forum 87

Newsletter of the Chair of Urban Water Systems Engineering

ANNUAL REPORT OF THE CHAIR OF URBAN WATER SYSTEMS ENGINEERING

2016

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Foreword

Dear Friends,

considering all the major political changes in the world recently, we are grateful for the privilege to be able to stay focused on generating good science and for a very productive year. I am happy to present to you our annual report 2016 summarizing our activities and accomplishments for the last year. We have been lucky in acquiring a significant amount in funding through new projects and our publication output by our PhD candidates and research staff remains at a very high level. We are particularly happy for Dr. Bettina Huber and Dr.-Ing. Max Huber for their successful completion of their doctoral degrees. We wish both all the best for their future career path. We also congratulate Thomas Lippert for winning the award by the German Seawater Desalination Association (DMW e.V.) for the best master thesis.

Last year, six new PhD candidates began their research projects at the chair and you can find more information about their projects in this annual report. No surprise to us, but Munich remains an attractive location for visiting scientists and last year we benefitted from continued and new collaborations and visits ranging from a couple of weeks to several months by colleagues from Australia, China, Czech Republic, and the USA. Learning from each other is a great experience for our students and we will further strengthen our international network through student exchanges and joint research activities.

In July 2016, we held our 44th Wastewater Treatment Workshop (ATS) entitled *"Tailored Energy Recovery for Wastewater Treatment Plants as a Cornerstone for Energy Transition"*. Dr. Konrad Koch took a lead in organizing this workshop with international presenters from Luxembourg, Austria and Germany. The 45th ATS is scheduled for June 28, 2017 and will focus on *"Advanced Removal Strategies for Phosphorus in Wastewater Treatment"*. You can find further information on the technical program at our website including online registration (www.sww.bgu.tum.de/ats). From November 2-4, 2016, we conducted for the first time under the leadership of Prof. Thomas Letzel the international workshop "Non-Target Screening and its Role in Various Disciplines". The workshop attracted more than 120 international participants and given this success and interest, we are considering a follow-up meeting this year.

Last year, we launched several new research projects, such as the multi-agency project *TrinkWave* funded by the Federal Ministry of Research, focusing on non-membrane based treatment schemes for water recycling to augment drinking water supplies; the project *UltraMethane* funded by the Ministry of Economy and Energy,

where we focus on using new generations of ultrasonic devices to pre-treat sludge for enhanced biogas production; or the project funded by the German Environment Foundation (DBU) that is investigating novel mass transfer systems for ozone into water.

Last year, we also made significant contributions to our undergradate and graduate programs in civil and environmental engineering. Overall, we supervised more than 80 master theses and study projects. It is noteworthy that we also contributed to a complete revision of the environmental engineering master program at TUM with new emphasis areas. You can find more information on our website (www.umwelt.bgu.tum.de). Since 2016, I am serving as the Program Director of the Environmental Engineering Program.

On behalf of our students and staff, I'd like to thank you for your continued interest and support in our efforts. We are in particular grateful to the many donors that support our foundation that provided travel grants to our students and the funds to acquire a new vehicle for the department. Again, thank you!

We wish you a successful year and enjoy reading this report.

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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 both for 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 Wastewater Treatment Plant Garching (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) (Figure 1).

Figure 1: Pilot-scale nanofiltration test skid (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 in different 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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Optimization of biological COD degradation from industrial wastewater

For investigation of biological degradability, different methods are available at laboratory and technical scale. These include “Offhaus-Inhibition-Test” and “Zahn-Wellens-Method” (DEV L 25, EN ISO 9880) as aerobic and static procedures. Furthermore methods are used for continuous dynamic “Activated Sludge Simulation Test” in accordance to DEV L 41 (EN ISO 11733) and also the cyclic SBR Technology. Static anaerobic tests are conducted usng AMPTS-Equipment to detect bio-methane-potentials (VDI TG 4630).

Within a research project with the aim to optimize biodegradability, an industrial wastewater characterized by high COD load (COD ~430 g/L) was pretreated with ultrasonic, UV/AOP (OH-radicals), and ozonation to evaluate the effects of COD reduction. The results are showing no significant effects of pretreatment for COD reduction and biodegradability was slightly delayed after ozonation.

Repeated static aerobic tests resulted in a biological degradation of more than 98% also without pretreatment but by dilution using municipal wastewater at a rate of 1:100. In static anaerobic tests it could be demonstrated that a methane production is possible at a co-substrate ratio of less than 1:50.

Long-term stability was proven at a dynamic simulation test in a SBR (125 L Volume) over a period of 12 weeks. As supporting medium (matrix), industrlal wastewater effluent was delivered directly from the client’s WWTP in IPC containers. The effluents were fed to the SBR in intervals with a process water ratio of about 1:140. With additional dosing of nitrogen-, potassium- and phosphorus salts, the nutrient supply was increased and after some tests with different precipitation agents it was possible to reach 50 % of the COD discharge limit value.

From the mass balance of different measurement periods, the results are showing optimal operational conditions at a hydraulic retention time of two days with sludge loading between 0.6 and 0.8 $g_{CSB}/(g_{TS}\ d)$ and a solid retention time of ~ 5 d. The primarily acetic acid containing process water could be treated at the client’s wastewater treatment plant.

Chemical-physical, Analytical and Microbiological Laboratory

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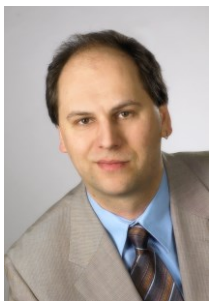

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A central facility of the chair and the research center is the affiliated laboratory, which is divided into three areas: the chemical-physical laboratory, the analytical, and microbiological laboratories led by Dr. Carolin Heim, Prof. Dr. Letzel, and Dr. Bastian Herzog, respectively.

The chemical-physical 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 (Figure 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 (AAS).

Figure 2: Sapromat for the analysis of the biological oxygen demand (BOD)

In the analytical laboratory, GC/MS, LC-TOF-MS, as well as LC/MS-MS (Figure 3) systems are available for target, suspected-target and non-target screening analyses. These are applied for characterization and identification of organic molecules in water matrices. New and established strategies enable the investigation of various molecules in water matrices.

Figure 3: LC/MS-MS System for analysis of trace organic chemicals at the sub ng/L level

The micro- and molecular biological laboratory provides conventional cultivation as well as molecular biological techniques. The detection of fecal indicator bacteria, i.e. *E. coli* and enterococci, and pathogenic bacteria, i.e. *Pseudomonas aeruginosa*, and *Legionella* spp. to monitor water quality, are conducted with a panel of routine classic cultivation techniques. In addition, molecular biological techniques, e.g. real-time quantitative polymerase chain reaction (qPCR), are applied to quantify a wide range of genes, including antibiotic resistance genes or specific bacterial groups e.g. enterococci (Figure 4).

Figure 4: PCR and qPCR systems to amplify and quantify different genes of interest

In addition, fluorescence in situ hybridization (FISH) combined with fluorescence microscopy is performed and used for semi-quantitative analysis of different bacterial communities that are relevant in biological wastewater treatment processes (e.g., nitrifiers, ANAMMOX bacteria, methanogens, and sulfate reducing bacteria). In addition, PCR combined with denaturing gradient gel electrophoresis (DGGE, Figure 5), as well as next-generation sequencing (amplicon sequencing on MiSeq Illumina) is used to characterize microbial community structure and function originated from natural and engineered water treatment systems.

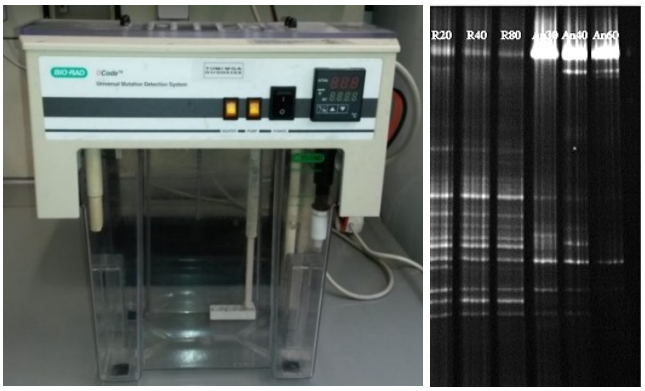

Figure 5: Denaturing gradient gel electrophoresis system for determination of the diversity of microbial communities

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Research Group
Anaerobic Technologies & Energy Recovery

Reliable treatment of municipal wastewater while meeting discharge standards to the aqueous environment remains the main goal of wastewater treatment. However, wastewater treatment plants (WWTP) are one of the major municipal energy consumers, while only little energy is recovered (mainly as methane) yet. By different approaches, energy recovery from wastewater can be enhanced.

One focus is the development of contemporary energy-saving processes in wastewater treatment, such as the removal of nitrogen from reject water by means of deammonification. However, energy savings sometimes come along with the possible emission of greenhouse gases (such as nitrous oxide), which can adversely affect the footprint of the entire process. Therefore, processes are optimized not only for their energy efficiency, but also for reduced emissions.

Another focus is directed to increase the efficiency of anaerobic digestion processes of residues. Innovative methods are tested for their suitability, whereby the transferability from laboratory to practice plays a central role (Figure 6 shows a system for the treatment of sewage sludge by ultrasound). In this specific case, three selected WWTPs will be finally equipped with the ultrasonic system, while investigating the effect on the overall process.

Figure 6: System for the treatment of sewage sludge by ultrasound

Another project goes beyond the actual main task of WWTPs, namely purifying wastewater, and is concerned with the question of how WWTP can also contribute to transition of renewable energy generation. Hydrogen produced by electrolysis of water from excess electricity by solar or wind is utilized to transfer CO_2 of the biogas generated in the digestion of sewage sludge into methane. This offers an opportunity to store energy in form of methane in the existing natural gas grid, independent of location and time. Preliminary results from pilot-scale investigations suggest that effective microbial methanation is possible under thermophilic conditions in trickling bed reactors.

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Optimizing the performance of the deammonification process while reducing nitrous oxide emissions (PANOWA)

High-strength ammonium loaded process water may be efficiently treated in a side-stream deammonification in order to reduce the nitrogen back load of the wastewater treatment plant. Advantages compared to conventional nitrification/denitrification are significantly reduced costs for energy, additives, and sludge disposal.

However, nitrous oxide (N_2O) can be formed as an intermediate or an unwanted by-product during the biological nitrogen removal and can be emitted with the off-gas. Due to its global warming potential of 298 compared to carbon dioxide, its long-term persistence in the atmosphere and the ozone layer-depleting effect, it has a highly negative impact on the environment. In order to provide both an ecological and an economic process, the development of strategies for an effective prevention of N_2O emissions as well as for an improved nitrogen conversion are essential.

To meet these objectives, experiments were conducted to investigate the influence of different operational settings (pH value, aeration and feeding strategy) during the one-stage deammonification process on the nitrogen conversion rate as well as on the N_2O emissions using a design of experiment (DoE). Based on these results, models were developed that allowed to predict both the plant's performance as well as the N_2O emissions, thus, enabling for an optimization of the one-stage deammonification process (e.g., continuous aeration being advantageous for reduced N_2O emissions). Additionally, results demonstrated that optimized conditions for both response variables differed from each other (Figure 7).

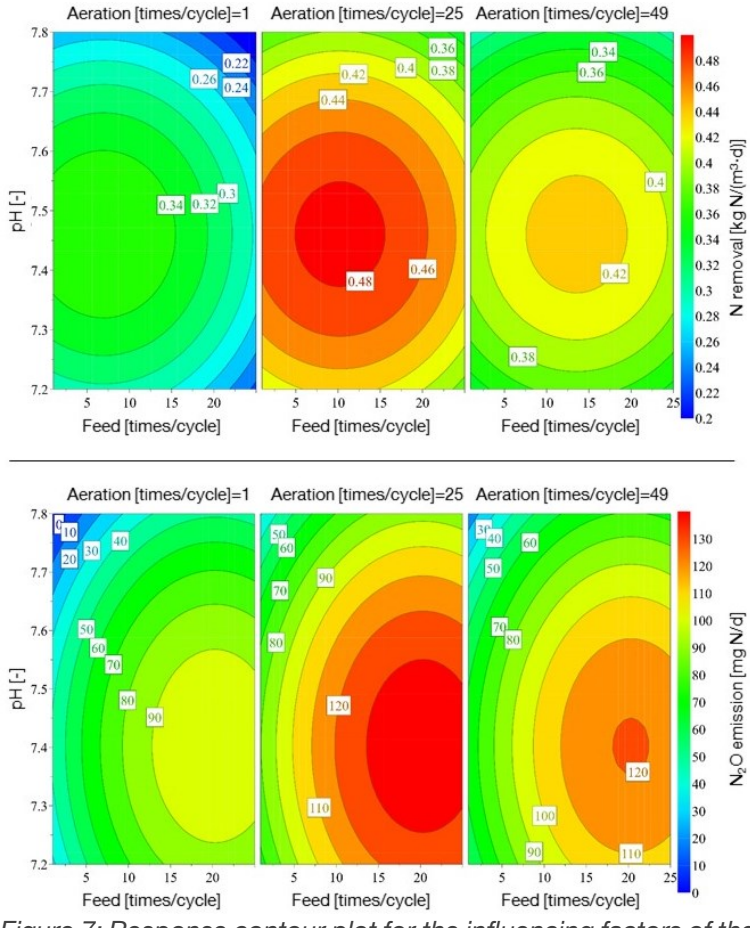

Figure 7: Response contour plot for the influencing factors of the pH value, feeding and aeration strategy on the nitrogen conversion rate (top) and the N_2O emissions (down)

FUNDING:
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COOPERATION:
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Nitrous oxide as innovative source for energy recovery from wastewater (PANOWA)

Nitrous oxide (N_2O) is an unavoidable intermediate within the biological nitrogen cycle and, as such, a common side-product from biological wastewater treatment trains. Its CO_2 equivalence of 298 makes it a potent green-house gas. Additionally, it catalyzes the destruction of the stratospheric ozone layer. To minimize its emission and hence, its environmental impact, various mitigation strategies are presently in the scientific focus (Leix et al., 2016). However, the exothermal decay to nitrogen gas allows its energetic utilization together with biogas from the anaerobic stabilization of sewage sludge and parallel decomposition. To assess potential technical application, integration as well as operation and control strategies are investigated besides novel online-measurement techniques of N_2O. For this purpose, the Coupled Aerobic-anoxic Nitrous Decomposition Operation (CANDO) as developed by the colleagues at the Stanford University has been established, operated as a double-stage bioreactor system (Figure 8).

