forum 89

Newsletter of the Chair of Urban Water Systems Engineering

ANNUAL REPORT OF THE CHAIR OF URBAN WATER SYSTEMS ENGINEERING

2018

Chair of Urban Water Systems Engineering

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Foreword

Dear Friends,

I am pleased to present our 2018 annual report. The past year brought us some personnel changes and related adjustments, but was also marked by exciting research activities and successful external fundraising.

The staff of the chair continue to be very active in publishing the findings gained in scientific publications. We are especially happy for Dr. Therese Burkhardt, Dr.-Ing. Max Weißbach, Dr. Lara Stadlmair, Dr.-Ing. Vasilis Dandikas and Dr-Ing. David Miklos for successfully completing their doctorates last year. Dr.-Ing. Konrad Koch was able to complete his habilitation at the end of last year, a notable achievement. A student of ours, Mr. Dominik Häring, received the H.P. Scholz prize for his Master's thesis. We congratulate you all once again!

In the past year, we have been strengthened by new doctoral students, introduced to you in this annual report along with their other colleagues at the Chair. In 2018 we continued to enjoy a direct exchange with visiting scholars from Australia, China, the Czech Republic and the USA, some of whom visited us for several months. Building on the diverse discussions, we look forward to further developing these contacts through ongoing and future research activities and return visits.

In July 2018, the 46th Wastewater Technology Seminar (ATS) took place with the topic "Innovative strategies for the treatment of sewage sludge", which was organized under the leadership of Dr.-Ing. Konrad Koch. The 47th ATS on "Further Wastewater Treatment - Requirements, Financing and Implementation" is planned for July 3, 2019 in Ismaning, organized by Dr.-Ing. Hübner.

After a few years on pause, we are reinstating the long tradition of water technology seminars (WTS) this year. The 30th WTS will take place on February 13, 2019 in Munich and will be on the timely topic "Strategies for dealing with groundwater contamination by perfluorinated compounds (PFCs)". The 30th WTS was presented by Dr. Knoop. Programs for these events can be found on our web portal, where you can also conveniently register (www.sww.bgu.tum.de/ats). We would be very pleased about your interest in these events.

In the past year, the chair made significant contributions to the education of students in the Bachelor's programs in Environmental Engineering and Civil Engineering, as well as in the Master's Degrees Environmental Engineering, Civil

Engineering, Environmental Planning and Engineering, as well as Sustainable Resource Management. In addition to a large number of lectures, exercises and internships, the staff members of the chair supervised more than 79 master theses, study projects, and bachelor theses. Last year, we significantly revised the bachelor's degree programs in Environmental Engineering and Civil Engineering, which will begin in their new formats in WS 19/20 (more on www.umwelt.bgu.tum.de).

Nationally, our employees have been involved in several working groups of the DWA, the German Water Chemical Society (GDCh) as well as internationally, in the NORMAN working groups at the European level, and in the International Water Association (IWA). In addition, I was appointed to the Drinking Water Commission of the Federal Ministry of Health in 2018.

2018 also brought some personnel changes. Dr. Christian Wurzbacher took over the working group "Microbiological Systems" as well as the Microbiological Laboratory on March 1st, 2018. We are pleased that Dr. Oliver Knoop joined us to lead the Trace Substances laboratory on April 1st, 2018. As previously mentioned, the new German ‘Science Time Act’ limits the continued employment of experienced academics in the academic middle class to a certain period of time. Unfortunately, this lack of perspective caused Dr. Carolin Heim to leave at the end of December 2018 for a place at Helmholtz Zentrum München. We wish Dr. Heim all the best in her new position! The Chemical Laboratory will come under new management on February 11th, 2019. You will find more information regarding these and other changes in this report.

On behalf of my employees, I would like to thank you for your continued support and interest in our students and our work. We are also particularly grateful for the support of our sponsoring association, which makes a very important contribution to the training of our doctoral students and students in the financing of travel for conferences and research grants.

We wish you a successful year, and hope you enjoy our 2018 annual report.

Sincerely,

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Research Center

The mission of the research center at the Chair of Urban Water Systems Engineering is to provide support for process validations for both drinking water and wastewater treatment technologies at laboratory and pilot scale. In addition, we are conducting studies on new materials and processes and support research and development in close collaboration with industry partners, small and medium-size enterprises, and public as well as regulatory agencies. The research center is comprised of a 400 m² pilot-scale facility and an adjacent research field, both with direct access to treated wastewater from the Garching Wastewater Treatment Plant (30,000 PE). This infrastructure enables us to conduct studies not only with drinking water, but also to examine wastewater processes fed continuously with differently treated effluent qualities. For these studies, we can conduct experiments at laboratory and pilot scale with reactor volumes between 30 and 800 L in size. This provides opportunities to upscale and validate processes from laboratory to demonstration scale. Beside Zahn-Wellens-Tests to examine the biodegradability of wastewater samples (following DEV L 25), we also conduct activated sludge simulation tests (following DEV L 41).

Regarding advanced water treatment processes, the research center is equipped with test skids for chemical oxidation (ozone, UV irradiation with hydrogen peroxide, electrochemical oxidation) and membrane filtration (ultrafiltration, nanofiltration, reverse osmosis) (Fig.1)

Fig. 1: Pilot-scale nanofiltration at 80 L/min

In addition, the center is investigating and advancing treatment processes for urban stormwater and street run-off. For these investigations, we can utilize laboratory-scale test and soil column experiments of various sizes to examine the fate and transport of heavy metals and organic contaminants. Regarding urban run-off from copper roofs, a demonstration-scale test bed is available at the center, which is comprised of a large-scale copper roof and associated sampling and monitoring devices.
The research center is directed by Prof. Brigitte Helmreich.

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Reduced nitrous oxide emissions during high nitrogen loading in wastewater treatment

Double stage or single stage processes

In comparison to single stage deammonification systems, double stage treatments with nitrification have resulted in large differences in N_2O emissions. Several studies identified nitrous oxide gas in biochemical reactors and exhaust gases during treatment of digestion centrate with NH_4-N concentrations about 1,4 g/L. This paper presents experiences from pilot-scale nitrification plants with continuous feeding and clarifiers (2018) and compares them to results of single stage SBR systems.

Varying biochemical conditions

During nitritation, >700 mg/L NO_2-N is present in the bioreactor, necessitating a second advanced treatment stage. In single stage SBRs with N_T reduction around 460 g/(m^3·d), NH_4-N is present at concentrations of 60 mg/L and NO_2-N concentration of <2 mg/L in the effluent . Though pH decreases during continuous aeration, it can be stabilized by employing intermittent aeration intervals, with careful consideration of associated processes, for example considering that the closing time of valve or fan actuators can be >10 min in large-scale plants.

More nitrous oxide generation at high nitrite concentrations

N_2O levels exceeded 4.2 µmol/(L·min) in the nitritation reactor at high nitrite concentrations during anoxic conditions, though it was stripped out during aeration. During continuous aeration, 600 ppm gaseous N_2O was measured, and after lengthy anoxic periods, N_2O temporarily exceed 3,200 ppm. In single-stage deammonification with very low NO_2 concentrations, <30 µmol/L N_2O was present in the liquid phase, and 50 ppm N_2O was present on average in the gas phase. With similar NH_4 reduction, our results show 90% lower N_2O emissions during treatment of high nitrogen loaded wastewater in a single-stage deammonification system.

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Physicochemical, Analytical and Microbiological Laboratories

A central facility of the chair and the research center is the affiliated laboratory, divided into three areas: the physicochemical laboratory led by Dr. Carolin Heim, the trace compounds analysis unit led by Dr. Oliver Knoop, and the microbiological laboratory led by Dr. Christian Wurzbacher.

The physicochemical laboratory is equipped with state-of-the-art analytical apparatus for the investigation of all relevant standard parameters in drinking and wastewater. Besides the characterization of water samples through sum parameters, such as COD and BOD (Fig. 2) organic parameters can be further determined using 3-D fluorescence and UV spectroscopy and measured quantitatively with the TOC analyzer. For analysis of anions either photometric test methods or ion chromatography are available. Determination of metals is carried out using atomic absorption spectrometry.

Fig. 2: Determination of single and sum parameters through cuvette tests using the HACH-photometer

The characterization and identification of organic molecules from aqueous samples with trace compounds analysis (target screening) can be carried out using chromatographic separation techniques coupled to highly sensitive mass spectrometric detection techniques (LC-MS/MS) (Fig. 3). Volatile organic compounds as well as particles originating from microplastics can be detected with the help of headspace-GC-FID and a thermo-desorption pyrolysis GC-MS, respectively.

Fig. 3: LC-QTRAP-MS system by AB Sciex for trace analysis

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The microbiological laboratory uses conventional cultivation techniques to determine the fecal indicator germs (*E. coli* and enterococci) and pathogenic bacteria (e.g. *Pseudomonas aeruginosa* and *Legionella spp.*) relevant for hygienic water quality. Furthermore, fluorescence microscopy for the quantitative detection of active and dead microorganisms is possible. Bacterial cell numbers, antibiotic resistance genes and certain bacterial groups such as enterococci are detected with the qualitative real-time polymerase chain reaction (qPCR) (Fig. 4). High throughput sequencing technologies based on RNA or DNA are used to characterize microbial communities and microbiomes from aquatic systems . Furthermore, the laboratory owns a collection of microorganisms (bacteria & fungi) from technical systems which can be used for further experiments.

Fig. 4: Left: PCR and qPCR system to amplify and quantify different genes of interest. Right: microbial cultures for experiments

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Research Group
Sewer Systems and Stormwater Management

The research group ‘Sewer Systems and Stormwater Management’ deals with strategies for condition assessment and rehabilitation of sewer systems, but especially with sustainable stormwater management. The challenges of climate change and demographic change mean that new concepts need to be developed in order to be able to react sustainably to these changes. One focus is the decentralized management of stormwater runoff of impervious surfaces in order to counteract intense stormwater peaks and thus mixed water overflows, but also the detection and disposal of contaminants in the runoffs (Fig 5).

Decentralized treatment plants for metal roof and traffic area runoffs are developed and evaluated for this purpose. In this framework, plants treating metal roof runoff according to the "Test criteria for preliminary assessment of infiltration systems for the retention of metal ions from precipitation discharges of metal roofs" of the Bavarian State Office for the Environment (LfU) of 30.6.2008 (AZ: 66-4402-26060 / 2008) are tested for companies.

Fig. 5: Vegetated infiltration swale treating zinc roof runoff

At the moment, a practice-oriented project is being carried to investigate the operating behavior of selected decentralized treatment plants within the framework of a research project financed by the Bavarian State Office for the Environment in cooperation with the city of Munich. These investigations are very valuable for the new leaflet of the DWA-M 179, which deals with such decentralized treatment plants. In addition, a new project studying the complexation of biocides from building facades with heavy metals from the guttering system began in 2018.

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Development of a strategy to use stabilized ammonium fertilizer to improve the P supply to young plants from poorly soluble P-fertilizers and the P-soil stock to minimize the input of N and P from agricultural land into water bodies

In agriculture, the elements phosphorus (P) and nitrogen (N) are essential for plant nutrition. Nitrogen, in the form of ammonia and after nitrification as nitrate, is available to plants, increasing the risk of its loss via leaching, which contributes to groundwater quality deterioration. In contrast, the P-content in the soil is mostly immobilized. One consequence of this is that particle transport (erosion) causes P displacement from the soil surface, leading to the eutrophication of water bodies.

In recent years, so-called nitrification inhibitors, which can stabilize the ammonium phase of a fertilizer for 4 to 6 weeks to mitigate loss, have been developed.
There is initial evidence that spatial proximity of ammonium, the nitrification inhibitor, and sparingly soluble phosphate in the fertilizer or soil could generate further benefits, namely better recovery of sparingly soluble P compounds. However, detailed knowledge about the reaction mechanisms, also in connection with so-called biostimulants, are still largely missing.

An important aspect is the use of the pH dependence of the P-supply in the soil solution (optimally pH 5 to 6.5).

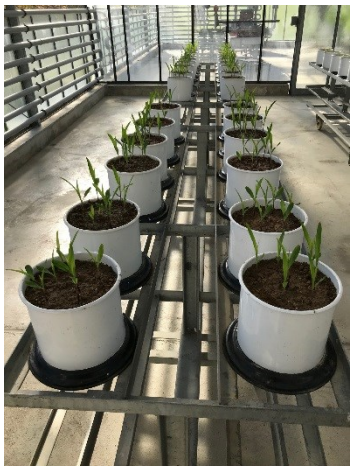

Fig. 6: Greenhouse experiments with corn (Zea mays) and oilseed rape (Brassica napus) plants in different soils

Three economically and ecologically relevant goals can be achieved through this research (Fig.6):

1) The use of previously poorly plant available P;
2) The reduction of P-reserves in soils and, associated surface water pollution by leaching; and
3) The use of alternative P-sources to achieve partial closure of the P-cycle.

COOPERATION:
CHAIR OF PLANT NUTRITION, TUM;
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Practical experience in handling decentralized stormwater quality treatment devices for traffic area runoff

Current trends in sustainable groundwater management feature increasing instances of on-site percolation of traffic area runoff. Due to traffic-related emissions, atmospheric pollution and temporary point emissions (accident/construction site/event), traffic area runoff can be mildly to heavily polluted by heavy metals or organic substances.

Fig. 7: Testing facility for traffic area runoff treatment

In urban regions, runoff retention which is normally naturally done by vegetated topsoil must instead be provided by technical solutions due to limited space. Technical solutions can prevent contamination of the soil and groundwater systems (Fig. 7).

However, apart from numerous laboratory studies, few scientifically documented field studies exist.

The objective of the research project is to perform independent application-oriented research on decentralized stormwater quality treatment devices, which are approved by the Deutsches Institut für Bautechnik (DIBt). For this, three treatment plants (two shaft systems and one filter substratum channel) with different functionalities were constructed in Munich, on a street with heavy traffic under equal conditions. To capture seasonal influences, the study will run for 1.5 years. The emergence of hazardous substances and their detention and remobilization under the influence of deicing salts and long-lasting impounding will be studied. Operational aspects will be recorded and analyzed. Additionally, behavior of insufficiently investigated substances, including gasoline additives (MTBE/ETBE), cyanides contained in deicing salts, and fine particles will be monitored.

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Feasibility of water reclamation for agricultural and urban reuse in northern Franconia, Germany

The increasing trend of urbanization and climate change impacts have significant consequences for drinking water supply and sanitation worldwide. In particular, the impact of climate change on water resource availability in regions that have not yet experienced a lack of freshwater supplies could be prevented by approaches including water reclamation and reuse.

The northern Franconia region of Germany experiences less than 450 mm of precipitation annually, and is traditionally characterized by limited water resources. Increasing competition and demand for water between the agricultural sector, industrial/commercial needs, public drinking water supply, and maintaining ecological base flows has recently begun to present problems. Impacts from climate change will further aggravate this situation.

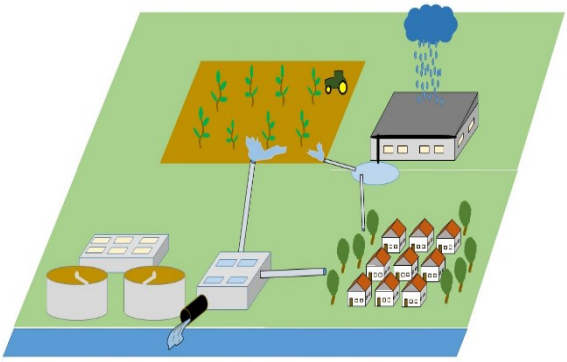


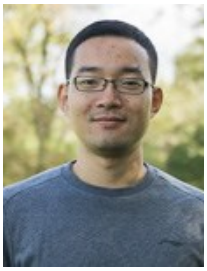
Fig. 8: Case study area for water reuse

Therefore, the aim of this study is to assess the feasibility of long-term water reclamation for agricultural and urban reuse in this region in order to expand the conventional water resource portfolio.

The study was launched with a comprehensive evaluation of available wastewater and stormwater run-off quantities that could potentially be reclaimed and treated centrally or decentrally to provide fit-for-purpose water qualities for various reuse applications. During the kick-off of this study, a stakeholder group was established with representatives from the user community, farm associations, wastewater utilities, drinking water providers, regulatory agencies, and environmental groups. Based on requirements elaborated within the stakeholder group, four case study areas representing urban landscape and agricultural irrigation were identified. For these study areas, the local demand and sources of reclaimed water as well as stormwater run-off are specified.

Given the seasonality of the demand, flexible and modular treatment options are desired. Treatment options for the various applications favor following secondary treated effluent with powdered activated carbon, ultrafiltration, and UV disinfection (Fig. 8).

FUNDING:
GOVERNMENT OF UPPER FRANCONIA



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Complexation behavior of biocides and metals in urban stormwater runoff

Biocides are chemical components used for the inhibition of unwanted organisms like algae and fungi. Terbutryn, diuron, and OIT, among others, are commonly used organic biocides, a typical integral component of hydrophobic renders (mortars) and paints, meant to migrate to the surface of façades during wetting events. Due to this, there is potential for the biocides to enter the environmental via façade runoff at the concentrations exceeding water quality standards and creating ecotoxicological concern. Their presence is also often coinciding with other contaminants. Heavy metal ions like Zn and Cu from the dissolution of surface materials and their corrosion layers are also important contaminants to urban stormwater runoff. However, the effect of coexistence of these two kind pollutants in urban runoff is still unclear, and therefore needs to be clarified in further studies.

Fig. 9: Biocides inhibit unwanted organisms on building facades

The main objective of this research is to use state-of-the-art technologies to analyze the formation and properties of complexes of biocides and metals, then investigate the fate and influence of these complexes in the environment (Fig. 9).

In order to achieve this overall objective, three specific sub-objectives are planned.

1) Investigation of biocides and metals in stormwater runoff from buildings - identifying the types and concentrations of biocides and metals in urban stormwater runoff, as well as factors influencing leaching behaviors.

