NaWaM
Sustainable Water Management

ERWAS

Future-oriented Technologies and Concepts for an Energy-efficient and Resource-saving Water Management

Interim results

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Future-oriented Technologies and Concepts for an Energy-efficient and Resource-saving Water Management

Interim results

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The BMBF funding measure ERWAS

Interim results

Water is our most important source of life. In modern industrialised societies, water quality is guaranteed by the use of plants that require a high amount of resources and energy. In times of decreasing availability of fossil energy sources, water management can contribute to the German energy turnaround by increasing the energy-efficiency of these plants and by using renewable energies. For this purpose possibilities should be identified and made available for everyday operation.

From this point of view, the German Federal Ministry of Education and Research (BMBF) supports the funding measure “Future-oriented Technologies and Concepts for an Energy-efficient and Resource-saving Water Management (ERWAS)”. This measure is part of the topic “Water and Energy” of the funding priority “Sustainable Water Management” (NaWaM), part of the BMBF framework programme “Research for Sustainable Development” (FONA).

This brochure presents first interim results of the funding measure ERWAS which has reached the middle of the project duration.

Background and objectives

Without energy, no water management plant can be operated. The existing German facilities for public water supply and wastewater treatment together consume 6.6 TWh of electrical energy per year, which is equivalent to the annual electricity requirement of about 1.6 million four-person households. Here, the wastewater treatment plants with 4.2 TWh per year are the largest electricity consumers in the municipal sector. They have a higher electricity demand than, for example, schools or street lighting. Through energy-saving measures and increased efficiency, there is an estimated saving potential of up to 25% of this electricity consumption.

In the scope of ERWAS, projects should contribute to sustainable, energy efficient water supply and wastewater disposal to use this saving potential. At that point the improvement of energy efficiency and resource saving energy generation are in focus. In the case of wastewater treatment, for instance, innovative approaches could provide energetic autonomy or even “energy positive” supply situations.

Fig. 1: Sewage treatment plant Dresden-Kaditz Stadtentwässerung Dresden GmbH

Furthermore, different joint research projects of the funding measure analyse how water management plants can be integrated into the future water and energy infrastructure in a smart way.

Especially, research projects with the potential of a quick and efficient implementation in operational practice of water supply and wastewater treatment plants will be supported.

The joint research projects

Within the framework of the ERWAS funding measure, the BMBF is supporting twelve joint research projects with more than eighty partners from science and practice (Fig. 1). To ensure the transfer of the research results into practical use and to adapt the research and development activities to the users' needs, stakeholders of science, economy and municipalities or federal states cooperate in each project.

A major focus of the funded projects is on developing new concepts for the interaction between the drinking water, wastewater and energy sectors. Examples are provided by the use of the load management potential and the energy storage capabilities of the water management sector for the future energy systems. Here, among other things, research is to be carried out into the extent to which water management facilities will be able to play a balancing role as an energy source or sink given by the more fluctuating electricity supply from renewable sources (wind and solar) in future.

Furthermore, innovative methods of energy production and energy conversion in water management facilities are to be developed, along with the optimised power generation in microbial fuel cells or the conversion into methanol. New ways to improve exploitation of the energy potentials in sewage sludge by simultaneously using the resources contained in wastewater, such as phosphorus, are also a priority.

In several joint research projects in the water supply plants, using the energy potential is in the foreground. A thematic priority focuses on process optimisation. Another research topic is the energy optimisation of future systems for the elimination of trace substances.

Interim results of research and development activities of the twelve joint research projects are presented below. It provides an interesting – also a fascinating – overview of yet water management's unused potentials. For operators and enterprises, the ERWAS research and development activities will offer many new opportunities for energy optimisation at individual plants.

Drinking water supply	ENERWA EnWasser EWave EWID H_2Opt
Microbial fuel cells	BioBZ BioMethanol KEStro
Wastewater treatment	arrivee E-Klär ESiTI KRN-Mephrec

Fig. 2: Projects of ERWAS funding measure

The steering committee

At the centre of the funding measure is the work of the joint research projects. These are also supported by a steering committee acting as an accompanying body. As with all funding measures within the framework of the BMBF funding priority NaWaM, it works at the interface between research and practice, to ensure that the research will deliver practice-oriented findings that are capable of implementation.

Members from industry, the authorities and other institutions, who are involved with the subject of "water and energy" in different ways as part of their daily work, are appointed to the steering committee. The project coordinators of all twelve joint research projects are also members of the steering committee, which guarantees a direct exchange of knowledge and information.

Although the very complex ERWAS joint research projects cover numerous different aspects and topics, many intersections arise e.g. in processes, methods, or subject-specific issues that are processed in several ERWAS projects. To bring this work together and to make active use of potential synergies, the steering committee defined four cross-cutting issues (Querschnittsthemen QT), which are elaborated in

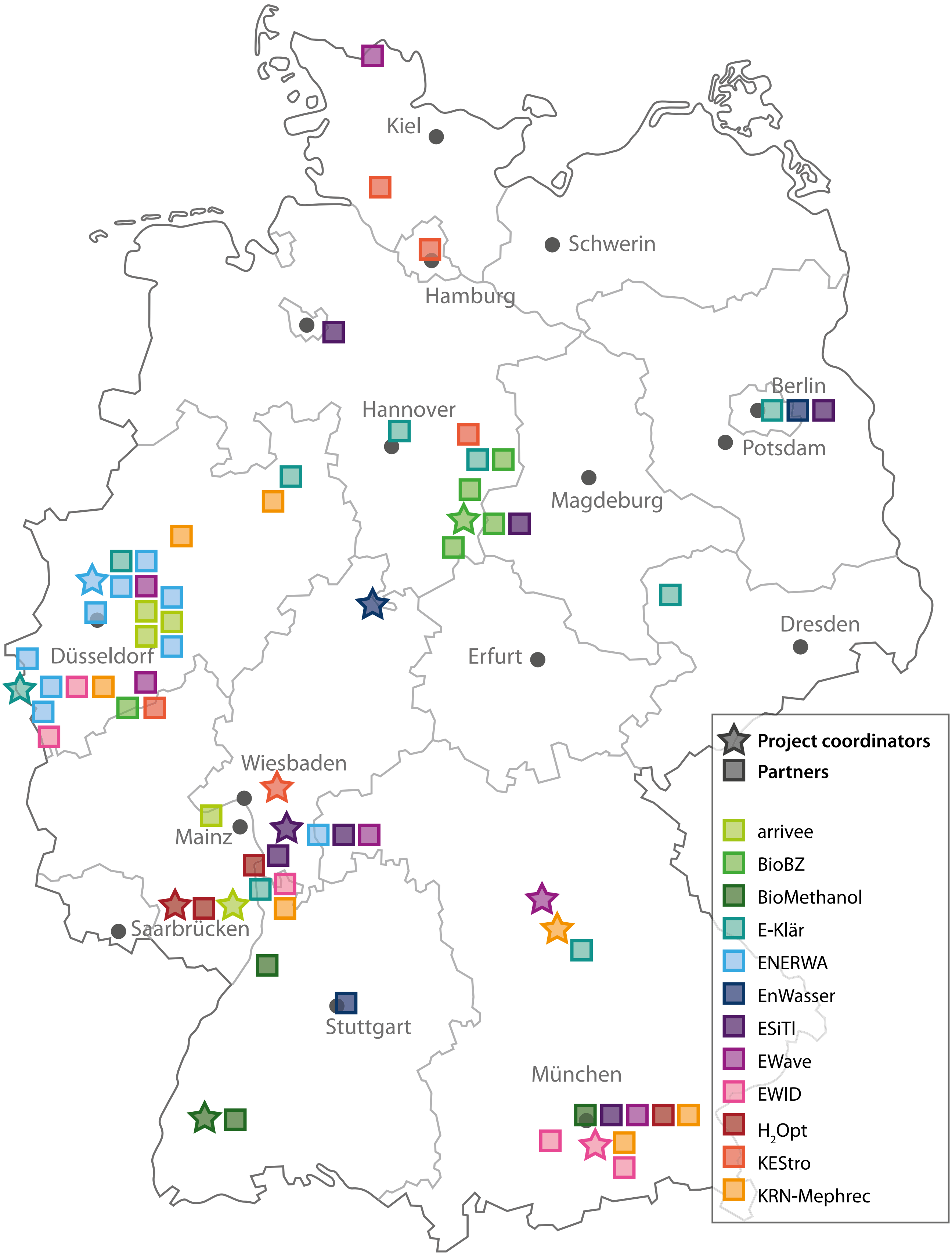

Fig. 3: BMBF funding measure ERWAS – Location of participating institutions

integrated working groups. Currently these are the following:

- QT Biofuel cell (BZ)
- QT Sewage sludge
- QT Energy storage and energy grids (ESpEN)
- QT Modelling and simulation

Task descriptions and preliminary results are presented in the respective parts of this brochure.

The networking and transfer project

The funding measure ERWAS is accompanied by an independent networking and transfer project (ERWASNET) that carries out organisational and substantive tasks and supports the joint research projects performing their work. Further tasks of this project include:

- Preparating, performing and monitoring of meetings, workshops, panels and status seminars on comprehensive questions
- Developing and provisioning of information materials on the funding measure (press and promotional materials, website, etc.)
- Ensuring coordination with the standard setting associations of the water management sector to enable the utilisation of the research findings in the technical rules and standards
- Networking with relevant national and international activities.

Internationally, three major events of the water-energy-nexus were visited (Washington, D.C., Stockholm and Exeter) in 2015. In summary it can be stated, that the joint research projects are at the top of the technological development at international scale.

The networking and transfer project ERWASNET is carried out by a consortium consisting of the German Association for Water, Wastewater and Waste (DWA) and the engineering company of water wastewater and energy TUTTAHS & MEYER Ingenieurgesellschaft für Wasser-, Abwasser- und Energiewirtschaft mbH.

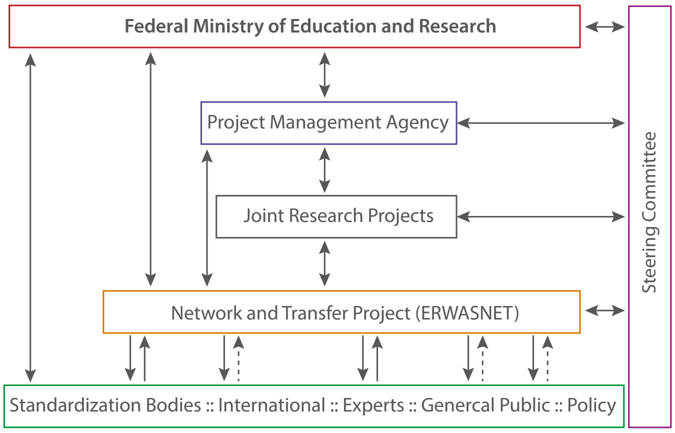

Fig. 4: Structure of the funding measure

Further information

Further information can be found on the ERWAS website (https://bmbf.nawam-erwas.de/en) and on the linked websites of the joint research projects.

Contact:

German Association for Water, Wastewater and Waste
Theodor-Heuss-Allee 17 • 53773 Hennef
A. Baum • Dr. N. Hüffmeyer • Dr. C. Wunsch
phone: +49 2242 872-124 • phone: +49 2242 872-209
baum@dwa.de • hueffmeyer@dwa.de • wunsch@dwa.de

TUTTAHS & MEYER Ingenieurgesellschaft mbH
Bismarckstr. 2-8 • 52066 Aachen
Prof. Dr. M. Schröder • Dr. M. Steinke
phone: +49 241 500005 • phone: +49 234 33305-0
m.schroeder@tum-aachen.de
m.steinke@tum-bochum.de


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ERWAS cross cutting issues (QT)

Bio-fuel Cell

Power generation at sewage treatment

Within the ERWAS-funded joint research projects BioBZ, KEStro, and BioMethanol microbial fuel cell technology plays a major role. Microbial fuel cells represent a new approach for energy-efficient waste water treatment. At the core of a microbial fuel cell a special kind of electroactive bacteria oxidize the organic waste water fraction and transfer the released electrons to the fuel cell's anode (Fig. 1). In this way, electricity can be directly generated from the waste water's organic fraction. At the same time, the energy-intensive aeration to degrade the organic matter is no longer required.

For the three joint research projects a number of common topics are relevant. Among these are suitable experimental methods, the integration of microbial fuel cells into domestic waste water treatment processes, as well as the construction and design of these devices. Furthermore, there are a number of promising synergies between the projects. Both, KEStro and BioBZ investigate the removal of trace organic contaminants. Similarly, cathode materials for hydrogen production are developed in the projects BioBZ and BioMethanol. In this context, first materials and results have already been exchanged.

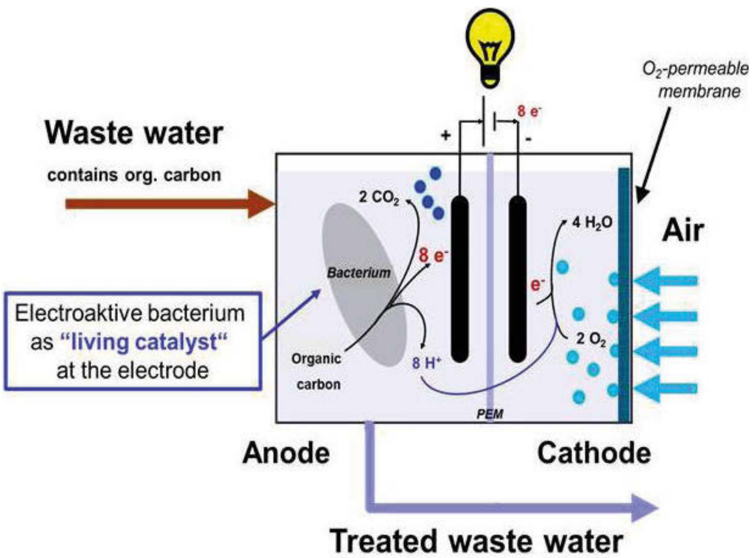

Fig. 1: Operation principle of a microbial fuel cell for simultaneous generation of electricity and waste water treatment (Source: IMTEK).

Already at the first meetings synergistic connections between the individual projects and the relevant people were identified, which will help to facilitate the exchange of ideas and results. Furthermore, basic lectures in the field of Electrochemistry and Microbiology were given, and methods to characterize microbial fuel cells as well as to deduce structure-relations have been intensively discussed.

Regarding the integration of microbial fuel cells into a domestic sewage treatment plant, first results from the joint research project BioBZ were presented. There is general agreement, that the removal of organic carbon should not have a negative effect on nitrogen elimination. Furthermore it is expected, that the microbial fuel cell technology will initially be successfully implemented mainly into smaller treatment plants. The reasons are that there are less strict regulations regarding nitrogen elimination, and that smaller plants are more suitable integrate and establish new processes. Besides the treatment of domestic sewage, in particular the field of industrial waste water treatment appears to be a promising field for the microbial fuel cell technology. In this context it is important to consider the requirements under which the technology will be accepted by the end users. To foster discussions with plant operators, engineering companies and other players in the field of waste water treatment it is planned to publish an easily accessible review article.

For future meetings it is planned to invite more participants from industry and other research projects to share their experiences and challenges.

Contact:

University of Freiburg, Department of Microsystems Enineering – IMTEK
Georges-Koehler-Allee 103
79110 Freiburg
Dr. Sven Kerzenmacher

phone: +49 761 203-73218
sven.kerzenmacher@imtek.uni-freiburg.de

Energy storage and energy grids (ESpEN)

Water management facilities provide flexibility components for the electricity market

Due to the energy turnaround, the energy sector passes through significant changes. In the future, the electricity market will need to control modules, which can feed or buy energy to compensate fluctuating amounts of energy. The objective of water management is to set the goal to play an important role in the "electricity market for the energy turnaround". The ERWAS cross-cutting issue Energy storage and Energy grids (ESpEN) covers the "potential for flexibility" in water management.

The current joint research projects analyse different courses of action and tangible contributions to the flexibility in the power industry. Besides a detailed portfolio analysis within the ERWAS-projects, the cross-cutting issue initially covers jointly the specific demand on the market and the monetary potentials. For this purpose, external experts and market participants were consulted.

As a result, the demand for flexibility, such as the integration of variable operation and storage in the integral system, became apparent. A further insight of the first analysis is the fact that water management, with its performance capacity in CHPs, pumping systems etc., disposes of interesting "flexibility components" for the power industry.

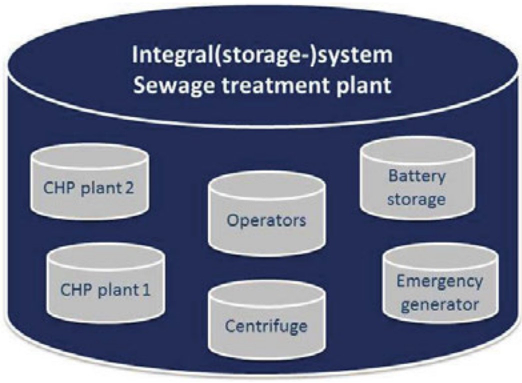

Fig. 1: Integral system – sewage treatment plant as energy storage

There is a need of „flexibility components", such as CHP plants, emergency generators or operators, which are available to a large amount and with high performance. Therefore, facility operators offer products in the electricity market without additional investments, precisely because the individual components are abundant available. Currently, the particular components are identified, recorded and collected by the specific joint research projects. The objective is to identify the possible overall potential using the example of the specific projects.

