

EFFECTS OF HIGH BATHING LOADS ON POOL WATER TREATED BY COAGULATION–ULTRAFILTRATION

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ABSTRACT

Because of their high efficiency in removal of particles and microorganisms, hybrid coagulation/ultrafiltration (UF) processes are increasingly used for pool water treatment. Water treatment by ultrafiltration membranes provides high efficiency particle and microorganism removal and may lead to improved water quality compared to conventional filters. The objective of this investigation was to evaluate the efficiency of pool water treatment by ultrafiltration at high bathing loads. Therefore a load test was carried out over a period of 5 days at an indoor pool where the water is treated by UF. Measured monitoring parameters such as pH, redox potential and conductivity remained almost constant during the test period. No correlation of total organic carbon (TOC) nor trihalomethanes (THM) and number of bathers per hour could be identified. But accumulation of both THM and TOC in the pool water cycle was observed. Furthermore, accumulation of combined chlorine and particles occurred in the pool water during the test period. Turbidity as well as combined chlorine showed distinct fluctuations which can be related to the course of bathing load at the pool. The total particle concentration (particle size > 1 µm) revealed the best correlation to the amount of bathers. However, despite the very high daily maxima of particle concentrations no pathogens were detectable in the chlorinated pool water. During the whole test period, all chemical and hygienic requirements according to German standard DIN 19643 were met safely.

Keywords	ultrafiltration, total organic carbon, particle counting, load test
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INTRODUCTION

Pool water quality is mainly affected by the introduction of contaminants by bathers, the efficiency of treatment technology installed and hydrodynamic conditions in the pool. Bathers introduce particular and dissolved substances such as skin flakes, hair, grease and cosmetics into the pool water. Additionally, 50 mL of urine and 200 mL of sweat are assumed to be released per bather on average (Judd & Bullock, 2003). This way, an amount of 1 to 1,5 mg/L total organic carbon per bather is brought into the pool water (Zwiener et al., 2007). In combination with treatment, this results in an average concentration of 0.6 up to 3.0 mg/L in the pool (Glauner et al., 2006). Keuten (2009) gave an overview about results of different studies about bather's release of dissolved organic carbon (DOC), urea, Kjeldahl-nitrogen and resulting oxygen demands. Results shown in this overview are very inconsistent which indicates that the released values of substances per bather are in a big range and might be dependent on the activities and hygienic constitution of the bather himself (Keuten, 2009). Due to the circulation of pool water, accumulation of pollutants may occur if treatment technology offers no sufficient removal of bather's pollutants.

Furthermore, pool water might be contaminated by infected bathers with bacteria, parasites and viruses that act pathogenic to humans. They have to be inactivated by efficient disinfection or removed by treatment. In order to maintain sufficient disinfection capacity, free chlorine is added in the re-

circulated pure water flow to keep a constant level of the disinfectant in the pool. However, free chlorine not only provides disinfection but may also lead to a formation of disinfection by-products (DBP) in the pool. Organic matter brought into the pool by bathers act as precursor for the formation of DBP, e. g. trihalomethanes (THM), haloacetic acids and chloramines. Excessive exposure to DBP is harmful to human's health and therefore their concentration should be minimised in pool water.

Ultrafiltration (UF) with membranes provides very efficient particle and microorganism removal and is increasingly used for pool water treatment. If UF is combined with coagulation and adsorption processes even dissolved inorganic and organic substances (for instance precursors for DBP) can be removed partly from the pool water. This way DBP formation potential can be decreased. In conventional coagulation-deep-bed-filtration there is always a risk of release of bacteria from the filters to the pool. This risk is not given in UF-Systems, as long as an additional GAC-filter or powdered activated carbon dosage is operated in front of the UF-system. Furthermore, fully automatic operation and a small food-print make UF treatment very suitable for pool water treatment.

The performance of UF treatment and its effects on pool water quality still needs assessment in order to support standardisation of this method. The objective of the investigations was to determine the efficiency of pool water treatment by UF and the potential accumulation of substances in the pool during high load periods.

METHODS

A load test was done over a period of 5 days at an indoor pool where the water is treated by UF. Prior the filtration step powdered activated carbon and an iron-based coagulant are injected in the water treatment cycle. The hollow fiber UF membranes are operated in dead end mode with a flux of about 200 L/m² h and comprise a total area of 240 m². They are installed in two lines, each backflushed separately. Once a day the membranes are cleaned by a chemical-enhanced backwash with sodium hydroxide, sulfuric acid and /or sodium hypochlorite. The effluent of the chemical-free backwashes is treated by a second stage of UF modules and is led back to the inlet of the pool water treatment. In order to maintain sufficient disinfection sodium hypochlorite is added discontinuously in the re-circulated treated water leading to a nearly constant level of free chlorine in the pool. pH-value in the pool is adjusted in between 6.5 and 7.6 by dosing acid or base in the circulated water, respectively.

The pool has a rectangular area of 136 m² and is not equipped with any attractions. Its base declines continuously causing a water depth between 1.07 m and 1.63 m. The design permits a maximum number of 50 bathers per hour according to German standard DIN 19643 – part 1 (German maximum bathing load). During the load test the maximum number of bathers per hour was reached or exceeded at least once per day for four days in a row.