2) Studying the complexation mechanisms of biocides and metals – investigating complexation kinetics of biocides and metals, factors influencing the complexation process, and physicochemical and toxicity changes of complexes compared to the initial biocides.

3) Studying the fate of complexes during stormwater treatment and designing new treatment strategies – transferring the knowledge of complexes to their behavior in water systems.

FUNDING:
CHINA SCHOLARSHIP COUNCIL

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BAV. MINISTRY OF ECONOMIC AFFAIRS, ENERGY AND TECHNOLOGY; FEDERAL MINISTRY FOR ECONOMIC AFFAIRS AND ENERGY; GERMAN RESEARCH FOUNDATION; CHINA SCHOLARSHIP COUNCIL

COOPERATION:
HEIDELBERG UNIVERSITY; BAV. STATE RESEARCH CENTER FOR AGRICULTURE; THE UNIVERSITY OF QUEENSLAND, AUSTRALIA; EAWAG, SWITZERLAND; AARHUS UNIVERSITY, DENMARK

Research Group Energy-Efficient Wastewater Treatment

Wastewater treatment plants are currently the largest consumers of municipal electricity, despite wastewater containing more than enough energy than required for its own purification. While the treatment of wastewater under given discharge limits is still the highest priority, certain approaches can simultaneously reduce the energy required for the treatment while recovering more energy from the wastewater itself.

An increase in efficiency in the conversion of hardly degradable substrates is possible by ultrasound pretreatment. Experiments have shown that besides the increased methane yield, additional effects should be considered. For a holistic assessment and possibly improved dewaterability, a reduced amount of biosolids for disposal, and the effects on sludge rheology and foaming tendency should be taken into account.

Interestingly, the anaerobic digestion process can also be stimulated by CO_2 enrichment. While this phenomenon has already been observed in many studies, evidence of the underlying processes is still missing.

Nitrogen-rich reject water from sludge dewatering can be treated via deammonification in the side stream as an alternative to the robust but energy-intensive process of nitrification/denitrification. This requires less energy for aeration and even completely eliminates the need for a carbon source through an autotrophic process. However, the comparatively low energy gain for the microorganisms involved also requires tight process monitoring and control. There is even the possibility of at least partially recovering the energy bound in ammonium present in wastewater. This process also uses a nitritation (conversion of ammonium into nitrite) as a first stage, but then switches to a denitritation step, in which nitrous oxide is intentionally generated with the addition of a carbon source. However, this novel process is still under investigation, with several challenges still to be overcome.

Finally, wastewater treatment plants can also contribute to the energy transition by applying microbiological methanation. Excess electricity from renewable sources can first be converted into hydrogen by means of an electrolyzer, and then, together with CO_2, converted into methane for storage. Biofilm-based technologies under thermophilic conditions have proven to be suitable particularly under dynamic operations.

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Optimization of microbial methanation in thermophilic anaerobic trickle bed reactors

The development of new energy conversion and storage technologies becomes increasingly important, as changing energy policies move towards renewable resources. Within the German gas grid, currently up to 250 billion kWh or 25% of the yearly gas consumption could be stored for long-term.

Therefore, the project *OptiMeth* aims to investigate and further develope the microbiological production of methane directly from hydrogen and carbon dioxide ("microbial methanation"), where storable biomethane can be used for a demand-oriented supply of energy or, for example, as LNG or CNG for the mobility sector. While hydrogen is produced electrolytically in phases with excess electricity, carbon dioxide can be used directly at the point of origin (e.g. wastewater treatment or biogas plants, CHP, industry) and is not emitted as a greenhouse gas. The carbon is recycled and used only as a carrier for renewable energies (e.g. from wind power, photovoltaics). The implementation of microbial methanation can thus lead to reduced consumption of fossil fuels, contributing to decarbonization and achieving climate protection goals. The possibility of making excess energy storable and providing energy when required is a decisive component of an efficient energy policy ("efficiency first"). As an efficient technology for biogas upgrading, it also opens up possibilities for the continued operation of existing biogas plants in the post-EEG era.

Fig. 10: Trickling biofilter

In the prior project *MikMeth*, microbial methanation was already investigated and established in thermophilic trickle bed reactors at pilot scale (Fig. 10). Trickle bed reactors represent a low-cost alternative to energy-intensive gas injection, which was used in similar approaches for microbial methanation. The aim of the *OptiMeth* project is to further investigate microbial methanation in different process states in order to design and control it flexibly, robustly and as efficiently as possible, to apply trickle bed reactors in various future energy conversion and storage scenarios. The Bavarian State Research Center for Agriculture as our project partner will investigate the microbial composition, focusing on enriching dominant species of hydrogenotrophic methanogenic archaea during long-term and intermittent operation, as well as on micro and macro nutrient requirements.

FUNDING:
BAVARIAN MINISTRY OF ECONOMIC AFFAIRS, ENERGY AND TECHNOLOGY

COOPERATION:
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Increase of energy-efficiency of wastewater treatment by means of innovative ultrasound disintegration

Wastewater treatment plants are the largest municipal energy consumers. Although wastewater theoretically contains enough energy to cover the entire treatment process in form of biogas potential, often only a fraction of the wastewater's chemical energy is recovered. Energy recovery is generally carried out during the anaerobic treatment of the sewage sludge that is produced during the purification process. However, typical degrees of degradation are only about 50% to 60% without sludge pretreatment.

Therefore, the goal of the research project is to improve anaerobic digestion via ultrasound application. Through ultrasound-induced cavitation, sludge flocs are disintegrated and microorganism cells are disrupted, which results in an improved microbiological degradation and consequently, in an increased biogas yield. However, practical experiences have shown that conventional sonotrode-based systems are relatively susceptible to interference. Therefore, an innovative split reactor is investigated as an alternative within this project.

Fig. 11: Continuously operated biogas test system

To ensure a design that is as efficient as possible with respect to increasing the methane yield, laboratory tests regarding reactor design optimization and energy-efficient reactor operation are conducted (Fig. 11). A computer-based simulation of the fluid dynamics and the sound field within the reactors accompanies the lab tests to find an ideal design. For a holistic performance assessment of the novel reactor type, the impact of the treatment on sludge dewaterability, sludge viscosity and sludge bulking in the digesters is evaluated as well.

Besides lab-scale experiments, full-scale implementation in selected wastewater treatment plants including scientific support will deliver valuable information on the practical performance of the novel reactor concept.

FUNDING:
FEDERAL MINISTRY FOR ECONOMIC AFFAIRS AND ENERGY

COOPERATION:
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Increasing Methane Productivity in Anaerobic Digesters by CO_2 Enrichment

Wastewater treatment plants use about 20 % of the municipal energy consumption and emit roughly 3 million tons of CO_2 every year. Thus, it is crucial to improve the balance between energy demand and energy production by additionally reducing the CO_2 footprint of wastewater treatment plants. Currently, the chemical energy bound in wastewater is, at least partly, recovered in form of energy rich methane gas gained by the anaerobic digestion of sewage sludge. During the anaerobic treatment, CO_2 is produced as a byproduct.

Recent studies reported an increasing methane productivity by CO_2 enrichment. However, the transformation pathways that lead to an increased methane formation by CO_2 conversion have only been hypothesized so far. The following assumptions of possible effects leading to the bioconversion of CO_2 to methane have been stated in recent studies:

1. Increased substrate turnover
2. Redox reactions
3. Change in the carbonic acid equilibrium
4. Reduced ammonia inhibition

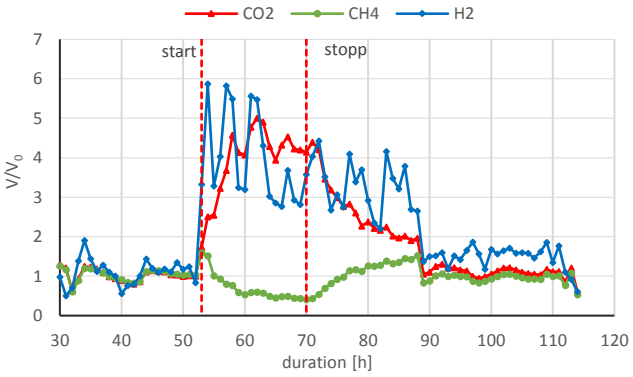

Fig. 12: Trends and changes in biogas composition after CO2 enrichment

This project aims to identify the main mechanisms of bioconversion of CO_2 by applying stable isotope labeling of the injected CO_2 and comprehensive microbial analysis of the digested sludge. Therefore, continuous anaerobic digestion tests will be carried out in two laboratory-scale biogas test systems. First, intermittent CO_2 enrichment tests showed an increased H_2 formation, possibly resulting from an enhanced substrate turnover (Fig. 12). In the next step, CO_2 will be injected continuously into the digestate, in order to get a comprehensive understanding of the CO_2 to CH_4 conversion mechanisms and the long-term effects in particular.

The results will help determine the best full-scale operation conditions to increase the methane formation by CO_2 enrichment in the digesters. Using the "waste product" CO_2 in anaerobic digestion to exploit the potential for energy production from waste streams can therefore make a substantial contribution to advance the energy transition.

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GERMAN RESEARCH FOUNDATION

COOPERATION:
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COOPERATION:
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EAWAG, SWITZERLAND

Recovering nitrous oxide from wastewater

The **C**oupled **A**erobic-anoxic **N**itrous **D**ecomposition **O**peration (CANDO) is a novel approach for the biological treatment of high strength ammonia wastewater. In this double-stage biological treatment train, aerobic (first stage) and anoxic (second stage) processing conditions are coupled for the generation of nitrite and subsequently nitrous oxide (N_2O). The generated N_2O is harvested for on-site energy recovery. Because of its exothermal decomposition (52 kJ/mol) during combustion, approximately 37% more energy compared to the combustion with oxygen can be generated using biogas as fuel. Additionally, oxygen and carbon demands in the biological stages can be considerably reduced compared to conventional biological nutrient removal by nitrification/denitrification.

The long-term operation demonstrated the potential for continuous N_2O generation under variable and realistic process conditions, considering the feed matrices applied. Eventually, the systems were operated under steady-state conditions for six months without operational failures. The observed process dynamics were similar to previous investigations under controlled conditions, and confirmed the relevance of endogenous substrate respiration as a key for high N_2O yields in biological systems also in technical application. Under time-controlled sequencing-batch-operation, stable nitrogen removal was achieved to average effluent concentrations of 1.8 $mg_{NO_2\text{-}N}$ /L. On average, 58±8% to 68±8% (depending on the applied removal strategy) N_2O production was observed under steady-state conditions applying either continuous gas stripping or a dedicated stripping phase as part of the sequencing batch cycles (Fig. 13).

Xuetong Yang will further optimize the CANDO process during her 4 year PhD scholarship.

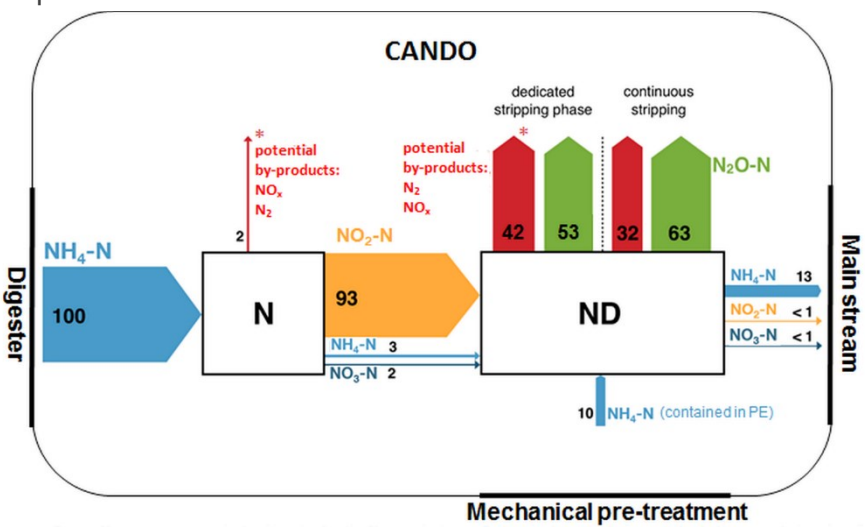

Fig. 13: Simplified diagram of the CANDO process (Weißbach et al., 2018)

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Research Group Advanced Water Treatment

Despite the high treatment efficiency of conventional wastewater treatment plants (WWTPs), concerns remain regarding the removal of emerging contaminants, include

- trace organic chemicals at ng/L to µg/L level (e.g. pharmaceuticals, personal care products, industrial chemicals)
- pathogens (bacteria, viruses, protozoa)
- antibiotic resistant bacteria and resistance genes and
- nutrients at low concentration (P, N).

Discharge from WWTP poses potential risk to aquatic ecosystems and human health. The work of this research group focuses on the evaluation and optimization of advanced water treatment processes and concepts for mitigation of these emerging contaminants.

Fig. 14: Bench-scale ozonation system

Our research includes the evaluation of efficiencies, kinetics, reaction mechanisms and the formation of by-products and transformation products in oxidative treatment processes (e.g. ozonation, advanced oxidation processes (AOPs)) as well as the elucidation of key factors driving the removal of emerging contaminants in natural and biological treatment systems.

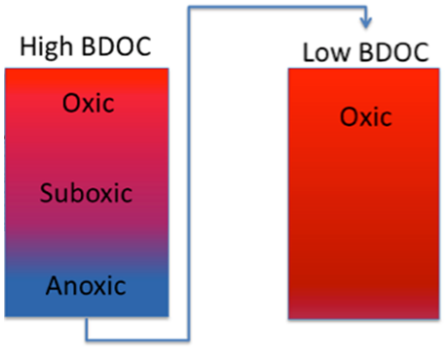

Fig. 15: Sequential managed aquifer recharge technology (SMART) diagram

Fundamental process understanding will be translated into the development and optimization of novel concepts for advanced water treatment. In addition, we investigate the fate and transport of chemicals, pathogens and antibiotic resistance in hybrid systems involving combinations of oxidation, microbial degradation and sorption. Such multi-barrier concepts are needed as alternatives to membrane systems to provide save water quality especially for potable and non-potable reuse purposes without the constraint of concentrate disposal.

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Investigation of Microbial Degradation of Trace Organic Chemicals during Groundwater Recharge

Managed aquifer recharge (MAR) systems, such as riverbank filtration (RBF), soil aquifer treatment and artificial recharge and recovery, have been used for decades to improve the availability of localized water supplies. During infiltration of water through the vadose and saturated zones, microbial degradation and assimilation plays a dominant role for the attenuation of trace organic chemicals (TOrCs). The concept of sequential managed aquifer recharge technology (SMART) combines two MAR systems with an intermediate aeration step to provide oxic, carbon limited conditions for TOrC removal in the second system (Fig. 16). This concept has been already successfully tested for treatment of wastewater-impacted surface water at a utility in the United States and in Berlin.

Fig. 16: Column experiments at TUM

However, little is known about key factors and metabolic mechanisms driving the transformation of TOrCs in MAR systems. Laboratory column studies are conducted at TUM to validate and optimize the SMART concept and to determine the effect of natural organic matter on (co-metabolic) compound removal. Further characterization of NOM and its removal under different conditions was conducted in cooperation with the Helmholtz Center. In addition, current studies with Eawag and the Federal Institute of Hydrology (BfG) apply metagenomic and transcriptomic analysis to correlate the removal of TOrCs with enzymatic activity of the microbiome.

Results from spiking different concentration of humic substances as a primary carbon source did not show a significant effect on biodegradation of TOrCs in parallel column experiments. Based on FT-ICR-MS results used to characterize NOM, the removal patterns of TOrCs in a column system simulating SMART could be correlated to the degradation of specific NOM fractions.

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A Novel Framework to Assess and Manage Contaminants of Emerging Concern in Indirect Potable Reuse

The research project FRAME was completed in June 2018. FRAME, which began in January 2015, included a cluster of seven European research institutions focused on developing an overall evaluation scheme to comprehensively assess and manage contaminants of emerging concern (CECs) and pathogens in indirect potable teuse (IPR) systems.

Within the project, TUM was responsible for the development of novel treatment combinations to be integrated in IPR schemes. The "Advanced Water Treatment" research group conducted pilot-scale studies to evaluate reliable and cost-efficient treatment strategies. Sequential biofiltration was found to be a promising technology for the mitigation of CECs in wastewater treatment plant effluents (Fig. 17). By establishing oxic and substrate-limited conditions in the system, the formation of a highly diverse microbial community, capable of degrading CECs, was targeted. The experimental setup with four independently operating filtration trains allowed for a variety of filtration configurations to be tested. In addition, hybrid systems combining biofiltration with other advanced treatment technologies such as adsorption and oxidation were tested. Besides the removal of compounds that are persistent to biodegradation, potential synergies between different individual treatment processes were also investigated.

Fig. 17: Experimental setup (Photo: Andreas Heddergott)

Results indicated that the establishment of oxic and substrate-limited conditions during biofiltration allowed an increased removal of various moderately degradable CECs compared to conventional biofiltration. Combining biofiltration with subsequent granular activated carbon filtration or ozonation resulted in an increased adsorption capacity and a slightly increased ozonation efficiency for the removal of CECs due to the biological removal of competing background organic matter. Biofiltration based process combinations were found to profit from synergies offering increased process efficiencies.

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BMBF

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KOOPERATION:
UBA, BFG, BGS UMWELT, HYTECON, COPLAN AG, BWB, DHI WASY, TUB, UO, TZW

Development of a non-membrane based innovation treatment approach including comprehensive assessment criteria for indirect potable reuse in urban water cycles

TrinkWave aims to innovate a multi-barrier treatment concept for indirect potable water reuse based on sequential managed aquifer recharge technology (SMART). Proposed monitoring concepts will consider emerging water quality issues, including detection of viruses, antibiotic resistance, trace organic chemicals and transformation products, in the interest of human health protection.