Some projects of this cross-cutting issue cover flexible operating modes, for instance adequate gas production. Through storage media such as gas, thermal energy or electricity, a decoupling from energy production and energy demand of the facility from the electricity grid is possible. This should support a further optimisation with the integration in the integral system. But potentials of flexibility by existing reservoirs will also be inspected. With due caution the adequate power-up and power-down of the operator will be examined, whereas the provision of drinking water and sewage treatment is still the priority.

The basis of the optimised usage of „flexibility components" is the detailed knowledge of individual components and systems. The more detailed the operating data is gathered and the more quickly and reliable the provision of flexibility is possible; the higher are the possibilities for revenue. Furthermore, these enhanced data sets allow insights of more efficient operation modes for facilities and increase in decentralised energy production. Despite the possibilities and price trends at the flexibility markets, conscious facility operation results in sustainable energy costs by reduced consumption and optimised energy production in water management. These data sets and experiences will be presented and exchanged within the cross-cutting issue. The information exchange should link the work in the different joint research projects in the field of energy storage and energy grids and should use synergies to implement the overall objective of the water management mentioned above. The variable overall potential of large-scale plants often amounts to several MW per facility, whereby the water management could get an important and reliable stakeholder within flexibility markets.

Contact:

bluemove Consulting Gmbh
Kellerbachstraße 8
82335 Berg
Arthur Dornburg

phone: +49 175 2232144
dornburg@bluemove-consulting.de

Sewage sludge

Utilization of sewage sludge as energy resource: sewage sludge and co-substrates, biogas, sludge recycling

The focus of the ERWAS cross-cutting issue „Utilization of sewage sludge as energy resource: Sewage sludge and co-substrates, biogas, sludge recycling" (ERWAS QT Sewage sludge) is on identification, cooperation and networking in the field of sewage sludge treatment and recycling. Under the leadership of Dr.-Ing. Christian Schaum (TU Darmstadt, Institute IWAR, joint research project ESiTI) regular meetings are held with about 20 participants from the joint projects arrivee, E-Klär, ESiTI and KRN-Mephrec as well as from the Scientific Networking and Transfer Project ERWASNET and the project management agency Karlsruhe.

So far, in the meetings the following joining factors have been identified and discussed:

- Use of a consistent technical terminology
- Standardization of system boundaries, application of a basis vector
- Investigation on the comparability of analysis methods

Due to the growing importance of the parameter COD (Chemical Oxygen Demand) in the field of sewage sludge treatment, the TU Darmstadt organized COD comparative measurements among the ERWAS members. The objective was to compare different analysis methods, including sample preparation, in order to allow conclusions on the plausibility and reproducibility of measuring data of (sewage) sludge samples. Overall, 10 laboratories took part in the comparative measurements. The scope of the investigation was the analysis of different types of (sewage) sludge (primary, surplus, digested sludge and flotation sludge) as well as of a COD reference solution. The analysis method to be used was not prescribed.

In general, the results of the comparative measurements showed that all applied methods qualify for COD testing. However, depending on the type of sample (homogeneity of the solids content, fat content) varying deviations were observed. Those methods are of advantage that allow the analysis of the original sample without further sample preparation (drying/grinding) and with only minor resp. without dilution. The detailed results have been compiled in a paper and will be published in KA Korrespondenz Abwasser, Abfall. In addition, the results will be taken account of in the revision of DIN 38414-9 on the COD determination of sewage sludge and sediments.

Within a next step, comparative measurements of laboratory-scale fermentation tests are planned. Furthermore, an expert workshop on the discussion of topics from the area of sewage sludge treatment and energy is being prepared. Here, the target is the scientific exchange between research and practice.

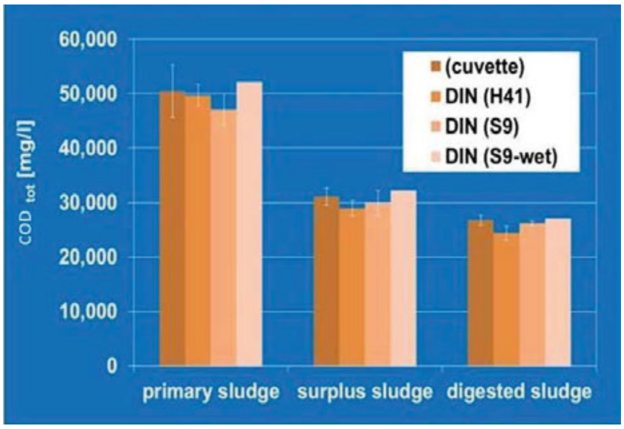

Fig. 1: results of the COD comparative measurements

Contact:

TU Darmstadt – Department of wastewater technology
Franziska-Braun-Straße 7
64287 Darmstadt
Dr. Christian Schaum

phone: +49 6151 16 20319
c.schaum@iwar.tu-darmstadt.de

Modeling and simulation

Energetic optimization of piping systems in drinking water supply

In the funding measure ERWAS, there are several projects which work on the optimization of drinking water supply systems in general, but also under the aspect of considering renewable energies as energy supply for the operation of the system as well as energy recovery. All projects have in common that they need to model the drinking water system.

Within the cross-cutting issue Modeling and simulation, the projects ENERWA, EnWasser, EWave, EWID and H_2OPT exchange and discuss their results, methods and problems with modeling the water network, the prediction of the water demand, the calculation of energy cost, the robustness of the simulations and the development of efficient optimization methods.

For some projects commercial or open-source software is used for modelling the water network. Other projects develop software for the network simulation themselves. Therefore it was decided that in the cross-cutting issue Modeling and simulation the software should be benchmarked. The results will be used for the verification of the codes. It is essential that the operation of the real system can be predicted with high accuracy with the developed models. Therefore in the projects, measurements from real systems are used to validate the models. Figure 1 shows as an example the comparison of the flow rate of the pumps in the water utility of Bürstadt.

Another important topic is the prediction of the water demand which is always a boundary condition for the simulation. The demand is known by past measurements, but needs to be predicted for future operations of the water systems. The prediction has to be made on several time scales. On the one hand, it is necessary to predict the water demand for a short period of time in order to optimize the operation of the system for example for one day. On the other hand, for planning efficient systems, it is necessary to predict the water demand for a long period taking into account the change of water demand due to the demographic change and the climate change.

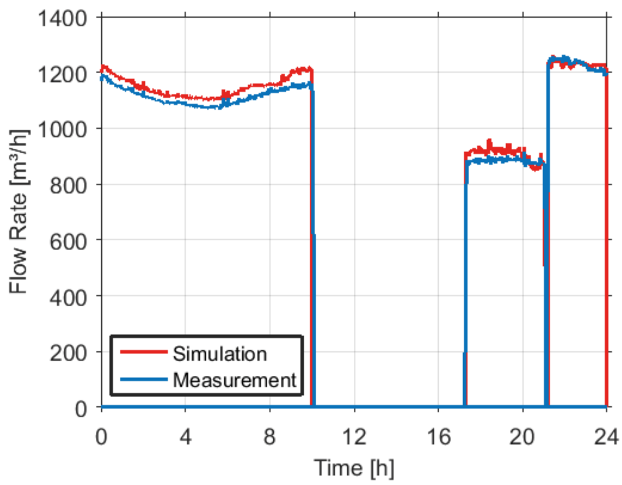

Fig. 1: Validation of flow rate for the pumps in the water utility of Bürstadt

In this context, also the robustness of the simulations plays an important role. It is necessary to investigate how uncertainties in the model parameters, e.g. for the water demand, influence the simulation results and how these uncertainties can be included in the simulation.

However, the current emphasis is on the benchmarking of the network simulation. A benchmark network has been defined. All projects will present their results in the next workshop for Modeling and simulation. After the benchmark it will be decided on how to proceed with the network simulation as well as with the forecast of water demand and robustness of simulations.

Contact:

TU Kaiserslautern, Institute for Fluid Mechanics and Turbomachinery
Gottlieb-Daimler-Str. 47
67663 Kaiserslautern
Prof. Dr. Martin Böhle

phone: +49 631 205-27 60
martin.boehle@mv.uni-kl.de

ERWAS joint research projects

ENERWA

Energy optimization of entire water supply chains: reservoirs-rivers • drinking water treatment • transport-storage-distribution

Background

The project ENERWA pursues new approaches to develop energy potentials in water supply systems in the entire process chain, on the level of technical components as well as in the control concepts. Reservoirs as a drinking water resource, water treatment plants at the water works and water distribution networks with their components such as pipes, pressure boosters and water storage tanks hold great potential for energy saving, -recovery and -storage and will be identified and assessed during this study.

Main focus lies on the dynamic operation of single plants against the background of fluctuating availability of renewable energies and varying energy costs. Furthermore, control concepts for energy efficient water distribution will be developed, handling the following questions: Are drinking water reservoirs and water distribution- and storage systems suitable to be used for the extraction and temporary storage of energy? Where are the limits and what barriers need to be overcome? A dynamic sampling from water reservoirs has the goal to optimally use the water release into the downstream section or the water works energetically, e.g. by using a turbine.

In this process, water economic, quality related and technical restrictions need to be considered, e.g. a minimum and maximum water release into the downstream section, resp. the drinking water treatment plant, but also the achievable income from the sold electricity. Furthermore, a change like this can cause extensive ecologic consequences and meet legal, economic or societal barriers. All these framework conditions will be analyzed and considered within ENERWA.

Interim results

The dynamic water extraction from water reservoirs by a precise control of the water discharge beyond the usual operation (amplitude, temporal dynamics) could be investigated during restructuring and control measures at the Bigge- and Hennetal reservoir. The special circumstances were monitored by a program for the capturing of different chemical-physical quality parameters in the reservoir, such as temperature, oxygen level and turbidity. First evaluations didn't show any significant influences on the raw water quality. The temperature layers of the reservoir stayed constant during the whole period of the monitoring program. Despite a variation in water release of up to 25 m^3 per half an hour, no short-circuit flows could be detected between the layers of the reservoir. Analyses of the ecologic parameters showed significant differences between reservoir-influenced and 'natural' water bodies in regard to the temperature regime in the water up to 10 kilometers below the reservoir and an accumulation of fine-grained sediments at the water bed. Studies about the effects on the aquatic fauna are still ongoing.

Optimization procedures regarding the dynamization of the process and in consideration of economic parameters are also developed for water treatment. A large saving potential of more than 200 thousand-kWh per year could already be identified in a water

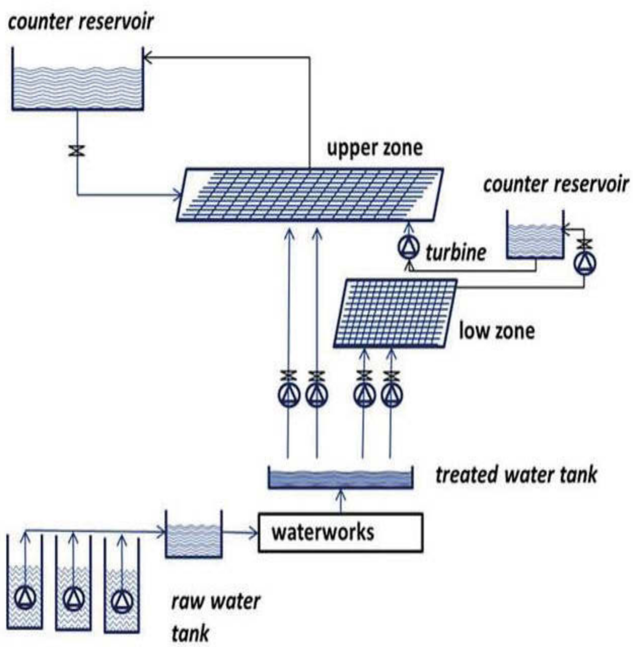

Fig. 1: Typical configuration of a water distribution network (Source: Rechenzentrum für Versorgungsnetze, Wehr GmbH)

Fig. 2: Underflow of the reservoir „Große Dhünn" (Source: Dr. Christian K. Feld, University Duisburg-Essen)

works. An energy saving potential of between 10 and 30 % as well as a better utilization of the rising amount of volatile renewable electricity generation is expected through the dynamization of the water work processes. Effects of the dynamization on single process steps, such as filtration, ozonation and ultrafiltration are being investigated at pilot plants right now.

For the water distribution networks with their tanks, optimization algorithms have been developed to reduce the energy need and costs. First studies show significant energy saving potentials for the operation of the pressure areas as well as for the operation of the whole network. For example, pressure and energy surpluses of the net can be reduced by the intelligent grouping of consumers at high altitudes to new pressure zones. A targeted use of drinking water storage tanks for load management against the background of the minimization of energy costs, including the spot- and German Electricity Balancing Market, is being investigated too.

Possible changes of the water supply system, which are linked to an energetic optimization (e.g. the use of reservoirs), require an open dialogue at an early stage. That is why a method for the transfer of new technical measures into society has been developed. Classical dissemination and public relations work are being accompanied by a new and within BMBF-ENERWA developed stakeholder and citizen participation procedure.

Outlook

The described energetic optimization measures can be effective at the single subsystems. But only a combine analysis will finally show, under which common conditions the single subsystems work optimally together and which conditions cause not acceptable operation situations. Furthermore, the identified optimization procedures are being tested and assessed regarding their practical applicability as well as their transferability towards other systems. To make the project results accessible to a broad circle of users they are being edited and generalized for method handbooks, Best-Practice-guidelines and web services.

Contact:

IWW Water Centre (Rheinisch-Westfälisches Institut für Wasserforschung gGmbH)
Moritzstr. 26
45476 Mülheim an der Ruhr
Dr. Wolf Merkel
phone: +49 208 40303-100
w.merkel@iww-online.de

Duration: 04/2014 – 03/2017
www.enerwa.org

EnWasser

Development of load management potential within water supply for the integration of renewable energies

Background

With the ongoing growth of electricity generation from renewable energy in Germany the challenges and chances of the fluctuating feed-in of electricity into the grid are unveiled. In times of short-term feed-in forecasts, balancing measures are increasingly needed which, for example, must be provided by conventional power plants. Another possibility to compensate fluctuations is demand side management where the consumption of electricity is aligned with the supply. This is profitable for consumers when they benefit from the varying prices at the spot market. Participation in the control reserve market can create additional revenues. Supra-regional water suppliers can be in line if they have a high electricity demand due to the pumping, treatment and transport of drinking water.

A supra-regional water supplier as such can be found in Zweckverband Bodensee-Wasserversorgung (BWV), which supplies about 4 million people in Baden-Wuerttemberg with approx. 125 million m^3 of drinking water per year. The raw water is extracted from Lake Constance and gets pumped up by 310m to the treatment plant on the adjacent mountain Sipplinger Berg. Usually this is done by up to three of the six pumps in total with an electric capacity of 8 to 11MW each. On Sipplinger Berg the water passes through several treatment steps with an intermediate reservoir (70,000 m^3) and a clean water reservoir (38,000 m^3). A scheme of the whole plant is shown in Figure 1.

The research project „EnWasser – Development of a load management potential in water supply structures for an improved integration of renewable energies" investigates the potentials for load shifting of the water pumping and treatment using the example of BWV. Furthermore the possibilities of new storage capacities to extend the flexibility of the plant and their energy-economic effects are assessed. Technical and operational constraints are being identified to ensure security of supply on one hand, and to allow to minimise electricity costs on the other hand.

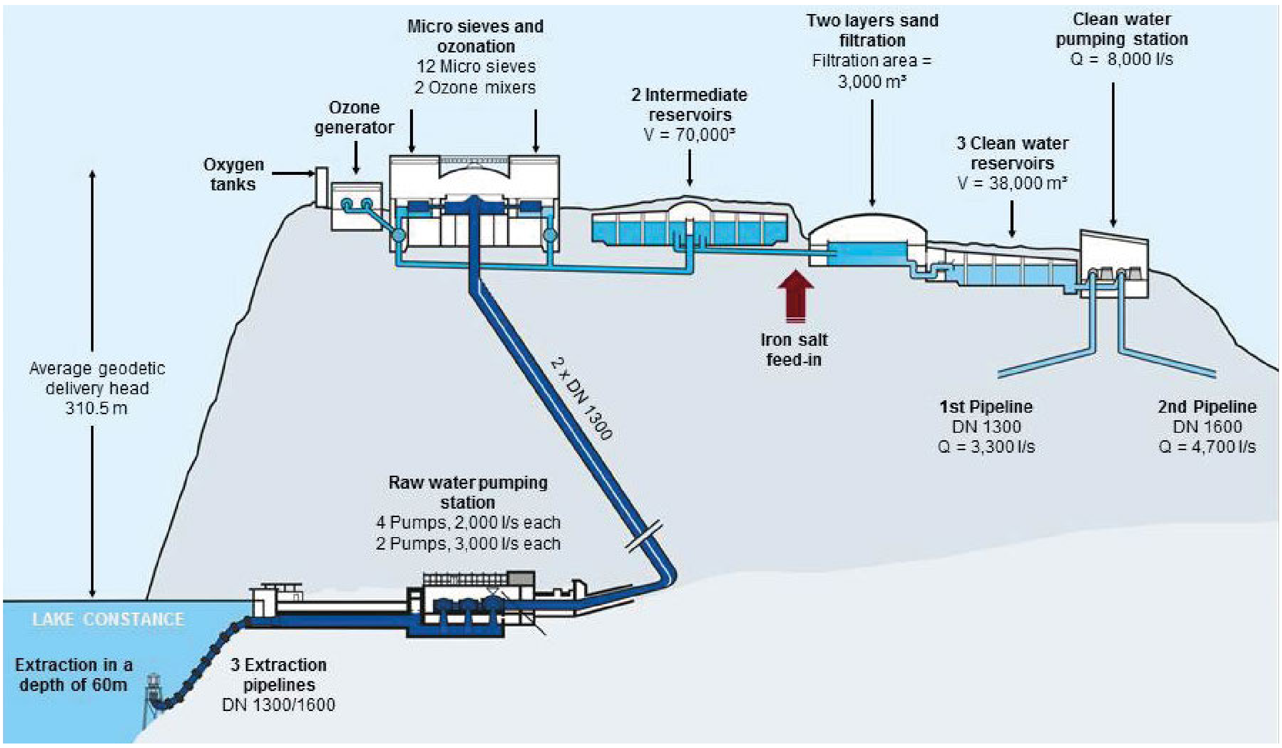

Fig. 1: Scheme of the pumping and treatment of Bodensee-Wasserversorgung at Sipplinger Berg

Interim results

Storage planning
The two existing water storages on Sipplinger Berg are a clean water and an intermediate reservoir. Before the intermediate storage an ozonation is carried out, so that this reservoir's flexible operation is limited. In order to flexibilise the electricity demand as much as possible, the energy-intensive raw water pumping has to be de-coupled from the following treatment processes. In this project different measures to increase the storage capacity have been taken into consideration.

