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EFFICIENCY OF DEEP BED FILTRATION IN TREATMENT OF SWIMMING POOL WATER

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The effectiveness of water filtration in gravel-sand bed filters has been studied in the rehabilitating swimming pool treatment plant. Apart from instrumental analysis of the water the investigation considered additionally particle size distribution as well as thermal analysis of the sediment collected in the sand bed of depth filters and removed during the process of washing. Variable value of TOC in the washings for each filter indicates indirectly their non-uniform loading. It has been proved that the size of particles in the suspension easily changes as a result of operation of shear stress. Derivatographic research has indicated approximately 30 % presence of organic substances in the sediment. In neither of the investigated samples loss of mass over >460^{o}C has been observed.

key words: swimming pool, deep bed filtration, particle size distribution, thermal analysis

INTRODUCTION

The testing of swimming pool water presented in the literature refers mainly to the health of the users (Panyakapo, 2008; Lahl, 1981; Nemery, 2002; Judd, 2000; Judd, 2003). Swimming pools are enjoying increasing popularity not only among adults and the youth but also among children, even several months old. Therefore, the cleanness of the water is of crucial importance, especially as its users are often infants. The swimming pool water contains both dissolved and suspended contaminants. Among those suspended there are among others: bacteria, viruses, protozoa and fungi. Pool water is treated in two ways. Contaminants which settled at the bottom are removed

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by water vacuum cleaner, while the suspended contaminants are separated on filters. The selection of the filters as well as frequency and intensity of washing are of fundamental importance so that the dangerous microbiological contaminants are effectively removed.

Effective functioning of depth filter, with regard to particles of colloidal size is dependant on addition of coagulant agents. The model research in sand filter have shown that the addition of coagulants results in 90-99 % removal of polyester molecules, replacing bacteria of variety *Cryptosporidium* (Croll, 2007). There is a need to improve disinfection and cleaning procedures, with consideration given to the different uses and daily bather loads of each pool type. There is also a need to monitor water quality and to increase users' knowledge and awareness of the risks (Guida, 2009).

The most frequently used filter bed is sand-siliceous bed, which with proper operation can function at least several years without blocking. The main reason of filters being blocked is the poor quality of swimming pool waters, presence of algae (Saravia, 2007) and improper washing of the filter. There are also in use filters with the addition of anthracite. Application of too high backwash water flowrate to these filters can result in the uplift of antracite. The literature of the subject describe the possibilities of elimination of resting spores *Cryptosporidium* in the filter with the sand bed (Croll, 2007). Tests of swimming pool water have been performed with the application of ultra filtration in the pilot installation (Hobby, 2004). Also vacuum filters were used with cellulose fibers or diatomaceous earth as filter aid.

Recently research has been carried out on new ways of treatment and disinfection of swimming pool water, involving application of ultra filtration in connection with adsorption on activated carbon (Barbot, 2008), ultrafiltration followed by hyperfiltration (Resissmann, 2005), or the application of advanced methods of oxidation (Glauner, 2005). There is still in use a number of swimming pools of the old type in which the water from overflow is directed to sewage system. In the process of filter washing there have been observed substantial water losses which after consecutive treatment could be used again.

This paper discusses the results of water filtration alongside thermal analysis of flocks accumulated in the sand bed of depth filters and removed by washing. It is expected that the research will contribute for the implementation of the new technology of water treatment, whose main goal will be the increase of safety of the users of swimming pools and economy of water and energy.

RESEARCH SYSTEM

The object of the research was a normally operated water treatment and disinfection installation of rehabilitating indoor swimming pool, with lower water

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overflow, with the basin capacity of 120 m^3. The water from the swimming pool flows through the hair separator and the pump directs it to the three layer gravel-sand filters. Ahead of the filters aluminum sulfate coagulant is dosed periodically at the amount of 3 g/m^3. After passing through the filters the water is heated in the counter current heat exchangers, aerated under pressure, disinfected with the solution of sodium hypochlorite and recirculated back to the pool basin.

Due to lack of equalizing tank, the pool water is used in the process of filters washing. In the first stage the filter is washed with water, next with water and compressed air. The time of washing depends on the level of contamination of the filter and can continue for the period from several minutes up to even one hour. The filter is considered washed up when no visual traces of suspended matter are present in the water.

For the prophylactic purposes against development of algae 0.2 kg copper sulfate in the solution is dosed for each filter. In the described swimming pool the filters are washed twice a week. There is neither automatic quality control of water nor automatic chemicals dosing.