Major tasks of TUM within this project include the development and testing of novel treatment concept for inactivation of pathogens and removal of antibiotic resistant and health relevant chemicals at pilot-scale, the identification of novel bio-molecular parameters for assessing biofilm-based treatment systems as well as quantitative microbial and chemical risk analysis to assess reuse strategies.

The novel concept SMART*plus* builds upon knowledge and experiences from SMART 1.0, aiming to manipulate sequential redox changes and primary substrate availability to stimulate microbial biodegradation. Important research questions include selection of oxidizing agents (i.e., reactive barriers) for *in-situ* aeration, longevity of system functionality, compatibility with downstream purification processes, and attunement of operational flow rate for optimum removal of target substances at minimal hydraulic retention times. Results from SMART 1.0, as well as the semi-industrial pilot scale model testing at TUM, will inform the design of a full scale SMART*plus* field model (Fig.18) for implementation in Berlin.

Fig. 18: The SMARTplus semi-industrial scale test facility at TUM (Photo: Andreas Heddergott)

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Status quo of unplanned reuse of treated municipal sewage in Germany (de facto reuse)

In Germany, treated municipal wastewater is generally discharged into surface water, making it part of the natural water cycle (Fig. 19). If receiving surface waters are extracted for groundwater recharge, irrigation, or other purposes, downstream of wastewater discharges, such a scenario is considered unplanned water reuse. The proportion of treated wastewater in rivers and lakes can vary greatly on a local scale, due to heavy rainfall events and runoff. Currently, national and international multidisciplinary assessment concepts for evaluating risks posed by the influence of dynamic wastewater discharges on surface water quality, especially when this water is used for potable purposes, is lacking. Despite dilution and natural degradation processes in surface water and soil passages (i.e., bank filtration or artificial groundwater recharge), the potential for pathogens and persistent chemical contaminants to reach raw water, then processed into drinking water, persists. This can increase potential risks to human health, and therefore requires appropriate countermeasures.

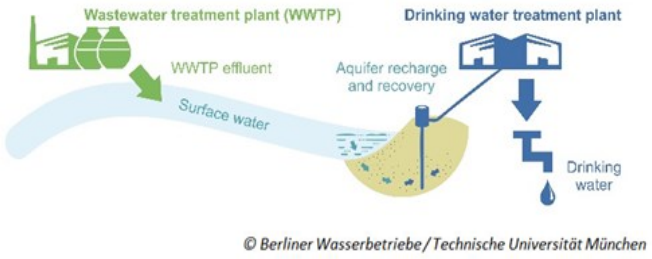

Fig. 19: De facto reuse

In the case of drinking water production via bank filtration or artificial groundwater recharge, the degree of pollution of surface waters essentially determines the quality of the raw water. Although the proportion of wastewater in surface water resulting in increased risks for drinking water has not been explicitly defined, preliminary studies point out challenges for trace organic substance and pathogen removal during subsequent conventional drinking water treatment, especially where the proportion of wastewater in surface waters exceeds 10%.

Within the scope of a research project funded by the German Environment Agency, the nationwide relative wastewater effluent contributions to streams under varying discharge conditions were quantified. Furthermore, a conceptual impact assessment of wastewater effluent occurrence in raw water of downstream drinking water treatment plants was developed. Occurrence of wastewater effluent in the drinking water source was defined as relevant if the concentrations of wastewater derived health-relevant chemicals are above defined monitoring trigger levels (MTL) and the drinking water supply is based solely on conventional treatment. For sites where the MTL exceedances are possible based on the calculated wastewater effluent contributions in this study and known or suspected bank filtrate, potential mitigation actions were recommended for a sustainable drinking water supply.

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UV-LED based water disinfection: Testing of synergistic and water matrix effects

Recently, sequential managed aquifer recharge technology (SMART) has been proposed as an innovative multi-barrier treatment concept for indirect potable water reuse. This concept utilizes modified engineered natural treatment systems including multiple barriers to deliver a water quality that is suitable for drinking water augmentation, while offering a high degree of groundwater protection. One stage of this multi barrier system is UV-disinfection which is investigated using Ultraviolet light emitting diodes (LEDs) (Fig. 20). UV-LEDs are an emerging technology for water and wastewater disinfection and have proven effective in inactivating various bacterial, viral and protozoan pathogens. Moreover, UV-C LEDs have shown high potential since they are smaller, lighter, and less fragile than traditional mercury vapor lamps.

Fundamental laboratory-scale investigations are conducted using a triple-wavelength UV-C LED system (HYTECON, Germany) with a PTFE reflector tube emitting at peaks of 265, 275 and 285 nm for inactivation of MS2 coliphages. UV-irradiance is determined using KI/KIO_3 actinometry and a UV-C broadband radiometer (sglux, Germany). Besides single peak-wavelength effects, the combination of two and three different LEDs is investigated to test the presence of synergistic effects. Furthermore, water matrix effects are investigated using a phosphate buffer solution as a pure reference system and different spiked real water matrices including municipal wastewater treatment plant effluent as well as effluent from a pilot-scale SMART system. Intensive testing of irradiance measurements shows discrepancies in between radiometer and actinometer results due to diffuse reflections of the PTFE tube. Preliminary results from disinfection experiments reveal highest dose response for LED 265 with an inactivation of 5 log followed by LED 275 with 4.2 log and LED 285 with 2.8 log inactivation at 60 mJ/cm², respectively. Combinations of different peak wavelengths LEDs did not result in synergistic effects.

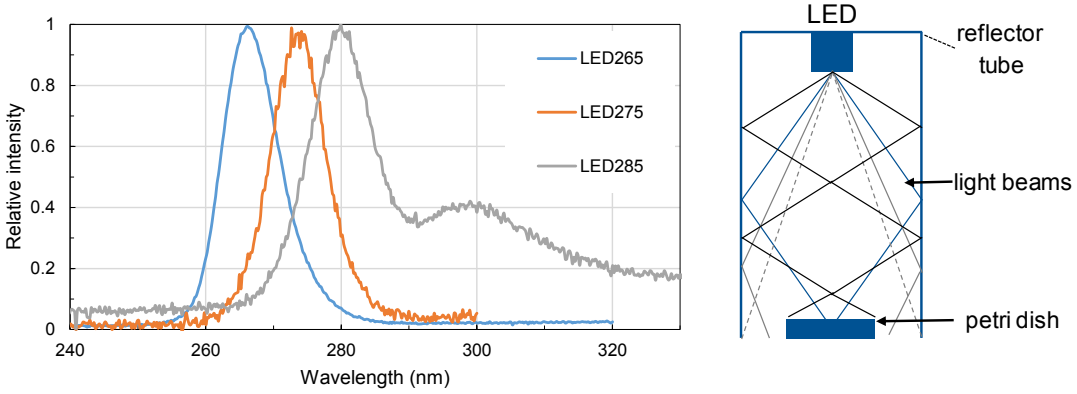

Fig. 20: Relative intensity emission spectra and schematic light beam distribution of LEDs

FUNDING:
FEDERAL MINISTRY OF EDUCATION AND RESEARCH

COOPERATION:
UBA, HYTECON, TZW

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Urban Water-Energy-Food Nexus

The research project "Urban Water-Energy-Food Nexus," conducted at the chair since April 2017, is financed by the Bavarian State Ministry for Environment and Consumer Protection.

With ongoing economic growth and urbanisation, demand for natural resources such as water, energy and food continue to rise worldwide, especially in cities. The result is serious environmental damage and climate change. Integrated urban planning to leverage on potential synergies of climate change mitigation and adaptation approaches urgently needs to be developed and implemented by 2030 to avert disastrous climatic consequences.

The Water-Energy-Food (WEF) Nexus approach is one way for cities to devise more sustainable development pathways. The approach advocates that supplying water to cities takes much energy, and that much water is also needed to produce energy and food. Planning these three sectors in an integrated manner may enable better water, energy and food security and implementation of the Sustainable Development Goals (SDGs). Water reclamation and reuse is a key synergy opportunity for the operationalization of the WEF Nexus approach.

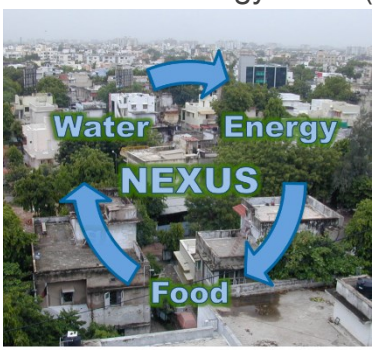

Fig. 21: Water-Energy-Food Nexus diagram

The aim of the Urban WEF Nexus Project is to study the interaction between the sectors water, energy and food and devise alternative future urban development scenarios to support the development of pilot projects at neighbourhood scale. The project takes Leh Town, the capital of Ladakh, a semi-arid high-altitude region in the Indian Himalayas, as a case study.

Fig. 22: Nexus Workshop in Delhi, 2017

FUNDING:
BAVARIAN STATE MINISTRY FOR ENVIRONMENT AND CONSUMER PROTECTION

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Research Group Membrane Filtration

Membrane processes play a central role in domestic water uses, municipal wastewater reuse, and seawater desalination. The focus of the membrane filtration research group is not only the removal performance of membrane processes with respect to unwanted water constituents, but also their energy efficiency and the aspect of the recovery of useful resources. The theoretically usable energy of wastewater is about 2.52 kWh m^{-3}.

For example, experiments have shown that a conventional activated sludge process in combination with a further purification stage (microfiltration, reverse osmosis and final UV-H_2O_2 treatment) has a net energy requirement of 1.09 kWh m^{-3}. Alternative process concepts utilizing membrane processes, such as combinations with anaerobic membrane bioreactors, have higher levels of energy recovery and consequently lower net energy requirements, up to 0.22 kWh m^{-3}.

As biofouling affects the energy efficiency of the membrane process, since the end of 2018, we have been addressing how much unwanted biofouling on membranes can be reduce,. Through the use of UV-C LEDs, we develop UV-membrane hybrid processes, in which the formation of biofouling is delayed. The UV-induced effects on microorganisms are investigated by studying properties of the biofilm formed, especially in regards to its permeability. UV-induced pretreatment to influence membrane cleaning is also investigated.

The feed spacer is an important component of a spiral wound membrane module and is responsible for the transport of the feed water to the membrane surface. The better this functions, the less, for example, fouling influences the performance of a membrane module. In a structural analysis of various commercial feed spacers in combination with numerical hydrodynamic modeling, we were able to establish important constraints (e.g., spatial resolution constraints on the numerical model) which will later allow a numerically optimized design of novel feed spacers.

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Development of a UV irradiation system to increase the resource efficiency of water treatment by reverse osmosis membranes

As part of a collaborative BMBF research project we aim to develop an innovative UV irradiation system that is based on pulsed UV-C-LEDs to mitigate biofouling in reverse osmosis (RO) membrane processes by UV pre-treatment. UV-C-LEDs have many advantages over conventional mercury vapour lamps, which makes them environmentally friendly and, due to their size, easy to physically integrate into membrane modules.

The membrane filtration research group investigates the efficiency of the novel UV-C-LED system in lab- and pilot-scale experiments (Fig. 23). Accelerated biofouling experiments are conducted by additionally dosing nutrients to the feed water. A pre-defined biofouling protocol allows conducting biofouling experiments with and without UV pre-treatment in a well-defined and reproducible manner.

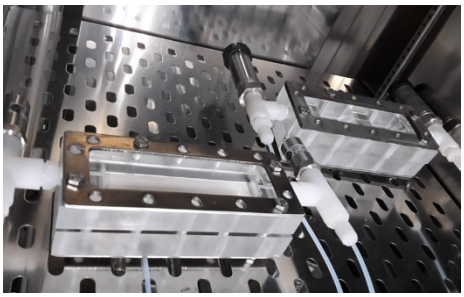

Fig. 23: Lab-scale RO biofouling simulator

The UV-C-LED system will be characterized with regard to its UV-dose by using actinometry and biodosimetry. A further research focus of this collaborative project is to evaluate the efficiency of the innovative UV-C-LED system on the basis of typical membrane module performance parameters, such as permeability decline, feed channel pressure drop, and UV-induced changes of relevant biofilm properties, such as removability during membrane cleaning.

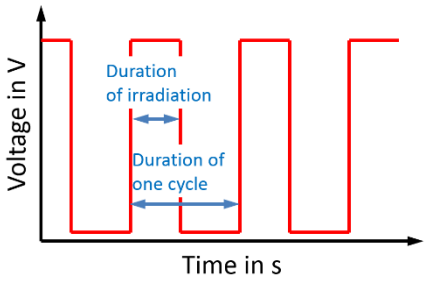

Fig. 24: Pulsed power supply of UV-C LEDs

When applying an intermittent current as power supply, UV-C-LEDs can generate pulsed irradiation (Fig.24). Through fundamental investigations, we plan to determine the inactivation efficiency and mitigating effects on biofouling of pulsed UV-C irradiation at a large range of duty cycles (0 – 100 %) and pulse frequencies (1 – 100 Hz).

FUNDING:
FEDERAL MINISTRY OF EDUCATION AND RESEARCH (BMBF)

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Energy-efficient Treatment Schemes for Water Reuse - Drinking Water Augmentation

Population growth, demographic changes (urbanization), climate change, lack of conventional freshwater supplies, and more frequent and severe drought conditions are stressing the availability of conventional freshwater resources. Water reuse is one option to close local water cycles and relieve the local water resources. In semi-arid and arid regions, including European regions with water scarcity the utilization of municipality wastewater for water reuse purposes is well established. A significant disadvantage of the used treatment schemes currently in water reuse is the high energy demand and generating objectionable waste streams. Alternative treatment schemes for water reuse are required to overcome these issues and guarantee a sustainable (water supply) development worldwide.

Fig. 25: Ultrafiltration membrane for municipal wastewater treatment.

Alternative treatment scenarios are developed and will be tested in laboratory- and pilot scale to analyze the optimal operational conditions (Fig. 25). Due to an integrated energy recovery by improved pretreatment and physical separation of organic matter (resulting in higher biogas yield) the overall energy footprint should be decreased. Additionally, integrated energy recovery is realized by the intended production of nitrous oxide from concentrated nitrogen process water streams (see project *PANOWA*). The nitrogen removal from the wastewater can be coupled via the aerobic-anoxic nitrous decomposition operation with the production of nitrous oxide as an additional energy source. Membrane processes will play a major role within the alternative treatment scenarios. In particular fouling and scaling effects will be analyzed and mitigation strategies developed and analyzed. Beside granular activated carbon (Fig. 26), hydrodynamic improvements of the membrane modules by usage of new developed feed spacers and cleaning effects by vibration of the membranes are considered.

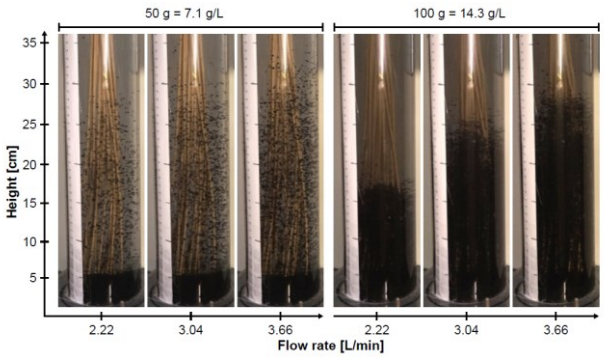

Fig. 26: Investigation of the cleaning effect of ultrafiltration membranes through granulated activated carbon

FUNDING:
TUM;OSWALD-SCHULZE-FOUNDATION

COOPERATION:
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TU DELFT, THE NETHERLANDS;
UNIVERSITÉ DU LUXEMBOURG, LUXEMBURG;
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Municipal wastewater treatment using reverse osmosis membrane process, biofilter and UV-AOP aiming for potable water reuse

Water reuse is a potentially viable alternative for combatting water scarcity. The treatment that water receives should consider the intended final purpose of its use, including direct or indirect potable reuse for human consumption. Reverse osmosis (RO) is an efficient membrane separation process in drinking water production using reclaimed water from wastewater treatment plants. Despite the advances in reverse osmosis, past experiences from operating RO membranes in water and wastewater reclamation plants demonstrated that membrane fouling continues to be one of the most important factors influencing successful application of this technology. Biofouling control is considered a major challenge in operating membrane systems (Fig. 27), as it leads to higher operating pressures, frequent need for chemical cleanings, membrane deterioration, and compromised water quality.

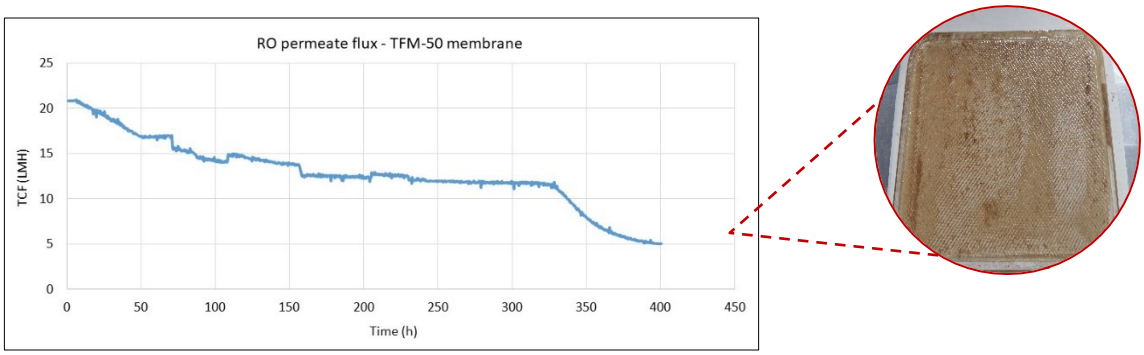

Fig.27: Monitoring of the RO permeate flux over time during municipal wastewater treatment and membrane surface after biofouling occurrence

Fig. 28 Bench-scale RO membrane system with a flexible configuration: (a) flat sheet or (b) spiral-wound module.

