

Impact of split flow treatment by coagulation/ultrafiltration on particle concentrations in pool water

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Synopsis

Because of their well-known water purification effects, hybrid coagulation/ultrafiltration (UF) processes are increasingly used for pool water treatment. Water treatment by ultrafiltration membranes provides high efficiency for particle and microorganism removal and may lead to improved water quality compared to conventional filters. Hence, it seems to be conceivable to treat only a part of the flow drawn off the pool by coagulation/UF while the rest is bypassed and simply disinfected. The objective of this investigation was to evaluate the efficiency of this split flow treatment in comparison to conventional pool water treatment in terms of particle concentrations. Accumulation processes of particles in pool water are of certain importance because they may enclose pathogens and inhibit sufficient disinfection this way. Studies were done at selected swimming pools in operation, where either conventional treatment (coagulation/ sand filtration) or coagulation/UF (with or without bypass) was used. Particle counts were carried out continuously for up to 10 days in pool water and treated water. As expected, particle elimination by coagulation/UF was more efficient than by conventional sand filtration. If UF-treatment is used particle concentration in pool water is mainly affected by bathers. The amount of particles released by bathers into the pool was calculated using a mass balance. A model was developed, which offers the possibility to calculate particle concentrations in pool water according to the treatment technology and the percentage of flow volume bypassed.

Introduction and problem definition

Pool water quality is mainly affected by contaminants introduced by bathers, the efficiency of treatment technology installed and hydrodynamic conditions in the pool. Pollutants in indoor swimming pools, such as particles, germs and organic and inorganic dissolved substances, mainly originate from bathers. Bacteria, parasites and viruses may act pathogenic to humans and have to be inactivated by efficient disinfection or removed by filtration. Usually a defined volumetric flow is drawn off the pool (standard flow) and treated by coagulation, filtration and adsorption processes (see Fig. 1). In order to maintain sufficient disinfection free chlorine is added in the re-circulated pure water flow leading to a constant level of the disinfectant in the pool. However, free chlorine not only provides certain disinfection but may also lead to a formation of disinfection by-products (DBP) in the pool. Organic matter released by bathers act as so-called precursor for the formation of DBP, e. g. trihalomethane (THM), haloacetic acids and chloramine. Excessive exposure to DBP is harmful to human beings health and therefore their concentration should be minimised in pool water. In German regulations (DIN standard 19643), threshold values for THM (0.02 mg L^{-1}) and chloramines (0.2 mg L^{-1}) in pool water are given while free chlorine concentrations range from 0.3 to 0.6 mg L^{-1} .

Due to the circulation of pool water, accumulation of pollutants may occur if treatment technology offers no sufficient removal of bather's pollutants. Accumulation processes of

particles in pool water are of particular importance because particles may enclose pathogens and hinder sufficient disinfection. In addition dissolved substances may adsorb on particles and may be transported and distributed by them [1]. The distribution of pollutants and particles in the basin is influenced by the respective hydrodynamic conditions.