The first option is to build a new raw water reservoir (Fig. 2) where the water can be stored before being passed on to the treatment process. For a better use of the topography the building of a new intermediate raw water reservoir would be an option, too. The existing reservoir could be used for raw water storage in this case.

Another possibility is to enlarge the intermediate reaction storage. The advantage is that this solution would have less impact on and little risk to change the current hydraulic conditions. This type of storage would have to fulfil two functions: It would have to ensure an appropriate reaction time for the ozone whilst providing enough storage capacity for a flexible operation of the raw water pumps.

Energy economical optimisation
For the optimisation of a flexible operation including electricity procurement at the EPEX spot market, the pumping and treatment plant has been modelled within the software RedSim (‚Renewable Energy Dispatch Simulation'). RedSim calculates optimised schedules for the operation of different plant configurations maximising the cost reduction of electricity procurement. Preliminary results show how relatively large cost savings can be achieved with an additional storage capacity up to 100,000 m^3. Even

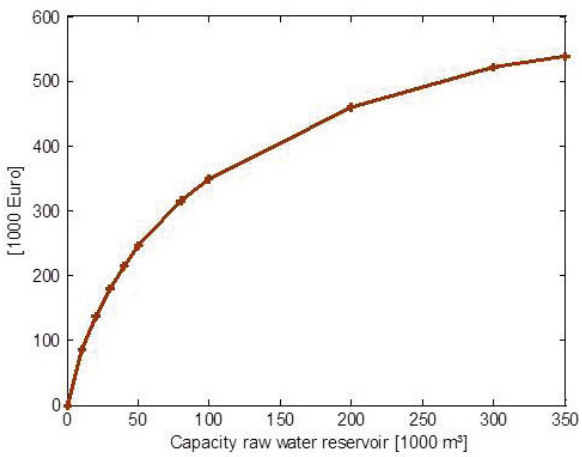

Fig. 2: Cost savings of this plant configuration dependent of the capacity of the reservoir

stronger effects can be found considering atypical grid utilization costs ('Atypische Netznutzung') in addition. This energy-economical way of operating the plant leads to a more extreme commitment of the plant, namely several thousand hours of operation at maximum pumping power (four pumps at once) and another several thousand hours without operation. This results in a slightly increased annual electricity demand while the electricity costs decrease. The feasibility of such unit commitment scenarios have to be investigated regarding the technical and operational constraints.

Hydraulic constraints
To identify the boundary conditions for a flexible system operation, a 1D transient hydraulic model of the pipeline system and the six delivery pumps has been evaluated.

In operation the maximum rated pressure in the pipelines must not be exceeded. During start-up cavitation at the pumps should be avoided. Validations of the hydraulic model with measurement data gained from an emergency shutdown of two pumps in the plant showed good agreement (Fig. 3).

Outlook

In the course of the project all technical and operational constraints will be determined and integrated in the evaluation of possible operational modes and in the calculation of energy-economically optimised schedules. This way different storage options are investigated and their profitability is evaluated from the energy-economical perspective. Furthermore, possibilities for the usage of self-generated electricity from renewable energy are simulated and evaluated under consideration of scenarios of the future electricity supply system. Newly developed methods to forecast the water demand will be applied to simulate the operation of the plant including the real-life schedule management. The results will be analysed with regard to the impacts on the entire business model for operating the pumping and treatment plant.

Contact:

Fraunhofer Institute for Wind Energy and Energy System Technology
Königstor 59
34119 Kassel
Patrick Hochloff
phone: +49 561 7294-214
patrick.hochloff@iwes.fraunhofer.de

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www.enwasser.net

EWave

Water supply energy management system

Background

The BMBF funded joint research project EWave aims to develop an innovative Decision Support System (DSS) for water supply systems. As a result, the user gets an optimised schedule for all controllable plant components and aggregates.

Water supply is subject to various conditions which arise from the demand of high quality drinking water together with aspects related to water law as well as procedural, operational and economical aspects. The solution of the multi-dimensional problem of optimisation to increase the energy and resource efficiency under the mentioned conditions is a challenge, which is covered broadly today by lessons learned of the plant operators.

In addition, the calculated energy demand can be projected and shared with the plant operator. With these results, the power industry can optimise the operation of the power plant complexes to achieve economic optimisation (beyond the boundaries of the water management system).

Interim results

Within the scope of this project, the requirements on the DSS were defined in general terms as well as specific to water works and coordinated among all partners. The facilities are controlled in hydraulic terms and in respect to quality. As a consequence, constraints of variability of plant operation emerge. At an exchange of best practice with different water utility companies, these requirements and the overall project approach were discussed, whereas the feedback was consistently positive. Besides the definition of the requirements, the data provision for the modelling was the crucial challenge. In addition to geodesic levels, plant-specific operational data (pressures, flow rates, energy demand etc.) had to be provided in 15 minute intervals.

Very early, the components and model equation of the simulation model, as well as the required data and their structures were specified with a model catalog. On this basis, the implementation of the simulation model TWaveSim took place. To guarantee both a reasonable calculating time, and an appropriate model complexity, the pressure zone Holsterhausen was abstracted through a new mesh generator. Furthermore, characteristics of the drinking water pumps for hydraulic and electric performance were extrapolated from the operational data. As a result, first successful simulations of the processes of water catchment, treatment and distribution could be made within the pilot zone Holsterhausen.
The calculation of a suggestion for an energy-efficient operation of the water supply plant takes place by the optimization model, rolling for a fixed period of time, for instance every 15 minutes for the next 24 hours. The optimization module consists of the software packets EWave-DOPT and EWave-NOPT.
EWave-DOPT is a software to optimise the operation of water supply plants with methods of mixed-integral mathematic optimisation. The software EWave-NOPT is based on ANACONDA, which is used both for the simulation of water supply plants, and for continuous optimisation of the operation points of all controllable network components.

With the selection of the optimising module, EWave-DOPT will calculate based on the latest consumption forecasts and with a simulated initial state, a suggestion for discrete control decisions (i.a. pump control and valve positions), as well as calculate a prognosis of the grid conditions. On the basis of the discrete decisions and status prognoses calculated by EWave-DOPT, EWave-NOPT can optimise the precise operation points of all operational network components and calculate the related, physically detailed development of all relevant state variables.

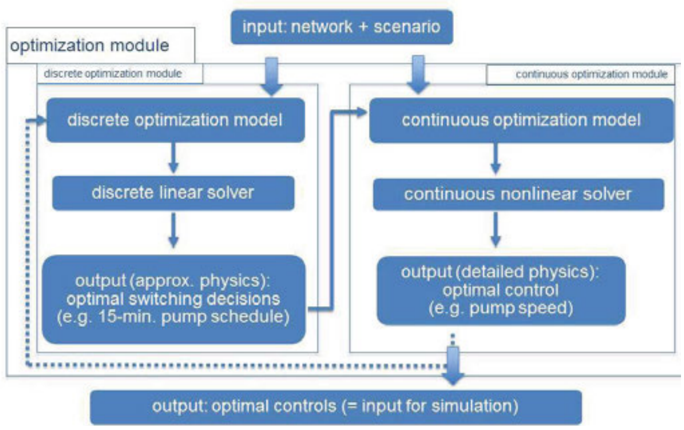


Fig. 1: Procedure of optimisation calculation

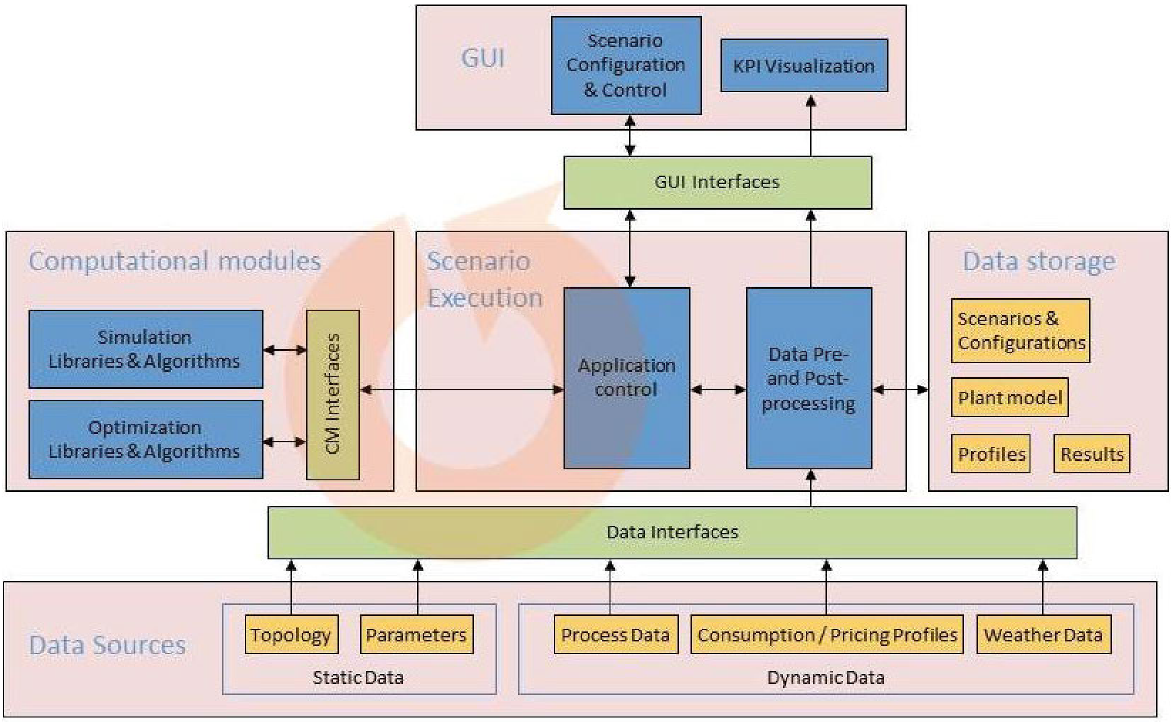


Fig. 2: Architecture scheme of the EWave system

By calculating the level of efficiency for every step of the process-chain catchment-treatment-storage-distribution, partly down to the aggregate level, in addition to the increased energy-efficiency, a better process transparency is obtained.

Already existing simulation results show that the mathematic model used within the EWave optimization module, display a high conformity with the real data.

For the assistance system, a modular software architecture has been designed.

The macro structure comprises of

- a central flow control,
- a graphical user interface for configuration, control and visualisation,
- analysis module for simulation and optimisation,
- a data storage for a plant model, configurations, scenarios and results,
- external data sources,
- and modules for data pre-processing and data post-processing.

The particular modules communicate via specified interfaces. The linkage of the analysis module is made by socket connections. The GUI will be implemented as web application. Initially, the external data will be available in a database; additionally a special database for internal use will be established. Currently, the macro structure of this architecture is already implemented. The single function modules, provided by the specific processors, will be integrated in the architecture successively.

Outlook

One of the forthcoming tasks is the developing and calibrating a drinking water demand forecast model. Methodical work has been started. Likewise, the other research projects of the funding measure address these topics as well, so that an exchange should take place within a cross-cutting issue.
The next working steps in regard to the simulation of processes of water catchment, water treatment and water distribution comprise the model calibration and validation, as well as the advancement of the simulator by methods for the calculation of consistent initial values and additional model components. In the future, after a specification, other water works can be displayed with the process simulator.
The system EWave will be applied and approved in practice within a subnetwork of RWW by October 2016.

Contact:

University of Erlangen
Cauerstraße 11
91058 Erlangen
Prof. Dr. Alexander Martin
phone: +49 9131 85-671 63
alexander.martin@fau.de

Duration: 04/2014 – 03/2017
www.edom.fau.de/ewave

EWID

Energy recovery in the water distribution system by intelligent pressure management

Background

Pressure-reducing valves (PRV) are used in water supply systems in order to control the pressure and to relieve the water pipes from material stress. At the same time by the classical pressure regulation with PRV, energy is transformed constantly into unusable forms as sound and heat. The research project „Energy recovery in the water distribution system by intelligent pressure management (EWID)“ identifies new ways to reduce this energy dissipation. For this purpose, a new system based on a reverse-running pump as turbine (PaT) in conjunction with an intelligent pressure management (IDM) is being developed. Aim is, on the one hand, to convert the maximal possible pressure energy of water into electrical energy, based on the water demand. On the other hand, a contribution to the reduction of water losses and the material stress in the water distribution network has to be shown.

Interim results

In the first development phase, the EWID-system is based on two concrete use cases within the participating water utilities AWA-Ammersee Wasser- und Abwasserbetriebe gKU (AWA) and Wasserversorgungszweckverband Perlenbach (PER). After the selection of suitable pilot areas, the boundary conditions of these locations were collected. Based on the recorded parameters at the pressure reducing manhole, pressure (inlet and outlet) and flow rate, the dimensioning of the PaTs and the determination of their working range was carried out. To guarantee supply safety in the supply area, even under unfavorable conditions (e.g. power failure), the PaT is located in a bypass to the existing pressure-reducing valve.

For a first potential analysis the theoretically possible energy yield P_{el} was calculated for the considered locations according to DVGW-Merkblatt W 613, assuming a total plant efficiency of 50 to 60 percent. Here, 340 W and 3,840

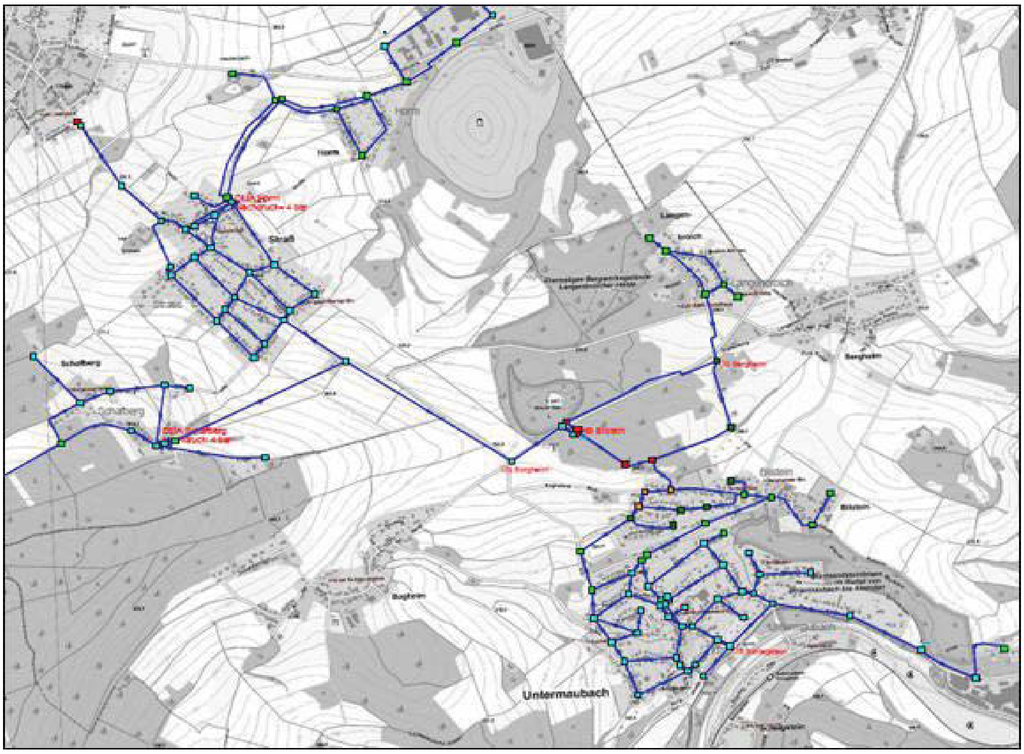


Fig. 1: Exemplary result from the hydraulic modelling

W could be determined for the AWA and PER, respectively. Thus, under suitable conditions in the supply area up to 25,000 kWh electricity could be generated.