A better understanding of biofouling characteristics and mechanisms can help to control biofilm growth, develop mitigation strategies and improve sustainable operation of membrane systems for production of drinking water. A bench-scale membrane system (Fig. 28) with a flexible configuration (flat sheet or spiral-wound module) has been used to evaluate the performance of RO membrane process in drinking water production. Biofilters has been evaluated to observe the degradation of low molecular weight organic compounds. The final permeate quality for purposes of potable reuse will be assessed by UV/AOP.

FUNDING:
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COOPERATION:
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Development of a Decision Making Framework for Upgrading and Operation of Wastewater Treatment Plants for Trace Organic Chemical Removal

The focus of this study is on the removal of trace organic chemicals and their correlated surrogate parameters. Issues relating to data, model structures, incorporations of variability and uncertainty, calibration, potential surrogate parameters and model validation will be investigated. The contributions of existing systems and parameters determining environmental contaminant concentrations (e.g., source variability, existing treatment, discharge dilution, environmental processing) will be accounted for.

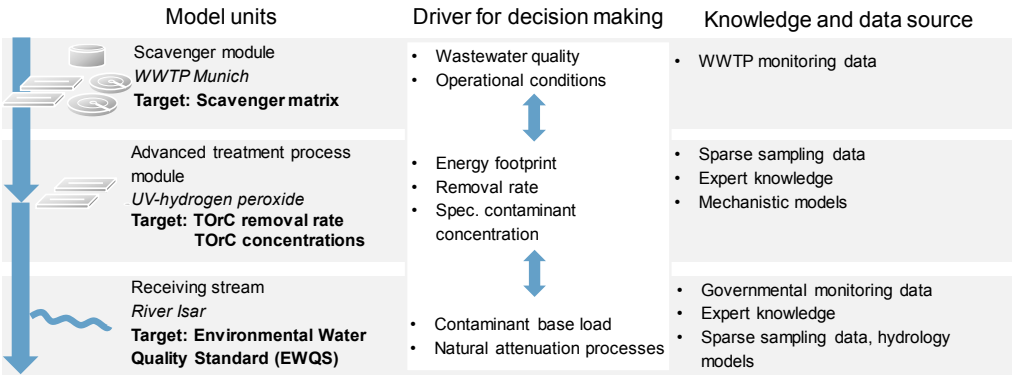

Fig. 29: Model units to achieve machine learning

The research study focuses on three different model units, where the first two use data driven machine learning strategies to model different target parameters (Fig. 29). The third model unit puts the developed models into an expert knowledge decision making framework, which presents central operational scenarios and individual uncertainties. This approach could result in significant savings in overall energy consumption, thus lowering costs and greenhouse gas emissions. Using state-of-the-art modelling approaches, this research will advance the predictive capacity for diverse contaminant concentrations in wastewater treatment and receiving environmental systems.

In 2018 we developed a program to pre-process data and further execute advanced multivariate analysis to evaluate the suitability and accuracy of several machine learning (classification) algorithms, respectively. Fig. 30 demonstrates some performance results for different machine learning algorithms used to predict a target variable, in this case total organic carbon. Machine learning can display distinct performance differences

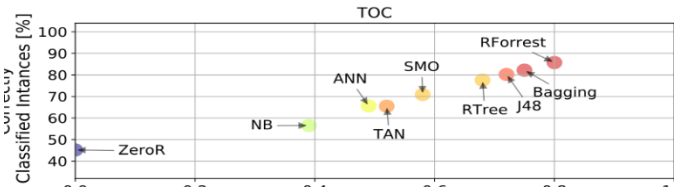

Fig.30: Machine learning algorithm comparison for classified prediction of total organic carbon (TOC). Algorithms: ZeroR, Naïve Bayes (NB), Tree Augmented Naïve Bayes (TAN), Artificial Neural Network (ANN), Sequential Minimal Optimization (SMO), Random Tree (R)

FUNDING:
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COLLABORATION:
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Research Group Microbial Systems

The microbial systems research group focuses on the investigation of microbial processes in aquatic and engineered systems, ranging from biological wastewater treatment to surface water ecosystems. We are researching new ways to better understand microbial functions, also on enzymatic levels. One focus of research is the interaction of microbial community members within microbial biofilms.

Microbes possess an array of enzymes for the degradation of all kinds of substances, ranging from high molecular weight polymers to low molecular weight aromatic compounds. Fungi are one group of microorganisms that produces very efficient exoenzymes that breakdown recalcitrant organic matter. Aquatic fungi, in particular, are an interesting target group, which are largely unexplored and which may facilitate enzymatic transformations of pollutants in wastewater reactors. Further research addresses the characterization of taxonomic and functional diversity of microbial communities with special functions, e.g. micro pollutant degrading communities, or the fate of antibiotic resistance genes in wastewater treatment and drinking water purification. Often, molecular methods such as qPCR or next generation sequencing (metabarcoding, metagenomics and metatranscriptomics) are applied (Fig. 31).

Fig.31: qPCR Analysis targeting different antibiotic resistance genes and a third generation sequencing based handhold sequencer for analyzing marker genes, microbial genomes and metagenomes

In addition, we are currently establishing a small culture collection by high throughput mixed model culturing with the goal of targeting the untapped potential of model cultures from urban waters (Fig. 32). These functional minimal communities will have the potential to remove pollutants such as trace organic chemicals, and thus may hold the key for applied treatment processes.

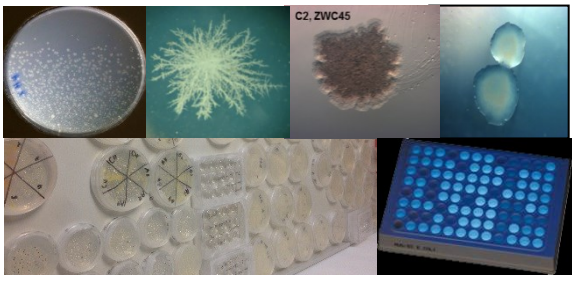

Fig.32: Classic and new minimal model community based micro-biological cultivation on agar plates and in liquid media (serum bottles and microplates; e.g. detection of *E. coli*, Most Probable Number counts) using specific nutrient formulations to detect and quantify a variety of microorganisms

FUNDING:
BAYFRANCE

COOPERATION:
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UNIVERSITY OF GOTHENBURG;
UFZ LEIPZIG;
FU BERLIN;
YOKAHAMA NATIONAL UNIVERSITY;
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Research Group
Trace Organic Compounds in the Environment

A broad range of compounds are introduced into the environment due to the modern human lifestyle, some of which show high biological activity.

These organic compounds include contain classes of (crude-)oil, pesticides, and industrial chemicals, as well as household chemicals and pharmaceuticals (analgetics, antibiotics, x-ray contrast media, etc.). Though normally only traces (<µg/L) of these compounds are found in the environment, the high biological activity of the compounds could lead to harmful effects for humans and organisms.

Fig. 33: Pharmaceuticals

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Hence, the focus of this research group is to develop new methods to detect trace organic compounds (TOrCs) in the environment, as well as detecting alteration of TOrCs by natural and oxidative processes. The main interest is to analyze water samples to evaluate water treatment processes and determine the condition of the aquatic environment.

An outline of the aims of the working group:

- Develop new methods to quantify known TOrCs (target screening)
- Apply state-of-the-art methods to identify unknown TOrCs in complex matrices (suspect/non-target screening)
- Develop new hybrid methods to identify biologically active TOrCs by combining separation techniques and effect assays
- Elucidate natural and oxidative degradation processes and identify degradation products
- Develop new methods to determine sorption behavior of TOrCs onto microplastic particles

Fig. 34: Triple-Quad mass spectrometer

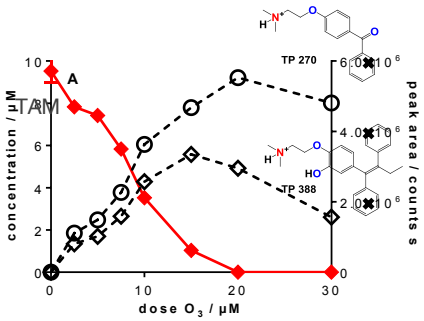

Fig. 3255: Loss of initial substance and formation of transformation products during ozonation

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Mass spectrometric investigation of enzymatic reactions – characterization, miniaturization and the application for environmental samples

Trace organic chemicals (TOrC) are carbon compounds which can be found ubiquitously in the aquatic environment in quantities between 10 and 100 ng/L. The spectrum of these substances is broad and includes TOrCs derived from pharmaceuticals, health care products or pesticides. Due to persistence, bioaccumulation and toxicity there is a need to develop efficient and economic removal techniques. For these purposes the targeted use of enzymes can be a convenient approach, since they often possess a broad substrate spectrum and are able to catalyze versatile reaction types. Thus, enzymes offer a widespread application spectrum and open up new possibilities for environmental technologies, especially for biological water treatment processes. Some studies already utilized the potential of oxidative enzymes such as peroxidases or laccases to degrade TOrCs. Very recently it was shown that enzymes such as amidases, monooxygenases and carboxylesterases seem to be involved in degradation of TOrCs.

In addition to spectroscopic methods, e.g. photometric or fluorescence detection, it is also possible to couple enzymatic reactions with mass spectrometric detection. The direct coupling allows cost-efficient and simultaneous mass spectrometric characterization of all ionizable assay components, in particular substrate(s), product(s) and intermediate(s).

A further objective is to investigate the potential of selected enzymes to degrade and transform TOrCs using MS-based *in vitro* enzyme assays. Rapid screening of enzymatic degradation is carried out with a chip-based robotic nano-ESI-MS tool. The TriVersa NanoMate® functions as an external ionization source for MS and can control reaction conditions such as incubation time and temperature. So far, three laccases, two tyrosinases, and two peroxidases were studied for their capability to degrade ten pharmaceuticals (carbamazepine, gabapentin, metoprolol, primidone, sulfamethoxazole, and venlafaxine) and benzotriazole. The peroxidase from horseradish and a laccase from *Trametes versicolor* appeared to be the most efficient enzyme system. In a next step, high-flow experiments using direct infusion via an injection valve to investigate enzymatic conversion in TOrC- and/or enzyme mixtures (Multiplex-assays). Targeted and non-targeted transformation product characterization and identification are conducted with two MS-workflows: (1) Reversed-phase liquid chromatography (RPLC) coupled to MS/MS and (2) RPLC-hydrophilic interaction liquid chromatography (ToF)-MS.
The rapid screening of degradation potential and efficiency of enzymes can contribute to optimize suitable removal techniques to diminish TOrCs. Furthermore, the characterization of reaction mechanisms will help to understand chemical behaves of TOrCs especially in WWTPs.

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FOR-IDENT – New strategies and workflows in the 'Hidden-Target-Screening' approach

The project FOR-IDENT (FI) is an onoging BMBF-funded project furthering the activities of the former RISK-IDENT project (2012-2014) related to the establishment of guidelines and the integration of the database STOFF-IDENT in an extended platform. In 'FOR-IDENT,' further software tools and databases are implemented to provide workflows for the evaluation of LC-MS/MS data.

Fig. 266: Illustration of the FOR-IDENT platform info in current research journals

New strategies and workflows will support the user in non-target screening approaches, for an easier and faster identification of organic molecules.
Currently two established workflows are integrated in the platform: the liquid-chromatography coupled to mass spectrometry for polar and very polar molecules (HILIC) and mid- to apolar molecules (RPLC).

The database STOFF-IDENT, which was developed within the RISK-IDENT project, plays a key role (see also https://www.lfu.bayern.de/stoffident/#!home). After water samples have been processes, the platform's suggested molecular hits can be reduced by different filter possibilities in STOFF-IDENT. The platform integrates MS/MS-databases like MassBank and prediction tools like MetFrag and EnviPath. This allows simultaneous application of biological, chemical, physico-chemical and analytical metadata to the water sample. Further data base incorporation, for example ecotoxicological data, is planned,. The project funding has been extended until 2019, after which FOR-IDENT will be permanently hosted at https://water.for-ident.org/ as product of an international 'open data concept'. Several (international) cooperations to extend the functionalities are ongoing (like with the NORMAN Network).

FÖRDERUNG:
BMBF RISKWA

KOOPERATION:
LANDESAMT FÜR UMWELT (LFU);
HOCHSCHULE WEIHENSTEPHAN-TRIESDORF (HSWT);
ZWECKVERBAND LANDESWASSERVERSORGUNG (LW)

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Novel Analytical Strategies for Anthropogenic Compounds in Plants: Vegetable Biomonitors for Contaminants in the Environment

Plants play an important role in the maintenance of life. They provide us with food and are considered a pool of new metabolites which can be used for treatment of various diseases. Moreover it has been shown that plants are capable of cleaning the environment, i.e. mainly water, from pharmaceuticals like diclofenac, which occur in ground and surface water in concentrations up to µg/L (Fig. 35).

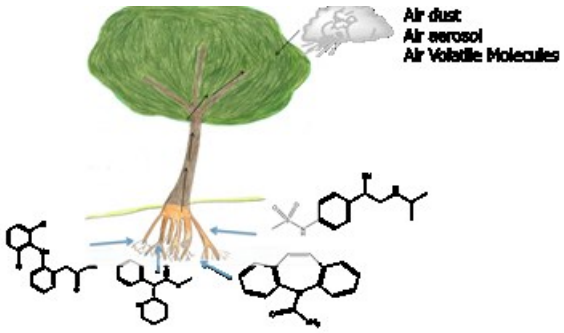

Fig. 277: Plant exposure pathways.

The project presented here will focus on the problem that typical enzymatic research does not concern the plant metabolite pathways, although knowledge about those pathways, the involved enzymes and the resulting transformation products is essential. In addition, whether the pollutant changes the plant biosynthesis cycle and whether the pollutants can push the biosynthesis cycle in a specific direction by generating a lot of substrates for a specific pathway will be investigated. Thus, the major goal was to figure out whether the biological degradation pathways can be reflected by the analytical data obtained from polarity extended RPLC-HILIC-MS analysis.

The aim of the project presented here is to provide a conceptual theoretical framework, based on analysis of different plant extracts before and after exposure, to different pollutants using novel RPLC-HILIC-ToF-MS technique. The project is conducted through the following steps; First, extraction methods applicable to extended-polarity chromatography analysis via target and non-target screening are validated. Second, changes in plants' metabolites and pathways changes behind them through statistical analysis of datasets. Finally, we will be able to use an open access database of plant metabolites to identify compounds affected by changes in the biosynthetic pathways.

FUNDING:
BAVARIAN STATE MINISTRY OF THE ENVIRONMENT AND CONSUMER PROTECTION

COOPERATION:
RESEARCH UNIT ENVIRONMENTAL GENOMICS, HELMHOLTZ ZENTRUM MÜNCHEN

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Analysis and environmental behavior of microplastics

Microplastics are a global environmental problem, the extent and effects of which have not yet been sufficiently researched. The following projects will develop innovative analytical methods and investigate the environmental behaviour of microplastics.

SubµTrack – Innovative Analysis Methods for Submicroplastic

The Chair of Urban Water Systems Engineering is coordinating a research project on microplastics funded by the Federal Ministry of Education and Research. Due to the lack of analytical methods and toxicological data, currently it is not possible to assess especially small microparticles (submicroparticles < 1 µm). Due to their possible cell permeability and their comparatively larger specific surface area, however, these submicroparticles have potentially higher (eco-)toxicological relevance. Innovative and networked approaches are needed to obtain knowledge about the abundance and effects of these particles in the environment.

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The research project will therefore develop innovative analytical and evaluation methods that allow the analysis of plastic particles of various sizes in different samples and processes and the assessment of their toxicity. In addition to the coordinating Chair of Urban Water Systems Engineering (Prof. J. Drewes), the Chair of Analytical Chemistry and Water Chemistry (Prof. M. Elsner), the Chair of Aquatic Systems Biology (Prof. J. Geist), the Chair of Animal Physiology and Immunology (Prof. M. Pfaffl) and the Professorship of Science and Technology Policy (Prof. R. Müller) of TUM are involved. Other partners are the Institute of Groundwater Ecology at the HelmholtzZentrum München, the Institut für Energie- und Umwelttechnik e.V. (IUTA) in Duisburg, the Bavarian Environment Agency and the German Federal Environmental Agency. Postnova Analytics GmbH and BS-Partikel GmbH are involved as industrial partners.

One focus of the Chair of Urban Water Systems Engineering in this project is the investigation of sorption processes of pollutants on submicroparticles. An innovative development of TED-Pyr-GC/MS enables identification of adsorbed pollutants and the type of plastic in one single analysis step. First the pollutants are desorbed from the particles by thermodesorption and analyzed with GC/MS. The polymers are then decomposed by pyrolysis. The pyrolysis products and thus the type of plastic are then identified by GC/MS analysis.

FUNDING:
FEDERAL MINISTRY OF EDUCATION AND RESEARCH (BMBF);
BAVARIAN RESEARCH FOUNDATION

In preliminary experiments, a suitable thermodesorption GC-MS method was established for the selected trace substances acetamiprid, benzophenone, bisphenol A, cypermethrin, tonalid and phenanthrene.
In further preliminary tests, a database for polymers will be generated. In this database, the pyrolysis behavior of different polymer types (polystyrene, polyamide, polyethylene terephthalate, polyurethane, polylactides, polymethyl methacrylate, polyethylene) is determined with pyrolysis GC/MS. For a qualitative characterization of the polymers, different sizes, additives and aged particles will be investigated.

In course of the project, the adsorption and desorption behavior of the selected trace substances on the different polymer types will be investigated. Samples from project partners from toxicological assays will be analyzed for trace substances and particle types.

At the end of the project, validated analytical methods and toxicological data will be available, which allow a risk assessment and, together with a social and jurisprudential evaluation, social and political framework conditions can serve as a basis for the development of action strategies.

Homepage: www.wasser.tum.de/submuetrack

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MiPAq - Research project on microplastics in waterbodies and foodstuffs

This project, funded by the Bavarian Research Foundation and coordinated by the Chair of Aquatic Systems Biology, focuses on the comparison of particles of biodegradable plastics, non-degradable plastics and natural particles.

