NEW APPROACH TO EVALUATION OF EFFECTIVENESS OF "IN-BED" COAGULATION

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Received: 19.19.2009; Revised:19.12.2009; Accepted: 06.01.2010

Abstract

Direct filtration is one of the most popular process in water treatment. Results of various research show that this process is very effective in removal of turbidity and low concentration of dissolved organic matter. In a lot of technological guidelines for treatment processes required maximum turbidity in filtrate is 0.1 NTU. Such strict requirements result from the danger of water quality deterioration when it is supplied to consumers and on the other hand it ensures high effectiveness of removal of microbiological contamination. However, sometimes microorganism cells are noted in water after treatment. It means that there is an additional factor which negatively influences disinfection and causes deterioration of filtration effectiveness.

The objective of this study was to determine the influence of a coagulant type and a coagulant dose on direct filtration effectiveness. In the study made on a laboratory scale both hydrolyzing and pre-hydrolyzed coagulants were tested. The effectiveness of treatment was measured on the base of filtrate characteristics, including particles concentration.

Streszczenie

Proces filtracji jest jednym z podstawowych i najbardziej popularnych procesów stosowanych w uzdatnianiu wody. Jako proces samodzielny, realizowany wraz z koagulacją powierzchniową jest szczególnie wskazany do uzdatniania wód o niskiej mętności i niskiej zawartości naturalnej materii organicznej. Jego zastosowanie zapewnia uzyskanie wymaganego w wielu wytycznych progu mętności na poziomie 0.1 NTU, co pozwala znacznie zmniejszyć niebezpieczeństwo skażenia wody organizmami chorobotwórczymi.

W pracy przedstawiono wyniki badań nad wpływem rodzaju koagulantu stosowanego w koagulacji powierzchniowej oraz jego dawki na efektywność usuwania zawiesin o wielkości tożsamej z rozmiarami typowych zanieczyszczeń mikrobiologicznych.

Keywords: **Direct filtration; Coagulation; Particle removal; Particle counter.**

1. INTRODUCTION

Coagulation is the basic process in treatment of waters contaminated both with solid particles and substances in a dissolved form, too. So that to improve treatment effectiveness hydrolyzing coagulants, which are still the most popular coagulants are often replaced by pre-hydrolyzed coagulants. Pre-hydrolyzed coagulants are regarded to be more effective and smaller dose in comparison to hydrolyzing coagulants is required. The basic parameter involved to evaluate pre-hydrolyzed coagulants is basicity (OH/Al). However, a lot of literature data prove that there is no strict correlation between basicity and coagulation effectiveness. It seems that the analysis of aluminum species may be a reliable method. This information allows to determine the mechanisms of coagulation which decide about flocs structure and properties, including flocs strength, and hence treatment results. Microscopic techniques are carried out to get a direct measurement of floc strength by taking individual flocs and finding the force required to pull or compress a floc until breakage [1, 2]. This technique allows to understand the mechanisms of how and where flocs break may be expected and a floc rupture force may be directly measured to give floc strength.

Based on the research the relationship between the velocity gradient in the flocculating vessel and aggregate size for the stable floc size was determined by means of an empirical expression:

$$d = CG^{-\gamma} \tag{1}$$

where

d – the floc diameter (m),

C – the floc strength coefficient; dependent on a floc size measurement method,

G – the average velocity gradient (s^{-1}),

γ – the stable floc size exponent; dependent on mechanisms for the breakage of flocs under different shear conditions.

Floc strength may also be determined theoretically. In a theoretical method flocs are exposed to hydrodynamic stress from a controllable oscillatory mixer [3]. The vibration is converted into an energy input for the system. The average strength per unit area in the plane of rupture may be defined:

$$\sigma \approx \frac{\rho_w \varepsilon^{3/4} d^{1/3}}{\nu^{1/4}} \tag{2}$$

where

σ – the floc strength [N m-2],

ρ_w – the density of water [kg/m3],

ε – the energy dissipation at height of floc rupture [m^2 s^{-3}],

ν – kinematic viscosity [m^2 s^{-1}],

d – the floc diameter [m].