The fundamental research has been carried out on gravel-sand filters with the measurements Ø800×2200 mm, with three filtration layers (from the top of the bed):

- I sand layer with granulation of 0.5-1 mm (the depth of the layer 900 mm),
- II sand layer with granulation of 1-2 mm (the depth of the layer 500 mm),
- III sand layer with granulation of 5-8 mm (the depth of the layer 300 mm).

RESEARCH METHODOLOGY

Sieve analysis of sand and gravel was performed for the three fresh granular media forming the increasing particle size layers. The first layer was sampled from the inside of the filter and for the sand that came into the aerator due to improper operation of the filters. For the sieve analysis a set of sieves with the opening sizes: 8; 6.3; 4; 2.5; 1.5; 0.85; 0.6; 0.5; 0.355; 0.212 mm was used. They were placed in the form of a stack on the shaker. The samples of 250 g of sand were dried to the constant mass at 105 ^{o}C and shaken over the period of 5 minutes. The residue on each sieve was manually shaken for the additional period of 1 minute and the minus mesh was added to the plus mesh on the sieve with smaller size openings and the mass of grain fraction was determined.

In order to determine the efficiency of filtration process the water samples were collected from the pool installation before and after the filters (after disinfection). Also the water from washing of each of the three filters was collected.

pH of the water samples was measured by means of multifunction device *Elmetron* with the application of combined electrode of the type ERH-111. The temperature was measured with the application of the sensor CT2S-121, and

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conductivity with the application of conductometric sensor of type EC-60. Redox potential was determined by the use of platinum combined electrode of type ERPt-13. Concentration of available chlorine was determined by means of titration with N,N-diethyl-1,4-phenylenediamine in compliance with Polish Standard PN-ISO 7393-1.

The measurement of concentration of total organic carbon (TOC), total inorganic carbon(TIC) as well as total nitrogen (TN) was carried out with the application of LiquiTOC *Elementar* manufactured analyzer in the presence of oxygen as the carrier gas. The contaminants present in the water samples after oxidation at the temperature of 800°C were determined with analyzer integrated detectors: infrared IR (carbon) and electrochemical – EC (nitrogen).

Distribution of particle size in the backwash water was examined by means of Mastersizer X laser diffraction particle sizing instrument manufactured by *Malvern.* The applied system enabled the measurements of particle size in the range of 0.5-180 μm and 1.2-600 μm. 200 ml of examined suspension was circulated through measuring cell in the closed circuit.

Thermal analysis (TG/DTA) of the flocks from filter bed was performed by means of derivatograph Q-100 D, *Paupik, Paulik ERDEY,* MOM Budapest. First, the deposit was separated from the washing water in the centrifuge type MPW-2, and next dried in the dryer KBC G-100/250 manufactured by *Premed* to the constant mass. The weighed amount totaled up to 100 mg. The temperature increase rate was set at 10°C/min. TG sensitivity was 100 mg, while DTA sensitivity was 250 μV. The reference sample was α-Al_2O_3.

The photographs of the flocks were taken with the biological microscope type *L300* coupled with digital camera Canon PowerShot A650 IS.

RESULTS AND DISCUSSION

SAND PARTICLES SIZE DISTRIBUTION

The required effectiveness of filtration can be achieved in the sand-gravel bed maintaining the grain size in the particular layers. Analyzing the data obtained for investigated filters one can observe (Fig. 1) that particle size distribution in the particular layers of the filtration bed has changed during the operation of filter batteries.

The investigated fresh sand or gravel were characterized by the following particle diameters: I layer 0.4-1.0 mm; II layer 1.0-2.5 mm; III layer 3.0-8.0 mm. The sand collected during the inspection from the inside of the filter corresponds to the diameter of I layer of fresh bed 0.4-1.0 mm, whereas the sand with the particle diameter in the range of 0.7-4.0 mm collected from the aerator is composed of the mixture of the 3 layers of the bed. The data obtained from the sieve analysis correspond to the data

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presented in the literature e.g. I layer 0.4-0.8 mm; II layer 1.0-2.0 mm; 2.0-3.15 mm; III layer 3.15-5.60 mm (Wyczarska-Kokot, 2002).

