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DEUS 21 – REGENERATIVE WATER MANAGEMENT

PURIFYING WASTEWATER BY RECOVERY OF VALUE INGREDIENTS

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SEMI-DECENTRALIZED WATER AND WASTEWATER MANAGEMENT

For more than a hundred years now, industrialized countries have been used to flushing feces together with valuable drinking water over long distances from urban areas to central wastewater treatment plants. This scheme has two costly drawbacks. It is expensive to build and maintain large sewer networks, and drinking water is a scarce resource, much too valuable to use for transporting waste. In the DEUS 21 project (Decentralized Urban Water Infrastructure Systems), the Fraunhofer IGB is looking for more reasonable alternatives to established water management systems – in order to save both resources and costs.

Saving water, utilizing resources

The innovative concept developed at the Fraunhofer IGB for semi-decentralized urban water and wastewater management encompasses:

- Using treated rainwater as high-quality water of reliable standards
- An intelligent form of transport for wastewater (vacuum canalization)
- Semi-decentralized, sustainable anaerobic wastewater purification

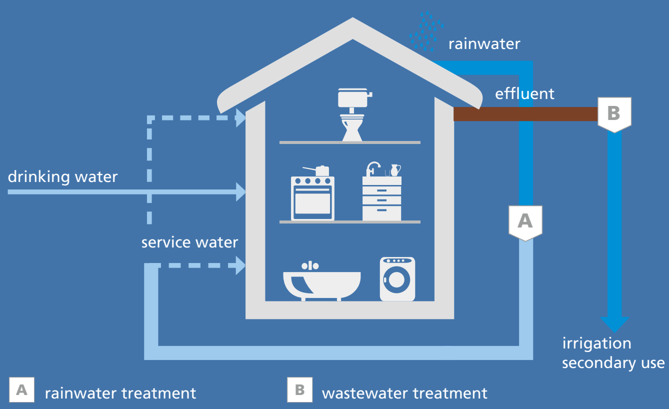
Vacuum suction systems for sanitary installations are already common in airplanes, on boats and on trains and are also available for municipal wastewater. Drastic reductions in water consumption and its costs can be obtained by using vacuum systems and by treating rainwater to become suitable for domestic use. Another advantage of the semi-decentralized concept is that wastewater channel pipes are smaller in diameter and can be buried closer to the surface. Plants for purifying wastewater can be built more accurately in size as they only have to treat wastewater, with no additional rainwater. Central wastewater plants and rainwater storage reservoirs are no longer necessary.

The main aim of the new technologies developed and established for purifying wastewater is to close the cycle of materials by converting the ingredients of wastewater into usable substances e.g. carbon compounds into methane, nitrogen compounds into ammonia fertilizers and phosphorous compounds into a phosphate fertilizer.

In the "DEUS 21 – Dezentralized urban water infrastructure systems" project in a development area belonging to the town of Knittlingen, the Fraunhofer IGB has been able to demonstrate that this recycling strategy really works.

1 *A look into the water house at Knittlingen.*
2 *Vacuum plant.*

Water system of DEUS 21



DEUS 21

DEMONSTRATION PLANT IN KNITTLINGEN

The Fraunhofer IGB developed and tested this new concept for water management in a development area belonging to Knittlingen, a town near Pforzheim, between 2006 and 2010. The project, entitled DEUS 21, was funded by the German Federal Ministry of Education and Research (BMBF). A vacuum plant was put into operation at the end of 2005. It is a reliable system for collecting wastewater from the houses on the new estate and passing it on for purification. The pilot plant was set up initially to cater for only a small number of inhabitants living on the development area at that time. From 2006 onwards, it operated from the so-called water house in order to gather the exact data needed for the technical plant. By 2008, the plant had been optimized technically to purify the wastewater of the meantime number of inhabitants viz. 175. It can easily be expanded to cope with the expected population of the development area. While the anaerobic wastewater technique was being developed, technologies for recovering phosphor and nitrogen from the plant's effluent were tested and then incorporated as technical units in the process line of the water house. The entire technology needed to realize DEUS 21 is built into the water house.

During the test period, rainwater was collected in separate tanks and stored in underground cisterns for subsequent treatment in the water house. The aim was to purify rainwater until it reaches drinking water quality and then deliver it to the inhabitants of the estate through a separate network in order to save large quantities of drinking water. Treated rainwater can be used for flushing toilets, watering gardens, operating washing machines and dish washers as well as for use in sinks and showers. Analysis of the collected rainwater showed that its quality was worse than expected. However, we were able to demonstrate that it is possible to purify this water up to the level of "service water" of hygienic drinking water quality. As there is no scarcity of drinking water in Knittlingen, it would not be economical to operate the rainwater purification process permanently. However, in regions with a scarcity of high quality water, rainwater utilization is an option which should not be neglected.

