Proven methods and high-tech analysis – management concepts to enhance health and hygiene

Around two million people worldwide die from a lack of drinking water or contaminated drinking water. Water, especially clean water, is a precious commodity – one that is however scarce in many regions of the world. There is an urgent need for new and efficient processes and management concepts to find ways to provide as many people as possible with a day-to-day supply of clean water. The aim is to achieve a high level of efficiency throughout the entire use cycle – from obtaining water through to cleaning wastewater.

The health of the global population is directly linked to the quality and quantity of fresh water available for use. According to data from the World Health Organization (WHO), the most important factor in world health is preventing the transferable pathogens (bacteria, viruses and parasites) present in contaminated drinking water. Unhygienic conditions, a lack of sanitation and poor-quality drinking water are the main reasons why a child under 5 dies every 3 seconds in developing and emerging countries.

In addition to mass contamination, the situation is also deteriorating in many developing countries due to a drastically worsening water shortage. Compared with developing and emerging countries, Germany and the other industrialised nations are mainly at risk through a multitude of new chemical substances and also pathogens that primarily spread via the waterways.

Germany's largest ultrafiltration facility

One of the world's largest ultrafiltration membrane facilities was commissioned in the Eifel region in 2005. Every hour, 7,000 cubic metres of water flow through the facility from the dam, and can then be used as drinking water. Dissolved substances, particles and micro-organisms are filtered out by the ultra-fine membrane pores within the facility. The BMBF funded extensive pilot tests as part of the research project on high-performance membrane technology before the facility was put into operation. The high-performance membranes tested in the Eifel regions met expectations in full: even when the water was extremely contaminated (e.g. after heavy rain), they eliminated almost 100% of the parasites and viruses present. The costs for materials and debt service including new buildings came to less than ten cents per cubic metre of drinking water (project 2.2.01).

AQUASens – a fast and mobile method for detecting water impurities

Even today, methods for detecting microbial contamination in water samples are incredibly laborious – and often take longer than a week. Within an interdisciplinary BMBF – research project involving scientific institutions and companies, a semi-automatic analysis device was developed that can detect both small molecules (such as hormones, antibiotics and pesticides) and much larger bacteria: by means of an immunological test that uses a tiny water sample and is complete within hours. This enables those responsible to obtain fast, reliable information on the degree of water contamination and the potential threats (project 2.2.02).

Pathogens in taps

Even top-quality drinking water can still be contaminated in the last few metres before it emerges from the tap: poor-quality seals and hoses are a bacterial paradise. Those working on the BMBF project researching biofilms in the home took 20,000 measurements over the course of four years to test the level of hygiene in hot water systems. The results showed that legionella was present in over 13% of these hot water systems (project 2.2.03).

Current aspects of swimming pool hygiene

When treating swimming pool water, chlorine must be used as a disinfectant (also see DIN 19643). However, the reactions of chlorine with substances that get into the pool either via the water or the pool users produce unwanted disinfection by-products. It is suspected that these by-products pose a risk to health. The aim of the project entitled "Gesundheitsbezogene Optimierung der Aufbereitung von Schwimm- und Badebeckenwasser" (optimizing the treatment of pool water with regard to health) is to investigate the effects of these by-products – particularly on those with respiratory or other chronic illnesses (project 2.2.04).

Dams as a source of drinking water – the benefits of the membrane procedure

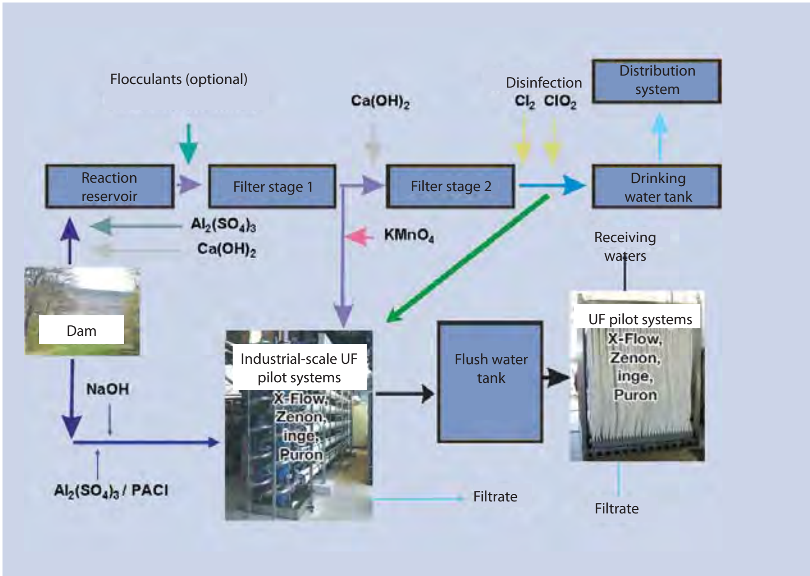
Pressure-driven membrane procedures◄ are gaining importance in the field of treating water. After several years of pilot testing, one of the world's largest ultrafiltration membrane facilities was commissioned in 2005 in the North Eifel region to turn the water from dams into drinking water. The expectations of this facility have been met in full. The preliminary tests were financed by the Federal Ministry of Education and Research.

