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INVESTIGATION OF PROPERTIES OF SWIMMING POOL WATER TREATMENT SEDIMENTS

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Two sediments resulting from swimming pool operation are characterized and the data discussed, namely the flocs which accumulated and were backwashed from deep bed filter, and bottom sediment collected from the pool by vacuum cleaner. Better understanding of sediments' structure and properties should allow for improvement of *Cryptosporidium* oocysts removal from pool water and as a consequence - increase the safety of pool users. Zeta potential, nano-size and micro-size of particles/flocs and derivatographic measurements were performed. The zeta potential data indicated easy flocculation and size distribution measurements revealed varied effectiveness of deep bed filtration. Derivatographic analysis indicated differences between sediments from filters backwashing and pool bottom sediments.

keywords: water treatment sediments, zeta potential, Cryptosporidium oocysts, floc particle size distribution, thermal analysis, swimming pools

1. INTRODUCTION

Swimming pools are becoming increasingly popular. Many hotels, motels, holiday resorts, schools and single-family homes are recently equipped with pools. In spas, hospitals and sanatoria they are used for therapy and rehabilitation (Angenent et al., 2005; Lumb et al., 2004). In our previous paper (Korkosz et al., 2010) selected aspects of water filtration in deep bed filters were considered with respect to rehabilitating

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swimming pool facility. Besides instrumental analysis of water, and sand grain size analysis, the investigation considered particle size distribution and thermal analysis of the sediment collected in the sand bed of depth filters, and removed during the process of washing.

Functioning of a swimming pool and treatment of pool water results in formation of two kinds of sediments:

– coagulant flocs residing mainly within the top layer of the deep bed filter,
– flocculated particles collecting at the bottom of the pool basin.

While filter backwash water with suspended flocs already received attention in the available literature (Bing-Mu and Hsuan-Hsien, 2003; Greinert et al., 2004; Goeresa et al., 2004; Schets et al., 2005), mainly with respect to water recycle (Wyczarska-Kokot and Piechurski, 2001; Wyczarska-Kokot and Piechurski, 2002; Reißmann et al., 2005), the basin bottom sediment composition and properties remain unknown. Comparison of properties of both sediments indirectly provides also insight into functioning of deep bed filters.

In this paper we concentrated on characterization of these two sediments with respect to separation of *Cryptosporidium* protozoa oocysts. Unlike other microbial contaminants, inactivation and removal of oocysts can occur only in water passing through filters and special treatment reactor, e.g. using ozone (Gregory et al., 2002). A pool - involving steady circulation of water - is a mixed and not a plug flow system, therefore the rate of reduction in concentration in the pool volume is slow. Effective functioning of a depth filter, with regard to removal of colloids and fine suspension, is dependent on appropriate metering of coagulant and flocculant.

2. EXPERIMENTAL

Aqueous sediment suspensions were procured from two swimming pools: 75 m^3 small pool used for children swimming lessons (sample code: PG), and 470 m^3 regular pool for sport and recreation (sample code: K). Samples originating from backwashing of filters are marked with letter "f" and samples collected by water vacuum cleaner are marked "vc."

The small swimming pool uses aluminum hydroxychloroide as coagulant, sulfuric acid for pH correction and sodium hypochlorite as disinfecting agent. The recreational swimming pool uses aluminum sulfate as coagulant and similarly sulfuric acid and hypochlorite. Less frequently an agent against growth of algae, fungi and bacteria is used. The small pool applies N,N Dimethyl-2-hydroxypropylammoniumchlorid. Sporadically sodium thiosulphate is applied to reduce excessive chlorine.

Electrophoretic mobility and nano-size particle diameter distribution measurements were performed in Zetasizer instrument (model: Zeta Plus) from Malvern. Flocs/particle size distribution in micro-size range was performed with Mastersizer X laser diffraction particle sizing instrument manufactured by Malvern. This system allows measurements in two specific ranges: 0.5-180 µm and 1.2-600 µm. Apart from flocs size distribution of freshly collected samples, changes of flocs when exposed to shear forces were monitored, 200 cm^3 of examined sediment suspension was circulated through measuring cell in the closed cycle.