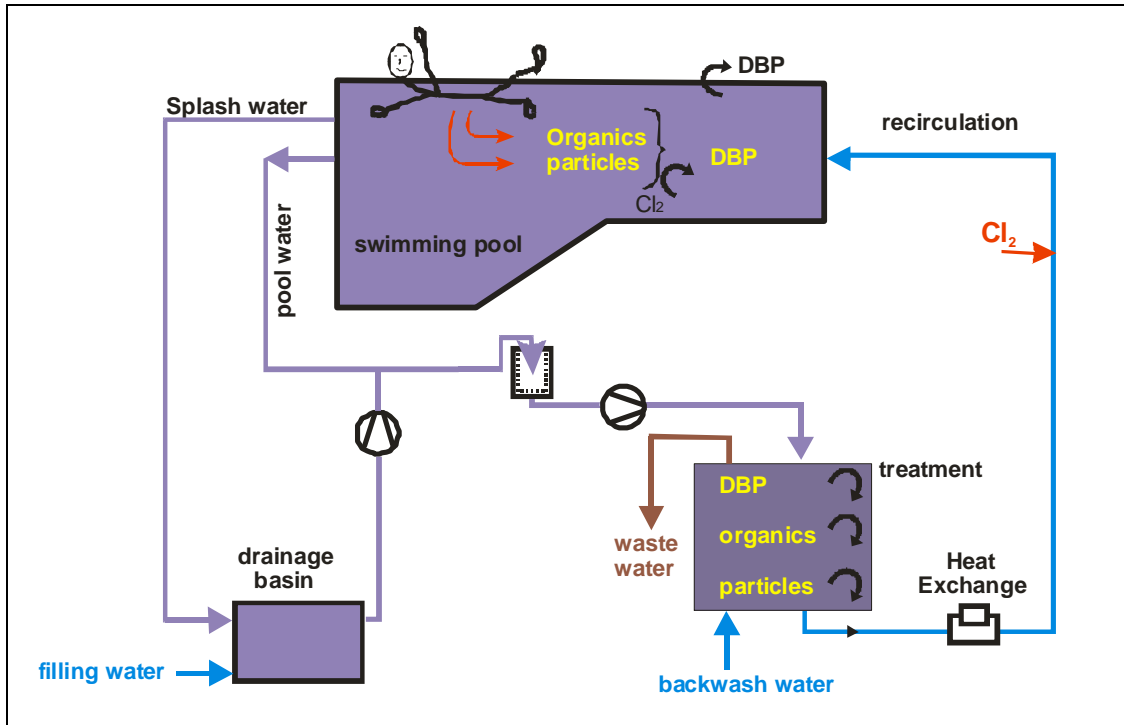


Fig. 1: Pool water cycle

Water treatment by ultrafiltration (UF) membranes provides very efficient particle and microorganism removal and is increasingly used for pool water treatment. If UF is used as filtration step after coagulation, improved filtrate quality compared to conventional filters may be attained. Hence, it seems to be conceivable to treat only a part of the flow drawn off the pool by coagulation/UF while the rest is bypassed and disinfected [2]. Previous research results showed that pool water quality requirements of German regulations can be met if only 40 % of the standard flow is treated by coagulation/UF and sufficient hydrodynamic conditions in the pool are provided [3].

The objective of this investigation was to evaluate the efficiency of this split flow treatment in comparison to conventional pool water treatment in terms of particle concentrations. Transport and accumulation processes within the pool water cycle should be determined by means of particle counts.

Methods

Particle counts were carried out continuously for up to 10 days in pool water and filtrate of several indoor pools. Investigations were done in pools with coagulation/UF treatment as well as in pools with conventional treatment (coagulation and sand or multi layer filtration). By means of laboratory tests the fraction of particles was determined that could be dissolved under acid conditions (at pH 2).

A model for particle transport within the pool water cycle was developed in order to calculate particle concentrations when different proportions of standard flow are treated by coagulation/UF (see Fig. 2). The bypassed water can be filtered by a sand filter or disinfected only.