The lowest σ values were noted for flocs formed in treatment of coloured waters. At typical levels of G the strength of humic flocs was of 0.1 $N \cdot m^{-2}$ order. In comparison to humic flocs, the strength of flocs formed in flocculation of solid particles was much higher i.e. 1,0 $N \cdot m^{-2}$ [16]. The highest σ values (100-1000 $N \cdot m^{-2}$) were calculated for flocs formed in water treated with polymer flocculants [1]. The results of the research over the influence of a polymerization degree on flocs strength show that flocs formed in coagulation with pre-hydrolyzed coagulants are more resistant to breakage than those produced on the basis of hydrolyzing one [4] (Tab. 1., Fig. 1.).

The knowledge of flocs properties may allow to limit negative consequences of their breakage in a treatment system. It is important, for example, in in-bed coagulation where flocs are under stress. Results of various research show that this process is very effective in removal of turbidity and low concentration of dissolved organic matter. However, the condition to achieve expected water quality is determination of proper technological parameters. It concerns both parameters of filter bed, a coagulant type and a coag-

Table 1.
Characteristics of coagulants tested in “strength” tests

parameter	coagulant			
	Flokor 1ASW	Flokor 1A	PAX XL 19	ALS
density [g/mL]	1.245	1.275	1.350	1.59
pH	3.94	4.21	3.5	3.4
Al [% weight]	9.32	11.46	12.5	9.2
Cl [% weight]	5.53	5.69	9	0
Al/Cl	1.69	2.01	1.0	0
alkalinity [%]	85.69	77.81	85.0	0

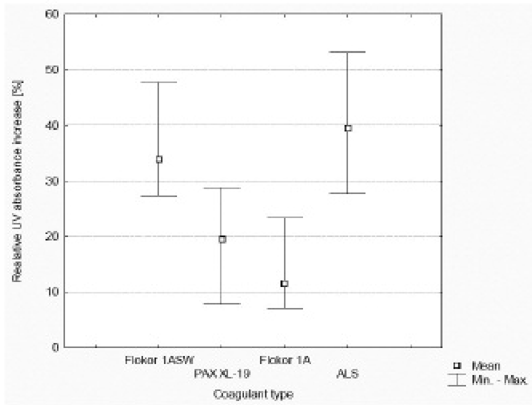

Figure 1.
Influence of coagulant type on water quality after flocs rupture

ulant dose. Besides physical-chemical parameters which are considered as a criterion of coagulation and filtration effectiveness, microbiological indicators are also taken into consideration. Such criterion especially concerns organisms e.g. Clostridium which are resistant to disinfectants typically used in WTPs. Clostridium are usually deactivated by strong chemical oxidants (ozone, chlorine dioxide) or UV lamps. The effectiveness of deactivation with UV lamps depends not only on the amount of dissolved organic matter, but the amount of suspended solids in filtrate, as well. When NOM concentration is high, the effectiveness of UV disinfection decreases because of the possibility that microorganisms cells may "hide" in "a shadow" of suspended particles. Therefore in the evaluation of filtrate quality in aspect of its preparation to UV disinfection this factor of water quality should be taken into consideration. It is usually presented as a required turbidity after rapid filtration. In a lot of technological guidelines for treatment processes requirements maximum turbidity in filtrate is 0.1 NTU [5]. According to most of literature data such a low turbidity level decreases the probability that these microorganisms cells or resting spore forms may appear in water supplied to a distribution system. However, so that to reduce that risk except for turbidity control particle size distribution should also be determined, because sometimes microorganism cells are noted in water after treatment in spite of the fact that the other water quality parameters (turbidity, UV absorbance, organic matter concentration) have almost become unchanged.

In this research the influence of a coagulant type and a coagulant dose on direct filtration effectiveness was examined. The study was made on a laboratory scale. The rapid filter model with sand bed was tested. Both hydrolyzed and pre-hydrolyzed coagulants were applied. The effectiveness of treatment was measured on the basis of filtrate quality parameters and particles concentration.

2. MATERIALS AND METHODS

2.1. Water sample

Water sample was prepared by mixing kaolin suspension and peat extract with dechlorinated and degassed tap water to get water sample of required turbidity (required particles concentration), colour and dissolved organic matter concentration. A stock solution of humic substances was obtained by extraction with 0,1 N sodium hydroxide. After 1 week ageing the clarified solution of humic acids was collected.

