Magazine of Civil Engineering. 2022. 111(3). Article No. 11107

Magazine of Civil Engineering

ISSN 2712-8172

journal homepage: http://engstroy.spbstu.ru/

Research article

UDC 628.168

DOI: 10.34910/MCE.111.7

Regularities of rapid filter backwash water clarification in reagent-free mode

D.A. Butko ✉, ***M.S. Volodina***

Don State Technical University, Rostov-on-Don, Russia

✉ *den_111@mail.ru*

Keywords: spent filter backwash water, precipitation, mixing, treated water, water recycling, coagulation

Abstract. Discharge of rinsing water from fast filters into surface water bodies as a way of their disposal is unacceptable for environmental reasons, and in some countries it is prohibited by law. Research by Russian and foreign scientists is aimed at studying the schemes for returning wash water to the main stream using reagent methods of clarification, ultrafiltration or filtration on ceramic filters. In this paper, the processes of removing suspended solids from rinsing waters by means of reagent-free clarification under static conditions of sedimentation facilities are considered. In this case, the treated water was exposed to mixing with Camp's criterion obtained as a result of the analysis of the modes of movement in pipelines from the fast filter to the settling facility for the treatment of rinse water, as well as under conditions of additional mixing inside the treatment facilities either by stirrers or by aeroflocculation. Based on the analysis of the results of water clarification under the conditions of reagent-free sedimentation with stirring, mathematical dependences of the clarification effect on the Camp's criterion, water temperature, initial content of suspended solids and clarification time were obtained.

1. Introduction

The contamination of surface water bodies (streams and reservoirs) with untreated wastewater under conditions of low water levels in recent year's calls into question their use as a source of water supply to populated areas. An increase in the content of phytoplankton, an increase in the concentration of aluminum, iron and phosphates leads to the fact that water treatment plants cannot cope with the task of preparing water for drinking needs. The volume of untreated wastewater entering surface water bodies in the period from 2010 to 2017 constantly increased from 2503.45 to 3416.60 million m^3 [1]. In 2017, 188645 tons of suspended solids, 504.98 tons of aluminum (as Al^{3+}) and 2137.02 tons of iron (as Fe^{2+}, Fe^{3+} – all water-soluble forms) were discharged into the rivers, which are one of the main components of the pollution from the backwash water of water treatment plants.

For a long time, less attention was paid to the research of systems for reuse of backwash water from rapid filters and water after washing of sedimentation treatment facilities compared with the other aspects of the operation of water treatment plants for municipal and industrial purposes. In Russia (USSR), this problem was explored by V.G. Vodin, V.L. Draginsky [2], V.N. Kuznetsov [3], M.I. Urvantseva [4, 5], and others. In the foreign literature, the topic of backwash water treatment is reflected in the papers [6–10], which offer various technological schemes for treatment and directions for further use of these waters, as well as evaluating the possibility of returning them to the head of structures. The most widely presented results are on the introduction of ultrafiltration into backwash water return schemes [8, 11–14] or on special ceramic filters [14, 15], co-coagulation and ultrafiltration [16], as well as sedimentation in facilities with flotation [9]. The vast majority of publications on the topic of treatment of backwash water rapid filters

Butko, D.A., Volodina, M.S. Regularities of rapid filter backwash water clarification in reagent-free mode. Magazine of Civil Engineering. 2022. 111(3). Article No. 11107. DOI: 10.34910/MCE.111.7

describe the process of clarification using a coagulant and (or) flocculant [9, 11, 17–20]. A survey of water treatment plants in the United States, where the requirement to recirculate backwash water from rapid filters is legally enforced, showed that 30 % of plants did not provide any treatment of backwash water. Among the plants that were treating 54 % used precipitation, 20 % – equalization, 14 % – precipitation and equalization, and 11 % – other processes [21]. Lilia Mazari and Djamal Abdessemed [19], unlike the others, investigated the possibility of reagentless treatment of backwash water and its use as a coagulant for clarification of feed water in the main flow.

Sedimentation is the cheapest method of treatment, but it is also important to consider that in most cases, constructions for reuse of wash water are located far from filters (the source of waste wash water) and suspended particles are affected by hydrodynamic forces caused by the processes of stirring the volume of water when moving through the pipeline.