Parallel to the potential analysis, a first economic analysis was conducted. Here the cost savings of the energy production, the water loss reduction and the prevention of pipe bursts were determined and compared to the investment costs for the use of the EWID-system (incl. operating and reinvestment costs). For PER, for example, a payback period of approximately eight to eleven years was calculated, depending on the fiscal remuneration (EEG, green energy or energy exchange). In addition to the monetary benefit, the additional improvement of the monitoring of the drinking water distribution network must be emphasized.

For the hydraulic modelling the selected supply network areas were mapped with the software package AQUA ++ by Tandler. For this purpose, the attributes (material, diameter, height, etc.) to the existing elements (nodes, pipes, elevated tanks, pressure reducers, etc.) were taken over from the existing databases and with additional measurements complemented. To study the network behavior, different operating conditions were simulated within the network modelling. Here, the respective pressure at all nodes can be calculated for a selected flow rate, so that it can be identified at which operating conditions for which nodes the pressure is no longer sufficient (see Figure 1). Here, the operating pressures recommended by the DVGW were considered (pressure at the highest hour consumption in existing networks (> 2.0 bar) and in fire-fighting case (> 1.5 bar)) (DVGW W 400-1).

In EWID, a system will be developed, which consists of a pressure control unit (PRV) plus an energy production unit (PaT + generator + transformer) located in a bypass, and a control unit for the intelligent pressure management (IDM). An additional intern electronic control is in charge of the interaction of the individual system components, the condition monitoring and the telecommunications. The higher-level controller for the IDM is made up of a Pressure Control Unit, the sensors located in the distribution network (pressure, flow) and a Telecommunication Unit for connecting with the PaT unit or the SCADA system of the water supplier. Within the project, the possibilities for decentralized use (in conjunction with energy storage) and the re-feeding of the recovered energy into the power grid are tested.

Fig. 2: Test track with testing facilities

In the first phase of the pilot testing, the actual state at the water utilities, the pressure reduction with a classic PRV, was designed and implemented. The aggregates and fittings were dimensioned according to the boundary conditions at the involved water utilities. The feed pumps provide the required inlet operating pressure and the PRV reduces these accordingly. Two control valves regulate the flow according to the characteristic flow hydrograph, measured at the water utilities. In the second development phase the PaT-systems were installed in the bypass to the main line (PRV) (see Figure 2).

This phase of the project is required to test the developed system unit at a technical scale before implementing it in the two distribution systems (verification in the water network (field trials)).

Outlook

To improve the efficiency and the flexible and safe control of the facilities in the water distribution network systems are required, which can dynamically respond to consumer behavior. Therefore, the „near real time" use of water network simulation models will be tested in the research project EWID. For this, the recorded data at the critical points on the water network, at the PaT-system, etc. should be transferred if possible in real time to the other stations (known as Com Units). The collected parameters (network pressure, flow rates, operating conditions, etc.) are used as input for modelling the hydraulic conditions in the water supply network and to control the PaT-system. The development of new control models as the basis for dynamic controlling is one of the major challenges in developing intelligent systems in engineering networks and one of the main objectives of the project EWID.

Contact:

University of the Federal Armed Forces,
Institute of Hydro Sciences, Sanitary Engineering and Waste Management
Werner-Heisenberg-Weg 39
85579 Neubiberg
Prof. Dr. F. Wolfgang Günthert
phone: +49 89 6004-2156
wolfgang.guenthert@unibw.de

Duration: 04/2014 – 03/2017
www.unibw.de/ewid

H_2Opt

Interactive decision support for operation and energy management of water systems based on multi-objective optimization methods

Background

The project is focused on the optimization of drinking water systems taking into account energetic and economic aspects. A software which can be used by water utilities as well as planning offices is to be developed.

The software allows an integrated analysis of drinking water systems. All components from the fields of water procurement, water treatment, water storage and water transport which are important for energy efficiency and their interaction can be analyzed.

Interim results

Currently, a model for the analysis of the operating behavior of the main pumps at Bürstadt waterworks which is run by the research partner EWR Netz GmbH is integrated into the software prototype. The simulation model includes all main pumps, the system curves of the network of pipes and both tanks. Four main pumps of different sizes are installed at Bürstadt waterworks. The pump curves were determined experimentally on the spot, compared to the manufacturer's information and integrated into the software prototype. The modelling of the water transport system is not based on a hydraulic calculation of the pipeline network. In fact it is based on

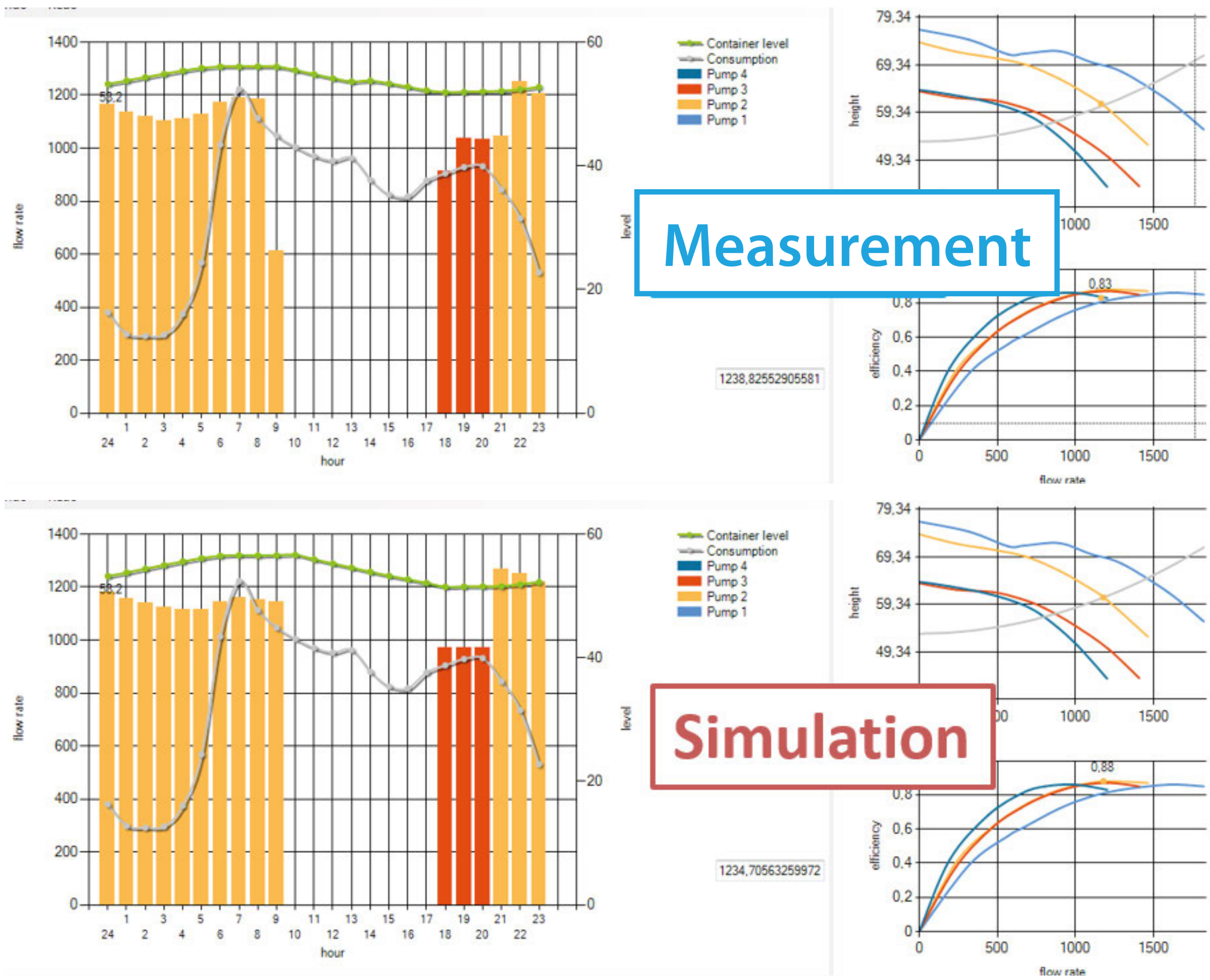


Fig. 1: Comparison of daily pump schedules

a calculation model which describes the system curve in relation to the consumption of drinking water and the water level of both elevated tanks at every time step. This model was built by means of measured data over a period of several years. Further the model is being proved with respect to the general validity and the applicability to other water transport systems which can be more complex than the water transport system at Bürstadt.

For a given distribution of the daily water demand, the software prototype is able to calculate different feasible pump schedules for a defined period of time, for example for one day, by means of numerical optimization methods. Currently the reduction of specific energy costs and the reduction of the number of on / off cycles of the main pumps are used as optimization parameters. The temporal resolution is specified to one hour at the moment. In order to ensure reliable optimization results the model of the drinking water system must be validated. Figure 1 shows a comparison between a measured (above) and a calculated daily pump schedule (below). The gray line shows a chosen daily water consumption profile. The water level of the two tanks is plotted by the green line. The colored bars represent the flow rates of the main pumps. In this example the main pump 2 (yellow bar) and the main pump 3 (red bar) were operated. The deviations between calculated and measured flow rates at the hours 9, 18 and 21 are caused by the fact that in this example the pumps are operated by a start/stop regulation. For the period under consideration main pump 2 was only operated in hour 9 for about 30 minutes before it was switched off. In the calculated daily schedule, however, main pump 2 was switched off after the whole hour 9.

On the one hand the software can support the user to specify energy efficient pump schedules; on the other hand the software can help to find pumps which perfectly fit to a system. As an example the water procurement system of the SWK Stadtwerke Kaiserslautern Versorgungs-AG is used. This drinking water system consists of 23 active well pumps and one spring which is used per 100 %. There are 11 well pumps and the spring used at the Kaiserslautern Ost. The characteristic curves of all active well pumps were determined by measurements in the system. An operating analysis of every well was done by means of the measured characteristic curves and by an extensive data analysis of measured data from the process control system. First, the current state of the wells was analyzed. Then it was tried to find a better pump layout by means of a pump data base of the Institute of Fluid Mechanics and Fluid Machinery of the University of Kaiserslautern. The comparison of a real pump (left) and a newly selected pump (right) is shown in figure 2 where the efficiency in percent is plotted against the flow rate in liter per second.

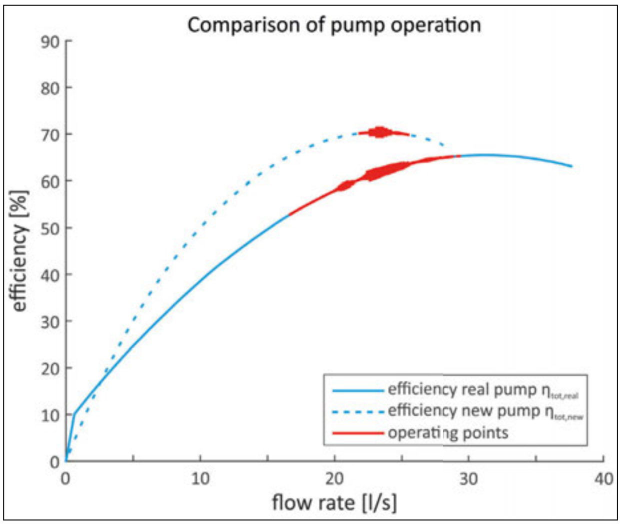


Fig. 2: Comparison of a real pump and a newly selected one

The overall efficiency curve is described by the blue lines. The operating points are shown in red dots. The bigger the dots the more often the pump is or would be operated at the respective point. The actually installed pump is been operated mainly at partial load. The newly selected one, however, would have been operated at the optimal range. A change of the pumps would lead to a decrease in energy costs of 12.2 % at this well per year.

Outlook

The realization of the graphical user interface which should enable the user to create models of arbitrary drinking water systems per drag and drop is in progress at the moment. The well area Kaiserslautern Ost operated by the research partner SWK Stadtwerke Kaiserslautern Versorgungs-AG will be implemented into the software in the near future. Further an interface to common piping calculators is planned. In this case studies are in progress. The integration of life cycle cost analysis for every component which is realized in the software is in progress, too.

Contact:

TU Kaiserslautern
Gottlieb-Daimler-Str. 47
67663 Kaiserslautern
Prof. Dr. Martin Böhle
phone: +49 631 205-2769
martin.boehle@mv.uni-kl.de

Duration: 04/2014 – 03/2017
www.mv.uni-kl.de/sam/forschung/h2opt

BioBZ

The bio-electrochemical fuel cell as a component of an energy-producing sewage treatment plant

Background

Municipal sewage is an important energy source because of its organic components. Energy is often indirectly used by sludge treatment like for example digestion or combustion. The efficiency of generating and using electrical energy is comparatively low by this indirect way of energy conversion, so that municipal sewage treatment plants are still one of the largest electricity consumers in municipalities.

One approach for the improvement of the overall efficiency in power production at sewage treatment plants is the energy production from chemically bound energy of dissolved organic substances. Bio-electrochemical fuel cells are able to achieve this kind of energy conversion, but the development of appropriate practice-oriented systems is still at the beginning. There is not only a lack of affordable materials, but also a lack of robust reactor concepts, control strategies and appropriate voltage conversion-, current consumption- and power storage systems as well as the lack of a practice-oriented integration of municipal sewage treatment plants.

Within the joint research project „The bio-electrochemical fuel cell as a component of an energy-producing sewage treatment plant (BioBZ)", these issues will be addressed. With the support of low-cost electrode materials in development, appropriate reactor concepts should be designed and analysed at pilot scale at the sewage treatment plant Goslar.

Interim results

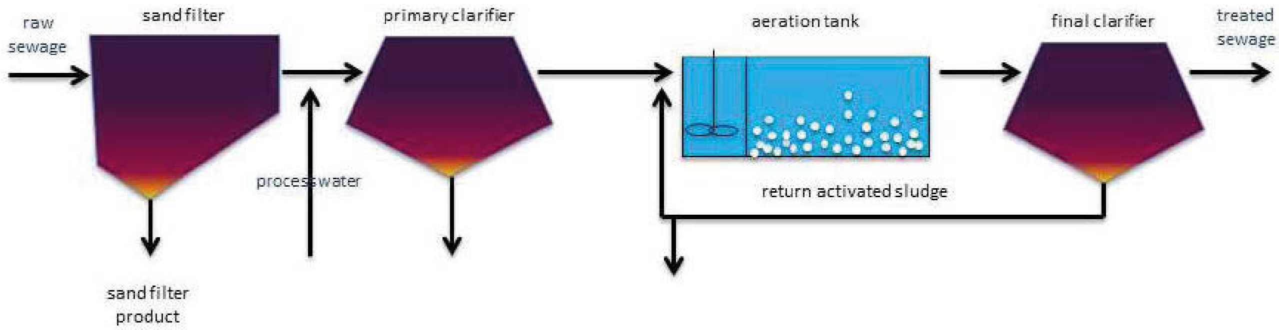
Appropriate low-cost materials have been developed on the basis of a graphite-polymer-compound comprising the manufacturing process for small-scale series production of composite-electrodes (Eisenhuth). Pilot experiments with continuous perfused cells show that the treatment of pretreated municipal sewage could be operated long-term stable (at the moment several month) (CUTEC, TUC and EBI).

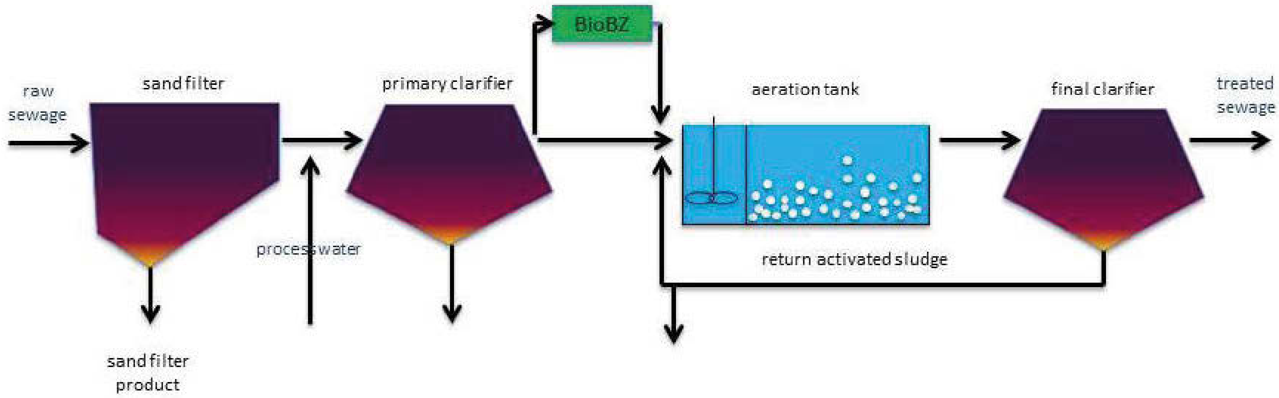
Likewise, the (partially-) reduction of several micro pollutants (40 – 95 %) has been detected (EBI and TUB). The area-specific output of the electrodes ranges between 40 – 220 mW/m^2 and requires an appropriate concept for the optimisation/maximisation of the current consumption. A series connection of several cells for the scale-up to larger stacks and systems have proven unsuitable because the weakest cell sets the output maximum and thus limits stronger cells. Consequently the concept of single cell systems has been developed (TUC and CUTEC), comparable to photovoltaic power systems. To realise the single cell systems, a galvanic separated constant current source has been developed (TUC) which is not commercially available. With these constant current sources and a computer-based MSR-technology the external resistor of every cell can be modified within seconds so that the ideal operation of the particular cell is guaranteed.

