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Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

Water in sufficient quantity and quality is fundamental for human health, the sustainable development of regions and an intact environment. However, water is becoming scarce not only in arid areas, but in many regions of the world. The ability to adequately supply households, agriculture and industry with water is becoming an ever greater global challenge. Water demand will drastically increase worldwide in the coming years. Main reasons are population growth, increasing industrial and agricultural activities and the expansion of metropolitan areas. At the same time, the availability of water is already severely limited and is even declining regionally. Contaminated and over-exploited water resources, climate change and the uneven distribution of supplies are contributory factors.

Against this background, the Federal Ministry of Education and Research (BMBF) has launched the funding measure "Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination" (WavE) within the framework programme "Research for Sustainable Development" (FONA³). Within WavE, the BMBF is funding 13 joint research projects and an accompanying project. Partners from science, industry and practice collaborate in practice-oriented teams across disciplines. Their aim is to develop innovative and efficient technologies, process concepts and management strategies to ensure water supply for the future.

How can industrially utilized water be recycled? Which opportunities are opened by the treatment of saline groundwater and surface water? How is it possible to reuse treated municipal water? These three topics are at the core of WavE. In addition to technical solutions and intelligent management of relevant material flows, the project partners also integrate communication and training measures into their projects. The investigations and developments are carried out with a practice-oriented approach both in Germany and abroad. This offers opportunities for German companies to strengthen their competitiveness and to position themselves on the international technology market.

The accompanying project TransWavE is coordinated by DECHEMA Gesellschaft für Chemische Technik und Biotechnologie e.V. and supports the work of the joint research projects. As the central interface, TransWavE promotes the dialogue between all players within the WavE funding measure. The project helps to accompany the joint research projects professionally, to strengthen their interdisciplinary network (internal and external) and to support the transfer of results into practice (national - European - international).

Contact to the Accompanying Project TransWavE
DECHEMA Gesellschaft für Chemische Technik und Biotechnologie e.V.
Dr. Thomas Track
Theodor-Heuss-Allee 25
60486 Frankfurt am Main
Phone: +49 (0) 69 7564-427
E-mail: track@dechema.de
www.bmbf-wave.de

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BMBF Contact
Dr. Christian Alecke
Resources and Sustainability
Federal Ministry of Education and Research (BMBF)
Phone: +49 (0) 228 9957-3890
E-mail: christian.alecke@bmbf.bund.de

Project Management Agency Contact
Dr.-Ing. Markus Delay
Projektträger Karlsruhe (PTKA)
Phone: +49 (0) 721 608-22530
E-mail: markus.delay@kit.edu

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WavE

National and International WavE Sites

Municipal Wastewater

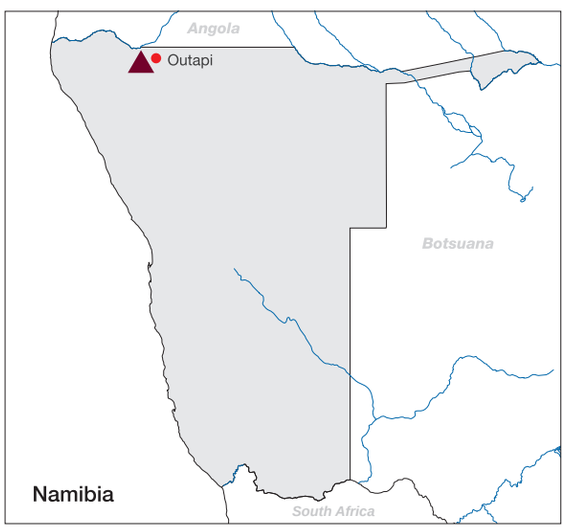
- ★ MULTI-ReUse
- ● TrinkWave
- ◆ HypoWave
- ▲ EPoNa

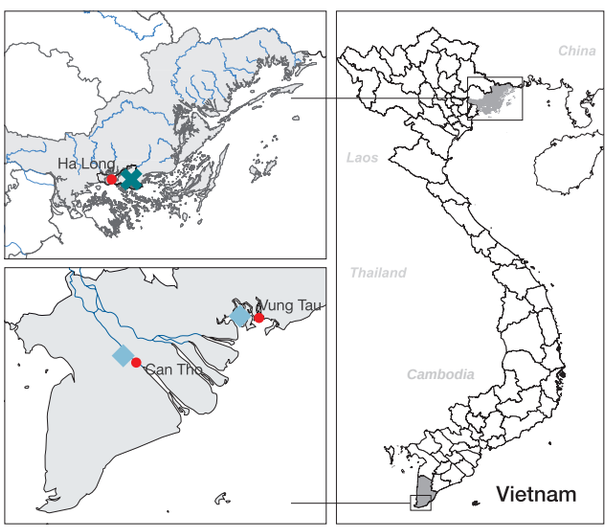
Saline Groundwater and Surface Water

- ▲ REMEMBER
- ◆ WaKap

Industrial Water

- ▲ DiWaL
- ◆ HighCon
- ★ PAkmem
- ● Re-Salt
- ■ WaRelp
- ✛ WEISS
- ✖ WaterMiner





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EPoNa – Upgrade of Wastewater Ponds in the North of Namibia

Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

High population growth in many African cities leads in many places to the overloading of the pond systems, which were built for the treatment of wastewater. However, insufficiently treated wastewater carries health risks for humans and animals. At the same time, cities are confronted with water scarcity problems as droughts may last often more than nine months. As a result, it is impossible to grow enough forage crops for feeding the animals. The joint research project EPoNa therefore addresses the question, how wastewater pond systems in Africa can be rehabilitated and upgraded with simple means, so that irrigation water for fodder plants is available all year round. The project participants want to develop techniques to increase the capacity of the overloaded pond systems. At the same time, methane emissions are to be reduced, the quality of the discharge improved and the nutrients contained in the water and sludge used as fertilizer for the crops. Special attention is paid to questions of profitability as well as the social and ecological impacts.

Opportunities Resulting from Reuse

The wastewater ponds constructed in the city of Outapi in the north of Namibia more than twelve years ago are an example of wastewater treatment in many African cities: Problems, such as overload and insufficient management, result in the inadequate processing of wastewater. During the rainy season, the discharge of the ponds is in direct contact with the flood waters of the Oshanas, a widely branched floodplain. This leads to water contamination problems and, hence, to health risks by the uncontrolled spread of pathogens. Municipalities and superior management structures in the region are lacking technical and operational know-how to adequately maintain, refurbish and upgrade such pond systems. Proper operation of wastewater ponds, however, would allow for the reuse of water as irrigation water all year-long. In addition, the nutrients contained in the water and sludge can be used to fertilize the crops. Hence, water reuse especially in dry rural areas is an important alternative to adapt to the impacts of climate change. Moreover, successful treatment of wastewater leads to a drastic reduction of pollution in the floodplains and decreases health risks caused by pathogens.

Plant of Model Character

When the wastewater ponds were built in Outapi, the town had about 4,000 inhabitants. Only few of them were connected to wastewater system. Meanwhile, more than 5,000 inhabitants use the sewage system in the ever-growing city. The ponds are now overloaded and muddy, and the water surface is covered with algae. Methane bubbles up and is released into the atmosphere. The originally built evaporation pond frequently runs over. As a result, the wastewater is only insufficiently treated. The aim of EPoNa is to demonstrate an exemplary refurbishment, extension, and upgrade of the wastewater ponds to a production plant for irrigation water in Outapi. For this purpose, new, close-to-practice technologies will be developed.

Sampling for water quality analysis in the sewage pond

EPoNa

WavE

Education and Training of Local Actors

The project partners from research and industry are investigating various methods of wastewater pretreatment, one being an anaerobic biological process, the other mechanical fine screening. Guide walls in the ponds are intended to improve the flow. A discharge filter is installed to enhance water quality in terms of solids and algae retention and hygienic characteristics. In addition, a robust irrigation technology is to be developed. Education and training of local actors and establishment of proper management structures will ensure sustainable operation of the systems. The results thus obtained are to be made available to the public.