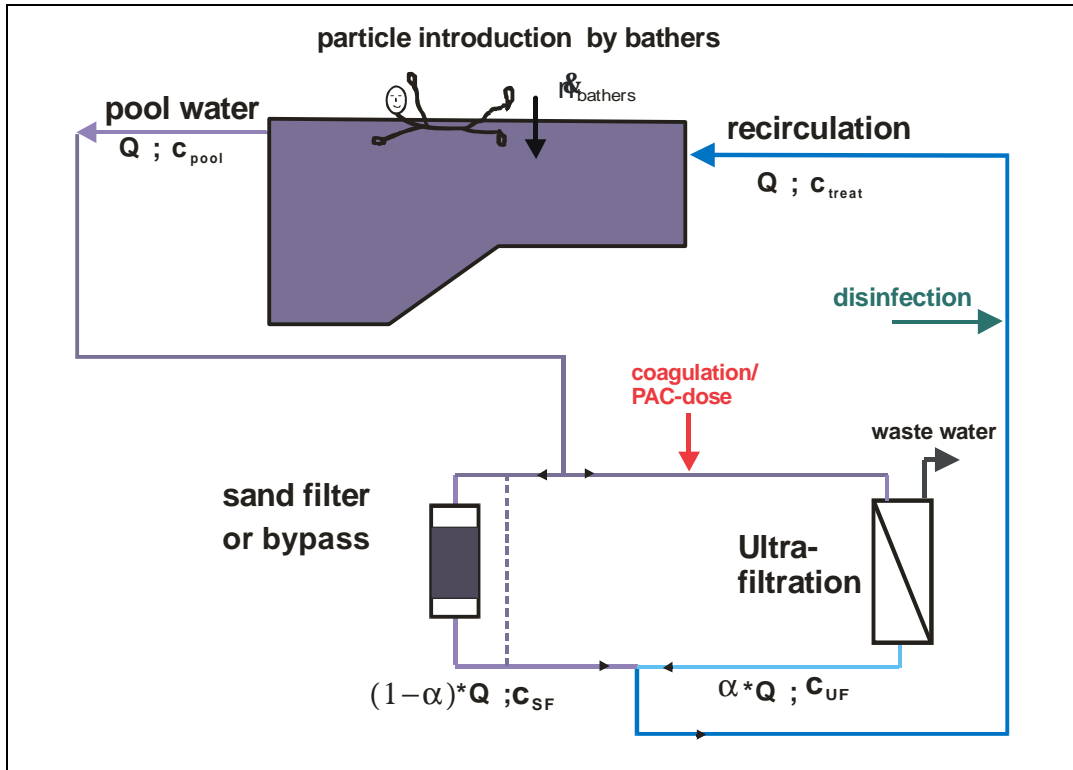


Fig. 2: pool water cycle with UF treatment and bypass

Equation 1 shows a balance of particle concentrations for steady state of the system. This balance takes into account the amount of particles introduced by bathers as well as particle elimination by the treatment step.

$$I_{bather} + Q \cdot c_{SF} \cdot (1-a) + Q \cdot c_{UF} \cdot a - Q \cdot c_{pool} = 0 \quad \text{equation 1}$$

- I_{bather} ... amount of particles introduced by bathers in $\text{in}\cdot\text{h}^{-1}$
- Q ... volumetric flow in $\text{mL}\cdot\text{h}^{-1}$
- c_{pool} ... particle concentration of pool water in mL^{-1}
- c_{SF} ... particle concentration of sand filtrate in mL^{-1}
- c_{UF} ... particle concentration of UF filtrate in mL^{-1}
- c_{treat} ... particle concentration in treated water in mL^{-1}
- α ... proportion of treated split flow relating to standard flow

By means of this mathematical model particle concentration in pool water can be described as a function of different split flow proportions from 0 to 100%. Provided that the respective bather's particle release and the particle removal efficiency of the treatment process (η_{treat}) are

known the model offers the possibility to predict particle concentrations for each different treatment method and mode.

Results

In Fig. 3 particle concentrations in pool water and in treated water measured at several indoor pools are compared. During the investigations UF-Filtrate showed constantly low particle concentrations, while with conventional treatment methods (coagulation/sand filtration) notable amounts of particles were found in the filtrate, especially after filter backwash. In pool A water is treated by coagulation/UF at a split flow proportion of 70 % and the bypassed water is filtrated by a simple sand filter. For this treatment mode the average particle concentration in pool water is similar to pools with conventional treatment (pool C and D). In pool E (V2), where only a split flow of 20 % is treated by coagulation/UF and the bypassed water is unfiltered, particle concentration of treated water (mix of UF filtrate and bypass) is almost as high as in pool water. Here the average particle concentration in pool water is up to five times higher than in pools with conventional treatment (pool C, D and E (V1)).

