PARTICLES AND TURBIDITY IN POOL WATER – REMOVAL BY IN-LINE FILTRATION AND MODELLING OF DAILY COURSES

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ABSTRACT

In summer 2009, the particle concentrations in the water of a public open air pool fluctuated between a few thousand and several million particles per liter (size range 1–100 µm) during the course of the day. These particle counts were in good correlation with the pool water turbidity's in the range of 0.01–0.85 NTU. With rising numbers of bathers, the pool water contained up to several thousand lar-ger particles per L (diameter > 30 µm). These particles have to be considered as relevant from a hy-gienic point of view since they can consist of viruses and bacteria which are incorporated e.g. in mu-cus or sebaceous matter and therefore cannot be disinfected even with high chlorine concentrations in the pool water. Measurements in the effluent of the dual-media filters treating the pool water showed that a very efficient removal of particles and turbidity could be achieved (> 90%). It was found out that larger, potentially infectious particles were removed completely by in-line/dual media filtration (> 3.6 log removal). The actual pool water turbidity and thus the concentration of potentially infec-tious particles are, however, only partially defined by the efficiency of the employed filter technology. The more relevant aspects are the number of bathers and the volume flow of the pool water treatment unit. This was demonstrated by a newly developed method for calculating the daily courses of pool water quality. An important consequence of the calculations for the design of pool water treatment systems is the priority of a high volume flow. This is of special relevance for open air pools which are periodically crowded and therefore exhibit a high risk from potentially infectious particles.

INTRODUCTION

One of the major challenges in the treatment of pool water is the removal of particulate contaminants which are introduced by bathers. Larger particles (diameter > 30 µm) can consist of aggregated or covered bacteria and viruses. Unlike suspended microorganisms, these aggregates resist disinfection and have to be removed by filtration as fast as possible in order to minimize the infection risk for the bathers (Gansloser et al., 1999).

The first part of this paper presents the results of analyses performed in a public open air pool in sum-mer 2009. Over a period of 4 weeks, online turbidity measurements were conducted in the pool water as well as in the filtrate of the treatment unit (flocculation and dual media filtration). Additional parti-cle measurements using laser light obscuration enabled a more detailed characterisation of the particu-late contaminants in the pool water and of the efficiency of the filter unit for particle removal.

Subject of the second part are calculations on the daily courses of pool water turbidity as a function of 1) frequency of bathers, 2) treatment efficiency of the filter unit and 3) volume flow of the filter unit. The employed method of calculation was newly developed and calibrated with long-term data on the daily pool visitors and on the pool water turbidity.

METHODOLOGY

Process photometers in accordance with DIN ISO 7027 were used for online turbidity measurements (scattered light method with monochromatic light of wavelength 860 nm, angle of measurement 90°). Calibration of the on line turbidity meters was performed using a method developed by Thyssen et al., 1997 which allows the reproducible measurement of even lowest turbidity values (< 0.05 NTU).

For particle analysis in the pool water and the filtrate of the dual media filter, a measurement device was used which works on the principle of laser light obscuration: A laser beam traverses the liquid in a capillary tube and falls on a photodiode. The signal of this diode is amplified and recorded. The parti-cle size is given as equivalent ball diameter and can be used for the determination of the cumulative and distribution curves for the particle number as a function of the particle size in the range of 1–100 µm.

The analysed pool has a water volume of 690 m³ and features a total of 13 attractions, among them two water slides. According DIN 16643-1 from the water surface of 690 m² a nominal capacity for the pool of 255 bathers per hour can be calculated. It is part of an open air water park which is visited by up to 12 000 bathers on hot summer days. The water treatment plant for the analysed pool has a nomi-nal capacity of 650 m³/h and consists of the following stages:

1. Flocculant dosing (approx. 0.05 mg/L Al)
2. Dual media filter (0.5 m sand 0.7–1.2 mm, 0.5 m anthracite 1,4–2.5 mm; v_F: 35 m/h)
3. pH adjustment (pH 7.0 in the pool water)
4. Disinfection with chlorine gas solution (0.45 mg/L free chlorine in the pool water).