The hygienic requirements of treating surface water for use as drinking water have increased considerably over the last few years. Membrane procedures are a solution with a great deal of development potential in order to meet these requirements: they can filter out dissolved substances and also serve as a barrier for particles and microorganisms. The universal application potential in removing salt from seawater, treating wastewater and producing process and drinking water provides the backing for the growth potential of pressure-driven micro◄, ultra◄ and nanofiltration◄ membrane procedures and also reverse osmosis◄.

The potential fields of application for the membrane filtration procedure depend on the impurities to be removed from the untreated water◄. Reverse osmosis for desalination has long been the technology of choice for treating brackish water and seawater for use as drinking water. The main methods used for processing untreated water inland are the ultra and microfiltration low-pressure membrane procedures◄ as well as nanofiltration. Wide-scale elimination of parasites and viruses has recently become a core interest. Both micro and ultrafiltration are used to remove most of these particles dissolved in the water (with microfiltration removing virtually all parasites, but ultrafiltration possibly not removing all the viruses). Processes using denser membranes are required to remove inorganic dissolved matter, e.g. nanofiltration or reverse osmosis.

Good combination potential

The success of the membrane procedure is in the way it can be combined with conventional water treatment procedures and techniques (e.g. flocculation◄). Other benefits are the greatly reduced price of membranes and the considerable reduction in energy requirements through low-pressure membranes and intelligent energy recovery.



Treatment schematic for the Roetgen water plant and integration of the pilot facilities

Wassergewinnungs- und -aufbereitungsgesellschaft Nordeifel (WAG) has been operating a membrane facility in Roetgen since the end of 2005, treating water obtained from dams for use as drinking water. The facility supplies around 500,000 people in the Aachen region with drinking water. With a capacity of up to 7,000 cubic metres an hour, the facility is one of the world's top-performing ultrafiltration membrane facilities producing drinking water from dam water. Even when the dam water is heavily contaminated (e.g. after heavy rain), it eliminates almost 100% of the parasites and viruses present.

Several years of preliminary testing

Before the facility was commissioned, WAG and the IWW Water Centre (Rheinisch-Westfälisches Institut für Wasserforschung) spent four years working together with the chair for water technology at the University of Duisburg-Essen carrying out tests: they used multiple test facilities with capacities of around ten cubic metres an hour and a pilot facility with a much higher treatment output (approx. 150 m^3/h). At the same time, pilot tests were performed using an immersed suction membrane to produce drinking water and to treat the flushing water for the membrane facility. The BMBF funded these tests as part of the research project entitled **"Hochleistungs-Membran-**

Ultrafiltration units for treating drinking water (stage 1)

Ultrafiltration unit for treating the flush water (stage 2)

technologie" (high-performance membrane technology). Wetzel + Partner Ingenieurgesellschaft mbH (Moers) was able to use the results of these tests to plan the industrial-scale facility in Roetgen, with scientific support from the IWW.

The facility in Roetgen combines flocculation and direct ultrafiltration. This reduces the amount of sedimentation on the filter membrane and thus the associated, irreversible drop in efficiency. The flakes collect on the surface of the membrane and stabilise filtration operation. Optimised membrane backwashing then enables the impurities to be removed from the surface of the membrane together with the flakes. Another feature of the facility is that the sludgy backwash from the membrane facility is treated during a second membrane stage. The resultant permeate – water cleaned through particulate filtration – is then mixed with the untreated water in the first stage. This increases the yield of the overall process to over 99%. The second stage has a treatment capacity of 630 cubic metres an hour, meaning it is also one of the world's largest facilities of its type.