RECYCLING RAINWATER

Pollutants in rainwater

It is important to keep pollutants out of rainwater while it is being collected. For this reason, a filter with a diameter of 0.6 mm was fitted to the inlet pipe in order to clean rainwater before it even enters the cisterns. Another effective measure is a valve at the inlet of the cisterns which closes automatically for a certain period of time once it has started to rain. This keeps the first flush which is heavily contaminated from overflowed upper surfaces, roofs and roads from reaching the cisterns. Most of the chemical parameters for raw water then already show drinking water quality.

In spite of these protective measures, traces of some pesticides which could come from the roof-insulation of surrounding houses were still detected in the cisterns. Concentrations of sodium and chloride were higher especially in winter, probably due to the salt sprayed on icy roads. During the other seasons of the year, the concentration of salt in the cisterns was low and cistern water was softer than drinking water. Rainwater flowing over surfaces such as roofs and roads in the newly developed area brings a multitude of microorganisms into the cisterns. Organic substances from surrounding vegetation and inorganic solids e.g. from construction work on the site are also flushed into the cisterns.

Multistage treatment process

Cistern water was treated to drinking water quality in a multistage treatment process. The first step is to eliminate particles from the cistern water with a filter whose pores are 1 µm in diameter. Then, organic components are oxidized by adding ozone with special focus on eliminating pesticides. The water subsequently flows through an active carbon filter where oxidation products can be adsorbed and degraded biologically. In this step, inorganic components should also be bound from the rainwater by adsorption. In the next phase, the water passes through an ultrafiltration unit which catches the finest particles and any microorganisms still remaining in the water. The final step is to irradiate the treated water with UV light to ensure that it is free of germs.

The strategy to reduce the concentration of salt in rainwater has more to do with good organization than with complicated chemical technologies. Reducing the amount of salt to free roads from ice and closing the cisterns off during adverse weather conditions would be steps in the right direction.

ANAEROBIC WASTEWATER PURIFICATION

Results from the first pilot plant in Knittlingen's newly developed estate and from a further Fraunhofer IGB test plant have shown that anaerobic wastewater purification works better when solids are separated before the wastewater is purified. A sedimentation tank has been set up to manage this process (Fig. 3).

Fermenting solids

Detached solids are treated separately at 37 °C using the high-load digestion method developed at the Fraunhofer IGB combined with integrated microfiltration. This gives a yield of up to 5000 liters of biogas per day. Hydraulic residence time in the reactor is approx. ten days. Residence times for solids can be chosen freely to a certain extent by removing the filtrate but are significantly longer.