Thermal analysis, including TG, DTG and DTA curves, of 50 mg of sediments from backwashing of filters and vacuum cleaning of pool bottom was carried out by means of derivatograph Q-1500 D, from MOM Budapest. First, the deposit was separated from the washing water in a centrifuge at 5000 rpm for 5 minutes, and next dried at 105ºC to the constant mass. The temperature increase rate was set at 10°C/min. TG sensitivity was 50 mg, while DTA sensitivity was 250 µV. Samples were heated up to 750ºC. The reference sample was α-Al_2O_3.

3. RESULTS AND DISCUSSION

3.1. ZETA POTENTIAL

Selected sediment samples were investigated for the electrophoretic mobility of suspended particles and flocs. Zeta potential together with basic data for the aqueous phase such as pH (actual pH of pool water) and conductivity are presented in Table 1. Small pool washing water samples showed negative potential of -10.6 and -11.7 mV, while vacuum cleaner samples had around 2 mV more negative potential. Considering zeta potential deviation between 3.2 and 6.5 mV for small swimming pool, the values are comparable. The recreational swimming pool sediment sample from washing water had positive potential of + 7.7 mV and vacuum cleaner sediment sample was -8.9 mV.

Table 1. Electrophoretic mobility data

Sample	pH	Conductivity, mS	Zeta Potential, mV	Zeta Potential Deviation, mV
Backwashing water sediment samples				
PG-f-25	6.6	0.85	-10.6	4.2
PG-f-28	7.4	0.48	-11.7	3.2
K-f-3	6.9	0.42	7.7	5.0
Water vacuum cleaner sediment samples				
PG-vc-1	7.5	0.37	-13.6	3.7
PG-vc-2	7.3	0.65	-13.7	6.5
K-vc-3	7.3	0.28	-8.9	6.8

According to measurements of electrophoretic mobility of oocysts of *Cryptosporidium* p. by Considine et al. (2002), they exhibit an isoelectric point below pH 3, and the zeta-potentials are negative at pH > 3. The pH of samples presented in Table 1 varies from pH 6.6 to pH 7.5. The corresponding zeta potential of oocysts can be found between -10 and -40 mV. In most cases samples from the examined swimming pools exhibited negative zeta-potential of coagulated flocs, and one can expect electrostatic repulsion between oocysts and flocs. In addition to electrostatic repulsion, steric forces due to hairy layer of surface proteins pose additional obstacle for oocysts to be adhered to sand particles.

Zeta potential smaller than 15 mV indicates destabilized system, therefore easy flocs formation.

3.2. PARTICLE SIZE DISTRIBUTION

Particle size distribution was investigated in both micro-size and nano-size ranges. Figure 1 presents small swimming pool micro-size range distribution of particles originating from sediments (A through C) separated from three backwashed filters and one from water vacuum cleaner sediment (D). On all graphs the initial distribution is shown with a dashed line, while distribution after 30 minutes of suspension circulation is shown with a solid line. The first sediment A initially contained two peaks around 50 and 300 μm. After circulation 50 μm peak shifted to around 20 μm and the 300 micron peak vanished, which indicates flocs decreasing their size. In the case of sediment B, there are initially two peaks, 30 μm and 320 μm. After 30 minutes, flocs/particles of size 320 μm almost entirely are sheared into 30 μm particles or are agglomerated to flocs of size above 500 μm. Sediment C exhibited the ability for agglomeration. 40 μm flocs slightly decreased and agglomerated forming 300 μm flocs. Obtained from water vacuum cleaner sediment (D) had initially two flocs sizes: 80 μm and 300 μm. After 30 minutes of suspension circulation, 80 μm peak significantly diminished and another strong peak, around 35 μm appeared. At the same time increased amount of 300 μm flocs.

Figure 2 presents sediments from recreational swimming pool. Washing water sediment (A) underwent shearing of flocs to smaller sizes as well as agglomeration. Peak 60 μm decreased and shifted to size around 55 μm, while peak 300 μm shifted to size 350 μm and increased its volume several times. Water vacuum cleaner sediment (B) initially had three size peaks: very weak 30 and 300 μm and strong 120 μm. After 30 minutes of circulation peak 300 μm decreased and 30 μm was no longer recognizable under strong and broad peak of around 70 μm, that replaced 120 μm peak. One can conclude, that observed in this case is only shearing of flocs and decrease of their size.