Expectations met in full

The stable operation and outstanding quality of the water produced meet all expectations. The costs for material use and debt service (including the new buildings) amount to less than EUR 0.10 per cubic metre of drinking water.

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AQUASens analysis system – a fast and mobile method for detecting water impurities

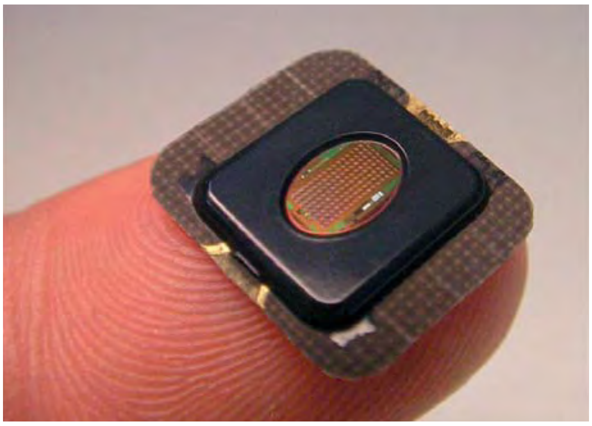
Microbiological tests of water samples have always taken a lot of time and effort. A new analysis system, the development of which was funded by the Federal Ministry of Education and Research, could provide a solution: it is fast, mobile and accurate – and good value to boot. There are many different ways this system could be used by industries and local authorities.

Before now, tracking water impurities through micro-organisms has required a specialised lab, where germs have had to be multiplied on a culture medium. While coliform (faecal) germs can be detected within a single day – as there are proven procedures in place – tests for most other bacteria still require a great deal more work and often take more than a week. However, if the water is potentially contaminated with microbes, those in charge need fast, reliable information on the degree of contamination and the potential threats.

Combined expertise

The Federal Ministry of Education and Research funded a project in order to provide a solution: "AquaSENS – Detection of micro-organisms in water with CMOS-based sensors". Companies and science institutes combined their expertise to develop a mobile analysis system that can quickly detect micro-organisms and germs in water – without the need for timely and costly cultivations in a lab. The parties involved in the project were Siemens AG, inge watertechnologies AG, Friz Biochem Gesellschaft für Bioanalytik mbH, the Institute of Hydrochemistry (IWC) at TU Munich, the IWW Water Centre (Rheinisch-Westfälisches Institut für Wasserforschung) and the Water Technology Centre Karlsruhe (TZW). Tasks within the project:

- Set up a compact, fully automated membrane filtration system for concentrating germs (from 10 litres of water into an eluate volume of 50 millilitres).
- Develop two sample preparation procedures on the basis of immunomagnetic separation and affinity chromatography for further concentration and transfer of germs in a 1 millilitre measurement buffer.
- Develop digital read-out biochips with built-in detection and analysis electronics.
- Develop and produce the compact and user-friendly read-out device for the biochips.



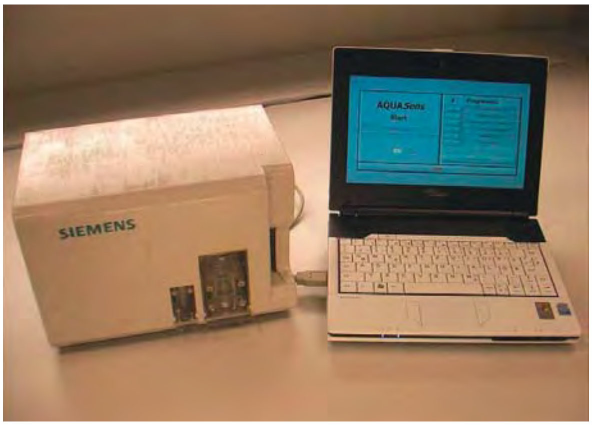
Small biochip, big performance: a sensor quickly detects micro-organisms in the drinking water.

- Identify biochemical detection molecules (antibodies) and DNA segments specific to the micro-organisms sought, and develop detection procedures (assays) for transfer to the biochips.