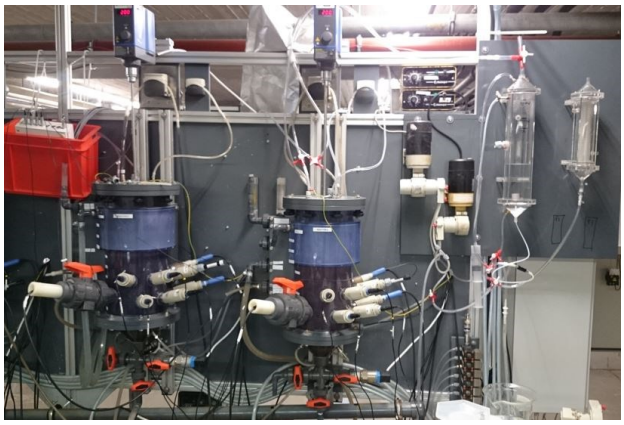

Figure 8: Automated bio reactor system according to the design at EAWAG

In contrast to the colleagues in California, the system is fed with real wastewaters i.e. reject water from sludge digester as well as primary effluent instead of synthetic substrates. In a long-term study, 50 % to 70 % of the incoming nitrogen loads could be converted to N_2O while applying different operational strategies. To enable energetic use, also different physical extraction techniques are investigated to enhance the mass transfer from the liquid to the gas phase. Promising results have been generated applying a gas membrane contactor enabling reliable removal of 99 % of the theoretically treated nitrogen loads.

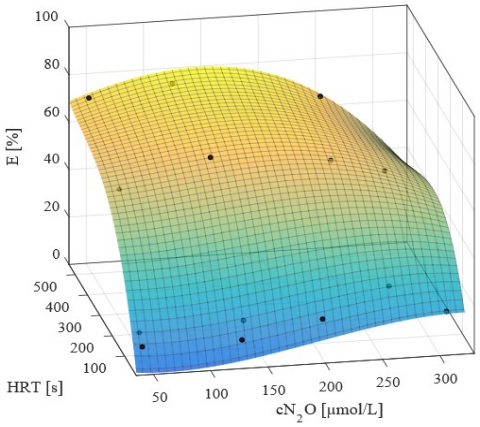

Figure 9: N_2O-removal efficiency of a gas membrane contactor

The investigations are accompanied by an innovative photoacoustic-based system provided by the Chair of Analytical Chemistry at TUM for online measurement of N_2O concentrations in the gas phase.

FUNDING:
INTERNATIONAL GRADUATE SCHOOL OF SCIENCE AND ENGINEERING (IGSSE); BAVARIA CALIFORNIA TECHNOLOGY CENTER (BACATEC)

COOPERATION:
STANFORD UNIVERSITY, USA; EAWAG, SWITZERLAND; CHAIR OF ANALYTICAL CHEMISTRY, TUM

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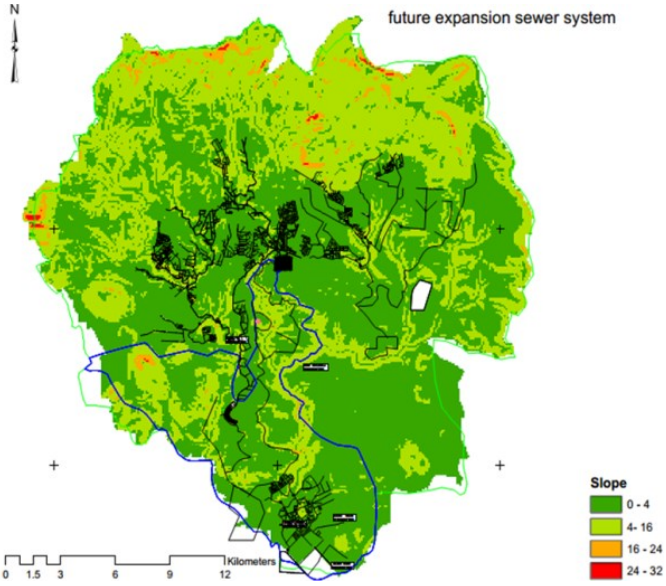
Multi sectorial approach for management of wastewater in Addis Ababa

Addis Ababa has currently 3.5 million inhabitants and extends over an area of 540 km². According to the Ministry of Water, Irrigation and Energy, the per-capita water supply to the community is about 20 L per day. Hence, the amount of wastewater discharge from the community is equivalent to 70,000 m³/day (excluding rain and urban run-off water). Addis Ababa Water Supply and Sewerage Authority (AAWSA) provides services of potable water supply, collection and disposal of wastewater.

The existing wastewater treatment plants Kality and Kotebe have a total treatment capacity of only 16,650 m³/day. Thus, these treatment plants can only handle about one quarter of the total wastewater discharge of the community. Consequently, AAWSA started to expand the existing sewer system by dividing the city into three catchments. By applying a centralized approach with sewer pipes draining the city to another three new WWTPs, a total treatment capacity of 366,000 m³/d is envisaged. Due to the topographical conditions of Addis Ababa, only a part of the city is suitable for such a centralized approach. In order to treat most of the city's wastewater, also decentralized systems are required.



By conducting a survey, the willingness of the community regarding its acceptance of water recycling and reuse options was studied. The results revealed that half of the community is already well informed and ready to adopt possible reuse methods. On the downside, 25% of the respondents were not interested in water recycling and reuse, especially when the source of wastewater included wastewater from toilets.

Having the support from most of the community, adapted schemes for decentralized wastewater treatment including water, nutrient and energy recovery will be developed. Finally, the most promising approach will be implemented as a small-scale pilot plant on the university campus for demonstration. The ability of a simple, but efficient and resilient wastewater treatment system will hopefully be the first step towards a more sustainable system for the capital of Ethiopia.

FUNDING:
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COOPERATION:
ADDIS ABABA SCIENCE AND TECHNOLOGY, UNIVERSITY, ETHIOPIA

Tailored energy supply by microbial methanation of H_2 and CO_2 using anaerobic trickle bed reactors

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The development of new energy conversion and storage technologies becomes increasingly important with changing energy policy towards renewable resources. Within the German gas grid currently up to 250 billion kWh or 25% of the annual gas consumption could be stored. In this context, the project aims to further study and develop the microbial generation of methane as a storable gas using hydrogen, generated via electrolysis of water, and carbon dioxide from different sources (e.g., industries, biogas plants).

Within the project *MikMeth,* microbial methanation is investigated in thermophilic anaerobic trickle bed reactors at pilot scale (58 L). Due to the larger gas-liquid interface surface area in these reactors, an improved hydrogen mass transfer can be expected even without pressurized gas supply. The investigated system already demonstrated the capability for stable long-term operation under thermophilic conditions and compared to previously studied systems resulted in high methane productions rates with methane concentrations above 95 vol.%. With regard to process efficiency and applicability micro and macro nutrient requirements of hydrogenotrophic methanogenic archaea as well as periods without gas supply and their impact on the microbial community and methane generation are studied, being an essential criterion for a flexible "on demand" operation. One central challenge is related to the production of water as an unavoidable side product of the reactor, which causes a continuous dilution of the trickle medium.

Figure 10: Trickle bed reactors at pilot plant scale

Furthermore, parallel microbiological studies at the Bavarian State Research Center for Agriculture revealed significant changes of the microbial composition within the trickle bed reactor. Out of a mesophilic inoculum, different thermophilic hydrogenotrophic methanogenic archaea enriched as dominant species during long-term operation. In addition, the initial formation of a methanogenic archaea biofilm on the trickle bed support material has been observed.

FUNDING:
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COOPERATION:
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Increase of energy-efficiency of wastewater treatment by means of innovative ultrasound disintegration (UltraMethane)

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

The main target of the project UltraMethane is to improve anaerobic digestion due to the application of ultrasound. Through ultrasound-induced cavitation, sludge flocs are disintegrated, microorganism cells are disrupted and intracellular enzymes are released. This results in an improved micro-biological degradation and consequently, in an increased biogas yield. However, practical experience has shown that conventional sonotrode-based systems are relatively susceptible to interference. Within this project, an innovative split reactor is investigated as an alternative. In close collaboration with an industry partner, the central aim of the project is to maximize the methane yield while minimizing the power consumption due to an optimization of reactor design and process parameters (e.g., acoustic intensity, duration, amplitude and sludge properties). The efficiency of the treatment will be evaluated based on both BMP tests and two continuously operated biogas reactors (Figure 11). Based on the lab-scale experiments, selected wastewater treatment plants will be equipped with adequate ultrasound systems to obtain reliable data from real plants. At the end of the project, the main results will be summarized in a guideline.

Figure 11: Continuously operated digesters with ultrasound test systems

FUNDING:
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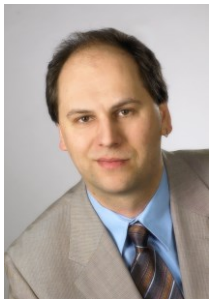
COOPERATION:
BANDELIN ELECTRONIC;
GFM BERATENDE INGENIEURE

Analytical Research Group



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In 2016, the Analytical Research Group was comprised of 10 members (including internship students, bachelor, master students, and PhD candidates) and has received funding from third-party including BMBF, EU, BFS, AiF/BMWi, WiFö, foundations and private industry.
Currently, the key aspects in research cover technological, analytical-methological, and analytical-chemical properties, which are applied in water and wastewater analysis as well as in other relevant environmental matrices, food analysis, beverage and plant extract analysis and others. A special focus is on the chemical analysis with simultaneous functionality analysis using mass spectrometric detection.
Specific activities include:

1) Analytical platform development for the targeted analysis of organic molecules in complex matrices (‚Target Screening‘),
2) Analytical platform development for the analysis of expected organic molecules in complex matrices (‚Suspected-Target Screening‘ including databases like 'STOFF-IDENT'),
3) Analytical platform development for non-targeted analysis of organic molecules in complex matrices (‘Hidden-Target Screening‘),
4) Analytical platform development for the analysis of organic molecules in complex matrices with simultaneous functionality analysis by mass spectrometric detection,
5) Software development of modular working-out tools for data analysis (‚Retention Time Index RTI', ‚Achroma‘ and ‚FOR-IDENT‘),
6) Application of analytical platforms (1-3) in the research area of oxidative treatment of water and the development of sustainable strategies,
7) Application of analytical platforms (1-4) in the research area of ingredient analysis and the search for biofunctional active compounds in environmental samples, after treatment, in plant extracts and beverages.

Finally, we conducted voluntary projects like our initiative ‚Wissenschaft vermitteln‘ including visits in Kindergarden or elementary schools via ‚Kinderuni on Road‘ or basic analytical courses for young apprentices and the ‘Chemnixblog‘ (http://www.sww.bgu.tum.de/wissenschaft-vermitteln/).

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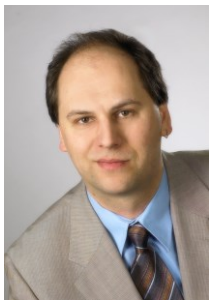

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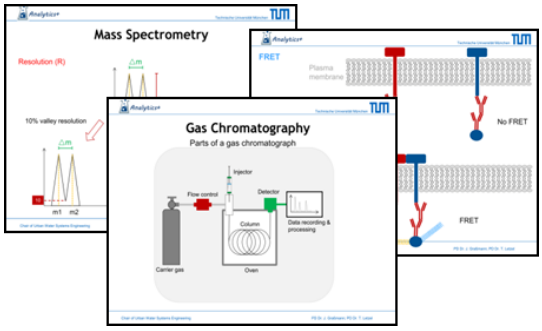
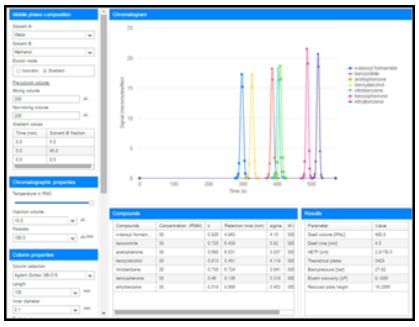
FUNDING:
TUM-LEHRFOND

COOPERATION:
HSWT

Project completion: „Development of an e-learning platform in the area of analytical chemistry (Analytics+)

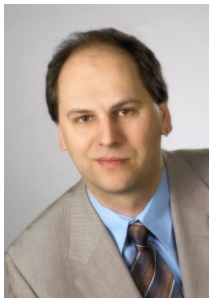
The e-learning platform Analytics+, which has been introduced in previous annual reports, was funded two years in a row by the TUM Lehrfond and was successfully completed in September 2016. Analytics+ is aimed at students and trainees of TUM as well as students with interest in analytical and bioanalytical topics. A TUM or LMU access code or a guest account is a prerequisite for the utilization of Analytics+. The content of **level 1** of Analytics+ is presented comprehensively in textual and graphical formats and contains basic chemical knowledge and learning content regarding (bio-) analytical topics. It comprises of chromatographic methods as well as slides regarding e.g. mass spectrometry, electro-phoretic separation methods, and immunoassays amongst others. The inclusion of workflows, which describe the identification procedure of unknown compounds in environmental samples, provides insight into common analytical problems. The self-made content is furthermore augmented with external content like “The Virtual Laboratory“ by Dr. Stefan Asam [1] or tutorial videos provided by companies like Agilent Technologies, GE Healthcare Life Sciences, oder Knauer Wissenschaftliche Geräte, which altogether supports the acquisition of a broad analytical knowledge. **Level 2** allows the recapitulation and deepening of the acquired knowledge. For one this is achieved by the implementation of a glossary, which briefly and concisely explains the most important terms. Furthermore “HPLC simulator” [2] and “Solid-phase extraction procedure” tools were implemented in collaboration with the University of Applied Sciences in Weihenstephan-Triesdorf. They provide insight into sample preparation procedures and improve the understanding of chromatography by allowing manual adjustment of HPLC parameter to directly observe effects in a chromatogram. The content of **Level 3** includes a quiz, which encourages the user to test their knowledge. Furthermore both the HPLC Simulator as well as the solid-phase extraction tool enable the planning and conduction of virtual experiments in the form of a test situation. Instantaneous feedback for each step of the experimental planning is provided, which enhances the learning outcome.