The model measures can be transferred to both, neighboring municipalities in the north of Namibia, and other parts of the country. There is also great demand in other countries in Africa and the Middle East where wastewater ponds are used and irrigation water is needed. Future projects could further optimize this process, using water from wastewater ponds for irrigation and production of hygienically safe plant foods.

Cattle on the way to the waterhole

Funding Measure
Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

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Upgrade of Wastewater Ponds to generate Irrigation Water, using the Cuvelai-Etosha-Basin in Namibia as an Example (EPoNa)

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Contact
Technische Universität Darmstadt
Institut IWAR
Fachgebiet Abwasserwirtschaft
Prof. Dr. Susanne Lackner
Franziska-Braun-Str. 7
64287 Darmstadt, Germany
Phone: +49 (0) 6151 16 20301
E-mail: s.lackner@iwar.tu-darmstadt.de

Project Partners in Germany
Aqseptence Group GmbH, Hanau
Hochschule Geisenheim University (HGU), Geisenheim
H.P. Gauff Ingenieure GmbH & Co.KG –JBG–, Frankfurt
Institut für sozial-ökologische Forschung GmbH (ISOE), Frankfurt
Institut für Umwelttechnik und Management an der Universität Witten/Herdecke (IEEM gGmbH), Witten

Project Partners in Namibia
Ministry of Agriculture, Water and Forestry (MAWF)
Ministry of Urban and Rural Development (MURD)
Olushandja Sub Basin Management Committee (OLBMC)
Outapi Town Council (OTC)
University of Namibia (UNAM)

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HypoWave – New Approaches to a Water-saving Agriculture

Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

Agriculture is the world's largest consumer of water and already uses around 70 percent of the available surface water and groundwater. In regions with limited water resources, this proportion can sometimes be as high as 90 percent. Large quantities of scarce freshwater evaporate or infliltrate unused into the ground. An increasing world population, climate change and the pollution of water resources therefore confront agriculture with the pressing need to use water more efficiently in the future. The joint research project HypoWave is the first to investigate a water-saving concept for agriculture, which uses specially treated wastewater for plant production in so-called „hydroponic systems". In such a system plants are not rooted in soil, but in nutrient solutions. The goal is to use water more sustainably and at the same time reuse the nutrients present in the wastewater as plant fertilizer.

Optimal Use of Valuable Nutrients

The hydroponic plant production the joint research project is focusing on works in a way similar to hydroculture for indoor plants: The plants are supplied by adding a nutrient solution to the soilless plant pots. The advantage is low water consumption - no water is lost by infiltration and only a little amount evaporates.

For irrigation, treated municipal wastewater will be used since it contains valuable nutrients which can thus be reused for plant growth. The innovation of the project lies in the specific adjustment of the irrigation water treatment process to enable an optimal nutrient reuse by the plants. Due to the adapted treatment process the project partners expect to obtain high-quality irrigation water, largely free of heavy metals, organic micropollutants or pathogens.

The plants are cultivated in a greenhouse in planters without soil using a nutrient solution based on treated wastewater.

Pilot Plant with Hydroponic Greenhouse System

The researchers are initially testing this concept in a pilot plant at the Hattorf wastewater treatment facility near Wolfsburg. Here, the specially treated municipal wastewater is reused in a hydroponic greenhouse system. Additionally, a biodegradable foil is used above the root zones of the plants for the first time. The foil is intended to further reduce water evaporation. Lettuce has been selected as test plant for the experiment.

In addition to the technical processes, the project partners are investigating plant production, economic efficiency of the system and the quality of the products produced. Thereby, they will also determine how an efficient network can be established between urban water management and agriculture to ensure that that the concept becomes sustainable in the long run.

Ecologically and Economically Viable Solutions

In a second step, the potentials and the marketability of the developed hydroponic systems will be assessed. To this end, several case studies with different framework conditions will be carried out among others in the Hessian Ried area in the Upper Rhine valley, in the border region between Belgium and Germany, and in the Portuguese city of Évora. The potential stakeholders of such systems – such as the authorities involved, consumer representatives, planners and potential plant operators – will be involved in the research project throughout its entire duration.

The project partners are looking for ecologically and economically viable solutions: They hope that water reuse in agriculture based on hydroponic systems can contribute to sustainably solving regional problems of water scarcity.

Lettuce plants are used as test plants for experiments in the hydroponic greenhouse.

Funding Measure
Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

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Contact
Technische Universität Carolo-Wilhelmina zu Braunschweig
Institut für Siedlungswasserwirtschaft (ISWW)
Prof. Dr.-Ing. habil. Thomas Dockhorn
Pockelsstr. 2a
38106 Braunschweig
Phone: +49 (0) 531/391-7937
E-mail: t.dockhorn@tu-bs.de

Project Partners
Abwasserverband Braunschweig (AVB), Braunschweig
ACS-Umwelttechnik GMBH & Co. KG, Rielasingen-Worblingen
aquadrat ingenieure Gesellschaft für Wasserwirtschaft und Informationssysteme mbH, Griesheim
aquatectura – Studios für regenerative Landschaften, Berlin
aquatune – Dr. Gebhardt & Co. GmbH, Hahnstätten
BIOTEC Biologische Naturverpackungen GmbH & Co. KG, Emmerich am Rhein
Fraunhofer-Institut für Grenzflächen- und Bioverfahrenstechnik IGB, Stuttgart
Institut für sozial-ökologische Forschung (ISOE) GmbH, Frankfurt am Main
Universität Hohenheim, Stuttgart
Wolfsburger Entwässerungsbetriebe AöR, Wolfsburg
Xylem Water Solutions Herford GmbH, Herford

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MULTI-ReUse – Multiple Use of Treated Water

Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

Treated wastewater is an important part of our water resources. However, it is usually unsuitable for direct use in industry and agriculture. The pressure on available water resources is growing, with pollution and over-use, uneven distribution and climate change having a negative impact. Therefore, the recycling of treated wastewater and its use as industrial process water, for agricultural irrigation and groundwater recharge offers great potential. The partners of the joint research project MULTI-ReUse have realized this. They will develop new methods and processes to treat already conventionally treated wastewater for various purposes in the required quality and quantity at competitive prices. This saves drinking water and protects groundwater resources. The technologies developed are to be marketed worldwide.

Developing New Possibilities for Use

Currently, treated wastewater – regulated by environmental law – is usually discharged into the adjacent rivers. The particle content or nutrient concentration in treated water is unproblematic from an environmental point of view. However, the water is often not suitable for industrial use. In other areas such as agriculture, for example, the concentration of dissolved ions or hygienic concerns can limit the use of treated water.

The aim of the MULTI-ReUse project is to close knowledge gaps regarding the implementation of process engineering and process quality monitoring. The partners want to develop new processes for wastewater reuse or optimize existing processes and combine and test them in flexible modular process chains. They particularly focus on cost issues and ecological and social requirements. In addition, various concepts are to be evaluated. The operators also want to exploit additional possibilities for the water leaving the sewage treatment plant after „classic“ wastewater treatment in order to be able to reuse it directly as process water in different qualities and quantities. Apart from industrial use, it can also be used in agriculture, for artificial groundwater recharge and even in drinking water production abroad.

Field Trial in a Pilot Plant

The new approaches are first developed in the laboratory and then put into practice in a pilot plant at the Nordenham sewage treatment facility in Lower Saxony. The researchers are testing innovative process combinations in the field of membrane processes – ultrafiltration and reverse osmosis. They also develop and test methods for microbiological monitoring that continuously control the quality of the treated water.

During the test phase, the MULTI-ReUse treatment technologies are used to produce and monitor the quality of three different process waters. Additionally, the project participants evaluate different pipe materials regarding their suitability for a distribution network of the respective process water type.

In the pilot plant at the Nordenham sewage treatment plant, the project partners are testing process combinations with ultrafiltration and reverse osmosis.