69 L of potable water were used per bather in average for dilution. Further information about the investigated pool and the treatment installed are summarised in table 1.

Table 1 Details of design and treatment at the investigated pool

pool volume	182 m ³
circumferential transfer channel	52 m
temperature	29°C ± 1 °C
hydraulics	wall inlets and 100 % deck-level removal
circulation rate	44 m ³ /h
dosage of iron chloride with aluminium ingredients	0.05 g/m ³ Al ³⁺ and 0.1 g/m ³ Fe ³⁺
dosage of powdered activated carbon	1-3 g/m ³ as required

For monitoring the pool water quality measurements of pH value, redox potential, conductivity, total and free chlorine were done in three hours intervals. Turbidity and particle counting were done continuously in pool water drawn off from the surface water level. Samples for further chemical and microbiological analyses were taken in three hours intervals too. Chemical analysis of total organic carbon (TOC), trihalomethanes (THM) and oxygen demand as well as microbiological tests with regard to aerobic colony counts, coliforms, *Escherichia coli*, *Pseudomonas aeruginosa* and *Legionella* species were done by a certified laboratory.

RESULTS

Figure 1 shows the number of bathers that entered the pool per hour (German bathing load) during the test period. During maximum loads, high amounts of organic matter are introduced into the pool. The input of organics can be measured as concentration of total organic carbon (TOC) representing the dissolved and suspended organic materials that are introduced by bathers or by fresh water into the pool water cycle. During the load test, TOC concentrations in the pool water appeared between 1.5 and 2.5 mg/L (see Fig. 1). No correlation of TOC and number of bathers per hour could be identified but accumulation of TOC in the pool water cycle was observed. Oxygen demand is another chemical sum parameter representing all substances that are oxidized by permanganate. Because of their reducing effects, these substances may derogate disinfection and contribute to the formation of DBPs. Oxygen demand mirrors the oxidation state of the pool water and depends on pH and on the free chlorine level (Erdinger, 2007). Although oxygen demand covers other substances than TOC, it shows a good correlation to TOC concentration during the test period (see Fig. 1).

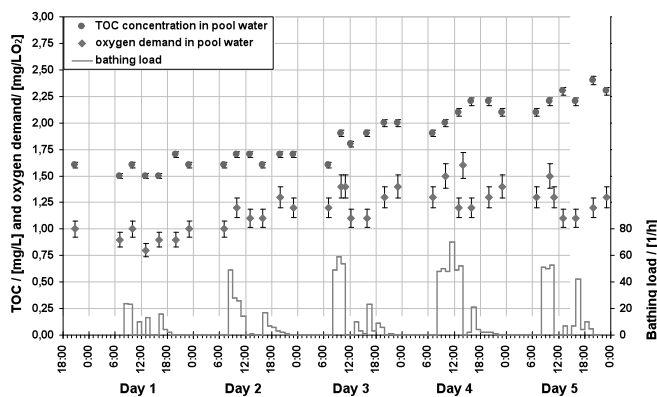


Fig. 1 TOC and oxygen demand in the pool water

Measured monitoring parameters such as pH, redox potential and conductivity remained almost constant during the test period. Not surprisingly, no influence of bathing load could be obtained for pH, which is maintained at a constant level in the pool automatically. Redox potential showed a slight decrease down to 800 mV during high bathing loads. Due to the high input of substances with reducing effects into the pool, the ratio of oxidizing and reducing matter is changed this way that the redox potential is changed. Moreover, free chlorine acting as an oxidant is added automatically in the pool water cycle by the treatment system if reducing effects intensify. This way, the decrease of redox potential was cushioned sufficiently. Conductivity is caused by dissociable substances (salts) that are introduced into the pool water by bathers or due to chemical dosing during treatment. High bathing loads may lead to an accumulation of salts in the pool water cycle and thus to an increase in conductivity. During the load test, only a slight increase in the mean conductivity of about 25 $\mu\text{S}/\text{cm}$ was detected.

Free and combined chlorine serve as basic parameters for monitoring the effectiveness of disinfection as well as the formation of disinfection by-products, such as THM. Due to the controlled addition of sodium hypochlorite into the water cycle a level of free chlorine in between 0.34 and 0.69 mg/L in the pool water could be maintained during the test period. This free chlorine level corresponds with the requirements according to DIN 19643 - part 1, which require a concentration between 0.3 and 0.6 mg/L. Furthermore, according to this standard the concentration of combined chlorine in pool water should not exceed 0.2 mg/L. As shown in Fig. 2 this requirement could be safely maintained for each bathing load situation. During the whole test period an increase in daily mean concentration of combined chlorine in pool water of 0.04 mg/L was detected. The same course could be observed for the THM concentrations in pool water. This indicates that during the test period more combined chlorine as well as more THM were formed as could be removed by the treatment process or by dilution with fresh water. The maximum THM concentration measured in pool water during the load test amounted 10 µg/L representing 50 % of the maximum level required by the German standard. The course of THM concentrations does not show a clear correlation to the bathing load.