The AquaSENS project was able to complete all tasks set successfully: the semi-automatic device designed detected both small molecules (such as hormones, antibiotics and pesticides) and much larger bacteria: by means of an immunological test using a tiny water sample. This detection is based on the concept of the immune system: the ability of antibodies to identify foreign substances from characteristic constituents – antigens.

Biochips developed

This approach uses a biochip with a fully integrated CMOS (Complementary Metal Oxide Semiconductor). The small biochemical sensor and the associated read-out electronics are ideal for use in portable, compact and economical analysis systems. They are particularly advantageous for situations involving many different germs in a single measurement process alongside antibody-antigen interactions or the detection of specific DNA segments. The biochip and biochemical detection procedures have been developed for both of these principles.



The mobile reader provides a read-out for water impurity results

Because harmful germs such as legionella, salmonella and coli bacteria are usually only present in water in low concentrations and the biochips use just tiny samples of 100 microlitres, it is necessary to augment the germs being sought first. The project partners established the system required to do this by coupling a membrane filtration system with an "immunomagnetic separation column◄".

The result: coli bacteria could be detected within just 90 minutes. The biochip detection limit for E.coli bacteria was determined at 2,000 germs per millilitre of sample concentrate, with a measuring time of 30 minutes. The analysis system can therefore detect bacteria within two hours.

Multiple uses available

As well as being used for the quality assurance of drinking water supplies, the analysis system could also be extremely useful for samples of process water, ultra-pure water, groundwater and surface water; tests are still underway to determine whether and how this is possible.

AQUASens could be used in public buildings and hospitals to test the process water in the sewage system or to test for harmful substances in the hot water system. The new analysis system would also be useful in the food and pharmaceutical industries, which require ultra-pure water for production.

It may even be suitable for measuring sewage sludge or for process monitoring in biotechnological fermenters◄. First the relevant micro-organisms would be determined, then the corresponding assays developed. The crucial thing here is to identify and produce suitable antibodies first, as they are not currently available for all use cases.

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Pathogens in taps – an underestimated problem

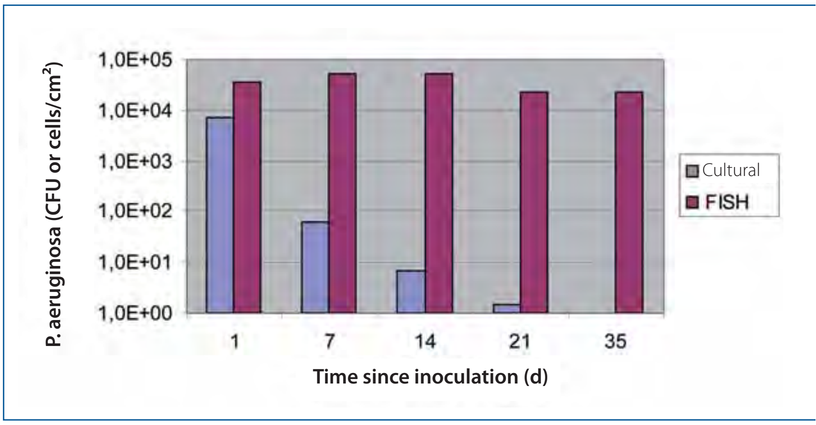
Even top-quality drinking water can still be contaminated in the last few metres before it emerges from the tap: poor-quality seals and hoses are a bacterial paradise – this can have serious consequences for people with a weakened immune system under certain circumstances. A new research project is currently investigating how to improve the hygienic safety of drinking water installations.

How does drinking water get to the consumer? It travels a long way to get there, from the waterworks through the pipelines and into the home, strictly monitored and kept at peak quality – until it reaches the water meter. "This is when it hits a grey area: the home installation. A highly visible variety of materials undergoing little control can be used here, some of which represent a paradise for micro-organisms", says Professor Hans-Curt Flemming of the University of Duisburg-Essen. Drinking water is not sterile and indeed should not be – it still contains bacteria that survive even with a lack of nutrients and are completely harmless. The key to success in waterworks is extracting the nutrient base for the bacteria. This produces "stable drinking water". "When these ravenous germs come across materials that provide them with food, then it's like paradise to them. They don't need much to thrive – small amounts of exuded softener, colouring, antioxidant and other products added to plastics are perfectly sufficient. They establish themselves there and form thick biofilms◄ in which pathogens can settle, grow, then be flushed out to contaminate the water", continues Flemming.