However, the ideal operation of a cell is still subject to current analyses, whereas different control strategies are developed and analysed (CUTEC). Lessons from observing the biofilm development (EBI) and the modification of preconditioned biofilms (TUB) should also contribute to a solution.

A considerable partial aspect in respect of further development is the fact that with the control on basis of the constant current source, a high reproducibility of test results and a concurrent operation of structurally identical cells has been proved. The requirements for the voltage conversion and the energy storage shouldn't be underestimated because there is also a lack of commercially available components. A first prototype for the conversion from 50 – 300 mV to 2.5/5 V has been developed and has been proven suitable (TUC), so that the further conversion can be realized at higher, practically relevant voltages or at alternating current with commercially available components.

Furthermore, the tests show that in respect of the maximisation of the current efficiency, a partially reduction of the COD is interesting until 30 %. How the bio-electrochemical fuel cell can contribute to the energy balance of a municipal sewage treatment plant is shown in figure 1.





kWh/PE*a	Consumption					Production			Energy balance
	Primary clarifier	Aeration tank	Final clarifier	Digestion	Con-sumptio	Digestion/ CHP	BioBZ	Production	
Without BioBZ	2	17	2	4	25	15	0	15	-10
With BioBZ	2	17	2	4	25	15	2 - 15	17 - 30	-8 – (+5)

Fig. 1: Energy balance of a model sewage treatment plant with/without bio-fuel cell (Particial flow operation bio-fuel cell comprises 30% COD reduction in respect of main flow)

Outlook

From the test results and the pilot tests at the sewage treatment plant (Eurawasser), the potential of an energy turnaround within municipal sewage treatment should be deduced and evaluated. At that point, practical oriented criteria are used and differentiated in size classes 1 to 5.

Contact:

Clausthal Institute of Environmental Technology (CUTEC-Institute)
Leibnizstr. 21+23
38678 Clausthal-Zellerfeld
Prof. Dr. Michael Sievers
phone: +49 5323 933-243
michael.sievers@cutec.de

Duration: 05/2014 – 04/2017
www.bio-bz.de

BioMethanol

Sustainable synthesis of the energy-carrier methanol from waste-water

Background

Currently, microbial fuel cells are being discussed as an alternative technology for energy-efficient wastewater treatment. In microbial fuel cells, so-called exoelectrogenic bacteria use the anode of a fuel cell as terminal electron acceptor instead of oxygen. This way, electricity can be directly generated from the organic fraction of the wastewater. At the same time, the energy-intensive aeration step to degrade organic matter in the conventional activated sludge process can be omitted.

If an additional voltage is applied between the fuel cells' electrode also protons can be reduced at the cathode and hydrogen gas is produced (microbial electrolysis cell). The energy required for this process is significantly lower as compared to classical water electrolysis, since part of the electricity is delivered by the exoelectrogenic bacteria. The interdisciplinary joint research project BioMethanol aims a treating industrial wastewater by means of a microbial electrolysis cell that generates CO_2 and H_2. Both gases will then be used to synthesize methanol in a subsequent catalytic process.

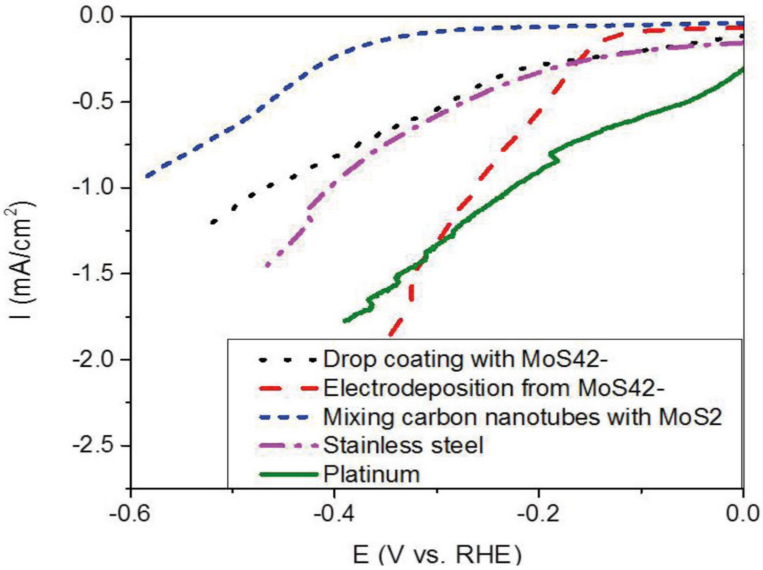


Fig. 1: Polarization curves of different hydrogen evolution cathodes, operated in industrial waste water at pH 2.4.

Interim results

Regarding the development of the microbial electrolysis cell, carbon-supported MoS_2 catalyst was evaluated as a cost-efficient alternative to platinum. In real industrial waste-water (pH 2.4), the new material exhibits a performance that is comparable to platinum, showing an overpotential of only 256 mV at a current density of 1.1 mA/cm². Also long-term stability tests over periods of up to 17 days yield promising results: here the MoS2-based material shows a significant increase in activity, which is in contrast to the poisoning observed with platinum electrode under the same conditions. Furthermore, an up-scaled electrolysis cell with a geometrical electrode area of 36 cm² was constructed and tested in first laboratory experiments (Fig. 2).

To evaluate the economic and ecologic potential of the technology the overall system was considered. It comprises the microbial electrolysis cell, compressors, the methanol synthesis reactor and its peripherals, and a distilling unit for product separation. For the economic evaluation different future scenarios for the price of energy (electricity) and methanol as well as investment cost of relevant system components were taken into account. Preliminary calculations already revealed that virtually no gaseous CO_2 will be available from the microbial electrolysis cell due to the relatively high pH-value of the industrial waste-water. Therefore, additional costs for an external procurement and supply of CO_2 have been included. Similarly, potential savings in wastewater treatment costs due to pretreatment in the microbial electrolysis cell have been taken into account.

For all regarded process variants, the major share (> 50 %) of investment cost results from the microbial electrolysis cell. A possibility to reduce its cost would be the significant reduction of the electrode- and membrane area by increasing the current density at the anode. Regarding the cost of operation the procurement and supply of external CO_2 for the methanol synthesis is another major cost factor. Here, the adjustment of the effluent pH to values below pH 6.9 would be sufficient to supply CO_2 and H_2 from the electrolysis cell at the stoichiometric ratio of 1:3, as required by the methanol synthesis reaction.

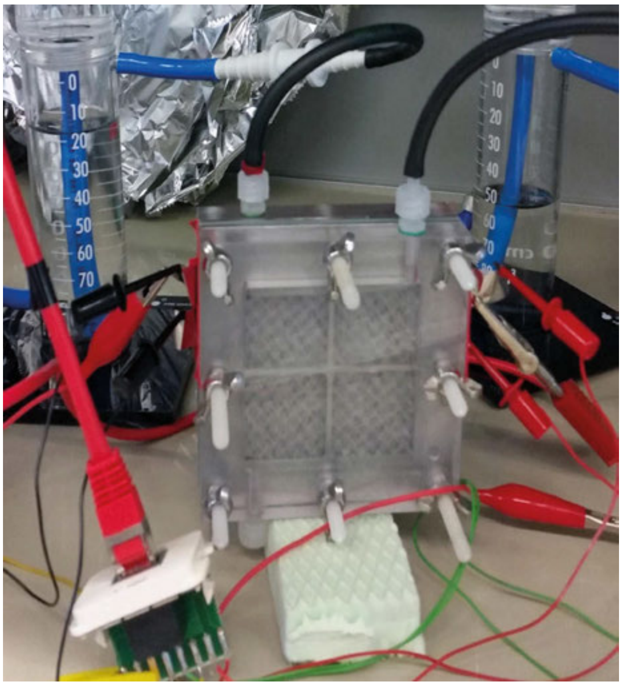


Fig. 2: First laboratory scale experiments with an up-scaled microbial electrolysis cell having a geometric electrode area of 36 cm².

Both, the external procurement of CO_2 as well as the origin of the electrolysis current are the factors governing the CO_2 emission of the overall process. The lowest specific CO_2-emission of 0.22 [Tons CO_2/Ton methanol] can be achieved when no externally procured CO_2 is used in the process and all of the electricity stems from renewable power. In contrast, the external procurement of CO_2 and the use of the current German electricity mix yields a specific CO_2-emission of 2.08 [Tons CO_2/ Ton methanol], which is almost twice the value of the conventional methanol synthesis from fossil resources (1.21 [Tons CO_2/Ton methanol].

In conclusion, the use of external CO_2 sources should be omitted for both ecologic and economic reasons. Furthermore, the main factor to increase the economic feasibility of the overall process is an increase in anode current density and the consequent reduction of electrode/membrane area.

Outlook

In the future course of the project the anode performance will be further increased, e.g. by the use of a specialized microbial consortium. At the same time, new catalysts for the methanol synthesis process will be developed to increase the overall process efficiency. In the third year of the project, a complete laboratory scale demonstrator to produce methanol from industrial waste water will be assembled, comprising the modules "microbial electrolysis cells" and "methanol synthesis stage".

Contact:

University of Freiburg
Fahnenbergplatz
79098 Freiburg
Dr. Sven Kerzenmacher
phone: +49 761 203-73218
sven.kerzenmacher@imtek.uni-freiburg.de

Duration: 04/2014 – 03/2017
www.biomethanol.uni-freiburg.de

KEStro

Wastewater treatment plants as energy storage systems for power grids

Background

The amount of energy provided by renewable sources, e. g. wind and solar power, is constantly increasing. Availability of renewable energy is subject to fluctuations. To balance this fluctuations energy storage systems are required, e. g. pumped-storage reservoirs. Wastewater treatment plants can also be used as energy storage systems. In this project an energy storage system operating in wastewater treatment plants shall be demonstrated. This system consists of a microbial fuel cell as energy source and an electrolysis of micropollutants as energy drain. The development and the testing of these two components and the complete system are the objective of this joint project.

Interim results

In a microbial fuel cell organic waste water ingredients are decomposed at a biofilm-covered electrode what leads to the production of electricity. On the other electrode, a gas diffusion electrode, atmospheric oxygen is reduced to water (hydroxide-ions). The microbial fuel cell was tested under laboratory conditions with synthetic (substrates: acetate and humic matter) and real waste water (return flow from sludge treatment). First tests were carried out in a simple laboratory cell (so called H-cell). Within a few weeks biofilms formed on carbon fleece electrodes. In synthetic waste water the biofilms established faster. The characterization of the biofilm-building bacteria has started. Microscopic methods revealed a significantly higher growth on the electrode compared to the growth in the medium. Switching off the microbial fuel cell temporarily doesn't influence the energy output. Therefore the microbial fuel cell can be used for the stabilization of power grids as intended.

Different gas diffusion electrodes that contained different types of catalysts were characterized electrochemically and tested regarding their suitability as cathode in the microbial fuel cell. It was shown that gas diffusion electrodes are not a limiting factor in the required current and potential region. Biofilms that deposit on the electrodes have no significant influence on the performance. Additionally it was demonstrated that the cell can be operated without a membrane to separate anode and cathode. Based on these results a new laboratory cell with a cylindric geometry was constructed (400 cm^2 anode area, see figure 1). This cell can be operated continuously and serves as a model system for the pilot plant that will be tested in the waste water treatment plant Steinhof (Braunschweig).

The elimination of micropollutants is a two-step process: First micropollutants are adsorbed on activated carbon. In this step no additional energy is required. In times of excess energy supply the activated carbon is polarized electrically what leads to desorption of the micropullotants. These concentrated substances can

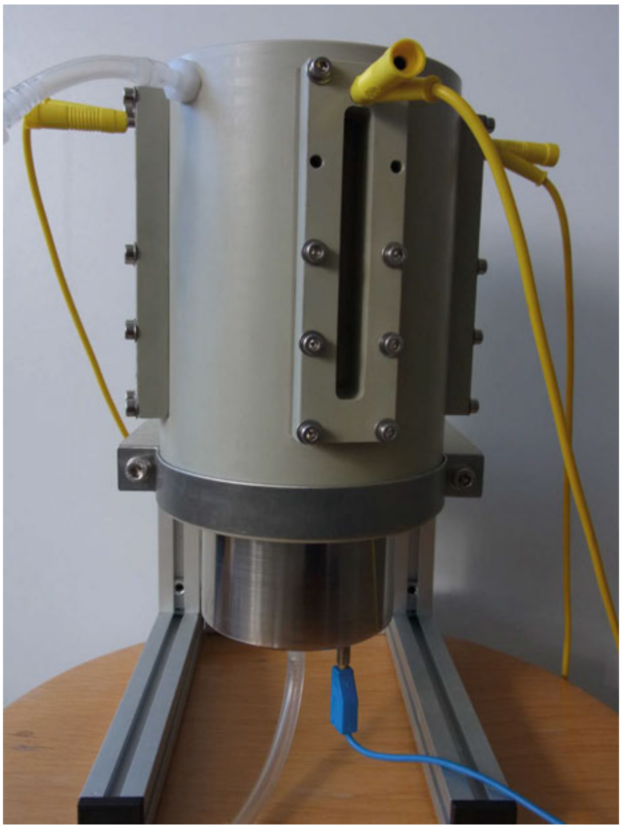


Fig. 1: Microbial fuel cell in lab-scale

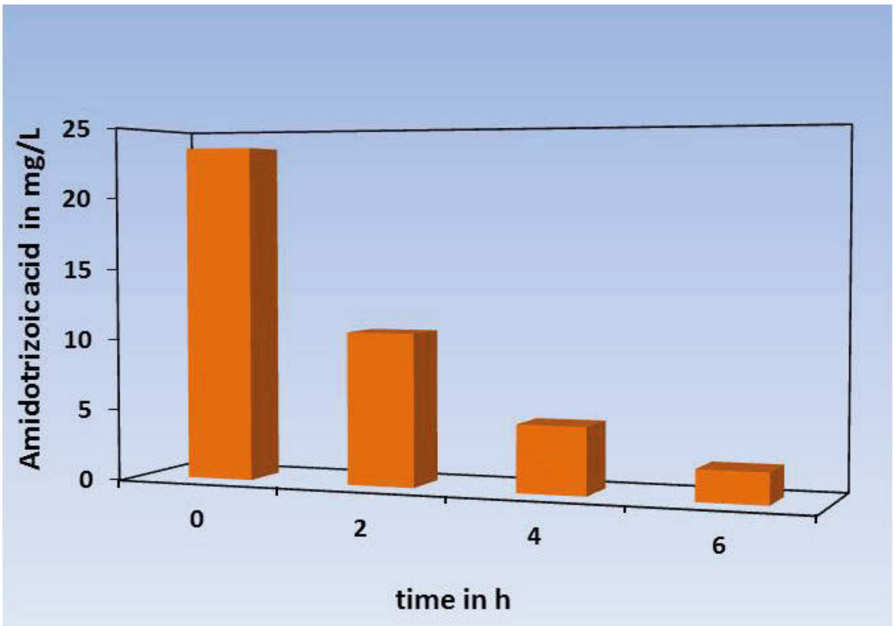


Fig. 2: Decrease of the x-ray contrast agent diatrizoic acid (ATS) during the electrolysis in a flow cell on a boron-doped diamond anode.

be decomposed on the other electrode, a boron-doped diamond electrode. Different porous carbon materials were characterized regarding their adsorption capacity and the most appropriate material was determined. Adsorption and desorption of different organic substances were examined. It was observed that polarization at negative potentials leads to a release of carbon from the activated carbon electrode. In the case of a halogenated x-ray contrast agent the reductive dehalogenation on carbon electrodes was demonstrated. Likewise the oxidative decomposition of these pharmaceuticals on boron-doped diamond electrodes was shown (see figure 2).

Several other pharmaceutical ingredients were decomposed as well. The required potentials and electric currents for desorption and electrochemical decomposition differ strongly. Therefore the two process steps adsorption/desorption and electrolysis were separated from each other and will be performed in two different reactors. Laboratory cells for both reactors were constructed and tested under laboratory conditions.

Outlook

To date it was demonstrated in lab-scale that the combination of microbial fuel cell and electrolysis of micropollutants for the stabilization of power grids can be realized in principle. The next step will be the upscaling of the process. Therefore further work has to be done on the construction of pilot plants that will be tested under real conditions in the waste water treatment plant Steinhof in Braunschweig. Process parameters for the laboratory cells will be optimized and the formation of biofilms, adsorption/desorption and the decomposition of micropollutants will be studied in detail. Based on the data obtained from the pilot-plants an economic consideration for the whole system will be conducted.

