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THE INFLUENCE OF THE FILTRATION BED TYPE IN THE POOL WATER TREATMENT SYSTEM ON WASHINGS QUALITY

WPŁYW RODZAJU ZŁOŻA FILTRACYJNEGO W UKŁADACH OCZYSZCZANIA WODY BASENOWEJ NA JAKOŚĆ POPŁUCZYN

Abstract: This paper presents the influence of the type of filtration beds, used in swimming pool water treatment systems, on the quality and the possibility of reuse of washings. The research covered 4 pool cycles with sand, sand and anthracite, glass and diatomaceous beds. The degree of contamination of washings was assessed on the basis of physical, chemical and bacteriological tests. The possibility of washings drainage into the natural environment was considered, and the results of the research were compared with the permissible values of pollution indicators for wastewater discharged to water or ground. A direct management of washings from the analysed filters proved impossible mainly due to the high content of TSS (total suspended solids) and free chlorine. Washings were subjected to sedimentation and then the supernatant was stirred intensively. As a result of these processes, the quality of washings was significantly improved. This allowed planning to supplement the pool water installations with systems for washings management.

Keywords: filter beds, washings, swimming pool, sedimentation

Introduction

The main equipment of each water treatment systems, both from surface and underground intakes, are filters [1, 2]. The search for modern, yet simple and inexpensive filtration methods is currently one of the basic directions of water and wastewater treatment technologies development. The conducted research concerns mainly new methods and materials for filters construction, modification of their operation methods, effective beds and an extension of the filtration cycle time without reducing its efficiency [3-10].

The high effectiveness of modern filtration technologies is mainly related to the high capacity of materials used as filter beds, and therefore the necessity of their effective washing and thus the management of large amounts of washings [11-13].

These issues also apply to the swimming pool water treatment systems. Closed circuits, in which specific contaminants are removed (disinfection by-products, micropollutants including the group of pharmaceuticals and personal care products [14-18]) require the use

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of highly effective filter beds. There is also a growing number of filtration methods, washing and management of washings streams from swimming pools [19-23].

The potential of washing streams from swimming pools is hidden in its large volume (a proper washing of 1 m^2 of bed requires the use of 4-6 m^3 of water [24-26]) and the possibility of using simple treatment systems to recover the supernatant [21, 27].

The basis for the proper operation of pool water treatment systems is the filtration process, the main purpose of which is to remove suspensions of different degrees of dispersion.

Thus, this process protects the further part of the installation against mechanical damage and silting. Nowadays, in pool installations, pressure filters (closed or open) are used, with a filtration speed of 30 m/h or vacuum filters (open), with a filtration speed of 4 m/h.

The simplest type of filters are mono-layer pressure filters with one type filtration bed - sand or gravel with different grain size. This solution is very popular, but the work carried out to increase the filtration efficiency resulted in multilayer filters, in which the filter bed consists of two or three layers of various types of materials. The filling of multi-layer filters is usually gravel, quartz sand, anthracite or activated carbon. After some time of operation and under favorable hydraulic conditions, sand, anthracite or activated carbon beds can become a favorable habitat for microorganisms, including pathogens. Microorganisms can form a biological membrane in the bed which may be washed out to the filtrate, posing a risk of contaminating the water in the pool circuit. In the case of one-stage disinfection or generally ineffective disinfection, these microorganisms, e.g. *Pseudomonas* sp., *Legionella* sp., *Cryptosporidium* sp. may pose a risk to health of both swimmers and swimming pool technical personnel [28-30]. This is one of the reasons why new generation beds are becoming more and more popular, e.g. a bed containing silver with a disinfection effect [31], which allows to prevent the multiplication of microorganisms, a glass bed in which the negative surface charge allows additional removal of small organic impurities and positive ions from water, like iron or manganese [3, 32], zeolite beds, diatomaceous or cellulose fibers that effectively remove fine suspended, colloidal and ammonium molecules from water [5, 8-10, 33].

