent University (Belgium),
Paques

Elena Cristiano

Effects of high spatial and temporal resolution of rainfall data on hydrological response

Research objectives

This research aims to study the influence of spatial and temporal variability of rainfall events on the hydrological response in urban catchments. This study develops considering different combinations of spatial and temporal resolutions as input, and evaluating the effects that catchment and rainfall event characteristics have on the outputs of the hydrodynamic model, in order to define which one of these parameters have the strongest influence.

New parameter to investigate the influence of rainfall and catchment characteristics on hydrological response sensitivity are proposed as part of this work and evaluated in different scenarios and conditions, in order to verify the general applicability.

Project outline

Introduction

Flooding in urban areas is one of the main weather-related problems of the last decades. It is due in particular to increasing of urbanization, caused by growing density of the population, as people are moving from rural areas to big cities. This effect is combined with the impact pf climate change that is expected to lead to more intense rainfall events than in the past. The runoff generated by intense rainfall in a densely urbanized environment is typically fast and characterized by high spatial variability and short response times.

Approach

Hydrological response of urban catchments is particularly sensitive to the variability of rainfall and catchment characteristics at high space-time resolutions. New technologies are developed in the last years to measure with an high resolution the rainfall and to forecast storm event that can cause huge damages. A particular attention was dedicated to the weather radars (Berne and Krajewski, 2013), instruments that allows to measure rainfall with high resolution in time and space.

The influence of catchment properties such as imperviousness, ground level variations and drainage network density on urban runoff and drainage flows is still poorly understood, but it seems these parameters could have a strong relevance. Also how the storm characteristics, as length, cell size, direction and velocity, can influence the transformation of rainfall in runoff in urban context is still not deeply investigated.

Previous researches have studied the effects of different spatial and temporal rainfall resolution data on urban catchments, highlighting correlations between rainfall resolution and model scales (Berne et al., 2004, Ochoa-Rodriguez et al., 2015). In particular Ochoa-Rodriguez et al. (2015) considered the impact of different combinations of spatial and temporal resolutions on hydrological response in seven urban catchments, with the aim to identify critical resolutions.

Rainfall events with different characteristics, like intensity and velocity, were chosen for this analysis.

Results

The study developed until now confirms a higher sensitivity of the hydrological response to the temporal resolution than to the spatial resolution and shows that some characteristics of the storm, as velocity and intermittency of the peaks, have a strong influence on the sensitivity of the model.

Scientific relevance

In the last years new instruments and techniques have been developed to measure rainfall with high spatial and temporal resolution (e.g. weather radars, microwave links, etc.). However, the sensitivity of hydrological response to high resolution rainfall data and the combination of rainfall measurements with model complexity in urban areas has not been deeply and still needs further investigations.

Social relevance

This study aims to better understand the behavior of the hydrological response in urban areas, in order to estimate possible flooding during rainfall events. A better knowledge of the runoff helps to choose the best solutions to apply in order to reduce pluvial flooding risk in urban area.

Literature

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Key words:
Urban hydrology, Drainage system, Rainfall, Radar

Cooperation with other institutes:
Deltares, Gemeente Rotterdam

Petra van Daal-Rombouts

Performance evaluation of real time control in urban wastewater systems

Research objectives

The main research question of this project is: "How can the effectiveness of real time control (RTC) in urban wastewater systems be determined?"

This question is divided into three sub questions:

- What tools are needed for an evaluation?
- What are the key elements of an evaluation methodology?
- How can such a methodology be applied in practice?

Project outline

Introduction

In this research urban wastewater systems are defined as a combination of combined sewer systems and wastewater treatment plants (WWTPs) that discharge onto the receiving waters. RTC is about the continuous adjustment of the operation of a system with respect to a predefined goal based on real time measurements. The application of RTC in urban wastewater management is interesting, since the urban infrastructure is rigid (long life span, high cost for replacement), but the circumstances in which the system is operated (aims and loading) vary.

Literature on system wide control displays a wide conviction in the possibility to optimise the functioning of urban wastewater systems through RTC. This conviction, however, seems unfounded as no convincing evidence is presented in literature so far that application of RTC can realize a significant improvement in the functioning of urban wastewater systems. Furthermore, no unambiguous methodology is available to determine the effect of RTC.

Approach

As the research questions imply, the project consists of both theoretical and practical elements. The research focused on defining a methodology for the evaluation of RTC in urban wastewater systems and its application in practice. The practical side is a follow up on the work described in (Langeveld et al., 2013).

Results

A methodology was proposed to for the evaluation of RTC in urban wastewater systems (Van Daal-Rombouts et al., 2017b), see figure 1. It does not prescribed in detail how this should be done, but it does point to all details that should be thought about and what choices should be motivated. The key elements are application of a representative evaluation period and the explicit evaluation of uncertainties.

The practical application of the proposed methodology is demonstrated for the wastewater system of Eindhoven (Van Daal-Rombouts et al., 2017a). Here the Smart Buffer Controls were designed, implemented and evaluated. One was evaluated based on measurements and resulted in 44% less discharges from a storm water setting tank and the other was evaluated based on model results and reduced ammonium peaks in the effluent by 20% in concentration and load. An example of the functioning of the Primary Clarifier Control can be found in figure 2.

Scientific relevance

Previous research on RTC in urban wastewater systems claims to have a positive impact but fails to signify their results. There is a lack of evaluations including uncertainty analysis and appropriate evaluation periods, and on evaluations of the functioning of RTC on the long term. The research preformed here aims at addressing these issues and showing such evaluations are practically feasible.

Social relevance

Social relevance is at the very basis of this project. It is aimed to decrease the impact of the sewer system and WWTP on the receiving water through RTC, therefore improving its quality and thus leading to a higher ecological/recreational value.

Literature

Langeveld, J.G., Benedetti, L., De Klein, J., Nopens, I., Amerlinck, Y., Van Nieuwenhuijzen, A., Flameling, T., Van Zanten, O., Weijers, S.R., 2013. Impact-based integrated real-time control for improvement of the Dommel River water quality. Urban Water J. 10, 312–329.

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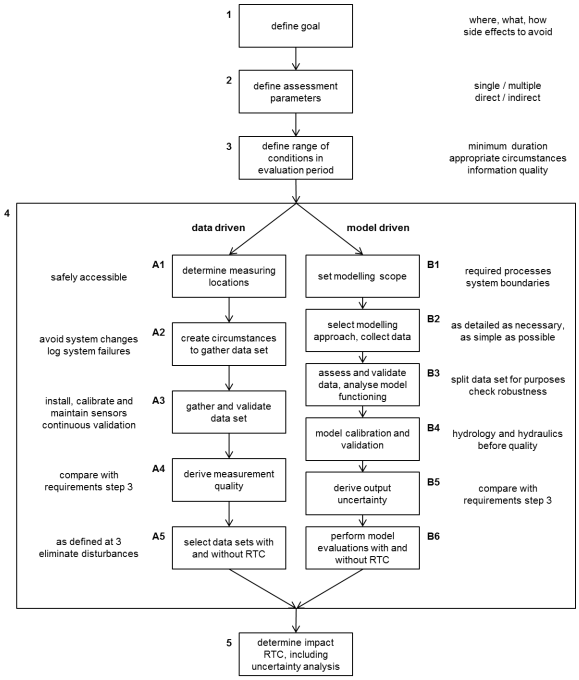

Figure 1. Methodology for the evaluation of RTC in urban wastewater systems (Van Daal-Rombouts et al., 2017b).

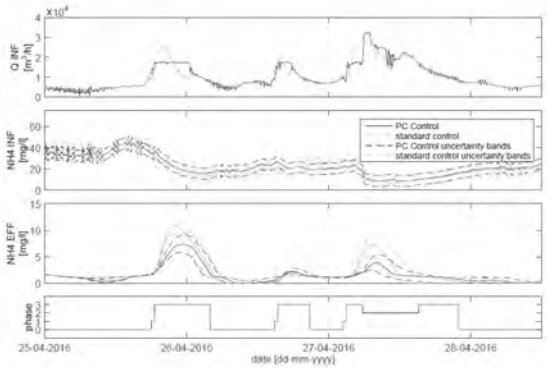

Figure 2. Example of the functioning of the Primary Clarifier Control as part of the Smart Buffer Controls (Van Daal-Rombouts et al., 2017a).

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Key words:
Urban wastewater systems, real time control, monitoring, integrated modeling, conceptual models, water quality, performance evaluation

Cooperation with other institutes:
Witteveen+Bos, waterboard De Dommel, municipality of Eindhoven, INSA de Lyon, Deltares

Daniel Daniel

Household water safety plan : A comprehensive approach in improving water quality at household level

Research objectives

This research aims to extend the water safety plan concept to household level in order to provide a better approach to improve the drinking water quality in developing countries and at the same time to increase the probability of HWT adoption among target group by appropriately influencing behavioral factors that are behind successful adoption of HWT through targeted interventions.

Project outline

Introduction

Household water treatment (HWT) is globally introduced as one of the options to improve the water quality at household level. HWT can safeguard public health in areas persistently challenged by efforts to achieve universal access to safe water, especially when the quality of the water distributed by water suppliers is untrustworthy. However, households often do not treat water regularly which leads to small impact on health.

Additionally, Water safety plans (WSP) is a preventive approach to improve the drinking water quality at community scale. WSP is a comprehensive risk assessment approach that encompasses the whole water supply from catchment to consumer.

While WSP considers the whole water supply system, HWTS is focused on managing water at the point of consumption. Thus, HWTS and WSP are complementary to each other and can provide multi-barrier prevention for maximum health gain.

Approach

This research presents a framework of extending the concept of WSP to household level called household water safety plan (HWSP). HWSP is a comprehensive and integrated approach which addresses household environmental characteristics, behavior related to water, sanitation, and hygiene (WASH), household water management, and preference on type of HWT in order to provide appropriate and sustainable solution for clean drinking water quality at household level (figure 1).

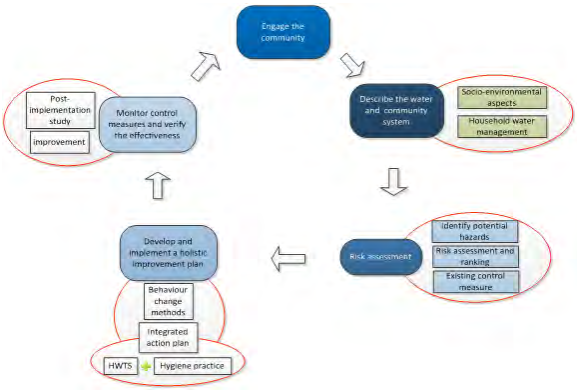

Figure 1. A proposed framework of Household water safety plan (HWSP)

Apart from the 5 main steps in HWSP, this research will deal only with partly steps 2 and 4. Step 2 mainly talks about socio-environmental characteristics which influence the adoption of HWT and discovering current practices of household water management. The interaction of those characteristics will be modelled in probabilistic manner and the model itself will visualize the relationship between behavioral factors with socio-environmental characteristics in explaining the adoption of HWT. The probabilistic model then can be used to propose appropriate behavior change intervention strategy.

Part 4 depicts the improvement plan which contains behavior change methods and integrated action plans which includes HWTS and hygiene practices. In order to find appropriate HWTS, people's preferences on the type of HWTS is needed to be considered. Choice modelling will be used to asses this.

Results

Five socio-environmental characteristics and behavior determinants were analyzed using Qualitative Comparative Analysis (QCA) from 41 case studies in low developing countries. Results show that there is no single characteristic that alone explains the adoption of HWT. This finding highlights the necessity for more research in analyzing an interaction of socio-environmental characteristics of household and behavior determinants

to determine the HWT adoption.

Scientific relevance

The research will address the gaps in our understanding of HWTS intervention in developing countries, in particular how to find appropriate HWTS and conduct an intervention to improve the water quality at household level in under-privileged areas. Moreover, this research will also reveal the relationship between household characteristics and behavioral determinants in order to predict the adoption of HWT.

Social relevance

This research will support sustainable development goal of access to clean drinking water for all, especially in low developing countries, and also to help decision makers or relevant stakeholders in designing an implementation program that can positively impact the health of its citizens.

Literature

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Key words:
Household water treatment, household water safety plan, probabilistic model of human behavior, choice model

Cooperation with other institutes:
EAWAG

Alex Duinmeijer

Research on the mechanisms to prevent FOG layer formation in wastewater pump sumps

Research objectives

Obtaining knowledge about mechanisms of formation and degradation of debris layers in wastewater pumping stations. Knowledge will be used to adapt the current design guidelines for wastewater pump sumps.

Project outline

Introduction

Wastewater pumping stations can experience problems due to the presence of floating debris in the pump sump. This floating debris mainly consists of solidified fat, grease and oil (hereafter called FOG) and the individual particles can accumulate to a closed floating layer. The presence of FOG can result in pump failures that can result in a 16% increase of yearly volume of combined sewer overflows as shown by Korving et al. (2006) for a specific case. Moreover, the removal of the FOG is an expensive, very unhygienic and labour intensive work and should be minimized.

The current guidelines for sump design (e.g. ANSI/HI (2012)) only deal with the transport of pollution in a superficial manner for a limited number of sump geometries (i.e. trench type and circular sumps). According to the author there is a need for a more generic formulation of design guidelines which provides a balanced compromise between avoiding poor flow conditions and air-entrainment on one hand and avoiding the formation of FOG layers on the other hand. Therefore, the author has started an experimental research on mechanisms to prevent the formation of FOG layers.

Approach

The use of free-surface vortices is defined as a potential mechanism for the transport of FOG particles towards the pump suction inlet. The ability and efficiency of this mechanism is initially qualitatively studied in a real scale test facility (Duinmeijer & Clemens, 2016). Based on this research, an extensive laboratory study is conducted in a ø600 mm vortex tank, see Figure 1.

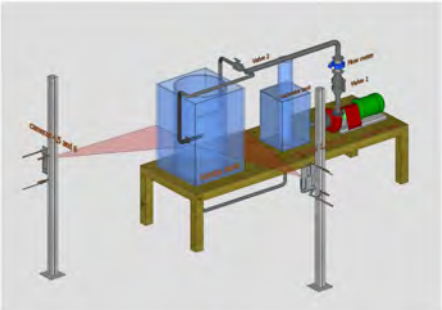

Figure 1. Schematic overview experimental vortex tank for research on the ability of the free-surface vortex as transport mechanism for FOG particles.

A theoretical vortex transport model is developed that predicts the transport ability of a vortex as function of a set of parameters. Next, the practical applicability and efficiency of a free-surface vortex is tested in real wastewater pumping stations that experiences problems with accumulation of FOG layers.

Results

Stereo PIV measurements showed that the vortex downflow is concentrated in a small radial region around the axis of symmetry with a maximum of approx. 10 to 20% of the total inflow. This is important data in understanding the behavior of a particle in the vortex flow. A novel 3D-PTV method is used to record the particle track in the vortex. The recordings of □600 experiments showed clear relations between particle transport and particle and vortex characteristics.

Scientific relevance

The experimental data from experimental and field research in wastewater pump sumps is considered essential for science-based optimized design of wastewater pumping stations. The experimental research provides insights in the flow phenomena's in wastewater sumps with respect to the accumulation of individual FOG particles into solid FOG layers and the prevention of FOG layer formation.

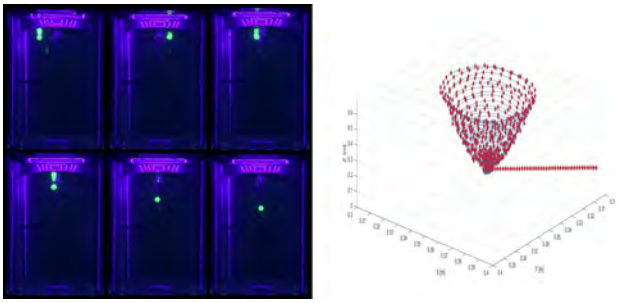

Figure 2. Left: transport of a ø38 mm sphere by the free-surface vortex. The particle travels with a helical movement towards the vortex air core and travels then along the vortex air core in downward direction. Right: computed 3D track of the sphere using the 3D-PTV method.

Social relevance

Preventing the formation of FOG layers decreases pump failures and therefore increasing the sewer system serviceability. As a result, the yearly volume of CSO spills of raw wastewater into receiving surface water bodies decreases which provides a better environmental health. Also, less pollution of pump sumps significantly decreases the annual costs for sump cleaning and pump failure repair costs.

Literature

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Key words:
Pump sump, FOG layers, vortex, experiments

Cooperation with other institutes:
Municipality of Rotterdam & Deltares

Carina Eisfeld

Removal of plant pathogens in agricultural tile drainage water by managed aquifer recharge for reuse in irrigation

Research objectives

AGRIMAR – Managed Aquifer Recharge for Agriculture

Determine water quality after managed aquifer recharge (MAR) treatment regarding plant pathogens. Assess the microbial risk due to recycling of water to finally provide safe and sustainably produced fresh water for irrigation.

Project outline

Introduction

AGRIMAR investigates MAR technology that collects fresh tile drainage water for storage in aquifers, and retrieves it in summer for crop irrigation. The TDW may contain plant pathogens which could be present in the recycled water. To prevent the spread of crop diseases by contaminated irrigation water the survival of selected plant pathogens in the MAR system will be studied. We focus on three plant pathogenic bacteria, namely Ralstonia solanacearum (RS; wilt), Dickeya solina (DS; blackleg), and Pectobacterium carotovorum (PC; soft rot, blackleg) which are of high ecological and economical importance. The goal is to study the fate of the bacterial plant pathogens in the MAR system and predict their decline during soil passage to ensure that it is safe to use MAR treated water for irrigation.

The AGRIMAR research is conducted by two PhD studies. My PhD research is focussed on microbiological water quality treatment during agricultural MAR. I work in close collaboration with Emiel Kruisdijk (the second PhD in the AGRIMAR research). Emiel's research is focused on the geochemical field characterization (including push-pull tests), regional MAR assessment and reactive transport modelling.

Approach

First, the pathogen fate will be studied in the lab with batch and column experiments, where the conditions of the aquifer will be simulated. The results of the bacterial survival will be used to model the die-off of the bacteria in saturated sediments using HYDRUS-1D and to predict their fate in the aquifer. Second, the removal of bacteria will be studied under field conditions at a MAR pilot location in the Netherlands. These results will be compared with the model predictions. To determine the risk MAR-treated water could pose for agriculture quantitative microbial risk assessment (QMRA) will be used. This includes dose-response experiments of the bacteria with susceptible plants to identify the acceptable risk level of plant pathogens in irrigation water.

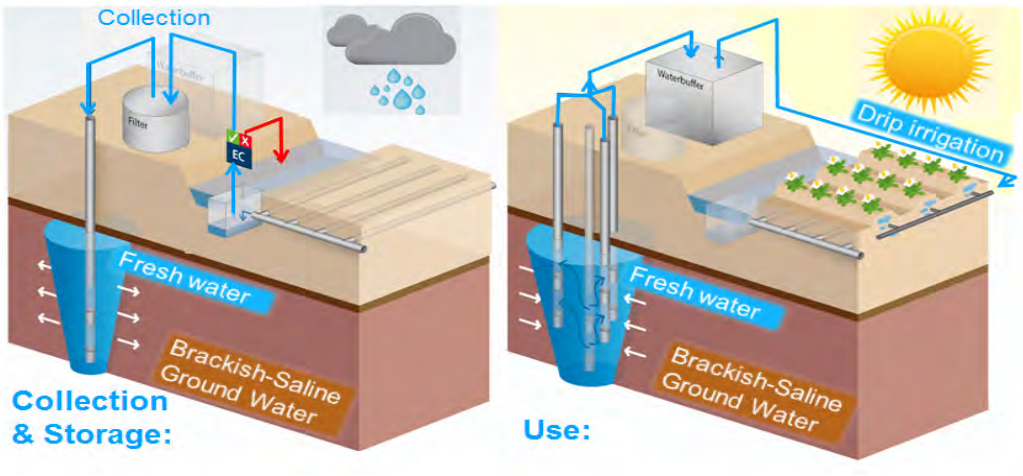

Figure 1 MAR technology: Tile drainage water (TDW) is collected and stored (left) in the underlying sandy aquifer confined by clay (the hydrogeological situation in the region). In times of water needs (summer), the stored water is used for irrigation (right). I

Carina Eisfeld

Scientific relevance

Transport processes in the soil are well studied for human pathogens but few is known about the transport and survival of plant pathogens. For the first time, transport process parameter estimation for plant pathogens in saturated sediments will be assessed. The results of the lab and field experiments combined with QMRA will show if MAR is a feasible technology to provide safe (contaminant free) irrigation water.

Social relevance

Fresh water is a scarce resource and especially in saline deltas like the Netherlands water availability for irrigation is limited. AGRIMAR proposes a local MAR system to secure fresh water with good water quality for agriculture. Therefore, the project faces a worldwide problem and we try to determine the conditions (QMRA) needed to apply the system for various environmental conditions. By providing pathogen free irrigation the spread of plant diseases will be reduced and loss of food crops is prevented.

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Key words:
Managed Aquifer Recharge, Plant pathogens, Brown and soft rot, Agriculture, Water quality

Cooperation with other institutes:
Utrecht University, Wageningen Plant Research

Astrid Fischer

Managing chemicals of emerging concern in the water cycle

Research objectives

The aim of this PhD is to develop a coherent understanding of the issue of chemicals of emerging concern (CECs) in the water cycle, by addressing the problem in a in a multidisciplinary way.

Project outline

Introduction

Water authorities responsible for the quality of the surface water and drinking water companies using the surface water for their production are challenged with the question if, where and how to abate the CECs in the urban water cycle. The most effective strategy under given conditions is often unclear to these stakeholders as it requires insight into several aspects of the contaminants such as sources, properties, and mitigation options. Furthermore the various parties in the urban water cycle such as water boards, drinking water companies, industry, agriculture, and the public are not always aware of each other's requirements and priorities. Processes to set priorities and come to agreements are lacking, hampering the articulation and implementation of possible solutions. At the moment the information is there, but it is scattered within various scientific fields. These fields include but are not limited to; (micro)biology, organic chemistry, (eco)toxicology, civil and chemical engineering, law and environmental policy. Much of this information has not yet been brought together and set in context of other relevant fields. An overview is missing that can enable new insights.

Approach

To solve the problem of dispersed information and a lack of overview, the Interreg project TAPES (Transnational Action Programme on Emerging Substances) was established. The aim of TAPES was to create a joint knowledge platform on CECs in the urban water cycle. As part of this knowledge platform a Decision Support System (DSS) was developed in strong cooperation with stakeholders within the whole water cycle. The DSS was developed to serve as a point of departure for getting the relevant stakeholders together and finding common ground. Stakeholders were interviewed to identify their requirements and expectations for the DSS. The overall conclusion from the interviews was that the stakeholders had sufficient information on CECs, but that the relevance of the information often was unknown. The main issues mentioned were:

1. Emerging substances in water
   a. Sources
   b. Are there adverse effects on human health, the ecosystem or susceptible functions of the water system
2. Possible mitigation measures
   a. Choice of measure, eg. removal efficiencies and costs
   b. Location of the measure (if relevant)

Results

To address the issues outlined above it was therefore decided to focus on environmental fate, decentral mitigation options, central mitigation options, legal frameworks and (eco)toxicology, as these were seen as the most relevant when trying to answer the question whether and where to abate these substances in the water cycle. The DSS will give the user information on the source, pathway, chemical characteristics and (eco) toxicity of individual emerging substances, together with information on the efficiency of water treatment technologies for drinking and wastewater. Also decentral technical and non-technical mitigation methods were included, as requested by a part of the stakeholders (Figure 1).

Besides filling the DSS the information gathered will be used to create a coherent understanding of CECs in the water cycle by exploring what (new) insights can be gained from addressing the issue of chemicals of emerging concern in the water cycle in a multidisciplinary way, by looking at environmental fate, decentral mitigation options, central mitigation options, legal frameworks and (eco)toxicology all together.

Scientific and social relevance

The DSS and the produced papers aims to be the link between the scientific knowledge available and the people that need to use this not always easily accessible knowledge in their daily work to make better and more

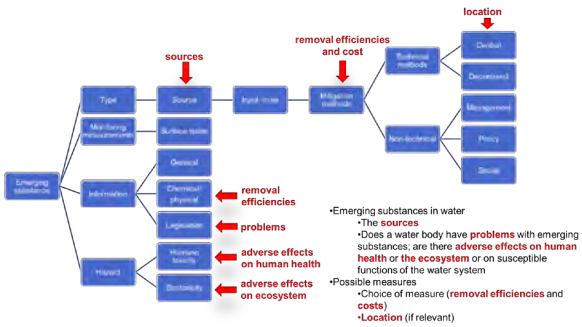

Figure 1. Diagram of information included in the DSS.

informed decisions. As such it is not only scientifically relevant, but it is actively making science relevant outside the scientific community, which is its social relevance.

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Emerging substances, water treatment techniques, water cycle

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KWR, Waternet, Waterschap De Dommel, TZW, VITO, De Watergroep, FHNW

Victor Servando Garcia Rea

Phenolic compounds degradation in AnMBR under mesophilic and thermophilic operation: BioXtreme-following up

Research objectives

This research aims to analyze the biological degradation process of phenol, p-cresol, and resorcinol in anaerobic membrane bioreactors (AnMBR) under mesophilic conditions and the degradation of phenol under thermophilic conditions.

This PhD project is part of the BioXtreme project, which its goal is to show the potential of AnMBR technology for the treatment of chemical wastewaters under extreme conditions. So, in this PhD research the extreme conditions are: 1) high toxicity, be given by the phenolic compounds and its mixture; 2) high temperature, given by the thermophilic (48-55 °C) operation.

Project outline

Introduction

Water is one of the most valuable resources not only for the human society development but all forms of life. Human population is growing and also the usage and the demand of water, while in some locations of the earth (especially in the western society and industrialized countries) there is an indiscriminate use of this resource, other countries present a shortage of water.

Rapid industrialization has resulted in the generation of large quantity of effluents (Shao et al. 2006; Ozgun et al. 2013). These include the major sources of industrial wastewaters from food processing, pulp and paper, textile, chemical, pharmaceutical, petroleum tannery, and manufacturing industries(Lin et al. 2013) among others.

These wastewaters present a challenge for the conventional biological treatment methods because usually implies characteristics like high organic strength and extreme conditions(van Lier et al. 2001): high toxicity, high temperature, high salinity and very high or low pH values.

Is in this niche in which the Bio-Xtreme project enters, having the goal of developing thermophilic anaerobic membrane (AnMBR) treatment technology for wastewater with high concentrations of salt and aromatics. The project targets the urgent need for sustainable and cost-effective treatment of these types of wastewaters making them suitable for reuse (van Lier 2013).

An AnMBR can be simply defined as a biological treatment process operated without oxygen and using a membrane to provide solid-liquid separation (Lin et al. 2013). In an AnMBR, biomass can be effectively retained inside the reactor providing optimal conditions for organic matter degradation without any carry-over of suspended solids (SS). By incorporating membranes to anaerobic wastewater treatment, superior effluent quality regarding chemical oxygen demand (COD), suspended solids and pathogen counts can be achieved in comparison with conventional anaerobic processes, and a stable treatment performance can be obtained to meet stringent discharge standards(Ozgun et al. 2013)

Approach

Three AnMBRs will be used for the experimental approach. Different sources of anaerobic biomass will be used and synthetic wastewater containing phenol and phenolic compounds will be used as a model compound for the toxic degradation research.

The degradation of the phenol (and probably the other two phenolic) compounds under anaerobic thermophilic conditions will be assessed as well; although, as a pioneer study in this area care should be taken due to the blockages of the operation in high temperatures.

Physicochemical studies of the biomass and the permeate obtained from the reactor will be held regularly. Molecular biology and metagenomic studies will be performed to unravel the microbial population involved in the degradation process of the toxic compounds.

Scientific relevance

This study will help to understand the degradation process of chemical wastewaters in anaerobic conditions and the effect of AnMBRs in the process. Nowadays this is a quite new technology so more research is need to be done in order to assess the AnMBR like the best technology for the treatment of this kind of effluents.

Social relevance

Every day tons of toxic wastewaters are generated and discharged (a great percentage without treating) all over the world, which is a major concern because of their environmental impact. If an adequate performance of AnMBR is achieved, a breakthrough for the chemical wastewater treatment will be delivered helping to reduce the water footprint and presenting a very viable option for closing water cycles.

Literature

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BioXtreme
AnMBR for chemical wastewater treatment

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Key words:
BioXtreme, AnMBR, phenolics degradation, extreme toxicity

Cooperation with other institutes:
-

Marieke de Goede

Broadening and renewal of the Dutch drinking water benchmark

Research objectives

This study is initiated to develop a framework to broaden and renew the Dutch drinking water benchmark. The benchmark can be broadened by adding new subjects to it. The idea is that adding new subjects will push organizations to learn and improve on these subjects leading to improvement of the drinking water supply sector. The research develops a framework that decides on adding new themes and deleting “exhausted” themes.

Project outline

Introduction

Benchmarking is a management instrument for performance comparison. In the drinking water sector it serves two goals. On the one hand improvement of the performances of the water supply companies and on the other hand it is a form of accountability for the sector (ILT 2012). The drinking water benchmark is first executed over the year 1997. Since then, the productivity of the drinking water supply sector has significantly improved (Dumaij and van Heezik 2012).

Approach

First an evaluation of the current drinking water benchmark is executed to get an overview of the effects of the Dutch drinking water benchmark. This evaluation is performed by literature research and interviews with the Dutch drinking water companies. Based on this evaluation a framework will be designed to make the benchmark fit for the future.

Results

When the drinking water benchmark is made fit for the future, with the use of the framework, the negative effects of the current benchmark are expected to be solved:

- The current drinking water benchmark has two goals: improvement and justification. If a benchmark serves two goals, organizations can become too focused on showing that there level of performance is sufficient that the improvement objective is under pressure (de Bruijn 2002).
- Benchmarking can slow down innovation: innovation means exploring of the unknown. Innovation increases the risk that the results are lower than expected. Benchmarking rewards reproduction of the known.
- The learning effect from the Dutch drinking water benchmark seems to be decreased. While productivity grew between 2000 and 2008, currently the growth stopped, as can be seen in Figure 1.
- Variations in performances between drinking water supply organizations have decreased. Because of small variation, there is less differentiation between good and bad performance. This makes the impact and learning effect of the benchmark smaller (van Helden and Brouwer 2005).
- Participating in the benchmark became mandatory in 2012. When performance measurements become mandatory the chances of undesired effects (i.e. strategic behavior) increase. The measures become targets and as Goodhart’s law explains: ‘When a measure becomes a target, it ceases to be a good measure’.
- The Dutch drinking water benchmark only has attention for the short term, and does not focus on long term plans of organizations.

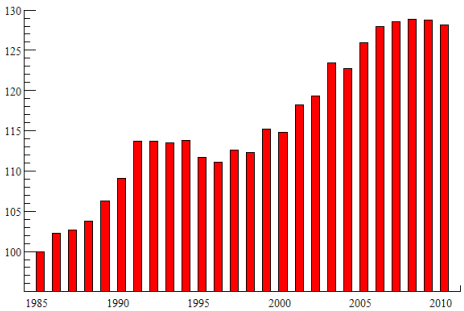

Figure 1. Productivity index numbers of drinking water

Further research plan

The goal to make the benchmark fit for the future requires that themes that are benchmarked should be able to change, because the future changes and some themes lose impact and get exhausted. Besides future developments and consumer preferences, also "sudden events" will be incorporated as in input variable. The research is framed along six specific research questions:

- How can a benchmark be made fit for the future?
- How can consumer preferences be integrated in a benchmark?
- how can "sudden events" be translated into a benchmark?
- What should a framework – that integrates future changes and "sudden event", that decide on adding new themes and deleting "exhausted" themes and that incorporate consumer preferences – look like?
- What are the effects of application of the framework?
- How does the designed framework fits in the current governance structure of the Dutch water sector?

Social relevance

Improvement of the Dutch drinking water benchmark should lead to improvement of the drinking water supply sector. Making the benchmark fit for the future will lead to a situation where drinking water organizations are learning from each other again. This is expected to improve their performance on the subjects which fit with the changed environment the drinking water companies operate in. Good performance on these subjects is expected to improve the overall performance of these organizations.

Literature

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Drinking water benchmark, risk management, assets management, innovation, sustainability, water cycle, future orientation

Cooperation with other institutes:
VEWIN, Oasen, PWN, Waternet

Adrian Gonzalez Ortega

Maximisation of energy recovery from sewage sludge with an innovative digestion process

Research objectives

1) to unveil the composition of the non-degraded fraction of waste activated sludge (WAS) after pre-treatment and anaerobic digestion; 2) to devise a method to increase WAS digestibility under a framework of energy neutrality.

Project outline

Introduction

WAS is produced at 60-90 g dry solids per day per person-equivalent (Appels et al., 2008) and consists of proteins, humic substances, carbohydrates and microorganisms. It also contains pathogens inorganic matter and heavy metals, therefore, it is a threat for both human and environmental health and needs to be disposed off safely. The most common method to stabilize WAS prior to dewatering and final disposal is via anaerobic digestion (AD), which results into volume reduction and methane production. However, AD requires a long solids residence time (SRT) of 20-30 days, while a low yield of COD to CH4 conversion is reached (Nielsen et al. 2011).

In order to increase the methane production during the anaerobic digestion of WAS, several sludge pre-treatment techniques (e.g thermal, chemical, ultrasonic) have been studied and applied. Pre-treatments usually increase the WAS biodegradability, however it is not clear which parts are especially affected during pre-treatment and during AD and which substances remain unaffected.