MiPAq

In contrast to existing studies on microplastics, this research project considers the use of biopolymers as a substitute for conventional plastics. In addition, this project is characterized by a holistic view of this topic from the environment to food. By combining analytical and engineering expertise as well as scientific and ecological considerations, a transdisciplinary and objective evaluation of the topic will assist in developing technological solutions that can be applied in the food industry. Besides scientific partners, numerous partners from industry are involved.

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Validation of analytical methods for microplastic particles in environmental matrices

Environmental matrices are very complex. Besides the many natural organic and inorganic materials, environmental matrices also include tiny particles composed of plastic polymers, the so-called microplastics (MP). In order to determine the MP content inside environmental samples, the natural organic and inorganic materials must be removed via suitable sample preparation methods. However, these methods often involve the use of strong acids, bases or oxidizing agents. These could adversely affect the microplastics, changing their surface structure and/or size distribution.

There is still insufficient information in the literature regarding the validation of sample preparation methods, including:

- Investigations of particles < 500 µm in diameter
- Comparison of the response of various sizes of particles
- Investigations of pure polymers vs polymers with additives
- Investigations of virgin vs aged particles

The aim of the first phase of this project is to investigate the effects of the sample preparation methods on different plastic particles, and the selection of a suitable preparation method for environmental samples. The focus will be around the effects of sample purification methods on different MP in the size range of 50-250 µm. The effects of the most widely employed purification methods in the literature will be investigated using optical microscopy. Quantitative (particle size distribution) as well as a qualitative (surface structure of the particles) analyses will be conducted in order to determine the changes in MP after sample preparation.

Fig.38: Sample preparation for investigation of pretreatment methods

FUNDING:
BAVARIAN
RESEARCH
FOUNDATION

Further Research Activities

NeXus of Water, Food and Energy

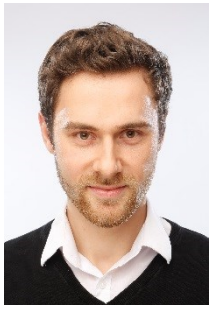
The Chair for Urban Water Systems Engineering is involved in the DAAD-funded project **NeXus of Water, Food and Energy**. The project deals with the interactions of the limited resources water, food, and energy together with academic partners in Ethiopia and Tanzania, and is coordinated by the Chair of Hydraulic and Water Resources Engineering (Prof. Rutschmann).

Young Water Reuse Professionals (YWRP)

Staff of the chair, led by Sema Karakurt, are actively involved in the **Young Water Reuse Professionals** (YWRP) group of the IWA Water Reuse Special Group (WRSG), founded in 2015. The goal is to promote international networking of young scientists in the water reuse sector, as well as facilitate exchanges with senior scientists and industry representatives in the field of water recycling. Activities include supporting a communication platform for information exchange (IWA Connect), contributing to WRSG newsletters, as well as assisting in planning the IWA Water Reuse Specialist conferences. Currently, the YWRP are supporting the organization and coordination of the 12th IWA International Water Reuse Conference, which will be held in June 2019.

Any interested parties can contact Sema Karakurt: sema.karakurt@tum.de

External Doctoral Candidates



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Jochen Bandelin is a process engineer developing highly efficient ultrasound systems for the pre-treatment of wastewater sludge at BANDELIN electronic GmbH & Co.KG in Berlin. His PhD thesis is supervised by Jörg Drewes and Konrad Koch.

The doctoral thesis focuses on the systematic investigation of disintegration via ultrasonically induced cavitation in highly viscous media. The ultrasonic energy, produced by piezo-ceramic ultrasonic systems, is intended to rupture the particles in anaerobic processes to increase biodegradability and consequently, increase biogas production. To obtain a positive energy balance, ideal ultrasonic configurations must be determined, to achieve highest sonication efficiency of different viscosities of sludge, by identifying the optimal ratio of amplitude, field size, ultrasonic frequency and power density in the configuration.
For this purpose, the formation and propagation of cavitation fields in highly viscous media was experimentally investigated, and compared to the behavior of cavitation fields in water (Fig. 39). This was accomplished with a novel acoustic measuring method to determine the cavitation noise level.

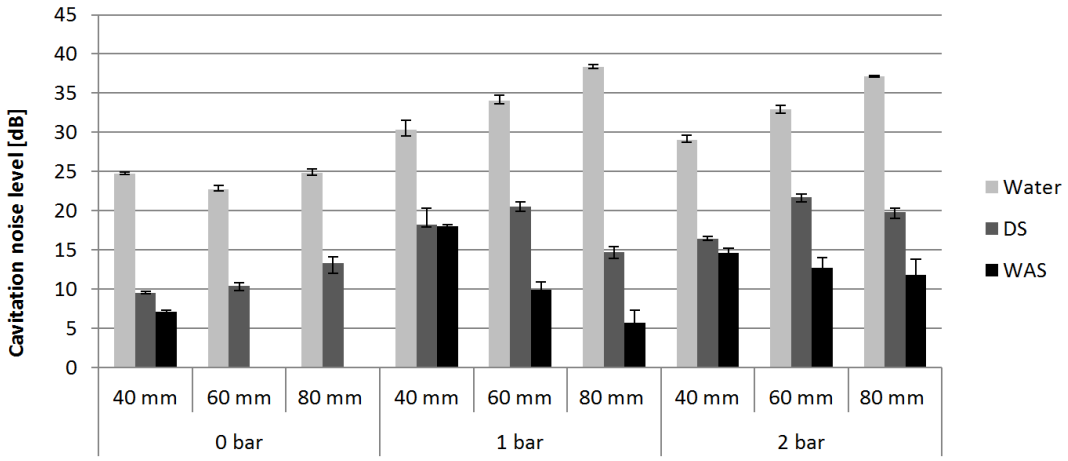

Fig. 39: Cavitation noise level in water, digested sludge (DS) and waste activated sludge (WAS) with different reaction gap sizes and static pressure levels (Bandelin et al, 2018)

Based on the results of the lab experiments, a new reactor concept enabling the efficient pretreatment of large amounts of sludge was designed. Subsequently, the cavitation intensity in wastewater treatment sludge and the increase of methane yield were compared to conventional ultrasound systems. The system was finally installed at the Starnberg wastewater treatment plant for full-scale testing. Beside the process engineering considerations of the various ultrasonic concepts, the cost-effectiveness with regard to production costs and lifetime will also be determined.

FUNDING: FEDERAL MINISTRY FOR ECONOMIC AFFAIRS AND ENERGY

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Vasilis Dandikas is a research associate at the Institute of Agricultural Engineering and Animal Husbandry of the Bavarian State Research Center for Agriculture in Freising, Germany. The goal of his dissertation was to develop mathematical models for the prediction of the biomethane potential (BMP) test results, which can be utilized by both scientific community and practitioners. The study proposes a novel approach for the prediction of biogas yield and biogas production rate simultaneously, based only on fodder analysis. In this study, fodder analyses (Weender analysis with van Soest fraction) and BMP tests (based on VDI 4630) with high temporal resolution were performed in order to identify statistical correlations between the biogas production rate, biogas yield and the chemical composition of various energy crops.

The statistical analysis showed that the biogas yield could be predicted by three analytical parameters, i.e., lignin (ADL), hemicellulose (HC) and crude protein (XP) with an estimation error of only 5 %. Non-fiber carbohydrates (NFC) and XP could serve as regressors for the prediction of the biogas production rate.

FUNDING:
BAVARIAN MINISTRY OF ECONOMIC AFFAIRS, ENERGY AND TECHNOLOGY

The independent validation of the models with each individual sample showed similar performance for all models (two previously published models, and one global and one specific model developed). The correlation between the measured and predicted values of BMP was moderate and the prediction error was 11 %. For the prediction of the average values of each cultivar, all four models performed better. Moreover, the grassland specific model represented the variation of the dataset with a correlation coefficient of 0.92 and achieved a prediction error of only 2 %. Hence, linear regression models are suitable to depict the variation of the BMP and to define a ranking of feedstocks. He successfully defended his dissertation on November 9th, 2018.

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Christian Hiller is the lead Process Engineer at the Zweckverband Klärwerk Steinhäule in Neu-Ulm, Germany. His PhD thesis is supervised by Professor Jörg Drewes and co-supervised by Dr. Uwe Hübner. The focus of this project is to investigate the removal of antibiotic resistant bacteria (ARBs) and antibiotic resistance genes (ARGs) during membrane filtration as an advanced treatment step for municipal wastewater treatment plants. Membrane processes using different commercially available ultrafiltration membranes are tested with secondary effluent, effluents after powdered activated carbon treatment, and activated carbon treatment with subsequent multi-media filtration. The goal of these studies is to determine optimal operating conditions to maximize ARB and ARG removal. Beside ARBs and ARGs, operational parameters for process control including TOC, UV absorbance, turbidity, particle counts, etc are examined.

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Bárbara Ricci is a visiting PhD student from the Department of Sanitary and Environmental Engineering at Federal University of Minas Gerais (UFMG), Brazil, supervised by Míriam Amaral. She is also an Assistant Professor in the Department of Chemical Engineering at Pontifical Catholic University of Minas Gerais, Brazil. As part of the UFMG student exchange program, she is assessing the effect of salinity build-up in anaerobic osmotic membrane bioreactors (OMBR) on the removal of trace organic compounds (TrOCs). The project is being carried out under the supervision of Konrad Koch and Bertram Skibinski.

OMBR is a novel integration of forward osmosis (FO) process and biological wastewater treatment. In these systems, a non-porous osmotically-driven membrane (i.e., FO membrane) is employed as an alternative to microporous membrane used in traditional membrane bioreactors (MBR). Water is spontaneously extracted from the mixed liquor by a high osmotic pressure of a concentrated solution, known as draw solution (DS). Compared to conventional MBRs, the high rejection capacity of the FO membrane results in the effective retention of small and persistent TrOCs in the reactor, thus increasing their retention time and subsequently improving their biodegradation. In this context, OMBR is considered a promising alternative in wastewater treatment and drinking water reclamation, particularly for the removal of emerging TrOCs.

Despite their advantages, the salinity build-up in OMBR is known to be one of the biggest challenges, as it may impair the microbiological activity in the bioreactor and reduce treatment efficiency. The salinity accumulation occurs due to high retention of salts coming from the influent into the FO membrane and by reverse salt flux from DS to the mixed liquor.

To elucidate the salinity build-up effect, biochemical methane potential (BMP) tests will be conducted using the steady-state salinity concentration predicted by an OMBR operating with an HRT of 8 hours, SRT of 20 days, and using a cellulose acetate FO membrane. Also, BMP tests using autoclaved biomass will be performed to understand the effect of abiotic mechanisms in the removal of TrOCs (i.e. due to absorption). Outcomes from this study will be important for understanding TrOCs fate in OMBR, as well as to recommend improvements such as inoculation with halophilic/halotolerant microorganisms.

FUNDING:
COORDINATION FOR THE IMPROVEMENT OF HIGHER EDUCATION PERSONNEL BRAZIL

MADS BORGBJERG JENSEN
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Mads B. Jensen, a PhD student from the Department of Engineering at Aarhus University, Denmark, visited our chair during the spring of 2018. Mads is researching the development of biomethanation technologies with industrial potential. Biomethanation is an energy conversion technology, which enables valorization of CO_2 through a microbially catalyzed H_2-reduction to bio-CH_4, considered critical in a fossil-free energy system. Mads worked in close collaboration with doctoral student Dietmar Strübing under the supervision of Konrad Koch during his stay.

The main technical bottleneck for industrial implementation of biomethanation is the lack of scalable and cost-efficient reactor systems that facilitate H_2 gas-liquid mass transfer at sufficiently high rate and efficiency. At Aarhus University, Mads has focused his work on development of a full-scale mass transfer system for direct injection of H_2 into conventional anaerobic digesters (AD), which already contains a concentrated source of CO_2 and the required methanogenic microorganism. This *in situ* injection approach benefits from exploiting already existing AD infrastructure, but currently suffers from the inability to introduce H_2 as sufficiently small bubbles for high H_2 conversion. The *in situ* system in its present configuration therefore requires a subsequent upgrading of the remaining CO_2 and unconverted H_2 that leave the AD. An external trickle-bed reactor unit for biological biogas upgrading, providing high volumetric CH_4 production rates and a product gas with >95% CH_4 is investigated at TUM (see project *OptiMeth* for more information). Potential synergies exist between the AU and TUM approaches in order to develop the most cost-efficient biomethanation system.

The collaborative research at TUM investigated the possibility of using liquid dilution rate to select for biofilm-forming methanogens on the carrier media that ensures high gas-liquid contact, i.e. CH_4 production rates, in the trickle-bed reactor. Based on a mesophilic sewage sludge inoculum, it was found that methanogenic biofilm formation was strongly enhanced when a high liquid dilution rate (0.056 h^{-1}) was applied, whereas only limited biofilm activity was observed at low liquid dilution rates (0.0042 and 0.0084 h^{-1}) even after 89 days of continuous H_2/CO_2 exposure. Implementation of these results in a trickle-bed system could significantly shorten the start-up time of a methanogenic trickle-bed reactor, and potentially increase its overall CH_4 productivity and robustness through formation of a stable methanogenic biofilm community.

FUNDING:
INNOVATION FUND DENMARK

Visiting Scientists

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Professor Dr. Stuart Khan, University of New South Wales, Sydney, Australia

Prof. Dr. Stuart Khan is a Hans-Fischer Fellow of TUM. Stuart Khan is professor at the School of Civil and Environmental Engineering at the University of New South Wales. As a Hans-Fischer Fellow, Prof. Khan received a three-year grant to carry out his research (2015-2018). Prof. Khan jointly supervised PhD candidate Philipp Michel with Prof. Drewes.

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Professor Dr. Karl Linden, University of Colorado-Boulder, Boulder, Colorado, USA

Prof. Dr. Karl Linden visited the chair from August 2016 until January 2017 as an August-Wilhelm-Scheer visiting professor. Karl Linden is the Helen and Hubercroft Professor of Environmental Engineering at the University of Colorado-Boulder, USA. As the world's leading expert in the field of UV processes, Prof. Linden supported ongoing research in the field of UV-based advanced oxidation processes at TUM.

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Associate Professor Dr. Jennifer Becker, Michigan Technological University, Michigan, USA

Prof. Dr. Jennifer Becker was a TUM Visiting Professor at the chair. From August 2016 – June 2017, she supported ongoing research on the removal of biological trace substances at the chair. Prof. Becker is Associate Professor of Civil and Environmental Engineering at Michigan Tech University, USA.

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Professor Dr. Eric Seagren, Michigan Technological University, Michigan, USA

Prof. Dr. Eric Seagren was a TUM Visiting Professor. From August 2016 – June 2017, he worked together with Prof. Drewes to set up a mentoring program for female scientists at TUM and MTU (PhD candidates, post-docs) who have an interest in pursuing an academic career. Prof. Seagren is a professor of Civil and Environmental Engineering at Michigan Tech University, USA.

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Soňa Fajnorová, M.Sc. University of Chemistry and Technology, Prague

A PhD student from the University of Chemistry and Technology in Prague, Czech Republic, under the supervision of Prof. Jiri Wanner, **Soňa Fajnorová** has been visiting TUM since August 2016. Funded by Bayerisch-Tschechische Hochschulagentur, she is investigating the inactivation of antibiotic resistant bacteria and removal of antibiotic resistant genes in advanced wastewater treatment processes and water recycling.

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Dr. Katrin Doederer The University of Queensland, Australia

Dr. Katrin Döderer, from the Advanced Water Management Centre of the University of Queensland, worked at the chair from April to June 2018. During this time she taught Prof. Drewes' Advanced Water Treatment and Recycling and Urban Water Management project courses. Together with Dr. Hübner and Dr. Knoop, she carried out a research project on the removal of acrylamide in water treatment during her time at the chair.