Water Reuse of Global Importance

The reuse of municipal and industrial wastewater is becoming increasingly important worldwide in order to ensure the economical and ecological availability of water. The results of the project are therefore not only important for Germany. The project partners are developing an export strategy to globally market the modular system developed in MULTI-ReUse and to make innovative water reuse processes from Germany more competitive.

For safe wastewater reuse, water quality is monitored using appropriate monitoring methods.

Funding Measure
Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

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Modular Treatment and Monitoring for Water Reuse (MULTI-ReUse)

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Contact
IWW Rheinisch-Westfälisches Institut für Wasserforschung gGmbH
Dr.-Ing. Wolf Merkel
Barbara Zimmermann, M.Sc.
Moritzstr. 26
45476 Mülheim an der Ruhr
Phone: +49 (0) 208 40303-322
E-mail: b.zimmermann@iww.online.de

Project Partners
De.EnCon GmbH, Oldenburg
Gesellschaft für Chemische Technik und Biotechnologie e.V. (DECHEMA), Frankfurt am Main
IAB Ionenaustauscher GmbH Bitterfeld, Bitterfeld
inge GmbH, Greifenberg
Institut für sozial-ökologische Forschung (ISOE) GmbH, Frankfurt
Leibniz-Zentrum für Agrarlandschaftsforschung e.V. (ZALF), Müncheberg
Oldenburgisch-Ostfriesischer Wasserverband (OOWV), Brake
Universität Duisburg-Essen Lehrstuhl Biofilm Centre, Essen

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TrinkWave – Engineered Natural Treatment Processes for Water Reuse

Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

Is it possible to treat used water in such a way that it can be reused to augment drinking water supplies? The partners of the joint research project TrinkWave are investigating this question. They are aiming to develop engineered natural treatment processes that provide high-quality and thus additional freshwater supplies. These processes are designed to ensure adequate water supply in times of increasing water scarcity. In order to increase social acceptance for water reuse, the researchers also include regulatory and social science aspects.

Augmenting Supplies with Alternative Water Resources

The effects of climate change, pollution and overuse of existing drinking water resources are exacerbating water scarcity issues worldwide. In addition, increasing urbanization and growing industrial and agricultural activities will result in an increased relative contribution of treated wastewater effluents in rivers and lakes. With insufficient dilution, this might pose a challenge to public health where water is abstracted for drinking water supplies.

To combat these issues, planned water reuse as an alternative water resource is becoming increasingly important worldwide. There are already many examples of various reuse practices, mainly in arid and semi-arid regions. Here, locally generated reclaimed water is used as a sustainable and cost-effective alternative instead of surface or groundwater resources. However, even in climatically moderate areas such as Germany, water can become scarce regionally in times of extended droughts. Consequently, planned reuse activities can make economic and ecological sense.

Development of Engineered Natural Treatment Processes

Building on the strong track record in groundwater management, artificial groundwater recharge and bank filtration in Germany, the twelve TrinkWave project partners from science, utilities, public authorities and industry intend to develop energy-efficient, natural-based treatment processes for potable water reuse. A key objective is to meet this goal without the use of high-pressure membranes. High-pressure membrane processes are characterized by a high energy demand and produce a concentrate stream that has to be disposed of at high cost. In order to ensure sufficient drinking water quality, several sequential process steps are combined in a so-called multi-barrier system. This means that the individual steps serve as barriers, retain as many undesired substances from the water as possible and thus ensure safety. TrinkWave is in particular focusing on the removal of pathogens, antibiotic resistance genes, and trace organic chemicals of emerging concern. In addition, the procedures are designed to ensure high infiltration rates, high groundwater protection and high process stability. The industrial-scale implementation of the newly developed treatment processes is tested in Berlin as a preliminary stage of drinking water treatment.

At a pilot-scale facility at the Technical University of Munich, the processes of sequential groundwater recharge for planned reuse of water are being tested.

Comprehensive Assessment of Water Reuse

Commonly, major obstacles for implementing water reuse projects are legal uncertainties regarding quality requirements, a lack of confidence in the reliability of the treatment processes, and public perception. For the first time, the TrinkWave project is therefore developing multidisciplinary assessment approaches to assess combinations of processes to ensure a safe water reuse practice. Technical, regulatory and social science aspects are taken into account and thus provide a holistic view of the topic.

Researchers collect samples of the filter material from the pilot-scale plant in order to determine the microbial community. These fulfill the function of degrading trace organic substances in the reclaimed water.

The comprehensive assessment approach also serves, among other things, to scientifically assess a current conflict regarding the regulatory practice between groundwater protection, wastewater discharge to streams, and planned water reuse. On the basis of selected case studies, specific criteria for quality requirements are established which serve to increase acceptance for planned potable water reuse. Accompanying social science research develops approaches for risk communication targeting different users and interest groups. As a result, the researchers will develop recommendations for action and technical guidelines for regulatory authorities and planners.

Funding Measure
Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

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Development of a Non-Membrane Based Innovative Treatment Approach including Comprehensive Assessment Criteria for Indirect Potable Reuse in Urban Water Cycles (TrinkWave)

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Contact
Technische Universität München
Lehrstuhl für Siedlungswasserwirtschaft
Prof. Dr.-Ing. Jörg E. Drewes
Am Coulombwall 3
85748 Garching/München
Phone: +49 (0) 89 289-13713
E-mail: jdrewes@tum.de

Project Partners
Berliner Wasserbetriebe (BWB), Berlin
Brandt Gerdes Sitzmann Umweltplanung GmbH, Darmstadt
Bundesanstalt für Gewässerkunde (BfG), Koblenz
Carl von Ossietzky Universität Oldenburg
Umweltbundesamt (UBA), Dessau-Roßlau
COPLAN AG, Eggenfelden
DHI-WASY GmbH, Syke
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Technische Universität Berlin
TZW: DVGW – Technologiezentrum Wasser, Karlsruhe
Universität Bayreuth

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DiWaL – Environmentally Friendly Cleaning of Industrial Water and Electrodeposition Paints by Electric Pulses

Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

Most paints today are water-based and therefore more environmentally friendly than those based on solvents. However, water-based coatings have one disadvantage: microorganisms such as bacteria feel very comfortable in them and spread. This also affects electrocoating lines in the automotive industry and other sectors. Until now, chemical toxins – so-called biocides – have often been used to combat microorganisms, especially bacteria. In addition, the disinfection process consumes a great deal of freshwater and produces wastewater. The six partners from research and industry of the DiWaL joint research project are working on an alternative solution. They want to decontaminate industrial water and electrodeposition paints by pulsed electric field treatment sustainably and without chemical additives.

Problems with Biocides

Before a car receives a top coat, the car body must be cleaned and pretreated. In addition, it is given a coat that protects it from corrosion. This is done in surface pretreatment and electrocoating lines. The latter is an electrochemical process which enables a uniform coating film via a direct voltage field in the immersion bath. In the water and electrodeposition paints used, however, bacteria can grow to such an extent that they impair the surface coating. Until now, biocides have mostly been used to combat them.

Coating in electrocoat bath: bacteria can easily grow in the waters and electrodeposition paints and impair the surface coating.

These can cause problems in wastewater treatment and are questionable from an environmental point of view. In addition, biocides can lead to bacterial resistance in long-term application and in the event of dosing errors. Process fluids must therefore be regularly discarded and labour-intensive cleaning and disinfection measures of the immersion tanks must be carried out.

Bacterial Decontamination without Chemicals

With the pulsed electric field technology, the DiWaL project relies on a process that works without chemical additives to conserve water resources and at the same time contributes to water protection. Pulsed electric field treatment exposes cells, such as microorganisms, to an electric field. This polarizes the cell membrane and opens up aqueous pores, which ultimately lead to the death of microorganisms. This phenomenon is used on an industrial scale to recover cell components and inactivate microorganisms ("cold pasteurisation"). Since the pulsed electric field technique acts purely physically, bacteria cannot develop resistance to this process – unlike with conventional biocides.