LONG TERM DATA ON THE TURBIDITY IN FILTRATE AND POOL WATER

Turbidity in the effluent of the filter unit and in the pool water was recorded for 4 weeks. As can be seen in the graphic representation of the results from 14.08–4.09.2009 in Figure 1, turbidity of the pool water exhibits a cyclic variation with pronounced peaks in the afternoon between 16:00 and 17:00. After closing at 20:00, turbidity values sank rapidly, resulting in values below 0.02 FNU and thus in a virtually turbidity-free water starting at approx. 23:00.

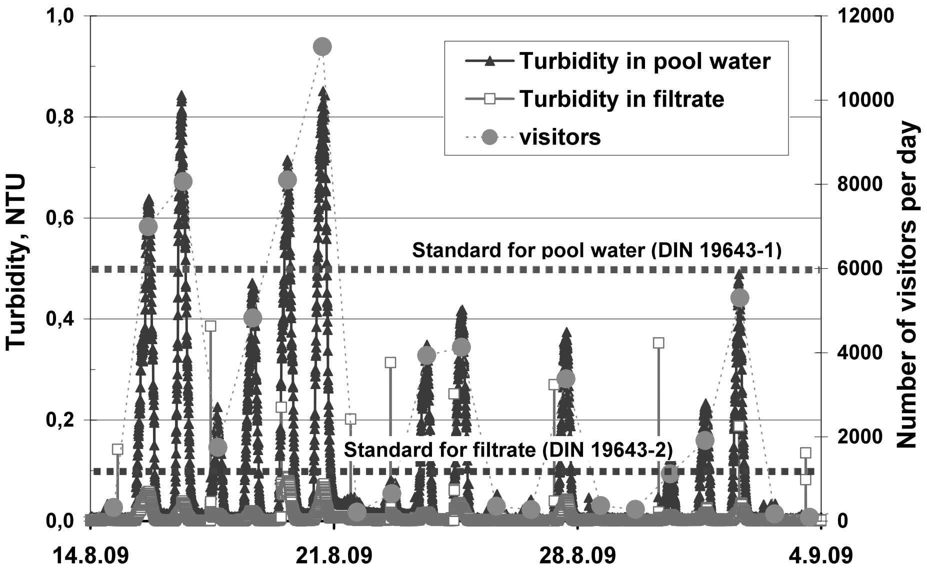

Figure 1 Turbidity in pool water and filtrate and number of visitors of the water park from 14.08 to 4.09.2009

Four times in total, the standard for the turbidity in the pool water of 0.5 NTU (according to DIN 19643-1) was exceeded for several hours. At these days, more than 6.000 bathers had visited the water park.

A comparison of turbidity in the pool water and in the filtrate as given in Figure 1 shows an efficient elimination of turbidity in the dual media filter unit. Even in the case of pool turbidity peaks above 0.8 FNU, the turbidity of the filtrate was clearly below the standard of 0.1 FNU according to DIN 19643-2. Temporary turbidity peaks in the filtrate of approx. 0.4 FNU indicate a restart of a filter after backwashing.

Figure 2 shows an exemplary daily course of the turbidity values in filtrate and pool water as well as the results of particle measurements (1–100 µm) in the filtrate on 1.09.2010. On this day the flocculant dosage was varied in order to determine the influence of flocculant on the turbidity and particle elimination by dual media filtration of pool water.