International Cooperation Partners

Last year, we further expanded our international partner network! (Fig. 40)

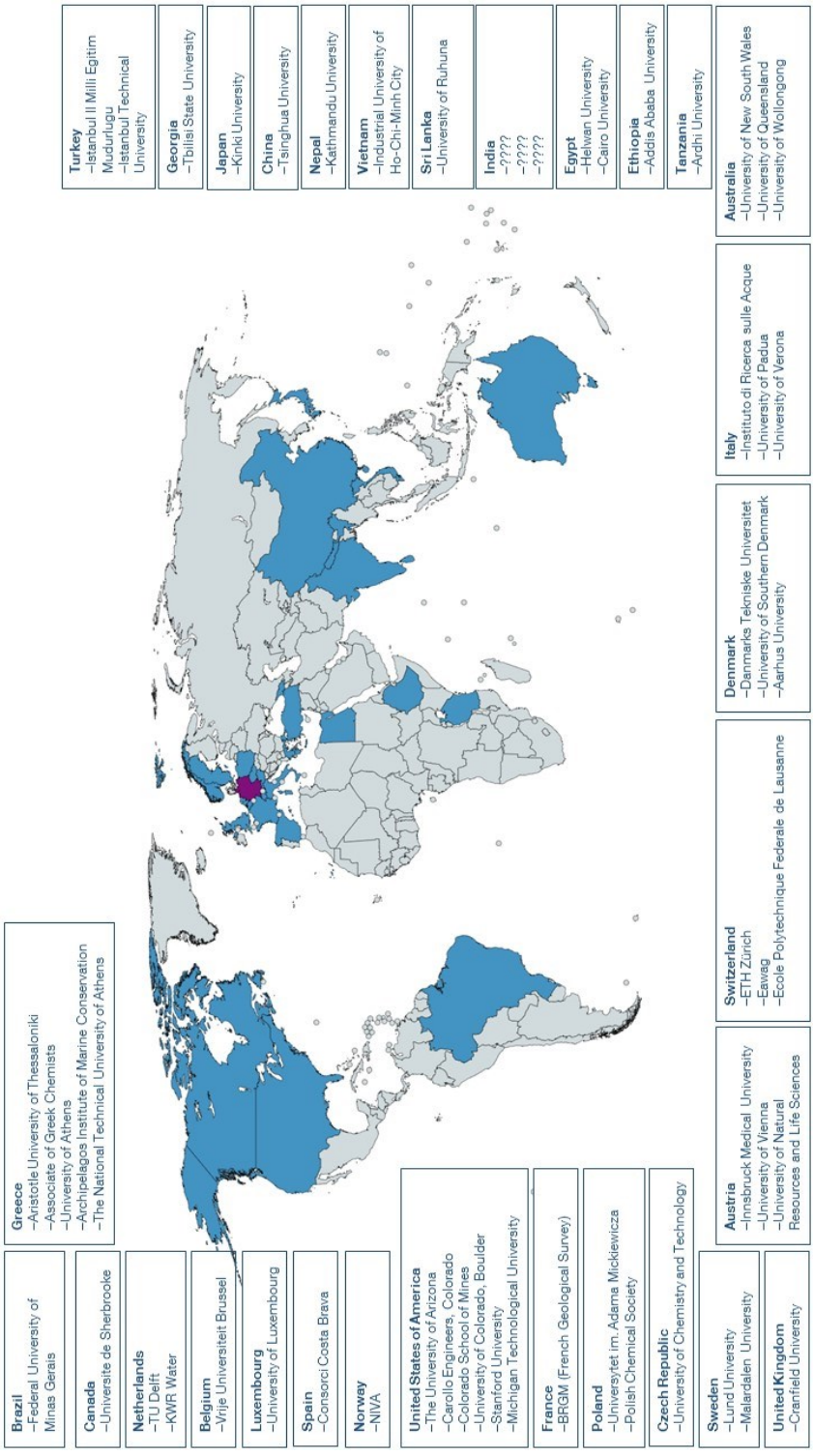

Fig. 40: International cooperation partners of the chair

National & International Committees

Water Reuse Specialist Group (IWA)

Since autumn 2013, **Jörg E. Drewes** is serving as chair of the **Water Reuse Specialist Group (WRSG)** of the **International Water Association (IWA)**. With over 3,400 members, WRSG is the largest specialist group within the IWA with experts in the field of water recycling from more than 110 countries.

The host of the 12th International Conference on Water Reclamation in June 2019 is Berlin, which won hosting rights over Amsterdam. Preparations for this meeting are already under way.

Prof. Drewes was recognized as an **IWA Fellow** in 2018 by the International Water Association.

DWA-Working Groups

Prof. Dr. Helmreich is currently actively involved in the **DWA-A 138** working group "*Planning, construction and operation of rainwater infiltration systems*" and the new leaflet **DWA-M 179** "*Decentralized rainwater treatment plants*". She is also an active member of the **DWA Technical Committee IG-2** "Sector-specific Industrial Waste Water and Waste" and of the **DWA Working Group IG 2.4.** "Wastewater from the starch industry".

Jörg E. Drewes is involved in the **DWA Committee KA-8** "*Advanced Wastewater Treatment*", in the **DWA-Working Groups Biz 11.4** "*Water Recycling*" and in the **KA-8.1** "*Anthropogenic Substances in the Water Cycle*".

German Water Chemistry Society

Uwe Hübner is involved in the specialist group "*Transformation Processes of Biological Wastewater Treatment and Wastewater Recycling*", a sub-committee of the **German Water Chemistry Society**. The group is currently developing a status paper that summarizes the current state of knowledge on biological degradation processes.

Journal International Journal of Environmental Research and Public Health – Guest Editor

Prof. Dr. Helmreich is a guest editor of the journal *"International Journal of Environmental Research and Public Health"* for a special issue *"Urban stormwater management".* More information can be found here: https://www.mdpi.com/journal/ijerph

Journal of Water Reuse and Desalination – Editor

Jörg E. Drewes is the editor of the new journal "*Journal of Water Reuse and Desalination*" (JWRD) since 2015. JWRD is an international journal that publishes contributions regarding water reuse and water desalination. For further information, please visit: http://jwrd.iwaponline.com

Journal Water Solutions – Editor

Since 2016, **Jörg E. Drewes** is editor of the new journal "*Water Solutions*" . Water Solutions is published quarterly. The journal reports highlights of the latest developments in the water and wastewater sector in Germany for an international audience. For more information, please visit: https://www.gwf-wasser.de/en/

Workshops & Other Activities

2nd International BMP standardization workshop

Biochemical methane potential (BMP) tests are used daily by academic and technical practitioners. In 2016, BMP test were mentioned in more than 1,500 ISI publications worldwide. The results of BMP tests are crucial for the design of biogas plants and biogas substrates, and the relevance of BMP tests is enormous, when considering that there are more than 17,000 biogas plants in Europe alone.
The aim of the first international workshop in Leysin (CH) was to develop a new guideline for conducting BMP tests in order to advance intra- and inter-laboratory reproducibility by defining apparatus and procedure of test set-up, quality criteria for seeding material and substrate, criteria for the validation of the tests, etc. When the first version of the guideline for the standardization of BMP tests was published by the international taskforce in 2016, it immediately attracted the attention of the scientific community as indicated by the more than 62 citations in two years, since it compiles the expertise of so many researchers from different countries. The diversity of the group allows a wide range of various approaches and technologies to be represented, allowing the guideline to be both precise and universally applicable.

However, the joint round robin test conducted in 2017 revealed that standardization was not sufficient to achieve a high reproducibility, as indicated by deviations of up to 100%. This was particularly disappointing, since all participants perform BMP tests routinely for either scientific or commercial purposes. Hence, the taskforce agreed that a detailed discussion of potential reasons for the bad performance is crucial to further improve the reproducibility of BMP tests.

Fig.41: Group phot of the participants of the 2nd international workshop on standardization of BMP tests in Freising in April 2018

Therefore, the taskforce of the 40 experts met for the 2nd International Workshop on Standardization of BMP Tests, supported by the TUM Global Incentive Fund, in Freising on April 23-24 to discuss reasons for the unsatisfactory results of the first round robin test and whether the existing guideline with need to be revised. The intensive roundtable discussion revealed that the test protocol was not precise enough, which led to misunderstanding by some groups. Furthermore, the proposed validation criteria need minor revision to better reflect acceptable and unacceptable variations. Currently, a second round robin test, organized by the

group of Christof Holliger at École Polytechnique Fédérale de Lausanne (CH), Sasha Hafner at Aarhus University (DK) and Konrad Koch (TUM), is being conducted to clearly elucidate whether the aim of standardization by the revised guidelines will be achieved. Assuming that the performance will improve, a revised form of the guideline will be published.

Second TUM summer course

From September 3-7, 2018, the second TUM Summer Course took place at the Chair of Urban Water Systems Engineering, on the topic of "Microbiomes of Engineered Water Systems". The summer course, designed for postgraduate students, was attended by five international doctoral students and introduced participants to the molecular, bioinformatic, and statistical foundations of modern high-throughput sequencing. The participants were able to work on their own samples and learned the basics of microbiological processes in urban water management through a series of lectures and guest contributions.

46th Sewage Handing Workshop (ATS)

On July 4, 2018, the 46th Wastewater Technology Seminar on the subject of "Innovative strategies for sewage sludge handling" took place in Ismaning.

"*Sewage sludge causes us the most difficulties. Although it only makes up 1% of the treated wastewater volume as raw sludge, it causes around 30% of wastewater treatment costs and 90% of headaches.*"

This sentence by the pioneer of wastewater technology, Karl Ludwig Imhoff, is again gaining in topicality today, when sewage sludge is seen less as an interesting resource, but rather as a problem. While policy decisions are being taken elsewhere, planners and operators of wastewater treatment plants must follow these guidelines and try to find the best possible concept for their plant. With the planned *de facto* phase-out of sewage sludge land application, thermal treatment remains the only alternative. The associated higher costs can only be countered with appropriate strategies to minimize the amount of sewage sludge, and this should not be realized at the expense of the cleaning performance of the entire plant.

As part of the seminar, the current legal framework and the consequences of the amendment to the AbfKlärV for the plant operators were discussed. A look at applied research revealed innovative ideas with which concepts in the future, for example, phosphorus can be recovered or the amount of sewage sludge to be treated can be reduced. Subsequently, three wastewater treatment plants presented their experiences with the usual disintegration processes for sewage sludge treatment and phosphorus recovery. Finally, we looked at the challenges in dealing with sludges from the treatment of industrial wastewater and were finally introduced to the current challenges in wastewater treatment in South America. Almost 100 interested participants from municipalities, sewage treatment plants, consultancies, manufacturers and water management authorities as well as research institutions and universities joined the seminar.

Scienclisten

In 2018, we collectively biked over 20,000 kilometers to and from the chair. This equates to 2.9 tons of CO_2 saved in comparison to an average car, and 7.8 tons of CO_2 in comparison to an economy flight. Though the total kilometers biked has steadily decreased over the last 4 years, we aim to increase overall and individual contribution in 2019!

Institute Outing – Summer 2018

Fig. 282 Chair employees in Regensburg.

This year we toured the Bavarian city of Regensburg on June 6th, 2018. A guided tour of the city was provided by tour guides. After a delicious lunch and time to cool off, there was time either for a castle tour or a walk around the city. It was a hot but great time!

Upcoming Events

30th Water Technical Seminar (WTS)

In recent years, more pollution events of perfluorinated and polyfluorinated chemicals (PFCs) have been detected in the environment. The high stability (persistence) and mixed polar and nonpolar properties of the PFCs are desired by industry, but are also problematic for the environment and water treatment. Due to their high mobility and persistence, PFCs are distributed in the environment, and especially in groundwater, and cannot be removed from the water even by the most well-established water treatment methods. Thus, the PFCs not only threaten the environment, but also the supply of clean drinking water to consumers.

In our seminar on **February 13th, 2019,** we want to give an overview of PFC remediation in Bavaria and Germany. As new limits are currently being discussed for PFCs, we also want to highlight the toxicity and uptake pathways of PFCs for humans. In addition, established and new water treatment methods and their potential for removing PFCs from contaminated waters will be discussed.

The seminar is primarily aimed at municipalities and operators of drinking water and wastewater treatment plants, representatives of authorities, appraisers and experts.

47th Sewage Handing Workshop (ATS)

According to a recent ZeroTrace survey, more than 80% of surveyed experts see trace pollutants as the most important challenge facing the water industry today. The introduction of a regulation for the removal of trace substances on municipal sewage treatment plants is expected between 2021-2025. But what will the regulations be? Which sewage treatment plants will need to be equipped with the more advanced treatment stage? What are the most practical treatment methods and how can the implementation and scale-up be financed?

In this workshop on **July 3rd, 2019**, we'll provide answers to current questions on the implementation of further wastewater treatment, the so-called 4th purification stage, in municipal sewage treatment plants. In 4 blocks, we'll discuss current developments and strategies in the EU, Switzerland, at federal level, in other federal states and in Bavaria to tackle the new challenges are presented, essential drivers for advanced wastewater treatments, possible procedures, and previous practical experience indicated. Costs and financing possibilities will also be discussed.

The seminar is primarily aimed at operators of sewage treatment plants and engineering companies, as well as municipalities, authorities, experts, appraisers and research institutions.

Registration can be found here: https://www.sww.bgu.tum.de/ats/

Publications

Books and book chapters

1) Gondhalekar, D., Al-Azzawi, M., Drewes, J.E. (2018). Urban Water Reclamation with Resource Recovery as a Cornerstone of Urban Climate Change Resilience. Handbook of Climate Change Resilience, Springer.
2) Gondhalekar, D., Drewes, J.E., Grambow, M. (2018). Risk and water management under climate change: towards the Nexus City. Sustainable Risk Management, Springer.
3) Gondhalekar, D., Vogt, C. , Eisenbeiß, K. (2018). Integrated Urban Development: Implementing the Sustainable Development Goals for Urban Resource Efficiency, Economic Prosperity and Social Inclusion. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH, Bonn and Berlin.
4) Helmreich, B. (2018). Umgang mit Metalldachabflüssen. Ökologie aktuell – Rückhalten, Nutzen, Versickern und Behandeln von Regenwasser. Mall GmbH, Donaueschingen.
5) Koch, K., Helmreich, B., Drewes, J.E. (2018). Innovative Strategien zum Umgang mit Klärschlamm, Tagungsband zum 46. Abwassertechnisches Seminar der TU München, Garching.

Peer-reviewed journal articles

1) Anslan, S., Nilsson, H., Wurzbacher, C., Baldrian, P., Tedersoo, L., Bahram, M.: Great differences in performance and outcome of high-throughput sequencing data analysis platforms for fungal metabarcoding. MycoKeys 39, 2018, 29-40
2) Bandelin, J., Lippert, T., Drewes, J.E., Koch, K.: Cavitation field analysis for an increased efficiency of ultrasonic sludge pre-treatment using a novel hydrophone system. Ultrasonics Sonochemistry 42, 2018, 672-678
3) Bieber, S., Snyder, S., Dagnino, S., Rauch-Williams, T., Drewes, J.E.: Management strategies for trace organic chemicals in water – A review of international approaches. Chemosphere 195, 2018, 410-426
4) Dandikas, V., Heuwinkel, H., Lichti, F., Eckl, T., Drewes, J.E, Koch, K.: Correlation between hydrolysis rate constant and chemical composition of energy crops. Renewable Energy 118, 2018, 34-42
5) Dandikas, V., Heuwinkel, H., Lichti, F., Drewes, J.E., Koch, K.: Predicting methane yield by linear regression models: A validation study for grassland biomass. Bioresource Technology 265, 2018, 372-379
6) Ettinger, F., Grotehusmann, D., Helmreich, B., Kasting, U.: Auswirkungen der Grundwasserverordnung auf die Überarbeitung der Regelwerke des DWA-Hauptausschusses Entwässerungssysteme. Korrespondenz Abwasser, Abfall (65), 2018, 378-379
7) Hafner, S.D., Koch, K., Carrere, H., Astals, S., Weinrich, S., Rennuit, C.: Software for biogas research: Tools for measurement and prediction of methane production. SoftwareX 7, 2018, 205-210
8) Hellauer, K., Karakurt, S., Sperlich, A., Burke, V., Massmann, G., Hübner, U., Drewes, J.E.: Establishing Sequential Managed Aquifer Recharge Technology (SMART) for Enhanced Removal of Trace Organic Chemicals: Experiences from field studies in Berlin, Germany, Journal of Hydrology 563, 2018, 1161-1168.
9) Helmreich, B.: Regenwasserbewirtschaftung im urbanen Raum: Eine große Herausforderung. GWF-Wasser/Abwasser, 2018
10) Hettwer, K., Jähne, M., Frost, K., Giersberg, M., Kunze, G., Trimborn, M., Reif, M., Türk, J., Gehrmann, L., Dardenne, F., De Croock, F., Abraham, M., Schoop, A., Waniek, Joanna J.J., Bucher, T., Simon, E., Vermeirssen, E., Werner, A., Hellauer, K., Wallentits, U., Drewes, J.E., Dietzmann, D., Routledge, E., Beresford, N., Zietek, T., Siebler, M., Simon, A., Bielak, H., Hollert, H., Müller, Y., Harff, M., Schiwy, S., Simon, K., Uhlig, S.: Validation of Arxula Yeast Estrogen Screen assay for detection of estrogenic activity in water samples: Results of an international interlaboratory study. Science of The Total Environment 621, 2018, 612-625
11) Horstmeyer, N., Lippert, T., Schön, D., Schlederer, F., Picioreanu, C., Achterhold, K., Pfeiffer, F., Drewes, J.E.: CT scanning of membrane feed spacers – Impact of spacer model accuracy on hydrodynamic and solute transport modeling in membrane feed channels. Journal of Membrane Science 564, 2018, 133-145
12) Horstmeyer, N., Huber, M., Drewes, J.E., Helmreich, B.: Räumliche Verteilung der Schwermetallgehalte in den Oberböden von 35 Versickerungsmulden für Verkehrsflächenabflüsse. GWF Wasser/Abwasser, 2018
13) Huber, M., Muntau, M., Drewes, J.E., Helmreich, B., Athanasiadis, K., Steinle, E.: Analyse einer möglichst weitestgehenden Phosphorelimination bei kommunalen Kläranlagen in Deutschland. Korrespondenz Abwasser, Abfall (65), 2018, 298-310
14) Knoop, O., Hohrenk, L.L., Lutze, H.V., Schmidt, T.C.: Ozonation of Tamoxifen and Toremifene: Reaction Kinetics and Transformation Products. Environmental Science & Technology, 52 (21), 2018, 12583-12591
15) Lindenblatt, C., Koch, K., Drewes, J.E.: Untersuchungen zum Anfahrbetrieb einer einstufigen Deammonifikation für die Behandlung von Zentrat mit schwingendem Redoxpotential. Korrespondenz Abwasser, Abfall 65 (9), 2018, 786-792.
16) Lippert, T., Bandelin, J., Musch, A., Drewes, J.E., Koch, K.: Energy-positive sewage sludge pre-treatment with a novel ultrasonic flatbed reactor at low energy input. Bioresource Technology 264, 2018, 298-305