Approach

1. Literature review to grasp the mechanisms and limitations of pre-treatment techniques and to select the best pre-treatment in terms of energy balance. The ideal pre-treatment technique implies low energy consumption, high methane production and volatile solids reduction.
2. Use laboratory grown WAS (with constant composition) in different pre-treatment experiments to keep track of the variation of its components after pre-treatment and AD.
3. Characterisation of the non-degraded fraction and to devise strategies for its degradation.
4. Scaling-up considering the variable composition of real WAS.
5. Energy balance of the proposed pre-treatment, and to devise strategies for its improvement.

Results

- An experiment was performed to exchange monovalent and divalent cations to lose the flocs of WAS. The sludge degraded faster but did not produce more methane.
- Literature review about pre-treatments (in progress) listing the effects of several pre-treatments in the main components of WAS (proteins, carbohydrates, humic substances, cells and combinations among them) and trying to explain the often-encountered contradictory results in literature.
- Tests using thermochemical pre-treatment and its effect on pathogen removal (in progress).

Scientific relevance

Several studies have been published on pre-treatments and their effect on WAS biodegradability. However, only few researches had their focus on the analysis of the non-degraded part after application of both pretreatment and AD.

Social relevance

Costs for WAS disposal determines to a large extent the economy of a sewage treatment plant (STP). In the Netherlands, where incineration is the sole option, the total costs are between €150-200 million per year. Any improvement in AD efficiency by means of pre-treatment will lead to a further reduction of sludge for disposal (Devlin et al., 2011) and in lower cost for the taxpayers.

Literature

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Figure 1. Biochemical methane potential (BMP) test of 36 reactors to unveil the effect of temperature and application time during pre-treatment

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Start date project: Feb 2016
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Key words:
Waste Activated Sludge, pre-treatment, anaerobic digestion, methane production

Cooperation with other institutes:
Royal Haskoning DHV B.V.

Bayardo Gonzalez Rodriguez

Arsenic Removal for Drinking Water Treatment in Nicaraguan Rural Communities

Research objectives

The aim of this research is to enhance fundamental understanding of As(III) and As(V) removal by NF membranes. These finding will be used to develop an effective and affordable NF treatment system driven by Human and Solar power for the removal of arsenic in groundwater for rural communities and small towns in Nicaragua.

Project outline

Introduction

Water ingestion with high concentrations of Arsenic (As), leads to greater cancer risk than any other common water contaminant. (Smith AH et al, 2007). In Nicaragua, a volcanic country in Central America, drinking water sources are influenced by geothermal waters - particularly in rural areas. As a result, rural communities are exposed to elevated arsenic concentrations (up to 900 µg As/L). The World Health Organization (WHO) has recommended a provisional guideline for safe drinking water of 10µg As/l.

A clean and safe drinking water supply is a basic human right that is being denied to poor and rural communities affected by arsenic poisoning and a limited access to water.

Figure 1 Keratosis caused by ingestion of water with arsenic to a resident of the community of El Zapote (Alina Gomez, 1996)

Approach

In the first PhD year, the aim was to gather all the available information related to arsenic in Nicaragua. This information is scattered in different institutions (e.g., the Nicaraguan Institute of Aqueducts and Sewers, Ministry of Health, etc.). The second step consists in locating arsenic affected communities and determine As concentration, As speciation, As source, as well as measuring the chemical and physical composition of water. This baseline study allowed for a smart design of experimental procedures for the laboratory experiments to be executed in the Netherlands. In this stage, a pilot research is currently ongoing to investigate the effect of elevated temperatures (50 degrees!) on the performance of low-pressure NF membranes for arsenic rejection. The pilot is built in the western part of Nicaragua, in the municipality of Telica. The shallow alluvial aquifer of this area is influenced by the hot fluids associated with active geothermal waters located in the volcanic chain of “Los Maribios”.

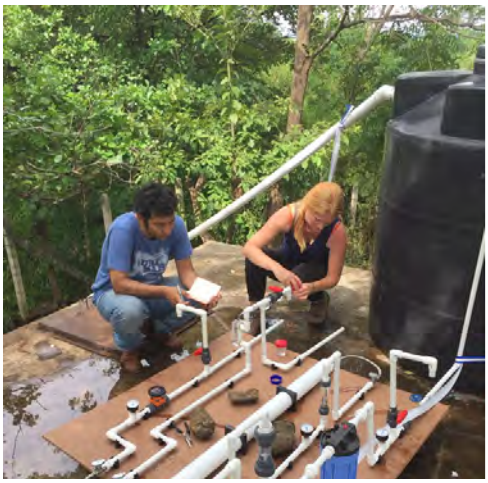

Figure 2 Testing an NF pilot plant for arsenic removal in a rural community in Nicaragua.

Scientific relevance

Nanofiltration (NF) membranes have proved to be reliable in removing arsenic species from water over a wide range of operational conditions. Furthermore NF is a promising technology for arsenic removal since it requires less energy than traditional reverse osmosis membranes. However the biggest challenges ahead lie in applying the technologies in poor and rural communities. Therefore is a need for systematic investigation of the use of NF membranes for small scale systems.

Social relevance

In Nicaragua the knowledge of arsenic removal systems comes from the research performed by local universities or NGOs working with water and sanitation. Despite the great efforts of the universities and NGOs, there is still very little hands-on experience with arsenic removal. For this reason, it can be said that this first and long-term study is aimed at evaluating, adapting and developing arsenic removal systems so they can be used at a local level.

By combining scientific inquiry with a concern for social welfare, this study will be useful as a document of reference in universities, research centers on water resources, NGOs and institutions working on water supply projects or managing this service at a private or public level.

The Director of UNICEF in Nicaragua, Philippe Barragne-Bigot, who a few years ago led several research related to arsenic problems in rural communities in Nicaragua, recently defined arsenic as a forgotten deadly threat. Therefore, this study will be of great help to understand the real reach of the arsenic problem in Nicaragua.

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Key words:
Arsenic, removal, groundwater, geothermal waters,Nanofiltration

Cooperation with other institutes:
The National Water Authority (ANA), Nicaragua

Jink Gude

Understanding arsenic mobility for smart fixation during drinking water treatment

Research objectives

- Understanding arsenic redox behavior and arsenic adsorption.
- Developing a water quality model for arsenic removal during groundwater treatment.
- Optimizing arsenic removal in groundwater treatment plants by adjusting operational parameters and/or adding natural groundwater components.

Project outline

Introduction

Arsenic removal is extensively researched because intake of arsenic can lead to skin disease, cancer, kidney heart failure and diabetes and paralysis. WHO guidelines on arsenic are 10 µg/l, but drinking water companies in the Netherlands recently set a new target value, arsenic concentrations smaller than 1 µg/L, to eliminate every health risk.

Expensive and invasive methods for complete arsenic removal exist. However, more elegant solutions for this concentration range are yet to be investigated for existing groundwater treatment plants. Current practices for arsenic removal include reverse osmosis, which has excellent arsenic retention, but such an installation is expensive for the removal of few micrograms of arsenic. The same is valid for building a polishing step that can be applied by passing the water through adsorptive media or ion-exchange resins. More realistic options are the use of strong oxidants in combination with coagulants like ferric chloride to adsorb all arsenic. However the use of these chemicals must be accompanied with extensive safety measures.

This research project will develop alternative solutions for smart fixation of arsenic to concentrations below 1 µg/L without expensive installations and 'dangerous' chemicals. Preferably natural components will be added before or during treatment to minimize cost, making large adjustments to the treatment schemes obsolete and do not compromise the stability of the groundwater.

Approach

The focus of the research will be to understand the natural arsenic removal capacity of groundwater treatment plants during (1) abstraction/mixing, (2) aeration, (3) short storage, and (4) sand filtration.

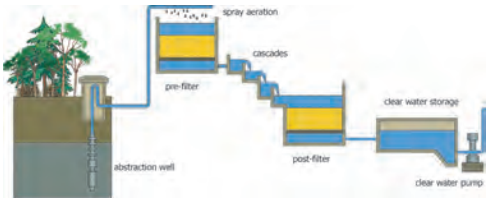

Figure 1. Typical groundwater treatment set-up in the Netherlands

For this purpose, extensive measurements in 3 typical groundwater treatment plants were executed. The measurements included typical groundwater parameters, but also arsenic speciation, analysis of filter sand coatings, backwash water and supernatant water experiments. A graphical abstract of the findings is shown in Figure 2. The results of these measurements are published and unravel the major aspects and mechanisms of arsenic oxidation and adsorption during groundwater treatment.

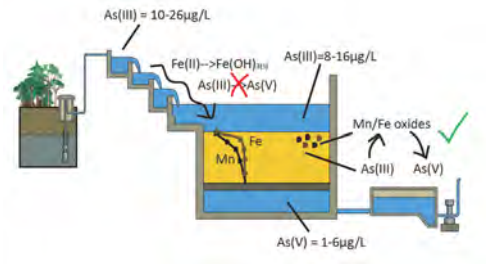

Figure 2. Arsenic mobility during full-scale aeration and rapid sand filtration

Results from extensive jar test with arsenic, iron and manganese are being interpreted. Subsequently batch reactors and column tests will be used to further investigate reaction kinetics under controlled, isolated conditions. Based on the results of the previous steps a model for kinetic arsenic behavior during oxidation, precipitation and adsorption reactions will be developed.

Jink Gude

Scientific relevance

Most detailed arsenic related studies are executed by geochemists and are concerning arsenic processes on an infinite time scale in the soil. In these studies the focus lies on equilibrium reactions, rather than kinetics. Existing arsenic removal studies are focussed on removal of moderate to high arsenic concentrations in groundwater containing low iron. Virtually no research has been done on arsenic oxidation and adsorption behavior at very low concentrations in a natural groundwater matrix. The aim of this research project is to develop a model that will predict arsenic oxidation, precipitation and adsorption processes during groundwater treatment.

Social relevance

The best drinking water for a reasonable price is the ambition of every drinking water company. Arsenic is a substance that even at low concentrations is now considered for removal, but not at all cost. By understanding the detailed mechanisms of arsenic removal at low concentrations, we are developing new, elegant technologies to assure safe water.

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Key words:
Arsenic removal, low concentrations

Cooperation with other institutes:
-

Noor Gulamussen

Potentials of sewage water reclamation for industrial use in Maputo, Mozambique

Research objectives

- Review reuse of water reclamation for industrial applications in sub-Saharan Africa.
- Identify water requirement for industries in Maputo.
- Develop appropriate technologies for wastewater treatment and reuse in those industries.
- Test the selected technologies.
- Evaluate the impact of implementing water reclamation.

Project outline

Introduction

Water is a critical natural resource that is becoming progressively scarce mainly due to increasing demand as a result of high population, economic growth and climate change (Schewe et al., 2014; United Nations, 2015). Serious water shortages and stricter regulations on wastewater discharge increase the interest in water reclamation worldwide (Rietveld, Norton-Brandão et al. 2011). On the other hand, the potential for resource recovery from wastewater and sludge is largely untapped and in developing countries only a small portion of wastewater is used in a planned and safe manner, while the majority remains untreated or partially treated, and is more commonly used in the unregulated than formal irrigation sector (Wichelns, Drechsel et al. 2015). Compared to surface water, reclaimed wastewater can be a more attractive source, because of low fluctuations of water quality and its abundant availability (Van Agtmaal, de Boks et al. 2007). The planning for water reuse is crucial for sustainable water resource management as it can constitute an essential component of local efforts to optimize water use and reduce the water shortage (Wichelns, Drechsel et al. 2015). This project will identify and evaluate technological and socio-economic options for water reclamation for industrial use in sub-Saharan countries – the case of Maputo, Mozambique.

Approach

In this project a mixed methods approach of qualitative and quantitative research and water cascading will be used. Key element of water cascading is determining combinations of water source qualities, water treatment and application requirements that create an optimal balance between maximum use of all available water and minimum treatment costs. Technological research will be designed based on the
observations in the field and technological options that are available (and under research at TU Delft and UNESCOIHE) and can be adapted to the local situation. Typically, the technologies, such as low-cost membranes, biological and crystallization processes, will be investigated in the lab, before being tested in the field at pilot scale. Knowledge sharing with experts in the field is part of the methods.

Results

Findings from the literature study of water reclamation for industrial use in Sub-Saharan Africa are following:The implementation of water reclamation in Sub-Saharan Africa is underdeveloped. Factors such as the increased demand for water, coupled with increased water stress, water scarcity, climate change and the compliance measures towards environmental legislation, are likely to be the driver for use of reclaimed water. At industrial level other factors, such as the reliability of the source and the competitiveness compared with desalination of sea water, are determining. The technical aspects should consider where the applications of reclaimed water are most valuable. Governmental support is fundamental in the planning phase if the intention is to integrate water reclamation in overall water supply and sanitation system. From investigations on water reclamation for the construction industry in sub-Saharan Africa – the case of Maputo, Mozambique, it was found that there is sufficient wastewater treatment plant effluent in Maputo, with flow of 5557,83 ± 763,06 m3/day, to supply all concrete companies in Maputo. However, the quality of the WWTP effluent should be improved to comply with quality requirements for concrete production. Coagulation and flocculation and ion exchange are the treatment methods proposed to remove phosphate and ammonia from this effluent.

Scientific relevance

The project will contribute on new approaches and

technologies in planning and design of wastewater treatment systems in the context of sub-Saharan countries by developing:

- Novel conceptual models for co-creative participation on water reuse, that provides insight in end users' drivers.
- New technologies for sewer mining, re-using water energy and nutrients on a profitable basis.
- The concept of "water-fit-for-use" that will result in a matrix tool linking raw water quality, required water quality and possible (scalable) water treatment technologies.

Social relevance

This approach will reduce the pressure on the limited water resources and increase the total available water supply for domestic use. It will also create driving forces for appropriate sanitation services. A direct impact of this project will be the reduction of nutrients and other pollutants entering waterways and the preservation of wetlands and sensitive marine ecosystems, reducing also health risks in touristic areas.

Literature

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Key words:
Water, reuse, industry, wastewater treatment, water reclamation

Cooperation with other institutes:
Eduardo Mondale University, UNESCO IHE

Hongxiao Guo

Anaerobic digestion of waste aerobic granular sludge and flocculent activated sludge: Degradation kinetics and characteristics variations of alginate-like extracellular polymeric substances

Research objectives

The overall research objectives of this study are:

1. Exploring the degradation kinetics of waste aerobic granular sludge (WAGS) during anaerobic digestion (AD), and
2. Investigating characteristic variations of extracted alginate-like extracellular polymeric substances (ALE) during AD. WAGS as well as waste flocculent activated sludge (WAS) will be compared for a better understanding of the mechanisms of anaerobic conversion of ALE.

Project outline

Introduction

Conventional activated sludge processes treating domestic and industrial wastewaters, create a large amount of WAS that needs to be stabilized before discharge. Besides activated sludge systems, also aerobic granular sludge (AGS) systems are applied often too nowadays. WAGS is currently mixed with WAS in anaerobic sludge digesters, but their degradation characteristics are so far unknown. AD has been widely used for sludge stabilization and energy recovery. Previous researchers focused on the biodegradability of WAGS in batch [1] and continuous systems [2]. However, the lack of knowledge about degradation kinetics of WAGS leads to inefficient design of AD systems at full-scale for WAGS digestion.

The quantity and composition of extracellular polymeric substances (EPS), and especially ALE, is capable of forming hydrogels surrounding the bacteria and are considered to determine the structure of sludge flocs and granules[3]. During the AD process, the structural properties of ALE are expected to change due to anaerobic conversion processes and therefore possibly weaken the structure of AGS. Being a large fraction of the granule biomass, a further understanding of ALE behavior during AD could also increase the insight in the mechanisms of sludge decomposition during this process and could eventually lead to an enhanced biodegradability of AGS.

Approach

1. The inoculum for AD and the WAS were taken from a municipal wastewater treatment plant Harnaschpolder (Den Hoorn, the Netherlands). WAGS was collected from a full-scale Nereda® plant (Garmerwolde, the Netherlands).
2. A modified ALEs extraction method will be used, which was developed by Lin et al. (2013) [3].

Results

Cumulative methane production of WAGS and WAS is presented in Fig. 1. The results showed that the WAGS exhibited a lower biochemical methane potential and slower hydrolysis rate than that of WAS. Fitting the degradation curves showed that WAGS reveals a clear two stage (rapid and slow) digestion behavior. Besides, the ALE presented different biodegradability for the two sludge types: 21% for WAGS and 27% for WAS (Fig. 2). The results indicated that the biodegradability of ALE (linked to the decomposition rate of sludge structure) was likely one of factors influencing the different degradation behavior of WAGS and WAS. It should be mentioned that the inoculum from WWTP Harnaschpolder was treating WAS during operation and was therefore not adapted to WAGS.

A further analysis of the different behavior of these two sludges in plug flow and CSTR like digesters will be studied in the future.

Scientific and Social relevance

In this study, differences in degradation behavior of WAGS and WAS are investigated in order to be able to design a suitable AD process and possible pre-treatment methods for WAGS.

Literature

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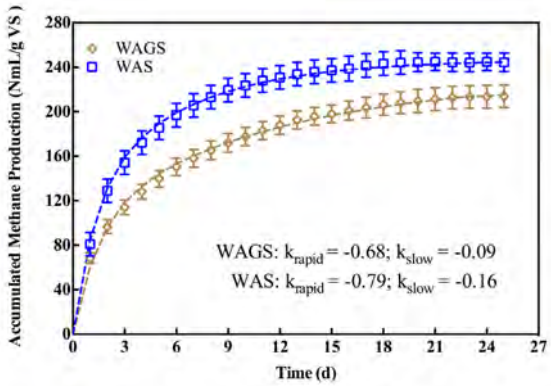


Figure 1. Measured and simulated methane production of WAGS and WAS

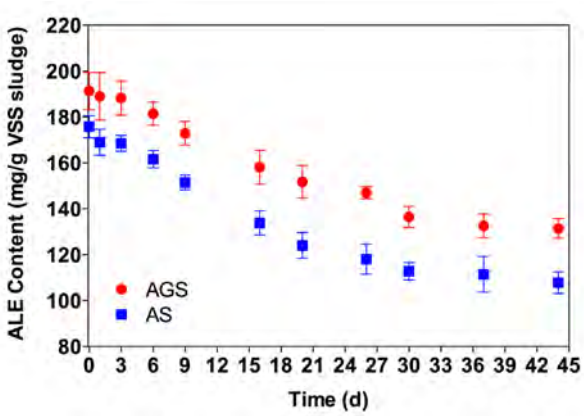
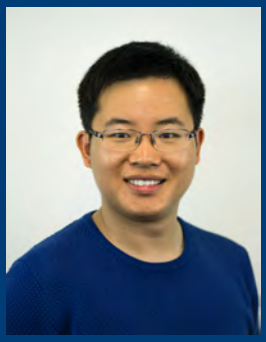


Figure 2. Degradation of ALE in WAGS and WAS, determined by isolation of ALE during the AD of WAGS and WAS



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Key words:
Anaerobic digestion, bioenergy, resource recovery

Cooperation with other institutes:
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Juan Pablo Gutierrez

Suspended sediments in a highly turbid river: implications for infiltration capacity in simulated bank filtration

Research objectives

The main purpose of this study is to evaluate the recovery of the infiltration capacity in a simulated RBF system because of physical clogging and subsequent self-cleansing processes. To achieve this, physical modeling was applied to assess the infiltration rates as a function of flow velocity-shear stress, riverbed grain size, and suspended sediment size and concentration. Cake and deep bed clogging was assessed during this study.

Project outline

Introduction

Riverbank filtration (RBF) is a surface water filtration method for drinking water through the banks and bed of a river source, using extraction wells located near the water body in order to ensure direct aquifer recharge. Riverbed clogging may occur on the surface (external clogging) or within the porous media (internal clogging). The extent of scouring is determined by the magnitude of the shear stress and the properties of the riverbed and cake layer deposited onto the riverbed. Scouring or self-cleansing capacity of RBF systems is commonly assessed in terms of riverbed particle size (considering critical shear stress) and the shear stress exerted by the river flow. Reported shear stress values typical for river streambeds range between 1 to 100 N/m2, considering a value of 20 N/m2 as reasonable (Hubbs, 2006). However, the incipient motion of sediments depends on critical shear stress, which is a function of riverbed-armor layer characteristics.

Approach

Physical modeling was applied to emulate the infiltration rate based on clogging and self-cleansing phenomena for a potential RBF system. A movable bed physical scale model based on a relationship between dimensionless bed shear (Shields parameter) was used to evaluate the recovery of the infiltration rate. In order to abridge the research, the following variables were selected: (1) bed particle size, (2) suspended sediment concentration, (3) suspended sediment size and (4) bed shear stress, as a function of the Shields parameter.

Results

A straight tilting flume with two canals was used for emulating the river flow (Figure 1). Infiltration columns placed at the bottom were used to determine the effect of variable shear stress conditions on self-cleansing and infiltration processes. The infiltration rate never recovers to its initial capacity regardless of the bed shear stress assessed. For the homogeneous suspended sediments, the infiltration rate did not show any increase even if the cake layers were partly removed because of the irreversible deep bed clogging happening under such conditions, which determines the overall infiltration capacity independently from the existing bed shear stresses. For the mixed suspended sediments, cake layer cracks during the clogging experiments were observed. Therefore, uneven erosion patterns occurred during scouring experiments caused by the presence of the existing cake cracks increasing the longitudinal cracks extent on cake layer formation. Even if a high mobilization of the mixture cake layer during the scouring experiments occurred, the immediate infiltration rate recovery is associated with preferential flows caused by the ameliorated cake cracking on the surface.

Scientific relevance

The scouring or self-cleansing capacity of RBF systems is commonly assessed in terms of riverbed particle size (considering critical shear stress) and the shear stress exerted by the river flow. This research assesses the influence of the suspended particles carried by the river as a key factor determining the production yield as a function of infiltration recovery.

Social relevance

This research allows to determine the feasibility of using RBF considering the characteristics of the particulate matter. However, it must be considered that the characteristics are seasonally dependent and variable through the time.

Literature

Hubbs, S.A., 2006. Changes in riverbed hydraulic conductivity and specific capacity at Louisville, in: Hubbs, S.A. (Ed.), Proceedings of the NATO Advanced

Research Workshop on Riverbank Filtration Hydrology: Impacts on System Capacity and Water Quality. Bratislava, Slovakia, pp. 199–220. doi:10.1007/978-1-4020-3938-6_9

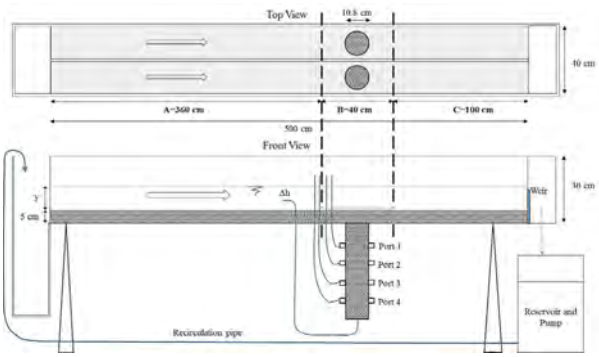

Figure 1. Scheme of the experimental setup

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Start date project: Oct 2011
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Key words:
Infiltration recovery, scouring, self-cleansing and shear stress

Cooperation with other institutes:
Cinara Institute / Universidad del Valle

Geert-Jan van Heck

How to close the gap between the outcomes of the asset management analyses and the decision-making process in Waternet's drinking water section?

Research objectives

Develop an asset management model for effective decision-making in Waternet's drinking water division.

Project outline

Introduction

The complexity of decision-making for drinking water utilities is growing. Drinking water systems are growing fully automated, existing of several subsystems and objects with more sophisticated and interconnected loops. At the same time, a large part of the utilities' infrastructure is aging, while the condition and the risk of failure are often unknown. Furthermore, the environment and society in which the utilities operate are changing and becoming more demanding. The interaction between the drinking water infrastructure and its densely occupied operational environment is increasing, causing a rise of conflicting goals. Also the utilities' internal goals are becoming more and more conflicting. Problems are becoming more confuse and ill-structured, and additionally decision-making has to deal with uncertainties.

Asset management provides methods for capital intensive utilities to translate the required service level of an organisation to operation, maintenance and investment activities for the assets. The goal of asset management is to provide present and future required service level in the most effective way. Although decision-making and asset management are aiming at the same goals, in practice the outcomes of asset management analyses and the outcomes of the decision-making processes in drinking water utilities show sometimes significant differences.

Approach

The research is aiming to answer the question: how to close the gap between the outcomes of the asset management analyses and the decision-making process? To answer the question the following steps are undertaken. Based on asset management literature an asset management framework is developed for Waternet's[1] drinking water division. This framework is applied in different cases in Waternet and decision-makers were interviewed to discover their opinions about asset management implementation within Waternet. Decision-making literature was explored, which will form together with the outcomes of the interviews the basis for the development of an improved asset management framework. This framework will be applied in another case and adopted based on the results of this case.

Results

The results so far include an overview of asset management frameworks world-wide [1], an asset management framework for Waternet's drinking water division [3] and different case studies applying the latter framework [4-7].

Scientific relevance

An improved the asset management process by incorporating relevant decision-making theory and learning from applying asset management theory in practice.

Social relevance

The asset management model, which will be developed, is supposed to increase transparency in decision-making and contribute to delivering drinking water utilities' goals at lowest social costs.

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[1] Waternet is a water cycle utility taking care of wastewater, drinking water, surface water, groundwater and safety behind dykes in Amsterdam and surroundings

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Start date project: Jan 2008
Expected end date: 2017

Key words:
Asset management, decision-making

Cooperation with other institutes:
Waternet

Alexander Hendriks

High-rate VFA production from industrial waste using the granular sludge process

Research objectives

For the production of bioplastics, polyhydroxyalkanoate (PHA) can be used as raw material. For efficient PHA production, volatile fatty acids (VFAs) are needed, which can be obtained through anaerobic fermentation using low-grade wastewater. Using granular sludge technology for the fermentation process could enhance conversion efficiencies, reduce reactor size and will lead to biomass free, but VFA rich effluent. The application of granular sludge technology for VFA production of wastewater is however a largely unexplored research topic. Aim of this research is to develop a novel reactor technology using different operational conditions and (mixtures of) substrates and study its effect on granule formation and VFA product spectra.

Project outline

Introduction

Polyhydroxyalkanoates (PHAs) are biopolymers produced by many different bacteria as an intracellular carbon and energy reserve material. In response to the problems and harmful effects of plastic wastes on the environment, PHAs attract considerable attention as alternative for petroleum based plastics because they are biodegradable and made from renewable resources (Braunegg et al., 1998; Leaversuch, R., 1987). This research will focus on the production of a VFA rich medium from effluent of agro- and food industries. This medium could be used hereafter for bioplastic production or utilised differently.

Approach

For efficient PHA production, the conversion of organic substrate into VFA should be maximized, the VFA composition should be controllable, production of hydrogen and methane gas should be avoided, biomass concentrations in the bioreactor's effluent should be minimized and the reactor should be as compact as possible to minimize investment costs. A possible way to fulfill these objectives is by using a granular sludge process. The research will focus on granule formation, stability and the effects of operational conditions, like temperature and pH, and suspended solids as substrate on granules VFA production and VFA spectra.

Figure 1 gives an overview of the reactor setup that is going to be used for this research.

Results

The project aims on elucidating typical process engineering related aspects of the process like the impact of solids retention time and operational variables. Figure 2 is an example of the temperature and pH dependent growth rate of Clostridium butyricum according to a Cardinal growth model. Experiments will be conducted with specific substrates and mixtures of substrates (artificial wastewater). Also the influence of (un)degradable solids on the granule formation and VFA product spectrum will be investigated.

Scientific relevance

The application of the granular sludge technology for pre-acidification of wastewater is a largely unexplored research topic. This results of this research should shed some light on the effects of different operational conditions and (mixtures of) substrates on granule formation and VFA product spectra.

Social relevance

As mankind we should shift to a more sustainable and biobased society. VFA's are a useful building block for products in this biobased society, as for bioplastics. The results of this research will bring valorization of wastewater streams a step closer.

Literature

Braunegg, G., Lefebvre, G., Genser, K.F., 1998. Polyhydroxyalkanoates, biopolyesters from renewable resources: physiological and engineering aspects. Journal of Biotechnology 65 (2-3), 127-161.

Johson, K., Jiang, Y., Kleerebezem, R., Muyzer, G., Van Loosdrecht, M.C.M., 2009. Enrichment of a mixed bacterial culture with a high polyhydroxyalkanoate storage capacity. Biomacromolecules 10 (4), 670-676

Leaversuch, R., 1987. Industry weighs the need to make polymer degradable. Modified Plastics 64, 52-55

Alexander Hendriks

Figure 1. Reactor set-up

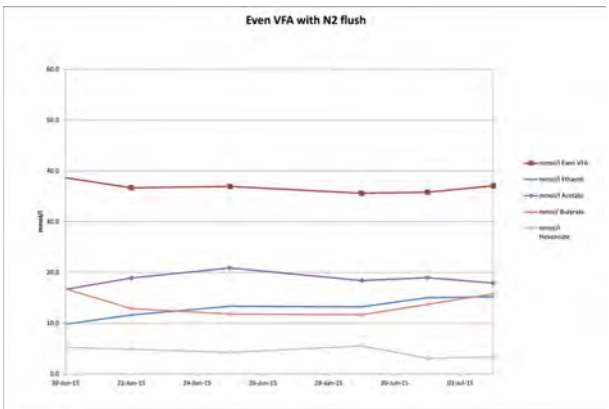

Figure 2. Example of a fermentation pattern during a stable period

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Key words:
Volatile Fatty Acids, Anaerobic Fermentation, Bioplastics, Hydrogen

Cooperation with other institutes:
STW, Paques

Nan Jiang

Zeolites as novel adsorbent in water treatment

Research objectives

The objectives of the project are removing organic micropollutants with high-silica zeolites. The aim is to ensure high water quality standards at lower operational costs and at a lower environmental footprint compared to activated carbon.

Project outline

Introduction

Currently, activated carbon filtration is the state-of-the-art for the removal of organic micropollutants(OMPs). While it can remove a broad range of targeted OMPs it will also remove non-targeted NOM. NOM can severely reduce the adsorption capacity for targeted OMPs due to adsorption competition, change in adsorbent surface characteristics and pore blockage(Newcombe and Drikas 1997). High-silica zeolites can be an attractive adsorbent for the removal of OMPs from drinking water and wastewater. Since most NOM molecules are larger than the zeolite pores (<1 nm), consequently they will not compete with targeted OMPs(Hung and Lin 2006). The objective of this research is to study the adsorption mechanism of pharmaceuticals by high-silica zeolites and to gain knowledge on how NOM fractions affect the adsorption efficiency of high-silica zeolites.

Approach

22 pharmaceutical mix with different molecular weight, hydrophobicity and charge were selected as target OMPs. The dosed concentration of each pharmaceuticals was ~ 2 µg/L in ultra-pure water and treated water from drinking water treatment plants (Anaerobic ground water with aeration, softener and sand filtration).

The framework types of 4 tested high-silica zeolites were FAU, BEA, MOR and MFI. The concentration of zeolites varied from 1–1000 mg/L. The concentration of pharmaceuticals were analysed by SPE-UHPLC-MS/MS.

Results

The adsorption efficiency of pharmaceuticals by 4 high-silica zeolites in ultra-pure water were shown in Table 1. In ultra-pure water, all pharmaceuticals could be partially or fully removed by high-silica zeolites. The removal rate of certain pharmaceuticals, e.g. metformin, lidocaine, metoprolol and sotalol were more than 99% when the dosage of high-silica zeolites was 1 mg/L. 6 pharmaceuticals were hardly removed by all four high-silica zeolites, e.g. furosemide, clofibrine acid, cyclofosfamide, primidon, caffeine and paracetamol with the adsorption capacity less than 100 µg/g.

The adsorption efficiency was well related to the charge of solutes. Generally, pharmaceuticals with positive charge were preferentially removed by high-silica zeolites over neutral and negatively charged solutes. 2 negative charged pharmaceuticals and 5 neutral pharmaceuticals were hardly removed by any zeolite. It could be assumed that high-silica zeolites with slightly negative charged framework might be responsible for the better adsorption efficiency of positive charged solutes. However, the results was not consistent with previous research that high-silica zeolites had higher adsorption capacity for neutral solutes than charged solutes(Fukahori et al. 2011).

The adsorption of pharmaceuticals were not obviously affected by their hydrophobicity. Some hydrophilic solutes, e.g. metformin with logD -3.36 which was hardly removed by activated carbon, could be well adsorbed by MOR, BEA and MFI zeolites(Scheurer et al. 2012). However, the adsorption capacity for certain hydrophobic solutes was low, e.g, for carbamazepine and paracetamol with logD 2.23 and 0.4 respectively, the adsorption capacity was less than 20 µg/g at zeolite dosage 100 mg/L.

High-silica zeolites with different framework types showed specific favour for the adsorption of pharmaceuticals. FAU zeolites had larger pore size and wider cages than other zeolites, thus may provide more accommodation for target solutes. 2 pharmaceutical with high molecular weight, e.g. pravastatine, and metoprolol were effectively adsorbed by FAU zeolite. BEA and MOR type zeolites with similar pore size had comparably same ability for the adsorption of pharmaceuticals. MFI zeolites had relatively small pore size showed least adsorption efficiency, since the pore size of MFI zeolites was less than the size of most tested pharmaceuticals.

Scientific relevance

Zeolites can be applied as a novel adsorbent to remove a broad range of micropollutants. Their mechanism and kinetics will be studied in detail. The effect of NOM on the adsorption of OMPs will be further explored and compared with the current results.