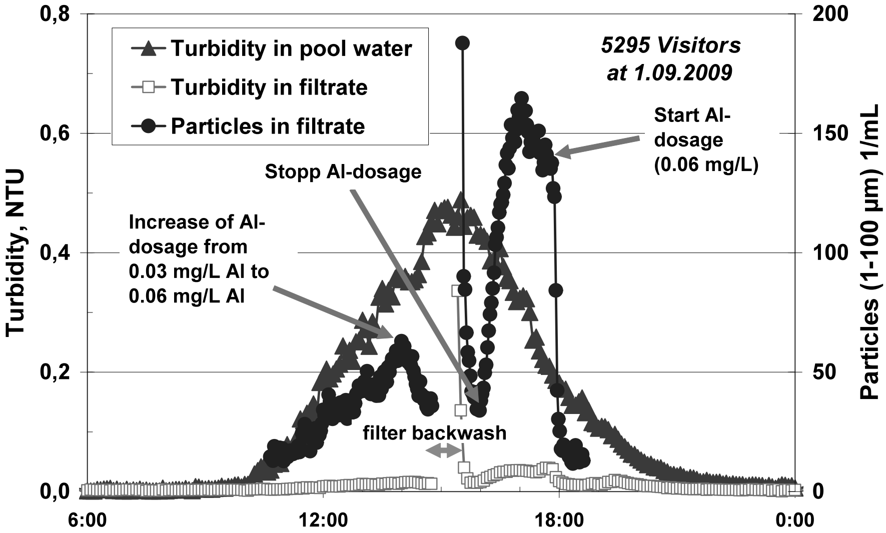

Figure 2 Turbidity of pool water and and particle concentration (1–100 µm) and turbidity in the filtrate, three dosages of flocculant on 1.09.2009

It can be seen that that the pool water turbidity increases at around 10:00 with rising numbers of visi-tors. The parallel increase in filtrate turbidity from < 0.01 to approx. 0.02 FNU lies within the range of the detection limit of the turbidity measurement. The more sensitive particle measurement shows, however, a certain decrease in filtrate quality with a rise in pool water turbidity from approx. 15/mL at 10:00 to a value of approx. 60 particles/mL (size range 1–100 µm) at 14:00. The measurements per-formed during the subsequent analyses on the influence of flocculant dosage show the importance of a correctly adjusted flocculation for the treatment efficiency of rapid filter units.

ANALYSIS OF PARTICLE SIZE DISTRIBUTION IN FILTRATE AND POOL WATER

As mentioned, larger particles (> approx. 30 µm) in the pool water are hygienically relevant as they can consist of aggregated or covered bacteria/viruses which can not be disinfected. The intake of even one single particle can trigger an infection. To assess the concentration of larger particles in the pool water and their removal during dual media filtration, the online particle measurement data of the pool water and the filtrate collected at two days with comparable numbers of visitors (approx 4000 each day) was evaluated. When interpreting the results in Figure 3, it has to be considered that the given amounts of particles refer to a water volume of 1 L. The semi-logarithmic presentation of the particle numbers shows a typical course: Particle numbers in the pool water as well as in the filtrate decrease exponentially with particle size. It can also be seen that the dual media filter unit removes particles the better, the bigger they are in diameter.

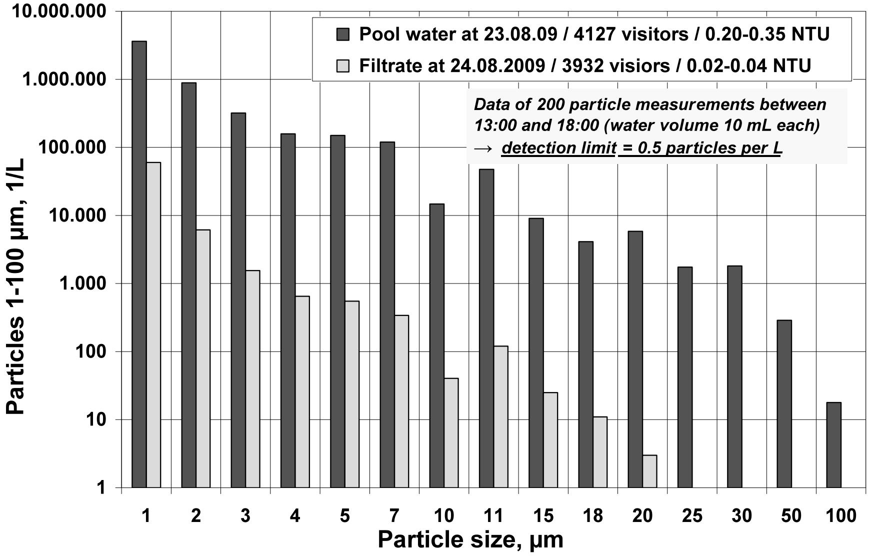

Figure 3 Particle size distribution in the pool water and in the filtrate at two days with high visi-tor numbers (given in particles per L)