Then even the best water loses its level of quality, all in the last few metres on the way to the tap. What circumstances cause this? Are there any epidemics? What level of monitoring is there? Which materials are authorised? How can problems be avoided?

Hot water systems tested

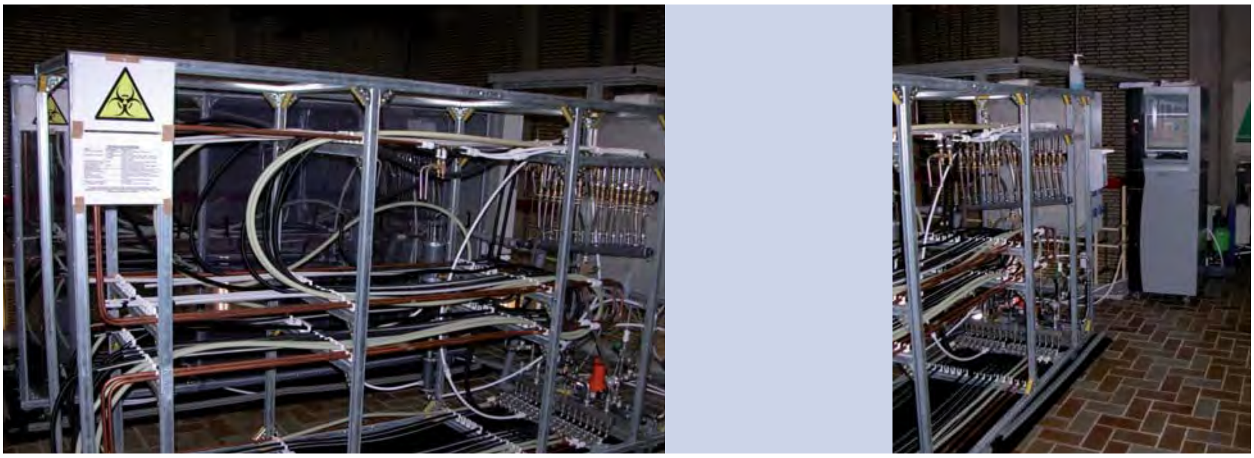
These questions were the main focuses of the large-scale study funded by the BMBF called **"Biofilme in der Hausinstallation"** (biofilms in home installations), which ran from October 2006 to March 2010. Five research facilities and 17 industrial partners spent four years examining these questions under the co-ordination of Professor Hans-Curt Flemming (University of Duisburg-Essen and IWW Mülheim). The results were certainly worth attention: "The statistical analysis of more than 20,000 measurements taken by health authorities showed that legionella was present in over 13% of the hot water systems tested", said Professor Thomas Kistemann from the Institute for Hygiene at the University of Bonn, one of the researchers involved. One particularly unpleasant pathogen is Pseudomonas aeruginosa, which causes inflammation of the lungs, urinary tract infections and also especially persistent infections of burns. This was found in 3% of the tests performed. Kistemann goes on: "Since monitoring was made mandatory four years ago, only half the public buildings and hotels affected have been tested. That is not to say that the authorities have not been active, simply that they are overwhelmed and understaffed. And who is responsible for water quality in multiple dwellings? Experience shows that anyone taking on this task quickly becomes unpopular."



Evidence of Pseudomonas aeruginosa through cultivation (left column, blue) vs. fluorescence in-situ hybridisation (FISH) (right column, purple)

Shower hoses – a bacterial paradise

The scientists were able to use true-to-life model systems to demonstrate that shower hoses and also relatively small seals become a paradise for bacteria when they contain materials that support germ growth. Biofilms could be spotted on some of them after one or two weeks – even with the naked eye. The usual suspects in such cases are plastics that no test has approved for use with drinking water. Low-cost taps often contain additives for biological use such as softener or remains of release agents, or become contaminated with substances during production and installation. An unfavourable combination of poor material quality (e.g. low-cost taps) and water quality encourages strong biofilm development – and thus provides a living environment for pathogens. "That does not necessarily mean that epidemics are going to break out,



Computer-controlled, semi-technical home installation for long-term testing with true-to-life consumption profiles

but illness could occur and lead to time off work and a temporary loss of quality of life", says Professor Kistemann. "When the immune system is weakened, e.g. after an operation, critical situations can arise", says Professor Martin Exner from the University of Bonn.