The main purpose of the research was to assess the quality of washings from pool water filtration systems and the possibilities of their management depending on the type of their beds.

Materials and methods

The research was carried out in 4 indoor swimming pools equipped with filters with different types of filter beds. They were marked as FP (sand filter bed), FPA (filter with sand-anthracite bed), FAFM (activated glass filter bed), FD (filter with diatomite bed). The basic technical parameters of the tested filters, with particular reference to the type of filter beds are presented in Table 1.

The working time of analysed swimming pools is 14 hours a day (usually from 7.00 a.m. to 10.00 p.m.). The pools with FP, FP and FD filters are typical sports swimming pools designed also for learning to swim and recreation. The pool with the FAFM filter is a pool designed for small children. The average attendance in these pools was: 18 person/hour in FP, 20 person/hour in FPA, 6 person/hour in FAFM and 24 person/hour in FD. On the basis of the surface area of water in particular pools and average attendance, it was possible to determine the usable area per one swimmers. It was respectively: 17.4 m^2/person in FP, 4.5 m^2/person in FPA, 5.0 m^2/person in FAFM and 13.0 m^2/person in FD.

Table 1

Characteristics of tested filters and filter beds

Characteristic parameter	**Swimming pool 1 (FP)**	**Swimming pool 2 (FPA)**	**Swimming pool 3 (FAFM)**	**Swimming pool 4 (FD)**
Filter type	pressure, closed	pressure, closed	pressure, closed	vacuum, open
Filter size [mm]	ø 1800	ø 630	ø 1200	4183 × 1870 × 1500
Height of filtration bed [mm]	1200	1200	1200	700 × 1300 (active surface of one side of the insert)
Type of filter bed	sand	sand-anthracite	activated glass AFM	diatomite (diatomaceous earth)
Characteristics of bed layers: grain size [mm] / layer height [mm]	sand: 0.4-0.8/950 gravel: 2.0-4.0/250	hydro anthracite: 0.80-1.60/600 sand: 0.40-0.80/350 sand: 2.00-3.15/150 gravel: 3.15-5.60/100	activated glass AFM: 0.5-1.0/840 activated glass AFM: 1.0-2.0/180 activated glass AFM: 2.0-6.0/180	diatomaceous earth F50 (dusty form)
Filtration area [m^2]	2.54	0.31	1.13	50 (28 inserts × 1.82 m^2)
Filtration flow [m^3/h]	76.3	9.3	34	190
Filtration velocity [m/h]	30	30	30	4
Filter cycle time [d]	3-4	3-4	2	7
The method of washing	with compressed air and water from the balance tank	water from the balance tank	water from the balance tank	flushing the filtration layer (diatomaceous earth) from filter fabric with water from the balance tank and tap water using a hose with a nozzle
Washing velocity [m/h]	50	50	50	-
The volume of water used for washing [m^3]	10.0	1.8	4.5	2.5

The active surface, porosity, size and shape of grains, mechanical strength and chemical composition are the parameters determining the effectiveness of various filter beds [1, 2, 34]. Figure 1 a-d shows the structure of the tested beds.

It has been assumed that the washings could be drained into waters or soil. For this purpose, the quality of washings was determined based on the physico-chemical and bacteriological analysis of pollution indicators. The results of the analyses were compared with the admissible values according to the Polish Ordinance of the Minister of the Environment regarding conditions to be met when introducing sewage into waters or to the soil [35] and European directives on this matter [36, 37].