Sediment flocs from backwashing of filters from small swimming pool exhibited broad range of responses to shearing flow. Presented three distributions show three different behaviours, flocs shearing to smaller size, flocs agglomeration to larger size and both phenomena together. Investigated sample from the same pool originating from water vacuum cleaner exhibited behavior of both shearing and agglomeration. In the case of recreational swimming pool, sample from backwashing of filters showed agglomeration and only very slight shearing, while water vacuum cleaner coagulated sediments were clearly sheared to smaller sizes only. This behavior might be attributed to the fact that recreational swimming pool had positive zeta potential of sediment flocs, therefore they were mostly agglomerating, while negatively charged flocs from vacuum cleaner sediments were sheared to smaller size.

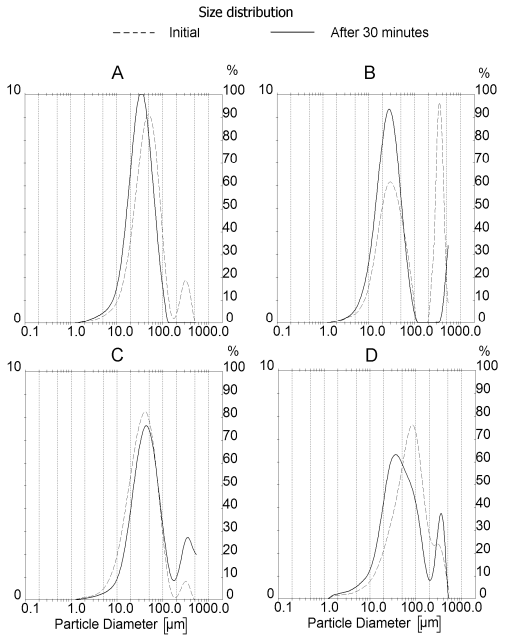

Fig. 1. Particle size distribution in micro-size range, small swimming pool sediments. A: PG-f-1; B: PG-f-3; C: PG-f-14; D: PG-vc-1

Two sediments from water vacuum cleaners were additionally investigated in nano-size range (Fig. 3). Both exhibited dual distribution characteristics. The small swimming pool sediment had a medium peak in range 80 to 90 nm size and strong peak at 500 nm. The recreational swimming pool sediment sample has only a weak peak at around 92 nm and strong peak at 1000 nm. Investigations of backwashing water from filters is further planned.

One can see on nano-size distribution mostly not coagulated particles such as bacteria, which are of size around 500 to 1000 nm. Since recreational swimming pool has a peak at larger size compared to small pool, one can speculate, that the recreational pool has particles to some degree coagulated. This would correlate well with the zeta potential measurement, that suggested larger dose of coagulant, aluminum sulfate, that charged flocs positively.

Particles of size below 100 nm can be attributed to organic macromolecules originating from human colloidal excretions. One can speculate, that other particles were trapped in water from the atmosphere or were released from water filtering installation.

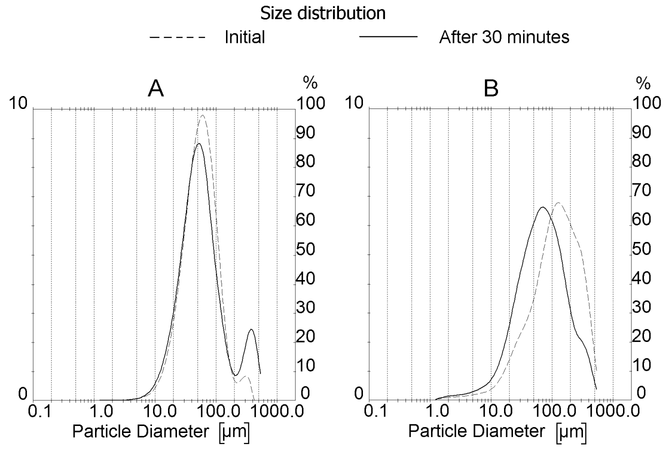

Fig. 2. Particle size distribution in micro-size range, recreational swimming pool sediments. A: K-f-3; B: K-vc-3