The stirring intensity is usually characterized by the root-mean-square (RMS) velocity gradient (G) (often referred to simply as the velocity gradient) or its product for the stirring time GT (Camp criterion).

Babenkov E.D. in [22] underlines that the minimum value of the RMS velocity gradient at which the destruction of flocs occurs is 100 s^{-1}, and that there is the following dependence between the shear stress τ_s in the mixed medium and the velocity gradient:

$$\tau_s = \frac{5}{2}\eta G, \tag{1}$$

where η is the dynamic viscosity of the medium, Pa·s.

In [22], the results of measurements of the shear stress of precipitation conducted by Baryshnikova and amounting to 1.5–6 mg/cm^2 (0.14715 – 0.5886 Pa) are presented, and this corresponds to a RMS velocity gradient from 58.84 s^{-1} to 235 s^{-1}. However, stirring has not only a negative effect on the suspended particles, but also contributes to the strengthening of the suspended solids and their intensive sedimentation. This paper presents the results of studies on the treatment of backwash water with different velocity gradients (with different Camp criteria) in construction for reuse of wash water.

The aim of the study is to obtain the dependencies of reagentless clarification of backwash water in constructions for their reuse. The following tasks contributed to the achievement of the research aim:

- determination of the magnitude of the RMS velocity gradient (G) and stirring time (T) during the movement of backwash water from rapid filters to their treatment facilities (construction for reuse of backwash water);
- experimental study of clarification processes in modelling the stirring in the pipeline and in the pipeline, followed by the implementation of the second stage of stirring in a flocculation basin, which is part of the construction for reuse of wash water;
- determination of influencing factors on the efficiency of clarification during the stirring and obtaining mathematical dependencies of the clarification effect when modelling stirring in the pipeline and in the pipeline, followed by processing in the flocculation basin.

2. Methods

2.1. Research objects

The research was conducted at the water treatment plants (WTP) of the Central water supply system of Rostov-on-Don, involving a two-stage reagent scheme of water treatment: sedimentation followed by rapid filtration using the reagent flocculant-coagulant FL 4540 (polyDADMAC). At WTP chlorination (with liquid chlorine or sodium hypochlorite) is used to decontaminate and improve the coagulation properties of the suspended solids. The rapid filters consist of a single-layer filter of 0.5–3.0 mm quartz sand with a coefficient of heterogeneity 1.39 or 1.47. The filters are backwashed with clarified water from the clean water tanks supplied by pumps at an estimated flow rate of 12 L/s·m^2. Currently, waste water is discharged through a system of beams in the Don river.

The quality of waste water after washing the rapid filters throughout the year is characterized by a concentration of suspended solids from 30 to 400 mg/dm^3 and color from 29 to 47 Pt-Co units, despite the fact that the feed Don water is characterized as "low-color" for most of the year. The indicators "Total alkalinity", "Active reaction of the medium (pH)", "Temperature" in the wastewater were equal to or slightly different from the values in the feed water. Total alkalinity was in the range from 1.8 to 4.9 mmol/dm^3, active reaction of the medium (pH) was in the range 6.6 – 8.21 with a predominance of values in the range 7.0 –

8.0, and temperature varied from 0.1 °C (winter) to 29.5 °C (summer). Residual concentrations of FL 4540 in the backwash water ranged from less than 0.02 to 0.23 mg/dm^3.

2.2. Description of flocculation process

The formula for calculating the RMS velocity gradient for a gravity pipeline takes the following form:

$$G = \sqrt{\frac{V^2 i g}{\nu}}, \tag{2}$$

where V is velocity of water movement in the pipeline, m/s; ν is kinematic viscosity of water, m^2/s; i is pipeline gradient.

Converting the formula (2) and involving the determination of the flow velocity by the Chezy equation, and the Chezy factor included in it by the formula of N.N. Pavlovsky, we obtain

$$G = \frac{i}{n}\sqrt{\frac{g\left(0.25d\right)^{\left(1+3\sqrt{n}\right)}}{\nu}}, \tag{3}$$

where n is friction factor in the Chezy formula, which depends on the pipeline material; d is internal diameter of the pipeline, m.