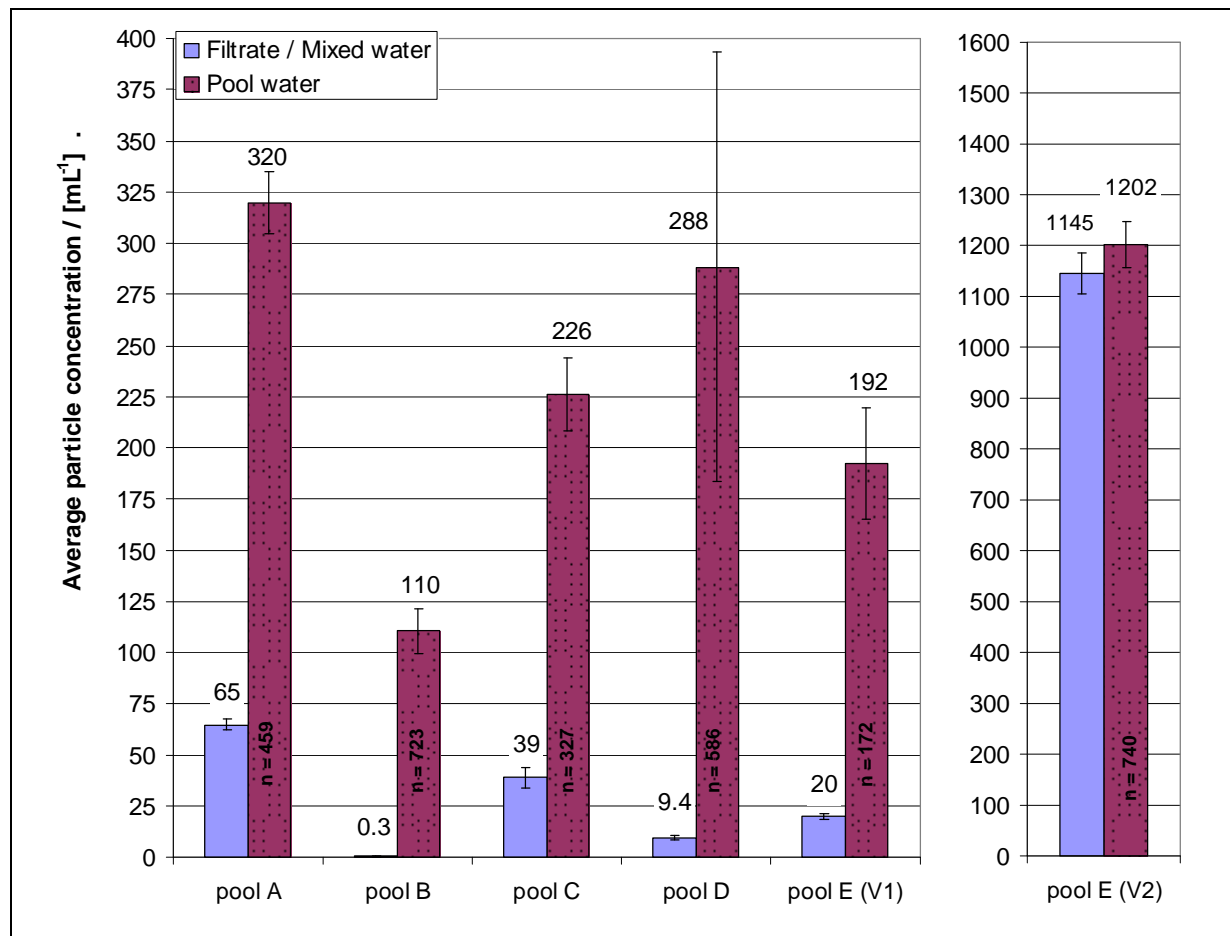


Fig. 3: Average particle concentrations in pools with different treatment methods (see Table 1, confidence interval 95 %)

Particle concentrations measured in indoor pool water result from the removal of particulate matter during treatment and particle introduction by bathers. As shown in Table 1, particle

removal efficiencies achieved by full flow coagulation/UF (up to 99 %) are considerably higher compared to conventional coagulation/fixed bed filtration (80 % in average).

Table 1: Determined degree of efficiency for particle removal at different treatment modes

Indoor pool	Treatment method	Treatment mode	Efficiency of particle removal
A	coagulation/UF	70 % coagulation/UF 30 % bypass with sand filtration	0.782
		100 % coagulation/UF	0.970
B	coagulation/UF	reduced flow (43 % of standard flow)	0.996
C	coagulation/ fixed bed filtration	full standard flow	0.638
D	coagulation/ fixed bed filtration	full standard flow	0.828
E (V1)	coagulation/ fixed bed filtration	full standard flow	0,785
E (V2)	coagulation/UF	20 % coagulation/UF 80 % bypass	0.070

By means of the described particle concentration balance the specific particle introduced by a bather into the pool water could be estimated for different pools. Results show that this specific particle charge depends on the type of pool (e. g. swimmer/non-swimmer/whirlpool). In a warm water relaxation pool with massage nozzles (pool B) specific bather's particle introduction was higher than in a sport swimming pool (pool A). By a test in pool B an impact of bather's pre-cleaning (with and without afore showering) was found.