17) Miklos, D.B., Remy, C., Jekel, M., Linden, K.G., Drewes, J.E., Hübner, U.: Evaluation of advanced oxidation processes for water and wastewater treatment – A critical review. Water Research 139, 2018, 118-131
18) Miklos, D.B., Hartl, R., Michel, P., Linden, K.G., Drewes, J.E., Hübner, U.: UV/H_2O_2 process stability and pilot-scale validation for trace organic chemical removal from wastewater treatment plant effluents. Water Research 136, 2018, 169-179
19) Nihemaiti, M., Miklos, D.B., Hübner, U., Linden, K.G., Drewes, J.E., Croué, J.: Removal of trace organic chemicals in wastewater effluent by UV/H_2O_2 and UV/PDS. Water Research, 145, 2018, 487-497
20) Rommel, S., Helmreich, B.: Influence of temperature and de-icing salt on the sedimentation of particulate matter in traffic area runoff. Water 10, 2018, 1738-1755.
21) Stadlmair, L.F., Letzel, T., Grassmann, J., Monitoring enzymatic degradation of emerging contaminants using a chip-based robotic nano-ESI-MS tool; Analytical and Bioanalytical Chemistry (410), 2018, 27–32
22) Stadlmair, L.F., Letzel, T., Drewes, J.E., Graßmann, J.: Enzymes in removal of pharmaceuticals from wastewater: A critical review of challenges, applications and screening methods for their selection. Chemosphere 205, 2018, 649-661
23) Strübing, D., Moeller, A.B., Mößnang, B., Lebuhn, M., Drewes, J.E., Koch, K.: Anaerobic thermophilic trickle bed reactor as a promising technology for flexible and demand-oriented H_2/CO_2 biomethanation. Applied Energy 232, 2018, 543-554
24) Ulliman, S.L., Miklos, D.B., Hübner, U., Drewes, J.E., Linden, K.G.: Improving UV/H_2O_2 performance following tertiary treatment of municipal wastewater. Environmental Science: Water Research and Technology 4 (9), 2018, 1321-1330
25) Weißbach, M., Drewes, J.E., Koch, K.: Application of the oxidation reduction potential (ORP) for process control and monitoring nitrite in a Coupled Aerobic-anoxic Nitrous Decomposition Operation (CANDO). Chemical Engineering Journal 343, 2018, 484-491
26) Weißbach, M., Gossler, F., Drewes, J.E., Koch, K.: Separation of nitrous oxide from aqueous solutions applying a micro porous hollow fiber membrane contactor for energy recovery. Separation and Purification Technology 195, 2018, 271-280
27) Weißbach, M., Thiel, P., Drewes, J.E., Koch, K.: Nitrogen removal and intentional nitrous oxide production from reject water in a coupled nitritation/nitrous denitritation system under real feed-stream conditions. Bioresource Technology 255, 2018, 58-66

Conferences

Oral presentations

1) Bandelin, J., Lippert, T., Koch, K., Drewes, J.E.: Energieeffiziente Klärschlammvorbehandlung durch innovative Ultraschalldesintegration. Proceedings of the 46th Sewage Handling Workshop „Innovative strategies for sewage sludge handling“ at TU Munich, 04 July 2018, Ismaning, Germany
2) Basnet, M., Drewes, J.E., Gondhalekar, D: Urban Water-Energy-Food Nexus: Decentralized water and wastewater management as a solution to conserve water resources in Leh town in Upper Indus River Basin in India. International Conference on "Water, Environment and Climate Change: Knowledge Sharing and Partnership", April 2018, Kathmandu, Nepal
3) Bieber, S: Internationale Managementstrategien für organische Spurenstoffe in Gewässern und unterstützende weitergehende analytische Techniken, Wasser 2018, Annual Society of German Chemists Meeting, 7-. May 2018, Papenburg, Germany
4) Croué, J.-P., Nihemaiti, M. Miklos, D.B. Müller, J., Hübner, U., Linden, K., Drewes, J.E.: Removal of micropollutants in wastewater effluent during UV/H_2O_2 and UV/PDS. 15th IWA Leading Edge Conference on Water and Wastewater Technologies, 27-31 May 2018, Nanjing, China
5) Fajnorová S., Hübner, U., Herzog, B., Müller, J., Hellauer, K., Miklos, D., Drewes, J.E., Wanner, J.: Fate of antibiotic resistance during advanced wastewater treatment. Vodárenská biologie (Water Supply Biology), 6-7 February 2018, Prague, Czech Republic
6) Dandikas, V.; Heuwinkel, H.; Lichti, F.; Drewes, J.E.; Koch, K.: Prediction of biogas production rate in batch test. International Conference on Anaerobic Digestion “Biogas Science 2018”, 17-19 September 2018, Turin, Italy
7) Drewes, J.E., Karakurt, S., Zhiteneva, V., Hübner, U.: BMBF-Verbundprojekt TrinkWave zur Stützung der städtischen Trinkwasserversorgung durch indirekte Wasserwiederverwendung. 51. Essener Tagung. 14-16 March 2018, Essen, Germany
8) Drewes, J.E.: Potable Water Reuse in the United States. FRAME Workshop Assessment and Management of Indirect Potable Reuse. 6-. March 2018. Koblenz, Germany
9) Drewes, J.E., Anderson, P., Denslow, N., Olivieri, A., Jakubowski, W., Schlenk, D., Snyder, S., Maruya, K., Waggoner, C. Findings of the 2018 Science Advisory Panel on CECs in Recycled Water. WateReuse California Annual Conference. Monterrey, CA, USA.
10) Drewes, J.E., Hübner, U., Regnery, J., Hellauer, K., Karakurt, S., Zhiteneva, V. Shifting biodiversity – a new concept for engineered natural water treatment systems. TUM Chair of Terrestrial Ecology – Seminar Series, 11 April 2018, Freising, Germany
11) Drewes. J.E. Wave-Querschnittsthema ‚Risikomanagement in der Wasserwiederverwendung’. BMBF Wave Statusseminar, 17-18 April 2018, Frankfurt/M., Germany

12) Drewes. J.E.: Planungsoptionen und Technologien der Wasserwiederverwendung zur Stützung der Trinkwasserversorgung in urbanen Wasserkreisläufen'. BMBF Wave Statusseminar, Frankfurt/M., 17-18 April 2018, Frankfurt/M., Germany
13) Drewes. J.E., Helmreich, B.: Planungsoptionen für eine Wasserwiederverwendung in Unterfranken. Government of Lower Franconia, 24 April 2018. Würzburg, Germany
14) Drewes, J.E.: Design Philosophies and Technologies in Water Reuse. IFAT Forum Water/Wastewater. Munich, 14 May 2018, Munich, Germany
15) Drewes, J.E., Karakurt, S., Zhiteneva, V., Hellauer, K., Hübner, U.: Innovative Concepts for Planned Water Reuse to Augment Drinking Water Supplies. IFAT IWRM Forum, 15 May 2018, Munich, Germany
16) Drewes, J.E.: Planungsoptionen und Technologien der Wasserwiederverwendung zur Stützung der Trinkwasserversorgung in urbanen Wasserkreisläufen. IFAT BMBF Wasser Forschung, 16 May 2018, Munich, Germany
17) Drewes, J.E., Karakurt, S., Zhiteneva, V., Hellauer, K., Müller, J., Hübner, U.: Development of a Resilient, energy-efficient novel biofiltration treatment concept ofr water recycling applications. Final TreatRec Conference. 13-14 June 2018 Girona, Spain
18) Drewes, J.E.: Challenges and Opportunities in the Water Cycle. Presentation to the Science Advisory Board of Siemens, 16 June 2018, Munich, Germany
19) Drewes, J.E.: Introduction and key lessons learned from non-potable reuse installations in Japan. Workshop ‚Water Reuse in Emerging Economies'. IWA World Water Congress. 19. September 2018, Tokyo, Japan
20) Drewes, J.E. Recent Regulatory Trends for Potable Reuse in California, USA. Workshop ‚Water Reuse Opportunities and Challenges', IWA World Water Congress. 19. September 2018, Tokyo, Japan
21) Drewes, J.E.: Recent Trends in Potable Water Reuse. IWA World Water Congress. Master Lecture, 20. Sept. 2018, Tokyo, Japan
22) Drewes, J.E., Karakurt, S., Zhiteneva, V., Hübner, U.: BMBF-Verbundprojekt TrinkWave zur Stützung der städtischen Trinkwasserversorgung durch indirekte Wasserwiederverwendung. 51. Essener Tagung. 14-16 March 2018, Essen, Germany
23) Drewes, J.E.: Moving Water Reuse Forward as a Safe and Sustainable Water Supply. IWA Regional Conference on Water Reuse and Salinity Management. 10 June 2018, Murcia, Spain
24) Gondhalekar, D.: Towards the Nexus City: Research Project Water-Energy-Food (WEF) Nexus in Leh, Ladakh, India. German Water Partnership / BMU India session. IFAT, 15 May 2018, Munich, Germany
25) Gondhalekar, D., Drewes, J.E. Nexus City: urban water reclamation and reuse as key synergy potential to close resource loops in Munich, Germany and Leh, India. Sust. Devt. of Energy, Water and Env. Systems, 7 July 2018, Novi Sad, Serbia
26) Gondhalekar, D. Operationalizing water reclamation with resource recovery for more effective SDG implementation as a city-to-city cooperation. European Week of Cities and Regions, 11 October 2018, Brussels, Belgium
27) Hellauer, K., Uhl, J., Lucio, M., Schmitt-Kopplin P., Hübner, U., Drewes, J.E.: Characterizing the transformation of natural organic matter in managed aquifer recharge systems. 13th European Fourier Transform Mass Spectrometry Workshop, 24-27 April 2018, Freising, Germany
28) Helmreich, B.: New Approaches in Urban Water Systems Engineering: 3rd World Congress on Civil, Structural and Environmental Engineering, 8-10 April 2018, Budapest, Hungary
29) Helmreich, B.: Herausforderungen der Niederschlagswasserbehandlung zum Schutz der aquatischen Umwelt. Training on the topic of the water cycle: Changes and risks of the German Meteorological Society, 16 November 2018 Oberschleißheim, Germany
30) Helmreich, B.: Regenwasserbewirtschaftung im urbanen Raum als große Herausforderung zum Schutz von Boden und Grundwasser. FUTURE WATER Summer 2018 Colloquium, 11 July 2018, Essen, Germany
31) Hübner, U., Hellauer, K., Müller, J., Karakurt, S., Zhiteneva, V., Drewes, J.E.: German (EU) approaches to deal with trace organic chemicals in drinking water quality management. Busan Waterworks International Workshop, 5-6 September 2018, Busan, Korea
32) Hübner, U., Müller, J., Karakurt, S., Zhiteneva, V., Hellauer, K., Drewes, J.E.: Development of a treatment concept based on technically modified hybrid filtration systems for indirect potable reuse. IWA World Water Congress & Exhibition, 16-21 September 2018, Tokyo, Japan
33) Koch, K., Lippert, T., Drewes, J.E.: The role of inoculum's origin on the methane yield of different substrates in Biochemical Methane Potential (BMP) tests. International Conference on Anaerobic Digestion "Biogas Science 2018", 17-19 September 2018, Turin, Italy
34) Koch, K., Helmreich, B., Hübner, U., Drewes, J.E.: Innovative Forschungsansätze der TU München für das Wassermanagement in Städten der Zukunft. IFAT, 14-18 May 2018, Munich, Germany
35) Lippert, T., Bandelin, J., Koch, K., Drewes, J.E.: Ökonomie der Klärschlammdesintegration mittels Ultraschall. Proceedings of the 46th Sewage Handling Workshop „Innovative strategies for sewage sludge handling" at TU Munich, 04 July 2018, Ismaning, Germany
36) Lippert, T., Bandelin, J., Schlederer, F., Drewes, J.E., Koch, K.: Power-to-cavitation (PTC): Proposing a new parameter to assess the energyefficiency of ultrasonic reactors for sewage sludge pre-treatment. International Conference on Anaerobic Digestion "Biogas Science 2018", 17-19 September 2018, Turin, Italy

37) Lippert, T., Bandelin, J., Drewes, J.E., Koch, K.: Energy-efficient pre-treatment of waste activated sludge using a novel ultrasonic flatbed reactor. Sludge Management in Circular Economy, 23-25 May 2018, Rome, Italy
38) Miklos, D.B., Wang, W., Linden, K.G., Drewes, J.E., Hübner, U.: UV-LED based water disinfection: Characterization and irradiance measurement of lab-scale LED irradiation systems. International Conference on UV LED Technologies & Applications, 22-25 April 2018, Berlin, Germany
39) Mößnang, B., Strübing, D., Lerch, B., Koch, K., Drewes, J.E., Lebuhn, M.: Microbial community analysis in thermophilic trickle bed reactors efficient for biological methanation of H_2 and CO_2. International Conference on Anaerobic Digestion "Biogas Science 2018", 17-19 September 2018, Turin, Italy
40) Peces, M., Pozo-Zamora, G., Koch, K., Astals, S.: Exploring the feasibility of co-fermenting waste lipids with primary or waste activated sludge. Sludge Management in Circular Economy, 23-25 May 2018, Rome, Italy
41) Rommel. S., Helmreich, B.: Feinpartikuläre Stoffe (AFS_{63}) in Verkehrsflächenabflüssen – Vorkommen und Relevanz für dezentrale Behandlungsanlagen, Aqua Urbanica 2018, 17-18 June 2018, Landau, Germany
42) Sanz-Prat, A., Greskowiak, J., Karakurt, S., Hübner, U., Drewes, J.E., Massmann, G.: Reactive Transport Modelling of Trace Organic Contaminants Attenuation by using the Sequential Managed Aquifer Recharge Technology (SMARTplus). 26th conference of the hydrogeology section e.V. in the DGGV e.V., 21-24 March 2018, Bochum, Germany
43) Strübing, D., Mößnang, B., Lebuhn, M., Drewes, J.E., Koch, K.: Demand-oriented biological methanation in an anaerobic thermophilic trickle bed reactor. International Conference on Anaerobic Digestion "Biogas Science 2018", 17-19 September 2018, Turin, Italy
44) Weißbach, M., Strübing, D., Koch, K., Drewes, J.E.: Mikrobiologische Methanisierung und der CANDO-Prozess - Neue Verfahren der Energierückgewinnung bei der kommunalen Abwasserbehandlung. Symposium „Technical Innovations in Wastewater Treatment", 27 September 2018, Münster, Germany
45) Wurzbacher, C.: Poorly known fungi in natural and engineered biofilms. 5th Biofilm Workshop 2018: Omic approaches in biofilm research: Advances in ecology and ecotoxicology, 11-13 September 2018, Kristineberg, Sweden

Poster presentations

1) Bandelin, J.; Lippert, T.; Drewes, J.E.; Koch, K. Cavitation field analysis for higher energy efficiency in substrate pre-treatment by ultrasound. Sludge Management in Circular Economy, 23-25 May 2018, Rome, Italy
2) Helmreich, B., Noceti, L. Stoffliche Belastung der Abflüsse von Nichtmetalldächern. Aqua Urbanica 2018, 17-18 June 2018, Landau, Germany
3) Hübner, U., Karakurt, S., Zhiteneva, V., Hellauer, K., Drewes, J.E. Developing a novel multi-barrier treatment concept based on sequential managed aquifer recharge technology (SMART) for indirect potable reuse. 26. Tagung der Fachsektion Hydrogeologie e.V. in der DGGV e.V., 21-24 March 2018, Bochum, Germany
4) Karakurt, S., Schmid, L., Timmermann, R., McCurdy, S., Hübner, U., Helmecke, M., Drewes, J.E. Abschätzung der Relevanz einer ungeplanten Wasserwiederverwendung und deren Einfluss auf die Trinkwasserversorgung in Deutschland. Jahrestagung der Wasserchemischen Gesellschaft, 7-9 May 2018, Papenburg, Germany
5) Kluge, M., Wurzbacher, C., Rautio, M., Wauthy, M., Peura, S. Exploring the fungal communities of Arctic ponds from continous and discontinous permafrost areas. ISME, 12-17 August 2018, Leipzig, Germany
6) Knoop, O. Unterschätzt: Tamoxifen – Ökotoxikologische Risikobewertung, Spurenstoffe und Krankheitserreger im Wasserkreislauf, 23-24 October 2018, Frankfurt am Main, Germany
7) Müller, J., Hübner, U., Drewes, J.E. Hybridsysteme: Optimierte Spurenstoffentfernung aus dem Ablauf kommunaler Kläranlagen durch Kombination von sequentieller Biofiltration mit adsorptiven und oxidativen Verfahren. Jahrestagung der Wasserchemischen Gesellschaft, 7-9 May 2018, Papenburg, Germany
8) Zhiteneva, V., Ziemendorf, E., Hübner, U., Drewes, J.E. Rapid small scale column tests (RSSCTs) for differentiating between sorption and biodegradation mechanisms removing trace organic chemical (TOrCs) in biological activated carbon (BAC) filters. Jahrestagung der Wasserchemischen Gesellschaft, 7-9 May 2018, Papenburg, Germany

Theses

Doctoral dissertations

1) Burkhardt, Therese: Mass spectrometric measurement of enzymatic activities - Miniaturization and application to environmental samples
2) Dandikas, Vasilis: Development of regression models to predict biogas production rate and biogas yield
3) Miklos, David: Enhanced removal of Trace Organic Chemicals from Wastewater Treatment Plant Effluents Using UV-Based Advanced Oxidation Processes

4) Stadlmair, Lara: Enzymatic Transformation of Trace Organic Chemicals – Characterization of Reaction Mechanisms using Mass Spectrometric Technologies
5) Weißbach, Max: Technical implementation and development of control strategies for the integration of the Coupled Aerobic-anoxic Nitrous Decomposition Operation (CANDO) into wastewater treatment schemes for simultaneous nitrogen removal and energy recovery from nitrogen