[1] http://vimp.wzw.tum.de/videos

[2] http://www.hplcsimulator.org



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

The project FOR-IDENT is a two years BMBF-funded project and continuous the activities of the previous RISK-IDENT project related to the establishment of guidelines and the integration of the database STOFF-IDENT in an extended platform. In this platform 'FOR-IDENT', further software-tools and databases are implemented providing workflows for the evaluation of LC-MS/MS data. New strategies and workflows should support the user of 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).

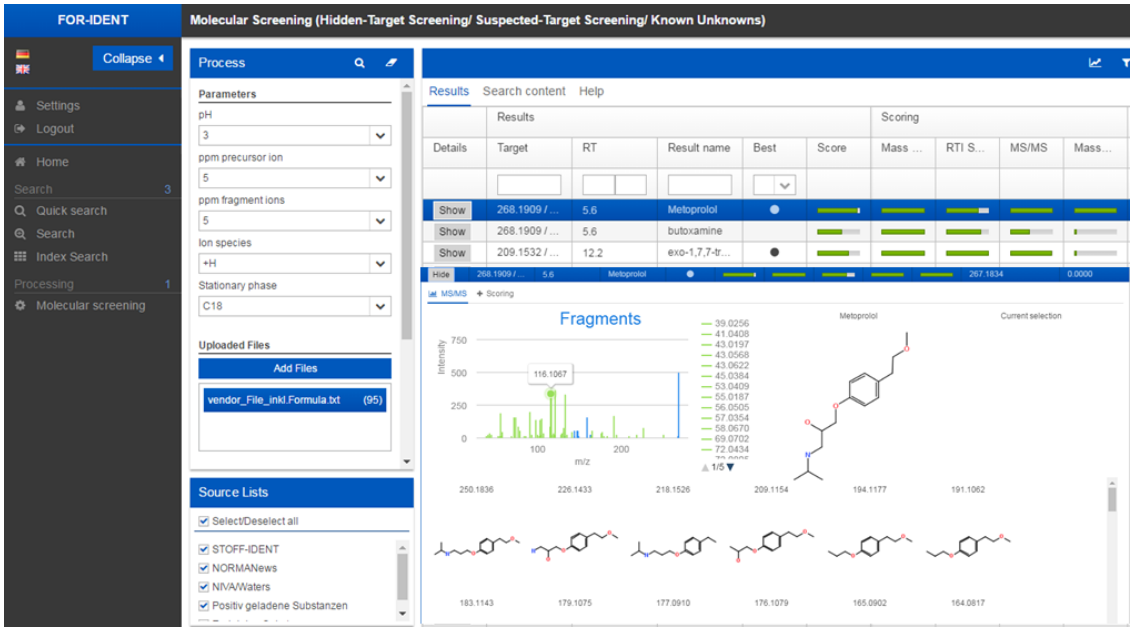

Figure 12: Illustration of the FOR-IDENTplatform with scoring system and MSMS fragmentation comparison (by the MetFrag tool)

The database STOFF-IDENT usage, which was developed within the RISK-IDENT project, plays a key role. Hereby, suggested molecules in water samples can be reduced by different filter possibilities in STOFF-IDENT. Furthermore, analytical MS/MS-databases like MassBank and prediction tools like MetFrag are already integrated. This allows at the same time the application of chemical, physico-chemical and analytical metadata. Within the FOR-IDENT project, further linkages are planned, for example with ecotoxicological databases. The consortium organized together with international partners in November the International SEWMSA16 Workshop with 100 participants discussing non-target screening strategies and workflows.

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(02WRS1354)

COLLABORATION:
BWB, HSWT,
LFU, LW, TUM

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Non-Target Screening Workflows Using RPLC-HILIC-MS

Analytical chemistry has improved greatly during the last decade, however, a comprehensive identification of the organic content in waters is still challenging, especially if one considers not only the thousands different possible water contaminants, but also their metabolism and transformation products.
Until now, most of the compound screening techniques that were applied to water samples have been targeted. It is only recent that with the advances in high resolution mass spectrometry the concept of non-target screening of samples has become popular in order to provide a more complete view of the organic contents of different water bodies. These organic compounds that are present in a sample are called in literature "Hidden Targets", as they are known in the chemical literature or MS reference databases, but unknown to the researcher regarding a specific sample.
Surface water samples are analyzed by RPLC-HILIC-MS in order to detect the various (very) polar and non-polar organic compounds. Subsequently, the Non-Target Screening is performed with the help of the STOFF-IDENT database. For (very) polar compounds (logD<0) the extracted exact masses from the HILIC region of the obtained chromatogram were loaded into the database. The returned results were then filtered and any suggested compounds with a positive logD were rejected. For the compounds with a positive logD, the results were obtained from the database by using the exact mass as well as the Retention Time Index (RTI), which takes advantage of the known retention time and logD correlation in RP chromatography, giving much more probable results.
Additionally, the results of the STOFF-IDENT database can be classified by category, like industrial chemicals, pharmaceuticals or transformation products.

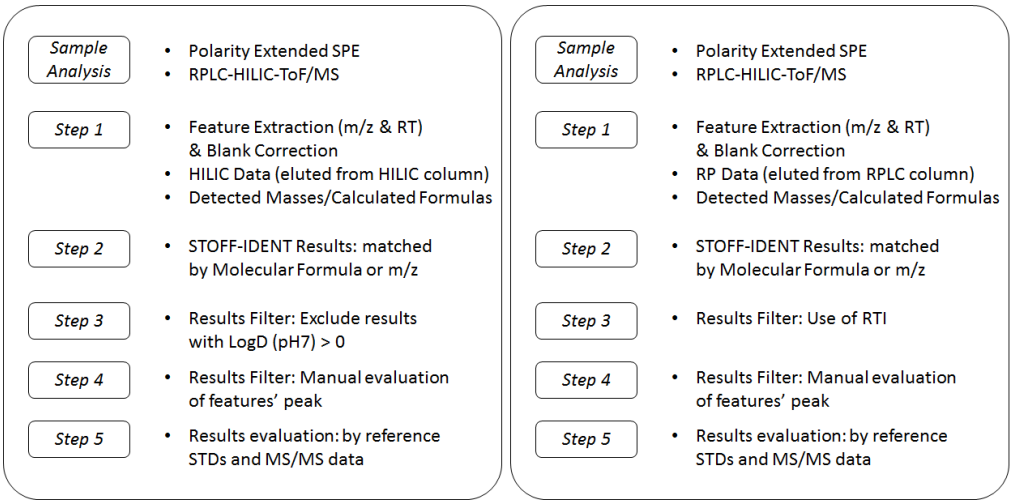

Figure 13: Non-target screening workflows for HILIC and RPLC data

FUNDING:
PHD SCHOLARSHIP: BAYERISCHE FORSHUNGSSTIFTUNG

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Parallel detection of very polar and nonpolar trace organic compounds in water samples by SFC

Trace organic compounds are of emerging concern for the analysis of water samples. These compounds are residues of pharmaceutical, everyday-chemicals, pesticides or others and can be found in waterbodies in a concentration range from ng/L to µg/L. For the analysis of trace organic compounds, mainly reversed phase chromatography, coupled to mass spectrometry is utilized. This technique is well established, and suitable for the separation and detection of medium to nonpolar compounds. The separation and detection of polar to very polar compounds is hardly possible, using reversed phase chromatography. Since very polar compounds occur in waterbodies and are environmentally relevant, new techniques for their detection have to be developed and assessed. One option here is supercritical fluid chromatography (SFC), a separation technique, which uses carbon dioxide above or near the critical point as mobile phase. At the Chair of Urban Water Systems Engineering, SFC is investigated regarding its applicability for the separation and detection of trace organic compounds with time of flight mass spectrometry (Figure 14). It could already be shown that SFC is well suitable for the separation of polar to very polar compounds, but additionally can also be used to separate medium from non-polar compounds. As a result, trace organic compounds which have so far been separated and detected by reversed phase chromatography and even more polar ones can be detected by SFC. Consequently, the application of SFC allows broadening the polarity range of detectable compounds significantly. The knowledge about the basic mechanisms of SFC separations is currently limited. In contrast to liquid phase separations, SFC separations are influenced by several additional factors. Impacts on separations and interactions between the factors are not fully understood yet. In order to improve the understanding about SFC mechanisms, in-depth studies are currently conducted at the Chair of Urban Water Engineering.

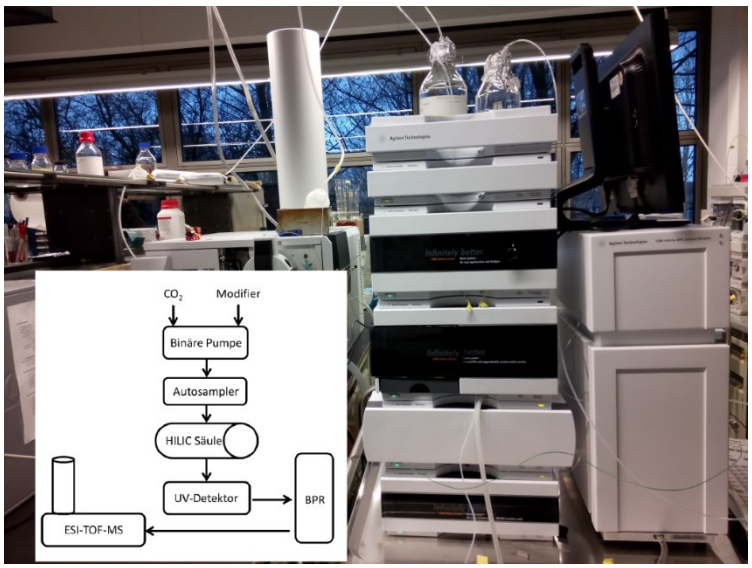

Figure 14: SFC with mass spectrometric detection

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

Trace organic chemicals (TOrC) are compounds which can be found ubiquitously in the aquatic environment in quantities between 10 and 5,000 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 those compounds.
In addition to spectroscopic methods, e.g. photometric or fluorescence detection, there is also the possibility to couple enzymatic reaction 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).

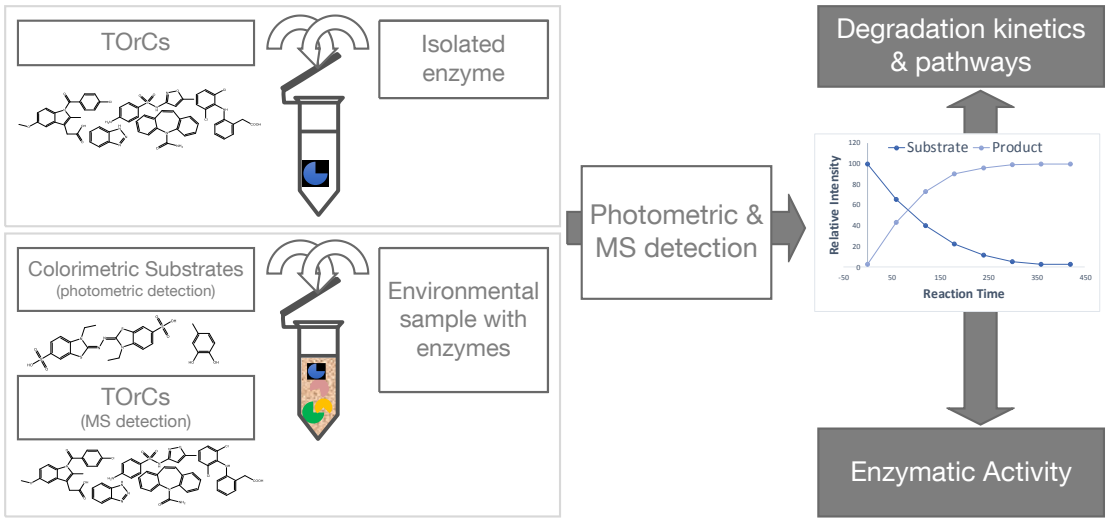

Figure 15: Procedure of investigating enzymatic reactions in model systems and environmental samples

Investigating the enzymatic activity in biological filtration systems (Therese Burkhardt)

In order to benefit from enzymes as TOrC metabolizing catalysts, the establishment of a method measuring the enzymatic activity in environmental samples is

a basic requirement. To establish a sensitive method, two different approaches, i.e. *in situ* measurement and an extraction procedure, were investigated for their applicability and efficiency. The enzyme dependent substrate conversion was examined photometrically. However, to distinguish between real enzymatic activity and substrate conversion by other mechanisms negative controls are needed. Therefore, various treatment procedures were investigated. Additionally, the transformation of TOrCs by extracted enzymes of a biological filtration system was investigated using direct pump infusion coupled to mass spectrometric measurement. Results indicate that substrate oxidation in the probed sample is affected by the applied method, pH, substrate, and used co-substrate. Due to the complexity of the probed sample, until now a general statement regarding a best practice negative control experiment cannot be made. Nevertheless, mass spectrometric measurements to investigate the transformation of TOrCs have been successfully established. The optimized photometric approach together with an appropriate negative control will serve as basis for assessment of enzymatic activity in biological filtration systems and offers the possibility to investigate the transformation of a variety of TOrCs using mass spectrometry.

Enzymatic transformation of TOrCs (Lara Stadlmair)

A further objective is to investigate the potential of selected enzymes to degrade and transform TOrCs using MS-based *in vitro* enzyme assays. To determine enzymatic reactions, two infusion procedures were applied. In a conventional syringe pump infusion, aliquots of one enzyme(s)-TOrC(s)-mix are taken after defined reaction times and the reaction is interrupted by adding organic solvent. The simultaneous addition of an isotopically labeled reference standard is used to correct any instrumental variations. To enable high sample throughput using different enzymes and substrates, a further aim is to transfer the syringe pump setup to a miniaturized and automated Robotic NanoESI. The TriVersa NanoMate® functions has an external ionization source for MS and can control reaction conditions, such as incubation time and temperature. Investigations were carried out in single assays as well as in mixtures. In multi-substrate or multi-enzyme assays, respectively, more than one enzyme and substrate are used. Analyzing enzymatic conversion in TOrC mixtures can contribute to reveal enzymatic specificity and provide important information on substrate competition. Moreover, a mixture of enzymes can potentially achieve higher transformation efficiencies. The evaluation of enzymatic reaction pathways will help to understand chemical behavior of TOrCs especially in WWTPs. The evaluation of degradation potential and efficiency of enzymes can contribute to optimize suitable removal techniques to diminish TOrCs.