So what can be done? Firstly, it was demonstrated in the research project that the current monitoring methods need to be expanded on considerably in problem cases. It has been shown that the pathogens being sought can go into a sort of coma, which causes them to disappear from the radar of standard methods. However, they wake up as soon as their living conditions improve and can be just as infectious as they were before. Practical problem cases were able to demonstrate the benefits of new molecular biology methods for identifying the causes of persistent bacterial contaminations and eliminating them.

Greater attention towards home installations

One conclusion from this successful research project is to dedicate more attention to home installations, as this is where even the best water can lose its quality. "We have drawn up important notes on methods to prevent this", concludes Hans-Curt Flemming. However, it was clear that there is still a great need for research and regulation – not only for materials but also for the testing procedures. The last few metres before the tap are crucial, and yet amazingly underexposed.

As a result of the findings from this project, the consortium has drawn up a research proposal that addresses the problems in detail. It particularly focuses on the temporary disappearance of pathogenic germs from the monitoring radar and their sudden recurrence, the conditions under which this occurs and how the hygienic safety of drinking water installations can be ensured. The proposal was successful and will receive over EUR two million total funding from September 2010 to August 2013.

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Swimming pools – health risks posed by pool disinfection

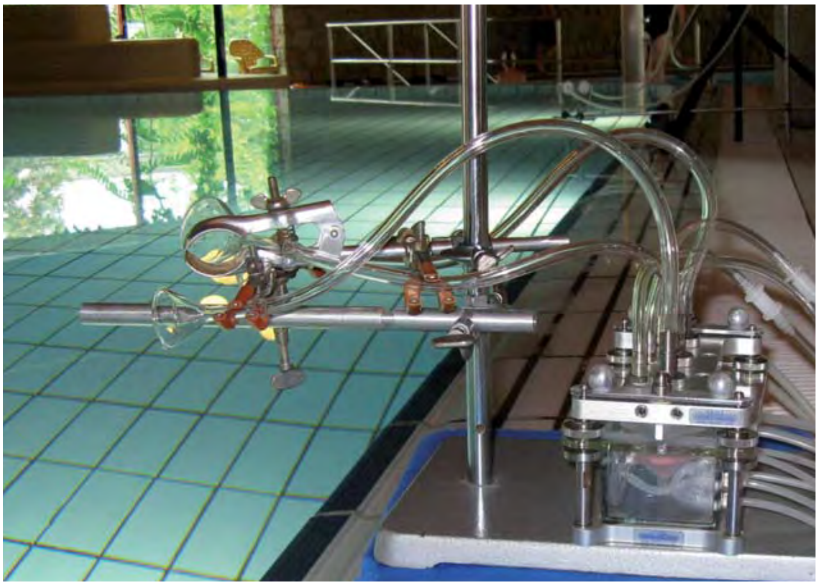
"Swimming is good for you": this is a commonly used phrase in health care. But does this also unequivocally apply to swimming in pools containing water disinfected with chlorine? Once water has been disinfected with chlorine, disinfection by-products can form – and these can pose a risk to human health. There are still many questions requiring greater scientific clarification regarding the risk posed to children and those suffering from chronic illnesses. A new research project is seeking answers to these questions.

When treating swimming pool water, chlorine must be used as a disinfectant (also see DIN 19643). However, the reactions of chlorine with substances that get into the pool either via the water or the pool users produce unwanted disinfection by-products. It is suspected that these by-products pose a risk to health. This is by no means a new problem, but the effects of pool water on hygiene have recently become the focus of scientific interest.

The results of studies conducted thus far connect respiratory and other chronic illnesses with swimming in chlorinated water. Particularly given the general acceptance of swimming from childhood ("swimming is good for you"), the issue is a hot topic for health policy. The public can often gain the impression that the risks of swimming in chlorinated water outweigh the health benefits. This is a task for health-related environmental research: it must provide reliable data that enables a scientific risk assessment in terms of prevention.

Instigating international momentum

Germany has a leading international role in pool water hygiene. The research work undertaken contributes towards sustainable health care and has an influence on international standards. Noteworthy projects are **"Swimming Pool Water Under Aspects of Health and Treatment Technology"** (funding reference: 02WT0004) and **"Integrated Risk Assessment for the new Generation of Disinfection By-products"** (funding reference: 02WU0649). The study involving top swimmers (project with funding reference 02WT0004) was the world's first population study that assessed the health risk of swimming in pools. It instigated international momentum to conduct similar studies.