Optimized Pulsed Electric Field Treatment

The project partners want to apply pulsed electric field treatment to electrodeposition paints and water in the electrocoating lines for the first time. They will test this technique in anodic as well as cathodic electrodecoating lines for coating common goods and car bodies. The researchers are developing innovative, solid state genera-

tors for the pulsed electric field treatment. Due to the high water consumption during electrodeposition coating – it is the most water-intensive area in automotive production – pulsed electric field technology will also be integrated into a new, automated and resource-efficient water management and equipment concept for pretreatment and electrocoating lines. This should make it possible to improve the circulation of water in the factory and to consume less freshwater.

The pulsed electric field technology makes it possible to decontaminate water without chemicals: The picture shows a pilot plant that inactivates bacteria in hospital wastewater.

Quality, costs and the environment are at the centre of the technical implementation of the plant. The user's perspective is also essential: DiWaL analyses the user's requirements as well as possible obstacles; the results are incorporated into the concept and the technical development. Owing to its resource-saving water circulation and the absence of biocides, the innovative pulsed electric field process is not only suitable for use in Germany. Production sites in regions suffering from water shortages or lacking wastewater treatment in particular could also benefit from it.

Funding Measure
Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

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Development of Resource-Efficient Water-Management and Plant Concepts for Electrocoating Lines: Application of Pulsed Electric Field Technology for Bacterial Decontamination of Industrial Water and Electrodeposition Paints (DiWaL)

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Contact
Karlsruher Institut für Technologie (KIT)
Institut für Hochleistungsimpuls- und Mikrowellentechnologie (IHM)
Dr. Christian Gusbeth
Hermann-von- Helmholtz-Platz 1
76344 Eggenstein-Leopoldshafen
Phone: +49 (0) 721 608 23869
E-mail: christian.gusbeth@kit.edu

Project Partners
BMW Group, Leipzig
Eisenmann SE, Böblingen
Emil Frei GmbH & Co. KG, Bräunlingen
Hochschule Pforzheim, Gestaltung, Technik, Wirtschaft und Recht (INEC)
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HighCon – Industrial Waste Water as a Resource

Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

The reuse of industrial wastewater generates highly concentrated residual streams. These concentrates contain salts, hardly degradable organic compounds and heavy metals. They currently end up almost exclusively in municipal sewage treatment plants or, in some countries, directly enter into the environment. In the joint research project HighCon, researchers and industrial partners are looking for ways to better utilize the concentrates. These are no longer regarded as waste products to dispose of, but serve as a valuable source of raw materials.

Comprehensive Approach to Reuse

In order to be able to reuse concentrates, a holistic concept is required taking into account various processing methods as well as prevention or substitution measures. The separation of inorganic substances, such as dissolved salts poses a particular challenge. On the one hand, this is the only way to prevent them from entering the natural water cycle. On the other hand, the recovery of these substances as valuable material is becoming economically attractive in more and more sectors. Recovered caustic solutions can be reused in the company's own process chain for industrial cleaning processes or be further processed for other applications. This includes soda, sulphuric acid or dry salts such as de-icing salt or other types of salt. Against the backdrop of limited potash salt reserves and sharply fluctuating prices, this is of particular relevance.

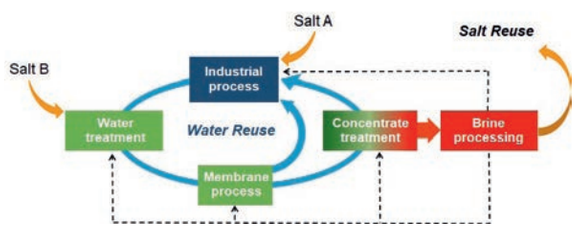
Sector-specific Solutions Required

Unlike in the municipal sector, water reuse in industry requires individual solutions. It must be adapted to the respective industry. Minimizing residual materials is essential for operators of water recycling plants. Reasons include very high disposal costs and ensuring safety of disposal. Consequently, the aim of the joint research project HighCon is to develop novel multi-stage processes suitable for selective recycling of recyclable materials for the companies involved in the project. They should allow for almost complete recycling of the resulting concentrates as well as an additional multiple use of treated wastewater.

For this purpose existing technologies are being further developed and adapted to the special applications of industrial partners from biotechnology, cosmetics production, food production and textile management.

One of the core components is the novel combination of membrane processes to separate inorganic salts from organic pollutants in concentrates. For example, a concentrate obtained by reverse osmosis is further treated using various processes such as nanofiltration or electrodialysis metathesis for adjustment of the salt composition. This step allows salts, which are normally the core problem in the disposal of concentrates, to be processed separately and with a significantly reduced volume. The concentrated material flow enriched with inorganic salts is further concentrated up to the saturation limit. This will be achieved, for example, by membrane distillation. This "super concentrate" can subsequently be separated as a solid in a crystallizer.

The main objective is to separate unmixed salts at different concentration levels and to further process the solids obtained to such an extent that they can be returned to the production process or to further recycling. For this purpose, the researchers are testing selective low-temperature distillation crystallization. This is an innovative distillation process that works under low-pressure conditions and can be operated energy-efficiently with waste heat from industrial processes.



In addition to conventional water reuse, the HighCon concept includes a separate concentrate treatment to separate and recycle salts.

Field Test in Industry

In order to develop and adapt the treatment technologies, the project team first carries out extensive laboratory tests with synthetic and real wastewater and in a second step converts these to the pilot scale. The practical tests will take place in various industrial companies – a manufacturer of soluble coffees, a bioethanol producer, a cosmetics manufacturer and a laundry for professional workwear. For the first time, HighCon aims to comprehensively optimize the process of water reuse. For this purpose, a simulation tool will be developed that depicts the complex relationships from raw water flows to concentrate recycling while also evaluating sustainability.

Recycling: In a nanofiltration plant, organic and inorganic components are separated from concentrates.

Funding Measure
Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

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Contact
Technische Universität Berlin
Fachgebiet Umweltverfahrenstechnik
Prof. Dr.-Ing. Sven-Uwe Geißen
Sekr. KF 2
Straße des 17. Juni 135
10623 Berlin
Phone: +49 (0) 30 314-22905
E-mail: sven.geissen@tu-berlin.de

Project Partners
DECHEMA Gesellschaft für Chemische Technik und Biotechnologie e.V., Frankfurt
DEUKUM GmbH, Frickenhausen
DVGW-Forschungsstelle am Engler-Bunte-Institut des Karlsruher Instituts für Technologie (KIT), Karlsruhe
Fraunhofer-Institut für Solare Energiesysteme ISE, Freiburg
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Terrawater GmbH, Kiel
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PAkmem – Treatment of Heavily Loaded Process Water with Ceramic Membranes

Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

During the extraction of crude oil and natural gas from inaccessible deposits such as oil sands, claystones or coal seams, water contaminated with hydrocarbons is increasingly generated. Ceramics production also leads to problematic wastewater. Salt- and organic-containing water from the petroleum, natural gas and ceramics industries can only be reused industrially after appropriate treatment. Eight partners from industry and research are developing such customized concepts in the joint research project PAkmem. The focus is on nanofiltration with ceramic membranes. The newly developed processes are intended to make the treatment of heavily polluted wastewater more energy-efficient and cost-effective in the future, thus contributing to improving their recycling.

Difficult Recycling of Problematic Water

Increasing water costs, stricter requirements for wastewater treatment and a growing interest in wastewater as a source of raw materials and energy make the recycling of water attractive – even in temperate climate zones. This particularly concerns water-intensive sectors such as the petroleum/natural gas and ceramics industries with an increasing demand to find solutions for process water treatment. However, the salt- and oil-containing, partly hot and aggressive wastewater produced by these sectors presents a major challenge for water purification. For example, produced water from oil sands cannot be processed with justifiable effort yet. Processes such as flocculation do not remove all problematic wastewater constituents sufficiently well. In addition, further chemicals are used that pollute wastewater, increase the amount of residual materials to be disposed of and make treatment more expensive.