Table 1 summarises the major results of the measurements on particle concentration in the pool water and on the efficiency of particle removal in the dual media filter unit at times of high visitor numbers. For particles of the size 1–3 µm (e. g. suspended bacteria), the elimination rate is approx. 98.6 %, cor-responding to 1.9 log units. For slightly larger particles of the size 3–10 µm (size range of cysts and oocysts of parasites pathogenic to humans), the elimination rate is 99.6 % (2.4 log units). No particles with a diameter > 30 µm were detected in the dual media filtrate. The elimination rate for particles in this size range is thus calculated from the detection limit of 0.5 particles/L and the pool water concentration to be above 99.98 %, corresponding to > 3.6 log removal.

Table 1 Particle concentrations in pool water and filtrate and particle elimination via in-line/dual media filtration at days with high visitor numbers

Size range	µm	1–3	3–10	30–100	1–100
Particle concentration in the pool water	P/L	4 830 000	418 000	2 014	5 900 000
Particle concentration in the filtrate	P/L	67 800	1 580	< 0.5	69 500
elimination rate	%	98.6	99.6	> 99.98	98.8

It has to be noted that in spite of a high elimination rate of 99.98% for hygienically relevant particles (diameter > 30 µm), approx. 2000 of these particles were found per liter pool water. This is caused by the permanent particle release by the bathers.

MODELLING THE DAILY COURSES OF TURBIDITY IN POOL WATER

For a better understanding of the contribution of the different parameters to the daily course of turbidity in the pool water, a mass balance was done. This led to the following equation which describes the variation of turbidity depending on the inflow of turbid matter caused by bathers on the one hand and the removal via filtration on the other hand.

$$\frac{dc}{dt}=\frac{P\cdot r_p(t)\cdot K_p}{V}-c(t)\cdot\frac{Q}{V}\cdot{}_F \qquad (1)$$

$c(t)$	[NTU]	turbidity of pool water
P	[bathers]	total number of bathers per day
$r_P(t)$	[1/h]	bather frequency
k_P	[NTU/(bather/m³)]	input of turbidity by one bather per m³
V	[m³]	water volume of the pool
Q	[m³/h]	volume flow into the filter unit (circulation)
µF	[-]	efficiency of turbidity removal in the filter unit ($\mu_F=(c_{zu}-c_{ab})/c_{zu}$)

Since the frequency of bathers entering the pool is not known, this equation cannot be solved in a closed-form expression. Nevertheless it can be fitted to the measurement data of turbidity in the pool water with the method of discrete elements. Doing this for the turbidity data of several days gives the following results:

1) The bather frequency $r_P(t)$ has a similar course every day (independent of the total number of bathers)
2) The derived values for kP are in the range of 0.25-0.5 NTU/(bather/m³)
3) The efficiency of the in-line/dual media filtration in turbidity removal can be calculated to μ_F=0.90-0.95

With the new calculation method, different scenarios for the pool water turbidity can be computed, depending e.g. on the volume flow and the efficiency of turbidity removal in the filter unit. The results of a computation of the scenario with an ultrafiltration plant instead of dual media filtration for pool water treatment are shown in Figure 4. For this calculation, the efficiency of turbidity removal in the filter unit was increased to μ_F=1.0 (100% turbidity removal instead of 90 % for in-line/dual media filtration). To stay cost-effective, ultrafiltration plants in pool water treatment are usually designed with a much lower nominal capacity compared to conventional sand filters. For the computation, the volume flow in the filter unit was cut down by half as proposed in the draft version of the DIN 19643-6.