Literature

Fukahori, S., Fujiwara, T., Ito, R. and Funamizu, N. (2011) pH-Dependent adsorption of sulfa drugs on high silica zeolite: Modeling and kinetic study. Desalination 275(1-3), 237-242.

Hung, H.-W. and Lin, T.-F. (2006) Adsorption of MTBE from contaminated water by carbonaceous resins and mordenite zeolite. Journal of Hazardous Materials 135(1-3), 210-217.

Newcombe, G. and Drikas, M. (1997) Adsorption of NOM onto activated carbon: Electrostatic and non-electrostatic effects. Carbon 35(9), 1239-1250.

Scheurer, M., Michel, A., Brauch, H.-J., Ruck, W. and Sacher, F. (2012) Occurrence and fate of the antidiabetic drug metformin and its metabolite guanylurea in the environment and during drinking water treatment. Water Research 46(15), 4790-4802.

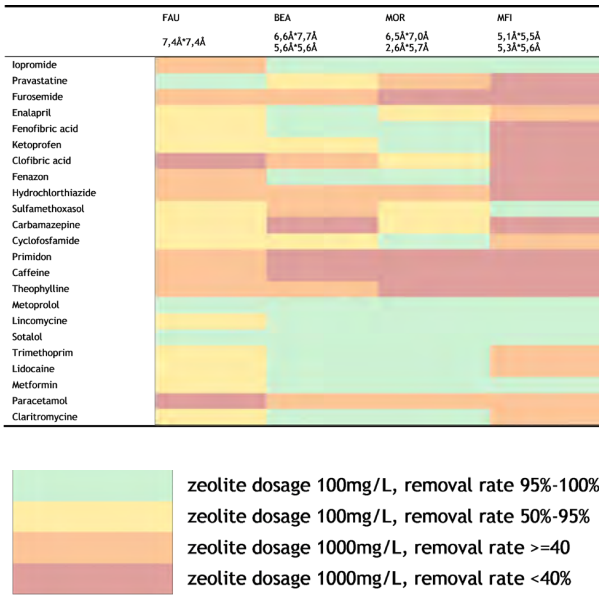

Table 1 The adsorption efficiency of pharmaceuticals by 4 high-silica zeolites in ultra-pure water

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Key words:
Zeolites, micropollutants, AOC, NOM, oxidation regeneration

Cooperation with other institutes:
Evides, PWN, Oasen, HWL

Maarten Keuten

DIPool: Dutch Innovative Pool
Advanced UV-based technology for pool water treatment

Research objectives

Reduction of chemical disinfectants in public swimming pools. This can be done by combining alternative disinfection techniques with adapted water treatment in a new pool water treatment concept including aspects of hygienic control of pool visitors. The goal is to have chemical disinfectant free swimming pool water for public swimming pools.

Project outline

Introduction

The main disadvantage of chemically disinfected swimming pools is the formation of unwanted disinfection by-products (DBPs). Reducing DBPs by abandoning chemical disinfectants introduces new challenges for pool water treatment. The DIPool project investigates swimming pool water treatment without chemical disinfectants to face these challenges. In cooperation with University of Twente, the effect of the "Watching Eyes" phenomenon on pre-swim shower behaviour of swimmers was investigated in 2017. The principle behind this phenomenon is that when someone has the feeling that he/she is being watched, they automatically behave pro-socially. This phenomenon also works with a picture of a pair of eyes.

Picture of "Watching Eyes" and shower pictogramm used during the study Results of observations

Approach

A desk study was done to select pictures of watching eyes and a shower pictogram. A field study was done in a holiday-park swimming pool, because this made it possible to investigate the effect of different interventions on the pre-swim shower behaviour of swimmers, with different population of subjects during each intervention but equal research conditions (e.g. lay-out, routing). To measure the effect of these "Watching Eyes", three different methods were used: visual observation, by means of a questionnaire and measuring the pool water quality.

Results

By observation, the effect of "Watching Eyes" showed to be effective in improving pre-swim shower behaviour by 28%, but the effect of a single showering pictogram was even more effective (40% improvement). Measured by observation, pre-swim shower attendance was 35-49%, while measured by questionnaire, it was 73-80%. The difference between observations and questionnaires can only be explained by dishonestly filled out questionnaires. Strangely, the effect on water quality was found to be even larger; "Watching Eyes" reduced the pollutant release by 56%, while a shower pictogram reduced pollutant release by 69%. The release of pollutants per swimmer was found to be reciprocal to the concurrent number of swimmers in the pool. Based on the results it is expected that swimmers are more likely to pee in the pool when there are less swimmers concurrently present. It was therefore concluded that the presence of watching eyes improves pool water quality, but the absence of watching eyes deteriorates pool water quality.

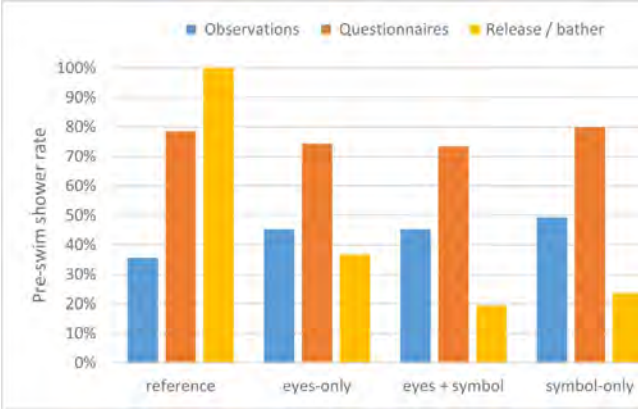
Scientific relevance

Current pool water treatment relies on chemical disinfection. The development of a pool water treatment with alternative disinfection techniques is a new field of expertise. The influence of the dynamic bathing load on the water quality must be kept in control. Creating stable

microbial pool water without the use of chemical disinfectants can lead to new viewpoints for comparable water treatment processes.

Social relevance

Since the early ages bathing and swimming play an important role in communities. The use of water basins changed over the ages from religious via hygienic to more recreational and educational purposes. During this development bathing and swimming has always been a social activity. Complaints about “swimming pool odour” and eye irritation are common reasons why nowadays some people never visit public swimming pools. UV-Disinfected swimming pools will provide healthy swimming without nuisance from disinfection by-products.



Questionnaires and water sampling during the study

Publications in 2017

Maarten Keuten, Marjolein Peters, Hans van Dijk, Mark van Loosdrecht, Luuk Rietveld
Microbial quality of swimming pool water with treatment without disinfection, with ultrafiltration, with UV-based treatment and with chlorination
Abstract and oral presentation for 7th International Pool and Spa Conference 2-5 May 2017 on Kos (Greece)

Marjolein Peters, Maarten Keuten, Merle de Kreuk, Hans Vrouwenvelder, Luuk Rietveld, GertJan Medema
Quantitative microbial risk assessment for an indoor swimming pool with chlorination compared to a UV-based treatment
Abstract and oral presentation for 7th International Pool and Spa Conference 2-5 May 2017 on Kos (Greece)

Joyce Ribbers, Maarten Keuten, Thomas van Rompay
I spy, I spy with my little eye
Abstract and oral presentation for 7th International Pool and Spa Conference 2-5 May 2017 on Kos (Greece)

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Start date project: Jan 2009
End date project: 2017

Key words:
Swimming pools, alternative disinfection, disinfection by-products, anthropogenic pollutants, pool water treatment, CFD, biofilm formation potential

Cooperation with other institutes:
Hellebrekers Technieken, Van Remmen UV techniek, Akzonobel Industrial Chemicals, Coram International, Sportfondsen Nederland

Rian Kloosterman

Improving the effectiveness of assetmanagement of the drinking water process

Research objectives

Vitens wants to know how they can integrate future uncertainties in their decisions of today. The investment and operational decisions, or governance, concern all the assets which are needed to produce drinking water. This is called asset management of the drinking water infrastructure.

All the processes which are needed to manage the assets is the assetmanagement process. The assetmanagement process is in a complex way influenced by a lot of stakeholders, physical conditions and technical possibilities, a so called (drinking water) system.

Project outline

The main question is to develop "rules" to handle future uncertainties in the assetmanagement drinking water process.

To answer this question the following sub-questions have to be answered:

1. Understanding and characterizing the system and the different components.
2. Understanding and describing the complexity of the system in different environments
3. Developing "rules" to handle future uncertainties

To handle future uncertainties in the assetmanagement drinking water process several theoretical concepts are important: Common pool resources, Time dependency, Uncertainty and Values.

Approach

The research area is defined and divided into 3 research parts, corresponding with the three questions. The three research parts are subdivided into smaller parts.

Results

Two draft publications are submitted.

1) A better relation between innovation and public infrastructures; Drivers for successful innovation.

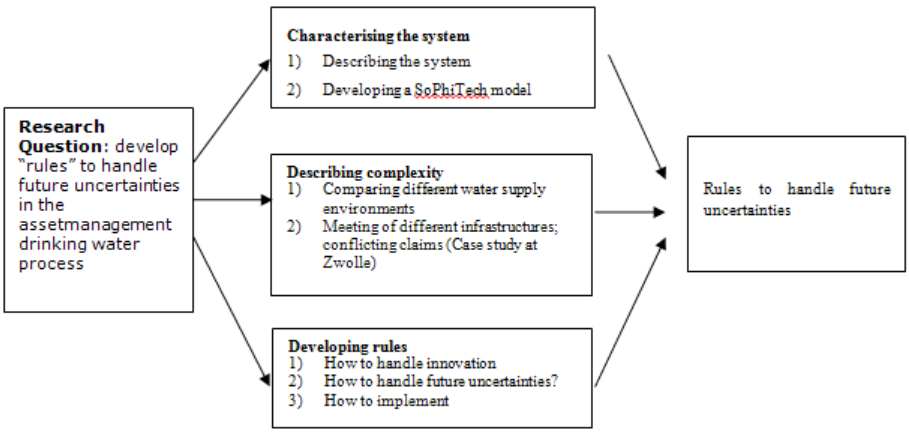
2) Conflicting claims; Water provision in a world of infrastructures

Scientific and social relevance

Assetmanagement is a young research field. Combining scientific (institutional) theories in assetmanagement theories for new assetmanagement questions is the scientific contribution.

Literature

PM



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Start date project: May 2012
Expected end date: 2017

Key words:
Strategic assetmanagement, governanace, long term uncertainty

Cooperation with other institutes:
PhD is a collaboration between the faculty of CiTG and TBM

Guido Kooijman

Application of flocculants in todays sewage treatment plant

Research objectives

Effects of application of flocculants as chemically enhanced primary treatment on a sewage treatment plant with a special focus on pharmaceutical removal, anaerobic digestion and sludge dewatering.

Project outline

Introduction

Application of chemically enhanced pre-treatment (CEPT) is not widely used in the Netherlands. This is mainly because the critical COD/N ratio for denitrification will be negatively influenced by extensive pre-treatment. However, with the perspective of a low COD/N tolerant sewage treatment plant (STP) such as Nereda with nitritation and Anammox (Winkler, Kleerebezem, & van Loosdrecht, 2012), CEPT is a concept that will regain attention in the future. Although CEPT is used already since the '30, in the Optimix project CEPT is evaluated as a solution for today's problems. Micro pollutant treatment, sludge dewaterability, improved biogas anaerobic digestion as well as small footprint sewage treatment plants (STPs) are considered in this project.

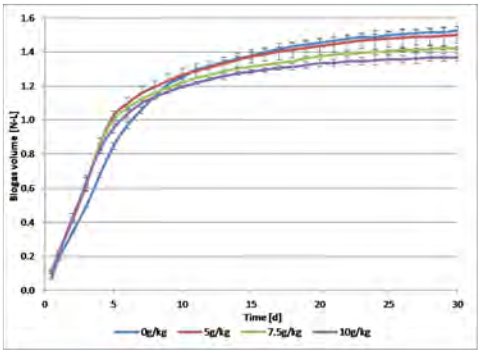
Approach

The consumption of pharmaceuticals has increased over the last decades and is expected to further increase in the future (Griens, 2010). The treatment of these compounds in STPs is not complete and therefore pharmaceuticals are accumulating in the environment. In literature, pharmaceuticals are reported to sorb to large extent to colloids. And since CEPT with flocculants enhances the removal of colloids, a large share of pharmaceuticals were expected to be concentrated in the primary sludge, facilitating the treatment of these persistent compounds. Application of CEPT will also have an impact on the subsequent STP treatment units. The anaerobic digestion (AD) may be affected and since flocculants are known to be poorly biodegradable in AD, the final sludge dewatering might be favored by CEPT as well. CEPT were used to flocculate raw sewage to create the samples for our laboratory experiments. Furthermore, experiments with primary, secondary and digested sludges were performed to study the effects of CEPT dosage.

Results

Although pharmaceuticals are reported to sorp to colloids in sewage to large extent, they could not be removed from wastewater by removing the colloids with flocculation. We investigated the reason for this and it appeared that pharmaceuticals do not sorp to small particulates (>0.1 µm).

The sludge resulting from CEPT with flocculants appeared to be better degradable in anaerobic digestion (AD) with higher degradation rates and higher biomethane potential (BMP) of the sludge. This was investigated and it was concluded that this was partially due to the flocculation of more easily degradable material and partially due to the reduced viscosity. Adding flocculants directly to the digester showed a higher digestion rate but a lower Biomethane potential (BMP) due to irreversible binding of the substrate. This is shown the figure below.



Also sludge dewatering is affected with the application of CEPT with flocculants. Even after digestion the effects of flocculants applied in the primary settler is well maintained resulting in a particulates and a lower soluble protein content.

Scientific relevance

This work gives more insight in the effects of flocculants on an anaerobic digester and opens the new perspective on pharmaceutical sorption in sewage.

Social relevance

The treatment plant of the future will allow for a lower COD/N ratio and this will open the opportunity to remove as much as possible COD from the wastewater as possible. Doing this with flocculants can have several advantages such as small plant food print, higher biogas or VFA production, lower aeration requirements and increased dewatering of waste sludge.

Literature

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Start date project: Jan 2011
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Key words:
Anaerobic digestion, micro pollutants, flocculants, sludge dewatering

Cooperation with other institutes:
Hoogheemraadschap van Rijnland
Nalco B.V.
Het Waterlaboratorium

Danai Konti

Use of multi-sensor condition assessment to support performance – based decision making in sewer asset management

Research objectives

The main objective of this research is to link condition data from sewer inspection to the performance of the system in order to support decision-making in sewer asset management (SAM).

Project outline

Introduction

Decisions for rehabilitation and maintenance in the Netherlands are mostly based on data gathered from CCTV inspections [1], of questionable reliability [2]. Pipes are categorized according to their condition in classes that reflect the perceived urgency of rehabilitation. However, the link between those classes and performance levels is weak, since, not only the magnitude of difference between successive classes cannot be measured, but also condition classes don't have a clear reference to performance objectives. Proactive approaches to SAM that serve the needs of the prevailed condition class rationale are available [3].

Integration of decision analysis, sewer condition, performance assessment and maintenance planning is important [4]. However, the efforts to structure the decision problem in sewer asset management are limited. Objectives defined in policy documents and legislation suffer from framing issues that hinder alignment between goals and measures used to assess their achievement. On top of that, the plethora of indicators proposed in the literature make it difficult for managers to choose what to incorporate in their management procedures. Thus, alignment of objectives, indicators and the monitoring and assessment methods used is questionable, as well as, the efficiency of activities taken in SAM.

Approach

A problem structuring method (PSM) that roughly follows SODA (Strategic Options Development and Analysis) will be used to structure the decision problem in order to link asset condition to performance objectives and highlight the needs for information. The output will be used to guide modeling of failures in the system. The predictive capacity of existing failure event-based models, proposed for water mains, will be tested for sewers in order to quit the condition class rationale. Last but not least, the value of alternative inspection techniques and automated defect detection, will be compared with the status quo using multi-attribute value theory in order to propose the optimal strategy based on decision-makers' criteria.

Scientific relevance

Sewer asset management has been documented as a complex problem, since it is characterized by multiple actors, differing perspectives, partially conflicting interests, significant intangibles and perplexing uncertainties but hasn't been addressed like that so far. A PSM will be implemented for the first time in order to create a common formulation of the decision problem and enhance understanding, with the ultimate goal of guiding modelling and data acquisition. In addition, failure event-based models will be used in order to investigate what is the added value of more accurate and reliable data in decision-making in SAM.

Social relevance

Budget restrictions, urbanization, climate change and the constantly aging system constitute challenges that increase the need for efficient management of the sewers. The risks related to sewer failures are highly connected to public health, safety and contamination of the environment, thus supporting proactive decision – making in that field is important.

Literature

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[4] Alegre, Helena, Coelho, Sergio, T., Covas, Didia, I., C., do Ceu Almeida, Maria and Cardoso, Adriana: A utility-tailored methodology for integrated asset management of urban water infrastructure. Water Science and Technology-Water Supply. 2013, Vol. 13, 6, pp. 1444-1451.

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Start date project: Dec 2016
Expected end date: Dec 2020

Key words:
Sewer asset management, failure modelling

Cooperation with other institutes:
Leiden university

Franca Kramer

Ceramic nanofiltration as the key step for sustainable wastewater treatment with reclamation of water, energy and nutrients

Research objectives

Where people live and work, wastewater is produced. This water needs to be cleaned before it can be discharged. Moreover, the quantity of clean and safe water is decreasing worldwide, as well as our current nutrient sources like phosphate mines that are depleting. The goal of this research project is to study a new concept of reclamation of water, nutrients and energy from municipal wastewater. The concept consists of a fine sieves to remove large particles followed by a newly developed ceramic nanofiltration (NF) membrane. The wastewater is expected to be concentrated with at least a factor 5, which results in a more than 80% water recovery. This water is polished with reverse osmosis to make it suitable for industrial use, while the concentrate from the ceramic membrane and the debris is fed to a digester to produce biogas, while nutrients from this flow are recovered by precipitation, see Figure 1.

This PhD research focusses on ceramic NF, the core of this concept. The research objectives are (i) testing the feasibility of this concept, (ii) investigating the quality and the robustness of the ceramic NF membranes on the long-term, (iii) researching how to control the fouling onto the membrane surface, and (iv) gaining insight in the phosphate rejection mechanisms of ceramic NF.

Approach

First, the feasibility of this sewer mining concept was determined by testing the filtration duration of pre-sieved municipal wastewater without cleaning. Moreover, the potential of using ceramic NF as pre-treatment for RO was studied. Second, the quality of new produced membranes and the robustness of these membranes on the long-term was assessed for the application of treating (pre-sieved) wastewater. Filtration of high organic loads requires treatment of hypochlorite to remove the fouling from these membranes. The long-term effect of this chemical treatment was determined. Third, different fouling methods will be tested to find the most efficient and sustainable method to prevent and/or remove (ir)reversible fouling. Finally, phosphate retention mechanisms will be studied to be able to find the best strategy to recover phosphate from the municipal wastewater.

Results

Pre-sieved municipal wastewater can be treated by ceramic NF for over 5 days without cleaning the membranes (Figure 2). More details about the feasibility of this sewer mining concept can be found in Kramer et al. 2015.

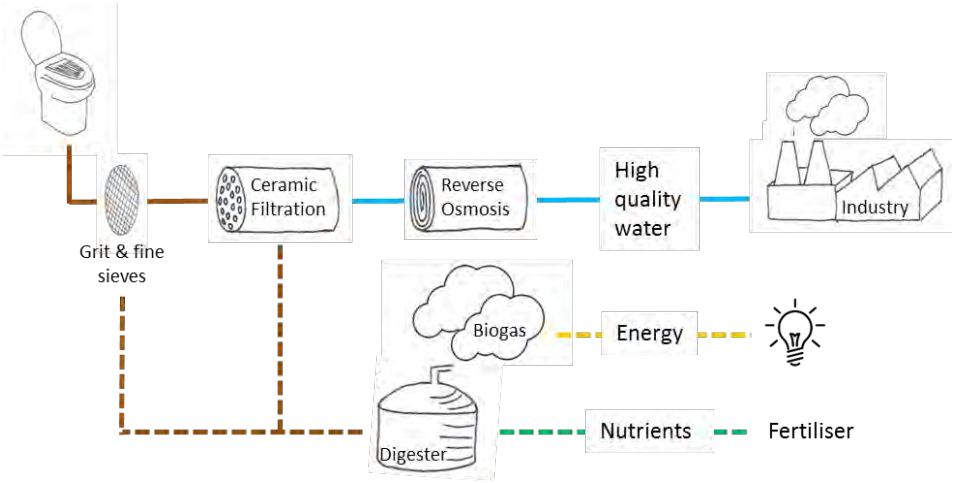

Figure 1. Sewer mining concept for treatment of municipal wastewater for the recovery of high quality water, energy and nutrients.

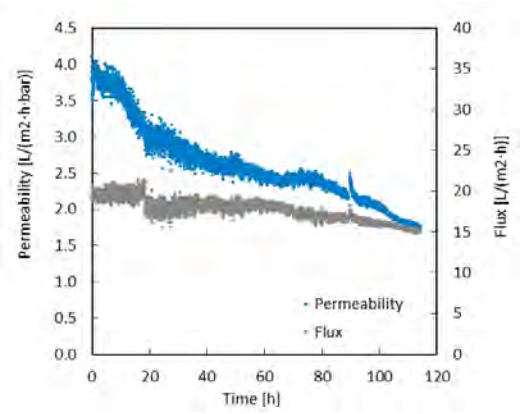

Figure 2: Permeability and flux in time of ceramic NF using pre-sieved municipal wastewater. Duration of 5 days without cleaning the membranes (Kramer et al. 2015).

Scientific relevance

Scientific knowledge on ceramic NF membranes is very limited especially in terms of wastewater treatment. This PhD research will lead to the understanding of the ceramic NF and the driving forces of the filtration process. With this knowledge, the ceramic NF process can be designed to operate in the most economical efficient way, considering the amount water produced and energy and chemical consumption.

Social relevance

Currently municipal wastewater is treated as a waste, after treatment the water is discharged into the river. In this ceramic NF concept municipal wastewater is used as a resource for the reclamation of high quality water, energy and nutrients. As our current reserves for fresh water, energy, and nutrients (e.g. phosphate) are becoming scarce, this concept will contribute to a more sustainable society.

This research is part of the RINEW (Rotterdam Innovative Nutrients Energy Water) project, which is searching for alternative concepts for the reclamation of municipal wastewater from city areas and transfer it to valuable products. RINEW is a collaboration between Evides Industriewater, TU Delft, the City of Rotterdam, Hoogheemraadschap van Delfland, Waterschap Hollandse Delta, and Clean Tech Delta.

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Ceramic Nanofiltration, wastewater, demi water production, sewer mining

Cooperation with other institutes:
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Onno Kramer

Hydraulic modelling of liquid-solid fluidisation in drinking water treatment processes

Research objectives

In general better understanding the hydraulic principles which makes improved modelling more easy, accessible and make full-scale implementation more achievable, sustainable and profitable.

Knowledge gap

The main objective is how can the liquid-solid fluidisation system fundamentally better be elucidated. A starting point of research is to improve the understanding of the fluidisation principles of natural particles in a full-scale pellets softening reactor and to be able to understand the dependency of the chemical phase to the fluid bed state.

Necessary models

A substantial aim of this research is to produce a more accurate prediction model of the inner particle-water movements and phenomena of the bed.

Implementation challenges

To improve the performance of full-scale reactors constrains and sensors have to be developed.

This will enable water engineers to design more efficient operating reactors which can effectively deal with the current challenges.

Project outline

Introduction

In the Netherlands annually 400 million m3 drinking water is softened in treatment plants applying fluidised bed pellet reactors. Generally, sand is used as seeding material and calcium carbonate pellets are produced as a by-product. To improve sustainability calcite pellets are grained and sieved and re-used as seeding material.

Theoretical knowledge of perfect round spheres in liquids is generally accepted and applied to predict the fluidisation behaviour. Regarding natural particles numerous semi-empirical models have been published however, there is no general agreement regarding which equation is the most accurate. In many cases shape factors are introduced for the particle diameter to improve the numerical results.

Research objectives

In the transition from a fixed to a fluidised bed state, after increasing the water throughput, the drag force existing on particles increases. This research will show the dependency of the drag of the actual particles size and change in orientation. It will be demonstrated that not the shape of the particle will decline, but the re-orientated will cause the drag force the decrease with 50%. This revisited approach will results to a better understanding and prediction of the fluid bed state.

In the well know Moody chart the friction factor is plotted against the Reynolds number, in which the emphasis is made on the turbulent flow. In liquid-solid systems the flow regime is in general assumed to be laminar. In an improved approach the friction factor is represented not using the default log-log method. The improved prediction model is more accurate and based on thoroughly carried out pilot plant experiments. The performance of the chemical process in pellet softening reactors is proven dependent of the state of the fluidised particle bed.

Approach

The aim is to obtain substantial more knowledge regarding the hydraulics of the liquid-solid fluidisation phenomena which will optimise the softening process in fluid bed reactors.

The research will take place at the Weesperkarspel facility in Amsterdam.

Results

Scientific relevance

Substantial fundamental knowledge regarding hydraulics of liquid-solid fluidisation phenomena. The use of the drag force substitutes the prolonged usage of the indistinct particle shape factors. The approach of many frequently used models can now be compared using the modified Moody's drag-Reynolds diagram without the log-log scales in which the laminar and turbulent regime better can be explained.

Models

Accurate both empirical and theoretical prediction models for liquid-solid fluidisation reactors which increase the opportunity to better maintain and optimise chemical

process circumstances improving the water quality. The model will be implemented at the softening process.

Opportunities

The acquired knowledge and models are a starting point for the optimisation and development of similar water treatment processes e.g. active carbon and sand filtration processes and even useful for other industrial processes. Besides application in the water treatment processes, in addition it can be used in interdisciplinary fields.

Economical relevance

In case the optimal fluidised bed conditions are successfully implemented in the full-scale facility of Waternet, at least 10% of caustic soda can be saved i.e. 200 k€/y.

Education

More than a dozen students, cooperating in this project, will learn both theoretical knowledge and practical scientifically skills which they as young professionals can use on a professional market.

Literature

Powder Technology, Chemical Engineering Science, Water Research, a Journal of the International Water Association, Water Science and Technology: Water Supply, Journal of Water Supply: Research and Technology – AQUA, Drinking Water Engineering and Science (DWES)

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Key words:
Drinking water; hydraulic modelling; liquid-solid fluidisation; drinking water treatment processes

Cooperation with other institutes:
Waternet, HU University of Applied Sciences Utrecht, Institute for Life Science and Chemistry

Emiel Kruisdijk

Agriculture & Managed Aquifer Recharge (AGRIMAR): Drainage Water Recycling for Irrigation and Surface Water Quality Protection

Research objectives

Agricultural Managed Aquifer Recharge is a promising method for securing water availability and economic gain in the agricultural sector. However, the risk of groundwater pollution with agrochemicals during storage in aquifers is currently unknown. The research objectives of this study are:

1. What conditions/processes control subsurface water treatment of pesticides and nutrients?
2. What is the optimal MAR design and operation for water treatment of pesticides and nutrients?

Project outline

Introduction

Flourishing agricultural areas are essential for food security and economic growth of the cities they sustain. AGRIMAR presents an innovative and interdisciplinary approach to achieve sustainable agriculture under climate change in saline deltas of the Netherlands and elsewhere. AGRIMAR aims to provide solutions for two major agricultural water problems:

1. Surface water carries plant pathogens causing diseases such as brown rot to (seed) potatoes and flower bulbs; its use for irrigation is prohibited or unwanted
2. Brackish groundwater and climate change further deteriorate fresh water availability.

AGRIMAR investigates managed aquifer recharge (MAR) technology that collects fresh tile drainage water for storage in aquifers, and retrieves it in summer for crop irrigation (Figure 1).

This nature based solution secures water availability, recycles water and nutrients, improves surface water quality, and yields economic gain. However, major research gaps are the (predictive) understanding of the conditions and processes improving both chemical and microbiological water quality in MAR. Water and agricultural legislations require this research to minimize risks of groundwater pollution and pathogen outbreaks.

The AGRIMAR research is conducted by two PhD studies. My PhD research is focussed on water quality treatment during agricultural MAR. I work in close collaboration with Carina Eisfeld (the second PhD in the AGRIMAR research). Carina's research is focussed on pathogen risk assessment of agricultural MAR systems.

Approach

My research is divided in three subtopics:

1. Aquifer reactivity

The fate of agrochemicals in the subsurface depend on the reactivity of the aquifer. Processes expected in the subsurface are degradation and sorption. This occurs during aquifer-groundwater interactions in the aquifer. The aquifer reactivity will be studied in-situ using push pull tests combined with reactive transport modelling.

2. MAR performance

An agriculture MAR system will be monitored for 2 years. The monitoring is focused on tracking the fate of agrochemicals in the MAR system. In collaboration

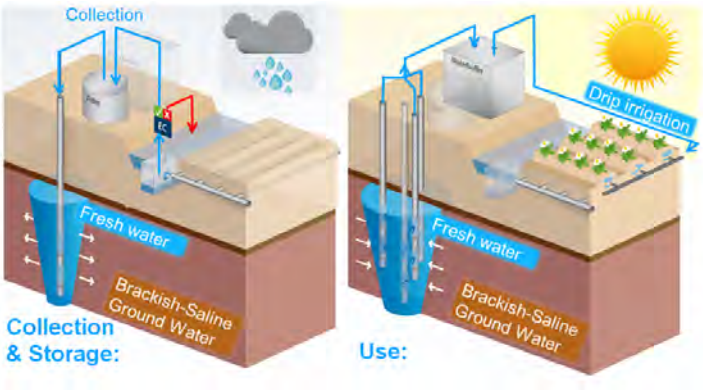

Figure 1: MAR technology drainage water (TDW) is co and stored (left) in the und sandy aquifer confined by cla hydrogeological situation i region). In times of water (summer), the stored water i for irrigation (right). In thi example, one water well wi screens is used for inj whereas three wells each wi screens are used for abstr Microbiological and chemical quality is improved during passage.

with Carina Eisfeld (PhD AGRIMAR – Plant pathogens) a MAR water quality and pathogen fate coupled density-dependent groundwater flow and biogeochemical reaction model will be built. The model will be used to optimize MAR system construction, application and treatment.

3. MAR prognosis

Regional scale-variations of physical and geochemical aquifer properties will result in differences in MAR performance. In this subject the MAR performance is assessed on regional-scale. By assessing the differences in aquifer properties, feasibility maps can be developed. These maps will indicate areas which are especially favourable or less well suited for agricultural MAR systems.

Scientific relevance

Whereas insight in physical water quantity aspects of MAR has recently made progress, (predictive) understanding of the biogeochemical and (micro)biological water quality aspects is limited, especially for this novel MAR application using abundant available TDW. The following research gaps are identified and addressed:

1. What conditions/processes control subsurface water treatment of pesticides and nutrients?
2. What is the optimal MAR design and operation applying the developed reactive transport model?
3. What is the projected variation of MAR performance at regional scale?

Social relevance

Fresh water is a scarce resource and especially in saline deltas like the Netherlands water availability for irrigation is limited. AGRIMAR proposes a local MAR system to secure fresh water with good water quality for agriculture. Therefore, the project faces a worldwide problem and we try to determine the conditions needed to apply the system for various environmental conditions. By providing pathogen free irrigation the spread of plant diseases will be reduced and loss of food crops is prevented.

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Sustainable Agriculture,
Water Security, Food Security;
Pesticides; Water Quality;
Managed Aquifer Recharge

Cooperation with other institutes:
Acacia Water

Niels van Linden

From pollutant to power

Research objectives

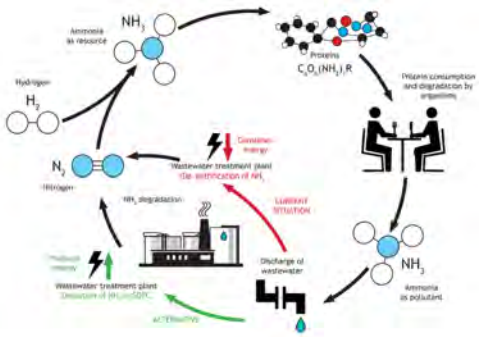
The objective of the From Pollutant to Power research is to develop an energy positive system, including a solid oxide fuel cell, removing ammonia from low carbon/high nitrogen residual water.

Project outline

Introduction

Ammonia (NH_3) is world's second most produced chemical and is a vital resource for protein production. One of the reasons NH_3 becomes present in residual (waste) water is protein degradation by organisms. NH_3 is seen as a pollutant in residual water, because excessive discharge of nitrogen (N) in residual water leads to eutrophication of receiving surface waters and subsequent deterioration of the aquatic environment.

In order to avoid environmental pollution, N must be removed from residual water, before the water is discharged. Current methods applied in waste water treatment plants (WWTP) consume significant amounts of energy: the energy consumption of N removal by nitrification-denitrification requires 57 MJ/kg-N, whereas the more recently developed energy-efficient Anammox process, which is applied at full scale to treat sludge reject-water, still requires 19 MJ/kg-N (Magri et al., 2013).



The From Pollutant to Power research focusses on the recovery of NH_3 from residual streams and subsequent energy recovery by using NH3 as fuel ¬in a solid oxide fuel cell (SOFC).

Approach

In an SOFC working at higher temperatures than 500 ºC, NH_3 is cracked into nitrogen gas (N_2) and hydrogen gas (H_2). The H_2 is oxidized using oxygen ions (O^{2-}), which is present in air. The off-gas of an SOFC contains harmless N_2 and water: no greenhouse gas emission. The electrochemical process results in the production of both electrical and thermal energy: the oxidation of NH_3 in an SOFC theoretically yields 14 MJ/kg-N in total. An SOFC is a highly efficient energy conversion technology, having an electrical efficiency of approximately 50% and a total energy efficiency of 85 – 95% (Ni et al., 2009). An SOFC has specific fuel requirements, which do not match the composition of the residual water streams: the fuel should be gaseous and contain very low levels of oxidants, H_2S and siloxanes (Papadias et al., 2012). Therefore, a suitable NH_3 fuel must be produced from the residual streams.