Innovation with Ceramic Filters

As an alternative, the PAkmem project focuses on treatment processes with ceramic nanofiltration membranes. Nanofiltration membranes are porous filters covered with a thin layer. This layer contains many pores in the dimension of a few nanometers. The pores of the membranes are thus only about three times the size of a water molecule. The filters are able to retain salt and organic molecules and can therefore desalt and treat process water purely physically. They are made of ceramic materials, since they are chemically, mechanically and thermally very stable.

The project team uses these properties to further develop ceramic nanofiltration. The new process is to be energy-efficient and should make it possible to treat wastewater with elevated temperatures, considerable organic load and abrasive components such as sand or ceramic particles. The goal is to obtain water which is partially desalinated and contains virtually no more organic substances.

Ceramic membranes with different geometries are used to clean salt- and organic-containing water (outer diameter from left to right: 41 millimeters, 25 millimeters and 25 millimeters).

Further water purification processes are also being developed and applied in the project. For example, the researchers are testing a combined flotation/microfiltration process as a pretreatment method for wastewater from the oil and gas industry. In the flotation process, solids and oil droplets are removed with air bubbles. Microfiltration uses filters with a pore size of less than one micrometer (equivalent to one thousandth of a millimeter).

For post treatment, the project team combines nanofiltration with other technologies. The aim is to process the highly concentrated residual substances retained by the

membranes and, if necessary, to extract raw materials and make the water available for industrial processes as required. The concentrates are treated with electrodialysis processes to separate acids, alkalis or salts from the water. Total oxidation removes organic substances by transforming them into CO2 and water. As a further, complementary strategy for concentrate treatment, the project partners are investigating evaporation. In the sense of a wastewater-free production, it leads to solid residues that can be recycled or deposited. Parallel to the process combinations, the researchers are developing new online measurement methods for the determination of particle and droplet size integrating them into the processing concepts.

Tests with Real Process Water

Process water treatment with ceramic nanofiltration as well as upstream and downstream steps is tested on site using real process water originating from the petroleum/natural gas industry or from the ceramics industry. The systems will be equipped with the measurement technology developed in the project. The project consortium assesses and evaluates the process flows to be treated and uses this as a basis for developing a process chain for the targeted treatment of wastewater flows. At the same time, they also take a look at economic efficiency. As a result, the treated water is to be reused industrially (in the case of extraction of crude oil and natural gas by direct discharge into the soil, and as process water in the ceramics industry). This is economically and ecologically advantageous for users. The new processes are not only suitable for the industrial sectors examined, but also for all other sectors with large quantities of salt- and organic-containing wastewater, for example in milk processing, biorefining, canteen kitchens and slaughterhouses.

In pilot filtration plants, researchers are testing ceramic membranes in process water.

Funding Measure
Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

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Effective Treatment of Complex Process Water and Wastewater using Ceramic Nanofiltration Membranes (PAkmem)

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Contact
akvola Technologies GmbH
Dr.-Ing. Matan Beery
Am Borsigturm 100
13507 Berlin
Phone: +49 (0) 30 959 998 950
E-mail: beery@akvola.com

Project Partners
Andreas Junghans - Anlagenbau und Edelstahlbearbeitung GmbH & Co. KG, Frankenberg
DBI Gas- und Umwelttechnik GmbH, Leipzig
DURAVIT Sanitärporzellan Meißen GmbH, Meißen
Fraunhofer Institut für Keramische Technologien und Systeme (IKTS), Hermsdorf/Dresden
LUM GmbH, Berlin
Rauschert Kloster Veilsdorf GmbH, Veilsdorf
SOPAT GmbH, Berlin

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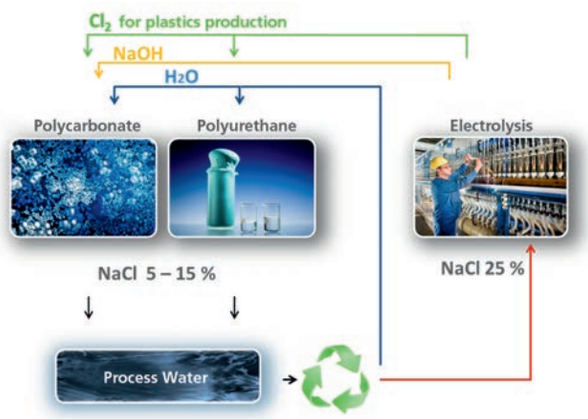
Re-Salt – Recycling Salt from Industrial Process Water

Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

Plastics, pesticides, pharmaceuticals - these and many other chemical products contain chlorine. Chlorine is produced from common salt by electrolysis. During industrial production, considerable amounts of process water with very high salt concentrations are generated. If these saline process waters enter rivers and lakes, not only will they pollute the environment but they will also make drinking water treatment more difficult. In the joint research project Re-Salt, partners from industry, science and research are looking for new ways to recover and recycle salt and water from industrial process waters in plastics production in a resource-efficient manner.

Closing cycles and Increasing Resource Efficiency

Electrolysis from common salt - sodium chloride (NaCl) - produces sodium hydroxide and chlorine. Both substances are among the most frequently used industrial chemicals: 60 to 70 percent of all chemically produced products come into contact with chlorine or caustic soda during their manufacturing process. This results in highly saline process water. The Re-Salt project is trying to recover this salt and recycle it as a raw material in electrolysis. In addition, the treated process water is also to be reused. The thought behind it: resource efficiency is improved, fewer substances enter the natural water cycle and water consumption in production decreases.



Saline process water from plastics production is to supply recyclable raw materials with the aid of a new process.

Obstacles on the Way to Recycling

In order to implement the targeted recycling in chlorine production by means of electrolysis, the project participants must tackle two challenges: industrial process water contains organic impurities that can affect the electrolysis process. Thus, it must be pretreated. Another problem is the insufficient salt concentration in the process water for electrolysis. For an optimal function, a minimum concentration of 25 percent is necessary. In most process waters, however, the salt concentration is below 15 percent.

Ecologically and Economically Viable Solution Required

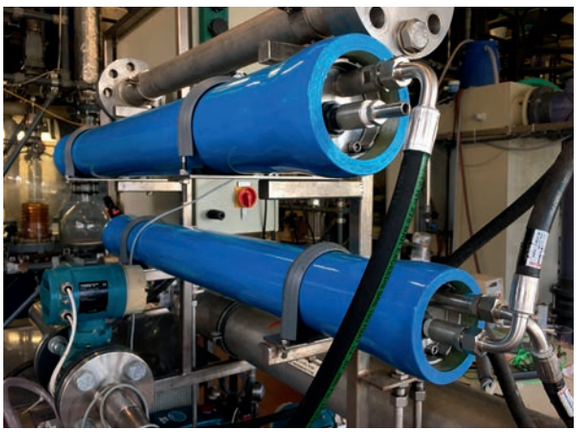
The aim of the joint research project Re-Salt is to develop solutions adapted to the production process for the recycling of salt and water from process water that are both environmentally friendly and economical. The partners proceed in three steps. In order to efficiently purify the process water generated during the production of plastics, information on the type and quantity of the organic compounds contained is required. However, the detection of these compounds is complicated by high salt concentrations. The project participants are therefore developing special analytical techniques for trace substance analysis and sample preparation.

The cleaning itself is impaired by the fact that the organic impurities are only present in very low concentrations in the process water. Thus, not all impurities can be removed with commercially available activated carbon.

The researchers are overcoming this challenge with a chemical or electrochemical adaptation: the activated carbon is modified to improve the accumulation of pollutants.

In order to achieve the 25 percent salt concentration required for electrolysis in process water, Re-Salt is developing a process for its concentration. The salt content is to be increased as environmentally friendly and economically as possible. The consortium partners plan to use an energy-efficient high-pressure membrane process – high-pressure reverse osmosis – and subsequent membrane distillation. The energy required for membrane distillation is obtained from waste heat, among other sources. The increase in salt content would make it possible to recycle most of the process water flow and to close the cycle for water and NaCl.