Laboratory tests show that a notable part of particles in pool water are dissolvable under acidic conditions (from 30 % to 90 %). Furthermore, analyses in pool water and filtrate indicate that only 40 % to 70 % of total aluminium is eliminated during treatment by coagulation/sand filtration and coagulation/UF, respectively. Hence, acid dissolvable particles in pool water are assumed to be mostly aluminium hydroxide flocs originating from the treatment process. If conventional filtration is installed, small aluminium hydroxide flocs may pass the filter and reach the pool. However, the phenomena of acid dissolvable flocs was detected in UF-treated pool water as well although UF membrane pores are able to retain flocs and particles bigger than 0.45 µm certainly. The reason for that may be the occurrence of remaining dissolved coagulant in the UF filtrate, resulting from unfavourable coagulation conditions (low coagulant dose, installations in pipes behind floc aggregation). From this follows that quantity and character of particles in pool water are influenced by the treatment process. Optimisation of coagulation and filtration processes may be a prerequisite to decrease particle concentrations in pool water.

The model described above provides estimation of particle concentrations within the pool water cycle, regardless which treatment method or mode is implemented. Different treatment types and treated split flow proportions can be examined. Fig. 4 exemplifies results of modelling pool water particle concentrations in one of the investigated indoor pools. Determined particle concentration is plotted against the part of flow treated and bypassed, respectively. In addition, particle concentration of pool water is calculated for the case of full standardised circulatory

treatment by conventional coagulation/filtration based on an average particle removal efficiency of $\eta = 0.8$ ascertained for conventional treatment methods. This value constitutes a horizontal reference line (green line) for comparison. The intersection of the function of determined particle concentrations (red line) and the green reference line shows that at least 82 % of standard flow has to be treated by coagulation/UF in order to get similar particle concentrations in pool water compared to conventional treatment. If the bypassed water is filtered by a sand filter with a degree of particle elimination of $\eta_{SF} = 0.35$, further decrease of UF-treated split flow down to 73 % of standard flow is possible without increasing particle concentration in pool water.