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Research Group
Sewer Systems and Rainwater Management

This year, the research group focused on heavy metal loads from traffic areas and metal roof runoff including possibilities for decentralized treatment. In this context, the working group was very successful in publishing results from the doctoral thesis of Maximilian Huber. In particular, a critical review of heavy metal pollution of traffic area runoff has led to a worldwide compilation of occurrence, influencing factors, and partitioning of heavy metals of traffic area runoff. Knowledge of metal partitioning is important to optimize stormwater treatment strategies and prevent toxic effects on organisms in receiving water bodies. The critical review paper has already emerged as a frequently cited article.

Figure 16: Installation of a decentralized treatment plant for road runoff

Whether topsoils in vegetated infiltration swales provide adequate protection for underlying groundwater, when the rainwater runoff from metal roofs are infiltrated, was investigated in a comprehensive sampling campaign at four infiltration swales.

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Experience on the heavy metal contents of infiltration swales at stormwater runoff from zinc roofs

The stormwater runoff of zinc roofing materials is polluted with high concentrations of zinc, which have to be treated before being discharged into the groundwater system. As a decentralized pre-treatment in Germany, topsoils of vegetated infiltration swales according to DWA-A138 and DWA-M 153 are state of the art. However, the topsoil layers are not replaced or maintained improperly despite long-term operation. It is also to be expected that the infiltration swales are unevenly charged with stormwater runoff and therefore with heavy metal concentrations. In a study project of the Master student Mrs. Vanessa Ebert, B.Sc., four fifteen-year-old infiltration swales at a zinc roof were sampled. All infiltration swales drain the same roof surface of the symmetrical roof, which is divided into four subregions. Soil samples were taken as a function of the distance from the downpipes and analyzed for their zinc content. The samples were also subdivided into different depth fractions. During sampling, it was observed that the required 30 cm layer thickness was not available in many areas, particularly in the critical areas at the inlet of the swales; in some areas it was even less than 5 cm. It was found that the zinc contents in the top soil were highest with up to 25 g/kg dry mass directly at the inlet. No vegetation can be established there, which leads to a reduction in permeability. In the feed area, the topsoil layer was saturated with zinc and can no longer perform its treatment function. Particularly with regard to groundwater protection, a stronger focus should be placed on the construction and maintenance of such installations on metal roof runoff. In addition, the load-bearing topsoil must be regularly replaced, but this is only necessary in certain areas of the swales. In general, it is necessary to discuss whether the passage through topsoils of infiltration swales has sufficient efficacy to pretreat metal roof runoff prior to discharge into the groundwater.

Figure 17: Vegetated infiltration swale at a zinc roof

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Microbial Systems Research Group

Microorganisms are key factors for the biotransformation of contaminants in natural and engineered systems. For that reason, the Microbial Systems Research Group focuses on the investigation of microbial processes in aquatic and engineered systems, ranging from biological wastewater treatment to the application of biological active filter in drinking water purification. By using state-of-the-art bio-molecular tools, new ways to better understand microbial functional groups and their specific activities, not only on cellular but also on enzymatic levels, open up. One focus is the identification of relevant functional bacterial communities and the detection of their specific activities, e.g. nitrogen conversion (nitrifiers, ANAMMOX bacteria), anaerobic processes (e.g., sulfate reducing bacteria, methanogens) and microbial induced corrosion (e.g., sulfide and sulfur oxidizing bacteria). Further research addresses the characterization of taxonomic and functional diversity of microbial communities with special functions, e.g. micro pollutant degrading communities in wastewater treatment and drinking water purification. Therefore, qPCR (Figure 18) and next generation sequencing (metagenomics and metatranscriptomics) based technologies are applied.

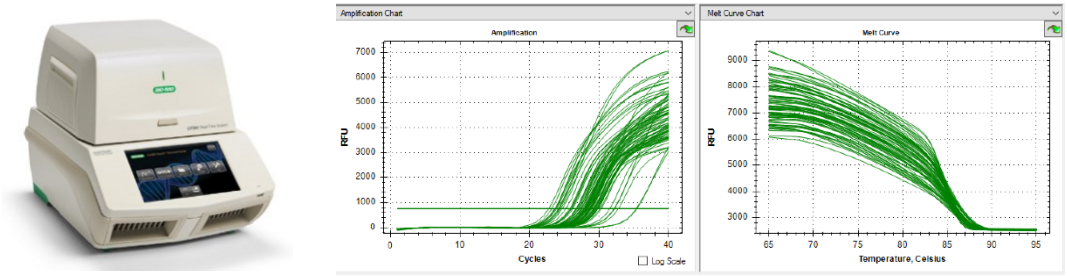

Figure 18: qPCR Analysis in 96 well format targeting different antibiotic resistance genes

In addition, efficient ways to monitor the inactivation of pathogens and the proliferation and dissemination of antibiotic resistance genes in drinking water and water reclamation systems are evaluated. Detection and quantification of fecal indicator organisms

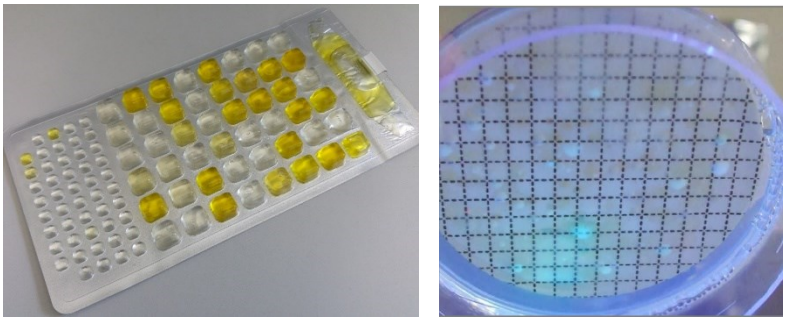

Figure 19: Colilert-18 analytical system (left) to quickly and reliably detect and quantify E. coli and total coliform bacteria in a given water sample, and the detection of Pseudomonas aeruginosa on specific agar plates by UV radiation

FUNDING:
BMWI, ZIM, JPI WATER

COOPERATION:
LFL, FREISING;
LFU, AUGSBURG;
KIT, KARLSRUHE;
CSM, COLORADO SCHOOL OF MINES, GOLDEN, COLORADO, USA

(E. coli, total coliform bacteria, and Enterococci, Figure 19) or specific pathogenic bacteria, e.g. *Pseudomonas* spp. and *Legionella* spp., are established and performed as routine methods.

These techniques are used to monitor fecal contamination of surface water, to evaluate disinfection efficiency of advanced treatment processes (UV, ozonation, peroxide), and the elimination capacity of biological active filters that are used, e.g. in wastewater treatment and drinking water purification.
Both classical microbial cultivation techniques (Figure 20) and molecular biological methods (Figure 21) are applied to answer current research needs:

- Quantification of pathogens and antibiotic resistance genes in aquatic systems by Polymerase Chain Reaction combined with Denaturing Gradient Gel Electrophoresis (PCR-DGGE), real-time PCR, metagenomics and meta transcriptomics
- Evaluation of activity and biodegradation potential of bacteria and microbial communities in a variety of systems, including porous media systems by Flu orescence in situ Hybridization, FISH applied with Confocal Laser Scanning Microscopy, CLSM
- Monitoring of the dissemination of antibiotic resistant genes in different wastewater treatment systems by (RT)-qPCR

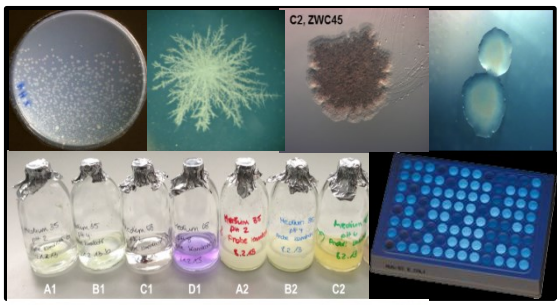

Figure 20: Classic microbiological cultivation on agar plates and in liquid media (serum bottles and microplates; e.g. detection of E. coli, Most Probable Number counts, MPN) using specific nutrient formulations to detect and quantify a variety of microorganisms

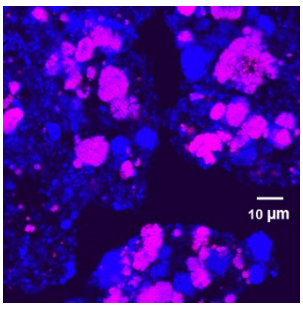

Figure 21: CLSM image of an activated sludge floc after the application of FISH. Nitrospirae (magenta, nitrite oxidizing bacteria, NOB) and DAPI stained bacteria cells (blue) to show their distribution within a sludge floc

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Research Group
Engineered Natural Treatment Systems

The removal of emerging trace organic compounds (TrOCs) in ground-, surface and drinking water is of increasing interest to reduce potential adverse effects on aquatic life and human health. Natural treatment processes, such as riverbank filtration, soil-aquifer treatment or biologically-active filters, are used in water treatment for many decades. Major objectives of this research group include

- an assessment of key factors for the removal of trace organic chemicals in microbial systems,
- the transitioning of passive natural treatment systems to active processes with predictable water quality,
- the development of new innovative treatment concepts for advanced water treatment and reuse based on biological processes and
- the integration of natural processes into hybrid processes with advanced treatment such as ozonation, advanced oxidation or membrane processes.

In order to actively steer the mitigation of TrOCs, a basic understanding of dominant removal processes is essential. Previous research revealed an optimized compound removal under oxic, carbon limited conditions. The role of refractory organic carbon as primary substrate for co-metabolic degradation, however, is not yet fully understood. Different column systems (Figure 22) are operated to evaluate the effects of concentration and composition of humic substances on chemical removal in natural treatment processes. In these systems, advanced analytical tools and next generation sequencing are used to quantify trace organic chemicals, characterize bulk organic carbon and to elucidate structure and functions of the microbial community.

Figure 22: Different setups for soil column experiments

COOPERATION:
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Sequential Managed Aquifer Recharge Technology (SMART)

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 by the utilization of less desirable water sources like storm water, impaired surface water, and reclaimed water. During infiltration of water through the vadose and saturated zones, microbial degradation, and assimilation is playing a dominant role for the attenuation of organic contaminants.

The innovative Sequential Managed Aquifer Recharge Technology (SMART) concept actively manipulates subsurface conditions and combines two MAR systems with an in between aeration step to provide favorable oxic, carbon limited infiltration in the second system (Figure 23). This concept has been already successfully tested for treatment of wastewater-impacted surface water at a utility in the United States. In May 2015, a joint collaborating project with TU Berlin (TUB), the University of Oldenburg (UO), and the Berliner Wasserbetriebe (BWB) was launched to assess the applicability of SMART for drinking water treatment in Berlin.

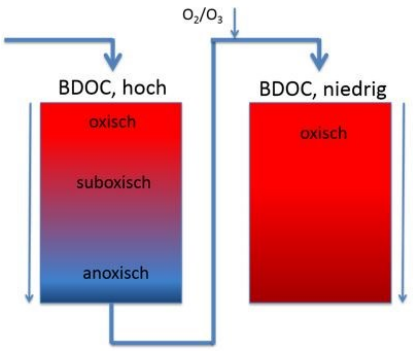

Figure 23. Principle of Sequential MAR Technology

Figure 24. Infiltration basin on the island Baumwerder, Lake Tegel

In addition to laboratory-scale column experiments, full-scale validation was started in 2015 using bank filtered water for infiltration at a groundwater recharge facility in Berlin-Tegel (Figure 24). Redox conditions and water quality parameters are monitored using in-situ oxygen sensors and lysimeters. Initial results from laboratory and field scale experiments confirm an improved biotransformation of several relevant chemicals including compounds classified as health relevant by the German EPA in comparison to conventional groundwater recharge.

FUNDING:
BERLINER WASSERBETRIEBE

COOPERATION:
TU BERLIN;
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FRAME: A Novel Framework to Assess and Manage Contaminants of Emerging Concern in Indirect Potable Reuse

Within the research project FRAME, which started in January 2015, a cluster of seven European research institutions aims to develop an overall evaluation scheme to comprehensively assess and manage contaminants of emerging concern (CECs) and pathogens in Indirect Potable Reuse (IPR) systems.
Within the project, TUM is responsible for the development of novel treatment combinations to be integrated in IPR schemes. The research group Engineered Natural Treatment Systems conducts pilot-scale studies to evaluate reliable and cost efficient treatment strategies. Enhanced biofiltration is a promising technology for the mitigation of CECs in wastewater treatment plant effluents. The novel concept aims to combine the benefits of a high microbial diversity in low-rate biofilters and the high throughput in rapid media filters. The experimental setup integrates experiences from sequentially operated aquifer recharge systems (SMART). By establishing oxic and oligotrophic conditions in the system, the formation of a highly diverse microbial community, capable of degrading CECs, is favored. The experimental setup with four independently operating filtration trains allows for a large variety of filtration modes. In addition to that, hybrid systems are tested combining biofiltration with other advanced treatment technologies, such as adsorption and oxidation. Besides the removal of compounds that are persistent to biodegradation also potential synergies between different individual treatment processes are investigated. Obtained results indicate that the establishment of oxic and oligotrophic conditions during biofiltration leads to an increased removal of various moderately degradable CECs compared to conventional biofiltration. Combining biofiltration with subsequent granular activated carbon filtration resulted in an increased adsorption capacity for CECs due to reduced competitive adsorption of background organic matter. Further studies aim to optimize the system and also investigate the potential of combining biofiltration with ozonation.

Figure 25: Experimental setup

FUNDING:
JPI WATER

COOPERATION:
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IRSA, ITALY;
ISS, ITALY;
NIVA, NORWAY;
BRGM, FRANCE;
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Research Group Advanced Water Treatment and Water Recycling

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The Research Group Advanced Water Treatment and Water Recycling is led by Professor Helmreich and Dr. Uwe Hübner. The research group deals with advanced treatment methods of nutrient removal (deammonification, advanced P-removal), including oxidative processes for the disinfection and removal of trace organic substances (Advanced Oxidation Processes, ozone, electrochemical processes), membrane processes (ultrafiltration, nanofiltration, reverse osmosis) as well as water recycling.

The research especially focuses on different process options for advanced water treatment, in particular for the removal of nutrients, trace organic substances and pathogenic germs. These hybrid processes include modified biological technical filters, advanced oxidation processes (UV / peroxide, nanomodified diamond electrodes, ozone), granular activated carbon, and membrane processes (ultrafiltration, nanofiltration, reverse osmosis), which can be used in various applications.