Master's theses

1) Afsharpour, Rouhallah: Modelling of Microplastics in Stormwater Basins
2) Al-Azzawi, Mohammed: Optimization of a decentralized treatment system using clinoptilolite in a dual media configuration for the removal of heavy metals from road runoff
3) Albert, Dominik: Expansion of the German high-voltage grid in accordance with the NABEG - Procedure analysis and evaluation of the legal requirements
4) Ansarian, Hormos: Modeling of wastewater treatment plant runoff time series for the assessment of dry-weather runoff hydrographs and a derived determination of the plant-specific proportion of external water
5) Arbash, Jad: Passive in-situ introduction of oxygen into porous media with a PDMS membrane
6) Batzdorf, Lotte: Determination of Transfer Processes and Biodegradation Rates within Biological Filtration Systems
7) Bonanno, Giacomo: Water resources sustainability assessment in Leh town, Ladakh, India, and alternative solutions using the Water-Energy-Food Nexus
8) Brambila Tamariz, David Pablo: Impact of ultrasonic treatment on methane production, organic matter degradation and digestate dewaterability in continuously operated anaerobic digesters
9) Davies, Mariel: Strategy to mobilisation of sparingly soluble phosphate from wastewater products for more efficient fertilization
10) Dietrich, Carina: Development of an innovative disposal concept with underfloor containers as part of the development of a new urban quarter on the site of the Bayernkaserne
11) Fluck, Lena: Investigating the Influence of Wastewater Effluent Matrix on the Enzymatic Transformation of Trace Organic Chemicals
12) Ganthaler, Sophia: Characterization of Unplanned Water Reuse in Italy for Agricultural Purposes
13) Gössl, Dennis: Determination of surrogates and indicator compounds for SMARTplus system for indirect potable reuse
14) Höhner, Mirjam: Investigating the fate of antibiotic resistant bacteria and antibiotic resistance genes during ozonation
15) Imig, Anne: Taking advantage in cloudburst projects in Copenhagen during minor-medium rain events by using above-ground control
16) Jell, Johannes: Concept for upgrading the wastewater treatment plant Schwabmühlhausen
17) Lahmouri, Mounia: Carbon footprint analysis of wastewater treatment strategies in Leh Town, India, and potential for greenhouse gas emissions reduction in the context of the Water-Energy-Food Nexus
18) Larasser, Martin: Investigations for the optimization of the process wastewater treatment at the wastewater treatment plant Salzburg-Siggerwiesen
19) Levai, Silvia: Advancing sequencial biofiltration: Investigation of key operational parameters and the potential of hybrid systems
20) Little, Emily: Examining the Effects of a European Co-optimized Day-Ahead Market Couping
21) Musch, Alexandra: Ultrasonic treatment of sewage sludge using an innovative flatbed reactor – impact of specific energy input on treatment efficiency
22) Neumaier, Marina: Concept study with demand planning on the extension of the municipal wastewater treatment plant Gersthofen
23) Rempe, Lisa-Marie: Heavy metal retention of filter systems under the influence of the ionic strength of stormwater
24) Scharrer, Julia: Pollutants in traffic area runoff: Temporal variations in heavy metal partitioning and suspended solids, particle size distribution and zeta-potential
25) Schmid, Felix: Advanced wastewater treatment for removal of trace organic chemicals - Process selection and design for the wastewater treatment plant Winterhausen
26) Schmid, Ludwig: Assessment of treated wastewater shares in German surface waters and associated impacts on drinking water supply.
27) Schmitz, Adrian: Biochar supplemented substrate to treat greywater – Column trials to evaluate startup and treating performance.
28) Schneider, Roland: Influence of air-sparging on the methane concentration in the soil of a former refinery site poluuted with petroleum hydrocarbons
29) Schön, David: Conversion and Product Formation of Pharmaceuticals by Enzymes in Multiplex Approaches

30) Schwaller, Christoph: Assessment of the impact of on-site sanitation systems on groundwater quality in Leh Town, India
31) Schweiger, Daniela: Development of an in-situ oxidation step for pilot scale sequential managed aquifer recharge technology (SMARTplus) system for indirect potable water reuse
32) Sembera Elizabeth Claire: Testament of dosing with high levels of food waste and dairy waste in anaerobic co-digestion: A Moosburg wastewater treatment plant case study
33) Spieß, Marina: Investigating the fate of antibiotic resistant bacteria and antibiotic resistance genes during UV disinfection and advanced oxidation
34) Sperle, Philipp: Development and Investigation of Vibration Based Membrane Fouling Mitigation and Cleaning Strategies
35) Tittl, Alexander: Economic analysis of co-digestion at the wastewater treatment plant Moosburg
36) Titzschkau, Leonardo: Optimization of a sequential biofiltration system by using coagulation as a pre-treatment step
37) Wiese, Felix: Process optimization of biological methanation in an anaerobic thermophilic trickle bed reactor.

Study projects

1) Al-Azzawi, Mohammed: Decentralization of wastewater treatment: a pipe dream or a reality?
2) Batzdorf, Lotte: Investigation of performance of sequential managed aquifer recharge technology at field site Baumwerder
3) Bein, Emil: Development of a virtual assessment tool for indirect potable reuse treatment trains
4) Bleicher, Daniel: Development of a wastewater and stormwater treatment concept for a cheese dairy based on constructed wetlands
5) Bonschier, Scharifa: Development of a qPCR-based detection system for phototropic Cyanobacteria
6) Ciofalo, Anna: Characterization of Phosphate Rejection during Ceramic Nanofiltration for RO pre-treatment
7) Davies, Mariel: Literature review on technology options for faecal sludge management in first phase emergencies
8) Eckert, Jennifer: Situation assessment for the infrastructure rehabilitation and restoration of water supply and sanitation services in Sana`a
9) Eibach, Veronika: Master plan for the wastewater situation of the Zott dairy in Mertingen
10) Even, Max: Determination of the biochemical methane potential (BMP) of solid, organic substrates and the evaluation of validation criteria in round robin tests
11) Fayez, Nadim: Concept and implementation of a structural prototype database for long-term analysis of water networks
12) Feickert Fenske, Carolina: Scenarios for decentralized wastewater management in Leh Town, India using a trickling filter or a horizontal flow constructed wetland
13) Hallsdóttir, Bryndís: Design of a Decentralized Wastewater Treatment System in Leh Town, India Using a Vertical Subsurface Flow Constructed Wetland
14) He, Jiaying: Oxidation performance comparison of UVAOPs (UV/H2O2, UV/PS and UV/Chlorine) by tracking optical surrogates of dissolved organic
15) Hendrik, Tyas: Microbial Communities in Wastewater
16) Hesam Mahmoudinejad, Termeh: Analysis of correlation between influencing factors on clogging of a sand-filter for traffic area runoff
17) Jell, Johannes: Concept for the installation of a grease separator system at Freising station
18) Khan, Muhammad: Studying the effects of re-circulation of various proportions of liquid digestate obtained from anaerobic co-digestion of rice straw and cow manure on its biogas yield and process stability
19) Kiesecker, Lea: Impact of ultrasonic pretreatment on foaming in anaerobic digesters
20) Levai, Silvia: Effects of different empty bed times on the removal of trace organic chemicals in sequential biofiltration
21) Lutz, Simon: Startup and operation of a deammonification system at Hersbruck wastewater treatment plant
22) Mahmood, Ammad: Ultrasonication of sewage sludge using an innovative flatbed reactor – Impact of specific energy input on methane yield
23) Moeller, Andreas: Demand-oriented Operation of an Anaerobic Trickle-bed Reactor for H2/CO2 methanation
24) Munz, Verena: Emissions of organic pollutants from vehicles - A pilot study of an experimental car wash
25) Orlowska, Agnieszka: Biofouling Assessment on Reverse Osmosis Membrane
26) Rizou, Zoi: Impact of ultrasonic pretreatment on the dewaterability and viscosity of waste activated and digested sludge
27) Sahanoglu, Hazal: Excess Power from Wind and Solar Sources in Germany
28) Sari, Kasih Ditaningtyas: Automation of the data analysis of stormwater quality treatment devices
29) Scharfenberg, Niklas: Anaerobic co-digestion in rural Africa - Case study St. Rupert Mayer
30) Scharrer, Julia: Treatment of traffic area runoff: Comparison of test protocols and monitoring programs
31) Skiebe, Axel: The oxidation-reduction potential as a control parameter in anaerobic digestion - A literature review

32) Sperle, Philipp: 3D-Fluorescence Spectroscopy Coupled with Parallel Factor Analysis – Principles, Model Approaches and Application in Wastewater Treatment SchemesSprafke, Aileen: Implementation of the umu-test for genotoxicity screening in accordance with DIN 38415-3
33) Torres, Miranda: Comparative Analysis of the Effect of a Biofiltration Step on the Ozonation of a Wastewater Treatment Plant Tertiary Effluent and The Removal of Trace Organic Contaminants
34) Wehrheim, Carolin: Investigation of the production of nitrous oxide in the treatment of highly nitrogen-containing wastewater
35) Weihofen, Björn: Identification of critical problems with biochemical methane potential tests from methane production curves
36) Wiese, Felix: Setup and start-up of a trickle bed reactor for microbial methanation

Bachelor's theses

1) Becker, Lukas: Pathogens in water reuse systems
2) Bertram, Janina: Phosphate reduction by algae biocenosis
3) Egle, Marina: The spread of potato Synchytrium endobioticum and other potato pest by application of sewage sludge from industrial potato processing - Significance, consequences, solutions
4) Fundneider, Jakob: Ecological considerations of green roofs in the urban environment
5) Gugel, Pascal: Drinking water disinfection with UV LEDs - opportunities and challenges compared to conventional UV disinfection
6) Hackbarth, Tom: Development of a method for sample application for Pyrolysis-GC/MS (UI)
7) Hartmann, Sabine: Drinking water disinfection with UV LEDs - opportunities and challenges compared to conventional UV disinfection
8) Hofmeier, Veronika: Representative selection of municipal wastewater treatment plants for socioecological questions
9) Honal, Sophie: Green roofs as building blocks of a sustainable water balance
10) Janicek, Maximilian: Investigation of process water treatment at wastewater treatment plant Karlsfeld
11) Lenert, Charlotte: Quantitative Microbial Risk Assessment
12) Milde, Luca: Wireless sensor network based monitoring system for risk assessment of water contamination in India
13) Nieß, Daniel: Passive in-situ introduction of oxygen and ozone into porous media
14) Ruf, Anastasia: Fluorescence spectroscopy of ultrasonically treated sewage sludge
15) Schaufler, Jonathan: Microbial risk assessments in water reuse systems
16) Schücking, Georg: Removal mechanisms of pathogens in sand, granular activated carbon, reactive/sorptive material, and soil filtration systems
17) Seidel, Jakob: Pretreatment of lignocellulosic biomass for improved substrate degradation
18) Wang, Yifang: Implementation of PLFA analysis in wastewater treatment processes
19) Willibald, Valentin: Detection of last resort antibiotic resistance genes in the clearwater of wastewater treatment plants

Dissertations and Awards

Fig. 43: Committee of Dr. rer. nat. Therese Burkhardt

Congratulations to **Dr. rer. nat. Therese Burkhardt** for successfully defending her dissertation, titled "*Mass spectrometric measurement of enzymatic activities - Miniaturization and application to environmental samples*" on February 26th, 2018. Her committee members included PD Dr. Michael Weller (Bundesanstalt für Materialforschung und prüfung, Berlin), PD Dr. Thomas Letzel, and Prof. Jörg Drewes.

Congratulations to **Dr.-Ing. Max Weißbach** for successfully defending his dissertation, titled "*Technical implementation and development of control strategies for the integration of the Coupled Aerobic-anoxic Nitrous Decomposition Operation (CANDO) into wastewater treatment schemes for simultaneous nitrogen removal and energy recovery from nitrogen*" on June 29th, 2018. His committee members included Prof. Liu Ye (University of Queensland, Australia), Prof. Craig Criddle (Stanford University, USA) and Prof. Jörg Drewes.

Fig. 44: Committee of Dr.-Ing. Max Weißbach

Fig. 45: Committee of Dr. rer. nat Lara Stadlmair

Congratulations to **Dr. rer. nat. Lara Stadlmair** for successfully defending her dissertation, titled "*Enzymatic Transformation of Trace Organic Chemicals - Characterization of Reaction Mechanisms using Mass Spectrometric Technologies*" on July 24th, 2018. Her committee members included Prof. Peter Schröder (HelmholtzZentrum München), PD Dr. Thomas Letzel, and Prof. Jörg Drewes.

Dr. rer. nat. Stefan Bieber received the PhD dissertation award from the Water Chemistry Society of the German Association of Chemists at their annual 2018 meeting in May in Papenburg. He received the award for his dissertation "*International management strategies for trace organic compounds in waterbodies and supporting advanced analytical techniques*."

Fig. 46: Prof. Torsten Schmidt and Dr. Stefan Bieber in Papenburg.

Congratulations to **Dr. rer. nat. Vasilis Dandikas** for successfully defending his dissertation, titled "*Development of regression models to predict biogas production rate and biogas yield*" on November 9th, 2018. His committee members included Prof. Jin Mi Triolo (SDU Biotechnology), Prof. Hauke Heuwinkel (Weihenstephan-Triesdorf) and Prof. Jörg Drewes.

Fig. 47: Committee of Dr. rer. nat. Vasilis Dandikas

Fig. 48: Committee of Dr.-Ing. David Miklos

Congratulations to **Dr.-Ing. David Miklos** for successfully defending his dissertation, titled "*Enhanced Removal of Trace Organic Chemicals from Wastewater Treatment Plant Effluents Using UV-Based Advanced Oxidation Processes*" on December 10th, 2018. His committee members included Prof. Torsten Schmidt (Duisburg-Essen), Prof. Karl Linden (CU Boulder, USA) and Prof. Jörg Drewes.

Dominik Häring, M.Sc., received this year's **H.P. Scholz Prize** for Special Study Achievements and his master's thesis, titled "*Phosphate recovery from secondary wastewater effluent with microalgae*". In August 2017, Mr. Häring finished the Environmental Engineering (Master) program as the best in his year. He completed his master's thesis under the supervision of Apl.-Prof. Brigitte Helmreich.

Fig. 49: Dean Prof. Dr. Christoph Gehlen (left) with Dominik Häring at the day of the faculty on July 6th. (Photo: Andreas Heddergott)

The **Roland Mall Foundation** presented three gifted students from the field of water and environment each with a scholarship of €500/month for the entire standard period of study of the Master's program. The selected students (David Mohndorf, Alexandra Geist and Luca Noceti) were selected based on their previous accomplishments. The scholarships were personally presented by Mr. Michael Mall, Chairman of the Foundation Board, at the day of the faculty on July 6th, 2018.

Fig.50: From left: Michael Mall, David Mohndorf and Luca Noceti (Photo: Andreas Heddergott)

Teaching

The Chair of Urban Water Systems Engineering offers a wide range of different courses for the Bachelor study program *Umweltingenieurwesen* and *Bauingenieurwesen* as well as for the Master programs *Environmental Engineering*, *Civil Engineering*, *Environmental Planning and Engineering* and *Sustainable Resource Management*. The emphasis of these courses is placed on water chemistry, advanced water treatment, energy recovery from wastewater, water recycling as well as conceptual design for sustainable water supply and wastewater disposal systems for urban areas. In 2018, the following lectures were offered:

Summer Term

Bachelor

- Brauchwasser (BSc): Glas, Karl
- Thermodynamik und Energietechnik (BSc): Hübner, Uwe
- Projektkurs Siedlungswasserwirtschaft (BSc): Drewes, Jörg
- Umweltanalytik (BSc): Letzel, Thomas

Master/PhD

- Advanced Water Treatment Engineering and Reuse (MSc): Drewes, Jörg
- Anaerobic Treatment and Energy Recovery (MSc): Koch, Konrad
- Hydrochemistry Laboratory (MSc): Helmreich, Brigitte; Heim, Carolin; Hübner, Uwe
- Modelling of aquatic systems (MSc): Koch, Konrad
- PhD Seminar SiWaWi (PhD/MSc): Drewes, Jörg; Koch, Konrad
- Process simulation and design of wastewater treatment plants (MSc): Becker, Jennifer
- Wastewater Treatment (MSc): Koch, Konrad

Winter Term

Bachelor

- Grundlagen Verfahrenstechnik (BSc): Böhm, Bernhard; Koch, Konrad
- Ökologie und Mikrobiologie (BSc): Wurzbacher, Christian
- Siedlungswasserwirtschaft Grundmodul (BSc): Helmreich, Brigitte; Koch, Konrad

Master/PhD

- Engineered Natural Treatment Systems (MSc): Hübner, Uwe
- Hydrochemistry (MSc): Helmreich, Brigitte
- Hydrochemistry Laboratory (MSc): Heim, Carolin; Helmreich, Brigitte; Hübner, Uwe
- PhD Seminar Siedlungswasserwirtschaft (PhD/MSc): Drewes, Jörg; Koch, Konrad;
- Practical Aspects of Engineered Natural Treatment Systems (MSc): Hübner, Uwe
- Sanitation in the Global South (MSc): Drewes, Jörg; Hübner, Uwe; Karakurt, Sema; Lippert, Thomas; Rommel, Steffen; Schwaller, Christoph; Zhiteneva, Veronika
- Technical Communication Skills in Water and Wastewater Treatment (MSc): Drewes, Jörg; Koch, Konrad
- Water and Wastewater Treatment Engineering (MSc): Drewes, Jörg

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Friends of the Chair

The Development Fund of the Chair of Urban Water Systems Engineering e.V. at TUM is a non-profit organization to support research and teaching at the chair.

Membership is open to anyone who supports the goals of the foundation. Funds of the foundation are used to:

- Provide seed grants for research efforts
- Supplement to cover printing costs of scientific reports/publications
- Publish the book series “Reports of Urban Water Systems Engineering”
- Support teaching funds
- Support travel fellowships for doctoral candidates and graduate students
- Partially support of research infrastructure
- Facilitate scientific meetings and workshops in the area of water treatment and wastewater treatment and reclamation

We publish our annual report **forum** to keep our members informed regarding activities at the Chair of Urban Water Systems Engineering.

In order to fulfill these tasks, we depend on donations. Thus, we welcome financial and in-kind contributions. We do not charge a membership fee.

Donations can be transferred electronically to the following account at the Postbank München (IBAN: DE04 7001 0080 0034 9498 02, BIC: PBNKDEFF). All donations are tax deductible.

The office of the Development Fund is led by Raphaela Hoffmann.

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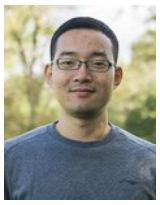

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