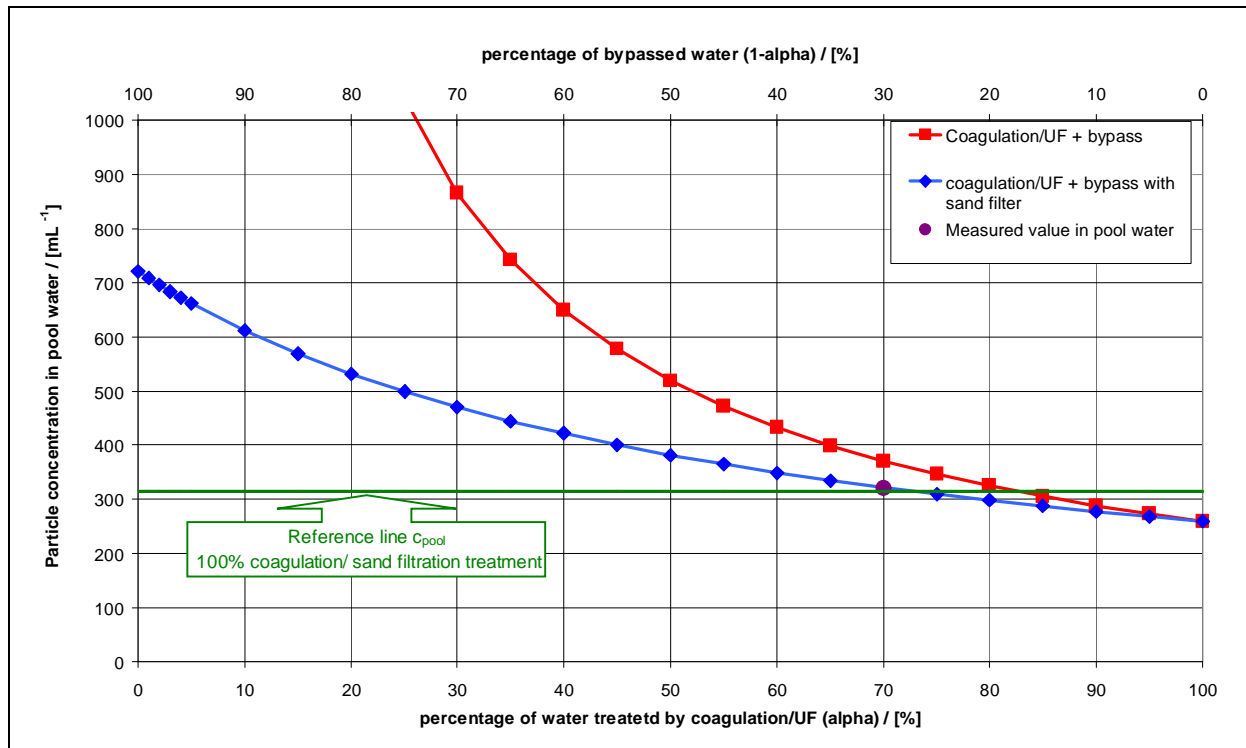


Fig. 4: Particle concentration in pool water while different flow proportions relating on standard flow are treated by coagulation/UF (example)

Fig. 5 shows calculated results for the required flow that has to be treated by coagulation/UF in order to get similar particle concentrations in pool water as attainable by conventional treatment methods. In the pools investigated a reduction of the treated split flow to 65 to 85 % of the standard flow is possible when pool water is treated by coagulation/UF without any quality violation concerning particle concentrations in pool water. If the bypassed water is treated by a simple sand filter, further decrease of UF-treated flow is possible. Using this treatment mode in pool C the treated split flow can be reduced to 45 % of the standard flow, which might provide economical advantages due to saving of energy and chemicals.