In fact, (3) is a linear dependence of the RMS velocity gradient on the pipeline gradient where the angle of the line to the abscissa axis depends on the diameter and material of the pipeline and the temperature of the transported water (Fig. 1). It should be noted that the value of friction factor should be taken from reference data, but not in a consistent manner, as is recommended for hydraulic calculations of gravity (n = 0.014) or pressure networks (n = 0.013). The design of gravity pipe from filters is usually performed on the calculated flow rate from simultaneous backwash of filters (one or two), while the geodetic gradient coincides with the hydraulic one. The conditions of a real multi-functioning pipelines for drainage of backwash water from rapid filters are characterized by a probabilistic distribution of costs values, coming in it and reduced pipeline capacity due to different factors that can incur an increase in hydraulic gradient and formation of pressure mode with a change in the hydrodynamic mode of motion.

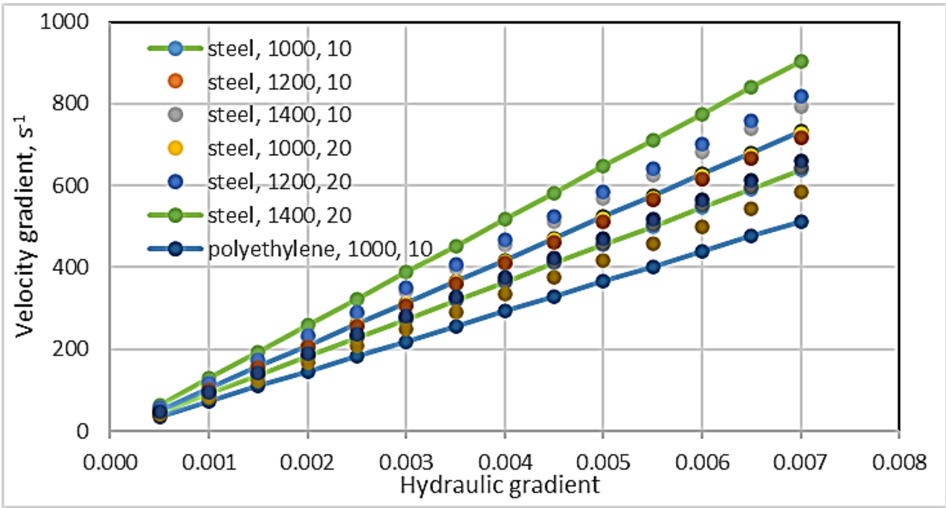

Figure 1. Changing of the RMS velocity gradient in a gravity pipeline at different hydraulic gradients.

The recommended value of the RMS velocity gradient for mixers is in the range of 60–300 s^{-1}. For flocculation basin they depend on the design and are in the range of 25–60 s^{-1} [12]. Analyzing the values of the RMS velocity gradient obtained by the formula (3) (Fig. 1), we can conclude that they are at the level recommended for stirrers or higher, which inevitably causes the impact on the suspended flocs leading to their destruction.

2.3. Studies on the sedimentation treatment of wash water

Based on this, two groups of experiments were conducted in the study: clarification of wash water by sedimentation after hydrodynamic impact with RMS velocity gradients characteristic of water movement through the pipeline and clarification by sedimentation after hydrodynamic impact with RMS velocity gradients characteristic of water movement through the pipeline plus stirring with RMS velocity gradients characteristic of flocculation basins. Water treatment was carried out under laboratory conditions with a sedimentation depth of 0.2, 0.26 and 0.32 m.

Processing of the obtained results was based on the previously derived dependence for sedimentation of backwash water impurities under static conditions [23] and theoretical conclusions from the theory of M.S. Smolukhovsky. Experimental work to determine the efficiency of water clarification under static conditions was carried out by the author in different periods of the year on the water that was taken directly from quartz sand rapid filters during their washing. The subsequent sedimentation tests were done in the laboratory. As a result of processing the results, an equation is obtained for determining the time of sedimentation for a given clarification effect:

$$Ef = 12.19 ln\left(th^{0.51}\right) - 0.93T + 0.019C_w, \quad (4)$$

where t is the clarification time of the backwash water to reach the given clarification effect, s; Ef is given clarification effect, %; C_w is initial concentration of suspended solids, mg/dm^3; T is the temperature of the backwash water in the process of clarification, °C; h is height of the sedimentation layer, m.