Contact:

DECHEMA Research Institute
Theodor-Heuss-Allee 25
60486 Frankfurt
Dr. Klaus-Michael Mangold
phone: +49 69 7564-327
mangold@dechema.de

Duration: 05/2014 – 04/2017
www.kestro.de

arrivee

Wastewater treatment plants as control component in intelligent distribution networks with renewable energy generation

Background

The increasing need for a compensation of severely fluctuating power generation is a result of the ongoing extension of wind and solar power plants. These renewable energy sources depend on their naturel availability, which can cause energy network problems by fluctuating energy supply. This is caused by the abandonment of nuclear power and the reduction of fossil-based energy production, which covered a large part of the basic load and the commitment to raise the part of renewable energy to 80 % by 2050. As a consequence the impact of renewable energy sources will increase. In case of an energy surplus their input cannot be fed into the energy grid and the generators are shut down. In future, that gap between supply and consumption has to be closed by an additional amount of control reserve as well as storage capacities which could be supported by the local water management. The superior function of WWTP is the treatment of (waste-) water which must not be affected in a negative way. Nonetheless the energy potentials of WWTPs have to be taken into account as far as technically and economically feasible.

The core objective of the joint research project "arrivee" is the integration of widely available wastewater treatment plants (WWTP) with anaerobic sludge digestion into an optimized control reserve and storage concept. Therefore the excellent technical conditions of municipal WWTPs, such as combined heat and power (CHP) units as well as gas storage units, will be used and enhanced by using innovative technologies. System services are provided with new developed solutions which are necessary today and in the future to compensate fluctuating energy production (Fig. 1). Therefore external influences on the WWTP are analysed and assessed.

Currently WWTP use the produced digestion gas in most instances for self-sufficiency purposes to reduce the use of external energy sources. In the future WWTP could act as a more active participant in the energy grids. This could be realised by a more energy grid related energy production and smart intermediate storage of the gas. Furthermore WWTPs provide the opportunity to transform energy into a chemical long-term storage matter (methane - CH_4) which can be fed into the natural gas grid and use that stored energy to provide system services in a Power-to-Gas-to-Power concept with multiple synergy effects on (waste-)water treatment and the energy sector.

Interim results

Within the arrivee project a survey of the national anaerobic digestion plants has been performed to determine the potential to provide flexibility via electricity production from existing CHP units throughout Germany. The basis to that potential are the consideration of so far unused gas, efficiency improvements on the plants, conversion of WWTPs from aerobic into anaerobic sludge digestion (if economic feasibility is given) and the use of spare capacities of existing digestion tanks (operation as "sludge assembly centres"). Results show that the actual electricity production of 1.25 TWh/a could be augmented up to 2.11 to 2.61 TWh/a. This corresponds to nearly 300 MW_{el} which is equivalent to around 15 % of the current demand of negative control energy.

To make full use of this potential of WWTP besides the CHP-units, additional flexibility options are identified (Figure 2). Every WWTP differs in operation, size, polluting load and other local boundary conditions. In this regard, different plant concepts are developed to ensure a wide application area. This includes innovative plant concepts using energy surplus in the energy grid to produce hydrogen (H_2) and oxygen via an electrolyser. H_2 and the digestion gas are used to produce high quality methane (Sabatier-reaction) which can be fed into the natural gas grid. With that plant configuration WWTP work as a Power-to-Gas plant and provide long-term energy storage with the additional benefit of producing electric energy with their CHP-units if needed.

The utilization of WWTP as a storage and control unit in energy grids has to be taken into account in conjunction with the regular operation of the WWTP. Negative influences on the purification processes have to be excluded. To ensure this objective a mathematical model of the pilot WWTP has been created, tested and verified with field tests on the pilot plant. Load-shedding was tested for the aerator and the return sludge pumps. So far, no negative impacts have been observed on outlet values for different stress periods and switch-off durations. The possibility to switch on/off plant components to provide flexibility is realised with a developed tiered control concept. To offer that obtained flexibility on the energy markets WWTPs have to be "pooled" in a virtual power plant because a

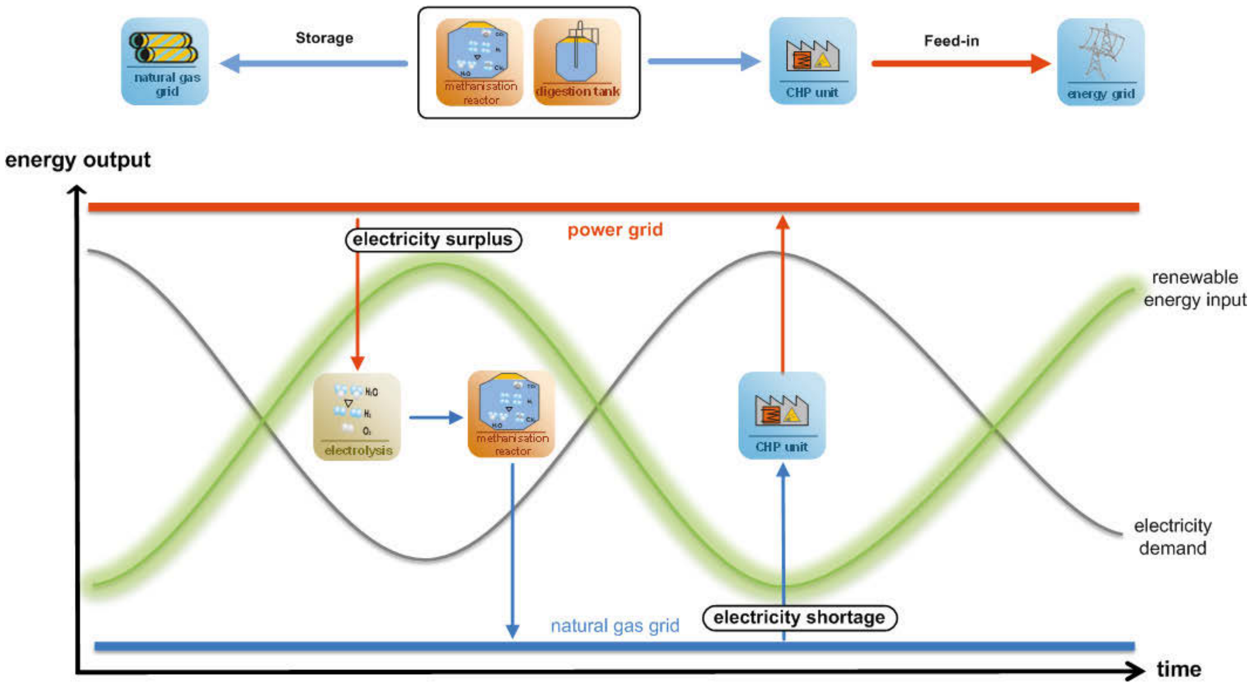


Fig. 1: Depending on the energy grid – storage or supply of energy

single plant can't provide enough power capacity to act on the market individually. These plant pools consist of many small power plants to match the restrictions given by the transmission system operators. To test the impacts of those external interventions measuring and control devices are installed at the pilot WWTP. The flexibility of WWTP can be used for different purposes. Under this aspect today and future markets are determined and rated.

Furthermore an in-depth analysis of significant energy-law relations between the different actors (WWTP, transmission system operators, network operator, and electricity suppliers) was performed. In addition, the current legal and political framework was examined and with regards to the project objectives assessed. With these findings there could no fundamental obstacles or restrictions be identified on providing flexibility with WWTPs. On the contrary, multiple (political) declarations of intent support the objectives of arrivee.

Outlook

Results show that WWTPs in Germany already now could provide 143 MW_{el} and are capable to yield up to 300 MW_{el} by optimising the existing infrastructure. Investigations on load-shedding and switch on onside plant components are continued to provide maximum flexibility for the required services for the energy grid. Along with implementing electrolyses and smart plant management energy surpluses and deficits could be used to enhance energy efficiency and/or store energy instead of losing it by shutting down renewable power plants due to overproduction. Field tests and simulations for the pilot WWTP show that load-shedding doesn't affect the treatment processes significantly under controlled conditions and can be used in a smart control concept. The implementation of PtG-concepts will increase the impact of WWTPs as municipal participant for system services significantly and will show that those plants are capable to operate not only as a consumer, but as a producer of energy on a stable operation of energy grids. Hence WWTPs will become a valuable source of flexible energy production which is needed in the future German energy sector. Furthermore an expert workshop for practitioner, researcher and decision maker will take place on the second quarter of 2016 to develop potential energy market based scenarios. This input will match the requirements from the practical side with the project status and will give an important feedback of the current project status and future development.

Contact:

University of Kaiserslautern
Paul-Ehrlich-Str. 14
67663 Kaiserslautern
Prof. Dr. Theo Schmitt
phone: +49 631 205-2946
theo.schmitt@bauing.uni-kl.de

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www.erwas-arrivee.de

E-Klär

Development and model-based integration of innovative treatment technologies for transformation processes

Background

The project E-Klär aims both at developing technologies and strategies for the best possible use of the energy and other resources contained in wastewater and at reducing the energy demand of wastewater treatment plants (wwtp) in the future. This municipal „waste water treatment plant (wwtp) of the future" will not only cater to today's requirements for nutrient removal. In many cases, further processing steps regarding the elimination of micropollutants and / or pathogens will be included. At the same time the wwtp of the future will recover the energy contained in the wastewater as well as material resources as far as possible.

Interim results

In the first subproject (SP I) innovative processes are being tested in the laboratory as well as in pilot- and full-scale plants. Based on test results and/or literature data, a fact sheet has been prepared to model each process in SP II. Aiming at segregating energy-rich streams from wastewater, pilot-scale tests were performed in the first stage of a two-stage biological process. Full-scale tests have been conducted with a screenings wash press on a first wwtp and are currently taking place at a second location with an optimized wash press. A full-scale fine screen including a fine screenings wash press will be installed at the same site by the end of 2015. Furthermore, laboratory studies are being carried out to improve organics separation by the use of chemicals.

The model for nitrogen removal from sludge centrate or filtrate is being prepared using a one-stage process with sequencing batch reactor and interval aeration. The biological basics of the model have been extended with the appropriate biological parameters and organisms to describe the deammonification process. Tests on inhibitory substances and calibration tests for the biological models were started in batch processes with the selected reference sludge.

The anaerobic digestion of both the sludge treated by a thermal hydrolysis process and a co-substrate from the screenings wash press has been under investigation at a first wwtp since June 2015. Furthermore, a screw press has been under examination for dewatering sludge on four wwtp. After revision work, the screw press will be operated at a wwtp in Brunswick until March 2016.

Currently, information on micropollutants removal and disinfection using ozonation, adsorption on activated carbon, UV disinfection and membrane filtration is being gathered and revised. Tests aiming at assessing effects caused on elimination of micropollutants and disinfection by changing feed conditions are under preparation. Detailed literature reviews on metal concentration and recovery options from wastewater and sludge were undertaken.

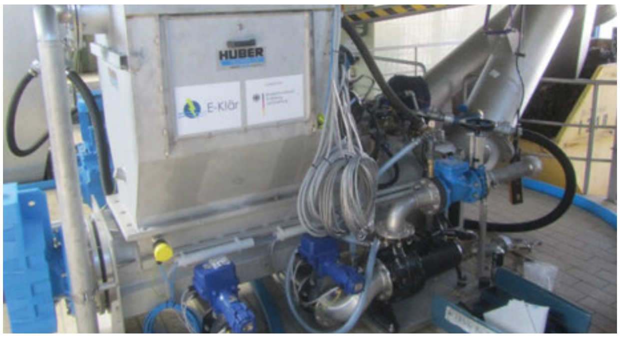

Fig. 1: Screenings wash press investigated in SP I

In the second subproject (SP II) the project partners are developing a method to calculate plant-specific parameters as input values for the selection of the best transformation process towards the wwtp of the future. The conventional mass-flow model is being extended to include energy and costs for the whole wwtp. The overall model will allow the integration of new modular units. In cooperation with SP III, an overall operating procedure has been set up to describe the interactions between model use, results evaluation and the transformation process. The requirements for input and output data of the overall model have been compiled. New results on processes investigated in SP I are being continuously integrated.

The schematic structure of the energy level of the model has been mostly completed. The processes and elements requiring energy were identified. Furthermore, the interface between the mass-flow and energy level was specified, as were further factors influencing the calculations of energy requirements. High resolution data will be collected during a measuring campaign at the wwtp in Schwerte in order to assess the dynamics and sensitivity of each parameter used in the energy calculations. According to the original project schedule, the cost model allowing an estimation of annual costs will be developed during the second half of the project. Furthermore, a second cost model will enable the determination of the best possible time for investment.

In order to evaluate various process combinations and define the best option for the long-term development of a specific wwtp, the overall model is being used at two occasions (Fig. 2). Plant specific indicators are calculated based on the daily data, which are aggregated for the wwtp into annual values for energy, costs and mass flows and projected for the next 50 years. This forecasting calculation requires an accurate assessment of the probable plant operating conditions under various scenarios and is based on historical data. First methodological approaches have been tested to statistically generate data of future operating conditions. The model has been configured for three wwtp of the Ruhrverband that have been chosen to test and improve the methodology.

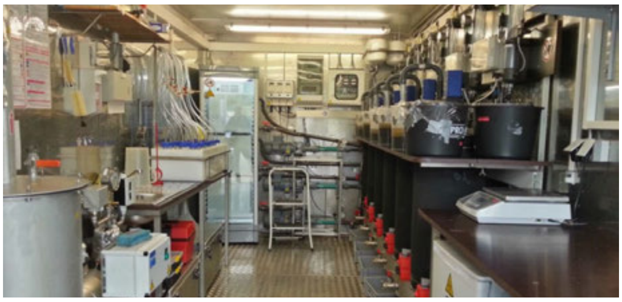

Fig. 2: anaerobic reactors investigated in SP I

An explorative method with a stepwise approach is applied in the third subproject (SP III) to define robust overall concepts for energy-efficient and economic wastewater treatment plants as well as transformation pathways towards these plants. The method consists of following steps: (a) determination of the context or "storyboard" (wwtp location, assessment aims); (b) definition of the options for action and scenarios; (c) evaluation of the wwtp chosen for the future; and (d) analysis and choice of the pathway to reach this future state. The method helps finding the right strategy for a sustainable development of the wwtp and can incorporate innovative processes. It prepares recommendation for investment in future steps. The high forecasting uncertainty of influencing factors can be accounted for in long-term investment decisions in order to reduce the risk of bad investments.

Through many discussions, partners from different disciplines found a largely congruent comprehension of the methodical approach, of the information and data requirements as well as of the further steps. Interactions and dependencies were agreed upon between the subprojects and data transfer was organized.

The stepwise approach has been differentiated and is currently being adapted to three real wwtp, which serve as case studies. The first case study is the wwtp in Wickede. For this plant, the relevant options for action were narrowed down according to its storyboard (step (a) of the stepwise approach). The structure of the scenarios was established for step (b). Currently, empirical data and plant information are being inspected; forecasting values are being integrated into the scenarios.

Project partners are currently seeking for an appropriate method to assess indicators on the treatment processes under different plant operating conditions. These indicators are supplied by the overall model (SP II) and will be required to implement further steps.

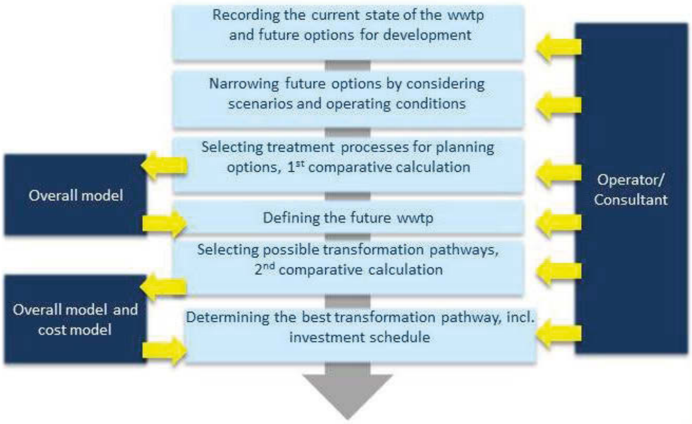

Fig. 3: Operating procedure describing the interactions between model use, results evaluation and the transformation process

Outlook

In the second half of the project, the innovative processes will be investigated further. Relevant indicators and parameters will be gathered under various operating conditions. The cost level of the model will be further developed and integrated in the overall model. The stepwise approach will be applied to the three wwtp selected as case studies. The following steps will be undertaken: Forecasting of future operating conditions, comparative calculation of various treatment process chains, definition of the wwtp of the future, and analysis of the best transformation pathway.

Contact:

Institute of Environmental Engineering,
RWTH Aachen University
Templergraben 55
52062 Aachen
Prof. Dr. Johannes Pinnekamp
phone: +49 241 80-25207
pinnekamp@isa.rwth-aachen.de

Duration: 05/2014 – 04/2017
www.e-klaer.de

ESiTI

Wastewater treatment plant of the future: energy storage in interaction with technical infrastructure between the poles of energy generation and consumption

Background

Due to the change from fossil resp. nuclear energy sources to renewable energy sources, the energy sector worldwide is experiencing a major challenge. As renewable energy sources show volatile generation characteristics, there is increasing need for flexible capacities in the power supply system that cover the remaining electricity demand resp. handle the surplus from wind and solar energy. The expansion of renewable energy generation is accompanied by the removal of conventional and controllable plants that up to now have guaranteed grid stability. In a smart grid, these functions must be covered more and more by other flexible power generating and consuming plants. The changing requirements regarding energy management offer high potentials for wastewater treatment plants (WWTP) as major energy consumer, but, at the same time, energy producer by biogas utilization. Flexible load management facilitates the optimization of the WWTP's energy management and allows for additional income in its role as energy provider.