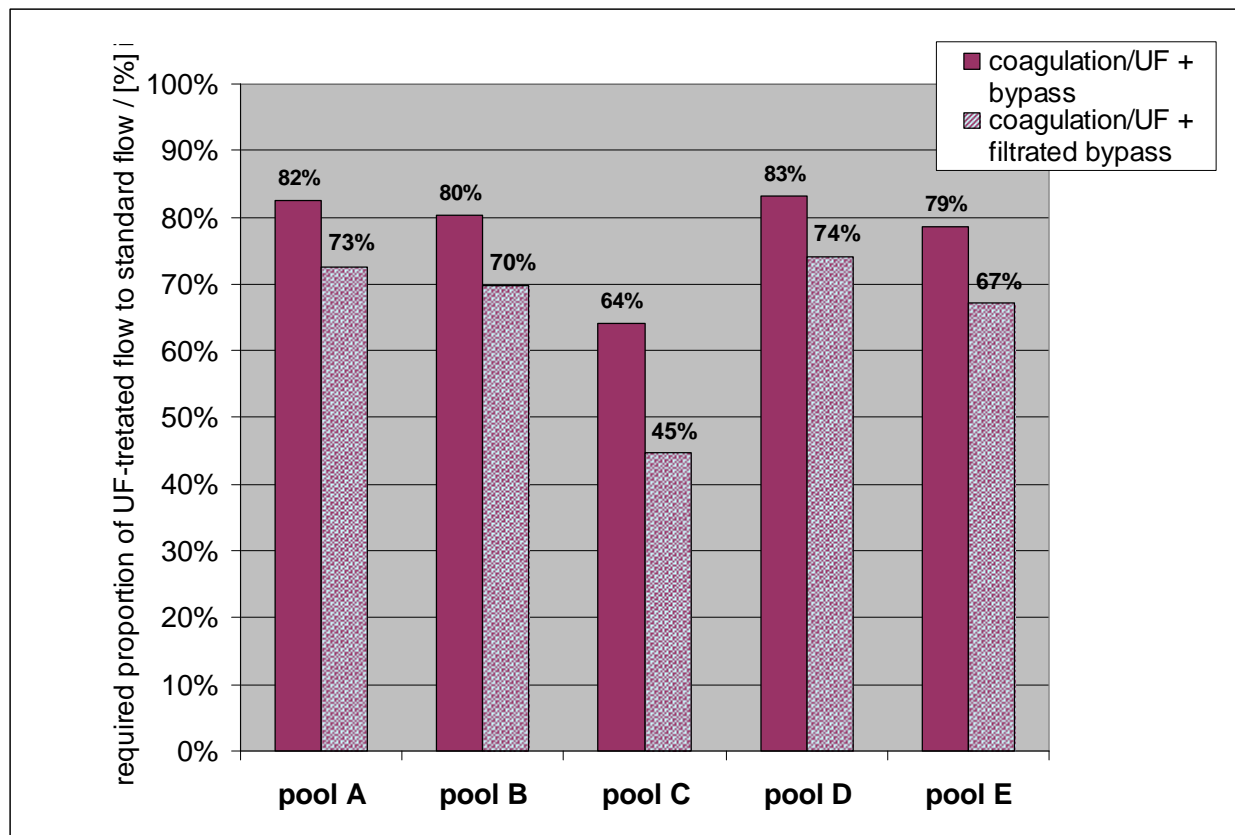


Fig. 5: split flow proportions treated by coagulation/UF required for adjustment of particle concentration similar to conventional treatment

If the flow treated by coagulation/UF is reduced more than the calculated reference value, particle concentrations in pool water will increase and exceed particle concentrations that are normal at conventional treatment. This was proven by the measurements in pool E (V2) where only 20 % of the standard circulatory is treated (see Fig. 3).

Conclusions

Results of investigations showed that particle elimination by coagulation/UF was significantly more efficient than by conventional pool water treatment (coagulation/sand filtration). UF-treated filtrate is nearly free of particles while at conventional filtration higher particle concentrations in the filtrate were measured, especially after filter backwash. This indicates that particle removal by UF-filtration is more unsusceptible against influences of operations and interferences compared to sand filtration. Furthermore, UF-filtration provides high hygienic safety because the growth of pathogens in the filter (e. g. *Pseudomonas aeruginosa*) is prevented because of the thin filter layer and short filter run times. From this follows that particles in pool water mostly derive from bathers while treated by coagulation/UF but at conventional treatment a considerable part of particles originates from the treatment process itself.

Laboratory tests show that a notable part of particles in pool water are dissolvable under acid conditions. These particles were found in pools with conventional treatment (coagulation/ sand filtration) as well as in pool water treated by coagulation/UF. They are assumed to be aluminium hydroxide flocs originating from the treatment process. In order to reduce this part of particles in

pool water further research concerning to optimal coagulant dose and floc aggregation is necessary.

Using a mathematical balance of particle concentrations for the steady state of the system a model was developed, which offers the possibility to calculate particle concentrations in pool water according to the treatment technology and the percentage of the split flow treated, compared to standard flow. With this simplified approach estimation of the quantity of particles originating from bathers is possible. First results showed that the specific particle introduction by a bather depends on the type of pool (e. g. swimmer/non-swimmer/whirlpool) and the pre-cleaning of the bather. Particle concentrations in pool water were calculated for different split flow proportions treated by coagulation/UF. Results for all investigated pools show that 65 to 85 % of full flow has to be treated by coagulation/UF in order to get similar particle concentrations in pool water compared to conventional treatment. If the bypassed water is filtered by a sand filter further decrease of UF-treated split flow without increasing particle concentration in pool water is possible.

If the volumetric flow treated by coagulation/UF is reduced further than the calculated value, particle concentrations in pool water will increase and exceed particle concentrations that are normal at conventional treatment. However, the endangerment of higher particle concentrations in pool water is still not assessable. Further investigations considering to spatial distribution of particles in pool water as well as ascertainment of hygienic hazards emanating from high particle concentrations have to be carried out.

Literature

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