Raw water quality parameters ranged:

– particles concentration (0.5÷93 μm): 11800÷ 13050 mL^{-1},
– turbidity: 14÷16 FNU,
– colour: 149-150 mg Pt/L,
– total organic carbon (TOC): 3.3÷ 3.5 mg C/L,
– UV absorbance ($UV^{1\ cm}_{251\ nm}$): 011 ÷ 0.13.

2.2. Research scheme

Raw water of proper turbidity and colour was prepared in a 8 L-tank and it was continuously mixed with the use of a magnetic agitator so that to prevent suspension from sedimentation. In filtration cycles raw water was pumped by a peristaltic pump (PP1B-05A, ZALiMP) to a plexiglass model of a filter (Φ40 mm). Hydraulic load of the sand filter was 4.3 m^3/m^2h. Before the filter a coagulant was added. There were two cycles which consisted of 7 series Two aluminium coagulants: Flokor 1.2A (F1.2A) and aluminium sulphate (ALS) were tested. In each series various coagulant doses were applied before the filter. The doses of Flokor 1.2A were: 3, 6 and 9 mg/L (0.35; 0.71 and 1.06 mg Al/L). ALS was added in doses: 5, 10 and 15 mg/L (0.42; 0.83 and 1.25 mg Al/L). One of 7 series was a comparative one and no coagulant was added then. In each series 13-14 filtrate samples were collected and one sample of raw water. Samples after filtration were collected every 5 minutes since the 10^{th} minute of filtration cycle and then analyzed.

2.3. Reagents

Two coagulants were tested in the research: pre-hydrolyzed Flokor 1.2 A and aluminium sulphate. Flokor is a commercial name of aquatic solution of complex aluminium chlorohydroxide at a stated polymerization degree supersaturated with $Al(OH)_3$ which in this solution is in a metastable equilibrium. The characteristics of the coagulants are presented in Table 2. Both ALS and Flokor 1.2A were dosed as 2% solution.

Table 2.
Characteristics of tested coagulants

parameter	Flokor 1.2A	ALS
density [g/mL]	1.275	1.31
pH	4.21	2.4
Al [% weight]	11.46	4.2
Cl [% weight]	5.69	0
Al/Cl	2.01	0
alkalinity [%]	77.81	0

2.4. Range of analysis

Samples collected in testing were analyzed with Pastel UV so that to measure :

- Total organic carbon (TOC),
- UV absorbance at 251 nm ($UV_{251\,nm}^{1\,cm}$) and 263 nm ($UV_{263\,nm}^{1\,cm}$).

Colour and turbidity (spectrophotometr Linus – Mechery Nagel) and particles concentration in the range 0.5-93 μm (particles counter IPS-L of Kamika) were also measured. During filtration the increase of head loss in a filter bed was also determined.

3. RESULTS AND DISCUSSION

The results indicate that the effectiveness of direct filtration is dependent on a type of filter bed, but the crucial factors are a type and a dose of the coagulant. Figures 2a and 2b present relation between the amount of particles and a coagulant dose (2a – Flokor 1.2A, 2b – ALS) in water after treatment during the whole filtration cycle. The results of filtration without a coagulant addition are also presented there.

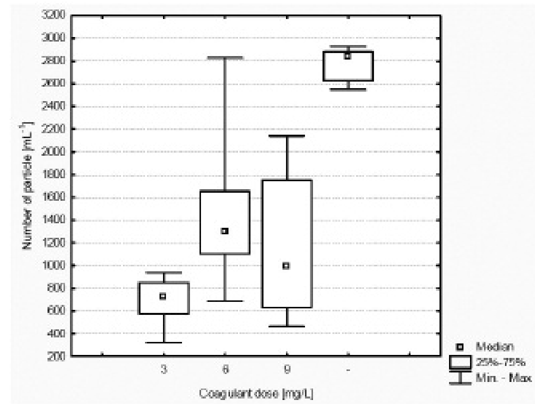

Figure 2a.
Relation between the amount of particles and a coagulant dose – Flokor 1.2