A demonstration plant is planned at the Krefeld-Uerdingen site to test the processes developed in the laboratory. In the plant, real saline process water from the production of plastics is to be recycled. It is to be cleaned, concentrated and then tested in electrolysis. On-site the researchers collect long-term experiences in order to assess the sustainability of the recycling solution developed in the project and its suitability for other saline process waters.



An important task is to concentrate the process water. This is a prerequisite for closing the cycle for water and NaCl.

Funding Measure
Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

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Contact
Covestro Deutschland AG
Dr. Yuliya Schießer
Kaiser-Wilhelm-Allee 60
51365 Leverkusen
Phone: +49 (0) 214 60095461
E-mail: yuliya.schiesser@covestro.com

Project Partners
DECHEMA-Forschungsinstitut, Frankfurt am Main
Donau Carbon GmbH, Frankfurt am Main
EnviroChemie GmbH, Roßdorf
SolarSpring GmbH, Freiburg
Technische Hochschule Köln
TZW: DVGW - Technologiezentrum Wasser, Karlsruhe
Universität Duisburg-Essen, Duisburg

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WaReIp – Optimizing Water Use in Industrial Parks

Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

For reasons of regional compatibility and to ensure supply and disposal, industrial production plants are increasingly located in industrial parks worldwide. This opens up a wide range of possibilities for saving resources, energy and costs through joint use, recycling or the exchange of material flows. The aim of the joint research project WaReIp is to treat the wastewater (production, sanitary and kitchen wastewater) in an environmentally friendly and economical way to reuse it on-site as required.

High Potential for Saving Resources

Water resources are under increasing pressure in many regions of the world, so that operators of industrial production plants are increasingly focusing on a future-oriented water supply. Industrial parks with their large number of production facilities offer particularly favorable conditions for the efficient use of water and other resources. This way, substances that are considered as waste in one company can become production raw materials for another. There is still a great amount of untapped potential in the internal and inter-company recirculation of water. The opportunity to use partially treated wastewater from other production facilities in an industrial park or from the sanitary and kitchen wastewater produced, and thus to reduce the water demand to be covered externally, is still hardly seized. The chemical-pharmaceutical industry, which is one of the sectors with the highest water consumption and wastewater generation, offers a particularly high innovation potential in this field.

Recovering and Reusing Production Raw Materials as Required

In wastewater technology, numerous treatment technologies already exist, the combination of which makes it technically possible to produce almost any water quality. However, to date synergies resulting from the networking of processes and partial flows and their effects on energy, resource consumption and costs have often not been sufficiently taken into account in process development. This is where the WaReIp joint research project comes in: the production, sanitary and kitchen wastewater arising in an industrial park is to be treated according to demand via cascaded treatment steps. This means treating the wastewater only to the extent necessary to obtain process water of a certain quality required in another production plant or for other purposes in the industrial park (e.g. irrigation). This way, the project partners want to achieve the highest possible degree of utilization with less resources and costs.

For this purpose, the researchers determine, describe and combine recognized wastewater treatment processes with regard to their potential for optimized material flow management. They are also developing new approaches and technologies for more severely polluted wastewater with high salt contents and high concentrations of persistent organic compounds. Integrated water and resource management promises numerous advantages for production plant operators: both the demand for drinking water and groundwater and the costs for water supply and wastewater treatment can be reduced. The approach also offers the possibility to recover production raw materials from wastewater – e.g. surfactants and proteins – in order to further reduce the external supply of such raw materials and the treatment costs of the wastewater in downstream steps.

The biological treatment of typical industry wastewater is investigated in laboratory tests.

Selecting the Optimal Processing Technology

For the practical implementation of the research results, the project team will develop a suitable technical infrastructure and measurement concept. The sewer must be suitable for different water qualities, serve as a storage system and at the same time ensure that the required water qualities and quantities are available. The regulation of this complex system places high demands not only on the measurement concept, but also on the employees: in extreme cases, faulty controls can lead to production failure. The scientists are therefore developing a safety concept that makes it easier for employees to take the right decisions, even in complex situations and during peak loads.

In order to facilitate the selection of the best possible processing technology for future users, various evaluation systems are further developed and tested for each individual application. This includes a decision-making system that takes several objectives into account: On the one hand, the project partners want to test a specific material flow management under ecological and socio-economic boundary conditions. On the other hand, they evaluate environmental aspects and resource savings.

Apart from positive ecological and economic aspects, which WaReIp aims to achieve by saving drinking water and groundwater in industrial parks, the project also strives for a worldwide transferability of the results obtained. For the project team the integrated approach is promising to enable industrial developments in areas with natural water poverty. With the help of a set of indicators, different site qualities are to be recorded and, based on this, the concepts and processing technologies are to be transferred to other sites.

Industrial park with wastewater treatment plant in Vietnam: the results of the WaReIp project are to be internationally transferable.

Funding Measure
Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

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Contact
Technische Universität (TU) Darmstadt
Fachgebiet Landmanagement
Prof. Dr.-Ing. Hans Joachim Linke
Franziska-Braun-Str.7
64287 Darmstadt
Phone: +49 (0) 6151 16 21964
E-mail: linke@geod.tu-darmstadt.de

Project Partners in Germany
Endress + Hauser Conducta GmbH & Co. KG, Gerlingen
EnviroChemie GmbH, Roßdorf
IEEM gGmbH, Witten
Kocks Consult GmbH, Koblenz
Leibniz Universität Hannover, Institut für Siedlungswasserwirtschaft und Abfalltechnik (ISAH), Hannover
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International Project Partners
Hanoi University of Civil Engineering, Vietnam
Qingdao Technical University, China
Tongji Universität Shanghai, China

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WaterMiner – Sensible Reuse of Mining Wastewater

Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

The region around the Ha-Long Bay in northern Vietnam is characterized by a wide variety of competing land uses in a limited area: coal mining, urban living space and tourism in the area of the UNESCO World Heritage Site „Ha-Long Bay“ meet in direct vicinity. The WaterMiner joint research project uses the example of the urban Ha Long mining area in Vietnam to develop innovative processes and concepts for recycling and reusing mining wastewater.

A Region Characterized by Mining

The project area, the city of Ha Long in the Quang Ninh province in Northern Vietnam, is located in the Gulf of Tonkin surrounded by Ha Long Bay with its unique limestone islands. In 1994, Ha Long Bay became a UNESCO World Heritage Site. Since then it has developed into a tourist center for domestic and foreign guests.

At the same time, Quang Ninh province is an important mining and industrial location. Approximately 95 percent of Vietnam‘s total hard coal originates from there. The rapidly growing city of Ha Long is the political, economic and cultural center of the province.

A coal transport ship in front of the limestone cliff silhouette of Ha Long Bay

The interplay between coal mining, urban living space and tourism leads to considerable challenges and conflicts in the Ha Long Bay water sector. This also affects a sustainable urban and regional development. The environment and daily life are heavily burdened by polluted water from mining activities.

Contaminated Water and High Water Demand

Coal mining in Ha Long is currently operated by nine mines, which are assigned to six different subsidiaries of the Vietnam National Coal Mineral Industries Holding Corporation Limited (VINACOMIN). Currently, a reorganization from opencast mining to underground mining is taking place. After the expected closure of the opencast mines by 2025, a post-mining landscape with an opencast mining lake will be created.

Mining activities in the province of Quang Ninh entail a number of environmental problems, including water management problems: On the one hand, large quantities of polluted mining water are produced. On the other hand, there is a considerable demand for drinking water, process water in mining, industrial and commercial water and irrigation water for agriculture, especially during the dry season between November and April. Ecological concerns pertaining to Ha Long Bay are of particular importance.

An integrated water management coordinated between the coal mining industry and the city can significantly contribute to solving this problem, with special focus on water recycling and water cycle management. To this purpose, the WaterMiner joint research project will develop an innovative and sustainable concept that takes into account the spatially and temporally changing water supplies of the mining industry and the different water requirements in the region. The project partners will develop proposals on how mining wastewater can be treated and distributed with the help of technical processes and concepts.