To this end, a concentration step and a gas extraction step are required. By concentrating the amount of TAN (Total Ammoniacal Nitrogen, the sum of NH_3 and NH_4^+), higher NH3 concentrations in the fuel can be achieved in the gas extraction step, while the thermal energy consumption can be reduced in addition. The selection of the most suitable technologies for these steps is key to this research. After the selection, experiments will be conducted in order to optimize the energy efficiency of the respective technologies. Simultaneously, a mass and energy balance tool will be developed to evaluate various scenarios.

The produced electrical and thermal energy can internally be used, in order to produce a suitable fuel from the residual water streams. When the energy consumption of the fuel production process is lower than the energy production of the SOFC, an energy positive system to remove NH3 from residual streams can be realized.

Results

Initial experiments with an SOFC on NH_3 fuel showed that 8.5 MJ/kg-N of electrical energy could be produced when using a 10% w/w of NH_3 fuel.

In addition, electrodialysis and ion exchange have been identified as suitable technologies for concentrating TAN:

both technologies were able to concentrate 1.5 kg-TAN/m3 by a factor of 6.

Furthermore, vacuum membrane distillation proved to be able to produce a gaseous permeate, containing NH_3 in concentrations 6-8 times higher than the liquid feed.

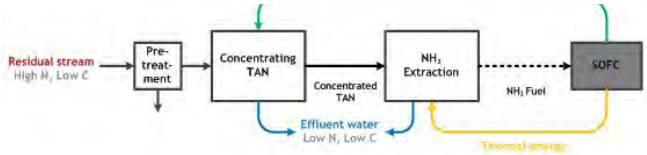
Scientific relevance

Multiple topics in this research will be of scientific relevance, such as the mass transport mechanisms and energy consumption for concentrating TAN. The same holds for the extraction of gaseous NH_3 for SOFC fuel purposes. Finally, the performance of an SOFC on NH_3 fuel produced from residual streams has not been studied yet.

Social relevance

The processing of NH_3 in the described system addresses both the production of clean energy and the treatment of residual water. Since NH_3 is no longer seen as pollutant, but as an energy carrier, this could lead to a paradigm shift: from pollutant to power.

Recognizing NH_3 as a clean alternative energy carriers complements the promotion of NH_3 usage for residual produced sustainable energy storage (from wind, sun, water, etc.) (ISPT, 2017).



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Key words:
Ammonia, SOFC, Electrodialysis, Electrochemistry

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Antonio Manuel Moreno Rodenas

Uncertainty propagation in water quality integrated catchment modeling

Research objectives

This research has as main target to increment the current knowledge on catchment scale water quality modeling.

The objectives involve:

- Study how operational applications of integrated catchment modeling affect the model structure definition
- Evaluate the effects of spatiotemporal variability in rainfall inputs on receiving water impacts at large scale urbanized systems.
- Assess how uncertainties propagate through the different components of a simplified integrated catchment model
- Use knowledge extracted on error propagation to direct models structure improvements and monitoring efforts.

Project outline

Introduction

The use of an Integrated Catchment Models (ICM) is a common strategy to assess the compliance of environmental requirements on water systems, to generate optimal decisions in infrastructure investment or acting as a valuable tool for policy makers. Those models aim to simulate together urban drainage systems, WWTPs and the receiving water quality dynamics. Unfortunately, due to the number and complexity of the linked processes and the scarcity of monitoring data, the predictive capability of these models is often compromised. It is of importance to acknowledge the degree of uncertainty present in their responses. This allows taking decisions from an informed perspective and avoiding "blind" confidence on the model outcomes. Large water systems at catchment scale are composed by several urban systems, which drain excess water to a natural water body. Heavy storm events induce combined sewer systems to overflow untreated wastewater at different locations in the river, which can have an impact in the local ecology. Modeling this phenomenon is a challenge since it involves several systems operating at different time-space scales. However, by studying how uncertainties propagate through the chain of linked submodels we aim to extract knowledge in order to direct further modeling and monitoring efforts.

Approach

In the Eindhoven catchment, calibrated detailed water quality models are available for the sewer, WWTP and receiving waters, together with a simplified integrated model (eg. in Langeveld et al., 2013). In addition, validated monitoring data are available in all sub compartments.

This provides an excellent opportunity to assess the propagation of uncertainties in integrated models, as monitoring data are available on the input (rainfall) and the output (ammonia and dissolved oxygen concentration in the receiving waters), as well as intermediate locations (CSOs, WWTP influent/effluent). This enables the influence of model structure uncertainty transmission to be examined by comparing the uncertainty in the full and simplified models.

Scientific relevance

Watershed management under model-based decision making requires of a deeper knowledge of the uncertainty produced in current water quality models, this project will try to provide a more complete identification of the production and transmission of it in each sub model part. This can lead to a better understanding of the overall process and to be able to highlight the further research needs on data acquisition techniques features.

Social relevance

An incorrect investment plan can either overestimate or underestimate the real needs of the physical system, wasting social resources or not fulfilling the quality requirements. With a finer assessment of the uncertainty in model results, decision makers can select corrective measures and management practices under an objective and informed perspective.

Literature

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Key words:
Uncertainty Analysis, Integrated Catchment Modelling, Geostatistics

Cooperation with other institutes:
EAWAG Swiss Federal Institute of Aquatic Science and Technology, Luxemburg Institute of Science and Technology, University of Sheffield, University of Bristol, Ch2m (Jacobs), Wageningen Universiteit, Justus-Leibig-Universitaet Giessen, University of Coimbra

Julian Muñoz Sierra

BioXtreme – Anaerobic wastewater treatment under extreme conditions

Research objectives

The aim of the study is to understand the bioconversion of model organic compounds (e.g., phenol) existing in industrial wastewaters streams under extreme conditions such as high and fluctuating salinity and high temperatures. The research is focused on the most suitable technology for this purpose (i.e. anaerobic membrane bioreactors, AnMBrs) to encourage reclamation of process waters for reuse. Attention is paid to the bioaugmentation of specific microbial communities and their growth dynamics.

Project outline

Introduction

Industrial wastewaters generated in oil and chemical industries are often characterized by extreme conditions such as the presence of refractory and hazardous chemical compounds, high salinity, high temperatures. Particularly for these extreme types of wastewaters, the conventional biological technologies have many limitations, but membrane assisted bio-treatment offers many advantages such as in-reactor bio-augmentation of the required bacterial species and maximized sludge retention times (SRT), ensuring high metabolic conversion properties per unit of reactor volume. In case auto-immobilization or sludge granulation is difficult, application of membrane technology for pre-treating industrial process waters has several striking advantages: i) system compactness, allowing installation at or even inside the industry; ii) production of suspended solids free effluents, simplifying effluent upgrading techniques; iii) full retention of specific bacterial communities that are required for conversion of complex, recalcitrant and hazardous compounds.

There is an urgent need for sustainable and cost-effective treatment technology that can make this water suitable for (re-)use. BioXtreme is aiming to deliver such a technology. If industrial effluents are properly treated, pollution can be prevented, and water produced can serve as an alternative source for existing freshwater resources or industrial processes.

Approach

A selection of waste streams of interest was made, i.e. at those industries where increased water efficiency is considered but hampered by the nature of the organic pollutants present. The treatability of the process water stream is researched under controlled lab conditions and synthetic wastewater making use of down-scaled reactor systems. Relevant aspects of interests are addressed such as biomass retention/bio-augmentation, conversion/toxicity of organic compounds, microbial population dynamics, sludge filterability, and fouling potential. Studies are conducted with phenol. Phenol is a key intermediate in the anaerobic conversion of a wide variety of aromatics, and, therefore, is of particular interest. Anaerobic treatment of phenol-containing wastewater has been mostly carried out using granular reactors, and its application has been limited to mesophilic and ambient temperature making the anaerobic degradation of phenolic compounds under thermophilic condition a challenge for AnMBRs.

Experimental set-up

The experiments are performed using three laboratory scale anaerobic MBR reactors with an effective volume of 6.5 L, and using an ultra-filtration (UF) membrane modules. The systems are equipped with feed, recycle and effluent pumps, pH and temperature sensors and gas meters. Biogas recirculation pumps are used to mix the liquor. The temperature of the jacketed reactors is controlled at 35.0 and 55.0 ± 0.8 °C by thermostatic water baths. Currently, tubular PVDF membranes with 5.5 mm inner diameter and 0.64 m length are employed. The experimental system is connected to a computer running LabView software to control all pumps and collect pH, temperature, pressures, and biogas flow data on-line.

Scientific relevance

Extreme conditions in the process water and wastewater of the industrial sector encourage the development of non-conventional biological treatment solutions. The research will increase the understanding of how the complex compounds

Figure 1. Experimental set-up/Research keywords

are converted by the microorganisms, what is the influence of different conditions on the biomass properties, microbial community and functionality, and how the process is addressed within the technology selected (AnMBR). Findings are compared with current technologies, elucidating the added advantages of the developed extreme bioreactor concept, including new process configurations and water reuse possibilities.

Impact

Enabling the An-MBR application to a wide range of industrial processes with the potential of water reuse.

Challenge

Finding the optimum operational condition for maximised bioconversion under extreme conditions, without being limited by reduced membrane fluxes.

Social relevance

In the Netherlands, about 80% of the freshwater use is industrial use. The research is focused on fundamental and applied research into the wastewater treatment for application in the industry to compile know-how for optimizing the industrial water cycle and reducing its water footprint. Research with the final aim in water recycling has the potential to improve the effectiveness of the existing technologies and invest in the future well-being of the world's population.

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Key words:
AnMBR, high and fluctuating salinity, thermophilic, chemical wastewater

Cooperation with other institutes:
Evides Industriewater, Paques B.V

Eva Nieuwenhuis

Dutch urban drainage systems in transition: dealing with the uncertainties of a multi-actor context

Research objectives

This study aims for a better understanding of the complexity and the inherent uncertainties of Dutch urban water systems in transition. It uses the urban drainage sector as the focus point. The research focuses on the uncertainties that are introduced by complex urban water problems; i.e., problems in which, besides actors responsible for urban drainage, more actors, e.g. urban planners, but also citizens or even energy suppliers, can be involved. The aim of this research is to provide an answer for urban drainage decision-makers how to actually deal with uncertainties in both the physical system and the network of actors in their day-to-day decisions.

Project outline

Introduction

Ongoing urbanization, changing environmental conditions, stricter emission laws and increasing economic concerns put increased pressure on both the performance and the management of our urban drainage system. Additionally, the system becomes deteriorated; we are in a replacement era that is projected to last until around 2050. Hence, both scholars and policy makers have been raised the question if we should reconsider our traditional wastewater management practices. While it is yet unknown how such new urban water systems should exactly look like, smart solutions have to be found where problems are approached in a more integrated way. This implies that sub-systems will be more tightly coupled, introducing more, and more diverse, interrelationships between subsystems and interdependencies between actors.

Accordingly, the government aims for integrated water management and environmental planning. This implies that more actors are involved in (re)designing the urban water system, all having different interests, responsibilities and perceptions. The (behaviour of the) complex urban water system becomes harder to model, monitor and understand. Since complex socio-technical systems are subjective to many uncertainties, this increases the risk for unforeseen, undesirable, events to occur. It is unclear how different types of uncertainty affect the behaviour of the urban drainage systems and the interacting subsystems. A better understanding of the complexity and the inherent uncertainties of the technical system is required to prevent severe flooding consequences of climate change and continuing urbanization. As actors make the decisions and thereby directly influence the (emergent) behaviour of the urban water system, a better understanding of the uncertainties in the social network is also needed.

Approach

This research uses the urban drainage sector as the focus point. Since the urban drainage system interacts with all other sub-systems of the urban water system, e.g. treatment plants, but in the future maybe also energy plants, the urban drainage system cannot be considered in isolation.

To understand and solve problems occurring in complex socio-technical systems, knowledge of both the technical system and the network of actors in the urban water system is required. This study therefore focuses both on the behaviour of the urban water system from a technical perspective, and on the organisational processes shaping this system.

Scientific relevance

Transition studies provide barriers to implement sensitive urban water systems, but do not provide an answer for decision-makers how they can make decisions that deal with uncertainties.

Meanwhile, technical studies, focusing on how to build robust and flexible systems, only focus on dealing with uncertainties related to the content. They do not provide answers how to make decisions that deal with uncertainties originating from the network of actors.

This study therefore focuses both on the behaviour of the urban water system from a technical perspective, and on the organizational processes shaping this system.

Social relevance

Annually, Dutch inhabitants pay around 1.5 billion euros for sewer system services. We are now in a replacement era that is projected to last until 2050. Replacement decisions define the system's characteristics and functioning for a long time-period, and are therefore costly decisions.

Eva Nieuwenhuis

This implies that we should design urban water systems offering water services that fulfil the needs of today and are flexible enough to adapt to the needs of the future. There are, however, many (new) uncertainties introduced in both the physical system and the network of actors that could reduce system service levels when designing such systems. To keep our feet dry and our environment healthy for lowest costs, urban drainage decision-makers need an answer on how to actually deal with such uncertainties.

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Key words:
Sewer asset management, multi-actor decision-making, transitions, socio-technical systems

Cooperation with other institutes:
Delft University of Technology, Faculty of Technology, Policy and Management, Multi-Actor Systems department, Policy, Organisation, Law & Gaming Section

Celma Niquice

Water reclamation for irrigation in Maputo, Mozambique

Research objectives

Identify and understand current safe practices of water reclamation and gather insights that allow translating those findings into the context of sub-Saharan Africa and, in particular of Maputo; Perform a mass balance to the water in the city. In parallel study the flows of N and P; To conduct and identify risk associated with use of reclaimed water in Maputo in order to determine the existing microbial risks of irrigating with wastewater available; To investigate the fate of nutrient and balances in peri- urban area of Maputo irrigated with wastewater.

Project outline

Introduction

Mozambique is facing water shortage: agricultural water uses accounts with around of 80% of total water uses (DFID, 2003). From total available water flow only 46% is produced in the country and projections indicate that urban water demand will increase by about 40%, with industrial use being expected to augment by about 65% (TWWW and GWP, 2013). Additionally, the storage capacity is low and limits the expansion of agriculture, industries and the overall economic development of the country. Furthermore, access to sanitation services both in cities and rural areas, is deficient. Less than half of population has improved sanitation systems, and only limited amounts of wastewater, which, in some areas, is unsafely reused in irrigation. Also in, Maputo, many of these issues can be identified with the situation being further exacerbated by population growth. A possible solution to address these issues is water reuse. Some studies have pointed positive effects of water reuse in agriculture, such as that adequate water reclamation contributes to addition of water source as well the addition of nutrients for the crops increasing yields (Duran et al 2003) and contributes to urban development (Agodzo et al 2003). This study aims to evaluate the potentials for water reuse for agricultural purposes in Maputo.

Approach

The research methodology will involve both quantitative and qualitative analysis based on available primary and secondary data obtained through direct observations, direct interviews to individuals and field measurements. In addition, a literature review will be conducted to analyze current practices for irrigation with reclaimed water in Sub-Saharan countries, to evaluate reclaimed water potential for irrigation in Maputo . A QMRA tool will be used to estimate the human health risks associated to using non-treated wastewater in irrigation, which will serve as a baseline that will contribute for the selection of most proper treatment technology reuse technique.

Preliminary resultsrelevance

The main reasons for the gap between produced and treated urban waters are obsolete, inappropriate and/or mismanaged sanitation infrastructure, lack in urban planning and limited financial resources.

Irrigation water does not have to necessarily meet the quality as defined in the guidelines' standards to ensure human health protection, the use of a multi barrier approach might be much more cost-effective in ensuring environmental and human health. This alternative comprises a combined approach for selecting wastewater treatment options, followed by post treatment health protection and control measures, such as crop restrictions and post-harvest handling.

Scientific relevance

This project is expected to contribute to:

- Development of water reclamation solutions for irrigation that can be applied to the local situation.
- Knowledge about local water quality available from different sources.

Social relevance

From this research is expected that contribute to:

- Reducing the risks associated with untreated water for irrigation purposes.
- Building a realistic approach for water reclamation in agriculture for Maputo.
- Increasing the relevance of water reuse as means of adding water to the water cycle guaranteeing the availability of water in Mozambique for irrigation.
- Influencing institutions and companies to change their decisions making and contributing to sustainable
- development of Mozambique.

Literature

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Key words:
Water reuse irrigation, waste water treatment, Agriculture water reclamation

Cooperation with other institutes:
UEM, UNESCO IHE

Gabriela Karina Paulus

Development and application of Multiplex qPCR for Antibiotic Resistance Genes in the Water Cycle

Research objectives

Develop, Evaluate and Apply Multiplex qPCR assays to detect ARG and dissemination in environmental water systems with higher accuracy than NGS and a higher throughput than regular qPCR, to obtain an accurate picture of ARG in the urban water cycle.

Methods

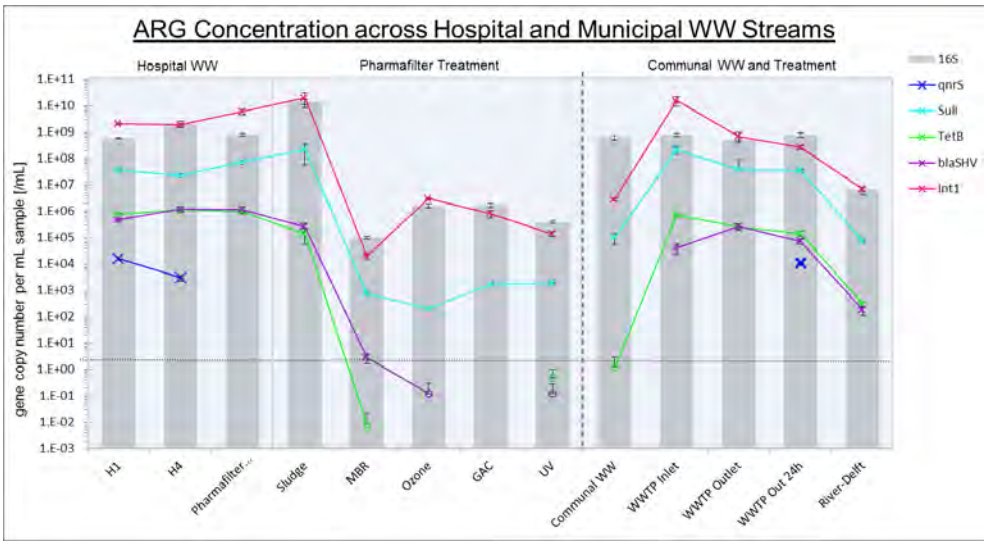
Six genes were included in the study: 16S rRNA, blaSHV, IntI, qnrS, SulI and TetB. The selection was based on the available literature and the clinical relevance. Multiplex Q-PCR assays were composed by combining M1: internal control, SulI and qnrS and M2: 16S rRNA, blaSHV, TetB and IntI. Compatible probes were designed and the Multiplex qPCR assays were evaluated using composite controls with varying, predetermined concentrations of ARG as well as with spiked environmental samples. After development the Multiplex qPCR, assays were applied to different surface water samples collected along the river Rhine catchment (NL, DE and CH) , starting from relative undefiled conditions upstream in Switzerland to more anthropogenically polluted area's in Germany and the Netherlands. Furthermore wastewater samples from a Dutch hospital were investigated for the presence of ARG, the standard communal treatment was compared to on-site waste water treatment with a Pharmafilter.

The ARG concentrations measured were corrected by the factor of loss of genetic material of the internal control added before the DNA extraction process. All qPCR experiments were done in triplicate.

Conclusion

Multiplex qPCR

Accurate quantification of genes in composite and spiked environmental test samples could be achieved and exact quantification of ARG is therefore possible with the developed Multiplex qPCR assays. ARGs could accurately be identified and quantified through the developed multiplexes, even at in test samples with concentrations of ARGs varying as far as 100-fold. The high throughput and accuracy of the multiplex qPCR efficient quantification system is of additional value as the concentration of the significant spectrum of ARG in environmental samples is often unknown and large concentration disparities between different ARG are to be expected.



Gabriela Karina Paulus

ARG Distribution along the Rhine

SulI and IntI were the most abundant ARG found. IntI concentrations varied across the Rhine with 3.3E+02 (Diepoldsau, CH) up to 3.6E+06 (Utrecht, NL). SulI concentrations were more stable with variotions from 1.2E+03 to 1.0E+04. TetB and blaSHV could detected in the area between the Swiss-German border. A correlation between the concentration of IntI and the concentration of other ARGs could be observed. Overall, the expected increase of ARGs across the Rhine could not be observed.

ARG Concentration in Hospital and Municipal WW and the Advantages of local WW Treatment

High concentrations of ARGs could be detected in hospital WW. Further, a broader range of ARG could be detected in hospital WW when compared to municipal WW, with the Quinolone resistance genes (qnrS) being present only in hospital effluent.

The local treatment of hospital WW (with Pharmafilter installations) reduced the ARG concentrations by 3 to 5 log units, reducing the ARG concentrations to below ARG concentrations in communal WW effluent, both in total numbers and normalized to 16S rRNA.

A local treatment of high-risk WW effluents might therefore be beneficial in terms of ARG reduction.

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Key words:
antibiotic resistance, bioinformatics, mobile genetic elements, toxicology

Cooperation with other institutes:
KWR Watercycle Research Institute

Javier Pavez Jara

Formation and impact of recalcitrant and/or toxic compounds generated in Thermal Pressure Hydrolysis (TPH) of waste activate sludge

Research objectives

To understand mechanisms behind formation of recalcitrant and/or toxic compounds generated during Thermal Pressure Hydrolysis (TPH) of Waste Activated Sludge(WAS) as pretreatment prior to anaerobic digestion as well as the implications in the subsequent steps of the sludge digestion, rejection water, and waste water treatment.

Project outline

Introduction

One of the most significant uses of Anaerobic digestion (AD) can be observed in Waste Water Treatment Plants (WWTP) in order to reduce, stabilize and recover energy from primary and secondary sludge generated in the treatment of municipal sewage [1].The sludge management is a fundamental issue to be approached by modern WWTP where it can represent about 50% of the total costs of the treatment[2].Thus, actions that seek to improve the sludge conversion to methane and reduce the excess sludge production are desirable in WWTPs.

Many researchers agree that generally, the limiting step in AD of sewage sludge is the hydrolysis of particulate matter and complex polymers to soluble substrates[2-4]. In order to enhance the hydrolysis, improve the methane yield, and reduce the sludge retention time in the reactors, varieties of sludge pre-treatments have been developed in lab scale with various levels of success, such as mechanical, thermal, chemical, biological or integrations of these[5]. The aim of the current investigation is focused on Thermal Pressure Hydrolysis (TPH), and how the compounds generated in this process could affect the rest of the waste water treatment.

Several TPH pre-treatment technologies are commercialized at industrial scale, such Cambi®, Biothelys®, Exelys®, TPH®, Lysotherm®, Turbotec®. All full-scale TPH processes operate close to a temperature around 160-180°C and a time: 20-40min to reach an acceptable extent of disruption, avoiding the formation of refractory compounds at higher temperatures. The formation of refractory components has been reported by several authors without a clear consensus about which are the specific components that are being formed and how to avoid its formation. This refractory compounds may affect the subsequent steps of the waste water treatment causing unknown or even undesirable side effects.

Recalcitrant compounds formed in TPH may interact negatively in the subsequent steps of treatment, possibly affecting the biological consortia both anaerobic and/or aerobic. Possibly the formation of toxic compounds generated in TPH may affect the anaerobic process causing inhibition with the subsequent loss in organics degradation and methane production. On the other hand, the recalcitrant compounds that cannot be degraded by the anaerobic biomass can leave the anaerobic step without alterations, leading to disturbances during the next treatment steps, especially in those which are focused on the treatment of the sludge reject water. In many WWTPs, the digestate is recirculated to the aerobic treatment sometimes pre-treated by N and P removal systems. In this respect, it is very important to assess the effect of the formed recalcitrant compounds on sensitive processes like Anammox where toxic compounds may lead to process perturbation. Also an increase in nutrients release after WAS pre-treatment prior to anaerobic digestion may have undesirable side effects. This solubilisation may have unexpected consequences in the next steps of sewage treatment, such as: pipe clogging (phosphates or other ions precipitation), inhibition of the anaerobic biology by ammonia, or others. Therefore a clear understanding of the effects caused by the nutrients solubilisation is required in order to propose strategies to overcome problems associated with these phenomena.

Approach

The proposed research consists of literature research, laboratory research, on-site research.

Results

No tangible results yet.

Scientific relevance

This project allow to understand the behavior of the recalcitrant compounds and the effect on the next steps in waste water treatment. This field has not been well explored, thus there is space to disseminate the generated knowledge via scientific conferences and scientific articles.

Social relevance

Recalcitrant compounds formed during TPH process, may have a toxic effect in the receptor water bodies or even human health. Hence, a well understanding of the processes involved in the formation of these compounds is fundamental to prevent their formation and their possible negative side effects.

Literature

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3. Eastman, J.A. and J.F. Ferguson, Solubilization of Particulate Organic Carbon during the Acid Phase of Anaerobic Digestion. Journal (Water Pollution Control Federation), 1981. 53(3): p. 352-366.
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Key words:
Thermal pressure hydrolysis, anaerobic digestion, melanoidins.

Cooperation with other institutes:
TU Delft, Vechtstromen, De Dommel, Vallei en Veluwe, Waterbedrijf Limburg, Paques BV

Antonella Piaggio

Use of (an)aerobic DAF systems for efficient biomass retention in anaerobic sewage treatment reactors

Research objectives

The aim of this research is to deeply understand and assess the coupling of Anaerobic Digestion with Dissolved Air Flotation Systems, and compare it to Anaerobic Membrane Bioreactor, when treating domestic wastewater.

Project outline

Introduction

Anaerobic Digestion (AD) is a strictly anaerobic process where oxygen is toxic for the methanogenic bacteria, and generally operates at an oxidation-reduction potential (ORP) of about -400 mV. AD has four main phases: hydrolysis, acidogenesis, acetogenesis and methanogenesis, where either hydrolysis or methanogenesis determines the overall conversion rates (van Lier, et al., 2008). During hydrolysis, enzymes convert undissolved matter (lipids, proteins and carbohydrates) into dissolved and less complex one. This process may be the slowest and bottleneck of all anaerobic digestion, especially when treating wastewater with a high particulate matter content (Visvanathan and Abeynayaka, 2012). In the last step of AD, methanogenic bacteria convert the compounds from acetogenesis (mainly acetate), into methane, carbon dioxide and new cell material. Both steps (hydrolysis and methanogenesis) are affected by wastewater characteristics and reactor operation conditions such as, operating pH, temperature, possible toxicity, nutrient content, and the nature of the organics.

Hydrolysis process can be done by facultative and anaerobic microorganism. Thus, if both microorganisms are able to convert undissolved matter into dissolved one, this step will be faster. According to Jenicek, et al. (2014), establishing microaerobic conditions is a possible approach to improve anaerobic digestion products. He defines microaerobic digestion as one with limited amount of oxygen and a small increase in the ORP caused by micro-consumption of oxygen in comparison with anaerobic conditions. Under these conditions, facultative microorganism may grow and promote hydrolysis, enhancing the overall AD process.

Micro-aeration may be a novel treatment to enhance AD, but it is also being used for separation of liquid and particulate matter in Dissolver Air Flotation systems (DAFs). As anaerobic Membrane Bioreactors (AnMBR), DAF are able to decouple hydraulic and solids retention times. Furthermore, when comparing DAF with ANMBR, the two main constrains of the latter (cake formation, and operation costs) are overcome by DAF. Additionally, DAF performance is not as compromise when dealing with vary fluxes and low strength wastewaters. On the other hand, DAF removal efficiencies and effluent quality are lower than in AnMBR. Thus, coupling DAF and AD is a novel treatment train that needs to be further assess.

Approach

The research will focus in the evaluation of two different laboratory scale treatment trains (DAF+AD and AD+DAF) ran with air and biogas, treating synthetic wastewater. Planning is divided in 6 main topics, considering the working load, possible publications and research manuscript: 1. DAF particle removal and modelling in laboratory scale: 2. Microaeration as a pre-treatment of anaerobic digestion: effects on biogas and sludge; 3. DAF couple with AD: performance assessment; 4. AD couple with DAF: performance assessment; 5. Comparison of the performance and removal efficiencies of the best treatment train from points 2 and 3 with AnMBR; and 6. Pilot plant build-up and set-up.

Scientific relevance

This research will help in the deep understanding of effects of microaeration in anaerobic digestion. Furthermore, it is a promising approach for wastewater treatment, where the system is decentralized, flexible, focus on resource recovery and treated (waste)water reuse.

Social relevance

The outcomes of this research may be useful for water stress cities, where water availability plays a key role in economic development and population health, because it is centre on resource recovery and treated (waste)water reuse.

Literature

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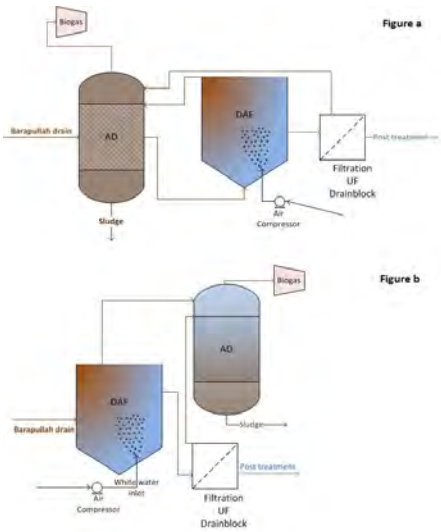

Figure a represents AD+DAF, while Figure b shows the DAF as a pre-treatment to AD

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Key words:
Wastewater, DAF, anaerobic digestion, resource recovery

Cooperation with other institutes:
IHE Delft, National Environmental Engineering Research Institute (India), The Energy and Resource Institute (India), Nijhuis.

Matthijs Rietveld

Solids in sewer systems

Research objectives

Post et al. (2016) have shown that most failures of sewer systems occur in the anterior part of the sewer system. This anterior part consists of lateral house connections and gully pots. This research will mainly focus on the maintenance in that part of the sewer system. Proactive maintenance is used to prevent flooding, but proactive maintenance can only be provided in a cost efficient way if enough information or knowledge is available.

Currently, the physical phenomena of transportation and accumulation of solids in sewer systems are not fully understood.

The objective of this research is to increase the knowledge on solid transport and accumulation of solids from streets. These enter the sewer system via gully pots during wet weather conditions.

Project outline

Introduction

Sewer systems have two inputs, namely wastewater and storm water. Both streams consist almost entirely of water, but the small amount of entrained solids give raise to a wide range of problems.

The two main problems caused by these solids are accumulation and pollution. Accumulation occurs at all places in sewer systems. This leads to restrictions and blockages, which causes, according to Fraser and Ashley (1999), premature spills.

These events do not only cause nuisance, but also environmental damage and health risks, because these solids are highly polluted, according to Fulcher (1994).

One of the sources of these solids are the solids that accumulate on streets. Especially the small particles on streets get mobile during wet weather conditions, as shown by Grottker (1987). These mobilised particles enter the sewer system via gully pots.

Approach

The research will be divided in five research questions:

1. What solids are transported to gully pots?
2. What solids got retained in gully pots?
3. What physical mechanism influences the retention efficiency of gully pots?
4. Does street sweeping decrease the amount of solids transported to gully pots?
5. Does the amount of removed solids from main sewers increase by increasing the cleaning frequency?

These research questions will be answered by the results of five different experiments. The relation between the research questions and the five experiments is shown in figure 1.

Scientific relevance

This project will give insight in the accumulation and transportation of small particles. These phenomena are important in many different research fields. The tests that will be performed will increase the knowledge of these phenomena in the world of sewer systems.

Social relevance

By increasing the knowledge on accumulation and transportation of sewer solids, the maintenance programme can be improved. This will decrease the costs and improve the serviceability of the sewer system. This reduces environmental damage, health risks and nuisance.

Literature

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Matthijs Rietveld

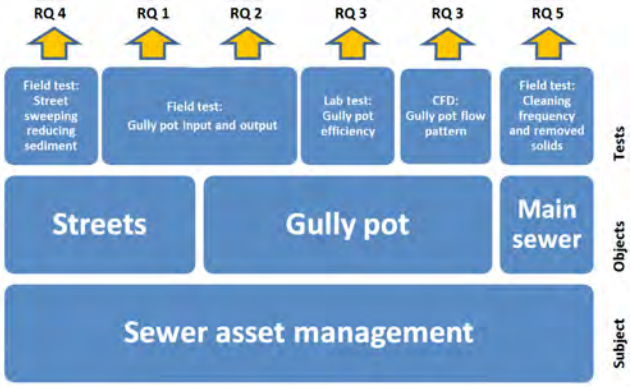

Figure 1. The five blocks at the top represent the tests that will be performed. These cover three different objects and one subject. The five research questions are covered by the five tests, which are needed to develop a cost-effective maintenance program for solid management in sewer systems.

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Key words:
Sewer asset management, gully pots, solids, accumulation

Cooperation with other institutes:
KU Leuven

Muhammad Risalat Rafiq

Water quality assessment of small-scale managed aquifer recharge systems for drinking water provision in coastal Bangladesh

Project outline

Introduction

Sustainable drinking water supply is a major concern issue for achieving millennium development goals. Nevertheless, it becomes a major challenge due to rapid population growth in urbanizing deltas. Groundwater and surface water often become vulnerable to climatic change, over-exploitation, and to some extent economic development. This situation becomes worse in coastal regions of Bangladesh. In the coastal regions (Khulna-Satkhira-bagerhat) of Bangladesh, groundwater is brackish to saline and surface water becomes scares in the dry season.