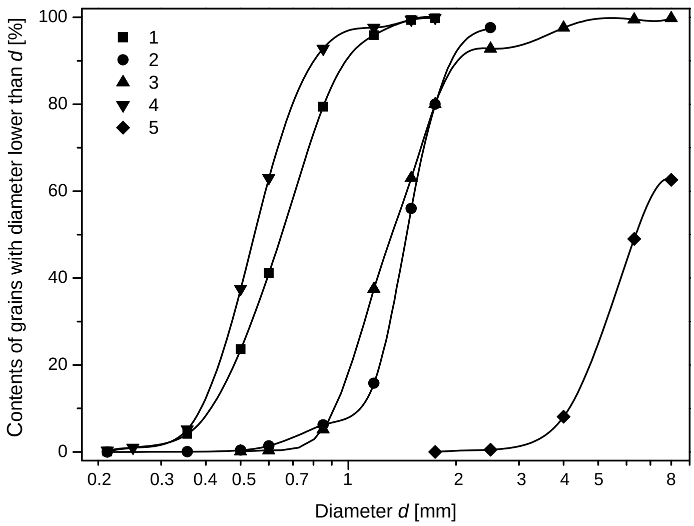

Fig. 1. Sieve analysis of 1- fresh fine sand; 2 - fresh medium-size sand; 3 - sand washed-out to aerator; 4 - fine sand bed in use, sampled during filter inspection; 5 - fresh gravel

As the sieve analysis curve indicates (Fig. 1. curve 4), the sample collected from the inside of the filter (layer I) is characterized by more fine particles than the fresh sand. The sieve analysis of fresh gravel for the II layer shows that 75% of particles belong to the size fraction 1.0-2.0 mm which can be explained by the fact that the beds undergo size reduction when washed, due to friction, especially in the fluidal state. Overturbulent conditions during washing of the filters caused by e.g. excess of the air forced, result in mixing layers I and II, which significantly increased the presence of the 0.355 – 1.0 mm size fraction in layer I. In the sample collected between the filter and the aerator the amount of the 1.0-2.0 mm size fraction present is characteristic to that of the II layer and confirms mixing of the layers during the process of filter washing. Due to the lack of possibility of collecting a representative sample from the layers II and III the current particle distribution in these layers has not been presented.

PHYSICAL AND CHEMICAL ANALYSIS OF WATER

Physical and chemical testing included swimming pool water before filters, water after filtration and washing water from 3 filters. The water samples were collected shortly before filter washing. The average tests results are presented in the table 1. The data indicates the proper functioning of the filters. TOC of water after passing through the filters decreases from 3.0 mg/dm^3 to 2.7 mg/dm^3.

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The redox potential increases due to the increase of chlorine concentration to 0.6 mg/dm^3 which, after mixing with the water in the swimming pool, decreases to the acceptable level. Variable value of TOC in the washings for each of the filters indicates indirectly their non-uniform load. It is important to observe a similar tendency with regard to the general nitrogen content, as well as the total inorganic carbon (TIC).

The presence of fine sand particles in the layer I, has been observed in the filter 1, which translates into a better filtration effect. More suspended organic matter has been stopped in layer I than in the two remaining filters (see derivatographic results). In the filter 3 the thickness of the layer I was 25% lower than in the filter 1.

Table 1. Physical and chemical parameters for investigated indoor rehabilitating swimming pool

Water sampling location	Water temperature (°C)	Free chlorine level [mg/dm^3]	pH	Redox potential [mV]	TOC [mg/dm^3]	TIC [mg/dm^3]	TN mg/dm^3]
Tap water	18	0.0	7.8	-469	1.2	29.1	-
Before filters	32	0.1	6.9	-521	3.0	34.3	0.2
Washing water from filter 1	30	2	8.1	-864	8.3	40.9	0.4
Washing water from filter 2	28	2	8.3	-813	5.5	30.7	0.1
Washing water from filter 3	30	2	8.2	-750	4.8	40.7	0.3
After filters	33	0.6	7.8	-898	2.7	38.1	0.1

In filter 2. the sand level in layer I was similar to the level in filter 1, with aprox. 30% more of finer particles (in the range 0.7-1 mm). During the testing and sampling period, the users of the swimming pool were infants with their parents, therefore, the water temperature in the pool was high, at 32°C. With respect to swimming pool activities for infants the level of free chlorine was decreased to 0.1 mg/dm^3 while its concentration for the other age groups should be 0.5 mg/dm^3.