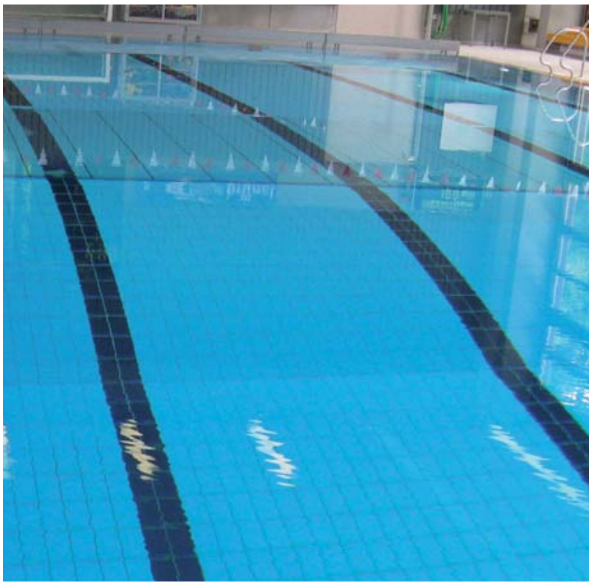


On-site measurement to determine the potential risk from disinfection by-products in the pool hall's air

Symposium held

A symposium called "Aktuelle Aspekte der Schwimmbeckenwasserhygiene – Pool Water Chemistry and Health" was held in Dessau in March 2009. The event brought leading scientists from around the world together; a survey was conducted and open issues identified. The scientists overwhelming agreed that German research has a clear edge in pool hygiene: all key aspects of risk management have already been examined in terms of their interactions – be it treatment of pool water or hazard assessment and risk evaluation of disinfection by-products.

The two research projects mentioned have shown that there are potential health risks associated with swimming in pools with chlorinated water. The aim of ongoing project **"Gesundheitsbezogene Optimierung der Aufbereitung von Schwimm- und Badebeckenwasser"** (optimizing the treatment of pool water with regard to health) is to work through pending issues that are extremely hot topics in health policy, especially regarding respiratory illnesses and with a particular focus on children. The overriding objective is to define parameters to rule out health risks across a broad consensus of science, authorities, politics, pool operators and the public.



Three questions are of particular interest to the project:
- Are the discussed exposure paths and associated chronic illnesses (inhalation/asthma, dermal/bladder cancer) relevant potential risks?
- If so, which exposure scenarios are responsible (chemical substances/treatment)?
- What options (treatment techniques/range of measures) are available to reduce or eliminate these potential risks?

The key element to the scientific work involved is the establishment of a pool model for conducting controlled tests. The various treatment options are accompanied by extensive chemical and toxicological analyses. The latest procedures were used to do this (e.g. exposure models for inhalation and dermal contaminants◄).

Bulletin published on baby swimming and disinfection by-products in swimming pools

A risk analysis of disinfection by-products as well as technical and legal measures based on the results is planned with the aim of reducing the build-up of these by-products. One key objective is to drive forward environmental research with regard to health. It is expected that research into pool hygiene will find its way into legal regulations. The first result is the publication of the bulletin entitled "Babyschwimmen und Desinfektionsnebenprodukte in Schwimmbädern" (baby swimming and disinfection by-products in swimming pools) by the Swimming Pool Water Commission (BWK) of the Federal Ministry of Health, which appeared in the Federal Health Gazette 2011 (54: 142–144). A potential risk was highlighted in terms of the care principle. Another aspect is the availability of equipment to minimise the concentration of TCA in the air of the pool hall through technical rules for treating pool water and for indoor pool ventilation. Current developments show that pool operators and visitors have become clearly conscious of a problem associating baby swimming and asthma as a result of the UBA's activities. Although the scientific evaluation of the toxicology data from the BWK and the Indoor Air Hygiene Commission's ad-hoc working group for indoor guidance values is as controversial as ever, the technically feasible guideline stipulated of 0.2 mg/m3 trichloramine within the pool hall's air means there is now a suitable monitoring parameter available in order to minimise the health risk.

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