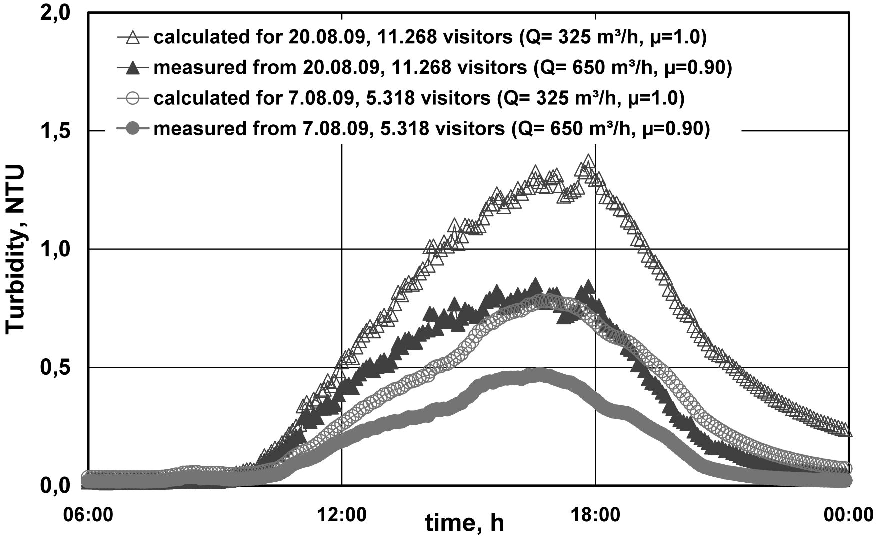

Figure 4 Measured data of the pool water turbidity on 7.08. and 20.08.2009 and calculated tur-bidity for the scenario "ultrafiltration" (Q= 325 m³/h, μ_F=1.0) on both days

Figure 4 shows that using ultrafiltration instead of in-line/dual media filtration would result in much higher values for the pool water turbidity. This is somehow unexpected because the calculation was based on a complete turbidity removal in the ultrafiltration plant (μ_F=1.0). These results demonstrate the major importance of a high volume flow for the pool water treatment systems for minimizing tur-bidity, and potentially infectious particles in the pool water respectively.

CONCLUSIONS

From each bather particles are introduced into the pool water which causes e.g. certain turbidity. The measured particle numbers in water from a public open air pool are between a few thousand and several million particles per liter (size range 1–100 µm) during the course of the day. The particle counts correlated very well with the pool water turbidity which was also measured on-line over longer pe-riods of time (values in the range of 0.01–0.85 NTU). On hot summer days when the pool is crowded, the pool water contained up to several thousand larger particles per L (diameter > 30 µm). These parti-cles have to be considered as relevant from a hygienic point of view since they can consist of viruses and bacteria which are incorporated e.g. in mucus or sebaceous matter and therefore cannot be disin-fected even with high chlorine concentrations in the pool water.

Measurements in the pool water and in the effluent of the filter unit showed that an efficient removal of turbidity (> 90%) and particles (~ 99 %, for size range 1–100 µm) could be achieved by in-line/dual media filtration. It was also found out that larger, potentially infectious particles were removed com-pletely (> 3.6 log removal). Worth to mention is the fact that this excellent results were obtained at comparatively high filter velocities of 35 m/h and rather low flocculant dosages (0.05 mg/L Al).

The actual pool water turbidity and thus the concentration of potentially infectious particles are, how-ever, only partially defined by the efficiency of the employed filter technology. The more relevant aspects in this context are the number of bathers and the volume flow of the installed pool water treatment unit. This was demonstrated by calculating the daily courses of pool water turbidity as a function of 1) volume flow of the treatment unit, 2) treatment efficiency and 3) the number of bathers. The employed method of calculation was newly developed and calibrated with long-term data on the daily pool visitors and on the pool water turbidity.

By fitting the mathematical equation derived from a mass balance for turbid matter to the measured turbidity data and the total number of bathers per day it was found out that the bather frequency had a similar course every day, e.g. it is independent of the total number of bathers. Moreover it can be calculated that one bather per m^3 pool water brings in turbid matter which is equal to an average value for the turbidity of 0.3 NTU.

The most important consequence of these calculations for the design of pool water treatment systems is the priority of a high volume flow. A cut down of the volume flow for circulation and treatment of pool water by half, as e.g. implemented in many pools using ultrafiltration for pool water treatment, will not only increase the average turbidity in the pool water by approx. 70 %. More important is the fact that this also doubles the retention time of potentially infectious particles in the pool. This is of special relevance for open air pools which are periodically crowded and then exhibit a current high input of particles and other pollutants.

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