Within the frame of the joint research project "Wastewater treatment plant of the future: energy storage in interaction with technical infrastructure between the poles of energy generation and consumption (ESiTI)", the crosslinking of energy consumption and generation of the WWTP as energy storage is investigated (www.esiti.de). Investigations are carried out using the municipal WWTP Darmstadt with its 240,000 population equivalents as example. While complying with its major task of wastewater treatment, the focus is on flexibilized energy generation.

Interim results

Based on the registration of the energy flows at the WWTP Darmstadt, recorded with a high data resolution down to minute values, the generation and consumption of electricity was evaluated – in contrast to previous investigations – also as diurnal variations. The need of flexibilization of municipal WWTP and its activation time is hereby based on the demand of the energy sector (Fig. 1).

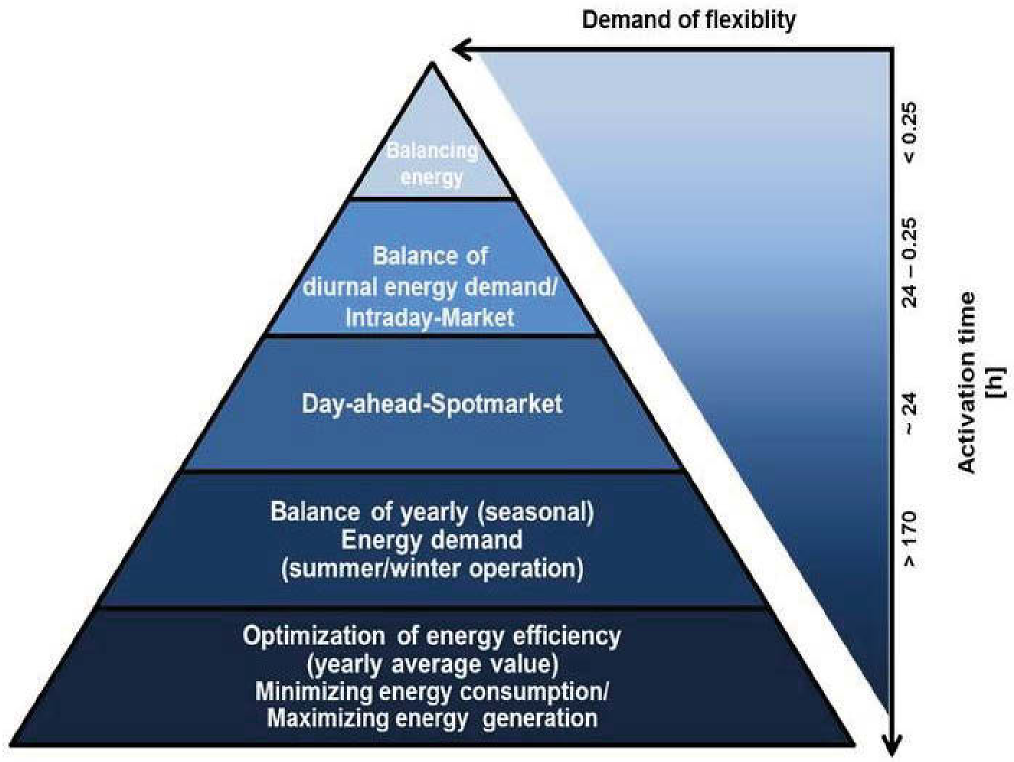

Fig. 1: Level of flexibilization and activation time as a function of the optimization goal

Flexibilization can be realized using the following different management strategies that are subject of the current investigations. The target of load management, as already been (partly) realized in practice, is the balancing of power demand and generation on a diurnal basis to the greatest possible extent. Here, the focus is on intelligent controlling of state-of-the-art-technologies ideally combined with innovative technologies for increasing the biogas generation, e.g. via co-substrates (Fig. 2). Sewage sludge resp. co-substrates with their chemically bound energy will become energy storages, whereby in particular co-substrates with easily degradable ingredients are predestinated for load peaks. The comparison of energy densities shows that the storage of chemically bound energy in the form of primary/surplus sludge as well as co-substrates with an energy density of 0.03 – 0.2 kWh_{el}/kg is in a similar magnitude as that of batteries.

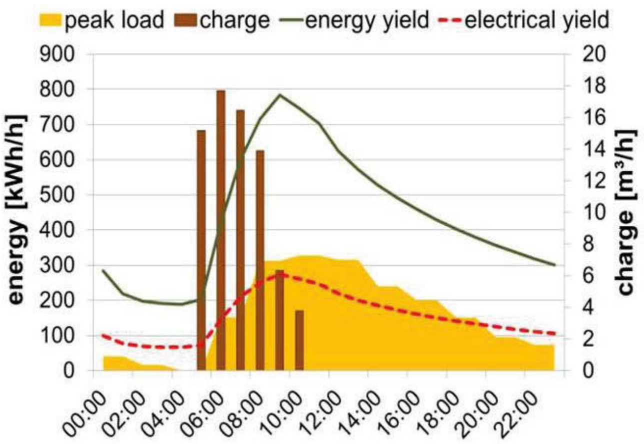

Fig. 2: Charging strategy for sewage sludge with regard to biogas generation

The price for electricity at the short-term electricity markets (day-ahead or intra-day) is subject to severe fluctuations, whereby the cost structure is changing due to the volatility of renewable energies. By participating in the spot markets, foreign power is consumed during low-tariff periods resp. self-produced power is used during high-tariff periods. The supply of balancing energy is needed to compensate imbalances between power generation and demand. The positive balancing energy is the capacity that – in case of need – compensates an underproduction on the power market and feeds electricity into the grid. Negative balancing energy, in contrast, is defined as the capacity that is needed for storing or retaining electricity. Looking at the WWTP Darmstadt, it is solely with the capacity of the CHPs that revenues can be achieved by participating in the electricity balancing market. The cooperation is hereby realized via a virtual power plant with other providers from the electricity balancing market.

The required operation procedures for characterizing substrates and technologies are investigated at various laboratory and pilot plants within the work package „Technology". The objective is to assess – based on key figures – the flexibilization potential of the respective technology resp. substrate. The focus is on technologies such as thermal pressure hydrolysis for sludge disintegration, conventional digestion and digestion with downstream microfiltration membrane for decoupling digestion and hydraulic retention time. Peripheral dependencies are also looked at. Furthermore, sewage sludge drying and incineration including phosphorus recovery are taken into account regarding their role within the future demands on WWTPs.

Fig. 3: Digestion test plant

Outlook

Based on the test results, technology modules are to be developed that – combined with indicators of multi-criteria evaluation – will be assessed using economical, ecological, technological and sociopolitical criteria. Presently, an expert survey is prepared to determine the weighting of criteria/indicators for multi-criteria investigation of the process variants. Further, an evaluation tool for supporting decision-making by different stakeholders groups (politicians, economists and engineers) will be developed.
The consolidation of the technology modules, their assessment and the needs of WWTPs regarding flexibilization resp. their boundary conditions will be compiled in a manual to be used as assessment tool and to be validated using the WWTP Darmstadt as example.

Contact:

TU Darmstadt, Institute IWAR
Franziska-Braun-Str. 7
64287 Darmstadt
Prof. Dr. Peter Cornel
phone: +49 6151 16-27 48
p.cornel@iwar.tu-darmstadt.de

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www.esiti.de

KRN-Mephrec

Transforming sewage sludge to energy, fertiliser and iron in a single step using metallurgical phosphorus recycling

Background

In Germany wastewater treatment produces about 7.5 million tons of drained sewage sludge. Almost all pollutants, which are flushed with sewage into the wastewater treatment plant, can be found within this sewage sludge. With regard to the environmental impact these are highly toxic organic and metallic compounds, but on the other hand valuable resources which should be recycled. The caloric value of the sewage sludge after drying is comparable to brown coal. As valuable substance, metals, and especially the scarce phosphor, are interesting. This element is listed as critical natural resource in Europe, whereas about half of the German demand could be covered by sewage sludge.

The economical solution of this task is probably not the single process of pyrolysis, combustion or gasification, but the combination of these processes in one step. The objective is, to separate a fluid, light mineral scoria from the heavy metal melting within phases of different density.

The joint research project “Sewage sludge processing of the region Nuremberg with metal phosphor recycling” (KRN-Mephrec) in this respect analyses the traditional melting processes of metal smelting. What succeeded at experimental stage will be tested as experimental reactor at semi-technical scale and developed further, so that it will be possible to decide about an economically large-scale plant.

Interim results

The technological concept as modified cupola furnace was elaborated. Instead of iron scrap, iron-containing sewage sludge is melted. Instead of srcap iron ferrous sewage sludge is melted.

The carbon-rich organic of the sewage sludge generates carbon-rich synthesis gas. The melting products of the experiment in TU Bergakademie Freiberg/Germany were tested and are free of organic residuals. All heavy metals, including uranium, are neutralized within the ferrous alloy. The phosphor-rich scoria has the quality of fertilizers, which are appropriate for organic farming. Besides a minor amount of fly ash and the purification products occurring due to the usage of the synthesis gases, no waste emerges.

The first sub-process of the procedure is the drying and provision of the sewage sludge. The quality and structure of the starting product were analysed chemically within a multi-annual study. To attain a low-dust dry substance, a belt drier was chosen which meets the degree of drying of 90 per cent dry substance. There will be dried 6,700 Mg sewage sludge to sewage sludge pellets within this project.

In the second step, the pellets will be pressed to stable briquettes. The different procedures of briquetting were tested by experiments. Due to these results, stamping presses were chosen which form especially concrete, stable and cylindrical briquettes. For the pilot project, an efficient briquetting plant is now in fabrication.

The constructive specifications for construction and operation of the furnace are defined. The thermo-chemical process of melt-gassing process takes place in

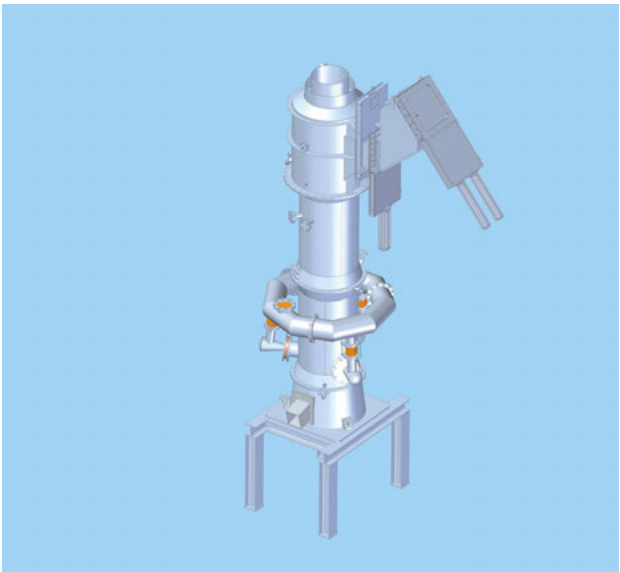

Fig. 1: Conduction planning of the reactor (Source: Baumgarte Boiler Systems GmbH)

one step within the shaft furnace which is designed in a way that pyrolysis, gasification and melting take place in different zones under monitored conditions. With this procedure the risk of bridging and sintering should be reduced.

The performance of gasification and melting of the briquettes was analysed with experiments to gather conclusions about the manner of the furnace installation. The design of the refractory lining of the furnace is based on the thermo-chemical performance tested within former experiments. The cladding of the furnace is double-walled with a water cooling system. For the operation, a specific hot blast and pure oxygen injection will be installed.

The emerging synthesis gas will be tested exactly in respect of fuel quality and its composition (i.a. tar content, CxHy, SOx). The furnace operation and the purification of the synthesis gas can be modified during the experimental phase to produce a high quality mixture of gases if possible.

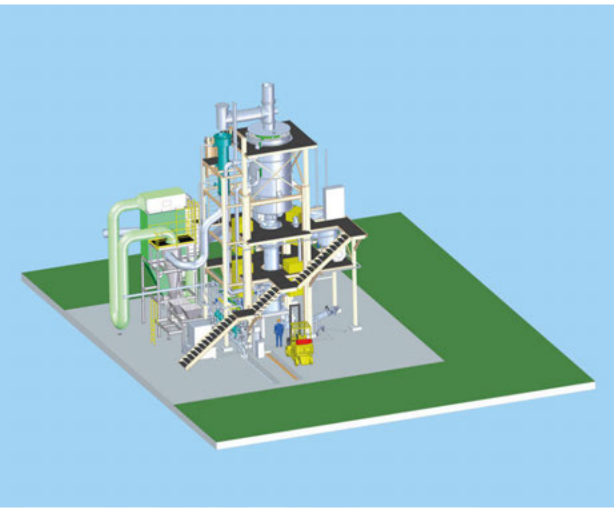

Fig. 2: View of the experimental plant with shaft furnace and waste air treatment (without preceding operational plant and building) (Source: Klärschlammverwertung Region Nürnberg GmbH)

Outlook

The planning process is completed, the components of the pilot plant are defined and the accompanying test programme is created. The construction and operation of the plant is authorised by the integrated authorization process in accordance with the federal immission control ordinance. Within five milestones, the approval of construction and operation and the procurement of operating material took place.

The extensive infrastructure at the wastewater treatment plant Nuremberg develops. The plant components shaft furnace, recuperator and waste gas treatment are ordered at specialist firms and will be installed at the beginning of 2016. Special components, which affect the furnace´s inflow and outflow, will be optimised from the operational point of view. In January 2016 the construction of the furnace will start. The cold initial operation will start in April 2016. The warm initial operation will be performed under instruction of an experienced production engineer with the support of various specialist engineers and technicians.

Initially, multiple short experiments will be conducted to test the infrastructure and the furnace construction. After these tests, longer operational phases to optimise the operating resource consumption, the production of synthesis gas and the melting results will follow. The quality of the phosphor scoria will be varied in its substantial and mineralogical structure and the loss-free segregation of the iron will be maximized.

The furnace will be operated in a long duration test for several weeks around the clock to gain insights in long-term usage and the need for improvement within the components of the plant.

Within an additional operational phase, sewage sludge ash of a further joint research partner will be melted to gain additionally insights about applicability and profitability of the melt-gassing process within two-stage procedure as supplement to mono-incineration plants.

The various measurement series will be evaluated by scientific institutes and the results will be assessed. The produced products will be trialled to gauge the quality and potential of the recycling. Based on these results, the ecological and economic contribution to energetic and material recycling of the sewage sludge will be classified.

Contact:

Klärschlammverwertung
Region Nürnberg GmbH
Adolf-Braun-Str. 33 • 90429 Nürnberg
Burkard Hagspiel
phone: +49 911 231-4520
burkard.hagspiel@stadt.nuernberg.de

Duration: 11/2014 – 04/2017
www.nuernberg.de/internet/klaerschlammverwertung

Contact data of the project partners

arrivee

Project coordination
University of Kaiserslautern, Institute of Urban Water Management
Paul-Ehrlich-Str. 14
67663 Kaiserslautern
Prof. Dr. Theo Schmitt
phone: +49 631 205-29 46
theo.schmitt@bauing.uni-kl.de

Project partners
University of Wuppertal
Rainer-Gruenter-Str. 21
42119 Wuppertal
Prof. Dr. Markus Zdrallek
phone: +49 202 439-19 76
zdrallek@uni-wuppertal.de

iGas GmbH
Bonner Str. 305 • 42697 Solingen
Karl-Heinz Lentz
phone: +49 212 88 09-33
kh.lentz@igas-engineering.de

ITB – Institut für Innovation, Transfer und Beratung gemeinnützige GmbH
Berlinstr. 107 A
55411 Bingen am Rhein
Prof. Dr. Ralf Simon
phone: +49 6721 98 424-25 90
simon@tsb-energie.de

Stadtwerke Radevormwald GmbH
Am Gaswerk 13
42477 Radevormwald
Christoph Richtarski
phone: +49 2195 91 31-0
c.richtarski@s-w-r.de

Wupperverband
Untere Lichtenplatzer Str. 100
42289 Wuppertal
Dirk Salomon
phone: +49 202 583-114
sal@wupperverband.de

Wupperverbandsgesellschaft für integrale Wasserwirtschaft mbH – WiW
Untere Lichtenplatzer Str. 100
42289 Wuppertal
Dr. Gerd Kolisch
phone: +49 49 202 583-0
kol@wupperverband.de

BioBZ

Project coordination
Clausthal Institute of Environmental Technology (CUTEC-Institute), Dep. Wastewater Process Engineering
Leibnizstr. 21+23
38678 Clausthal-Zellerfeld
Prof. Dr. Michael Sievers
phone: +49 53 23 933-243
michael.sievers@cutec.de
Dr. Torsten Zeller
phone: +49 53 23 933-206
torsten.zeller@cutec.de

Project partners
DVGW test laboratory at the Engler-Bunte-Institut of the Karlsruhe Institute of Technology (KIT)
Engler-Bunte-Ring 1
76131 Karlsruhe
Prof. Dr. Harald Horn
phone: +49 721 608-42581
harald.horn@kit.edu

Eisenhuth GmbH & Co. KG
Friedrich-Ebert-Str. 203
37520 Osterode am Harz
Dr. Thorsten Hickmann
phone: +49 5522 9067-14
t.hickmann@eisenhuth.de

EURAWASSER Betriebsführungsgesellschaft mbH
Odermarkplatz 1 • 38640 Goslar
Sabrina Lohmar
phone: +49 5321 33 76-63
sabrina.lohmar@eurawasser.de