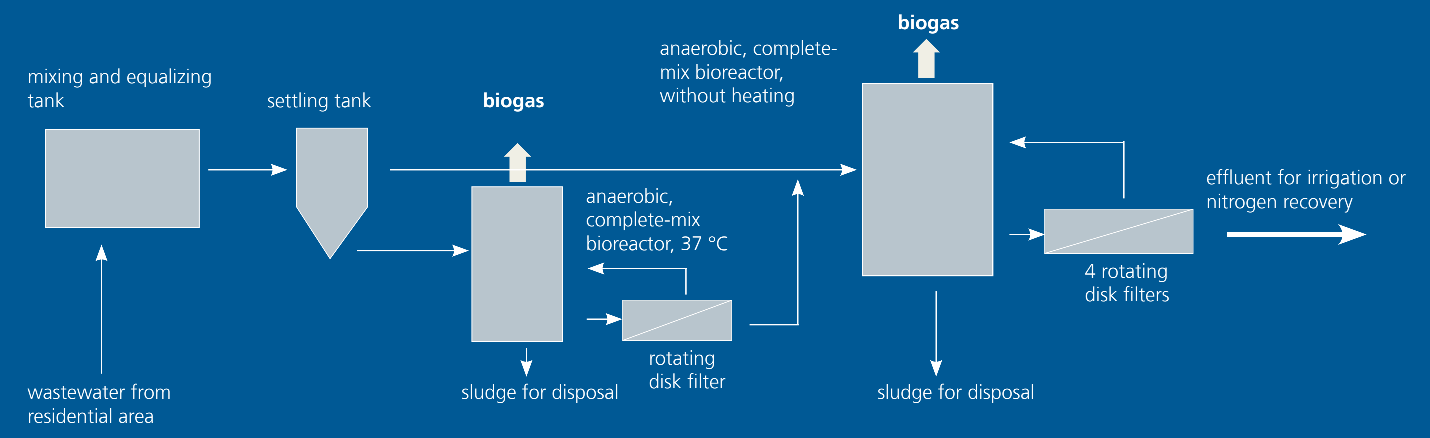
Anaerobic wastewater purification

The overflow of the sedimentation tank (approx. 99 percent of the inflow) is treated in an unheated, complete-mix bioreactor with a volume of 10 m^3. Effluent leaves the reactor through four parallel rotating disk filters with pore diameters of 0.2 µm. At present, the microorganisms needed for anaerobic wastewater purification have to be cultivated specifically because there are no plants in Germany which treat communal wastewater anaerobically at low temperatures to provide the microorganisms. For this reason, the load of the bioreactor was increased in slow steps.

1 *Tank for wastewater purification.*

2 *Bioreactor.*

3 *Diagram of anaerobic wastewater purification with membrane filtration.*



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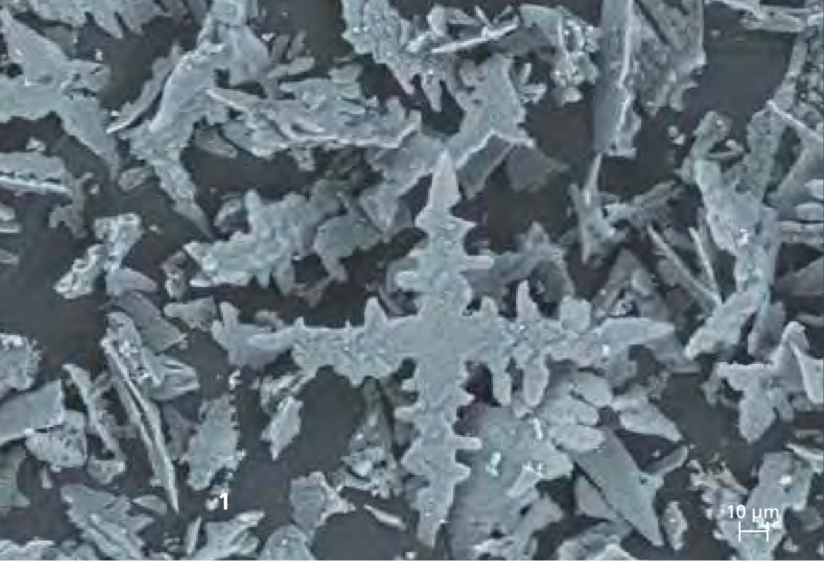
Excellent purification – less sludge

In the summer of 2009 (at reactor temperatures of 22 – 27 °C), we succeeded in keeping the chemical oxygen demand (COD) of the effluent constant at under 150 mg / l (the limit set by the authorities for purification plants serving less than 1000 inhabitants for a longer period). For more than a month, it was even possible to keep this figure under 120 mg / l. In fall / winter of 2009 (reactor temperatures between 13 – 19 °C), figures were constantly under the limit of 150 mg COD / l although the concentration of methane bacteria in the bioreactor was still relatively low at that time. The minimum residence time for wastewater in the bioreactor was 26 hours. Inflow concentrations were between 400 and 1100 mg COD / l and the average degree of decomposition was 85 percent for the mentioned time periods. A maximum yield of 3000 liters biogas was produced per day. The amount of sludge for disposal is reduced significantly, as the excess sludge from the plant in Knittlingen equals about 16.5 percent of the excess sludge produced in the conventional activated sludge process. The membrane filtration is operated with a flux of 12 to 14 $l/m^2/h$ in anaerobic sludge at low temperatures, a chemical cleaning is necessary only once a year.

Biogas production

With the purely anaerobic technology, most of the organic components found in wastewater can be converted into biogas. Without addition of kitchen wastes, about 34 liters of biogas per capita and day could be produced and with kitchen wastes, this amount can be more than doubled. In comparison, conventional wastewater purification by sludge digestion yields approx. 20 to 25 liters of biogas per person and day. The energy content of the biogas produced when wastewater is purified anaerobically is more than 100 kWh per resident and year. If one considers that approx. 30 kWh of electric energy is needed per capita and year to run a large treatment plant together with the same amount again of thermic energy, then the gain of 100 kWh per capita and year obtained with anaerobic technology proves that such a plant could at least be run independent of exterior energy sources.