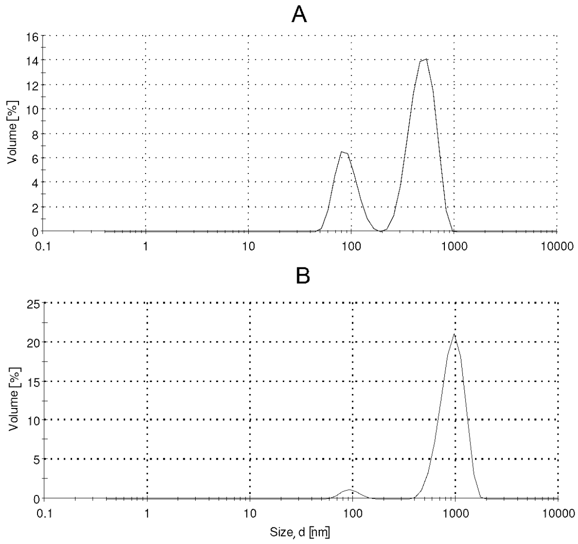

Fig. 3. Particle size distribution by volume in nano-size range, water vacuum cleaner from: A: small swimming pool, sample PG-vc-1; B – Recreational swimming pool, sample K-vc-3

3.3. DERIVATOGRAPHY

Table 2 shows mass lost in derivatographic analysis. Samples contained various amounts of sand and silt, therefore, the mass loss varied from 51.6 to 81.5 %. In order to compare samples based on material that could be combusted or volatilized during the analysis, mass losses in the specific temperature intervals are referred to the mass loss only and all four values in a given column from A to D add up to 100 %. The intervals are (Siewert, 2004):

– A, up to 200ºC, water region
– B, 200–450ºC, thermolabile organic region
– C, 450–550ºC, stable organic region
– D, 550ºC and above, inorganic region.

One can notice, that washing water samples had higher water and thermolabile organic matter losses, while sediments obtained from water vacuum cleaner showed few percent more stable organic matter.

Table 2. Mass loss in derivatographic measurements

Temp. Interval	Backwashing water samples				Water vacuum cleaner samples		
	PG-f-1	PG- f-3	PG- f-4	PG- f-5	PG-vc-1	K-vc-1	K-vc-2
Total Mass Loss, (wt. %)							
Total Loss	66.8	58.8	59.4	61.2	79.6	51.6	81.5
Absolute Mass Loss by Temperature Interval, (wt. %)							
A	11.1	10.1	11.0	7.9	10.0	4.8	6.1
B	42.6	37.6	39.3	40.6	47.7	33.8	51.2
C	10.0	7.7	6.6	10.3	17.6	11.7	21.8
D	3.0	3.4	2.6	2.3	4.2	1.3	2.4
Relative Mass Loss by Temperature Interval, (wt. %)							
A	16.6	17.2	18.5	12.9	12.6	9.3	7.5
B	63.8	63.9	66.1	66.4	59.9	65.5	62.8
C	15.0	13.1	11.1	16.8	22.1	22.7	26.7
D	4.5	5.8	4.3	3.8	5.3	2.5	3.0
Total A - D	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Table 3 presents comparison of exothermic and endothermic peaks. water washing from filters sample exhibit strong exothermic peak around 350ºC, while around 450ºC only sample PG-1 shows a strong peak. The remaining samples have only weak exothermic peak. Characteristic for water vacuum cleaner samples is a strong exothermic peak around 500ºC, in stable organics region. Endothermic peaks, that were broad and weak could be explicitly visible only in two backwashing water samples from small swimming pool and in vacuum cleaner sample. Figures 4 and 5 show two derivatographic samples, washing water sediment and vacuum cleaner sediment respectively.

There is evident difference between sediments from backwashing of filters and sediments from water vacuum cleaner. It is speculated, that higher molecular organic matter may more easily remain in the pool avoiding circulation through filters. Also, substances remaining in the pool and later picked up by water vacuum cleaner were longer exposed to higher concentration of chlorine.