To combat against above described scenario, MAR (Managed Aquifer Recharge) is introduced as promising technique in coastal areas of Bangladesh. A typical MAR system consists of infiltration wells which are constructed to recharge the shallow aquifer using pond and rain water during times of water abundance in the monsoon period. During the dry season when surface water resources dry up, the stored freshwater is recovered from a central well (Figure 1). Other advantages of MAR systems include filtering of pathogens and availability of water sources being protected during cyclonic storm surges that sometimes flood the area.

A consortium of UNICEF, Department of Public Health (DPHE), Dhaka University (Department of Geology) and Acacia Water (Consultants, the Netherlands) built 20 pilot MAR systems in Khulna-Satkhira-Bagerhat regions in 2012. At present, a total of 99 sites have been constructed after initial successes. The NWO UDW DeltaMAR project investigates scientific knowledge caps in relation to the self-propelling of MAR systems in the region. The project includes 4 PhD projects concerning water quantity and quality, governance, and hydrogeological research questions.

Research objectives

In Managed Aquifer Recharge (MAR), aerobic fresh surface water is injected into anoxic brackish aquifers. The research objective of this water quality PhD project (started January 2016) is to assess the hydro-geochemical changes (water quality improvements and deteriorations) that could occur when surface water is stored in these aquifers. A focus issue is the potential mobilization of arsenic which has been observed at some sites.

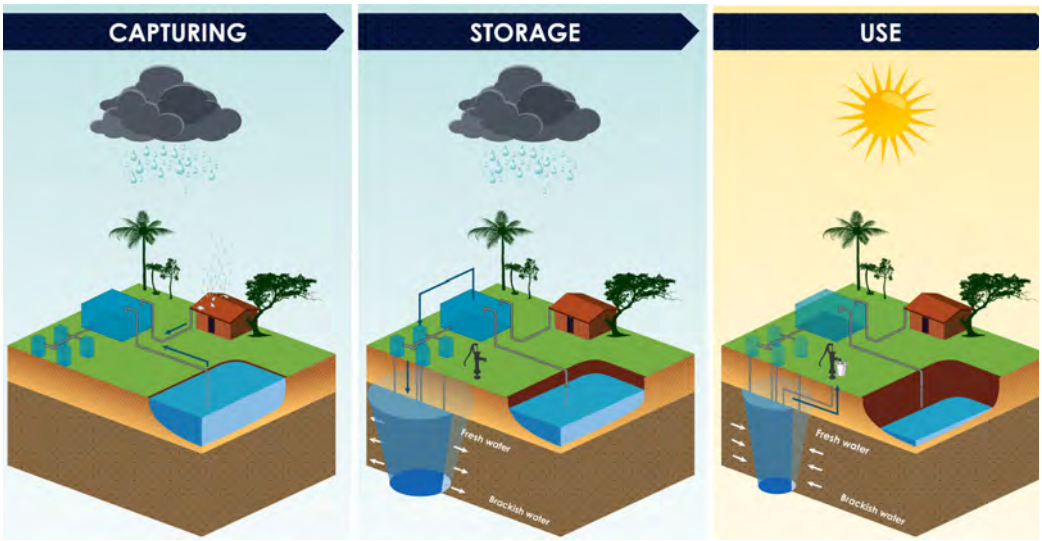

Figure 1: Conceptualized diagram of Managed Aquifer Recharge (MAR) system in Bangladesh

Approach

a) Interpretation of existing data of 99 MAR sites: Python-pandas programming will be used to define groups of sites with similar geochemical behavior. 4-6 representative sites in terms of geochemistry will be identified for the further research.

b) Conducting Push Pull Tests (PPTs) and Batch experiments at selected sites to understand water-sediment interactions for developing site-specific geochemical hypotheses for trace metal (focus on arsenic) (im)mobilizations.

c) Two years of detailed monitoring at 2 selected sites to zoom in and for better understanding of the various hydro-geochemical processes.

d) Hydrogeochemical reactive transport models will be developed and tested with field data using PHREEQC software in order to enable quantitative assessment of water quality changes during MAR at specific locations.

Scientific relevance

Elevated arsenic in shallow groundwater in one of the major water quality issues in Bangladesh. Besides saline to brackish groundwater, high arsenic concentrations is one of the major issues in the project areas. This research will provide insights in arsenic mobilization and immobilization reactions during MAR. With the developed geochemical model site specific conditions can be identified that produce the best water quality and low arsenic levels.

Social relevance

The DeltaMAR project aims to set the scientific framework and provide (practical) knowledge to build many more of these MAR systems in coastal Bangladesh and comparable delta settings ensuring water quality and good governance.

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Key words:
Groundwater quality

Cooperation with other institutes:
Department of Geology, University of Dhaka

Mona Soliman

Enhanced low-cost ceramic membrane filters for drinking water treatment

Research objectives

The objective of this project is to enhance the LCMFs for >log3-5 removal of viruses, in order to reach the "protective" to "highly protective" WHO performance target. This goal can only be reached by making innovative changes to the current membranes.

Project outline

Introduction

The proposed project consists of three sub-projects:

a) Enhanced top layer LCMFs are currently composed of one homogeneous porous layer, whereas for virus removal it is desirable to develop (1) a-symmetric membrane structure, and (2) biofilm promotion on the influent side of the membrane to enhance biological degradation of viruses.

b) Incorporation of metal nanoparticles (with ChemE) Metallic nanoparticles have been found to kill viruses, but have not yet been applied in LCMFs. On-site production and smart mixing of nZVI, nAg and nCu ratios would enhance the current recipe for the removal of both viruses and bacteria.

c) Valorising local materials for human-centered design (with IDE) Improved, integrative LCMF design taking into account end-users' needs, awareness, habits, aesthetic appreciations, existing knowledge, cultural values; and dependency on outside sources for material supply, manufacturing and maintenance.

Particular attention will be given to unraveling virus inactivation pathways, including role of reactive oxygen species (ROS), sub-lethal injury, water quality matrix and post implementation inhibitors.

Results

Initial results point out towards low log removal (1-2 logs) under stable conditions which is less that the target removal. However change in conditions lead to 5 log removal of MS2 –used as virus indicator. The latter is still under investigation.

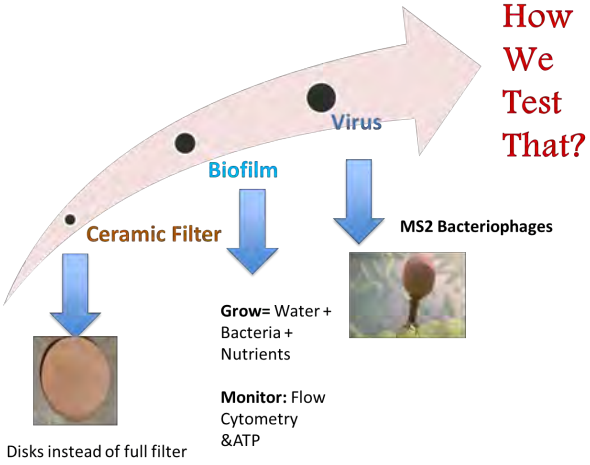
Scientific relevance

The current approach in investigating virus removal and retention in biofilm grown in household treatment has never been investigated before. Despite the natural growth of biofilms in household treatment, it remains unknown if it is a positive addition or negative. Moreover, biofilms grow in drinking water pipes, in soil filtration systems, such as slow sand filters. Thus understanding the interaction between biofilms and Virus is valuable knowledge –not just within the studied context but rather on other studies that investigates the relation between them on general manner.

Social relevance

Ceramic water filters (CWFs) are a point-of-use technology aimed to provide safe water for those in low resource settings. CWFs have been shown to effectively remove bacteria and parasites but fall short of meeting World Health Organization targets for virus reduction. Given the global burden of disease of viruses such as rotavirus and norovirus, improvements in virus reduction could potentially lead to greater health impacts.

Mona Soliman



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Start date project: Jan 2016
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Key words:
Virus, Household treatment, Biofilm

Cooperation with other institutes:
UNI, Nigaragua, UNAN, Nigaragua, Nuevas Esperanzas, Nigaragua, Potters for Peace, Nigaragua, Filter Pure and RDI, Cambodia, University of North Carolina, USA, Practica Foundation, Marcel Tielemans, Het Waterlaboratorium

Bram Stegeman

Sewer Leak Detection, Quantification and Location

Research objectives

This research aims to develop a methodology for detection, quantification and location of sewer leakage based on a combination of existing and new techniques .

Project outline

Introduction

Leakage is one of the dominant causes of structural failure of pressure mains and an important cause of structural failure of gravity sewers. In addition, exfiltration of sewage (wastewater flowing from the sewer system into the ground) might have detrimental environmental effects and threaten groundwater quality used for drinking water production. Infiltration of ground water (groundwater flowing into the sewer system) results in an increased hydraulic loading of wastewater treatment works and a decreased treatment efficiency. Consequently, sewer operators need methods and techniques to be able to detect, quantify and locate leaks.

Approach

In this research two existing in-sewer techniques, focused electrode leak location (FELL) and QUEST-C (Rieckermann et al. 2007) will be further developed and improved and two new techniques derived from geosciences, electrical resistivity tomography and self-potential monitoring will be tested on the same locations. The experiments will be performed on full scale, operational sewers and pressure mains. The potential of the new (geo-electrical) methods will be analyzed for their capabilities to detect and locate and possibly quantify leaks. The monitoring data of the in-sewer techniques will be used to be able to validate the geo-based methods.

Scientific and social relevance

The current available methods do not provide the necessary information about leakage of sewers, pressure mains and subsequent infiltration or exfiltration. In order to obtain the necessary information, there is a need for a clear strategy based on a combination of existing and new techniques. The introduction of new techniques will complement the available technologies for detecting, quantifying and locating infiltration or exfiltration (I/E). The greater choice of techniques will enable sewer system and transport system operators to select an appropriate and cost effective strategy for dealing with leakage that can be readily applied, enhancing the development of novel operation and maintenance concepts.

Literature

Rieckermann, Jörg, Vojtěch Bareš, Oliver Kracht, Daniel Braun, and Willi Gujer. 2007. “Estimating Sewer Leakage from Continuous Tracer Experiments.” Water Research 41(9):1960–72.

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Start date project: Feb 2017
Expected end date: Feb 2021

Key words:
Leak detection, sewer, infiltration, exfiltration, electrical monitoring

Cooperation with other institutes:
Research is part of Cooperation Programme TISCA (Technology Innovation for Sewer Condition Assessment)

Maja Taucer-Kapteijn

Cellular slime moulds as regulators of bacterial numbers in faecal droppings and soil - are they important to the drinking water industry?

Research objectives

Microbial contamination of drinking water abstracted from infiltration areas and water bodies in general may occur via faecal contaminations, containing large numbers of faecal indicator bacteria (FIB) and possibly also pathogens, on the surface near shallow abstraction wells or receiving water bodies. The consumption capacity of cellular slime moulds (CSMs) can be important in the regulation of bacterial numbers. This study aimed to determine whether CSM (dictyostelids) can be isolated from soil and dung obtained from infiltration area and if they are able to consume FIB. In order to estimate the potential predation pressure caused by these organisms in terrestrial ecosystems, the growth rate of D. mucoroides was examined using P. fluorescens as a nutritional source.

Project outline

Introduction

When FIB and possibly also the pathogens are released into the environment, they may be rendered inactive due to starvation, drought, UV (sunlight) etc., but also due to biological factors such as predation (Byappanahalli et al., 2012). Grazing by protozoa, bacteriophage infection followed by virus-mediated lysis, and predation by some bacteria are among the biotic effects that control the abundance of prokaryotic organisms in the environment (Byappanahalli et al., 2012). Protozoa (e.g. cellular slime moulds) are present in soil and faecal matter and they also feed on bacteria (Raper, 1984). In terrestrial systems, amoebae are considered important predators of bacteria and many of these amoebae belong to slime moulds. However, the role of protozoa in soil and faeces on the concentration of FIB has not yet been explored. This study examined the potential of CSMs to reduce the microbial numbers in both faecal droppings and the soil.

Approach

Culture methods were applied to isolate CSM (Dictyostelium mucoroides) from the soil samples and faecal samples (Ovis aries, Capra hircus and Oryctolagus cuniculus) collected from the Dutch dune area. Predation on FIB was studied by using Escherichia coli, Clostridium perfringens, Enterococcus faecalis, E. faecium, E. moraviensis and E. hirae as bait for the D. mucoroides. In order to evaluate the possible impact of these grazers on the microbial abundance in soil and dung, the maximal growth rate of D. mucoroides was determined using P. fluorescens as food.

Results

This study confirmed the presence of CSMs (dictyostelids) in both soil and dung obtained from an infiltration area. The ability of D. mucoroides to feed on several species of indicator bacteria (E. coli, C. bifermentance and five species of Enterococcus) was experimentally demonstrated. It was found that D. mucoroides is able to grow within three days up to 1.6×10^5 amoebae in a single test area of c. 10 cm^2. This indicates that CSMs have a considerable influence on the microbial community in both soil and dung.

Scientific relevance

This study is the first exploration in the field of CSMs in relation to the production of drinking water via shallow recharge wells. Laboratory experiments demonstrated a) the presence of CSMs in soil and dung collected in the dune infiltration area, b) their ability to consume FIB and c) to multiply massively in a relatively short period of time and be able to reduce substantial numbers of bacteria in dung and soil.

Social relevance

The results of the study lead to a recommendation to include the possible impact of CSMs in microbial risk evaluations in infiltration areas and recharge installations for the production of drinking water.

Literature

Byappanahalli MN, Nevers MB, Korajkic A, Staley ZR, Harwood VJ. 2012. Enterococci in the environment. Microbiol. Molec. Biol. Rev. 76(4):685–706.

Raper KB. 1984. The Dictyostelids. Princeton University Press, Princeton, New Jersey.

Maja Taucer-Kapteijn

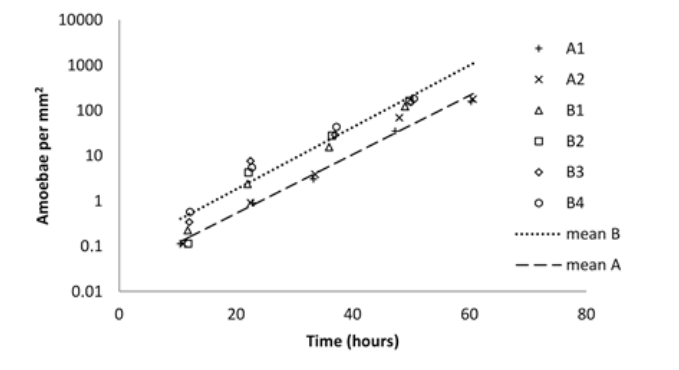

Figure 1: Growth curves of Dictyostelium amoebae cultured on water agar with an abundance of P. fluorescence P17 as food bacterium. The dashed line shows the average curve of regression duplicates tests A1 and A2; the dotted line shows the average curve of regression of four-fold measurement B1, B2, B3 and B4.

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Start date project: Jan 2012
Expected end date: 2017

Key words:
The role and source tracking of *Enterococci* als feacal indicator in dune recharge area

Cooperation with other institutes:
Het Waterlaboratorium

Adithya Thota Radhakrishnan

D-SHiT: Domestic Slurry Hydraulics in Transport systems

Research objectives

Focused on studying the transport aspects of domestic slurries, the study aims at characterizing the slurries with respect to its rheological behavior and building a 1-dimensional non-Newtonian multiphase flow model. This enables us to design efficient slurry transport systems for future sanitation concepts.

Project outline

Introduction

New sanitation concepts (Fig. 1) stem from the need for better nutrient recovery from domestic slurries and water management. Traditional sanitation concepts use large amount of water, thereby making the slurries dilute. Whereas, new sanitation concepts focus on reducing the consumption of water and possess pressurized pipelines to transport them. This reduction in the consumption of water are generally attributed to the success of these new sanitation concepts, and investigations show that these slurries can be treated more efficiently.

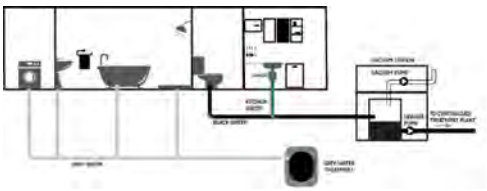

Figure 1. Schematic of a new sanitation concept

Future domestic slurries are likely to contain a significant fraction of grinded kitchen waste; with low water consumption, it makes the slurry concentrated with solids and therefore they exhibit non-Newtonian behavior. A number of transportability issues for new sanitation concepts arise, related to the dilution and multiphase interaction.

The D-SHiT (Domestic Slurry Hydraulics in Transport systems) project was initiated to address these issues of concentrated domestic slurry (CDS); for this the project is divided into three parts.

- Rheological characterisation of non-Newtonian multiphase CDS
- Transport experiments at the pipeline test loop
- Developing a transport model for these slurries

Approach

The rheological characterisation of the slurries will be done using a rotating viscometer resulting in a relation for shear stress for shear rate applied on the fluid. The influence of solid concentration and temperature on the rheology will be determined. The experiments will be performed using slurry samples collected from a small-scale pilot project in Sneek (Leuwarden) running these sanitation concepts.

Artificial slurry which mimics the rheological behaviour of CDS will be used to perform the experiments in the pipeline test loop. Initially the turbulent flow of the fluid will be studied and later the flow with gas. Using the data from experiments, a 1-dimensional transport model will be built to design the transport system. Assumptions that reduce the complexity of the model will be validated using CFD.

Results

The viscosity and yield stress of grinded kitchen waste and brown water increase with concentration of total solids present as seen in Fig. 2. This can be attributed to the complex solid-solid and solid-liquid interaction. A decrease in yield stress and viscosity can be observed with the increase in temperature; due to the increase in thermal activity.

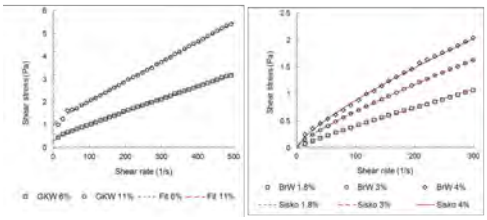

Figure 2. (Left) Rheology of Grinded Kitchen Waste at 11% and 6% solid concentration with Combined Herschel-Bulkley model fit. (Right) Rheology of Brown Water at 1.8%, 3% and 4% solid concentration with Sisko model fit

The assumption that CDS can be modelled as a homogenous single-phase fluid represented by its bulk viscosity and density is verified using CFD (Fig. 3). This is done by mirroring the rheological experiment in CFD where the fluid is modelled as being homogenous and comparing the results (Fig. 4).

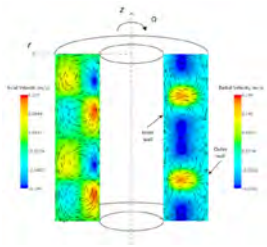

Figure 3. CFD mirror of the rheological experiment

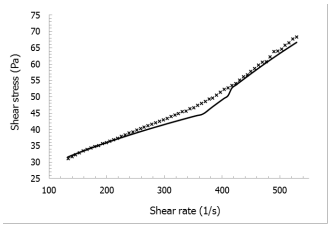

Figure 4. Comparing the experiment results (-) to that from CFD (x)

Social & Scientific relevance

In the industrialized world, flushing the toilet with large quantities of water is a routine. In other parts of the world sanitation is not that simple. Due to lack of infrastructure and water scarcity, around 2.5 billion people have no sufficient sanitation at their disposal. The new sanitation concept overcomes the sanitation problems due to lack of water resources. Moreover, the sanitation concept offers promising results with respect to recovery of nutrients and production of energy (bio-gas). All these benefits can be achieved in large scale if the whole chain of new sanitation systems are economically competitive with the common practise. Although all recent research on the new sanitation concept focus on treatment processes and source separation, to benefit from these concepts all aspects of sanitation systems including the collection and transport need to be considered.

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Start date project: Oct 2014
Expected end date: Oct 2018

Key words:
Domestic slurries, rheology, pressure loss, transport design, hydraulics, CFD, non-Newtonian, multiphase

Cooperation with other institutes:
Research is conducted within the framework of a STW project: Waternet, Rioned, STOWA, Deltares, Waterschap Zuiderzeeland, Grontmij, XYLEM

Héloïse Thouement

Safer monitored natural attenuation of chlorinated ethenes through stable isotopes study and modeling

Research objectives

This project aims at facilitating the tracing of environmental pollution and degradation by the use of isotope analysis. For this aim, the computer simulations of pollutants isotope fractionation during degradation and transport in aquifers are created based on the available literature, and interpreted.

Project outline

Introduction

Chlorinated ethenes (CEs) are widespread groundwater contaminants. Their potential for natural biotic and abiotic degradation encouraged monitored natural attenuation (MNA) as an alternative to invasive and potentially more costly remediation technologies. MNA requires unquestionable evidences of the CEs degradation and its quantification. The study of compound specific isotope analysis (CSIA) data links degradation extent to quantifiable changes in the isotope composition of the CEs (Hunkeler and Aravena, 2000). At field sites, the complexity of CSIA studies resides in the diversity of the degradation pathways and resulting isotope enrichment patterns, the potential for other processes (diffusion, sorption) to modify the CEs isotope composition (Kopinke et al., 2005; Wanner et al., 2016), and the generally limited number of data available for the characterization of complex underground processes.

Approach

The project investigates three complementary applications of CSIA tools. Carbon/chlorine/hydrogen (C/Cl/H) CSIA data of several CEs at a well described polluted site in Utah were studied first without additional modeling, and then through a batch model study of the said data, using a previously published degradation model (Breukelen et al., 2017). In a second time, a synthetic carbon CSIA dataset of an aquifer-aquitard-aquifer system was created and investigated, including CEs degradation in the aquitard and isotope fractionation for all fractionating processes (sorption, diffusion and degradation). The numerical models are developed on open-source or freely available software (PHREEQC, ModFlow) and with python.

Results

At the field site, CSIA data put in evidence the existence of two degradation pathways. Additionally, the effect of diffusion on isotope fractionation could be discerned from those of degradation. The model study, despite being a simple batch model, successfully retrieved some of the observed degradation patterns at the field site including the two different degradation pathways, and was able to narrow the CEs degradation extent. This was the first attempt to model C/Cl and H CSIA field site data.

Finally, the synthetic dataset suggested that CEs degradation in a reactive aquitard could be detected based on aquifer samples, easier to obtain than aquitard samples, and was discernable from diffusion and sorption fractionation effects.

Scientific relevance

In the western world, numerous CEs polluted sites were already remediated. Remaining sites might present additional complexity such as long term back-diffusion from low-permeability layers. The methods and conclusions of this project can be employed by remediation specialists in the context of those ageing sites with plumes in contact with low-permeability layers.

Social relevance

The result of the study is to be employed for insuring safe monitoring natural attenuation. The risk to contaminate water supply with CEs is therefore reduced, preventing the development of sicknesses in the population or extra decontamination costs.

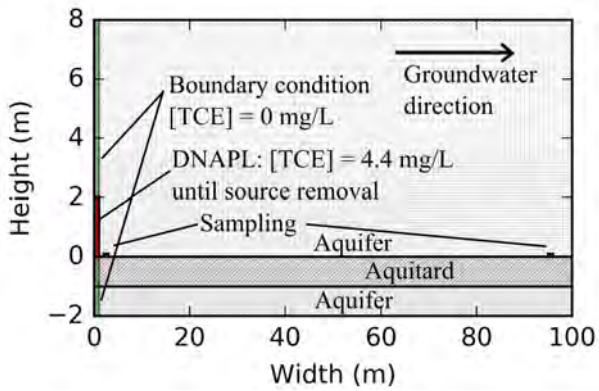
Literature

Breukelen, B.M. Van, Thouement, H.A.A., Stack, P.E., Vanderford, M., Philp, P., Kuder, T., 2017. Modeling 3D-CSIA data : Carbon , chlorine , and hydrogen isotope fractionation during reductive dechlorination of TCE to ethene. J. Contam. Hydrol. 204, 79–89. doi:10.1016/j.jconhyd.2017.07.003

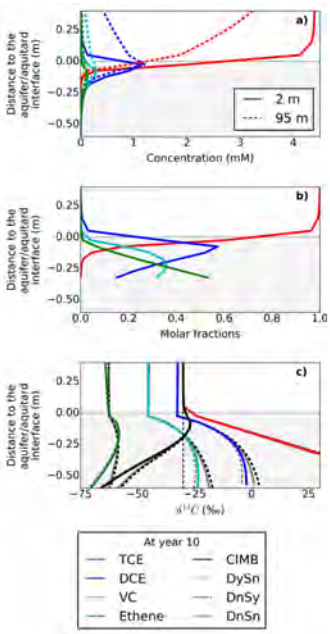
Hunkeler, D., Aravena, R., 2000. Determination of compound-specific carbon isotope ratios of chlorinated methanes, ethanes, and ethenes in aqueous samples. Environ. Sci. Technol. 34, 2839–2844. doi:10.1021/es991178s

Kopinke, F.D., Georgi, A., Voskamp, M., Richnow, H.H., 2005. Carbon isotope fractionation of organic contaminants due to retardation on humic substances: Implications for natural attenuation studies in aquifers. Environ. Sci. Technol. 39, 6052–6062. doi:10.1021/es040096n

Wanner, P., Parker, B.L., Chapman, S.W., Aravena, R., Hunkeler, D., 2016. Quantification of degradation of chlorinated hydrocarbons in saturated low permeability sediments using compound-specific isotope analysis. Environ. Sci. Technol. 50, 5622–5630. doi:10.1021/acs.est.5b06330



Model set up for the creation of synthetic datasets.



The base case model of sequential degradation TCE→DCE→VC→ethene shows little impact from diffusion (Dy) and sorption (Sy) isotope fractionation in the aquifer, but the simulations with and without (Dn,Sn) those effects differ in the aquitard (grey zone).

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Start date project: Nov 2012
Expected end date: Dec 2017

Key words:
Coumpound specific isotope analysis, chlorinated ethenes, modeling

Cooperation with other institutes:
VU Amsterdam, University of Oklahoma, SERDP

Sara Toja Ortega

Removal of suspended solids using Aerobic Granular Sludge

Research objectives

The aim of the project is to understand the mechanisms of removal of suspended solids by aerobic granular sludge (AGS). Specific objectives include:

- To assess the ability of AGS to degrade suspended solids
- To evaluate the contribution of suspended solids to biomass growth and nutrient removal.
- To understand the relationship between wastewater composition and AGS characteristics (e.g. morphology, microbial composition, settling behavior)
- To develop experimental methods to track suspended solids and their products.

Project outline

Introduction

Aerobic granular sludge (AGS) is a relatively new water treatment technology that provides an alternative to conventional sewage treatment plants (i.e. activated sludge technology)[1]. It offers the possibility of building compact plants with much lower energy requirements due to the optimal settling properties of aerobic granules. This enables an efficient biomass-effluent separation without the need for additional settling tanks and biomass-recirculating pumps. Furthermore, the microbial composition of aerobic granules allows nitrification, denitrification, phosphorus removal and COD removal in a single compartment[2], which further contributes to the reduction of the space needed for wastewater treatment. In municipal and industrial wastewater, a high percentage of the chemical oxygen demand (COD) to be treated is composed by particulate substrate: in the Netherlands, it accounts for around 50% of the total COD. Suspended solids are removed sufficiently well by using aerobic granular sludge, with average removal efficiencies of 91-99% removal in full-scale installations. However, lab-scale experiments using synthetic or real wastewaters containing suspended solids resulted in changes in granule structure, creating a rough, irregular surface that negatively affects settleability of granules, and could eventually lead to system instability[3,4].

Despite the strong presence of suspended solids in wastewater, little is known about the mechanism of removal or the fate of these compounds. Localising hydrolysis (i.e. bulk liquid, granule surface, flocs), measuring the amount of degradation of suspended solids and their contribution to the system, and understanding their impact in granule structure and function is of great interest to exploit the full potential of aerobic granular sludge.

Approach

Hydrolysis and degradation of different types of complex contaminants will be studied. Experiments will be done in full-scale installations, as well as lab-scale reactors, under different operating conditions and influent composition. Conversions, granule morphology and microbial composition associated to the different influents and operating conditions will be explored. The experiments will be done using model substrates (e.g. cellulose, proteins) as well as real influents.

Scientific relevance

This PhD project will contribute to a better understanding of AGS systems, and the interactions between microbial populations, influent composition and reactor performance. Understanding the fate of suspended solids is a gap that should be filled in AGS research. Furthermore, knowledge on the behavior of SS in AGS could make possible to optimize the system towards a better utilization of the SS present in the influent.

Social relevance

By understanding the degradation and utilization of suspended solids in granular systems, it will be possible to improve the current AGS technology to provide an even more efficient and environmentally friendly sewage treatment technology

Literature

[1] De Bruin, L. M. M. et al. (2004) 'Aerobic granular sludge technology: an alternative to activated sludge?', Water Science and Technology, 49(11-12), pp. 1–7.

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[4] Wagner, J. et al. (2015) 'Effect of particulate organic substrate on aerobic granulation and operating conditions of sequencing batch reactors', Water Research, 85, pp. 158–166.

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Start date project: Jun 2017
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Key words:
Aerobic granular sludge, Suspended Solids, Degradation, Imaging

Cooperation with other institutes:
Montana State University, Wageningen UR, Royal Haskoning DHV, Department of Biotechnology (TU Delft)

Steef de Valk

Enhanced Enzymatic Anaerobic Fermentation of Organic Residues (EnzyFOR)

Research objectives

Aquatic worms that degrade sludge, offer great opportunities to investigate the way nature efficiently hydrolyses complex organic matter. The aim of this research is to explain the increase of sludge biodegradability, observed in worm predated excess activated sludge. This research will give insight into ways to mimic the biological activity of these worms for large scale processes in order to increase the valorisation of waste streams by degradation of complex organic substrates.

Project outline

Introduction

The activated sludge process is most used process to remove organic carbon and other pollutants from waste water. The organic fraction of waste water is aerobically respired and partly converted into biomass. The surplus biomass is a by-product of this process and is called excess activated sludge. The main constituents of activated sludge are biomass, organic matter and water. In general, this sludge stream is partly converted in biogas and partly processed e.g. incinerated.

The major fraction of excess activated sludge consists of complex organic matter, which could be utilized if transformed into volatile fatty acids (VFA) which can serve as precursors for (bio)-chemical industrial processes or biogas. Hereby increasing the valorisation of sludge and reducing the amount of sludge that has to be disposed of.

It has been shown that the aquatic worms increases the solids removal rate of excess sludge significantly. Worms feed on complex bio matter present in sludge and by hydrolyses convert this bio matter into VFA and simple sugars. However the mechanisms in the intestines of the worms are unknown.

Approach

The aquatic worm Tubefix is used as model organism. Worm predated sludge was compared to untreated sludge, both processed under the same conditions to gain more insight into the distinct hydrolytic activity of the worms & intestinal microbial flora and overall enzymatic activities of the worm predation process. Additionally, the microbiology associated with the worm predation process was elucidated. Currently, an in-depth analysis is made regarding the biodegradability of excess (worm predated) sludge and what this means in relation to our extent of sludge degradation.

Results

Batch worm predation tests showed an increased volatile solids reduction compared to a reference process without worms, namely 47% ± 15 for worm predation and 9% ± 5 for the control process (de Valk et al., 2016). Especially the protein fraction of the sludge was consumed by the worms (results not shown). To make a distinction between the activity of the worms and the microorganisms living inside the worms, worms were treated with antibiotics and fed a protein. The results show that worms are at most 70% responsible for the degradation of protein (figure 1 part 2). Interestingly, when the microbiology of activated sludge, the worm faeces and the predated protein-rich substrates, fish food and Azocasein were compared (figure 1 part 3), the sludge based worm faeces showed a large resemblance to the degraded protein substrates. The overall results indicate that sludge worms consume protein with help of or due to a bacterial community geared towards protein degradation.

Scientific relevance

This project will give insight into the hydrolysis of complex organic molecules by the efficient hydrolyser T. Tubifex. In turn this research will help develop a cost effective process for the degradation of complex organics into VFA or biogas by using the knowledge gained through this research namely that proteolytic enzymes are key in efficient sludge reduction.

Social relevance

In order to achieve a sustainable bio-based and circular society, complex organic waste (such as excess sludge) should be transformed into useable products that can serve other bio-chemical industrial processes and thus transform organic waste streams into profitable resource streams. Additionally, this research shows that more sludge solids can be removed which will reduce disposal

costs and thus societal cost associated with waste water treatment.