In tap water chlorine amount remained below the detection limit. Prior to washing the filters swimming pool water was subjected to chlorination up to the value of 2 mg/dm^3.

Swimming pool water pH was too low (according to the recommendation it should be 7.2-7.6), while filter washing water pH was 8.1-8.3 (due to the addition of carbonate with coagulant to raise the pH). The value of the redox potential correlates well with the level of water contamination. After filtration and chlorination redox potential level reached almost -900 mV.

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THERMOGRAVIMETRY (TG) AND DIFFERENTIAL THERMAL ANALYSIS (DTA) OF FLOCKS

When heating deposit samples, loss of mass (TG curve) has been observed – whereas for the investigated system there was no increase of mass - and heat emission (exothermic reactions) or heat release (endothermic reactions) (DTA curve). The result of this measurements are presented as two curve pairs, see Fig. 3. The obtained TGA curves show that flocks are degraded thermally in three steps, which could be attributed to dehydration, fragmentation of the macromolecular structure which is probably the main thermal degradation step, and the carbonization of the product to ash. The investigation of the deposits from the washing of the filters 1 and 3 indicate similar content of organic suspended matter in both quantitative and qualitative respect.

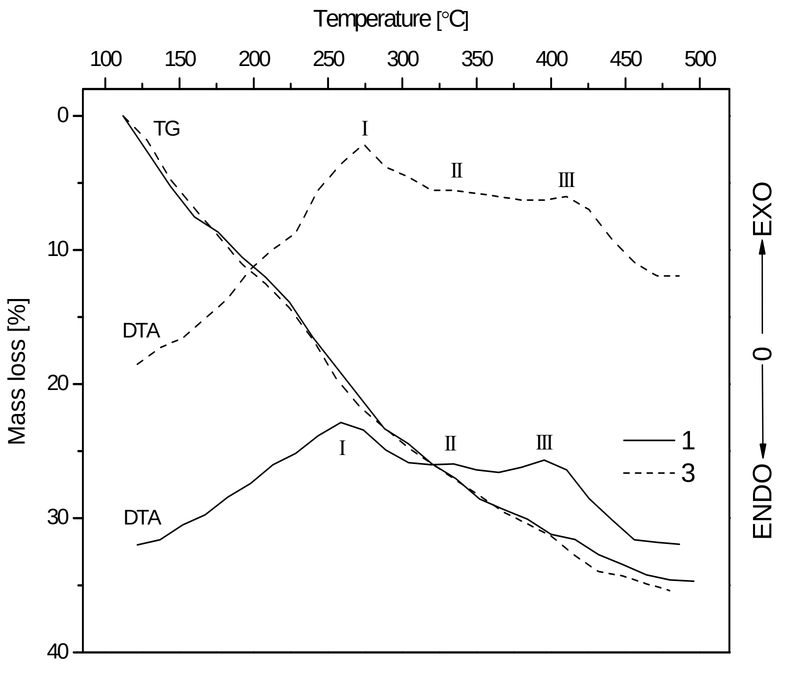

Fig. 2. TG and DTA curves of flocks washed from filter 1 and 3

As summarized in Table 2, water content of samples amounted from 7.4 to 11.7 weight %. The average loss of mass in the range of temperature 105-460°C amounted to 32.4 %. In none of the investigated samples the loss of mass over > 460°C has been observed. In the DTA curves 3 maxima are observed. In both sediment samples a strong maximum I has occurred – for filters 1 and 3 at 256°C i 272°C. Very weak maximum II corresponds to temperatures 344 and 365°C respectively. The third, more pronounced, maxima occurred at 400°C and 408°C.

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From the course of DTA curves one can speculate that more fine particles including microorganisms have been captured by filter 1.

Table 2. Results of thermal analysis of flocks backwashed from filters

Flocks from	TG Curves			DTA Egzothermic Effects Maximum		
	Moisture 20-105°C	Mass Loss 105-460°C	Mass Loss > 460°C	I	II	III
Filter No. 1	10.1 %	32.9 %	0 %	256°C strong	344°C weak	400°C medium
Filter No. 3	7.4 %	31.4 %	0 %	272°C strong	365°C very weak	408°C weak

PARTICLE SIZE DISTRIBUTION OF FLOCKS

The investigation of particle size distribution of flocculated sediment washed from the filters indicates a significant range of flock size. Under the microscope it can be observed that there are numerous impurities trapped in the structure of the flocks among them bacteria and protozoa, but also fibrils and mineral particles. The adhesion forces of contaminants into the precipitated aluminum hydroxide flocks with positive surface charge result mainly from interaction with negatively charged particles. The interactions are weak which is clearly seen in Figure 3.