Table 3. Exothermic and endothermic peaks in derivatographic analysis

Sample	Peaks (deg C)			
	Exothermic		Endothermic	
PG- f-1	347 455	strong strong	160 630	broad broad
PG- f-3	350 440 520	strong medium weak	155 670	broad broad
PG- f-4	315 400 445 490	very strong very weak weak weak		
PG- f-5	352 450	strong strong		
PG-vc-1	350 400 495	medium weak strong	105 175 600	very weak broad weak broad broad
K-vc-1	330 425 503	strong weak very strong		
K-vc-2	270 425 490 505	very strong strong weak strong		

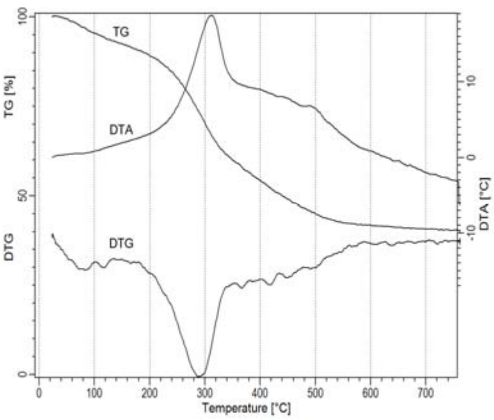

Fig. 4. Backwashing water sediments from small swimming pool filters

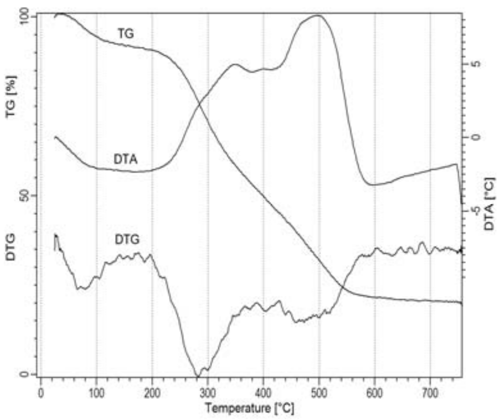

Fig. 5. Water vacuum cleaner sediments from pool bottom from small swimming pool

4. FINAL COMMENTS

A comparison of pool bottom sediment and filter washing sediment can be a new indicator of proper functioning of swimming pool water treatment. Flocs present in both sediments are vulnerable to a different degree to the shear force field, which should correspond to the effectiveness of deep bed functioning. Derivatographic data indicates that higher molecular organic matter may more easily remain in the pool avoiding circulation through filters. The zeta potential shows, that all samples used for the research indicate easy flocculation and rather destabilized contaminant particles as evidenced by zeta potential smaller than -13 mV and for some suspensions even in the positive charge range.

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Korkosz, A., Niewiadomski, M., Hupka, J., *Badania właściwości osadów pochodzących z uzdatniania wody basenowej.*, Physicochem. Probl. Miner. Process., 46 (2011) 243-252, (w jęz. ang), http://www.minproc.pwr.wroc.pl/journal

Dwa rodzaje osadów pochodzących z instalacji basenowych zostały scharakteryzowane i otrzymane wyniki przedyskutowane, w szczególności flokuły, które zatrzymały się na filtrze piaskowo-żwirowym i następnie zostały usunięte w płukaniu zwrotnym oraz osady z dna niecki basenowej zebrane tzw. odkurzaczem wodnym. Lepsze zrozumienie struktury i właściwości osadów powinno usprawnić usuwanie cyst *Cryptosporidium* z basenów i w efekcie podnieść bezpieczeństwo kapiących się użytkowników. Przeprowadzono pomiary potencjału dzeta, rozkładu wielkości cząstek/flokuł w zakresach nano i mikro oraz pomiary derywatograficzne. Potencjał dzeta wskazał na łatwość flokulacji cząstek w układzie, a rozkłady wielkości ujawniły różnorodną efektywność filtracji. Analiza derywatograficzna wskazała na wyraźne różnice składu pomiędzy osadami z filtracji a osadami z dna basenu.

słowa kluczowe: potencjał dzeta, cysta, analiza termiczna, baseny kąpielowe, rozmiar flokuł