A further focus of this research group is on water recycling processes to augment both drinking water and industrial water supplies. One focus is on the development of energy-efficient processes and the integration of energy recovery in water recycling processes. Monitoring of these installations, especially for decentralized applications with new measuring methods, are common overlapping topics of all research fields.

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

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

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 public health protection. In addition, novel bio-molecular parameters for assessing biofilm-based treatment systems will be identified, and appropriate risk communication strategies will be developed. SMART 2.0 building upon knowledge and experiences from SMART 1.0, will manipulate sequential redox changes and primary substrate availability to stimulate microbial biodegradation. Important research questions include selection of electron donors and acceptors (i.e., reactive barriers), 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 pilot-scale model testing at TUM, will inform the design of a full-scale SMART 2.0 field system (Figure 26) for implementation in Berlin.

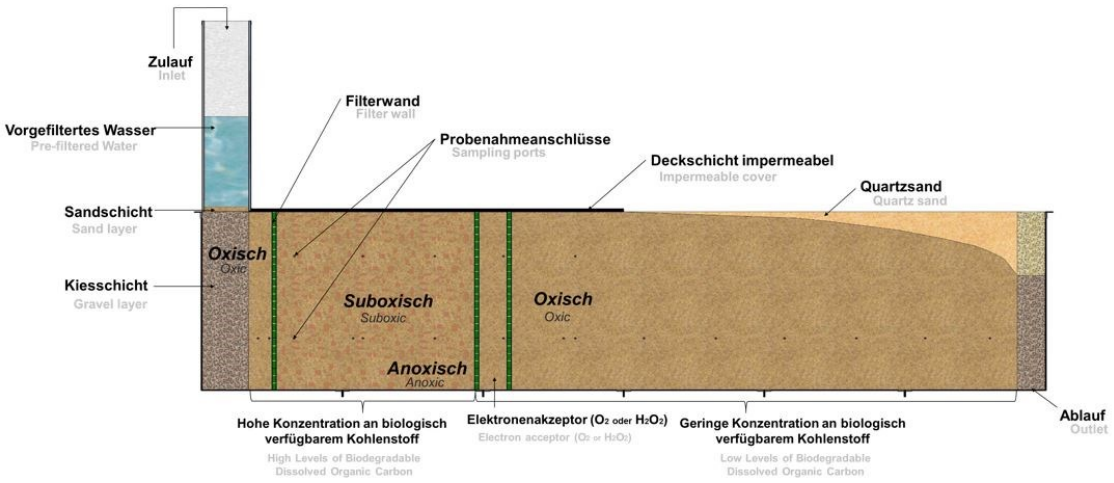

Figure 26: Planned SMART 2.0 pilot-scale test facility at TUM

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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 generation of objectionable waste streams. Alternative treatment schemes for water reuse are required to overcome these issues and guarantee a sustainable (water supply) development worldwide. Alternative treatment scenarios are developed and will be tested in laboratory- and pilot-scale to analyze the optimal operational conditions (Figure 27). Due to an integrated energy recovery by improved pretreatment and physical separation of organic matter (results in higher biogas yield), the overall energy footprint should be decreased. Additionally, an 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. By usage of modeling software, we will analyze the hydrodynamic and solute transport effects within the membrane cell-holders/modules (Figure 28). Additionally, we will develop fouling and scaling mitigation strategies.

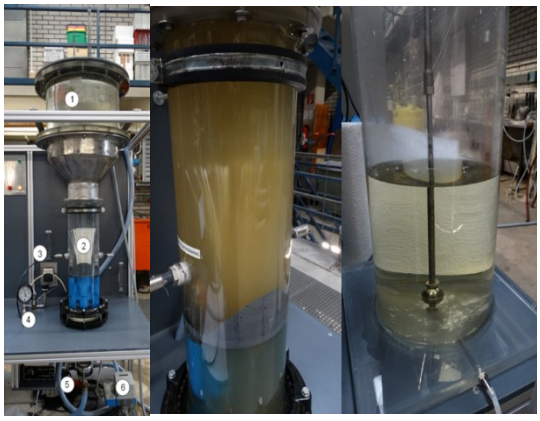

Figure 27: Ultrafiltration test-skid for municipal wastewater treatment

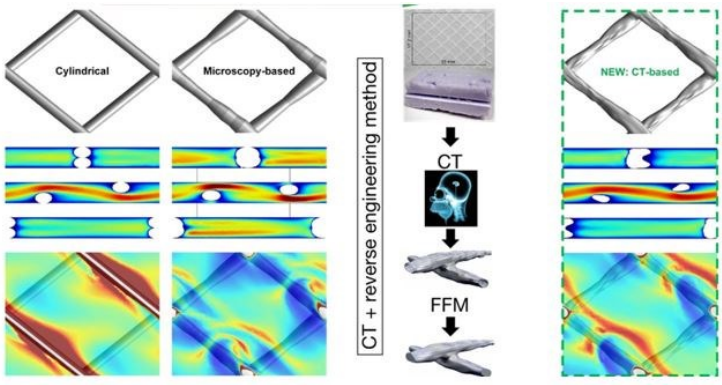

Figure 28: Evolution of feed spacer geometry and impact on hydrod ynamics and concentration polarization

FUNDING:
TECHNISCHE UNIVERSITÄT MÜNCHEN;
OSWALD-SCHULZE-FOUNDATION

COOPERATION:
COLORADO SCHOOL OF MINES, USA;
TU DELFT, THE NETHERLANDS;
UNIVERSITÉ DU LUXEMBOURG, LUXEMBURG; UNIVERSITY OF NEW SOUTH WALES, AUSTRALIA

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Evaluation of water reuse and recovery of energy and salts during treatment of domestic and industrial wastewater effluents using a combination of biological and membrane separation processes

The sustainable development in the world has been challenged by water scarcity due to population growth, urbanization, climate change, and environmental pollution. This challenge calls for the use of developed and improved technologies that can enhance water supply through the use of alternative water sources, such as domestic and industrial wastewater effluents.

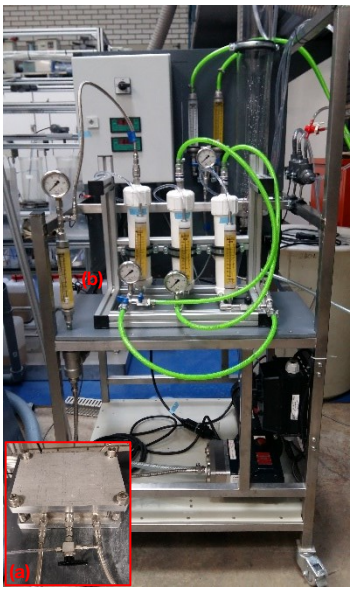

Figure 29: Bench-scale RO membrane system for drinking water production from municipal wastewater treatment with a flexible configuration: (a) flat sheet or (b) spiral-wound module.

Membrane separation processes in wastewater treatment and water reclamation are widespread in developed countries and they are occupying more and more prominence in Brazil. Membrane processes most commonly used in the water sector are: reverse osmosis (RO), applied mainly for water purification in seawater desalination and brackish water; nanofiltration (NF), used in water purification, bleaches, and elimination of micro-pollutants; ultrafiltration (UF) and microfiltration (MF), applied in bioreactors with membranes (MBRs) for the treatment of domestic sewage and industrial effluents aiming for the reuse of treated water.

Figure 30: Pilot-scale anaerobic MBR with two reactors in series for vinasse treatment.

The aim of this project is to confirm the technical feasibility of an anaerobic biological process application (anaerobic MBR) coupled with subsequent membrane separation processes (ultrafiltration, nanofiltration, and electrodialysis) to establish water reuse, energy recovery, and salts recovery strategies from treatment of two waste streams (municipal wastewater and vinasse). Therefore, the combination of these processes may be displayed as a promising technology in transitioning domestic and industrial effluents, which are perceived of turning waste streams into valuable products. This project has been developed in partnership with the Federal University of Minas Gerais, Brazil.

FUNDING:
DAAD-GERMAN ACADEMIC EXCHANGE SERVICE, GERMANY

COOPERATION:
FEDERAL UNIVERSITY OF MINAS GERAIS, BRAZIL

PHILIPP MICHEL (M.SC.)

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

During the recent years, anthropogenic trace organic chemicals (TOrCs) have become a focus of regulatory authorities. In contrast to conventional biological wastewater treatment systems, a more complete removal of these contaminants can be achieved by various advanced treatment processes. However, all these treatment approaches usually have a larger energy footprint. Therefore, this PhD-Project focuses on a more holistic optimization of TOrCs removal while also considering the local discharging situation into the receiving stream.

The traditional concepts of regulating complex contaminants are rather linear in nature and usually assume a direct or mechanistic correlation between surrogate parameters and the linear contaminant fate model. Regarding the prediction of trace organic chemicals (TOrCs), this is not very promising, while facing a wide variety of TOrCs and possible fate relevant processes. The proposed novel approach uses powerful multivariate statistics and software-sensor-based machine-learning concepts to define additional surrogate clusters (latent variables), which enhance modelling and predictions. With these probabilistic methods even real-time monitoring of surrogates in combination with partially static and dynamic data sets can result in a comprehensive dynamic monitoring approach. This concept offers a large potential to optimize current wastewater treatment systems through more flexible operational regimes. Adjusting the treatment system to the individual contaminant load probability will result in significant energy savings.

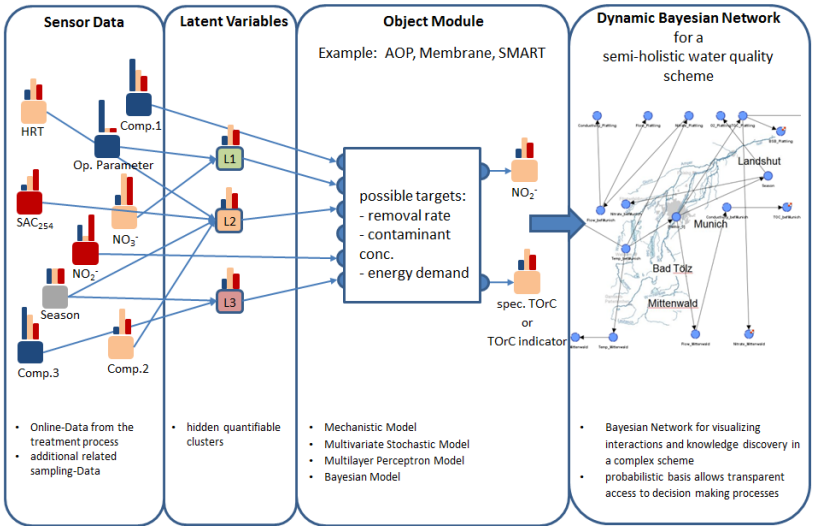

Figure 31: Schematic data processing

In 2016, one central focus was to complete a review paper which discusses common and alternative regulatory tools and controls for a dynamic water quality risk profile in water quality management. Additionally, a big field sampling campaign at the wastewater treatment plant Munich II was performed, which is the basis for the data analysis and allow the first implementation of probabilistic methods.

FUNDING:
TUM-IAS
DAAD

COLLABORATION:
UNSW, AUSTRALIEN

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The use of advanced oxidation processes (AOP) as an advanced treatment stage for the removal of trace organic chemicals from WWTP effluents

In recent years, trace organic chemicals (TOrC) have been detected in the aquatic environment. Besides urban and agricultural run-offs, wastewater treatment plant effluents are the most significant TOrC emitters. Hence, it is likely that environmental quality standards for TOrCs, such as diclofenac, will be implemented at the European level in the foreseeable future. To meet future quality standards, advanced treatment options for wastewater treatment plant (WWTP) effluents cannot be excluded. In the framework of this project, TUM investigates the applicability of UV/H_2O_2 for the oxidation of TOrCs in WWTP effluents in Bavaria as an alternative to ozonation and activated carbon. Research is conducted in cooperation with LfU und MSE.

The study investigates in particular i) whether and to which extent the established UV disinfection system at WWTP Munich II is applicable for AOP-UV/H_2O_2 treatment, ii) whether UV/H_2O_2 reaches comparable removal efficiencies to ozonation and iii) whether UV/H_2O_2 is an economically and operationally viable alternative compared to existing systems for TOrC removal from WWTP effluents.

A pilot system (Wedeco, Germany) was installed in 2016 at the Munich WWTP Gut Marienhof in a 7-m container. It is operated with effluent from the tertiary sand filters for denitrification. The pilot plant consists of two cylindrical reactors equipped with low pressure-high output Hg lamps (LBX 90e & LBX 10). All lamps have mechanical cleaning wipers to minimize the influence of reduced intensity over time. UV-fluences of 400-45.000 J/m² can be tested in the system.

Figure 32: UV/H_2O_2 pilot plant at WWTP Gut Marienhof (Munich II)

FUNDING:
BAVARIAN STATE MINISTRY OF THE ENVIRONMENT AND CONSUMER PROTECTION

COOPERATION:
BAVARIAN ENVIRONMENT AGENCY (LFU);
MÜNCHNER STADTENTWÄSSERUNG (MSE)

JÜRGEN EDERER (B.SC.)

Development and validation of a novel and energy efficient system for ozone injection to treat wastewater treatment plant effluents

Ozone is a well-established treatment process for advanced wastewater treatment, disinfection of drinking and bathing water as well as the treatment of industrial wastewaters. However, high energy consumption for ozone generation and gas to liquid transfer results in elevated costs for the application of ozone. The cavitation generators developed by Cavtec Systems are designed to enable an efficient and fine dispersed introduction of ozone into water and wastewater. In addition, injection with cavitation generators occurs at substantially lower pressures compared to the frequently used venturi injection and therefore considerably lowers energy demands.

In the first phase of a DBU research project, an ozone injection system by hydrodynamically generated cavitation is developed and tested in comparison to the Venturi injection. Major objective is to investigate the feasibility and energy efficiency of the newly developed injection system for drinking water disinfection and the removal of trace organic compounds in wastewater treatment plant effluents. After successful testing in the first project phase, the system will be tested for various applications within a second phase. In addition to a more detailed evaluation and optimization for oxidation and disinfection process, the main goal is to determine the formation of relevant by-products and transformation products. Furthermore, a design for a full-scale system including correspondingly larger cavitation generators will be developed in the second phase of the project.