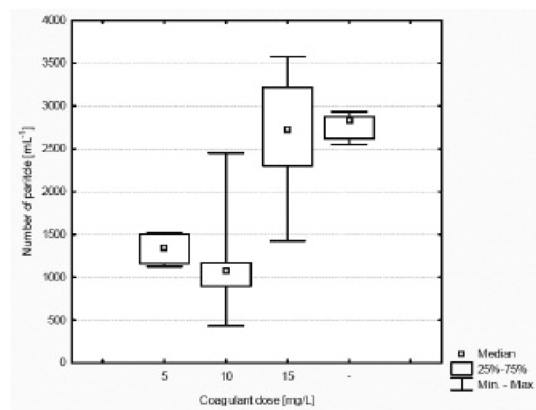

Figure 2b.
Relation between the amount of particles and a coagulant dose – ALS

The analysis of the results indicates that when the dose 3 mg/L of a pre-hydrolyzed coagulant (F1.2A) was applied the lowest value of particles concentration in filtrate was observed. When a dose 6 mg/L was applied filtrate quality deteriorated. Median of particles amount increased from 750 to 1300 particles/mL. The increase of F1.2A dose to 9 mg/L caused further deterioration of filtrate quality. Although median lowered to 1000, a distinct scatter of results was observed – centile 75% increased to 1750 particles in 1 mL. When direct filtration was run with ALS its lowest dose resulted in particles decrease to 1400 in 1 mL. In case of a dose 10 mg/L the effectiveness of direct filtration significantly improved. The amount of particles decreased to 1100 in 1 mL. In case of further increase of a dose to 15 mg/L effects were similar to the effects observed when Flokor 1.2 A was used. Particles concentration in filtrate increased (to about 3000 in 1 mL) and as a scatter of results, as well. After rapid filtration (without coagulation) particles concentration in filtrate was at much higher level (2600-2900 in 1 mL) than in filtrate collected after direct filtration at the optimum coagulant dose.

The effectiveness of particles removal may be determined by the equation [6]

$$d_{min} = C\,(d_{10} {*} V_f)^{0.5} \qquad (3)$$

where d_{min} = solid particles size stopped in a filter bed at the beginning of a filtration cycle [m]; C = empirical coefficient (0.0095); d_{10} = effective diameter of a filter bed; V_f = hydraulic load of a filter.

Figure 3 presents particle size distribution in filtrate.

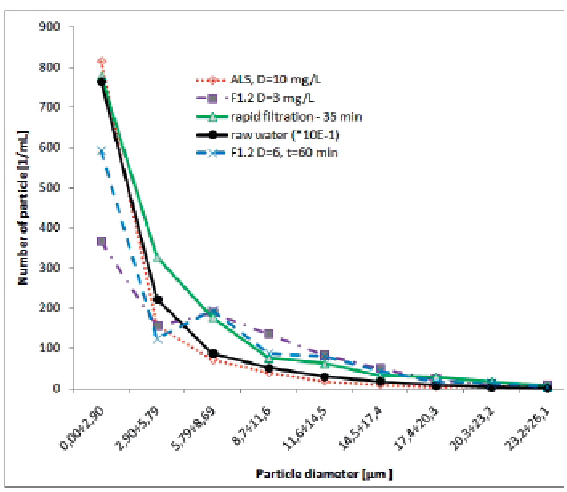

Figure 3.
Particles size distribution in filtrate

In comparison to samples without a coagulant addition and with ALS as a coagulant, direct filtration with Flokor resulted in the increase of particles concentration of a size ranged from 5 to 20 µm. It confirms the earlier research results that flocs produced on the basis of Flokor are more resistant to breakage than those formed on the basis of ALS. However, the mechanism of particles attachment in the filter bed depends not only on a size of particles of post-coagulation suspension, but it is also determined by the changes of the filter bed properties during its operation. The mechanism of suspension attachment is probably based on the theory of „an additional collector". The base of this theory was created by O'Melia i Ali [7] and then developed by others. According to this model particles are stopped not only by grains of a filter bed, but also by previously accumulated suspension. The model was verified experimentally and allowed to determine guidelines of effective operation of filters after backwashing [8].