Literature

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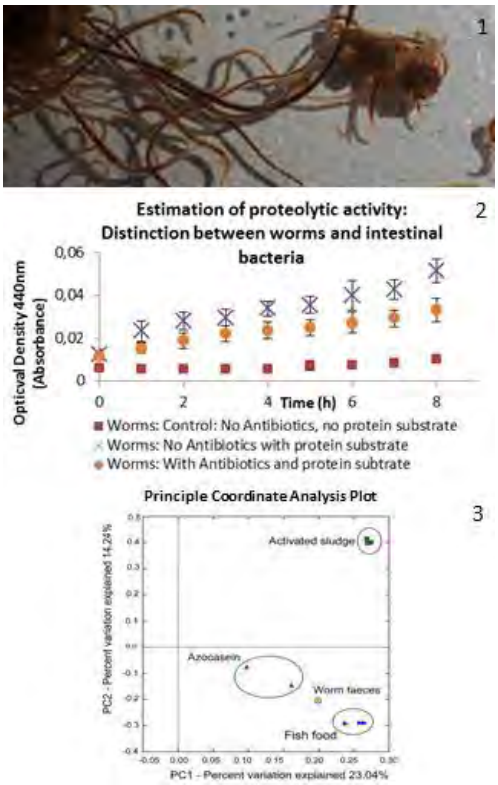

Figure 1: EnzyFOR results and worm pictures. Part 1: A photo of wriggling worms. Photo made by Frank Auperlé.; Part 2: The distinction between intestinal bacteria and the worms themselves by using antibiotics and a protein substrate (de Valk et al., 2017b). Part 3: PCoA which represents the microbial resemblance between different samples namely the sludge based worm faeces (yellow), the protein rich substrates: azocasein (red) and fish food (blue) and the fresh, (non)predated activated sludge (green) (de Valk et al., 2017a).

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Key words:
Sludge reduction, Aquatic Oligochaetes, Worms, Hydrolysis

Cooperation with other institutes:
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Feifei Wang

The Fate of hydrogen peroxide and bromate as by-products of AOP within MAR

Research objectives

- to investigate the reactions of H_2O_2 with various biotic (bacteria/catalase in water and soil) and abiotic constituents (pure sand, organic matter and minerals).
- to evaluate the effect of H_2O_2 on bacterial population and bacterial diversity.
- to study the feasibility of bromate removal within MAR. Specifically, in NO3- reducing anoxic zones and in Fe-reducing anoxic zones.

Project outline

Introduction

The combination of advanced oxidation process (AOP) and managed aquifer recharge (MAR) is a potential system to remove more organic micro-pollutants during drinking water treatment processes. Bromate (BrO_3-) formation has been observed to happen during ozonation of bromide containing water. The disinfection by-product, BrO3-, is an issue to be considered since BrO_3- has been designated as carcinogenic to humans. To prevent bromate formation through O_3 during UV, alternatively H_2O_2 can be dosed, leaving residual H_2O_2 in the treated water. An improved understanding of the fate of H_2O_2, in terms of H_2O_2 decomposition mechanisms, during MAR is key to set the maximum allowed H_2O_2 concentration in the infiltrated water of MAR. There is a great potential in microbiological BrO_3- removal. Studies have shown that bio-reduction of bromate occurs best under anoxic conditions since it is inhibited by oxygen. A cheaper alternative was pointed out by Hijnen, namely the possibility of BrO_3- reduction in the anoxic zones of bank filtration sites. However, no further research about BrO_3- removal in MAR has been conducted.

Approach

To investigate the fate of H_2O_2, batch experiments were performed to simulate MAR using slow sand filter sand with natural microbial communities and synthetic MAR water. 5mg/L H_2O_2 was dosed into different batch reactors containing different types of sand and water to compare decay rate of H_2O_2.

To investigate the BrO_3- removal in NO_3--reducing anoxic zones of MAR systems, batch experiments with and without NO_3- and 8 meter anoxic columns simulating MAR zones were carried out. To investigate the BrO_3- reduction in Fe-reducing zones and its reduction mechanism by Fe^2+, anoxic batch experiments using different pH and different BrO_3- doses were performed.

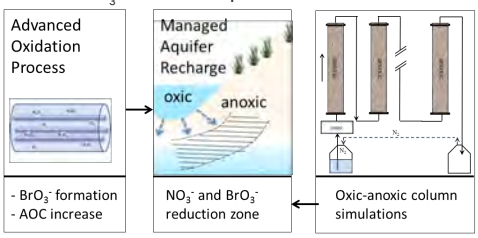

Figure 1 graphic abstract of BrO3- removal simulation in NO3--reducing zones of MAR

Results

The results of oxic and anoxic column (1 m) indicate that BrO_3- and NO_3- compete for reduction by denitrifying bacteria, but BrO_3- reduction and NO_3- reduction can occur simultaneously even if denitrifying bacteria prefer NO_3- to BrO_3- as an electron acceptor. The presence of NO_3- is a precondition for denitrifying bacteria to reduce BrO_3- in NO_3--reducing anoxic zones of MAR systems.

The results of Figure 2 indicate that in the 8 m long anoxic column (retention time 6 days) simulating anoxic NO3--reducing zones of MAR systems, initial 60 µg/L BrO_3- biodegraded to a concentration of 1.3 µg/L, indicating that BrO_3- biodegradation by denitrifying bacteria can happen in anoxic NO_3--reducing zones of MAR systems. MAR systems following ozonation are potentially effective to biodegrade BrO_3-, provided that anoxic NO_3- reducing conditions are reached in MAR systems. The reduction rate of BrO_3- with a concentration similar to MAR depends on the Fe2+ concentration was very slow. Within the 120 hours' contact time, BrO_3- reduction by 0.033 mM Fe2+ (74% in the absence of NO_3- and 58% in the presence of NO3-) was found. The molar mass sum of BrO_3- and Br- was lost, indicating the formation of Br intermediate species, which is agreement with previous studies 1, 2. BrO_3- can be reduced by naturally occurring Fe2+ during MAR, as extensive retention times in the subsurface will compensate for the slow reaction kinetics of low BrO_3- and Fe^2+ concentrations.

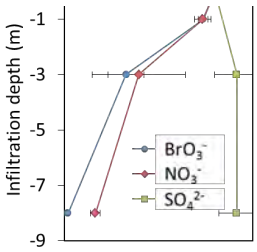

Figure 2 Average concentrations (n=5-8) of BrO_3, NO_3- and SO_4^{2}- with depth in the 8 m anoxic column with acetate supplemented MAR water. T=11.5±0.5 °c.

Scientific relevance

An improved understanding of the fate of H_2O_2within MAR is key to set the maximum allowed H_2O_2 concentration in the infiltrated water. The research on BrO_3- fate in MAR is the precondition for improving BrO_3- removal efficiency. Investigation on bromate fate and removal mechanism within MAR is valuable for developing a natural microbiological bromate method.

Social relevance

For drinking water companies, an improved understanding of the fate of H_2O_2 is useful to make an optimal H_2O_2 decomposition solution before MAR by adding some kind of H_2O_2 decomposition catalyst and the feasibility of BrO_3- removal by denitrification biodegradation in MAR would be a big discover as a new and cost-efficient BrO3- removal method.

Literature

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Key words:
Drinking water, AOP, MAR, H2O2, bromate

Cooperation with other institutes:
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Liangfu Wei

Fluoride removal from groundwater by low-cost mineral-based adsorbents

Research objectives

The main objectives of this paper are to a) investigate and compare the F- uptake by the selected adsorbents from groundwater; b) explore the mechanisms of F- removal; and c) evaluate the (dis)advantages of selected adsorbents for F- removal from groundwater.

Project outline

Introduction

Fluorosis due to excessive concentration of fluoride in drinking water has been reported in at least 28 countries. Around 200 million people over the world are under the dreadful fate of fluorosis [1]. The removal of the excess fluoride from groundwater is essential in terms of protection of public health and environment.

Among the different methods reported in literature, adsorption process is considered to be one of the most promising technologies due to its advantages such as low cost, simple operation, and high effectiveness. In the past several decades, over 100 adsorbents have been developed. Various adsorbents have shown strong potential for the removal of fluoride. However, most adsorbents also have drawbacks that cannot or unsuitable be used in drinking water treatment [2, 3]. By means of comparison to over 100 different materials, Bhatnagar et al. (2011) concluded that mineral-based adsorbents are promising for fluoride removal [4]. This might be due to the fact that mineral-based adsorbents normally possess layered or reticulate structure with electropositive multivalent metal ions which present strong affinity for fluoride because the high electronegativity and small ionic size of fluoride [5].

Approach

Experimental studies were carried out with six different, low-cost adsorbents. Before use, all the adsorbents were crushed using a ball mill, then washed using deionized water for several times and dried in an oven at 65 ☐ for 24h. Fluoride solutions with different concentrations were prepared with sodium fluoride (NaF) as the source. All the initial solutions were adjusted to pH 8.5 using NaOH (0.01 M). The batch adsorption experiments were carried out in 100 mL glass bottles with 100 mL fluoride solutions at room temperature (25±0.5☐). After stirring for 7 days, the solutions were filtered by 0.45 μm membrane then were analyzed by Ion chromatograph (IC).

Results

Figure 1 shows the adsorption isotherms of fluoride uptake on slag based geopolymer, struvite and pellets from Bunnik and Sint Jansklooster. The initial F- concentration was 2, 5, 10, 20, 40, 80mg/l, adsorbent dose was 20 g/l.

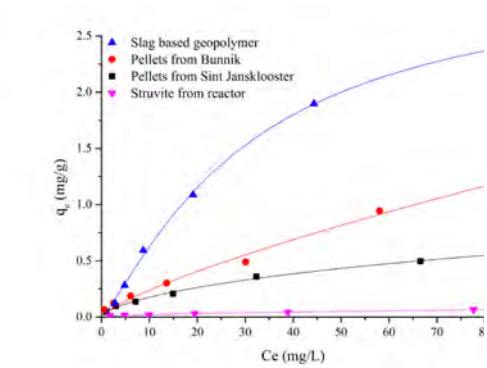

Fig. 1 Adsorption isotherms of fluoride uptake on mineral-based adsorbents.

For all adsorbents, fluoride uptake increased with an increase in the initial fluoride concentration. For the same initial fluoride concentration, the fluoride uptake by slag-based geopolymer was higher than the other sorbents. However, at low concentrations, also softening pellets showed affinity for fluoride. Fluoride removal by struvite was very limited, and there were problems to keep the struvite stable during the experiments. Fly ash- and metakaolin-based geopolymers did not show defluorination effect. These preliminary sorption experiments have shown the potential of softening pellets and slag-based geopolymers for fluoride removal. Future experiments will focus on kinetics, regeneration and leaching.

Scientific relevance

This paper provides the studies on fluoride removal by low-cost mineral-based adsorbents. Six different types of adsorbents were compared for defluorination.

Equilibrium studies were carried out and the best adsorbents performer was selected for the optimization.

Social relevance

An optimized defluoridation system with effective adsorbents will be developed, which can be applied to remove fluoride from groundwater to protect the health of people living in the high fluoride regions.

Literature

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Key words:
Fluoride, Adsorption,
Groundwater, PHREEQC

Cooperation with other institutes:
CSC

Peng Wei

Mixing Characterisation for Enhanced Biomass Conversion Using CFD Modelling in Gas-mixed Anaerobic Digester

Research objectives

(1) In full-scale anaerobic digesters, the influence of specific key factors (rheology, temperature, mixing mode) on mixing processes will be identified and quantified by CFD modelling and experimental validation.

(2) Obtaining an optimised reactor design for better operational performance based on improved mixing and hydrodynamics in practice.

Project outline

Introduction

Anaerobic digesters are commonly applied for the stabilisation of excess sewage sludge, converting the biodegradable organic matter into energy-rich biogas. Effective conversion of the organic mass can only be accomplished when proper mixing of the digester content is warranted, maximising mass transfer between substrates and microorganisms. Hence, anaerobic digesters are generally implemented as continuous stirred tank reactors (CSTR) [1]. Nonetheless, full scale treatment performances are sometimes below expectations: sludge stabilisation and gas production are less than expected. Possibly, the actual full scale mixing regime differs from the theoretical design [2]. In order to better understand the discrepancy between full scale reactor performance and theoretical potentials, enhanced insight in the actual mixing regime is of crucial importance. Possibly, the full scale performance is limited by short-circuiting or appearance of dead zones inside the reactor [3].In the current research, we use computational fluid dynamics (CFD) modelling as a numerical simulation for solving fluid flows, in combination with extensive rheological characterisation of waste activated sludge (WAS), to identify imperfections in flow regimes in anaerobic digesters aiming at a better digester design.

Approach

(1) CFD modelling implementation, mainly by package ANSYS Workbench and Fluent, using non-Newtonian fluid characteristics, gas-liquid phase and turbulence are solved by specific models.

(2) The full-scale digester with gas mixing in WWTP de Groote Lucht (Hoogheemraadschap van Delfland) is selected for investigation. Tracer experiments will be implemented to determine the actual mixing performance of the digesters.

(3) Validation, including simulation referred to published experimental results in lab-scale digesters [4], and the tracer experiments in the full-scale tank.

(4) The concentric rotational rheometer is utilised for measuring the sludge rheological properties, applying different solid concentrations at various temperatures.

Results

A lab-scale reactor experiment from literature [4] was successfully described by a CFD model choosing proper input parameters (Fig. 1). The impacts on velocity field prediction from interphase force, bubble size, liquid viscosity and scheme accuracy were well described and found to be important. Using parameter settings from the simulation of the lab experiment, simulation in a full-scale digester was implemented as well. Based on experimental results, the WAS from de Groote Lucht showed TS-dependent, yield-pseudoplastic and thixotropic rheological behaviour (Fig. 2).

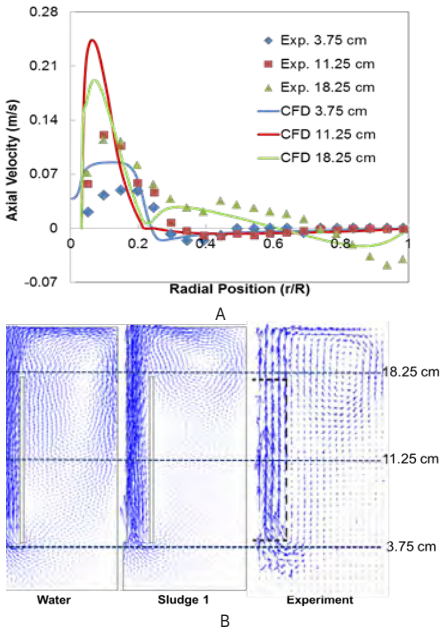

Fig. 1 Simulated and experimental[4] results of velocity distribution at (A) local and (B) entire regions in laboratory scale digester.

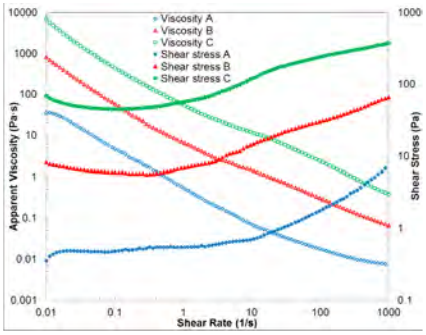

Fig. 2 Rheogram of the WAS from de Groot Lucht, A: TS 1.2%, B: TS 3.6% and C: TS 6.0%.

Scientific relevance

Most mixing studies have been carried out so far on laboratory scale and pilot scale installations. Full-scale studies are limited to tracer experiments, only returning an overall image of solid retention times. The detailed mixing properties in current systems therefore need to be unravelled to reach better performance of current digester systems.

Social relevance

Optimised operation and enhanced biomass conversion in practice will result in more biogas from waste activated sludge. This leads to more energy recovery from wastewater and less release of greenhouse gases during digestate storage and transport. Modification and/or improvement of the design of full-scale digesters will lead to a more sustainable processing of residual organic streams.

Literature

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Key words:
Anaerobic digestion, two-phase flow, computational fluid dynamics (CFD), mixing, temperature, rheology

Cooperation with other institutes:
coupled to STOWA project "Community of Practice -Menging slibgisting"

Mostafa Zahmatkesh

Bioremediation of Humic compounds from water using fungi

Research objectives

The objective of this research is to study the possibility of removing humic compounds, namely humic acid (HA), from wastewater by fungal treatment.

Project outline

Introduction

This project is part of a STW project entitled "Increasing the utilization of organic waste and low value feeds with the help of lignin degrading fungi", in cooperation with Wageningen University. The research in TU Delft is focused on using White Rot Fungi (WRF) to remove recalcitrant compounds from wastewater. For the last three years the research was focused on humics as targeted compounds for fungal treatment. Humic substances are natural organic substances, which are ubiquitous in the environment, both aquatic and terrestrial. In nature, humic substances are extremely resistant to biodegradation. WRF constitute a physiological group comprising mostly of basidiomycetous, and to a lesser extent, litter-decomposing fungi. WRF are the most abundant wood degraders in nature, which possess the unique ability of efficiently degrading lignin to CO2 [1]. Thanks to WRF non-specific enzymes, they can also degrade other recalcitrant compounds with molecular structure similar to lignin, like azo dyes, poly aromatic hydrocarbons, and humics [2]. Lignin Peroxidase, Manganese Peroxidase, Laccase and versatile peroxidases are the major extracellular enzymes produced by white rot fungi, which are responsible for degradation of recalcitrant compounds [3].

Approach

Prescreening of several strains of WRF has been done in agar plates to evaluate their ability to grow and bleach humic acid. Selected strains tested in liquid phase, and based on results of the jar tests, a 7 Lit fungal reactor was designed to treat wastewater containing humic acid.

Results

Four strains of WRF were selected after prescreening in humic-agar plates for their ability to grow and bleach the humic acid (Fig 1).

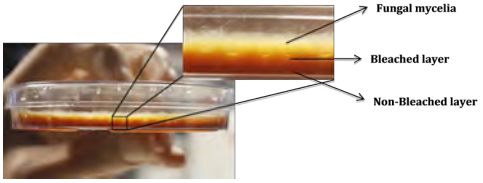

Figure 1. White rot fungi growing on Humic-agar plates, degradation of humics would cause bleaching layers on agar

In the next step, the selected strains were used to remove humic acid from wastewater. Results showed that *Trametes versicolor* could remove around 40% of the humic acid after 3 days and 90% after 15. Laccase activity was correlating with color removal (Fig 2). Results of the liquid chromatography revealed that mechanism of humic removal by WRF is a combination of absorption (by fungal mycelia) and degradation (by fungal enzymes).

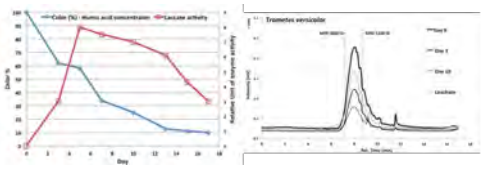

Figure 2. Left: Color removal (humic acid removal) and enzyme activity, Right: Results of Size exclusion chromatography

Based on the previous results of jar tests, a sequential batch fungal reactor was applied to treat HA-containing wastewater. Three batches were done and each batch lasted 3 weeks. Results are shown in Table 1.

Figure 3. Left: Fungal reactor (Beginning), middle: Fungal reactor (end of first batch), Filtered samples at the beginning and end of the batch

Table 1. Results of the sequential fungal reactor (Decolorization represents the removal of humic acids)

Batch No.	Decolorization 1st week	Decolorization 2nd week	Decolorization 3rd week
1	41%	87%	92%
2	60%	83%	77%
3	74%	89%	79%

Scientific relevance

Humic compounds can limit the bacterial growth in digesters, cause fouling in membrane units and also reduce the quality of the effluent due to their color. Therefore, removal of humic compounds in wastewater will increase the efficiency of wastewater treatment plants.

Social relevance

Removal of recalcitrant or hardly degradable compounds would increase the efficiency of the wastewater treatment plants, which results in a cleaner and healthier environment, which benefit all living species in it, namely humans.

Literature

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Key words:
Humic acid, Bioremediation, Wastewater treatment, Fungi

Cooperation with other institutes:
Wageningen University

André Marques Arsénio (Postdoc)

Sustainable freshwater supply in urbanizing Maputo, Mozambique

Introduction

Maputo, like other Deltas cities in the Global South, suffers from freshwater shortage and insufficient sanitation services. Despite the good work done in the country in the WaSH sector since the independency from the colonial power in 1975, there is still a long road ahead: Mozambique has demonstrated a “slow rate of progress” regarding access to safe drinking water and basic sanitation and [1] predicted that the MDG goals for both indicators will only be reached after 2025 instead of 2015.

Research objectives and approach

The main project aims at developing tools and models that allow including water reclamation in future city-wide water and sanitation projects. In this way it will be possible to alleviate the pressure on the existing freshwater sources, reduce risks associated with current unsafe wastewater handling practices while generating revenue that will ultimately allow financing more inclusive sanitations services.

Results

Throughout 2017 I worked on characterizing the flows of Nitrogen and water in the city (Fig. 1). This work has showed that current improvement plans to the city’s sanitation infrastructure will have little impact in minimizing the ongoing groundwater contamination with Nitrate. It also demonstrates the link between drinking water supply and sanitation services and an obvious reason to improve both in order to improve general urban health and wellbeing [2].

I am now planning to forecasting the future water demand and the projected availability (e.g. through dam building) for different development scenarios. Approaches to offset the scarcity will be discussed and evaluated in a workshop-type meeting with local stakeholders. This will be the second pillar of the project whereby the need to follow a different approach rather than building new dams will have to be implemented. To get more information about the project please scan the QR-code (Fig. 2).

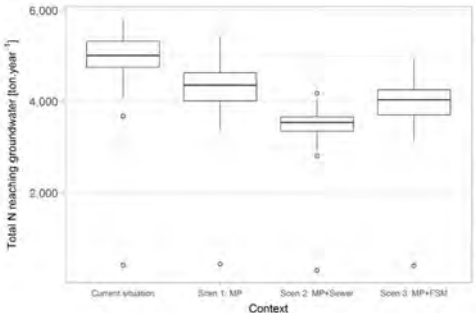

Fig. 1. Nitrogen reaching groundwater each year for the current situation and for three improvement scenarios, depicting median, upper and lower quartiles, minimum and maximum; outliers are presented as circles.

Fig. 2. Scan this QR-code or surf to https://sustainablewatermz.weblog.tudelft.nl/ for more information about the project.

Scientific relevance

The project will allow studying water reclamation from an integrated socio-technical. Simultaneously it will be possible to develop new technologies for a sanitation-based circular economy. Finally, the project aims at helping to implement policies for sustainable development of freshwater supply and inclusive sanitation services, both on large and small scale, making use of innovative combinations of public and private service providers.

Social relevance

One of the projects objectives is improving the current situation regarding water and sanitation in Maputo the livelihood of its dwellers. This will be done through capacity building and by providing a platform where novel approaches to water management can be discussed.

Ideally, the technologies, tools and models developed for Maputo can be implemented in other Mozambican cities and elsewhere, helping to improve the lives of millions of people worldwide.

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Key words:
Water reuse, wastewater treatment, digestion, sewer mining, governance, ecosan, fecal sludge management, sustainability

Cooperation with other institutes:
UNESCO-IHE, Erasmus University, Universidade Eduardo Mondlane (Mozambique), FIPAG, VitensEvidesInternational, Royal HaskoningDHV, DNA, CRA, Municipality of Maputo, WSUP, WSP, Pamodzi

Yasmina Bennani (Postdoc)

Re-designing the value and supply chain of water and minerals: a circular economy approach for the recovery of resources from saline impaired effluent (brine) generated by process industries - ZEROBRINE

Research objectives and approach

This project aims to facilitate the implementation of the Circular Economy package and the SPIRE Roadmap in various process industries by developing the necessary concepts, technological solutions and business models to re-design the value and supply chains of minerals (including magnesium) and water, while dealing with present organic compounds in a way that allows their subsequent recovery. This is achieved by demonstrating new configurations to recover these resources from saline impaired effluents (brines) generated by process industry, while eliminating wastewater discharge and minimizing environmental impact of industrial operations through brines.

Project outline

The project will bring together and integrate several existing and innovative technologies aiming to recover end-products of high quality and sufficient purity with good market value. It will be carried out by large Process Industries, SMEs with disruptive technologies and a Brine Consortium of technology suppliers across EU, while world-class research centers ensure strong scientific capacity and inter-disciplinary coordination to account for social, economic and environmental considerations, including LCA. A large scale demonstration plant will be developed in the Energy Port and Petrochemical cluster of Rotterdam Port, involving local large industries. The demo plant will be treat part of the brine effluents generated by the industry water supplier (EVIDES), while waste heat will be sourced by neighboring factories. The quality of the recovered end-products will be aimed to meet local market specifications. The involvement of representatives covering the whole supply chain will provide an excellent opportunity to showcase Circular Economy in Rotterdam Port, at large scale. Finally, three large-scale pilot plants will be developed in other process industries, providing the potential for immediate replication and uptake of the project results after its successful completion.

Scientific relevance

The project will build scientific and technological relations between the research partners. It is expected that the integration of technologies at the pilot plants will create new technological knowledge and solutions.

Social relevance

The project will contribute to solving the issues of water scarcity and brine disposal, and lead to s a cost efficient alternative water supply and recovery of resources.

Literature

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Key words:
Brine effluent, Water recovery, Minerals recovery, Salt, Magnesium recovery, Waste Heat, Industrial Symbiosis, Circular Economy, Closing-the-loop

Cooperation with other institutes:
NTUA, CTM, Witteveen & Bosch, UNIPA, SUT, FACSA, SEALEAU, WssTP, Revolve Media, UNIABDN, Lenntech, IVL, TYPSA, IQE, Evides Industriewater, TUBITAK, Huntsman, DLR, Europiren, ARVIA, ISPT

Mathieu Lepot (Postdoc)

FOULC: Fast Over-all scanning of Underground and Linear Constructions

Research objectives

The FOULC project (in the TISCA program) aims at obtaining information on some of the main functionalities of a sewer using non-intrusive techniques. Information can be gathered in-situ to quantify the actual hydraulic capacity, the presence and the amount of sediments and biofilm, detailed 3D information on the actual sewer geometry and information on the locations where and the amount of infiltrating groundwater. To this end an aquatic drone is developed as a platform for the sensors and the data-acquisition system. The development of this sensor platform is dedicated to sewer systems, but the application is not limited to sewers since it can also be applied for obtaining information on hydraulic capacity of and the presence of sediments in ditches and canals.

Project outline

Introduction

CCTV is known to be inaccurate and subjective. In order to deliver reliable data to sewer manager, new inspection techniques are needed. Recent advantages in this field showed that sonar, laser profiling or acoustic measurement can be used for such purposes.

Approach

This project (in collaboration with CT2MC) will combine several sensors: laser profiler, Infra-red Camera, velocity/turbidity profiler and a sonar. All these sensors will be set up on an amphibious drone that can inspect sewers pipes with service disruption. CT2MC is in charge on the drone design and construction based on the selected sensors and the required data acquisition system. Both data acquisition and processing software are under development.

Results

Preliminary results are quite promising:

= the laser profiler is able to detect any shape of deformation above the free surface with an uncertainty lower than 2 mm,

- the IR camera can detect active lateral connections with a discharge of minimum 2 % of the main discharge,
- the velocity/turbidity profiler has been improved by the supplier to reach our objective. The reconstruction of the 3D velocity and turbidity fields are now feasible.

Scientific relevance

This project already encounters some positive feedbacks from practitioners waiting the prototype to be ready for testing and then on the market. From a scientific point of view, this project is quite challenging (specially for the data treatment) and will be able to deliver reliable data for asset management and decision-making research projects.

Social relevance

The do-it-yourself end product (by just combining the platform and the selected sensors) and the expected open-source software and hardware (data acquisition and treatment) will ensure a potential wide use of this technique during the coming years.

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Key words:
sewer, inspection, sensors

Cooperation with other institutes:
-

Maria Lousada Ferreira (Postdoc)

Bio-methane production from urban organic matter (BeWaMet)

Research objectives

a) Adapt fouling monitoring methods to AnMBRs.
b) Identify the most suitable flux enhancer for anaerobic domestic sludge.
c) Develop an on-line control tool for AnMBRs, able to monitor fouling, add flux enhancers and increase the operational flux.

Project outline

Introduction

The BeWaMet is an ERA-Net project, aiming at demonstrating Anaerobic Membrane Bioreactors (AnMBR) technology at demo-scale for treatment of municipal wastewater. Within the project, the goal of TUD is to develop an on-line control tool aiming to increase the flux of AnMBRs, which is currently one fourth to one fifth lower than in aerobic MBRs. The demo-scale AnMBR pilot of the BeWAMet project is located at the Vigo, Spain; is designed to treat black water and is currently at the start-up phase.

Approach

Firstly, to develop a method to quantify fouling, as the cause of flux decline in AnMBRs. Fouling, as the accumulation of material in and on the membrane, was quantified as sludge filterability. A dedicated method was developed at the TUD water lab and tested at an AnMBR pilot. Secondly, to improve the sludge filterability and consequently increase the flux, 8 flux enhancers were tested, through preliminary tests and short-term membrane filtration tests. Thirdly, to develop the on-line control tool, and taking into account that the goal would require an extended time-frame, PhD student Magela Odriozola was hired one-year ago, to proceed with the work beyond the project time-frame.

The method development and flux enhancers tests were performed with anaerobic sludge from full-scale or pilot locations. Weekly samples were collected at the digester of Harnaschpolder Sewage treatment plant (HNP STP) in Delft, during a total period of one year. An installation, previously used at the TUD to quantify sludge filterability in aerobic MBRs, was adapted to measure anaerobic samples [1], and a method comprising measurements of membrane resistance, anaerobic sludge filtration and chemical cleaning was defined [2]. The adapted installation was connected in-situ to an Aqualia AnMBR pilot, at Alcazar de S.Juan, Spain, for a period of 2 weeks, where the aforementioned method was tested and applied.

Results

Figure 1 shows the sludge filterability results obtained with the HNP STP sludge. Tests at AnMBR pilot of Alcazar de S.Juan, indicate that the cross-flow of 1.5 m s-1 provides a more accurate fouling quantification (results not shown). Figure 2 shows chemical cleaning results, where the most successful cleaning is obtained by a sequence of chemicals starting with sodium hydroxide. The weekly measurements of filterability where complemented with analysis of Particle Size Distribution, Biopolymer Clusters, Extra Polymer Substances, Soluble Microbial Products, Volatile Fatty Acids, among other parameters. The full data base of results is being analysed by advanced statistical methods, such as Partial Least Squares, aiming to explain the filterability trend in time.

Jar-tests were performed to determine optimal dosages of 1 adsorbent, 2 coagulants and 5 flocculants. Specific Methanogenic Activity (SMA) tests were performed to evaluate possible inhibition effects. Short-term membrane filtrations tests were carried out with 6 flux enhancers, at the obtained optimal dosage. The integration of the sludge filterability method with flux enhancer additions is planned to occur during the first semester of 2018, at the BeWaMet AnMBR pilot in Vigo, Spain. The results of the latter campaign will be a part of the PhD work of Magela Odriozola.

Scientific and social relevance

The goal is to contribute to explain filterability of real municipal anaerobic sludge, for which 3 scientific articles will be produced, the first concerning the method, the second flux enhancers and the third filterability trends. AnMBRs produce water free of solids and rich in ammonia and orthophosphate, particularly suitable to agriculture fertilization, with simultaneous production of methane-rich biogas. Turning fouling into a manageable issue will boost a potentially sustainable technology.

Figure 1. Sludge filterability expressed as ΔR20, obtained with a flux of 60 L m^{-2} h^{-1} and cross-flow velocities (v) of 1 m s^{-1} (full bullets) and 1.5 m s^{-1} (open bullets).

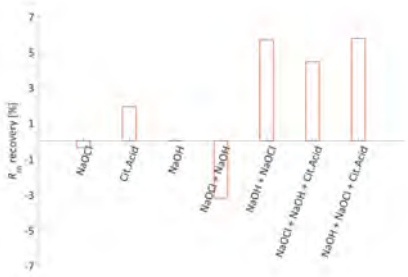

Figure 2. Chemical cleaning efficiency, measured as average recovery of the membrane resistance (Rm). Membrane resistance measured with de-mineralized water before and after chemical cleaning.

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Key words:
Anaerobic Membrane Bioreactors; Filterability

Cooperation with other institutes:
FCC- Aqualia (Spain); University of Southampton (UK)

Dhruv Mehta (Postdoc)

Computational studies on the flow of domestic slurry

Research objectives and approach

We wish to attain the following objectives.

1. Numerically model (through computational fluid dynamics) the flow of concentrated domestic slurry through circular horizontal pipes and bends.
2. Predict the pressure drop incurred as the slurry flows through pipes.
3. Model the flow of slurry mixed with air through circular horizontal pipes and bends.

Project outline

Introduction

This project is aimed supporting experimental studies on the flow of concentrated domestic slurry in pipes. The idea behind concentrating domestic slurry is the reduction of water usage, the concomitant increase in the concentration of recoverable substances and the subsequent local processing of the slurry to produce energy.

Experiments have shown that on reducing the amount of water, domestic slurry behaves as a non-Newtonian fluid. Therefore the pipes, pumps etc. must be designed to include this non-Newtonian behaviour, which cannot be modelled correctly with existing engineering models designed for Newtonian fluid. To modify these models, we must gain a more fundamental understanding of the flow of non-Newtonian fluids in pipes.

Approach

Our approach involves the following.

1. Prepare a suitable Navier-Stokes solver to simulate HB fluids (done).
   a. Model the wall behaviour of HB fluids (done).
   b. Explore relevant turbulence models (done).
2. Validate the solver for a range of experimental cases (done).
   a. Compare our wall behaviour model against those reported in literature (done).
   b. Use data from departmental experiments (done).
3. Use the solver to simulate pipes with bends.
4. Use the solver to simulate a multiphase air-slurry mixture.
5. Use the solver to simulate a pulsatile pipe flow or a pump-induced start-up.

Results

Our first results relate to the behaviour of HB fluids near walls. We used data from existing literature and departmental experiments to test the specified shear approach we developed. We noticed that our approach helps simulate HB fluids more accurately that other methods mentioned in existing literature.

Scientific relevance

The domestic slurry being studied behaves like HB fluid, a type of non-Newtonian fluid that does not flow until a certain 'yield stress' is applied to it. Although much have been done in terms of experiments, numerical studies are rare.