The research was carried out under operating conditions in 4 swimming pools. In each swimming pools, the studies were carried out within 5 weeks. Samples of washings for tests, from each type of filter, were taken 5 times (once a week) at intervals determined by the time of the filtration cycle (Table 1). To obtain average samples, washings from pressure closed filters FP, FPA and FAFM were taken at the initial, middle and final washing stages. The average washing time of these filters, including the time of setting the washing armature, was 10-15 min. The time of proper washing with FP and FAFM water was about 5 min, and FPA 7 min. Samples from the open vacuum FD filter were collected at the point of the washings outflow to the sewage well. Due to a different mechanism of filtration and washing, in vacuum filters, the method of sampling was also different. About 1 dm^3 of water was taken during emptying the filter tank, about 3 dm^3 during flushing diatomaceous earth from the filter fabrics and about 1 dm^3 during the flushing of the bottom of the filtration tank. The average sampling time was about 20 minutes. The total volume of each sample was about 5 dm^3.

a) b)

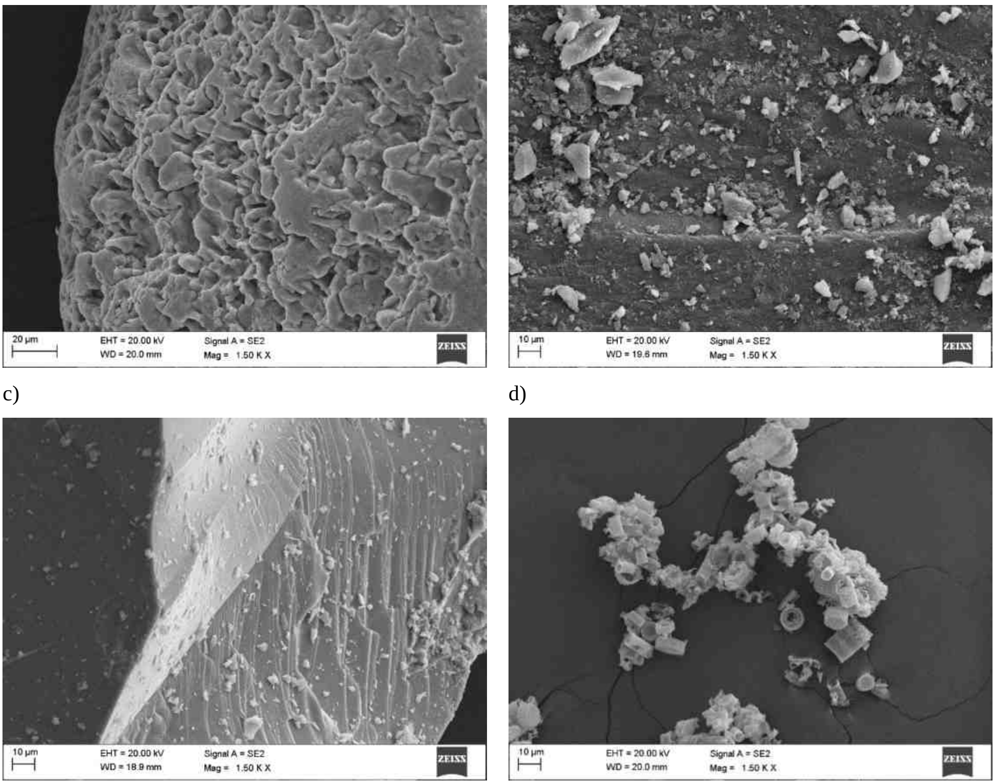

Fig. 1. The structures of tested filter beds: a) sand FP, b) anthracite FPA, c) glass FAFM, d) diatomaceous earth FD (Photos were taken with a high-scanning electron microscope ZEISS SUPRA 35); EHT - electron high tension, WD - working distance, Signal A - signal selection register, Mag - magnification

The tested pollutant indicators were divided into basic (Fig. 2) and characteristic (Fig. 3) parameters. Indicators determining the possibility of draining the water to the ground or its discharge into a watercourse, that is BZT_5 - 5-day biochemical oxygen demand (dilution method, Oxi Top®OC 100), COD - chemical oxygen demand, total nitrogen, total phosphorus (spectrophotometry, DR5000 UV/VIS, HACH®), and total suspensions solids

(TSS) and TSS in supernatant (gravimetric method) were considered as "basic pollutants indicators". Indicators that result from the method of water treatment in swimming pool were considered as "characteristic pollutant indicators".