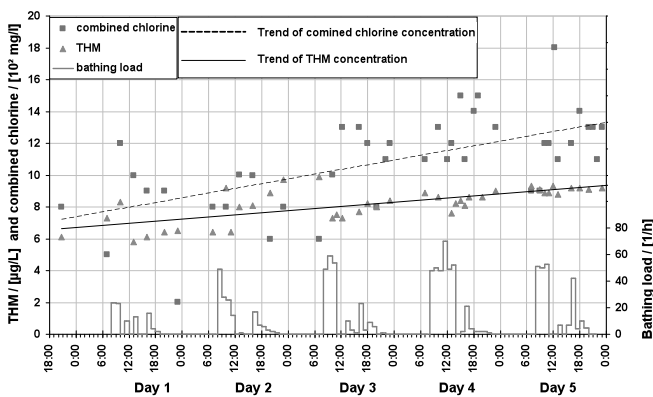


Fig. 2 Concentrations of combined chlorine and THM in the pool water

Usually, particles in water of indoor pools mainly originate from bathers. However, hydroxide flocs generated by the treatment process may also get into the pool water. During the load test, turbidity showed a proportional relation to the bathing load which occurs slightly time-shifted. The maximum value of turbidity (0.5 FNU) was measured on the fourth day following the total maximum bathing load. Fig. 3 shows the total particle concentration (particle size > 1 µm) over time during the load test. This parameter revealed a very good correlation to the amount of bathers. This indicates that the introduction of particles into the pool water is primarily caused by the bathers. It can also be seen from Fig. 3 that particles with a size of 1 to 5 µm accounted for the major part of the total number of particles. Analyzing the particle concentration in pool water in relation to the average particle concentration in the treated water (10/mL) during high bathing loads, a treatment efficiency of more than 99 % could be achieved. At days 3, 4 and 5, when very high bathing loads occurred, particle concentrations in the pool water decreased slowly after the peak and the daily minimum of the previous days was not reached anymore. A distinct increasing trend in total particle concentration could be observed too. This indicates that the number of particles that are introduced into the pool water cycle exceeded the particle removal rate by the treatment plant leading to a distinct accumulation effect. The maximum of the total particle concentration was about 2500 particles/mL and occurred at the time of the maximum number of bathers. Due to limited knowledge about particle concentrations in pool water in other pools under similar conditions, evaluation of these particle concentrations and comparison to pools with conventional treatment is not possible currently.

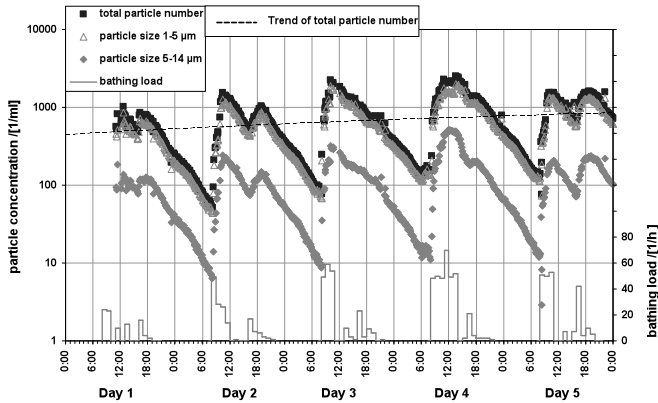


Fig. 3 Particle concentration in the pool water

Accumulation of particles in pool water is of particular importance because particles may enclose pathogens and hinder sufficient disinfection. However, despite the very high daily maxima of particle concentrations none of the analysed pathogens were detectable in the chlorinated pool water at all. Aerobic colony counts (at 36°C) resulted in an average number of 6 /mL demonstrating the very low load of bacteria in the pool water.

CONCLUSIONS

The load test showed that by application of coagulation-ultrafiltration treatment with adsorption by powdered activated carbon safe hygienic conditions can be maintained even at high bathing loads. However, accumulation effects were detected for several substances in the pool water over the test period. This indicates that the amount of these substances introduced into or generated in the pool water cycle exceeded the treatment capacity under the investigated circumstances (e.g. circulation rate). In order to maintain sufficient hygienic conditions during longer lasting high bathing load periods, either the circulation rate has to be increased considerably or the treatment efficiency has to be increased even more. That applies in particular to the removal of organics that act as a precursor for the formation of DBP and combined chlorine.

In spite of high bathing load, during the test period hygienic conditions in the pool water always met the standards. No pathogens were detectable in the chlorinated pool water at all. German standards according to DIN 19643 – part 1 were met safely in all regulated parameters.

TOC partly showed a correlation to chemical oxygen demand concentration during the test period. Hence, it seems to be conceivable to use TOC as a substitute parameter for oxygen demand to monitor the load of organic substances in the pool water.

The results show that when high treatment efficiency is guaranteed, even at high bathing loads a free chlorine level in between 0.3 and 0.6 mg/L is sufficient for an adequate disinfection of the pool water.

Continuous particle counting presented a very good correlation to the number of bathers per hour. Thus, this method offers a more accurate monitoring of particle load in pool water than turbidity measurements.

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