WaterMiner

WavE

Computer-aided Material Flow Model

By installing a pilot plant and modifying existing treatment plants or retention basins, the researchers also plan to recover and to recycle coal dust. Furthermore, economic efficiency and eco-efficiency of water reuse will be considered as well as public acceptance of the measures. The core of the project is a computer-aided material flow model, which can be used to simulate both water treatment and reuse as well as long-term wastewater treatment and distribution. Particular challenges exist in the planned conversion from opencast mining to underground mining and the subsequent use of the mining areas.

The project is carried out in close cooperation with the mining company VINACOMIN, which as a major Vietnamese partner is closely involved in project communication and implementation of the project results. The results achieved in the project can also contribute to solving problems at other sites with similar challenges.

Coal extraction in opencast mining

Funding Measure
Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

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Contact
Ruhr-Universität Bochum
Umwelttechnik + Ökologie im Bauwesen
Prof. Dr. rer. nat. Harro Stolpe
Universitätsstr. 150
44801 Bochum
Phone: +49 (0) 2343 2-27995
E-mail: harro.stolpe@rub.de

Project Partners
Disy Informationssysteme GmbH, Karlsruhe
Dresdner Grundwasserforschungszentrum e.V., Dresden
ribeka GmbH, Bornheim/Rheinland
Universität Koblenz-Landau, Landau

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WEISS – Using Cooling Water More Efficiently

Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

Cooling water is used worldwide in industry for process and product cooling. In view of the increasing water scarcity in many places, this means new challenges – especially in dry developing and emerging countries with increasing industrial activities, but also in Europe. Using the steel industry as an example, partners from science, research and industry are working on new processes and concepts in the WEISS joint research project to increase the efficiency of cooling water circuits. Their goal is to reduce blow down water amount in these circuits by up to 50 percent.

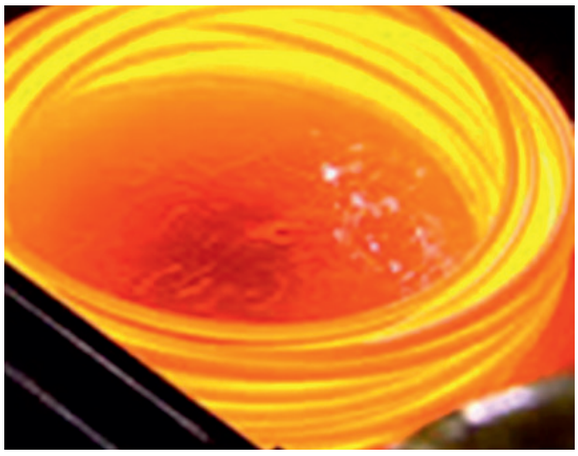
Complex Cooling Circuits in the Steel Industry

In Germany alone, more than 92 percent of 27 billion cubic meters of non-public supplied water per year (around 23 billion cubic meters of water) are used across sectors for industrial cooling purposes. Due to the circulation of the cooling water and to evaporation, process-related salts and hardness components accumulate in the water. Between one and five percent of the circulation water flow must be discharged in order to prevent salt-related corrosion of the systems. Using the example of the steel industry, this corresponds to a so-called blow down flow of up to 200 cubic metres per hour. During desalination, cooling water and treatment chemicals are lost, and several hundred tons of phosphorus and other environmentally relevant substances are also released into water bodies. The loss is replaced by additional freshwater and chemicals.

Cooling water in the steel industry is also characterized by a complex chemical composition: one reason is that the water is treated with various chemicals such as biocides, hardness stabilizers and flocculants before and during use in the cooling circuit. They also contain solids, oils and fats. Due to their complex composition, no chemical-free and economical treatment process for these cooling waters has been established on the market yet. The use of membrane processes is linked to a high technical risk. Due to deposits on the membranes caused by high concentrations of hardness components – so-called scaling – as well as due to interactions between water constituents and the membrane surface – called fouling – the required filtrate capacities cannot be achieved without pretreatment of the cooling water.

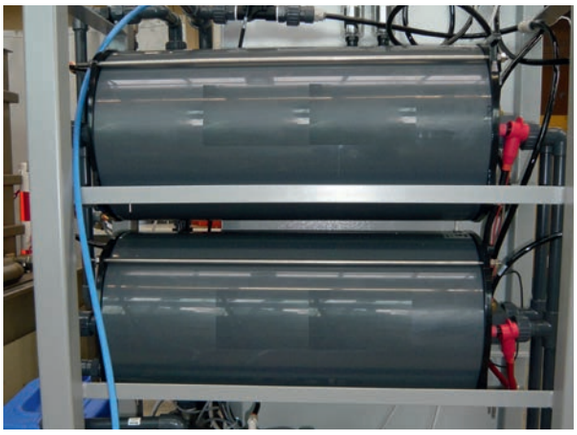
Separating Salts and Dosing Chemicals as Required

The WEISS joint research project aims at using cooling water more efficiently – i.e. well beyond the current state of the art – in order to reduce the amount of blow down water and thus the consumption of fresh water. The aim is to achieve savings of blow down water up to 50 percent. That way, an average steel mill could save up to 800,000 cubic meters water per year in the future. To achieve this goal, new processes for integrated desalination in cooling water circuits are to be developed and tested: capacitive deionization, in which the water is desalinated electrochemically, evaporation with salt-resistant polymer heat exchangers and novel coated reverse osmosis membranes that prevent scaling and fouling. Development and testing is initially carried out in laboratory tests. Subsequently, the project participants test the processes over a longer period of time at two selected operational cooling circuits under industrial conditions.



Cooling water is used in the steel industry in large quantities for direct cooling. The example shows a wire in water cooling.

Further key aspects of the project are the development of processes for pretreatment before desalting to remove potential disturbing impurities from the cooling water as well as a measurement and control concept for demand-oriented dosing of cooling water chemicals. The optimized use of chemicals is intended to further reduce salt input into the cooling water circuit and thus minimize water consumption as well as the input of environmentally relevant chemicals and salts into water bodies. The researchers want to determine suitable process combinations, for example with regard to the use of energy and chemicals, by modelling the cooling circuits with the SIMBA software.



Cooling water desalination with capacitive deionization: the method is being tested in a pilot plant at a BFI technical center.

Cross-industry Concepts and Procedures

The efficient use of water resources and cooling water chemicals enables the cooling circuits to be adapted to the respective situation on-site. This means that the production processes can also become more independent of water availability. The developed processes and concepts are to be marketed globally for the direct cooling circuits of the steel industry. For indirect cooling systems – system/process cooling without contact between cooling water and product – they can even be transferred to all cooling water circuits across all industries. Consequently, other industries with high cooling water demand, e.g. the chemical, paper and petroleum industries, power stations, air-conditioning and refrigeration systems, machine and plastics factories, glass works or non-ferrous metal works, will also offer possibilities for application.

Funding Measure
Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

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Efficient Operation of Cooling Water Circuits by integrated Desalination at the Example of the Steel Industry (WEISS)

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Contact
VDEh-Betriebsforschungsinstitut (BFI)
Abteilung Ressourcentechnologie Flüssige Medien
Sohnstr.65, 40237 Düsseldorf
Martin Hubrich
Phone: +49 (0) 211 6707-343
E-mail: martin.hubrich@bfi.de

Project Partners
Deutsche Edelstahlwerke GmbH (DEW), Witten
Ifak Institut für Automation und Kommunikation e.V., Magdeburg
SMS group GmbH, Düsseldorf
Technische Universität Berlin, Institut für Technischen Umweltschutz, Berlin
Universität Duisburg-Essen, Lehrstuhl für Technische Chemie II, Essen
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REMEMBER – Clean Water Thanks to Novel Membranes

Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

Groundwater and surface water are the main sources of water supplies for households, agriculture and industry. Before the water can be used as drinking, irrigation or service water, it must be cleaned using suitable processes. For this purpose, membrane technologies are used in particular. Membrane filters, however, suffer from deposits on their surface caused by the organic and inorganic water constituents to be separated: they considerably reduce the filter performance in continuous operation. The joint research project REMEMBER is looking for solutions to this problem. The partners are developing new types of membranes that remain considerably cleaner during the filter process and thus enable a more economical operation.