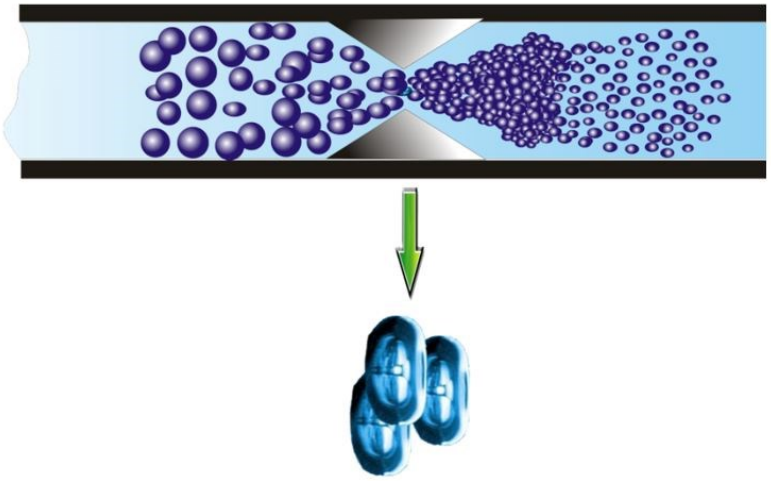

Figure 33: Principle of hydrodynamically generated cavitation

FUNDING:
GERMAN ENVIRONMENT FOUNDATION

COOPERATION:
SEWEC OZON GMBH;
CAVTEC SYSTEMS

Assessment of advanced phosphor elimination in municipal sewage treatment plants

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Due to the latest surface waters regulation (Oberflächengewässerverordnung), a new benchmark for total phosphor emissions has recently been introduced. High concentrations of phosphor can lead to eutrophication of surface waters, therefore negatively affecting the aquatic environment. This has led to a greater emphasis on phosphor elimination in municipal sewage treatment plants within the last years since their discharges are defined as point sources for phosphor. The current technical guideline exhibits obvious gaps for phosphor eliminations aiming threshold concentrations below 0.5 mg/L.

The aim of this research project funded by the Bavarian Environment Agency (AZ: 67-0270-34797/2016) is to realize an inventory of existing technical measures and implementations of advanced phosphor elimination in municipal sewage treatment plants as well as review and analyze the possible courses of action. This encompasses both chemical and biological treatments as well as process combinations including mechanical-physical separation processes for precipitation products.

In a first step, a comprehensive literature review will be conducted. In a second step, an inventory of existing wastewater treatment plants within the German-speaking regions will be executed and technical experiences (including inspection) of selected plants will be collected and evaluated. Afterwards, the applicability of the attained findings for other municipal sewage treatment plants, in particular in Bavaria, will be reviewed. Depending on the type and size of the treatment plant, specific investment and operational costs will be ascertained and also estimated for future implementation in municipal wastewater treatment plants. Besides data collection, it will be assessed whether the combination of advanced phosphor elimination and potential treatment steps for the elimination of organic micropollutants is feasible. Great importance will also be given to the detection of operational problems, for example the formation of magnesium ammonium phosphate (MAP).

FUNDING:
BAVARIAN ENVIRONMENT AGENCY

The research project is running from July 2016 until July 2017 and is executed in close collaboration with Fa. Dr.-Ing. Steinle Ingenieurgesellschaft für Abwassertechnik mbH, Weyern.

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.

Young Water Reuse Professionals (YWRP)

During the *10th IWA International Conference on Water Reclamation and Reuse* in Harbin, China, in 2015 the *Young Water Reuse Professionals (YWRP) Group* within the IWA Water Reuse Specialist Group (WRSG) was established. The purpose of this group is to facilitate networking between the YWRP and professionals within the WRSG, who are more advanced in their career. Activities of YWRPs are prominently featured both in the WRSG Newsletter and on the IWA Connect platform (www.iwaconnect.org).

If you are interested in being featured as an „YWRP of the month" or using the opportunity to have your work being showcased on the IWA Connect site, please contact us (Nils Horstmeyer: nils.horstmeyer@tum.de).

External PhD Candidates

VASILIS DANDIKAS
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Vasilis Dandikas is a scientific assistant and doctoral candidate at the Institute of Agricultural Engineering and Animal Husbandry of the Bavarian State Research Center for Agriculture in in Freising, Germany. In his PhD, he deals with the question whether the biogas yield and the biogas production rate of different energy crops can be predicted by their chemical composition. For that purpose, the plants are characterized by fodder analysis (so-called Weender analysis with van-Soest fraction). Additionally, the biogas yield is determined in an anaerobic batch test.
For his PhD thesis, the following hypotheses are tested: a) the differentiation of biogas yield is a function of the plant's chemical composition, b) the biogas potential can be mathematically described by the plant chemical components, and c) for high estimation accuracy plant-specific models are required.
By a principal component analysis, statistical correlations of the parameters and the biogas yield as well as among each other are identified in order to select those parameters, which are most suitable for the prediction of the biogas yield. Based on those, global (enabling the prediction over different plant species) and local (is only valid for a specific group or species, but with high accuracy) models are developed. Based on the chemical compounds lignin (ADL) and hemicellulose (HC), the biogas yield of energy crops can be predicted with an accuracy of 10%. The biogas yield of specific grassland species can be predicted by lignin (ADL), hemicellulose (HC) and crude protein (XP) with an accuracy of 5%. The models can then be used for calculating the biogas yield at known chemical composition.

SEBASTIAN HIEN
(M. SC.)

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Sebastian Hien is a research associate at the Chair of Urban Water Management and Hydraulic Engineering at the University of Luxembourg. His PhD thesis is supervised by Professor Joachim Hansen and co-supervised by Dr.-Ing. Konrad Koch from the Anaerobic Technologies and Energy Recovery group at TUM. The dissertation is investigating possibilities to predict biogas and methane production rate in digesters at biogas plants and wastewater treatment plants to support their integration in the concept of virtual power plants. In particular, parameters influencing the prediction of biogas formation above average should be identified. Therefore, data from different digesters were collected and used within the framework of modelling dynamic simulations. The simulation results were analyzed and based on the identified parameter(s) and machine learning approaches like "random forest" and "artificial neural networks", a tool to predict the biogas production in a short term perspective was developed. Utilizing the predictions of the tool, an approach to support demand orientated biogas production will be developed.

CHRISTIAN HILLER
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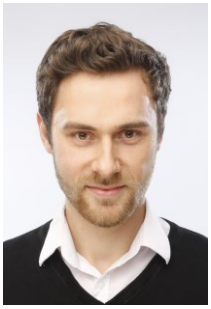
Christian Hiller is the lead Process Engineer at the Zweckverband Klärwerk Steinhäule in Neu-Ulm, Germany. His PhD thesis is supervised by Professor Jörg Drewes and co-supervised by Dr. Uwe Hübner. The focus of this project is to investigate the removal of antibiotic resistant bacteria (ARBs) and antibiotic resistence 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 are examined including TOC, UV absorbance, turbidity, particle counts, etc.



JOCHEN BANDELIN
(DIPL.ING.)

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Jochen Bandelin is a process engineer for the development of highly efficient ultrasound systems for the pre-treatment of wastewater treatment plant sludge at BANDELIN electronic GmbH & Co.KG. His PhD thesis is supervised by Professor Jörg Drewes and co-supervised by Dr.-Ing. Konrad Koch from the Anaerobic Technologies and Energy Recovery group at TUM.
The doctoral thesis is focused on the systematic investigation of the disintegration ability of ultrasonically induced cavitation in highly viscous media. The ultrasonic energy, produced by piezo-ceramic ultrasonic systems, is intended to open up the particles in anaerobic processes in such a way, that an increased biodegradability and consequently an increased gas production can be achieved. For a clearly positive energy balance of the process, those types of ultrasonic configurations have to be determined, which achieve the highest efficiency at the sonication of sludge of different viscosities, due to an optimal ratio of the amplitude, field size, ultrasonic frequency and power density.
For this purpose, the formation and propagation of cavitation fields in highly viscous media is investigated experimentally and compared with the behavior of cavitation fields in water. This is to be carried out with a novel acoustic measuring method for determining the cavitation noise figure.
Within the scope of two research projects, both the sonication of sludge in the flow-through process and the completely new approach of a fermenter-internal sonication, with application-specific submersible transducers are investigated. In this approach, the ultrasound systems are positioned directly in the substrate and fed with a substrate flow by means of agitators. The measurement of the expected increase in gas yield is to be carried out in laboratory tests as well as on the technical scale and on a large technical scale. Beside the process engineering consideration of the various ultrasonic concepts, the cost-effectiveness with regard to the production costs and the service life is also to be investigated.

Visiting Scientists

MIKE MANEFIELD
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Associate Professor Mike Manefield, University of New South Wales, Sydney, Australia

Prof. Dr. Mike Manefield was was visiting us in 2015 as an August-Wilhelm-Scheer visiting professor and continued our collaboration in the field of microbiological structures and functions in modified biofiltration systems during several short-term visits in 2016. Mike Manefield is an associate professor at the School of Biotechnology and Biomolecular Sciences at the University of New South Wales, Sydney, Australia.

STUART KHAN
(ASSOC. PROF.)

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Associate Professor Stuart Khan, University of New South Wales, Sydney, Australia

Prof. Dr. Stuart Khan is a Hans-Fischer Fellow of TUM. Stuart Khan is an associate professor at the School of Civil and Environmental Engineering at the University of New South Wales. As a Hans-Fischer Fellow, Prof. Khan receives a three-year research grant (2015-2018). Prof. Khan jointly supervises with Prof. Drewes our PhD student Philipp Michel.

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

Prof. Dr. Karl Linden was visiting 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.

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

Prof. Dr. Jennifer Becker is a TUM Visiting Professor at the Chair. Since August 2016, she has been supporting ongoing research on the removal of biological trace substances at the Chair. Prof. Dr. Becker is Associate Professor of Civil and Environmental Engineering at Michigan Tech University, USA.

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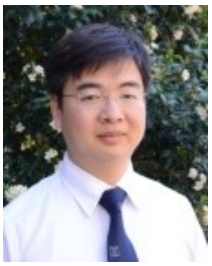
Professor Dr. Eric Seagren, Michigan Technological University, Michigan, USA

Prof. Dr. Eric Seagren is a TUM Visiting Professor. Since August 2016, he has been working 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. Dr. Seagren is a professor of Civil and Environmental Engineering at Michigan Tech University, USA.



LONG NGHIEM
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Professor Dr. Long Nghiem, University of Wollongong, Wollongong, Australien

Prof. Dr. Long Ngheim visited the Chair in May 2016 as an August-Wilhelm-Scheer visiting professor. Joint activities in the field of energy recovery from waste water as well as co-fermentation have been prepared in close cooperation with Dr. Konrad Koch. Prof. Dr. Nghiem is a professor at the School of Civil, Mining and Environmental Engineering at Wollongong University, Australia.

WENLONG WANG (M.SC.)

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Wenlong Wang, M.Sc.
Tsinghua University, China

Mr. Wenlong Wang is visiting the Chair since October 2016 as a visiting researcher. Wenlong is a PhD Candidate at the School of Environment, Tsinghua University, China, where he is supervised by Prof. Dr. Hong-Ying Hu. Wenlong works on the topic "Use of UV-LED for the disinfection and oxidation of organic trace elements". He works closely with Dr. Uwe Hübner and the research group "Advanced Wastewater Treatment and Water Recycling" at the Chair.

SONA FAJNOROVA

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Sona Favronova, M.Sc.
University of Chemistry and Technology, Prague

Ms. Sona Favronova is a Visiting Researcher since August 2016. Sona is a PhD candidate at the University of Chemistry and Technology in Prague, Czech Republic, and is supervised by Prof. Dr. Jiri Wanner. Sona works on the topic "Advanced Water Treatment Processes for Removal of Trace Organic Chemical and Antibiotic Resistance for Water Reuse Applications". She is co-advised by Prof. Drewes, Dr. Hübner and Dr. Herzog works closely the various research groups at the Chair.

FUNDING:
BAYERISCHES STAATSMINISTERIUM FÜR FINANZEN, LANDESENTWICKLUNG UND HEIMAT

International Cooperation Partners

Last year, we could further expand our network with international partners (Figure 34).

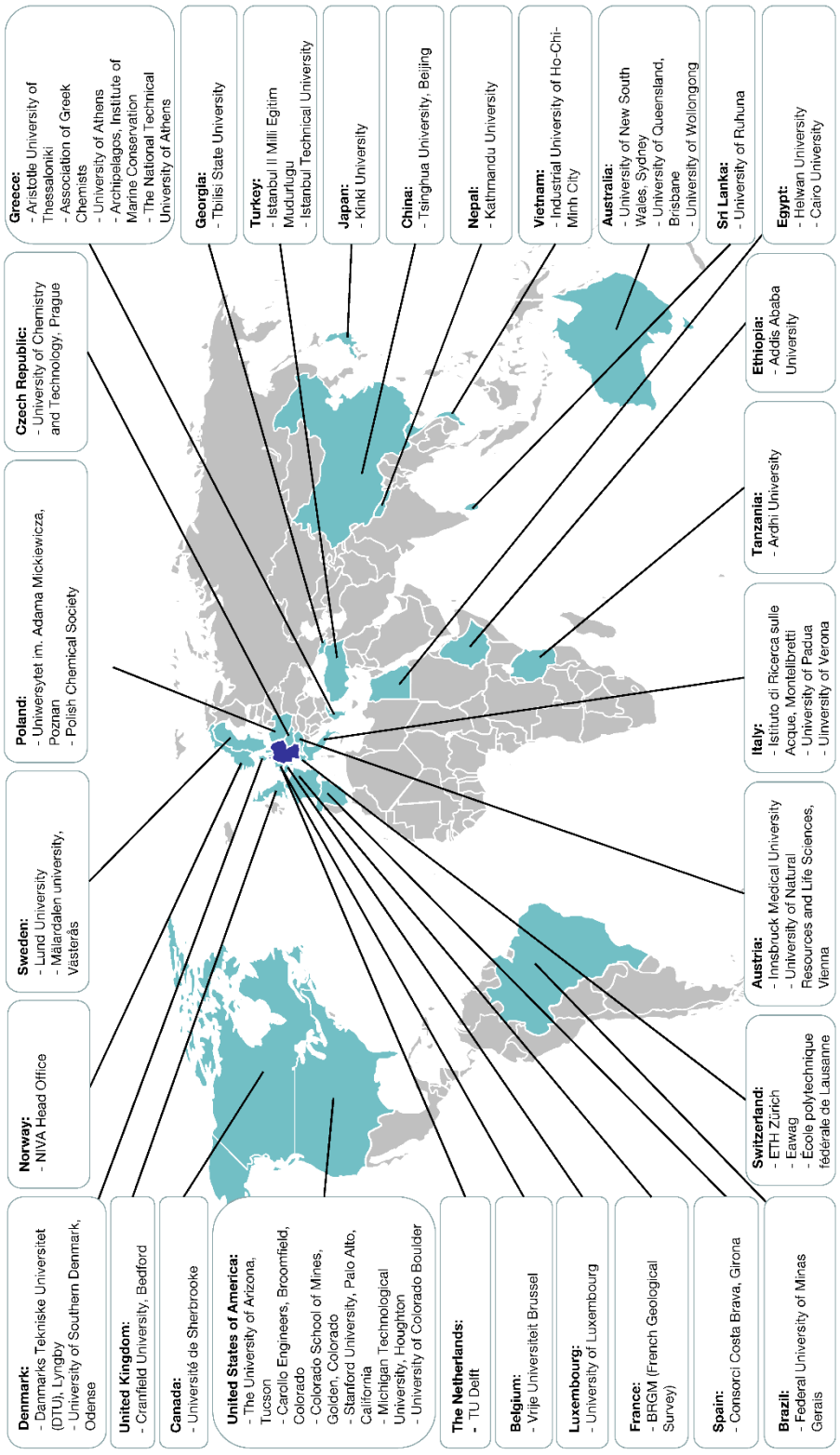


Figure 34: Overview of international collaboration partners

National/International Committee

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 3,000 members, WRSG is the largest specialist group within the IWA with experts in the field of water recycling from more than 110 countries.
At the IWA World Water Congress in Brisbane, Australia, October 9-14, 2016, the WRSG offered several workshops and panel discussions on the topic of "Direct Potable Water Reuse", which were very well attended (Figure 35). Currently, preparations are under way for the 11th IWA International Water Reuse Conference in Long Beach, California, scheduled for July 24-27, 2017.