The main condition to ensure proper operation of the process is that particles accumulated in pores of a filter bed are electrically neutral or their charge is opposite to a charge of particles of removed suspension. Therefore so that to determine a coagulant dose, it is very important, that this dose should result in full neutralization of charge of contaminants in raw water and on the other hand it should prevent from colloid restabilization when a colloid charge is the same as coagulant hydrolysis products. The suggested mechanism of suspension attachment is confirmed by changes of filtrate quality in a filter run. Fig. 4 presents changes of filtrate quality when Flokor 1.2 A at the dose 6 mg/L was applied. Since 50-60th minute of filtration cycle no changes of effectiveness were observed. It means that at that moment the lowest porosity of the bed was achieved and it determined its ability to post-coagulation particles removal. Higher bed loading did not improve the effectiveness of suspensions separation, it only decreased bed capacity until it was exhausted. After that moment deterioration of filtrate effects started. That phenomenon was also observed for ALS at the dose 15 mg/L. Such a high coagulant dose caused rapid increase of particles concentration in filtrate (from about 1400 to 3400 in 1 mL) since 60th minute of filtration run. In comparison to rapid filtration, direct filtration was characterized by faster lowering of active capacity of a filter bed. That is why it is very important to determine possibly the lowest coagulant dose which ensures assumed filtration effects and at the same time effective length of filtration cycle.

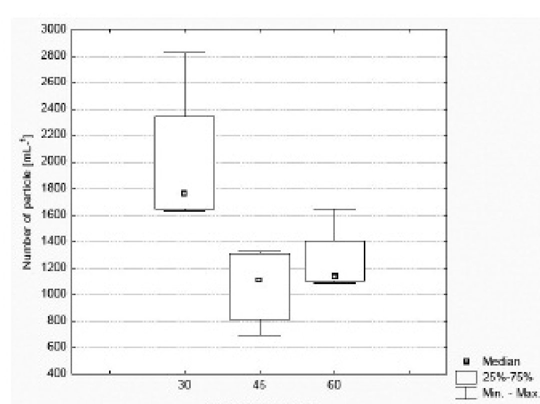

Figure 4.
Relation between particles concentration in filtrate and filtration time – Flokor 1.2 A, D= 6 mg/L

The analysis of filtrate quality changes shows that in comparison to particles removal the relationship between effectiveness of organic matter removal and coagulant doses is different.

Figure 5 presents the results of absorbance UV251 values removal in relation to a coagulant dose (Flokor 1.2A). moval in relation to a coagulant dose

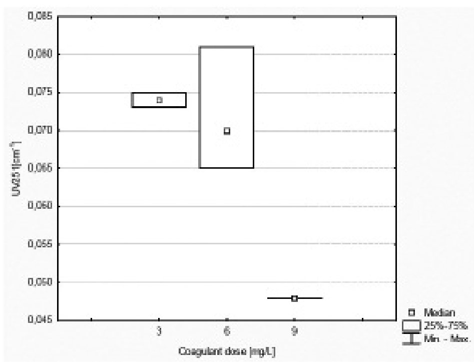

Figure 5.
Relation between absorbance UV251 values removal in relation to a coagulant dose – Flokor 1.2 A

In opposite to the relation observed for particles changes, values of absorbance decreased with the increase of a coagulant dose. The presented relationship confirms earlier observations that mechanisms which in direct filtration decide about turbidity removal and dissolved organic matter removal are different.

4. CONCLUSIONS

1. Flocs strength is a very important property for the effectiveness of water treatment.
2. Flocs produced in coagulation with the use of prehydrolyzed coagulants are more resistant to breakage in comparison to hydrolyzing coagulants.
3. The results of the research show that direct filtration is a very effective method of removal of turbidity and natural organic matter. In comparison to a hydrolyzing coagulant when a pre-hydrolyzed coagulant was applied better effects were noted and a lower dose was required then.
4. The process of direct filtration should be optimized on the basis of assumed criteria. If the aim of the process is particles removal, coagulant doses are lower than for decrease of natural organic matter concentration. When NOM removal is the treatment criterion, a required coagulant dose is much higher, because it is necessary to produce proper sorbent amount of required active area.

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