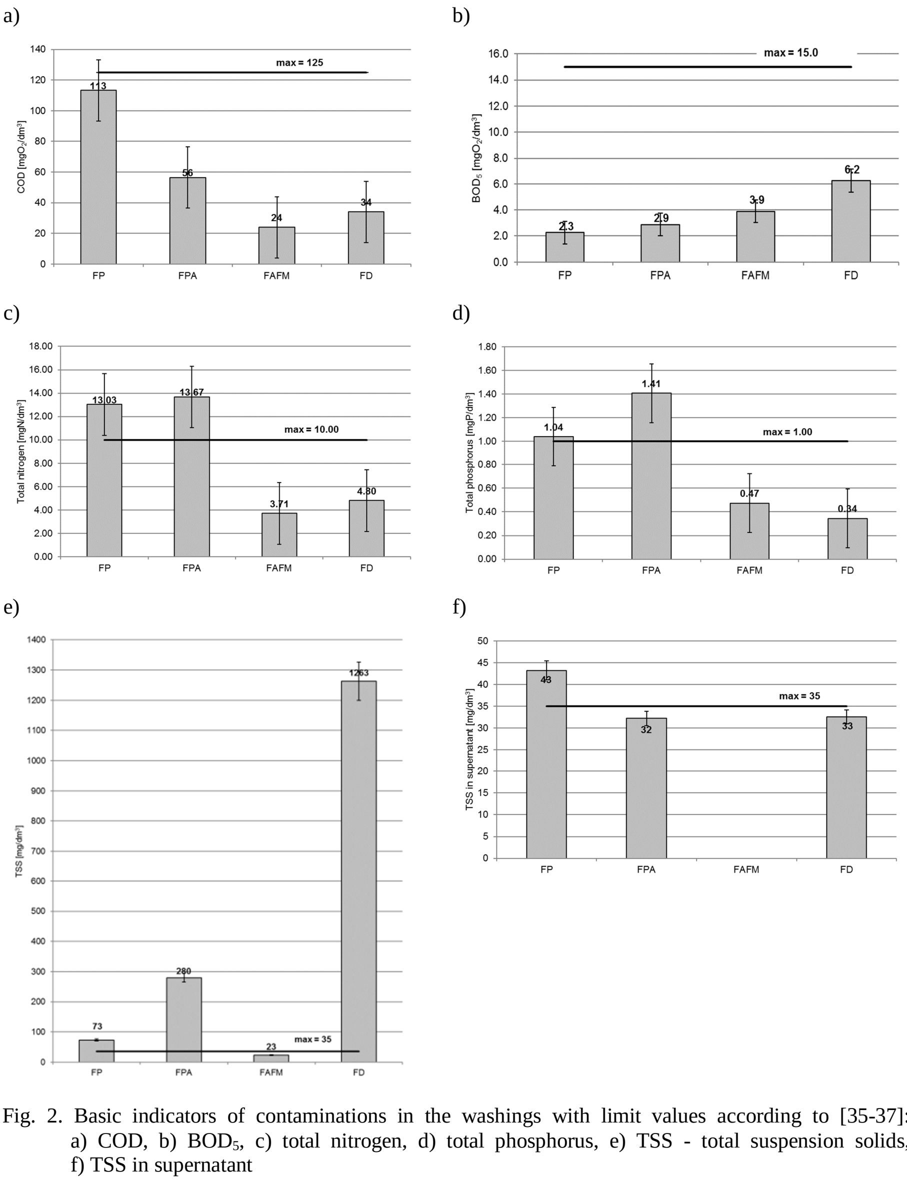

Fig. 2. Basic indicators of contaminations in the washings with limit values according to [35-37]: a) COD, b) BOD_5, c) total nitrogen, d) total phosphorus, e) TSS - total suspension solids, f) TSS in supernatant