Figure 35: IWA Specialist Group Leader Meeting, Brisbane, Australien in October 2016

EU-COST Action

Brigitte Helmreich is serving as member of the **EU-COST Action** *„Conceiving wastewater treatment in 2020. Energetic, environmental and economical challanges“* (http://www.water2020.eu/) and active in working group 3 entitled *„Environmental and economic impact“*. COST Action represents *„Intergovernmental framework for European Cooperation in Science and Technology*“. These networks are funded by the EU to coordinate national-funded research activities at the European level. COST working groups are meeting regularly to prepare joint research proposals and publications.

ESSEM-COST Action

Thomas Letzel is member of the **ESSEM COST Action ES1307** "*Sewage biomarker analysis for community health assessment*" and serving representing Germany in the Management Committee. He is leading the 2015-created analytical subgroup '*Non-target screening strategies*' and is an active member in the group *"Finding biomarkers and stability of these biomarkers in wastewater"*. The action develops and expands an existing pan-European inter-disciplinary network, bringing together experts from relevant disciplines interested in the application and development of using the quantitative measurement of human biomarkers in sewage to evaluate lifestyle, health, and exposure at the community level. In 2016, the group organized a LC-MS/MS round robin together with the Medical University of Innsbruck. Current results (e.g. from the annual meeting at the TUM and the SWEMSA16 workshop in Garching) can be found at the webpage http://score-cost.eu/.

NEREUS-COST Action

Jörg E. Drewes is a member of the **NERUS-COST Action ES1403** "*New and emerging challenges and opportunities in wastewater reuse*" (http://www.nereus-cost.eu) and acts as a mediator between the individual working groups. Last year, two meetings were held in Malta and Sarajevo. Further information can be found at http://nereus-cost.eu.

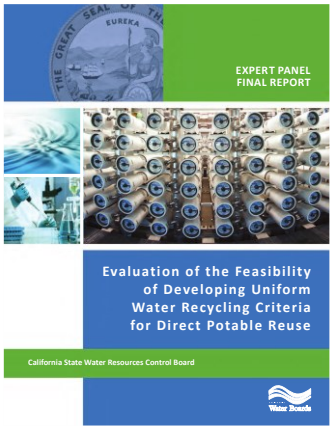
NORMAN Network

Thomas Letzel is representative member of our chair in the **NORMAN Initiative** und acts for the research experience of the German Academia in the chemical analysis of organic compounds in water matrices. In that predominant eco-political European group, we are active in the topics 'retention time index' (RTI), i.e. the harmonization of HPLC, in the 'introduction of the HILIC technique' and the 'establishment of an international round robin'.
Current work and results supported by NORMAN (e.g. from the international NTS Workshop in Ascona at the 29.05.-03.06.16, the SWEMSA16 Workshop as well as the general assembly in Vienna at the 30.11.-02.12.16)) can be found at the webpage http://www.norman-network.net.

Wasser Recycling in California, USA

Jörg E. Drewes has been an active member of the advisory panel "*Development of Water Recycling Criteria for Indirect Potable Reuse through Surface Water*

Augmentation and the Feasibility of Developing Criteria for Direct Potable Reuse" for the state of California (USA). These activities are intended to facilitate the further expansion of the use of alternative water resources, including water reuse, for drinking water supplies in California. The final report was submitted to the State Water Resources Control Board end of 2016 and can be downloaded from the following link: http://www.waterboards.ca.gov/drinking_water/certlic/drinkingwater/documents/rw_dpr_criteria/app_a_ep_rpt.pdf



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*".
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* **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.

‚FA Non Target Screening' – Committee II within the German Water Chemistry Society

Thomas Letzel is active member in the committee of experts for the harmonization and adjustment of water analysis by LC-MS in Germany. In the third level a round robin was organized in 2016 to comprehend several analytical LC-MS(/MS) systems. Our institution was responsible for the inter-laboratory normalization of retention times and delivered separate reference materials for that.

Our chair organized (with others) **in all three initiatives / consortia** (with Thomas Letzel) round robins to normalize and harmonize -amongst others- the liquid chromatographic retention times.

Journal Water – Guest Editor

Prof. Dr. Helmreich was guest editor of the journal *"Water"* for a special issue *"Urban drainage and urban stormwater management".*

Journal of Water Reuse and Desalination – Editor

Jörg E. Drewes is 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/

Promotion of Young Talents/ Workshops/ Other Activities

Annual Meeting of PhD Candidates of Water Institutes in Munich

In September 2016, we had the opportunity to welcome more than 70 young PhD students from German speaking institutes from Germany, Austria, Luxemburg, and Switzerland working in the field of urban water systems engineering. The topic of this year's annual meeting at the TU Munich was "*Engineering under Climate Change Impacts & Water Reuse*". Within the scope of the conference program, the keynote speakers Prof. Dr.-Ing. Peter Cornel und PD Dr. Thomas Kluge provided a basis for interesting discussions and information exchange (Figure 36). Additional workshops and an excursion to the drinking water abstraction Mangfalltal (Stadtwerke München) ensured a diverse program. This 37th so-called "Assistententreffen" offered participating PhD students a great platform for networking and exchange of experiences. We are looking forward to the next "Assistententreffen 2017" in Kaiserslautern.

Figure 36: Keynote speech at the 37th "Assistententreffen"

Universities Australia-DAAD Joint Research Cooperation Scheme

The program "Universities Australia-DAAD Joint Research Cooperation Scheme" is a bilateral research funding program, which was agreed on in 2014 between the DAAD and the Universities Australia. The aim of the program is to intensify the cooperation between Australian and German research groups working together on a specific scientific project.

Figure 37: Exchange with UQ

Within the framework of this agreement, a total of three projects were funded in 2016, enabling an exchange for Philipp Michel (University of New South Wales (UNSW)), Konrad Koch (University of Wollongong (UOW)), and Jörg E. Drewes and Carmen Leix (The University of Queensland (UQ), Figure 37).

Workshop China

A workshop on the topic "*Status and Opportunities to Introduce Potable Water Reuse Practices in Europe and China*" was held from 08th-12th May 2016 in Beijing in collaboration with Tsinghua University, Beijing, China. This has already been the third scientific exchange between the two research groups (Tsinghua University, School of Environment and Research Center for Eco-Environmental Sciences / TUM, Chair of Urban Water Management) since July 2015 that either


Figure 38: Participants of the 3rd workshop at the Tsinghua University in Beijing, China

took place in Munich or Beijing. The aim is the development of suitable concepts and technologies for a sustainable energy-efficient wastewater treatment, which also enables for the reuse (water recycling) of the purified waste water, e.g. to support drinking water production via groundwater enrichment. In particular, the focus is on the establishment of energy-efficient process combinations with the aim of water recycling in Europe and China, as well as a new approach to assess the performance, taking into account new water quality requirements and the associated risk. Jörg E. Drewes, Uwe Hübner, Konrad Koch, Johann Müller, and Nils Horstmeyer took part as representatives of the Chair for Urban Water Systems Engineering. The workshop was supported by travel grants from the *Bavarian University Center for China* (BayCHINA).

Team outing in summer 2016

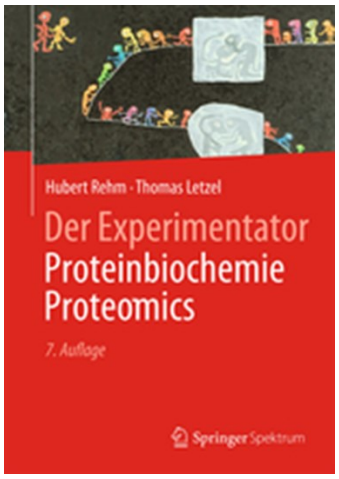
This year's team outing took place on the 21st of June, 2016. We hiked up to the peak of the mountain Hochries (1569 m above sea level) where we had an amazing panoramic view over the Alps (Figure 39).

Figure 39: Team outing

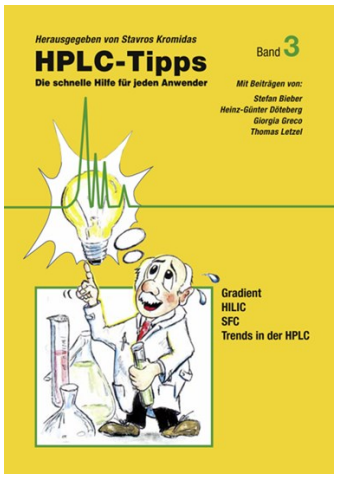
Scienclisten

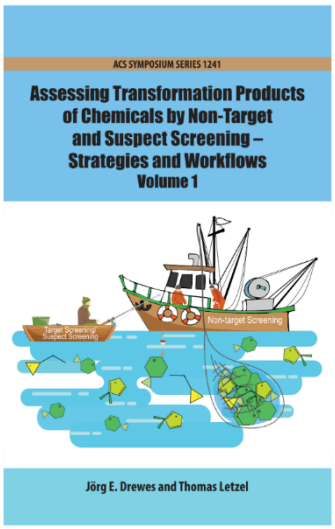
The team of the Chair of Urban Water Systems Engineering cycled more than 30,000 km in 2016. We saved approximately 4.4 t of CO_2 in comparison to using cars (144 g CO_2/km).

Published Books



Thomas Letzel published in 2016 two German books.
The first book is the 7th edition of the *‚Experimentators Proteinbiochemie / Proteomics‘* together with Hubert Rehm, and the second book is the 1st edition of German *‘HPLC-Tipps 3’* together with Stavros Kromidas, **Stefan Bieber** and others.





A joint book by **Jörg E. Drewes** and **Thomas Letzel** entitled "*Assessing Transformation Products of Chemicals by Non-Target and Suspect Screening and Workflows*" was published in two volumes in December 2016 within the framework of the American Chemical Society Book Series.

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TUM Water Cluster

The TUM Water Cluster is the cross-disciplinary focus program of Water Research at the TUM. Its central objectives are to coordinate research and teaching related to water, to establish harmonized information exchange regarding water related issues, and to carry out outreach activities to increase awareness of water related topics.

Research Projects

In 2016, several joint research proposals were prepared and submitted, e.g. to the grant program *„Forschung für Nachhaltige Entwicklung“* (FONA) of the BMBF or to the *„Bayerischen Forschungsstiftung“*.

Lecture Series

The TUM Water Cluster Lecture Series was continued with contributions from internationally renowned lecturers:

- **„At the Confluence: nutrients, trace chemicals, and sustainability in the urban water sector”**; AEESP Distinguished Lecturer Prof. Nancy Love (University of Michigan)
- **“Floods in a Changing World”**; Prof. Günter Blöschl (TU Wien), recipient of the Horton Medal
- **„Advanced Wastewater Treatment Systems and Upgrade to High Quality Process Water for Reuse Purposes“**; Dipl.-Ing. Heribert Möslang, Veolia
- **“From Science To Policy in the Water World – Work at the German Environment Agency”**; Dr. Lilian Busse, German Environment Agency
- **“Seeing Things Differently: Rethinking the Relationship Between Data, Models, and Decision-Making“**; Darcy Lecturer Prof. Ty Ferre (University of Arizona).

On July 6th, 2016, an interactive workshop was organized to discuss and develop research strategies related to water among TUM researchers.

Exhibition on Water Research during the opening of the TUM Science & Study Center Raitenhaslach

The new Academy Center of the TUM was opened in the historic monastery Raitenhaslach on 4 June 2016 by a ceremony with Prime Minister Horst Seehofer. The TUM Water Cluster supported the opening event with a poster exhibition on the subject of water. The academy center and the poster exhibition were open to the public on 5 June. The exhibition and guided tours of the Academy Center attracted a great interest among the more than 4,000 visitors.

Contribution to the Munich Science Days

The TUM Water Cluster presented a *„Market Stand of Sciences“* at the Munich Science Days, which in 2016 were under the slogan *“Water – Resource of Life”*. Visitors could learn about latest research, about natural drinking water treatment, water catchment from fog, energy efficient treatment of wastewater, invasive species, and water and species protection. Further topics were the contamination of water, flood protection, and the generation of energy from water.
Moreover, several members of the TUM Water Cluster gave lectures which aimed to convey water topics to a wide audience.

Co-Organization of the Workshop ‚SWEMSA 16‘

The Chair of Urban Waters Systems Engineering organized in November 2016 as member of the TUM Water Cluster in collaboration with the BMBF-funded FOR-IDENT consortium as well as the European NORMAN initiative and with participants from three COST initiatives the international workshop *‚Non-Target Screening embedded in (Open Access) Platforms and its role in various disciplines‘*. The more than 100 participants discussed 20 scientific talks and four panel discussions on the current strategies and future perspectives of non-target screening of emerging contaminants.