Through our research, we wish to contribute to the numerical modelling of HB fluids in pipes. We have already proposed a function that models the behaviour of HB fluids near pipe walls. We wish to explore if this could also be used to study the effects of bends and having an air-slurry mixture through a pipe.

Social relevance

A thorough numerical analysis of HB fluids could have two benefits. Firstly, it could complement experimental studies and generate more details on the nature of the flow, turbulence etc. Secondly, with ample numerical data to complement experimental data, one could develop engineering models that could be used to quickly calculate pressure drops in pipes carrying HB fluids, instead of using high-fidelity computational models.

With both these contributions, civil engineers would be able to design and size urban sewerage more effectively should the transport of concentrated domestic slurry be deemed beneficial.

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Key words:
CFD, non-Newtonian, urban drainage, pipe flow

Cooperation with other institutes:
Deltares, Stowa, Stichting RIONED, Waternet, Waterboard Zuiderzeeland, Grontmij, XYLEM and Stichting TTW

Literature

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Annemarie Mink (Postdoc)

Mobile crowd participation as innovative methodology for water research

Research objectives

1. Investigate to which extent local stakeholders, and specifically end-users, are able to monitor their own water supply systems in order to improve the sustainability, operation and maintenance of these systems.
2. Apply Mobile Crowd Participation (MCP) as an integrated research and monitoring tool for small-scale piped water supply systems in Bangladesh and India by developing a smartphone application.

Project outline

Introduction

Technologies shape and change our world and have the potential to support people in doing what they want to do and being who they want to be. However, technologies can also have unintended consequences or fail. Many failed products are unsuited to the user and / or their environment as they are either based on poorly defined needs (Donaldson 2006), or focus merely on needs instead on what people actually want (Bowman and Crews 2009). To improve the accessibility, applicability, acceptance and adoption of products and systems the end-users and other stakeholders should be included in the development and monitoring of these products and systems (Donaldson 2009; Nakata and Weidner 2012; Robertson and Simonsen 2012; Wilkinson and De Angeli 2014).

Urbanization of deltas puts a severe stress on the availability of clean, safe drinking water and therefore threatens the lives of millions, mostly affecting the poorest. In this area, centralized water supply through Small-scale Piped Water Supply (SPWS; Trifunovic 2002; Kayaga and Reed 2005) offers crucial advantages over other technological interventions, as it targets the safest source in the area, provides a degree of centralization for water quality control and treatment (<100 households), provides socially-economically desirable in-house or courtyard tap connections, and limits the number of (re-)contamination events between water collection and consumption.

To root SPWS systems into the local context, Mobile Crowd Participation (MCP) can be deployed. MCP is a novelty in water research and can be deployed to improve the users' knowledge and awareness about water quality (also by enabling them to test the water quality themselves), to enable communication between relevant stakeholders, to improve service and maintenance, and to make billing easier. According to GSMA (2013) access to mobile services in developing regions has outpaced the rate at which much of the population is gaining access to basic services such as electricity, sanitation, and banking. This is especially true for India and Bangladesh (GSMA 2016, 2017). Therefore, there seems to be scope for a smartphone application to investigate and monitor SPWS systems.

Approach

Comprehensive interviews with end-users and other local stakeholders have been conducted to get to know the local context, identify the current issues with existing piped water supply systems and propose relevant functionalities for a water monitoring smartphone application. Currently, the app functionalities are being developed in a participatory, co-creative manner with local stakeholders and local app developers in Bangladesh. This development is an iterative process in short sprints with extensive field testing.

Results

Practical results: A water application ready to use in the field in Bangladesh by end-users, caretakers, NGOs and local governments.

Scientific results: generic and context specific boundary conditions for MCP which are empirically validated.

Scientific relevance

Mobile phone applications (apps) are a novelty in water research, and by this project its relevance for researching and monitoring SPWS systems will be determined. Generic and context specific boundary conditions for MCP will be established.

Social relevance

The results of this study can be used by governments, NGOs working in SPWS projects in Bangladesh or in other urbanizing delta areas in order to improve the operation and maintenance of SPWS systems in these contexts and in that way contribute to sustainable safe water supply for its end-users.

Literature

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Key words:
Mobile Crowd Participation, End-User Interaction, Small-scale Piped Water Supply

Cooperation with other institutes:
AN College Patna India, Dhaka University Bangladesh, National Institute of Design Ahmedabad India, Industrial Design Engineering TU Delft

Marjet Oosterkamp (Postdoc)

Microbial community analysis of anaerobic bioreactors treating extreme wastewater

Research objectives

- Detailed characterization of the microbial community present in anaerobic membrane bioreactors and an upflow anaerobic sludge blanket reactor treating (synthetic) industrial wastewater containing various concentrations of phenol and salt and under mesophilic as well as thermophilic conditions.
- Identify functional metabolic pathways employed by the variety of microorganisms in the anaerobic bioreactors under different conditions.

Project outline

Introduction

Anaerobic digestion is important for wastewater treatment, combines reduction of waste and pollutants with energy production and is low-cost compared to aerobic treatment methods. Recently, the advantages of membrane technology and anaerobic bioreactors have been combined into the anaerobic membrane bioreactor. To ensure optimal performance, a more fine-grained insight in the composition and functionality of microbial communities of bioreactors is important.

Approach

Samples from bioreactors treating wastewater with various concentrations of phenol and salt and under mesophilic as well as thermophilic conditions are studied using molecular techniques such as DNA isolation, polymerase chain reaction and high throughput deep-sequencing techniques (Illumina MiSeq, Figure 1). Advanced bioinformatics tools, such as QIIME and the R environment, allow us to get information of community composition as well as diversity. To address the functions of the community in the bioreactors in more detail, more advanced omics techniques such as RNAseq and proteomics will be used. Furthermore, single-genome sequencing and isolation of key microorganisms from the bioreactors can provide more information about the bacteria or archaea present in the bioreactors.

Influence of microorganisms on safe drinking water production

Research objectives

- Verify the importance of microorganisms in drinking water systems for the production of clean and safe drinking water.
- Study the optimal conditions under which microorganisms can contribute significantly to drinking water treatment.

Project outline

Introduction

Clean and safe drinking water is a basic human need and contributes to health and wellbeing. In the Netherlands, a major part of drinking water is produced from groundwater that contain compounds such as iron, manganese, ammonia and arsenic that are removed in drinking water production systems. Chemical interactions and conversions are important in these systems. Microorganisms may be important in mediating partly the treatment process and may be able to help refine the production of clean and safe drinking water.

Approach

Drinking water treatment systems will be sampled and the microbial communities will be studied using molecular techniques and bioinformatics approaches. Further microbial studies may be applied to gain a further insight in the importance of microorganisms for the removal of hazardous compounds from groundwater for drinking water production.

Scientific relevance

This research will lead to novel insights in microbial communities treating wastewater and involved in drinking water production. We will identify and further understand microbial specialists involved in this process, which will increase our understanding of optimal anaerobic digestion of extreme wastewater and also of optimal drinking water treatment.

Marjet Oosterkamp

Social relevance

Insight in microbial communities of anaerobic bioreactors will help to enhance the treatment of wastewater. Improvement of extreme wastewater treatment will lead to more environmental-friendly industry as it will not only reduce the release of industrial pollutants, but also increase green energy production. A further understanding of microorganisms involved in drinking water treatment and removal of hazardous compounds can help to keep drinking water clean and safe.

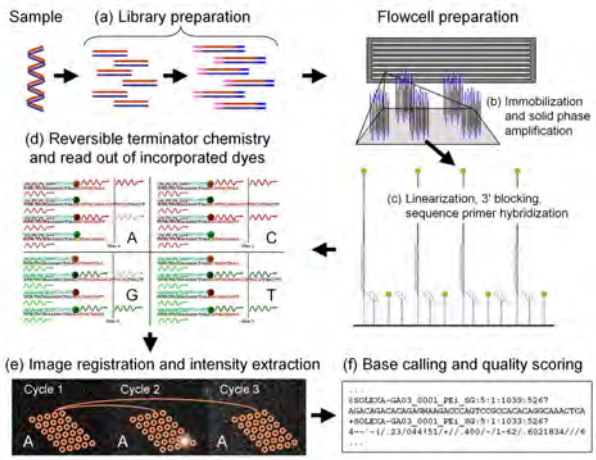

Figure 1. Overview of the Illumina sequencing workflow.

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Key words:
Microbial community analysis, next generation sequencing, anaerobic digestion, wastewater, drinking water, recalcitrant compounds, biochemistry

Cooperation with other institutes:
Via TTW

David de Ridder (Postdoc)

Understanding iron and arsenic removal

Research objective

Improve Arsenic removal from groundwater to below 1 µg/l by enhancing the availability of its main adsorbent – iron oxide.

Project outline

Introduction

Iron oxides are known to be effective adsorbents for arsenic. Groundwaters that contain arsenic may also contain dissolved iron, which can precipitate after aeration and remove arsenic, making the groundwaters a (potentially) self-cleaning system during water treatment. Iron precipitation depends on charge interactions. The solution pH has an important influence on the surface charge of iron oxides, but the presence of anions and cations, such as Ca^2+, Mg^2+, HPO_4^2- and natural organic matter can enhance or neutralize charge interactions, depending on their relative concentrations. Also, the presence of particles may help iron oxide precipitation.

When arsenic removal is considered, both the efficacy of iron oxide precipitation (i.e. formation of the adsorbent) as well as adsorption competition are relevant.

Approach

Jar tests were carried out in demiwater in the presence of Ca^2+, HPO_4^2-, and fine particles that carried a surface charge that was either positive (ZnO) or negative (SiO_2). In additional jar tests with various natural groundwaters, the removal of iron and arsenic was followed in the waters as is, and after manipulation by adding Ca^2+, Mg^2+, HPO_4^2- and humic acid, or removing these by an/cation exchange. The influence of particle characteristics was further investigated in pilot experiments with a fluidized bed of either sand, garnet, olivine or stainless steel.

Results

The growth of iron flocs was delayed at pH 6 and pH 9, where all iron particles carry a positive or negative surface charge, respectively. This could be negated by introducing ions or particles with the opposite charge, i.e. HPO_4^2- or SiO_2 at pH 6, and Ca^{2+} or ZnO at pH 9.

In natural groundwaters, it was found that removing Ca^{2+} an Mg^{2+} resulted in limited iron floc growth, while their addition enhanced it. In two groundwaters, this enhancement was the same for equimolar additions of Ca^{2+} an Mg^{2+}, suggesting that the main underlying mechanism would be charge neutralization. In a third groundwater, addition of Ca^{2+} led to much larger particle volumes than addition of Mg^{2+}, indicating that hydroxyapatite potentially precipitated as well, or that iron flocs with a more open structure (thus larger volume, but lower density) were formed in the presence of Ca^2+. In this same groundwater, addition of HPO_4^2- led to a substantial increase in floc growth, contrary to what was found for the other groundwaters. The $(Ca^{2+}+Mg^{2+})/P$ ratio could be used to explain floc growth for two of the three groundwaters. For all groundwaters, removal of arsenic mainly depended on the removal of iron; any competition effects, while observed, were of lesser importance. At environmentally relevant concentrations, As adsorption seemed to be hindered more by adsorption competition with Si, than with HPO_4^2-.

Iron (Fe^{2+}) removal in a high flowrate fluidized bed reactor was strongly pH-dependent. At pH>7.5, iron floc formation occurred in the water phase and the flocs were not retained in the fluidized bed. At pH<6.75, iron removal was most likely limited by the slower oxidation rate of Fe^{2+}. While this prevents floc formation in the water phase, it also prevents regeneration of the adsorbent, since Fe^{2+} needs an (oxidized) iron oxide to adsorb onto. At relatively low flow velocities, more iron was removed in the top part of the fluidized bed with the smallest particles (and highest surface), but this shifted to lower layers in the bed when the flow velocity increased. This is probably related to the effective particle surface per reactorvolume during operation.

Scientific relevance

While the importance of charge interactions has been addressed by various authors, these effects are barely investigated in realistic, multi-element conditions, and literature on the impact of charged particles therein is sparse. The concept of removing iron in a high flowrate fluidized bed reactor has only been explored by a handful of researchers.

Social relevance

Arsenic is nasty.

Literature

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Start date project: Jan 2016
Expected end date: Jan 2019

Key words:
Iron and arsenic removal, rapid sand filtration

Cooperation with other institutes:
Vitens, Brabant Water, Dunea, Pidpa, Evides, RoyalHaskoning DHV, Hatenboer Water, RIVM

Ran Shang (Postdoc)

Ceramic nanofiltration as the key step for sustainable wastewater treatment with reclamation of water, energy and nutrients

Research objectives

- To optimize the ceramic nanofiltration process for domestic wastewater filtration
- To develop effective cleaning methods for the ceramic nanofiltration membranes filtrating wastewater.
- To investigate a new route to prepare ceramic nanofiltration (NF) membranes with homogeneous micropores, high organic and P rejection and yet high water flux.
- To study the performance of the new NF membranes during sewer mining application.

Project description

Sewer mining using a commercially available ceramic nanofiltration membrane (450 Da cut-off) has been previously studied by direct nanofiltration of sewage 1. The aim of sewer mining is to concentrate COD (chemical oxygen demand) and/or phosphate from the sewage so that energy and nutrients can be reclaimed in an anaerobic digester (Fig. 1).

This research is part of the RINEW (Rotterdam Innovative Nutrients Energy Water) project, which is searching for alternative concepts for the reclamation of municipal wastewater from city areas and transfer it to valuable products. RINEW is a collaboration between Evides Industriewater, the City of Rotterdam, Hoogheemraadschap van Delfland, Waterschap Hollandse Delta, and Clean Tech Delta.

Recent results show that an advanced deposition technique is feasible route to synthesize tight ceramic NF membranes with high water permeability. The deposition was applied on a commercial ceramic NF membrane with 450 Da, in order to narrow its pore aperture. The synthesized tight ceramic NF membranes had a molecular weight cut-off (MWCO) ranging from 260 to 380 Da. Yet, they maintained high water permeability at 11-16 L m-2 h-1 bar-1, which is notably higher than the commercial tight polymeric NF and traditional sol-gel-made tight ceramic NF membranes.

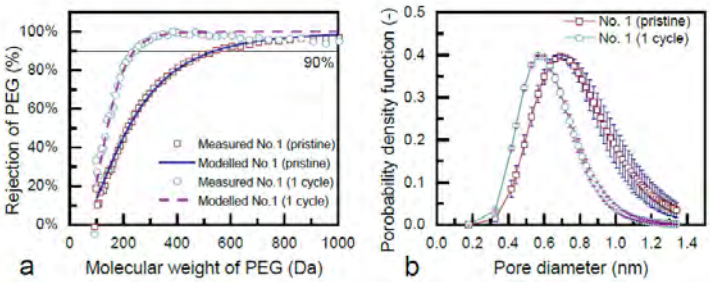

Figure 1 PEG rejection (a) and modelled active pore size distribution (b) of the pristine (substrate) membranes and the synthesized membranes.

Zeolites as novel adsorbent in water treatment

Research objectives

- To investigate the efficiency of high silica zeolites (of various pore size and Si/Al ratios) for adsorption of the organic micropollutants (OMPs) and the assimilable organic carbon (AOC) from drinking water.
- To study the competitive adsorption between the natural organic matters and the OMPs or AOC.
- To investigate if the zeolites can be effectively regenerated by in-situ oxidation.

Project description

Activated carbon is typically used to remove organic micropollutants from contaminated water, but during this process, natural organic matter (NOM) present in the water competes with adsorption sites and may restrict pore access. Both these effects reduce the filtration time until regeneration, and during regeneration, energy is wasted on removing NOM. Zeolites have pore sizes that are too small for NOM to enter, and initial lab tests have

already shown that equilibrium adsorption of organic micropollutants on ZSM5 zeolite was similar with or without the presence of NOM 2.

The research focus will be on understanding what molecule and zeolite properties affect adsorption (both equilibrium and kinetics). Based on this, combinations of zeolites will be selected and agglomerated to granules. The adsorption capacities of these granules for a broad range of organic micropollutants and AOC will then be tested.

The regeneration of saturated zeolites will also be investigated. Since zeolites are chemically inert, oxidative techniques can be used for their regeneration. These techniques are envisioned to be more cost-effective than the current thermal regeneration used for activated carbon regeneration.

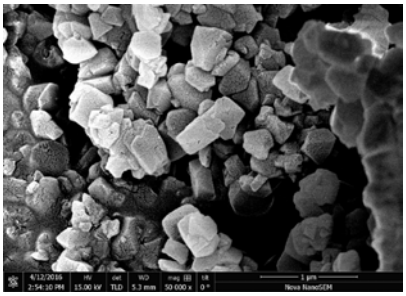

Figure 2. Scanning electron microscope image of FAU type zeolite with a Si/Al ratio of 500

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Start date project: May 2014
Expected end date: May 2018

Key words:
Ceramic NF, Sewer mining, Zeolite, Adsorption

Cooperation with other institutes:
STW, Evides, Logisticon

Franz Tscheikner-Gratl (Postdoc)

Quantifying Uncertainty in Integrated Catchment Studies (QUICS)

Research objectives

Quantifying Uncertainty in Integrated Catchment Studies (QUICS) performs high quality research for developing and implementing uncertainty analysis tools for Integrated Catchment Modelling. The main aim of the QUICS ITN is to educate and train researchers capable of operating at academic research institutions, water utilities or other public bodies so as to provide them with a comprehensive understanding of water quality processes, uncertainty issues and knowledge of appropriate decision making strategies for integrated catchment management. The objective is to establish a framework for the application of uncertainty analysis in integrated modelling including definitions for the observable uncertainties in integrated catchment studies, a linkage to scientific literature and further reading on the topic, guidance for the practical application of uncertainty analysis in integrated catchment studies and practical examples for the application of the proposed framework.

Project outline

Introduction

Integrated modelling uses a set of interdependent components to construct an appropriate modelling system for a certain task. This joint modelling of two or more systems of the urban water system works by interweaving a sequence of sub-models for the various elements of the system. However, the integration of too many subsystems and processes irrelevant to the problem formulation can lead to unnecessary complexity (and errors) of the applied models. Furthermore, the decision on what is relevant for the actual question leaves room for subjective interpretation and differences of approach from the practitioners, who apply them to plan measures, to optimize systems as well as to evaluate the need of certain measures. The stepwise process of abstraction from reality to model representation with its simplifications and idealizations of the real systems comes with the unavoidable occurrence of uncertainties.

Approach

The problem is approach by implementation of existing frameworks for a global assessment of modelling uncertainties and uncertainty propagation analysis into a step-wise integrated urban water modelling approach, while expanding the scope of uncertainties incorporated. The idea is to see uncertainty analysis not as a standalone and separate process from the usual modelling workflow but as an integral part of it. The used model and sub-models need to be revised and if necessary refined with every step, creating a feedback loop for the model. Contemporaneously with this process, a thorough continuous documentation of the information, data, changes and assumptions used during the process and the uncertainties of the before mentioned should be included to enable other people to comprehend what has been done and what every bit of data means. The treatment of uncertainties is incorporated here not as one step included in model analysis or calibration, but as a continuous work accompanying the entire integrated modelling process.

Results

A key element of QUICS is the completion of publicly available reports and guidance documents which will allow practitioners to understand uncertainty and implement methods which have been developed during the QUICS project, available at https://www.sheffield.ac.uk/quics/dissemination/reports.

Scientific relevance

The project aims to examine the identification and quantification of uncertainty throughout a catchment, from rainfall to rural runoff and wash off processes, through to water and pollutant transport processes in urban areas as well as receiving surface waters. This complete coverage including both rural and urban sectors and the determination to deal with the temporal and spatial integration issues and the resulting uncertainties is unique and essential, if catchments are to be modelled effectively in an integrated fashion and the model outputs used to sensibly inform investment decisions.

Social relevance

The project will provide support for the development of abundant and dynamic world-class human resources in the European research system, taking into account the inherent international dimension of research by exposure

of the QUICS fellows to various internationally leading research centres and institutions and innovative private and public sector organisations.

Literature

https://www.sheffield.ac.uk/quics/dissemination

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Start date project: Mar 2017
Expected end date: Mar 2018

Key words:
Uncertainties, integrated modelling, decision support

Cooperation with other institutes:
University of Sheffield, CH2M

Ljiljana Zlatanovic (Postdoc)

The urban water cycle as enabler for circular cities: New Urban Water Transport Systems

Research objectives

This project aims to determine the extent to which the urban water transport infrastructure would change if resource recovery becomes an equally important design parameter as water quality, water quantity, public health, safety and comfort.

Project outline

Introduction

The concept of the engineered urban water cycle dates back to the mid-19th century and it consists of three separated domains: drinking water supply (production, transport and distribution), sanitation (wastewater collection, treatment and disposal) and stormwater management. Historically, all three domains have been linearly arranged, prioritizing comfort, public health and physical safety requirements rather than recognising and allowing for resource recovery from the urban water cycle. Awareness of depleting natural resources urged attention worldwide on the lack of circularity in handling the natural resources in metropolitan environments. The urban water cycle offers a great potential for relieving the water-food-energy nexus by recovery and re-use, as water itself, phosphate, and organic or thermal energy can be successfully recovered from the urban water cycle and re-used in various applications. To disclose the possibilities of efficient use, recovery and re-use of resources, the urban water cycle need to be comprehensively reconsidered as an integral system. For instance, the current water transport infrastructure, including subsurface pipes, pumps and treatment facilities, represents one of the weakest links in the urban water cycle with regards to the resource recovery. The weakness of the current infrastructure lays in its historical linear arrangements, which start from pristine water sources (without alternative water sources), and end up with a diffuse and diluted waste water streams that hamper resource recovery and closing urban cycles.

Approach

In this research, the local streetlevel network and the customer are set as the heart of the urban water cycle. While local streetlevel network, both drinking water supply and wastewater collection, contains over 80% of the total network length (Vewin, 2007, Stichting RIONED, 2010), the customer is the one who determines all the aspects of the water flow: in space, time, quantity and quality. However, the present network design is mostly based on common practice targeting on assumed seamless hydraulic functioning, resulting in diluted and diffuse streams, which restrict the resource recovery within the urban water system.

Two models will be developed in this research. The first model will focus on the effect of customer behaviour on drinking water use and consequently wastewater production (flow, compounds and concentrations) on a short time scale (seconds to minutes) and small spatial scale (tap level) (Blokker, 2010), taking into account resource recovery alternatives at a household level. The second model will simulate the hydraulic behaviour of the waste water load from the individual house in a newly conceptualised sewer collection system.

Results

The outcome of this project will be a set of verified and calibrated models that represent drinking water use and wastewater production based on the effect of the behaviour of the customer, both in quality and quantity. Results from these models will lead to novel design and operational requirements for the water transport infrastructure of the urban water cycle on the street level, maximizing the possibility of resource recovery in the urban environment.reduction in intact cell counts, i.e. 5-fold reduction in cell concentration after 168 hours was observed.

Scientific relevance

The urban water cycle plays a crucial role in the integration of water-material-energy flows within the urban environment. However, this integration requires a new design approach towards the urban water infrastructure in order to maximize the resource recovery. One of the most important issues in this new design approach is addressing the role of the customer and the technological infrastructure on the street level.

Social relevance

Worldwide, metropolitan environments face challenges to: 1) protect their citizens against water-related disasters, as droughts and floods; 2) guarantee water availability and water quality; 3) renew and upgrade the infrastructure in response to climate, demographic and economic trends (OECD, 2015). It is now the right time to start the transition towards new urban water transport systems which are targeted at the recovery of depleting resources within the urban environments.

Literature

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Key words:
Urban water cycle, water transport infrastructure, resource recovery

Cooperation with other institutes:
Amsterdam Institute for Advanced Metropolitan Solutions (AMS Institute)

Education

The Waterlab: where education and research meet

The department is proud of its unique laboratory facilities in the WaterLab. The WaterLab is a research and education lab providing an unique infrastructure for experimental research. We support numerous and very different kinds of permanent practical set-ups and research experiments, of course bounded by the safety regulations.

The WaterLab hosts permanent experimental set-ups for education: a gas-transfer cascade, filtration columns, bubble aeration column, the online nanofiltration, specific ultrafiltration resistance, sand columns for soil hydrology tests and a reverse osmose filtration setup. These facilities are also use by “Stichting opleiding actuele water zuiveringstechnieken bij drinkwater bereiding”.

The WaterLab facilitates MSc and PhD students with the experiments of wastewater treatment in a ML-I certified laboratory. Here we study the recovery of energy, biochemicals and water from the sewer or industrial effluent, with special focus on the hydrolysis processes, granular biomass and Anaerobic Membrane Bioreactors (AnMBR).

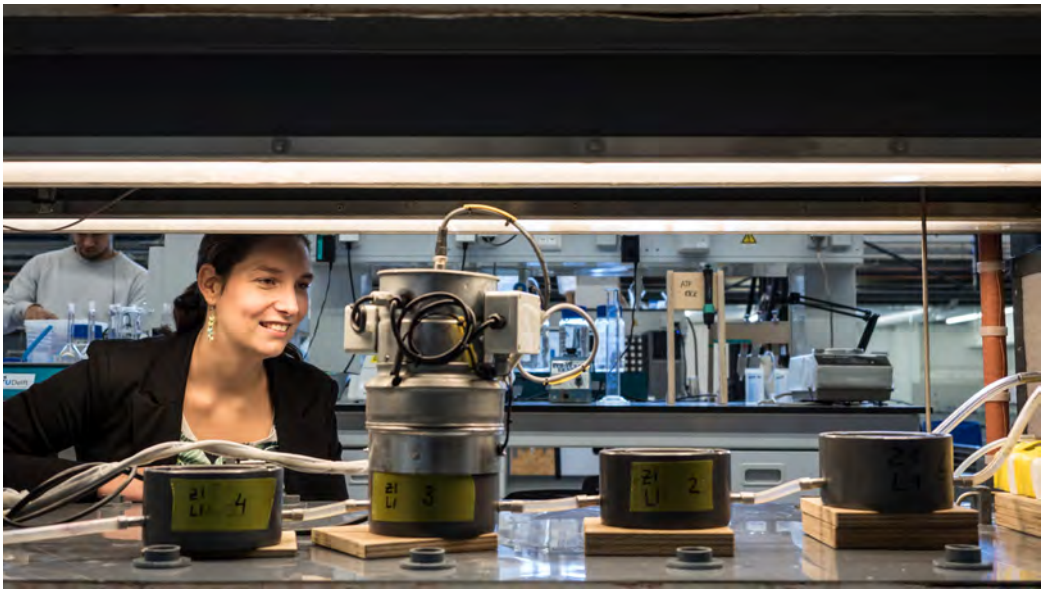
In 2017 the WaterLab created a small ‘clean-room’ facility for experiments and analysis. In the open lab area of the WaterLab the majority of the experiments are located. Here we see experimental set-ups like Zero Brine to recover resources from brine water, DFCm- Delft Filtration Characterization method, Ceramic Nanofiltration membrane installation, Ceramic water filter columns for the removal of phages, Drinking Water Distribution System, high-pressure reactors for waste-water treatment, Flat-sheet cross-flow module for arsenate removal.

In the WaterLab we also often see proof-of-concept experiments with novel sensors or set-ups, not seldom build using huge amounts of industrial Ducttape. Examples are smart-roofs for dynamic water storage on flat roofs using small-weirs, developing temperature sensing using glass optical fibres or measuring water content in tuff building blocks using radar scanning to protect e.g. frescoes on walls. After intense testing in the laboratory, the set-ups, sensors or reactors are taken to a real-life test.

The WaterLab of our department is managed by two enthusiastic lab technicians, Armand Middeldorp and Mohammed Jafar. They provide the training for analytical equipment. They provide support for designing and building experiments, safeguarding our high safety and environmental standards, purchasing equipment and consumables.

Our Water Laboratory is not a ‘standard’ analytical lab, but it does possess plenty high end analytical equipment like ICP-MS, GC, HPLC, IC, Automatic biomethane potential test system (AMPTS), TOC analyser, particle counter and PSD system, Solar simulator, water isotope analyser.

A small drinking water distribution network of grey PVC pipes is built to mimic the real distribution network situation, project of Jawairia Imtiaz Ahmad. Photo by TU Delft/Frank Auperlé



The DIPool project of Marjolein Peters and Maarten Keuten looks at how the formation of harmful disinfection by-products can be counteracted. Photo by TU Delft/Frank Auperlé

Study trip Dispuut Watermanagement

Morocco

During the summer of 2017 a group of twenty-seven enthusiastic Water management/Environmental Engineering students and three lecturers travelled all the way to the wonderful country of Morocco. For ten days the group toured through the southern part of Morocco and visited places like Marrakech, Ouzoud, Rissani, Ouarzazate and Agadir. Interesting water related projects were visited, like an irrigation system in the middle of the desert, traditional Khettaras, one of world's biggest solar plants, a tannery and drinking- and wastewater treatment plants. Besides these projects also some of the natural highlights of Morocco were on the list, for example the cascades in Ouzoud, natural (hot) water springs and the Tinghir canyon. The following extracts of the travel report give an impression of this unforgettable trip.

The Waterfalls

This day was one of the days with the most beautiful natural sceneries! After a night in which Ivar and Hugo were accompanied by a local cat in their bedroom, the waterfalls of Ouzoud were visited. A small basin downstream of the touristic part of the cascades was used for a private swimming session by the majority of us. Others went for a real multiple-hour hike under the Moroccan sun, while chasing the group that went swimming. They didn't really succeed in their chase, but anyways, they enjoyed several stunning views. On the way back the hikers followed Dorien who turned out to have a horrible sense of direction. This somehow resulted in finding some amazing ancient caves. Don't be disappointed if you were not in this group, as some nice pictures were made for you!

So far the smooth stories. After following the directions given by the hotel owner too closely, Margot, who walked alone later that morning, walked into a nearby village. Here, roads were dusty, people spoke no other language than Arabic and houses consisted of stacked mud. Let's just say that this village was not meant as a touristic sight. After this unintended escapade another surprising encounter with local fauna took place. Having found the main touristic route to the waterfalls, a baboon (monkey) showed up with a great interest in her vanilla flavoured fourré cookies which were meant as belated breakfast. Known as the person afraid for any other animal than goldfish, she dropped the cookies as soon as the baboon reached for them. Gone was the breakfast. At least the monkey had taste.

In the afternoon, we left Ouzoud again in order to visit the hydropower dam located in the El Abid River. The construction of the dam was finished in 1953 under the French control (Morocco regained independence in 1956). With an overheated engine, causing Mohammed's van not to be able to drive faster than 25 km/h uphill, we finally arrived at the power plant that was driven by water from the dam. We were told by our guide Ouzine that there are 3 turbines situated in the dam (45 MW each) and 2 turbines at the other side of the mountain range in the plant that we visited (40 MW each). However, energy supply was not the top priority of the dam. First of all, the dam was built in order to secure drinking water supply, secondly for irrigation water supply to 10,800 ha of land and only in the last place for energy production. With a miraculous 100% efficiency, the hydropower plant is operated. In case of an energy surplus in the national energy grid, water from the lower reservoir is pumped up to a high reservoir again in order to store energy which otherwise would be wasted. Because of the drought in the recent past, the lake behind the dam was filled for only 40% of its capacity. This of course affects the current energy production. After a visit to the control room of the power plant we were sent some 50 m down an enormous hole (which by the way was ideal for some paper plane experiments) via an elevator to have a look at the

turbines. After a quick look, we had to climb the stairs all the way up again. Interesting, as usually an elevator proves to be very helpful the other way around. After the visit we ended the day in Ouaouizeght. Here we ordered dinner in large groups in one of the two restaurants. After 1 1/2 they finally arrived with the groceries and started preparing the tajines. In the meantime we were waiting with a 'picturesque' view on the roundabout the meal was served. A first encounter with casual Moroccan punctuality.

Canyons and movies

To begin the seventh day of our journey through Morocco, the group departed Rissani for good at the early morning hour of 9:30 AM. The first primary destination was the Canyon of Tinghir, also known as Todgha Gorge, which has been carved through the Atlas Mountains by the Todgha and Dades rivers. Along the three-hour drive, two stops were made: first at a travellers' service center off a National road, and then an overlook next to the secondary road with a stunning view of an oasis and its village. The buses arrived at the canyon and we disembarked at the beginning of the parkland, downstream, that ran parallel to the roadway, wedged between magnificent and towering cliffs on either side. For approximately one kilometer, numerous small gatherings of families, friends, and tourists occupied the open space of the rocky beach, with abundant room remaining to traverse, albeit carefully, along or within the shallow rushing waters of the refreshingly cold stream, all the while pausing intermittently for photographs. At the upstream end of this parkland, we boarded the buses to the exclamations of "Yalla yalla!" alternating from LouLou and Rosa. We departed Todgha Gorge in anticipation of lunch.

Study trip Dispuut Watermanagement

Maintaining a pattern of the trip, lunch was again subject to the culinary expertise of the bus drivers under the guise of transit expediency. About 1.5 hours after departing Tinghir, we arrived outside the village of Kalaat M'Gouna at a large and isolated two story building containing one café/ restaurant busy with tourists upstairs, and an unmanned shop for rosewater enthusiasts on the ground floor. The menu was the usual tired variety of Moroccan fare and tourist-familiar options. Although the restaurant was reasonably comfortable inside and the wait for service not too arduous, the food itself was of dubious quality and consistency, enough for a certain Italian to advise our waiter to advise the cook to "try better next time." As we gathered outside to board the buses, suspiciously, and perhaps out of spite, the same waiter later accused us of not paying for one meal. This allegedly missing payment was determined to have been traced back to said Italian, and the discrepancy was rectified without trouble.