Due to the heating of the circulating water and constant pH correction, the temperature and pH of the samples were analysed (potentiometric method, HQD HACH®). In view of the aluminum coagulant dosing before FP, FPA, FAFM, aluminum content in the washings was checked (spectrophotometry, DR5000 UV/VIS; HACH®). Because disinfection of water is obligatory, free chlorine content was measured (DPD method; POCKET Colorimeter II, HACH®) and as there is the possibility of salt ions concentration in the swimming pool systems, also the contents of chlorides and sulphates were tested (spectrophotometry, DR5000 UV/VIS, HACH®).

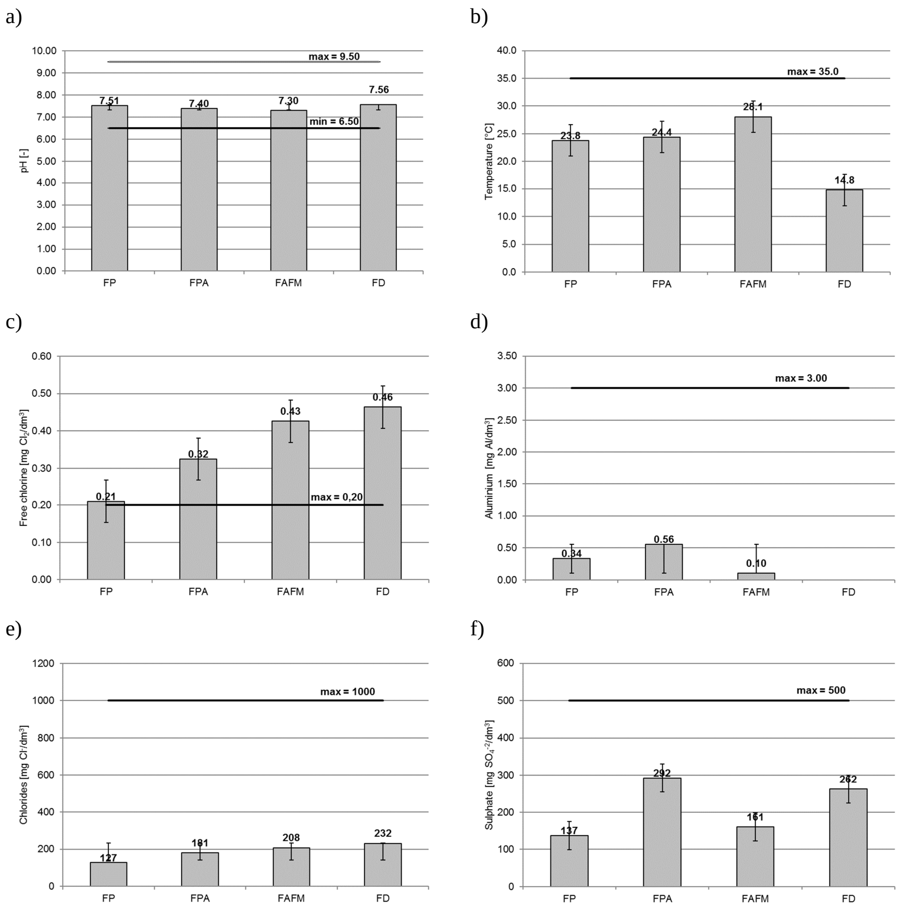

Fig. 3. Characteristic indicators of contaminations in washings with limit values according to [35-37]: a) pH, b) temperature, c) free chlorine, d) aluminium, e) chlorides, f) sulphate

In the third series of tests the general degree of bacteriological contamination of washings was also checked. The CFU (colony forming units) of microorganisms grown at 36 °C after 48 hours was determined (culture method on nutrient agar according to PN-EN ISO 6222: 2004 [38]).

In order to reduce the amount of suspensions in the samples of raw washings taken from FP, FPA and FD, they were subjected to 2 hour sedimentation in laboratory conditions in an Imhoff funnel.