Publications

Books and Book Chapters

- 44. Abwassertechnischen Seminar „Bedarfsgerechte Energiebereitstellung durch Kläranlagen als Baustein der Energiewende“, Band 214 (ISSN 0942-914X).
- Drewes, J.E., Horstmeyer, N. (2016) Strategien und Potenziale zur Energieoptimierung bei der Wasserwiederverwendung. Österreichische Wasser- und Abfallwirtschaft. DOI 10.1007/s00506-016-0298-3. © Springer-Verlag Wien 2016.
- H. Rehm und T. Letzel; ‘Der Experimentator: Proteinchemie/Proteomics’. Springer Spektrum; 7. Edition (03. Juni 2016), ISBN: 978-3-662-48850-8
- Helmreich, B.: Umgang mit Metalldachabflüssen. Ratgeber Regenwasser (Hrsg. König, K.W.), Eigenverlag Mall, ISBN-13: 978-3-9803502-2-8, 6. Auflage 2016, S.36-37.
- Water Science and Technology Board; Division on Earth and Life Studies; National Academies of Sciences, Engineering, and Medicine: Using Graywater and Stormwater to Enhance Local Water Supplies: An Assessment of Risks, Costs, and Benefits. National Academy of Sciences ISBN: 978-0-309-38835-1.

Peer-reviewed Journal Articles

- Branch, A., Trinh, T., Carvajal, G., Leslie, G., Coleman, H.M., Stuetz, R.M., Drewes, J.E., Khan, S.J., Le-Clech, P.: Hazardous events in membrane bioreactors – Part 3: Impacts on microorganism log removal efficiencies. Journal of Membrane Science 497, 2016, 514-523.
- Drewes, J.E.; Horstmeyer, N.: Strategien und Potenziale zur Energieoptimierung bei der Wasserwiederverwendung. Österreichische Wasser- und Abfallwirtschaft, 2016, 1—9.
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- Huber, C., Preis, M., Harvey, P.J., Grosse, S., Letzel, T., Schröder, P.: Emerging pollutants and plants – Metabolic activation of diclofenac by peroxidases. Chemosphere 146, 2016, 435-441.
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Conference Proceedings

Oral presentations

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- Drewes, J.E. (2016). Was kann Deutschland aus internationalen Projekten zur Wasserwiederverwendung lernen? 88. Darmstädter Seminar Abwassertechnik. Darmstadt. 25. Mai 2016.
- Drewes, J.E. and Olivieri, A. (2016). Feasibility of Direct Potable Reue in California – Recommendations of an Expert Panel. International Desalination Association Reuse and Recycling Conference. 25.-27.9.2016 (invited).
- Drewes, J.E., Bieber, S., Michel, P. (2016). Addressing multiple objectives while meeting water quality standards – A need for innovative concepts. Water Horizon Conference. Dessau. 28.-29.6.2016.
- Drewes, J.E., Geist, J., Disse, M., Grassmann, J. (2016). TUM Wasser Cluster. 10. Weihenstephaner Seminar für Wassertechnologie. 15.9.2016.
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- Letzel, T. (2016). Prof. Thomas Letzel on developing a worldwide screening system for preventative water sample analysis, Scientists Meet Scientists – Wednesday Coffee Talk, Garching (D), 27.01.2016. (Invited talk)
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- Huber, M. , Welker, A., Scharrer, J., Helmreich, B., Schwermetalle in Verkehrsflächenabflüssen: Methodikspezifische Einflüsse von Monitoring-Programmen auf Datenqualität und Untersuchungsergebnisse. Aqua Urbanica 2016. 26.-27.09.2016, Rigi-Kaltbad, Schweiz.
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- Huber, Maximilian: Development and Evaluation of an Assessment Method for Decentralized Stormwater Treatment Systems for Runoff from Traffic Areas.

Master's Theses

- Benserhir, Khaoula: Energy audit of potable water production plants
- Biel, Stella: Bewertung von Instrumenten der strategischen Planung für den Einsatz von Technologien zur Spurenstoffelimination in der kommunalen Abwasserbehandlung
- Brkljaca, Florian: Improving the removal of trace organic compounds during sequential biofiltration by varying different key parameters
- Dong, Quang Huy: Pressure modulation using pressure reducing valves and pumps as turbines in drinking water supply networks
- Emmer, Ludwig: Evaluation der Nutzung produktbezogener Umweltinformationen im Kontext aktueller rechtlicher und politischer Rahmenbedingungen sowie künftiger Anforderungen
- Faßnacht, Jakob: The development of co-digestion in wastewater treatment plants with a special focus on the legal framework
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- Gossler, Fabian: Evaluation of two Methods to Extract Dissolved Nitrous Oxide from Water with Respect to the Operational Conditions of the CANDO
- Grigoriadou, Vaia: Influence of background organic carbon ozonation on micropollutant degradation and oxygen consumption in soil aquifer treatment
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- Youl, Han: Isolation and characterization of Bacteriophages of Pseudomonas aeruginosa

Study Projects

- Dery, Alicia: Membrane Fouling of Nanofiltration Membrane (NF270): Fouling Potential and Cleaning Strategies
- Dong, Quang Huy: Studies on the effect of road salt on the sedimentation process in stormwater basins
- Ebert, Vanessa: Variation of zinc contents in the topsoils of four vegetated infiltration swales at a zinc roof
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- Posa, Andrea: Vorgänge im Transport- und Speichersystem von Cyperus alternifolius und Scirpus validus während der Phyto-remediation des Humanarzneimittels Diclofenac
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- Schlemmer, Felix: Development of a practicable activity test for deammonifying activated sludge as an operating method
- Thalmann, Christian: Investigation of different key parameters to improve the removal of trace organic compounds during sequential biofiltration
- Thiel, Paul: Investigation of nitrous oxide sensors for online monitoring of intentionally produced biogenic nitrous oxide concentrations
- Zeitler, Carolin: Solid waste management in developing countries: Characterization of municipal solid waste

Bachelor's Theses

- Bruckmaier, Felix: Removal of Trace Organic Compounds during Biofiltration: The Role of Hydraulic Residence Time and Dissolved Organic Matter - A Literature Review
- Burkart, Tobias: Untersuchungen zur Optimierung der biologischen Abbaubarkeit
- Cavedon, Oliver: OH-Radikalexposition als Vergleichskonzept weitergehender Oxidationsverfahren in der Wasseraufbereitung - UV basierte AOP-Verfahren
- Colina, Andrijana: OH-Radikalexposition als Vergleichskonzept weitergehender Oxidationsverfahren in der Wasseraufbereitung - elektrochemische und physikalische AOP-Verfahren
- Dendorfer, Laura: Low-Tech Desinfektionsverfahren zur Wasseraufbereitung in Entwicklungsländern

- Diepold, Daniela: Erarbeitung eines Untersuchungskonzepts zur Beurteilung der Leistungsfähigkeit der biologischen Filtration für die Spurenstoffelimination
- Eckert, Jennifer: Charakterisierung des Einflusses der Wassermatrix auf den UV/H2O2-Oxidationsprozess
- Eibach, Veronika: Untersuchungen zum Einfluss von Salinität auf die Viskosität der Sedimente von Regenbecken
- Even, Max: Bemessung von einstufigen Belebungsanlagen - Neuerungen des DWA-A 131
- Hentschel, Anton: Untersuchung zur Ertüchtigung von Pflanzenkläranlagen zur Abwasserbehandlung im ländlichen Raum
- Kern, Tobias: Aufbau dezentraler Behandlungsanlagen für Verkehrsflächen- und Dachabflüsse - Eine vergleichende Studie
- Mayerhofer, Marvin: OH-Radikalexposition als Vergleichskonzept weitergehender Oxidationsverfahren in der Wasseraufbereitung - katalytische AOP-Verfahren
- Pfluger, Samuel: Analyse und Vergleich verschiedener Infiltrationstechniken zur künstlichen Grundwasseranreicherung
- Pompl, Lucas: Comparison of different sample preservation strategies to ensure sample stability prior to measurement
- Prahtel, Marlies: Vergleichende energetische Betrachtungen am Beispiel einer Kläranlage mit und ohne vierte Reinigungsstufe
- Scharfenberg, Niklas: Light quality response in microalgae: Effects on growth and biochemical composition
- Schippan, Arne: Potentialanalyse der Energieertragssteigerung auf kommunalen Kläranlagen durch Anwendung des CANDO-Verfahrens
- Schmelzing, Helene: Classification of uncategorized compounds in the STOFF-IDENT database for the FOR-IDENT project
- Sprafke, Aileen: Biozide in Gebäudefassaden - Vorkommen und Relevanz
- Vidos, Matijas: OH-Radikalexposition als Vergleichskonzept weitergehender Oxidationsverfahren in der Wasseraufbereitung: Ozonbasierte AOP-Verfahren
- Wörl, Phillip: Revision der ISO 14001 - Änderung der Norm und Integration der Neuerung in das Umweltmanagementsystem der MAN

Dissertations and Awards

On September 13, 2016, **Bettina Huber** received her doctorate degree (Dr. rer. nat.) with the title "*Biogenic Sulfuric Acid Corrosion in Sludge Digesters Characterization of the Bacterial Groups and the Corrosion Potential*" under the supervision of Prof. Jörg Drewes (Figure 40). In her work, Dr. Huber dealt with biogenic sulfuric acid corrosion (BSK). The BSK is a serious and costly problem, which mainly occurs in wastewater sewers. The occurrence of typical BSK damage phenomena in the gas space of different digesters indicates that BSK can also play a role in these facilities. The aim of this thesis was to investigate the BSK process in digesters. These studies included the identification of the sulfate-reducing and sulfur-oxidizing bacteria (SRB and SOB) that are involved in the corrosion process and the analysis of the corrosion potential. For a better understanding of the BSK potential in the digester, chemical and biogenic sulfuric acid (H_2SO_4) tests were carried out with cement stone, which is contained as a binder in the concrete and with concrete, the dominant building material of digesters.

Figure 40: Examination board of Bettina Huber

On June 15, 2016, **Maximilian Huber** received his doctorate degree (Dr.-Ing.) under the supervision of Prof. Dr. Brigitte Helmreich. The topic of Mr. Huber's thesis was "*Development and Evaluation of an Assessment Method for Decentralized Stormwater Treatment Systems for Runoff from Traffic Areas*". In his dissertation, Mr. Huber dealt with the development of a standardized procedure for the evaluation of decentralized treatment plants for traffic area runoff, where the process-technical problem solution was the main focus. Mr. Huber has succeeded in linking fundamental investigations with highly targeted, practically validated solutions, which have already found their way into the engineering practice due to their high relevance. His results

Figure 41: Examination board of Maximilian Huber

are not only included in the eight publications published in the dissertation, but also have already found their way into the revision of existing technical test methods.

Thomas Lippert received the DME e.V. Award for the best thesis 2015/12016 for his Master Thesis *„Hydrodynamics and Transport Phenomena within Osmotic Membrane Modules – A Modeling Approach by Use of COMSOL Multiphysics™”.*
The master's thesis evaluates the complex hydrodynamic and solute transport mechanisms in spiral wound membrane modules. Results indicates that the feedspacers are responsible for the disruption of the hydrodynamic boundary layer. Unsteady / turbulent flow conditions don´t have an additional significant effect on the concentration polarization on the membrane surface but do have a significant higher pressure drop effect. The thesis is presenting a novel feedspacer measuring method by using computer-tomography (CT) as a new standard method for membrane simulations. The CT approach is offering new possibilities to develop improved spacer geometries with optimized hydrodynamic and anti-fouling properties. The thesis project was supervised by Nils Horstmeyer and Prof. Jörg Drewes.

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 2016, the following lectures have been offered:

Summer Term

- Advanced Water Treatment Engineering and Reuse: Drewes, Jörg
- Bewirtschaftung von Kanalnetzen und Regenwassermanagement: Helmreich, Brigitte; Horstmeyer, Nils
- Brauchwasser: Glas, Karl
- Ergänzungskurs Siedlungswasser- und Abfallwirtschaft: Helmreich, Brigitte; Drewes, Jörg;
- Exkursion Kanalisation: Weißbach, Maximilian; Helmreich, Brigitte
- Hydrochemistry Laboratory: Helmreich, Brigitte
- Klärschlammbehandlung: Koch, Konrad
- Microbiology of Groundwater Ecosystems: Griebler, Christian; Lüders, Tilman
- Modelling of aquatic systems: Koch, Konrad
- PhD Seminar SiWaWi: Drewes, Jörg, Koch, Konrad
- Projektkurs Siedlungswasserwirtschaft: Drewes, Jörg
- Thermodynamik und Energietechnik Übung: Hübner, Uwe
- Thermodynamik und Energietechnik: Hübner, Uwe
- Umweltanalytik: Letzel, Thomas
- Umweltrecht: Spieler, Martin
- Urban Climate - Anwendungen: Katzschner, Lutz
- Waste Water Treatment: Helmreich, Brigitte

Winter Term

- Fundamentals of Urban Climate: Katzschner Lutz; Helmreich, Brigitte
- Gewässerschutz: Gschlößl, Tanja
- Grundlagen Ökologie: Herzog, Bastian
- Grundlagen Verfahrenstechnik: Böhm, Bernhard; Koch, Konrad
- Hydrochemistry: Helmreich, Brigitte
- Hydrochemistry Laboratory: Helmreich, Brigitte; Hübner, Uwe; Horstmeyer, Nils; Weißbach, Maximilian
- Mikrobiologie: Lemmer, Hilde
- PhD Seminar SiWaWi: Koch, Konrad; Drewes, Jörg
- Planung, Bau und Betrieb von Kläranlagen: Schreff, Dieter
- Planungs- und Genehmigungsverfahren nach deutschem und europäischem Wasserrecht: Spieler, Martin
- Siedlungswasser- und Abfallwirtschaft Grundmodul: Helmreich, Brigitte; Koch, Konrad
- Siedlungswasserwirtschaft Grundmodul: Helmreich, Brigitte; Koch, Konrad
- Technical Communication Skills in Water and Wastewater Treatment: Drewes, Jörg; Koch, Konrad
- Water and Wastewater Treatment Engineering: Drewes, Jörg

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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 are publishing once a year 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 Mrs. Raphaela Hoffmann.

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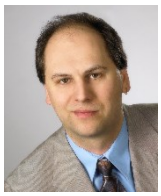

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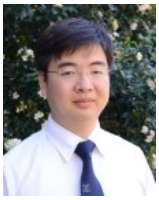

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