The plot in Figure 3 shows the size of particles analyzed by laser diffraction particle sizing instrument. The dashed line represents the particle size in sediment at the beginning of the measurement. The solid line represents the particle size after 85 minutes circulation through the measuring cell. Both lines show multimodal shape. Comparing both curves determined at the interval of several minutes one can observe that the size distribution of the particles varies as the suspension is the subjected to shear stress mainly in the pump. The measurement results indicate the need for the washing process of the sediments from the bed to be carried out by the rather low flowrate of water, which in fact, does not necessarily take place in practice, because of substantial turbulence of flow caused by the addition of compressed air.

On the curves 1 and 2 one can observe 3 maxima, corresponding to the medium size of particles in the size fractions 1.5-3 μm and 15-22 μm, 30 μm and 300-400 μm. The finest particles are bacteria, whereas the content of the particles 15-30 μm indicates the presence of fine flocks, resting spores, protozoa and even fragments of fibers (visible under the microscope, Fig. 4). The presence of stress in the suspension leads to both aggregation and degradation of already formed aggregates.

Figure 4 presents dried sediment, previously thickened in a centrifuge. The picture shows hair and synthetic fibrils, which also contribute to the presence of organic components in the sediment, see DTA curve in Figure 2.

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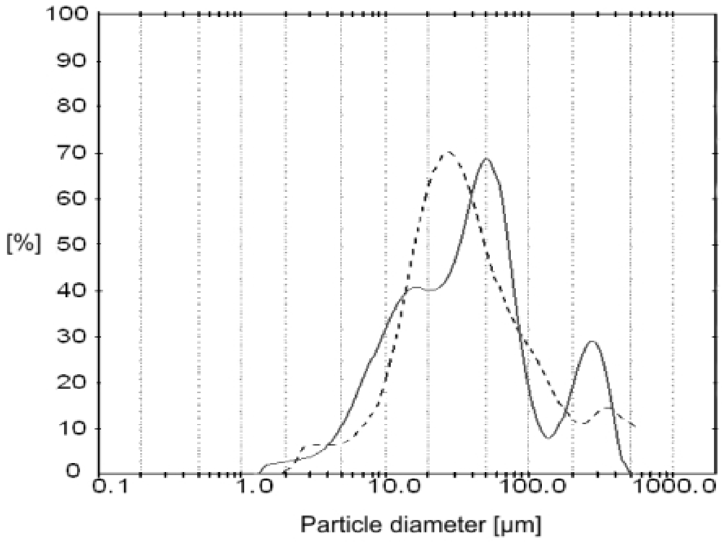

Fig. 3. Particle size distribution of flocks washed out from filter 1, Mastersizer X 1.2-600 µmlens; (dashed line – at the beginning, solid line – after 85 minutes of circulation)

Fig. 4. Sediment from backwashing filters – in the form of dried broken cake. Magnification 40x

FINAL COMMENTS

The quality of water in the swimming pool is controlled mainly by the effectiveness of the filtration process and by the intensity and frequency of back

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washing the filters. Swimming pool water contains a number of both dissolved and suspended impurities which in the consequence of coagulation are captured within the bed and in the process of washing are removed. The choice of filtration bed is of crucial importance.

The content of total organic carbon varied depending on the location of the water sampling point. Variable value of TOC in the washings for each of the filters indicates indirectly their non-uniform loading. The important observation is a similar trend with regard to the content of total nitrogen, as well as total inorganic carbon (TIC).

The suspensions stopped in the bed have polydisperse particle size distributions. Despite electrical attraction of positively charged coagulant flockes and negatively charged impurities the particle size in the suspension changes easily as a result of shear stress.

The derivatographic investigation has indicated approximately 30 % participation of organic substances in the sediment washed out from the filters. From the DTA curves can be read the diversification of contamination content, stemming from the presence of microorganisms, including bacteria, protozoa, and minute organic impurities.

The performance of sieve analysis of sand collected from the functioning filter, and from the fresh bed (reserve) allows to estimate the correctness of operation of water treatment system and anticipate the effectiveness of the process of water treatment.

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REFERENCES

BARBOT E., MOULIN P. (2008), *Swimming pool water treatment by ultrafiltration–adsorption process,* J. Membr. Sci., 314, 50–57.