In addition, the supernatant water was subjected to a 15-minute fast stirring process (jar test, laboratory coagulator, 200 rpm, Velp Scientifica) in order to aerate it and thus to reduce the free chlorine concentration.

Results and discussion

The analysis of the washings quality showed that among the basic indicators, the total nitrogen and total phosphorus (in the samples from FP and FPA - Fig. 2c and 2d), and TSS (in samples from FP, FPA and FD, Fig. 2e) did not meet the recommendations for sewage discharged into waters and soils [35-37]. The washings from the filter filled with the activated glass bed FAFM were of the best quality. Previous studies have shown that TSS are the main pollutants that prevent direct discharge of washings into the ground or watercourses [20, 21, 27]. Meanwhile, the average content of TSS in raw washings from the FAFM was below the limit value (35 mg/dm^3) and amounted to 23 mg/dm^3. The highest concentration of TSS was determined for FD (1263 mg/dm^3). It was a sample of washings from the filter with diatomaceous earth where the entire filtration layer that had been flushed on the filter fabrics was removed together with the washing stream. As a result of the sedimentation applied for FP, FPA and FD, the amount of TSS decreased by 41, 88 and 97 % respectively. In FP supernatant, the amount of TSS was still greater than the permissible value and amounted to 43 mg/dm^3. In order to remove such TSS, the washing process can be intensified, e.g. by preceding sedimentation with coagulation, applying membrane ultrafiltration system or a combination of these processes [22, 27, 39]. Sedimentation also caused a significant decrease in the content of nitrogen and total phosphorus, from 30 % in FP washings to approx. 85 % in FD.

Among the characteristic indicators, only the free chlorine concentration, regardless of the type of filter bed, was greater than the limit value (0.2 mg Cl_2/dm^3) for sewage introduced into waters or into the soil (Fig. 3c). The filter beds (FP, FPA and FAFM) were washed with chlorinated water from the balance tanks (0.3-0.6 mg Cl_2/dm^3). For this reason, the average free chlorine concentrations in the samples ranged from 0.21 mg Cl_2/dm^3 (FP) to 0.46 mg Cl_2/dm^3 (FD). After leaving the samples to stand for 120 minutes, the free chlorine concentration decreased by approx. 20 %, and after a further 15 minutes of intensive stirring of the supernatant by 48-54 %. As a result, 0.11 mg Cl_2/dm^3 (FP) to 0.22 mg Cl_2/dm^3 (FD) was determined in the supernatant water. Considering that the time between successive washes of the filter bed can be from 2 to 3 days, it can be assumed with high probability that the concentration of free chlorine in the washings discharged into the settling tank and left there for 2-4 hours, will be reduced to the required level (0.2 mg Cl_2/dm^3).

Despite the fact that for wastewater discharged into waters or soil it is not required to determine the CFU of mesophilic microorganisms, the result of such analysis gives a general view on the degree of bacteriological pollution (Fig. 4).

The highest number of CFU bacteria was determined in the sand-anthracite bed (FPA, $1.6 \cdot 10^5$ CFU/1 cm^3) and filters with diatomaceous earth (FD, $2.0 \cdot 10^5$ CFU/1 cm^3). Both are characterized by low oxidation potential, highly porous and cracked grain microstructure ensuring good absorption, and more favourable conditions for biofilm formation during the filtration cycle, compared to sand (FP) and glass (FAFM) bed [3, 8, 40].