Limits of Membrane Filtration

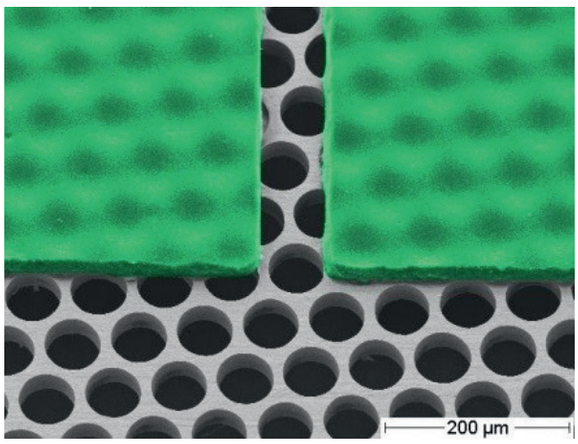
Filter membranes for water treatment have the advantage that they can be used very flexibly. In addition to large-scale plants, there are also small, decentralized systems for mobile on-site processing. However, membrane processes have a considerable disadvantage: the substances to be separated – dissolved or as particles – attach to the membrane surface. This can lead to (bio-)fouling in the case of organic residues and to scaling in the case of inorganic salts. In continuous operation, these deposits negatively affect the water flow through the membrane. Thus, the filter performance will decrease continuously. Depending on the degree of contamination of the water to be filtered, the filter surface must therefore be cleaned at certain intervals. Mechanical or chemical cleaning is time-consuming and expensive.

Better Filter Performance and Longer Service Life

The REMEMBER joint research project aims to get a grip on the deposits produced during water filtration with innovative membrane systems. The researchers are focusing on the physical effect of dielectrophoresis: non-uniform electric fields are generated above the membrane surface. These fields move charged particles away from the membrane and thus prevent contamination of the membrane without disturbing the filter process. Consequently, the membranes can perform their actual function much better, have a significantly longer service life and require less frequent cleaning. The systems are therefore more economical and resource-efficient.

To produce the membranes, the project partners are combining various new and cost-effective coating and structuring techniques, which they are developing further for this application. For example, thin conductor tracks and electrodes are to be applied to polymeric membrane surfaces using screen printing processes.

A new coating technique based on titanium oxide provides the membranes with a dielectric protective layer that reinforces the water-repellent effect and additionally counteracts deposits.



A special screen with perforated metal foil and a stencil made of emulsion coating is to make it possible to produce the improved membranes.

Use in Large and Small Plants

The performance of the newly developed membrane systems will first be systematically examined in practical tests on a laboratory scale. Subsequently, the operation of corresponding membrane modules in demonstration plants for the treatment of seawater in Bremen is planned (scale: 1 m^3/d).

After successful testing, the partners plan to use the technology in stationary large-scale plants and to also integrate it into small mobile plants in the long term. More effective and low-maintenance membrane filters with a longer service life can significantly contribute to providing sufficient quantities of drinking, irrigation and service water recovered from surface water and groundwater, especially in dry regions. In addition, it will be examined whether the novel membranes can also be used in the treatment of industrial wastewater.

Printed membranes promise better filter performance and longer service life.

Funding Measure
Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

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Contact
MARTIN Membrane Systems AG
Daniel Crawford
Von-Thünen-Str. 1-4
19071 Brüsewitz
Phone: +49 (0) 38874 4326110
E-mail: daniel-crawford@martin-membrane.com

Project Partners
Fraunhofer-Institut für Fertigungstechnik und Angewandte Materialforschung (IFAM), Bremen
NB Technologies GmbH, Bremen
Plasmatreat GmbH, Steinhagen
Universität Bremen, Zentrum für Umweltforschung und nachhaltige Technologien (UFT), Bremen
Weser Umwelttechnik, Bremen

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WaKap –Water Desalination and Arsenic Removal for Sustainable Water Supply

Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

Until a few years ago, many countries in Southeast Asia a – including Vietnam – were regarded as countries without significant water problems. However, the water supply of these countries is threatened by rapidly growing populations and increasing industrialization as well as climate change. In addition to the increasing salinity of coastal groundwater, many groundwater sources in Vietnam show high arsenic concentrations. For a sustainable solution, the joint research project WaKap is developing an innovative modular system for desalination and arsenic removal for groundwater, seawater and brackish water. The modular plant designed in Germany is to be set up and tested in Vietnam. The conditions there can be regarded as representative for many countries in Southeast Asia.

Salt- and Arsenic-rich Groundwater

Water resources play a decisive role in Vietnam's future economic development. However, seawater intrusion in many coastal regions of Vietnam causes the salinization of groundwater. The increased extraction of groundwater and the rise in sea level will accelerate the further salinization of groundwater in the coming years. In addition, some groundwater sources in Vietnam contain very high concentrations of arsenic – a very toxic substance. Arsenic is released from the natural sedimentary rock in Vietnam and many other Asian countries leading to a pollution of groundwater and wells. The uptake of arsenic through drinking water can lead to chronic diseases such as cancer in the population.

Typical irrigation of a vegetable field in An Giang province near the Cambodian border

Stand-alone Operation without Grid Connection

The objective of the joint research project WaKap is to develop an innovative modular and energy-efficient system for the sustainable desalination of groundwater, seawater and brackish water. In addition, arsenic is to be removed from the groundwater and a pilot plant will be built. By combining capacitive deionisation (CDI) and reverse osmosis, the energy consumption can be considerably reduced compared to existing desalination processes. At the same time, the amount of drinking water produced can be increased.

An important part of the project is to supply the treatment plant with renewable energies such as photovoltaics and wind energy. This should enable a self-sufficient and decentralized operation of the systems without the necessity of grid connection.

An in-situ treatment is planned for arsenic-containing groundwater. This process is based on introducing oxygen into the aquifer. As a result, dissolved arsenic in the water is oxidized and bound underground long-term in an iron-oxide matrix. The main advantages of this process are its high efficiency, low energy consumption and the chemical and waste free process.

The in-situ process to remove arsenic and the CDI to desalinate brackish water are being tested inland in pilot plants in An Giang Province, Vietnam. The production of drinking water from seawater is being tested on the coast in Vung Tau.

Sustainability Assessment

The project will also develop an adapted methodology for assessing the sustainability of the individual technologies and the overall process. Relevant criteria on ecology, economy and social aspects will be taken into consideration for the analysis. The operational reliability and susceptibility of the technical systems also play an important role in the evaluation. In addition, energy-autonomous desalination plants can promote regional economic development and thus contribute to social changes. Based on the project results, the participating companies will develop a ready-for-market prototype for municipalities and private users in Southeast Asia.

Installation of a reverse osmosis membrane in the Vietnamese company SDVICO

Funding Measure
Future-oriented Technologies and Concepts to Increase Water Availability by Water Reuse and Desalination (WavE)

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Modular Concept for Sustainable Desalination using Capacitive Deionization at the Example of Vietnam (WaKap)

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Contact
Hochschule Karlsruhe – Technik und Wirtschaft (HsKA)
Institut für Angewandte Forschung
Prof. Dr. Jan Hoinkis
Moltkestr. 30
76133 Karlsruhe
Phone: +49 (0) 721 925 1372
E-mail: jan.hoinkis@hs-karlsruhe.de

Project Partners
Fraunhofer-Institut für System- und Innovationsforschung (ISI), Karlsruhe
Karl Spiegl GmbH & Co. KG, Nufringen
SDVICO, Vung Tau
Vietnamesisch-Deutsche Hochschule (VGU), HCM City
Winkelnkemper GmbH, Wadersloh

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