CROLL B. T., HAYES C. R., MOSS S. (2007), *Simulated Cryptosporidium removal under swimming pool filtration conditions,* Water Environ. J., 21(2), 149-156.

DIN Standard 19643, 1997.

GLAUNER T., KUNZ F., ZWIENER C., FRIMMEL F.H. (2005), *Elimination of swimming pool water disinfection by-products with advanced oxidation processes (AOPs)*, Acta Hydroch. Hydrob., 33 (6), 585−594.

HAMEIRI Z., SPOONER T., SPROUL A.B. (2008), *High efficiency pool filtering systems utilising variable frequency drives*, Renew. Energ., 34(2), 450-455.

HOBBY R., HAGMEYER G., LANGE B., GIMBEL R. (2004), *Einsatz einer Ultrafiltrationsanlage im Pilotmaßstab zur Schwimmbadwasseraufbereitung*, GWF*, Wasser-Abwasser*, 145 (10), 700–705.

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HUPKA J., KORKOSZ A. (2009), *Fizykochemiczne podstawy uzdatniania wody w basenach kąpielowych*, Proceedings of V Ogólnopolska Konferencja Szkoleniowa Baseny Polskie 2-3.04.2009 Warszawa, 87-94.

JUDD S.J., BLACK S.H. (2000), *Disinfection by-product formation in swimming pool waters: a simple mass balance,* Water Res., 34(5),1611-1619.

JUDD S.J., BULLOCK G. (2003), The *fate of chlorine and organic materials in swimming pools*, *Chemosphere*, 51 (9), 869-879.

NEMERY B., HOET P. H. M., NOWAK D. (2002), *Indoor swimming pools, water chlorination and respiratory health*, Eur. Resp. J., 19, 790-793.

LAHL U., BATJER K., DUSZELN J.V., GABEL B., STACHEL B. (1981), *Distribution and balance of volatile halogenated hydrocarbons in the water and air of covered swimming pools using chlorine for water disinfection,* Water Res., 15(7), 803-814.

PANYAKAPO M., SOONTORNCHAI S., PAOPUREE P. (2008), *Cancer risk assessment from exposure to trihalomethanes in tap water and swimming pool water,* J. Environ. Sci., 20(3), 372-378.

PIECHURSKI F.G., WYCZARSKA-KOKOT J., NIESŁAŃCZYK J., *Porównanie jakości wody z charakterystycznych punktów obiegów basenowych*. In: Kuś K., Piechurski F., Instalacje basenowe, Gliwice 2009, 135-156.

REIßMANN F.G., SCHULZE E., ALBRECHT V. (2005), *Application of a combined UF/RO system for the reuse of filter backwash water from treated swimming pool water*, *Desalination*, 178, 41-49.

SUGIMOTO A. (1997), *Ceramic filter filtration apparatus for purifying swimming pool water*, U.S. Pat. No. 5632890.

WYCZARSKA-KOKOT J., PIECHURSKI F. (2002), *Ocena skuteczności filtracji wody i jakości wód popłucznych w instalacjach basenowych,* Ochr. Środow., 1(84), 33-36.

Korkosz A., Janczarek M., Aranowski R., Rzechuła J, Hupka J., *Efektywność filtracji wgłębnej w oczyszczaniu wody basenowej,* Physicochemical Problems of Mineral Processing, 44 (2010), 103-113, (w jęz. ang), http://www.minproc.pwr.wroc.pl/journal

Przebadano efektywność filtracji wody w filtrach ze złożem żwirowo-piaskowym w instalacji basenu rehabilitacyjnego. Obok analizy instrumentalnej wody, w badaniach uwzględniono rozkład wielkości cząstek i analizę termiczną osadu zgromadzonego w złożu piaskowym filtrów wgłębnych i usuwanego podczas płukania. Zmienna wartość TOC w popłuczynach dla każdego z filtrów wskazuje pośrednio na nierównomierne ich obciążenie. Wykazano, że wielkość cząstek w zawiesinie łatwo zmienia się w wyniku działania naprężeń ścinających. Badania derywatograficzne wskazały na około 30% udział substancji organicznych w osadzie. W żadnej z badanych próbek, nie zanotowano ubytku masy powyżej >460°C.

słowa kluczowe: basen, filtracja wgłębna, rozkład wielkości cząstek, analiza termiczna

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