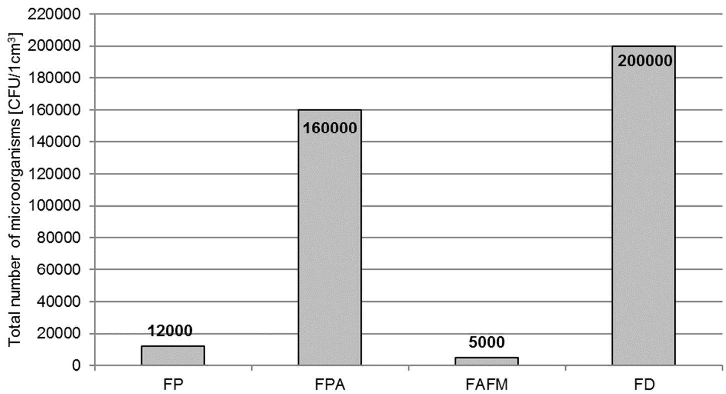

Fig. 4. Total number of microorganisms (in 36 °C after 48 h) in tested washings

Summary and conclusions

The occurring water deficits, the need to save water, and the rising prices of water and sewage have caused that the designers and owners of swimming pools are looking for new solutions in the field of water and sewage management. Washings from swimming pool systems, depending on the size of the swimming pool and the water treatment technology applied, may constitute from 20 % to even 70 % of the total wastewater volume. Nowadays, the plans for the construction of modern swimming pools are usually expected to contain solutions for heat recovery and recovery of supernatant from washings.

While deciding on the purposefulness and the manner in which the washings are to be managed, their volume and the degree of pollution should be taken into account. In spite of the different load of analysed pools, there was no definite relationship between it and the degree of contamination of washings. Despite this, both the quality and volume of washings depend on many factors, including the type of filtration system, type of bed, time of the filtration cycle, size and function of the swimming pool, number of swimmers. Therefore, for individual washing streams, individual research programs should be developed to assess the possibilities of their utilization.

The analysis of the filtration bed type influence on the quality and possibility of washings management through discharging them to the soil or to a watercourse, allowed to formulate the following conclusions:

- Direct drainage of the investigated washings into waters or soil was not possible due to too high contents of: total suspension solids (except for FAFM samples), free chlorine (in all samples), total nitrogen and total phosphorus (in FP and FPA samples).
- An attempt to improve the quality of washings by the use the sedimentation process and subsequent intensive stirring of the supernatant proved to be very effective. As a result of sedimentation, the content of TSS decreased from 41 % (FP) to 97 % (FD).
- In FP supernatant, after sedimentation, the number of TSS was still higher than the permissible 35 mg/dm^3 and was equal to 43 mg/dm^3. In order to remove such suspension solids, the sedimentation process should be preceded by coagulation, a membrane ultrafiltration system or a combination of these processes.

- Samples of the washings from the filter filled with the activated glass bed (FAFM) were characterized by the lowest content of total suspended solids (23 mg/dm^3) and the lowest number of mesophilic bacteria ($5 \cdot 10^3$ CFU/1cm^3).
- After leaving the washings to stand for 120 minutes, the free chlorine concentrations decreased by approx. 20 %, and after a further 15 minutes of intensive stirring of the supernatant by 48-54 %. As a result, the free chlorine content ranged from 0.11 mg Cl_2/dm^3 (FP) to 0.22 mg Cl_2/dm^3 (FD).

The Circular Economy Strategy published on December 2, 2015 by the European Commission contains the action plan for the Circular Economy in EU, which in one point draws particular attention to the need to reuse the water. One of the proposals considered in order to encourage the reuse of treated wastewater is to introduce the minimum legal requirements for the reuse of water. Undoubtedly, the above mentioned solutions proposed by the authors will be in line with these regulations.

Considering the principle of sustainable water and sewage management in facilities with a very high demand for water, which certainly include swimming pool facilities, it is worth considering the idea of authors introducing an obligatory water management system in an environmentally safe manner. These systems could be systems of "local" wastewater treatment stations ensuring the removal rate of contamination consistent with the legal requirements for conditions to be met when draining sewage into watercourse or into the ground. Worth considering are also water recovery systems with the possibility of its completely reuse. This solution requires the use of highly efficient modern membrane techniques or advanced oxidation processes in order to prepare water that meets the requirements of bath water quality.

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