TU Braunschweig, Institute of Environmental and Sustainable Chemistry
Hagenring 30 • 38106 Braunschweig
Prof. Dr. Uwe Schröder
phone: +49 531 391-84 25
uwe.schroeder@tu-bs.de
Prof. Dr. Robert Kreuzig
phone: +49 531 391-59 61
r.kreuzig@tu-braunschweig.de

TU Clausthal, Institute of Chemical Process Engineering
Leibnizstraße 17
38678 Clausthal-Zellerfeld
Prof. Dr. Ulrich Kunz
phone: +49 5323 72-2534
kunz@icvt.tu-clausthal.de

BioMethanol

Project coordination
University of Freiburg, IMTEK – Department of Microsystems Engineering
Georges-Koehler-Allee 103
79110 Freiburg
Dr. Sven Kerzenmacher
phone: +49 761 203-732 18
sven.kerzenmacher@imtek.uni-freiburg.de
Institute for Inorganic and Analytical Chemistry (Project management)
Albertstr. 21 • 79104 Freiburg
Prof. Dr. Ingo Krossing
phone: +49 761 203-61 22
krossing@uni-freiburg.de

Project partners
Fraunhofer-Institute for Solar Energy Systems, Hydrogen Production and Storage
Heidenhofstraße 2 • 79110 Freiburg
Dr. Achim Schaadt
phone: +49 761 4588-5428
achim.schaadt@ise.fraunhofer.de

Karlsruhe Institute of Technologie (KIT), Institute for Applied Biosciences
Fritz-Haber-Weg 2 • 76131 Karlsruhe
Prof. Dr. Johannes Gescher
phone: +49 721 608-419 40
johannes.gescher@kit.edu

Solvay Acetow GmbH
Engesserstr. 8
79108 Freiburg im Breisgau
Dr. Dirk Hölter
phone: +49 761 511-35 98
dirk.hoelter@solvay.com

E-Klär

Project coordination

RWTH Aachen, Institute of Environmental Engineering
Templergraben 55 • 52062 Aachen
Prof. Dr. Johannes Pinnekamp
phone: +49 241 80-25207
pinnekamp@isa.rwth-aachen.de

Project partners

CAMBI Deutschland GmbH
Schraderstr. 37 • 67227 Frankenthal
Henrik Kruchen
phone: +49 151 24024845
henrik.kruchen@cambi.no

DHI-WASY GmbH
Max-Planck-Straße 6 • 28857 Syke
Arne Hammrich
phone: +49 4242 163816
arh@dhigroup.com

E&P Anlagenbau GmbH
Mariannenstr. 38 • 12209 Berlin
Kerstin Zacherl-John
phone: +49 8122 8471879
ep.kerstin.john@t-online.de

Huber SE
Industriepark Erasbach A1
92334 Berching
Dr. Stefania Paris
phone: +49 8462 201-744
ps@huber.de

University of Hannover, Institute for Sanitary Engineering and Waste Management
Welfengarten 1 • 30167 Hannover
Prof. Dr. Karl-Heinz Rosenwinkel
phone: +49 511 762-2276
rosenwinkel@isah.uni-hannover.de

Ruhrverband
Postfach 10 32 42 • 45128 Essen
Dr. Dieter Thöle
phone: +49 201 178-2546
dth@ruhrverband.de

University of Braunschweig, Institute of Sanitary and Environmental Engineering
Pockelsstr. 14 • 38106 Braunschweig
Prof. Dr. Norbert Dichtl
phone: +49 531 391-79 35
n.dichtl@tu-braunschweig.de

University of Leipzig, Institute for Infrastructure and Resources Management
Grimmaische Straße 12
04109 Leipzig
Prof. Dr. Robert Holländer
phone: +49 341 973-3870
hollaender@wifa.uni-leipzig.de

Xylem Services GmbH
Boschstr. 4-14 • 32051 Herford
Arne Wieland
phone: +49 5221 930 129
arne.wieland@xyleminc.com

ENERWA

Project coordination
IWW Water Centre (Rheinisch-Westfälisches Institut für Wasserforschung gGmbH)
Moritzstr. 26
45476 Mülheim an der Ruhr
Dr. Wolf Merkel
phone: +49 208 403 03-100
w.merkel@iww-online.de
Anja Rohn
phone: +49 208 403 03-384
a.rohn@iww-online.de

Project partners
Aggerverband
Sonnenstr. 40 • 51645 Gummersbach
Dieter Wonka
phone: +49 22 61 36-350
won@aggerverband.de

University Wuppertal, Forschungsstelle Bürgerbeteiligung
Gaußstr. 20 • 42119 Wuppertal
Prof. Dr. Hans-Joachim Lietzmann
phone: +49 202 257 95 40
hans.j.lietzmann@uni-wuppertal.de

enwor – energie & wasser vor ort GmbH
Kaiserstr. 86 • 52134 Herzogenrath
Stephan Hunze
phone: +49 24 07 579-14 00
stephan.hunze@enwor-vorort.de

Research Institute for Water and Waste Management, German abbreviation: FiW
Kackertstr. 15-17 • 52072 Aachen
Dr. Friedrich-Wilhelm Bolle
phone: +49 241 80-268 27
bolle@fiw.rwth-aachen.de

Rechenzentrum für Versorgungsnetze Wehr GmbH
Wiesenstr. 21 • 40549 Düsseldorf
Dr. Dirk König
phone: +49 211 60 12 73-18
d.koenig@rzvn.de

RWTH Aachen, Institute of Power Systems and Power Economics
Schinkelstraße 6 • 52062 Aachen
Daniel Schweer
phone: +49 241 80-97659
daniel.schweer@iaew.rwth-aachen.de

RWW Rheinisch-Westfälische Wasserwerksgesellschaft mbH
Am Schloß Broich 1-3
5479 Mülheim an der Ruhr
Ronald Roepke
phone: +49 208 44 33-738
ronald.roepke@rwe.com

SYDRO CONSULT GmbH
Mathildenplatz 8
64283 Darmstadt
Dr. Hubert Lohr
phone: +49 6151 367-367
h.lohr@sydro.de

University Duisburg-Essen, Department Aquatic Ecology
Universitätsstr. 5 • 45141 Essen
Prof. Dr. Bernd Sures
phone: +49 201 183-26 17
bernd.sures@uni-due.de

WAG Wassergewinnungs- und aufbereitungsgesellschaft Nordeifel mbH
Am Filterwerk • 52159 Roetgen
Walter Dautzenberg
phone: +49 2471 17-61 00
walter.dautzenberg@enwor-vorort.de

Wupperverband
Untere Lichtenplatzer Str. 100
42289 Wuppertal
Dr. Torsten Frank
phone: +49 202 583-332
tfkn@wupperverband.de

EnWasser

Project coordination
Fraunhofer Institute for Wind Energy and Energy System Technology
Königstor 59 • 34119 Kassel
Patrick Hochloff
phone: +49 561 72 94-214
patrick.hochloff@iwes.fraunhofer.de

Project partners
Capgemini Deutschland GmbH
Potsdamer Platz 5 • 10785 Berlin
Dr. Jörg Katzfey
phone: +49 221 91 26 44-482
joerg.katzfey@capgemini.com

IHS Universität Stuttgart
Pfaffenwaldring 10
70550 Stuttgart
Dr. Albert Ruprecht
phone: +49 711 685-632 56
ruprecht@ihs.uni-stuttgart.de

Lake Constance Water Supply Association (BWV)
Hauptstr. 163 • 70563 Stuttgart
Matthias Weiß
phone: +49 711 973-22 18
matthias.weiss@zvbwv.de

ESiTI

Project coordination
TU Darmstadt, Institute IWAR, Department of Wastewater Technology and Department of Material Flow and Resource Management
Franziska-Braun-Str. 7
64287 Darmstadt
Prof. Dr. Peter Cornel
p.cornel@iwar.tu-darmstadt.de
Dr. Christian Schaum
phone: +49 6151 16 20319
c.schaum@iwar.tu-darmstadt.de
Prof. Dr. Liselotte Schebek
(Projektbearbeitung)
phone: +49 6151 16-31 41
l.schebek@iwar.tu-darmstadt.de

Project partners
Clausthal Institute of Environmental Technology (CUTEC-Institute)
Leibnizstr. 21+23
38678 Clausthal-Zellerfeld
Prof. Dr. Michael Sievers
phone: +49 5323 933-243
michael.sievers@cutec.de

Dr. Born - Dr. Ermel GmbH
Finienweg 7 • 28832 Achim
Jörn Franck
phone: +49 4202 758-0
jf@born-ermel.de

EnviroChemie GmbH
In den Leppsteinswiesen 9
64380 Roßdorf
Dr. Markus Engelhart
phone: +49 6154 69 98-57
markus.engelhart@envirochemie.com

Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB
Nobelstraße 12 • 70569 Stuttgart
Dr. Ursula Schließmann
phone: +49711 970-42 22
ursula.schliessmann@igb.fraunhofer.de

ENTEGA Abwasserreinigung GmbH & Co. KG
Frankfurter Str. 110
64293 Darmstadt
Dr. Julia Klinger
phone: +49 6151 701-40 98
abwasser@entega.ag

inter 3 GmbH, Institute for Resource Management
Otto-Suhr-Allee 59 • 10585 Berlin
Dr. Shahrooz Mohajeri
phone: +49 30 34 34 74-40
mohajeri@inter3.de

bluemove Consulting gmbh
Kellerbachstraße 8 • 82335 Berg
phone: +49 175 2232144
dornburg@bluemove-consulting.de

EWave

Project coordination
University of Erlangen-Nürnberg
Cauerstraße 11 • 91058 Erlangen
Prof. Dr. Alexander Martin
phone: +49 9131 85-67163
alexander.martin@math.uni-erlangen.de

Project partners
Bilfinger GreyLogix aqua GmbH
Heidenkampsweg 101
20097 Hamburg
Olaf Kremsier
phone: +49 4023 533 39-91
o.kremsier@greylogix.de

Bonn-Rhein-Sieg University of Applied Sciences, Department of Electrical Engineering, Mechanical Engineering and Technical Journalism
Grantham-Allee 20
53757 Sankt Augustin
Prof. Dr. Gerd Steinebach
phone: +49 2241 865-330
gerd.steinebach@h-brs.de

RWW Rheinisch-Westfälische Wasserwerksgesellschaft mbH
Am Schloß Broich 1-3
45479 Mülheim an der Ruhr
Ronald Roepke
phone: +49 208 4433-738
ronald.roepke@rwe.com
Dr. Michael Plath
phone: +49 208 4433-629
michael.plath@rwe.com

Siemens AG, Industry Sector
Gleiwitzer Str. 555
90475 Nürnberg
Dr. Andreas Pirsing
phone: +49 911 895-71 07
andreas.pirsing@siemens.com

University of Darmstadt, Department of Mathematics
Dolivostr. 15 • 64293 Darmstadt
Prof. Dr. Jens Lang
phone: +49 6151 16-2389
lang@mathematik.tu-darmstadt.de

EWID

Project coordination
Universität der Bundeswehr München, Institute of Hydro Sciences, Sanitary Engineering and Waste Management
Werner-Heisenberg-Weg 39
85579 Neubiberg
Prof. Dr. F. Wolfgang Günthert
phone: +49 89 6004-21 56
wolfgang.guenthert@unibw.de
Frank Krönlein
phone: +49 89 6004-26 16
frank.kroenlein@unibw.de
Salomé Parra
phone: +49 89 6004-2231
salome.parra@unibw.de

Project partners
AWA-Ammersee Wasser- und Abwasserbetriebe gKU
Mitterweg 1 • 82211 Herrsching
Thomas Tinnes
phone: +49 8152 91 83-503
tinnes@awa-ammersee.de

Dr. Krätzig Ingenieurgesellschaft mbH
Süsterfeldstr. 81 • 52072 Aachen
Dr. Thomas Krätzig
phone: +49 241 88 973-0
infoline@dr-kraetzig.com

KSB Aktiengesellschaft
Johann-Klein-Str. 9
67227 Frankenthal
Traugott Ulrich
phone: +49 6233 86-29 63
traugott.ulrich@ksb.com

Schraml GmbH
Herxheimer Str. 7
83620 Feldkirchen-Westerham
Dr. Stephanie Schraml
phone: +49 8062 70 71-17
stephanie.schraml@schraml.de

Wasserversorgungszweckverband Perlenbach
Am Handwerkerzentrum 31
52156 Monschau
Derk Buchsteiner
phone: +49 2472 9916-10
derk.buchsteiner@wasserwerk-perlenbach.de

H_2Opt

Project coordination
Technical University of Kaiserslautern, Institute for Fluid Mechanics and Turbomachinery
Gottlieb-Daimler-Str. 47
67663 Kaiserslautern
Prof. Dr. Martin Böhle
phone: +49 631 205-27 60
martin.boehle@mv.uni-kl.de
Dr. Harald Roclawski
phone: +49 631 205-43 08
roclawsk@mv.uni-kl.de

Project partners
EWR Netz GmbH
Klosterstr. 16 • 67547 Worms
Wolfgang Hausen
phone: +49 6241 848-530
hausen@ewr.de

Fraunhofer-Institute for Industrial Mathematics
Fraunhofer Platz 1
67663 Kaiserslautern
Dr. Michael Bortz
phone: +49 631 316 00-45 32
michael.bortz@itwm.fraunhofer.de

Obermeyer Planen + Beraten GmbH
Brüsseler Straße 5
67657 Kaiserslautern
Kasimir Mazur
phone: +49 631 303 29-177
kasimir.mazur@opb.de

SWK Stadtwerke Kaiserslautern Versorgungs-AG
Karcherstraße 28
67655 Kaiserslautern
Hilmar Württemberger
phone: +49 631 80 01-40 37
hilmar.wuerttemberger@swk-kl.de

KEStro

Project coordination
DECHEMA Research institute
Theodor-Heuss-Allee 25
60486 Frankfurt
Dr. Klaus-Michael Mangold
phone: +49 69 75 64-327
mangold@dechema.de

Project partners
Abwasserverband Braunschweig
Celler Str. 22 • 38176 Wendeburg
Bernhard Teiser
phone: +49 5303 509-11
bernhard.teiser@abwasserverband-bs.de

CONDIAS GmbH
Fraunhoferstr. 1 b • 25524 Itzehoe
Dr. Thorsten Matthée
phone: +49 4821 804 087-0
matthee@condias.de

DVGW – Water Technology Center (TZW)
Karlsruher Straße 84
76139 Karlsruhe
Prof. Dr. Andreas Tiehm
phone: +49 721 96 78-137
an dreas.tiehm@tzw.de

WaCo Wassertechnik Consult GmbH
Grottenstr. 3 • 22605 Hamburg
Dr. Oliver Debus
phone: +49 40 822 770-0
waco@wassertech.de

KRN-Mephrec

Project coordination
Klärschlammverwertung Region Nürnberg GmbH
Adolf-Braun-Str. 33
90429 Nürnberg
Burkard Hagspiel
phone: +49 911 231-45 20
burkard.hagspiel@stadt.nuernberg.de

Project partners
Fraunhofer Institute for Environmental, Safety, and Energy technology
An der Maxhütte 1
92237 Sulzbach-Rosenberg
Sonja Wiesgickl
phone: +49 9661 9084-423
sonja.wiesgickl@umsicht.fraunhofer.de

Institute for Energy and Environmental Research Heidelberg GmbH
Wilckensstraße 3
69120 Heidelberg
Horst Fehrenbach
phone: + 49 6221 4767-16
horst.fehrenbach@ifeu.de

INNOVATHERM Gesellschaft zur innovativen Nutzung von Brennstoffen mbH
Frydagstraße 47
44536 Lünen
Ute Blöthe
phone: +49 2306 92823-23
ub@innovatherm-gmbh.de

RWTH Aachen, Institute of Environmental Engineering
Templergraben 55
52062 Aachen
Prof. Dr. Johannes Pinnekamp
phone: +49 241 80-25207
isa@isa.rwth-aachen.de

Baumgarte Boiler Systems GmbH
Senner Str. 115
33647 Bielefeld
Gerald Gruener
phone: +49 521 9406-168
Ggruener@baumgarte.com

Universität der Bundeswehr München, Institute of Hydro Sciences, Sanitary Engineering and Waste Management
Werner-Heisenberg-Weg 39
85579 Neubiberg
Prof. Dr. F. Wolfgang Günthert
phone: + 49 89 6004-2156
wolfgang.guenthert@unibw.de

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Publisher:
DWA – German Association for Water, Wastewater and Waste
Theodor-Heuss-Allee 17 • 53773 Hennef
phone: +49 2242 872-333 • fax: +49 2242 872-100
info@dwa.de • www.dwa.de

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Contributions:
Coordinators of the ERWAS joint research projects,
Partners of the networking and transfer project ERWASNET

Contacts:
Contact person at BMBF:
Dr. Helmut Löwe – German Federal Ministry of Education and Research (BMBF)
Department 724 – Ressources and sustainability • 53170 Bonn
phone: +49 228 9957-2110 • helmut.loewe@bmbf.bund.de

Contact person at Project Management Agency:
Dr. Thomas Deppe – Project Management Ressources and Sustainability
Project Management Agency Karlsruhe, Water Technology and Waste Management Division
Karlsruhe Institute of Technology, Dresden branch
Hallwachsstr. 3 • 01069 Dresden
phone: +49 351 463-31443 • thomas.deppe@kit.edu

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