The present pilot plant in Knittlingen, built for demonstration purposes only, is too small to produce the amounts of biogas needed to run conventional systems e.g. in a combined heat and power plant or with a Stirling engine. However, burning puts it to good use by providing thermic energy for the wastewater purification process.



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RECYCLING PURIFIED WATER AND ITS NUTRIENTS

The effluent from the plant could be used to irrigate and fertilize land under agricultural cultivation. The nutrients ammonium and phosphate, found in relatively high concentrations in wastewater, are hardly decomposed in bioreactors. The microbiological contamination of the effluent is low, thanks to our membrane filter, so that it can safely be used for irrigating. In May 2009, samples were taken from the effluent of the membrane filtration. There was absolutely no evidence for the existence of *Escherichia coli* although millions of germs per milliliter are found in reactor sludge.

Recycling nutrients

In some cases, it is not possible to use effluent for fertilizing purposes so methods are being developed to recycle phosphate and ammonium from the effluent. An electrochemical process precipitates ammonium and phosphate as struvite (MAP, magnesium ammonium phosphate), an excellent fertilizer due to its composition (macronutrients N, P and Mg) and plant availability (Fig. 1).

Initial results from precipitation experiments carried out with filtrate from our plant in Knittlingen were more than promising. This technology has enabled us to lower the concentration of phosphate in the effluent by 93 percent to less than 1 mg/l. As the limit set by the authorities for plants for up to 100,000 residents is 2 mg/l, this gives us a secure safety margin.

Because significantly higher concentrations of ammonium are present compared to phosphate, the former is still found in the effluent after MAP precipitation. In order to recycle this as well, zeolite, a silicate mineral, is used as an ion exchanger and then regenerated with a concentrated saline solution which is subsequently treated by air stripping. This binds ammonium to sulfuric acid as ammoniac which can be recovered as ammonium sulfate for use as a fertilizer. Pilot scale experiments in Knittlingen showed that after 24 hours a 4 mg NH_4-N/l level in the effluent of columns filled with zeolite was exceeded. This means that 3600 liters of wastewater were purified at intake concentrations of 70 to 80 mg/l. When the concentration limit has been reached (this varies depending on the level of purification required) operators can switch to a second parallel column so that the first can be regenerated.

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DEUS 21 – SUSTAINABLE AND EFFICIENT

Applications

Profiting from our plant in Knittlingen together with our successful aerobic membrane activation plant in Heidelberg-Neurott, which is also part of the DEUS 21 project, we now have a choice of processes at our disposal for setting up a sustainable semi-decentralized water management system on a larger scale, of course after adaption to the circumstances prevailing on new sites. This approach is especially promising for areas with no former type of water infrastructure.

Furthermore, this concept is ideal for smaller communities in agricultural regions because anaerobically treated wastewater can be used for irrigation and fertilization. This saves transporting water over long distances. Another advantage is that nutrients can be recycled from wastewater, which can itself be re-used. As energy is also fed back, relatively small-scale material cycles can be set up profitably.

Advantages

- Drinking water can be saved by recycling rainwater
- No need to build and maintain a central wastewater canalization system connecting the area to a large purification plant
- Less costs for purification of wastewater thanks to modern membranes and reactor technologies as practically no sludge is produced
- Flood prevention and elevation of groundwater level because purified wastewater can be used for irrigation or allowed to seep into the ground
- Recovery instead of disposal: nutrients are recycled instead of disposed of so that biogas, ammonium and phosphate fertilizers can be produced

1 *Magnesium-ammonium-phosphate crystals.*
2 *Plant for recycling nitrogen.*
3 *Taking a filtrate sample.*

FUNDING AND PARTNERS

The “DEUS 21 – Decentralized Urban Water Infrastructure Systems” project was funded in two stages by the German Federal Ministry of Education and Research (BMBF) from October 2003 to May 2010. Further research partners to the Fraunhofer IGB were the Fraunhofer Institute for Systems and Innovation Research ISI in Karlsruhe and the Institute for Urban Water Management ISA from RWTH Aachen University in the first stage. The Fraunhofer-Gesellschaft funded the optimization of individual techniques between January 2009 and March 2013 as part of a market-oriented pilot research project entitled “InWasif – Concept for sustainable, integrated urban water infrastructure and utilization”.

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