After lunch, we pressed on to Ouarzazate. After continuing along National Road 10 for another 1.5 hours, we arrived to tour the Atlas Corporation Studios. But first we occupied the movie-themed hotel lobby and exploited their toilets to the chagrin of the manager, who was initially unaware of our arrival's purpose. Our group had a single guide, who resembled a Saharan-version of Bruno Mars (this was the limit of their similarities). We were paced through several sets (in varying stages of neglect and disrepair) meant to convey certain generically exotic locations, such as khasbas, a Tibetan Temple for Imperial China, and palaces of ancient Egypt, accompanied by explanations provided with thoroughly lackadaisical enthusiasm from the guide. Founded in 1983, the total property of the movie studio is about 30 hectares, but only about half of that is utilized. When there is a movie being shot, extras (including our tour guide) are usually residents of the surrounding towns and paid around 30 euros per day. However, we also learned that about 300 actors were flown in from Tibet for the movie "Kundun". After pictures were taken within the sets, we began boarding the buses, oblivious to the guide's irrational expectation of a generous tip. Upon the realization that no tip would materialize from any of us, he grew exponentially incensed as he stalked us through the parking lot. The guide even confronted the bus drivers, perhaps in the hopes of finding a sympathetic ear attached to a convincing and/or authoritarian body—but no luck.

After stopping in a small village for food and water, approximately half of the group stayed back to explore the nearby Ksar of Aït-Ben-Haddou, which is a group of earthen buildings, recently known for their use in the television program "Game of Thrones." The rest went on to the hotel in Ouarzazate. Later in that evening, we split into small groups to explore the area around the hotel and get dinner..

Desert fieldwork in 45 °C

After an early rise, a long wait, and a very bumpy and messy breakfast in the bus, it was time to further explore the desert agriculture of Morocco. This day, we visited a region that is characterized by so called "kheterras" – an old system of underground tunnels for groundwater storage and water supply, sometimes extending for hundreds of kilometres. Sadly, due to the increase in private groundwater extraction, half of the kheterras have fallen dry. Our first stop was a scenic viewpoint.

Here, our guide explained the differences between the traditional and modern agricultural systems in this area; in the traditional system, water demand was strongly related to the household. Water was mainly used to grow your food and to keep your camels, cows, and sheep alive. The younger generation also produces food with the purpose of making as much money as possible, further increasing the water demand. In short, the traditional system is more focused on survival of the household, while in the modern system the focus has shifted towards making money. It is important to economize water in this area, especially due to the scarcity of water. The main question driving this project is "how can we modernize the kheterras?". Up until this day, it has proven to be difficult to introduce change to the traditional system, where every farmer has his own plot and gets water for a certain period per day. Up until now, the local population did not want to change this system of separate plots into a single large field, as they are still used to working individually.

So how can we use the same traditional system, without needing one single field with one single irrigation system? This was studied, and they think they have found a working experimental solution that is partly traditional and partly modern. However, for this to work a change in social organization is necessary, which often takes longer than technological development. At this moment, they see that the local population is not yet fully ready for this change, but they might be in a couple of years. It's a problem that many people only want to work by themselves and not collective, because the water scarcity in this area is so severe that collaboration is necessary.

Marc van Eekeren Reisfonds

Uit respect voor de bijdrage die Marc van Eekeren aan de watersector heeft geleverd en geïnspireerd door zijn passie voor het vak en zijn drive om de Nederlandse water sector internationaal te verbreden en te laten inspireren, is een fonds opgericht om Bachelor studenten van de TU Delft te motiveren en te ondersteunen om internationaal ervaring op te doen binnen de watersector: het Marc van Eekeren Reisfonds.

De TU Delft zet het Marc van Eekeren Reisfonds in als belangrijk strategisch middel om talentvolle Bachelor studenten aan de sector te binden.

Het reisfonds biedt de Bachelor studenten de mogelijkheid om binnen de Bachelor studie een reis gesubsidieerd te krijgen, welke onderdeel vormt van een watergerelateerde ervaring (stage/afstudeeropdracht/ bijwonen van een congres/studiereis).
Het fonds had in 2015 een redelijke omvang (ongeveer € 10.000 per jaar) en de resultaten waren erg positief. Zie hiervoor de enthousiaste reisverslagen van de studenten. Het Marc van Eekeren Reisfonds is onderdeel van een campagne Bachelor studenten van de TU Delft te interesseren in de watersector en uiteindelijk te binden en te werven voor de Mastertrack Watermanagement van de opleiding Civiele Techniek en Geowetenschappen.
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Het modelleren van bovenstroomse zijrivieren van de Oti Rivier

Lisa Swaalf en Noor ten Harmsen van der Beek

Voor ons bachelor eindwerk namen we contact met de sectie Watermanagement. Via hen kwamen we in contact met HKV Consultants. Het bedrijf had al eerder in Ghana voor het Volta bassin gewerkt aan een Flood Early Warning System en was nu bezig met een vergelijkbaar project in Togo en Ghana voor het Oti Basin. Via Burkina Faso (de Oualé rivier) en Benin (de Pendjari rivier) stroomt er water in de Oti rivier.

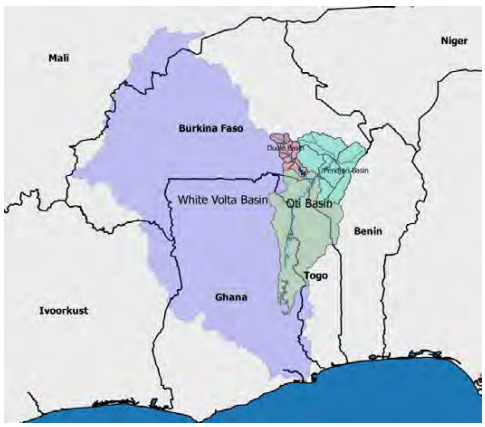
Ons onderzoek draaide erom om twee hydrologische modellen te maken: één voor bovenstrooms van Porga (Benin – Pendjari rivier) en één voor de instroom in het Kompienga Reservoir (Burkina Faso – Oualé rivier). Ook hebben we een advies geschreven over hoe je de uitstroom uit het Kompienga Reservoir (Burkina Faso) kunt modelleren. Hiervan was het niet mogelijk om een model te maken, omdat er geen gegevens gedeeld zijn over hoe de Kompienga Dam opereert. Om een beter beeld te krijgen van de problematiek en voor metingen aan de Oualé Rivier stond de reis naar Togo op de planning.

Met SOBEK kun je hydrologische modellen én hydraulische modellen maken. Wij gingen aan de slag met de hydrologische Sacramento module van het programma. De eerste twee weken hebben we zo veel mogelijk geleerd over SOBEK en over het gebied. In de derde week was het dan zover en reisden we af naar Lomé, de hoofdstad van Togo. Hier kregen we begeleiding vanuit WASCAL, West African Science Service Centre for Climate Change and Adapted Land Use, het West Afrikaanse opleidingsinstituut voor masterstudenten en PHD'ers. In tien West Afrikaanse landen zit zo'n opleiding en vanuit elk land wordt één student geselecteerd. Met een begeleider vanuit WASCAL zijn we op veldonderzoek geweest naar het noorden van Togo. Daar hebben we aan de Oualé rivier gemeten en vragen aan de lokale bevolking kunnen stellen. Ook hebben we het oude en het nieuwe meetstation in Mandouri bezocht. Het veldonderzoek was een hele ervaring op zich en had verassende uitkomsten waar we weer een stap verder mee konden.

We hebben veel aandacht besteed aan het analyseren van de gebieden: het bepalen van de grondsoorten en het landgebruik. Dit hadden we nodig als input voor ons model, samen met de neerslagdata en verdampingsdata. Het model van de Pendjari Rivier kon gekalibreerd worden op basis van afvoermetingen bij Porga. Dit was niet het geval voor de Oualé Rivier, want hier waren geen meetgegevens van bekend. Toen we op veldonderzoek waren kwamen we erachter dat de Oualé Rivier in de weekenden soms bijna helemaal droog stond. Dit betekent dus dat de Kompienga Dam in het weekend wordt gesloten. Door vragen

te stellen probeerden we de verschillen in waterstand tussen het droge en natte seizoen te ontdekken, en verder wanneer er hevige overstromingen in het gebied waren geweest. Hiervoor hebben we ook met het Togolese Rode Kruis contact gehad. Het was echter moeilijk om deze data te valideren, aangezien we de overstromingen niet goed terug konden vinden op satellietbeelden. Omdat de Oualé Rivier tussen Mandouri en Porga in de Oti Rivier stroomt en de afvoerdata op deze twee plekken wel werd gemeten, kon er toch een schatting gemaakt worden van hoeveel er vanuit het Kompienga Reservoir in de Oti Rivier stroomt. Het advies is dan ook om onder andere hier gebruik van te maken.

We willen het Marc van Eekerenfonds en zijn sponsors van harte bedanken voor het mogelijk maken van deze ervaring! Wij hebben enorm veel meegemaakt en geleerd door het onderzoek in Togo zelf uit te kunnen voeren.



Andreas! Where are you?

Rogier Buck, Andreas den Dekker en Bas Tijhof

Exploring the world, helping people with Dutch water knowledge, trying to have real impact on less developed parts of the world; all were reasons for a bachelor thesis in Addis Ababa, Ethiopia. There were a lot of interesting projects to choose from, but one was particularly exciting. Namely a project about the water distribution network in Addis Ababa, the capital of Ethiopia and sometimes dubbed the capital of Africa. Our project was the first of a larger program of the Delft University of Technology in collaboration with Addis Ababa. We would become pioneers in Ethiopia. We had to investigate the problems in Addis, building a foundation for further studies, but also come up with practical solutions ourselves. Ethiopia, located in the eastern part of Africa, has over 100 million inhabitants, making it the second most populous country of Africa.

Our first experiences in Addis were eye-opening. Everyone is so incredibly friendly and helpful. They are always offering to share their food and coffee, even to complete strangers. They are also very proud of their culture and history. The local pronunciation for Ethiopia sounds look Utopia, and the kindness of the people is absolutely utopian.

They say that in Amsterdam you are never more than a meter away from a rat; in Addis it feels like you are never more than 10 meters away from a minibus. Inexplicably they manage to cram 3 tall Ferenji (western people) and 19 Habesha (local people) in 1 Toyota minibus. After this they put a living goat and some furniture on the roof before driving away into traffic jams, honking at everything they are passing and then randomly just to see if the claxon is still working.

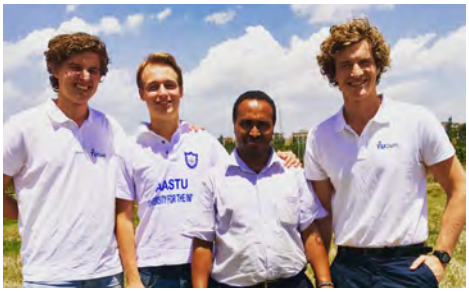
The development of Ethiopia is however still slightly below utopian standards. It took us three days to find the right university, even Google was clueless. Addis Ababa Science and Technology University (AASTU) is only six years old. The students and staff were still building up their university and a lot of people asked us questions about how our university is doing and if we could help them with scholarships and that kind of things. We were in fact the first European students at this university.

The university laid contacts for us with the Addis Ababa Water and Sewerage Authorities (AAWSA). They manage the water distribution and sewage disposal system of Addis and are experiencing severe difficulties. Because of an increase in both per capita demand and the total amount of consumers, consumption is increasing rapidly. Were the system properly managed, enough water would be available to supply everyone. However currently non-revenue water (NRW) percentages are upwards of 50%. In other words, more than half of the water goes unbilled, mainly through leaks in the system or because of meter errors. This creates serious water shortages and health risks.

In time we discovered that the problem of NRW was not only a technical problem but more a management problem. The head office and branch offices had poor communication. It was hard obtaining unreliable data, and reliable data even harder, because few people could help us. We were sent back and forth between different departments, and at the end of the day it frequently occurred that the data we requested either didn't exist or was unavailable.

We wrote a guideline for AAWSA on how to design district metered areas (DMAs), which will create a lot more insight in the water distribution system. The DMAs would help in locating the losses and reduce NRW in Addis Ababa. Furthermore we evaluated the financial consequences for this reduction. The next step is for AAWSA to implement the guideline into their NRW reduction plans.

All in all living and working in Addis for two months has been an amazing and very rewarding time. The kind people, incredible stories and daily amazement have made this experience truly unforgettable.



Research project naar een upflow gravel filter ten behoeve van druppelirrigatie in Rwanda

Roline Montijn, Gabrielle van Zwieteren en Anke Merkx

Wij zijn Roline Montijn, Gabrielle van Zwieteren en Anke Merkx, drie Civiele Techniek studenten van de Technische Universiteit in Delft. Voor ons Bachelor Eind Project zijn wij op zoek gegaan naar een oplossing voor het probleem wat druppelirrigatie in Rwanda op dit moment ondervindt. Druppelirrigatie zorgt voor een veel efficiënter waterverbruik, heeft minder energie nodig en hierbij is er geen risico op erosie. Voor een goede werking van druppelirrigatie is echter water nodig wat geen gesuspendeerde stoffen bevat groter dan 100 micron, iets wat boeren in Rwanda niet ter beschikking hebben.

Onze begeleider Nick van de Giesen, professor van de TU Delft, bracht ons voorafgaand aan ons project in contact met Norbert van der Straaten, van Holland Greentech in Rwanda, en Arjan Janknegt, van Rivulis in Nederland. Het doel van Holland Greentech is om de horticultuur van Oost-Afrika verder te ontwikkelen en doet dit door zich op alle disciplines van landbouw te richten. Rivulis levert irrigatie producten aan Holland Greentech. Samen met deze twee bedrijven en met assistentie vanuit de TU Delft zijn wij begin september van start gegaan met het project. De grootste uitdagingen van het project waren het maken van de filter van lokaal verkrijgbare materialen en de kosten van de filter zo laag mogelijk houden, zodat het voor boeren in Rwanda betaalbaar is.

De eerste twee weken zijn wij van start gegaan in Delft. Hier hebben wij literair onderzoek gedaan en zijn de eerste proefjes verricht in het Waterlab. Voor we het wisten zaten we op 19 september in het vliegtuig richting Kigali, met alle benodigde materialen voor de filter. Op het kantoor van Holland Greentech in Kigali en met behulp van alle mensen daar hebben we in de eerste weken in Rwanda omgevingsonderzoek gedaan in Bugesera en Nyanza en uiteindelijk een ontwerp gemaakt voor een upflow gravel filter in Nyanza.

De laatste 2 weken in Rwanda zijn we bezig geweest met het bouwen van de filter op een boerderij van HoReCo in Nyanza. HoReCo is een bedrijf dat de ambitie heeft om Rwandese boeren te helpen bij het vergroten van de productiviteit en te helpen om een plek te veroveren op de wereldmarkt, wat wordt gepromoot door de regering van Rwanda. Met hulp van Holland Greentech, Rivulis en HoReCo zijn wij erin geslaagd ons filterontwerp daadwerkelijk te realiseren.

Al met al hebben we in een korte tijd een goedwerkend filter neergezet op een boerderij in het zuiden van Rwanda. Het was een ontzettend mooie ervaring, omdat we samengewerkt hebben met lokale mensen en met z'n allen een goed resultaat hebben afgeleverd. De laatste dag dat wij in Rwanda waren hebben we samen met Holland Greentech een demonstratie dag georganiseerd, om meerdere instanties en bedrijven, waaronder de Nederlandse ambassade en de Rwanda Agriculture Board, te laten zien hoe wij het filter gemaakt hebben en hoe de filter te gebruiken is. De filter is op dit moment in gebruik en hopelijk wordt het binnen enkele jaren op meerdere plekken geïmplementeerd.

Marc van Eekeren Reisfonds

PDAM waterzuiveringsinstallatie Bandung Indonesië

Markus Pleij

In september 2016 besloot ik nog een jaartje te wachten met mijn master waardoor ik nog een invulling zocht voor de barre en koude winter in Nederland. Om aan de kou te ontsnappen besloot ik een stage te regelen voor mezelf in Indonesië met de hulp van Luuk Rietveld en Bas Heijman. Na twee weken intensief mailcontact en twee gesprekken met Luuk Rietveld later, had ik mijn ticket geboekt naar Jakarta om vanuit daar de bus te nemen naar Bandung waar mijn stage zou plaatsvinden.

Na mijn aankomst in Bandung werd ik ontvangen door professor Rusnandi in zijn huis. Ook heeft Rusnandi mij geholpen met het vinden van een kamer en mocht ik de eerste paar weken in zijn studentenhuis slapen wat eigenlijk alleen bedoelt was voor meisjes. Rusnandi heeft mij de gehele stageperiode begeleid en geholpen waarvoor ik hem er zeer dankbaar ben.

Tijdens mijn stage hield ik mijzelf bezig met het vergroten van de capaciteit van een van een toevoerpijpleiding naar de waterzuiveringsinstallatie van Bandung. Deze pijpleiding is 50 kilometer lang en was ontworpen om 850 l/s te transporteren naar de waterzuiveringsinstallatie. Echter in de toenmalige situatie was de capaciteit slechts 500 l/s. Omdat het waterzuiveringsbedrijf plannen heeft om in de toekomst te groeien en aan meer huishoudens water te leveren is het van belang dat de toevoer van ruw water ook stijgt om deze stijging bij te kunnen houden.

In de eerste paar weken van mijn project lag de focus vooral op het onderzoeken wat de exacte tracé en de bijbehorende hoogte is van de pijpleiding is. Daarnaast heb ik een week lang veldtesten gedaan naar de waterdruk in de pijpleiding. Na een maand ben ik een midweek naar Bali en Lombok gereisd met een aantal lokale vrienden. Op deze twee eilanden heb ik heerlijk kunnen bijkomen van het harde werken aan het strand met een biertje.

Toen ik terug kwam ging de tweede helft van mijn stage alweer in. In deze fase heb ik al mijn data verwerkt in een computerprogramma en hieraan een conclusie verbonden naar waarom de pijpleiding niet op volledige capaciteit opereerden. In mijn laatste week heb ik nog vier Delftse studenten op weg mogen helpen met hun afstudeerproject. Ik heb op de laatste dag in Bandung nog een eindpresentatie gegeven aan de gehele afdeling van het bedrijf wat mij ondersteund heeft met mijn project. Ook heb ik mijn verslag hardcopy ingeleverd aan het management van het waterzuiveringsbedrijf.

Na mijn stage heb ik nog drie maanden gereisd door Zuidoost-Azië en uiteindelijk terug naar Nederland gevlogen vanuit Bangkok. Eenmaal terug op Schiphol was het even wennen aan de kou en het feit dat dit het einde van mijn avontuur in Indonesië was.

Water reclamation Mozambique

Jelle Epema and Stijn Dijsselbloem

In the spring of 2017 we, Jelle Epema and Stijn Dijsselbloem students from the TU Delft, went to Mozambique to work on our BSc thesis on wastewater treatment. We stayed for a period of two months, from the beginning of April to the start of June.

Background

As people have written on this website several times before, the existing WWTP is not operating well (see Irene's work for more information) although things are changing and works at the plant have started. These include a wall and a gate that allow controlling the accesses and repaving of the roads in the plant. In the near future the Municipality of will also start the work of de-sludging the ponds. The main objective of our work was designing a system that would allow safe water reclamation for irrigation at Infulene, following the guidelines of WHO. We also wanted to design a system that would keep as much as possible the existing infrastructure. Thus, we went with a combination of a UASB reactor to replace the existing anaerobic ponds and, as polishing step, the introduction of baffles in the existing facultative ponds. Ok, so let's explain what we discovered.

UASB

From this part of the work we concluded that firstly, that a UASB reactor is a robust treatment method for wastewater. However, an Infulene, it is not only wastewater that needs to be treated: there's also faecal sludge (FS) being transported by truck to the plant. Applying a UASB reactor as the only treatment would not suffice and it became evident that the UASB reactor should be combined with FS drying beds. The final configuration consisted of four UASB reactors, with the remainder of the space used for the drying beds. With this configuration the polishing step would not get overloaded. It was also concluded that the BOD concentrations were lowered to acceptable levels for depositing onto flowing waterbodies

Polishing step

For this step, various systems were analysed and compared based on the criteria that were highly relevant for the Maputo situation. These included simplicity, cost and fecal coliform removal efficiency. Polishing ponds were considered the best system for this situation. Based on literature models, expected fecal coliform removal efficiencies were calculated. For optimal configuration, two possible adjustments to the existing ponds were considered: heightening of the bottom to make the pond shallower and introducing baffles that subdivide the pond into multiple channels. For both adjustments, removal efficiencies increased. For the best results a combination of both should be implemented. When using this combination, around 5000 m3/day could be treated sufficient for unrestricted agricultural use. When the full inflow of around 15.000 m3/day must be treated, 2 log removal could be obtained, which is not sufficient according to WHO guidelines.

Conclusions

A combination of a UASB and baffled ponds would reach removal efficiencies that would allow unrestricted irrigation. Although we did not quantify the risk associated with current reuse practices, these modifications would certainly increase the safety for farmers using the effluent water of Infulene WWTP. Overall experience Traveling to Mozambique was a great adventure. The Mozambican people are incredibly friendly and welcoming. The country itself has some of the most beautiful beaches we had ever seen. Outside of our project we went snorkeling, hung out at local bars and ate Mozambican food with our new Mozambican friends. They even invited us to partake in their weekly football competition. Overall it was a great experience which we highly recommend to every student thinking about going.

Overview of all completed MSc theses

Name	Subject
Luca Trotter	Sustainable asset management in water distribution systems
Jiaying Yang	Collaborative governance of urban stormwater utilization
Daniel Klein	Supporting the implementation of effective urban water conservation and demand management strategies
Jayden Liu	Organic micropollutant treatment by pre-ozonation and activated carbon
Hemant Arora	Optimising the ripening period of slow sand filters
Ward van Es	The Fresh Water Factory: removing organic micro-pollutants with ozonation
Timon Huijzendveld	Biological As oxidation during start-up of rapid sand filters
Evelien Martens	Vacuum membrane distillation for the production of ammonia fuel gas for solid oxide fuel cells
Max Admiraal	Decentralized sewage treatment by ceramic Microfiltration
Christiaan Hordijk	Concentrating Ammonium
Tsz Kit Liu	Organic Micropollutant Treatment by Pre-Ozonation and Activated Carbon
Lenno van den Berg	Characterization and modelling of full-scale aerobic granular sludge
Felipe Gonzalez Gonzalez	Crossflow reversal effect on removal of RO particulate fouling: a comparison of two spacers
Jesper Stuyling de Lange	Analysis of the challenges and solutions in the water and sanitation sector in Greater Maputo, Mozambique
Luca Trotter	Sustainable asset management in water distribution systems
Jiaying Yang	Collaborative governance of urban stormwater utilization
Daniel Klein	Supporting the implementation of effective urban water conservation and demand management strategies
Rob Deckers	Optimizing electrodialysis processes for concentrating ammonium rich streams
Alexandra Prodănescu	Dewaterability of thermophilic digestate: Characteristics and underlying processes
Xuan Li	Assessing water quality changes and transition effects in distribution systems by online particle sampling system (OPSS)
Brent Pieterse	MnO4 – Fe(III) dosing to rapid sand filters for removing arsenic from drinking water to <1 µg/l

Overview of all completed Watermanagement BSc theses

Name	Subject
Valerie Demetriades	Non-revenue water, Groot Paramaribo
Juliette Eulderink	Efficient water use in Colombia
Vita Vollaers	Efficient water use in Colombia
Emilie Wesseling	Efficient water in Colombia
Suzanne de Groot	Delfland, zuivering van drainagewater van de glastuinbouw
Nino Huijsman	Delfland, zuivering van drainagewater van de glastuinbouw
Donald Lagers	Aluminum removal using up flow limestone filtration from water in San Marcos
Joost Verbart	Ensuring a better water availability and quality in the Mathare Valley
Stijn Dijsselbloem	Post-treatment of wastewater Maputo
Volkan Hendriks	Welke bacterien van het gevonden consortium zorgen voor een oneven VFA productie?
Thomas Kaptein	Sustainable drinking water
Ileen de Kat	Removing pesticides from drinking water
Floris Sijbesma	Hydraulisch model waterzuiveringsinstallatie Oldeholtpade
Ileen Streefkerk	Drinking water quality and quantity improvement
Daan van de Ven	Stustainable drinking water
Katinka Verleg	MhlangaDrinking water quality and quantity improvement
Rens van der Vis	Hydraulisch model zuiveringsinstallaties Oldeholtpade
Kirsten Willemse	Drink water quality & quantity improvement in Lochiel
Lonneke Westhoff	Removing pesticides from drinking water
Iris Heemskerk	De haalbaarheid van zelfstandig monitoren van drinkwaterkwaliteit in verstedelijkt India
Kimberley van Batenburg	Adsorptieve ijzerverwijdering
Thies Blokhuijsen	Hydrological study on the Inhambane peninsula
Izaak Geursen	Modelleren waterzuiveringsproces Neveda met Biowin
Simon van Hees	Hergebruik van afvalwater als sproeiwater in Maputo
Sanne de Smet	Water filter straws
Vincent van Roon	Ontijzering van grondwater mbv pelletreactoren
Heysem Ugurlu	Scaling in reverse osmosis
Bart-Jan van der Werff	Filterability improvement by flocculants
Reinoud de Klerk	De invloeden op de concentraties Zwarte Zee met alen bij het grondwater bij PS Bergen
Rogier Buck	Guideline for DMA development with minimal data requirements
Andreas den Dekker	Guideline for DMA development with minimal data requirements
Philip Hageman	Arsenic removal from drinking water in Costa Rica
Ferdi Knoester	Uitbreiding hydraulisch model van productielocatie Oldeholtpade
Joris Memelink	Uitbreiding hydraulisch model productielocatie Oldeholtpade
Jeroen van der Veen	Arsenic removal from drinking water in Costa Rica
Fransje van Oorschot	Piped systems in Bangladesh and India
Chris Zeeuw van der Laan	Waterkwaliteit waterspeeltuin Delftse Hout
Milan Kant	Cellulose: van project tot marktproduct – Inventarisatie van huidige celluloseprojecten

Online Education

Online, publicly available education is regarded as part of TU Delft's social contribution and as an integral part of its goal to innovate. For these reasons, Open & Online Education was set up as a strategic innovation programme, with the overall mission to educate the world and enhance the quality of education. It seeks to create a comprehensive online portfolio, both in terms of the variety of course topics and in the type of courses on offer, while delivering an outstanding learning experience. It also aims to innovate education by conducting research into online courses and utilising the insights to benefit both online learning and teaching on campus.

MOOCs

It was back in 2007 that our section, as one of the pioneers of this university, offered its first courses on water treatment as OpenCourseWare (OCW). OCW is a free and open digital publication of high quality university-level educational material. OCW is openly licensed, accessible to anyone and anytime via the internet. A more recent and much more appealing form is a Massive Open Online Course (MOOC). A MOOC is a free online course aiming at large-scale interactive participation and open access via the web. In addition to traditional course materials such as videos, readings, and problem sets, MOOCs provide interactive user-forums that help to build a community for the learners, where professors and teaching assistants actively participate in forum discussions. MOOCs represent a form of web information systems that is revolutionising the way education is brought to people. MOOCs offer great opportunities to change how people learn, by analysing student interactions with the courseware and adapting the courseware to the learners. Today, the TU Delft has reached over one million enrolments in more than 36 MOOCs in the field of science, design and engineering. Hundreds of thousands of learners from all around the world are now able to gain access to the knowledge and expertise of the TU Delft through open online courses.

WaterX series

At the Sanitary Engineering department we have two MOOCs running, namely “Drinking Water Treatment” and “Urban Sewage Treatment”. We even won an award for them! In 2017 more than 26.000 learners from more than 165 countries enrolled for our online courses. When finishing the course, learners can buy a verified certificate. A verified certificate can provide proof for an employer, school, or other institution that the learner has successfully completed the online course. In 2017 more than 500 learners bought a verified certificate. Together with the MOOC “Water & Climate” from the Water Resources section, the three MOOCs form the WaterX series. When a learner successfully completes all three MOOCs, he will receive the XSeries Certificate, which is a true achievement!

Johan, from Albania, had always been a bit sceptical of online courses, but he found that “this experience proved me wrong”. “The course helped me learn how to stick with a problem and find ways of solving it. Perhaps most significantly, this experience taught me the skills that will enable me to continue to develop my passion for the water sector beyond the virtual classroom. Thank you TU Delft for bringing into my modest Albanian home such innovative technology in the simplest way possible. You make it easy for anyone to study online.”

Online Education

Blended learning

Because of the availability of the MOOC material, campus education has changed into a more blended way of teaching. The knowledge clips, tutorials and quiz questions that were developed for an online education purposes are now being used by our own campus students as additional educational material. A type of blended learning is the "flipped classroom" strategy in which campus students are required to have read and watched the online material before attending the lecture. This way the lecturer can actively interact with the students during the lecture itself, explore topics in greater depth and creates meaningful learning opportunities. This new way of teaching has shown that not only the inscriptions to these courses but also the passing rates have increased remarkably.

What else?

Some courses of the Water Management Master track are available online, this requires customization, since the courses aren't officially available online. When a student is interested in following a Master course, please contact your online education officer, Sabrina Kestens.

New developments: ProfEd

As the university promotes lifelong learning, our section has come up with a new product: the ProfEd (short for Professional Education). This is a short and intensive course for working professionals. The ProfEd is an online education product for which learners have to pay, in contrary to the MOOCs. Learners also receive more personal guidance from the course team and the team works actively together with (water)companies in creating the course. Therefore the course has a strong practical approach; participants can apply the learning material into their working environment and get personal feedback from the professors. Combining academics and action! For example, in the ProfEd about "Nanofiltration and Reverse Osmosis" from Bas Heijman, participants engage in practical applications such as designing a reverse osmosis installation with the use of computer programs.

Developing one ProfEd would be just plain, and since the "Nanofiltration" ProfEd was such a success that we will be running it again next year, the section is creating another two more! One is from prof. Merle de Kreuk about "Aerobic Granular Sludge Technology", the other is from prof. Jules van Lier and covers "Anaerobic Treatment". As the course teams strive to give the learners the best online learning experience, they stretch all their potential, like filming on a Marine ship, incorporate Virtual Reality components and include prominent scientists as lecturers. Feeling enthusiastic? Stay tuned!

More information & registration

For an overview and the look and feel of our MOOCs and ProfEds, visit the online learning website of the TUDelft. The online courses of our Mastertrack can be found on the website of our department. Or drop by your online education officer, Sabrina Kestens, for a chat over a good cup of coffee.

In depth; how does a ProfEd work?

Now we've told you about the creation of a new online education product, the ProfEd, we would like to give you a better overview of what it really is. In the text below we explain what the "Nanofiltration and Reverse Osmosis in Water Treatment" course is composed of.

Reliable access to fresh water is one of the fundamental pillars on which a society is built. However, only a tiny fraction of planet's water is directly readily available as freshwater. The shortage of potable water, as consequence of population growth, current consumption patterns and climate changes, will be a major problem in the coming decades and will have the same social impact as that of increased energy prices. Groundwater is by far the most abundant and readily available source of freshwater. When used for drinking water, fresh groundwater sources are preferred to other readily freshwater sources because of the absence of pathogens. However, regions with sustainable fresh groundwater resources are shrinking by the day, throughout the world. A solution to this problem is the use of saline water to produce drinking water. Among different desalination techniques, Reverse Osmosis (RO) has become an attractive solution for water shortage. The purified water from RO can be used in drinking water, dialysis, power generation, pharmaceuticals and medical devices, manufacturing of semiconductors, and paper, sugar and beverage industry as well as concentrating and reclamation of wastewater. Therefore, knowing how to use the RO-technologies is important for a significant number of people.

The sanitary engineering department of Delft University of Technology developed an online course about RO membranes, to offer working professionals from all over the world a flexible, convenient way to strengthen and enhance their professional skills, increase their value as employees, and advance themselves to a higher position. The course, which is on MSc level, reached 34 learners from over 20 countries, representing Asia, Africa, Europe and North and South America. Very successful for a first run!

The online membrane professional education course focuses particularly on the Spiral-wound membrane (SWM) configuration because that is predominately applied in NF and RO. The course is divided into seven weeks and each week has its own theme. First, the course provides general information about the RO, it's principle and calculation methods. Then, it will focus on the applications of the RO on different type of water: seawater, brackish water, fresh surface water and the main problems of using RO with this type of water: concentration polarization, scaling and biofouling. Finally, some design considerations will be explained in the last week.

Each week consist of several knowledge clips, quiz questions and homework. Knowledge clips are about the theoretical matters, practical matters or an excursion to a membrane based treatment plant. Excursions are planned to a seawater RO on a ship (Karel Doorman ship), a brackish water RO (Oasen water company) and industrial water RO treatment plant (Evides water company). The homework is also very diverse. For example, the participant has to do an online measurement by the provided animated simulation or making his own SWM modules by using colored papers and glue.

Bas & Amir receive flowers for creating a very successful ProfEd

Publications

Publications

Doctoral dissertation

Zlatanović, L. (2017) Fire sprinklers and water quality in domestic drinking water systems: A novel approach to improve public safety in homes

Salifu, A. (2017) Fluoride Removal from Groundwater by Adsorption Technology: The occurrence, adsorbent synthesis, regeneration and disposal

Taucer-Kapteijn, M. (2017) Occurrence of enterococci in the environment and their value as an indicator of water quality

Haidari, A. (2017) One Step Membrane Filtration: A fundamental study

van Daal-Rombouts, P. (2017) Performance evaluation of real time control in urban wastewater systems

Bennani, Y. (2017) Photoelectrocatalysis in water treatment

Reyes Perez, M. (2017) Water supply and demand management in the Galápagos: A case study of Santa Cruz Island

Journal refereed papers

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