With 95 % confidence, equation (4) can be used in the quality range of backwash water with a suspended solids content from 50 to 400 mg/dm^3 and a water temperature from 5 to 25 °C.

Smolukhovsky's theory of coagulation states that the velocity (intensity) of coagulation depends on the radius of the sphere of attraction of the particle (approximately equal to two radii of the particle), the intensity of diffusion due to Brownian motion and the initial number of particles in the system. In this case, from the point of view of the efficiency of the collision of particles, the coagulation processes are classified into two types: rapid – each collision ends with the formation of an aggregate and slow – not all collisions end with the formation of aggregates.

For the case of rapid coagulation, the equation describing the change in the number of particles per unit of volume of the system at time τ has the form

$$n_\tau = \frac{n_0}{1 + 8\pi D r n_0 \tau} \quad \text{or} \quad n_\tau = \frac{n_0}{1 + \tau / T_{1/2}}, \quad (5)$$

where D is the diffusion coefficient of single particles; r is the radius of the particles; n_0 is initial concentration of particles; $T_{1/2}$ is coagulation time, during which the number of particles per unit volume of sol is halved.

The equation looks similar for slow coagulation with the introduction of the efficiency coefficient of convergence of particle collisions ψ:

$$n_\tau = \frac{n_0}{1 + \psi 8\pi D r n_0 \tau} \quad \text{or} \quad n_\tau = \frac{n_0}{1 + \psi \, \tau / T_{1/2}}. \quad (6)$$

In water treatment plants, perikinetic coagulation processes take place, although it is almost impossible to meet their "pure" form due to the constant movement of water and the presence of a minimal RMS velocity gradient. According to the data presented in the monograph [22], orthokinetic coagulation begins to prevail over perikinetic when the particle size is about 1 mcm. The backwash water contains the particles with sizes exceeding 1 mcm (see Fig. 2).

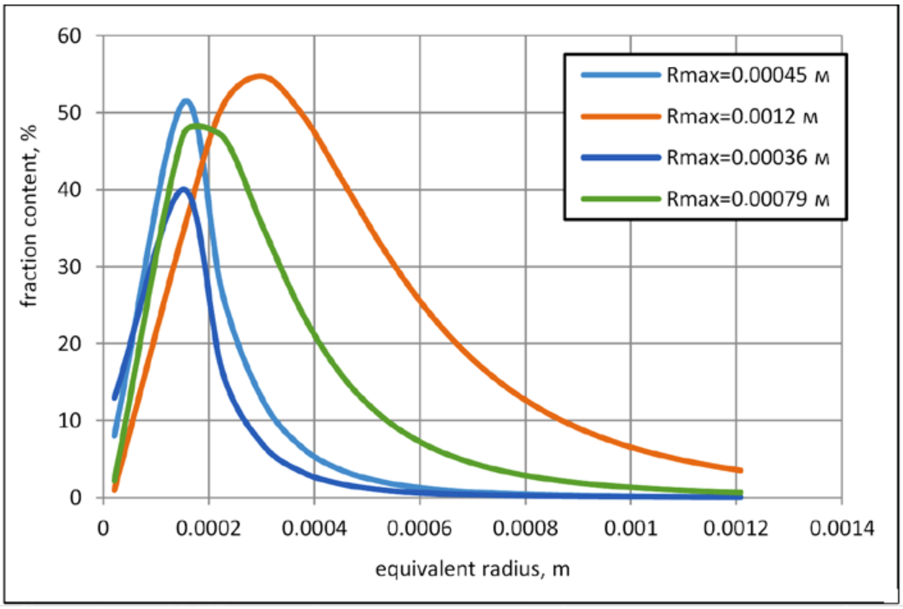

Figure 2. Derived curve of particle distribution in the backwash water obtained during clarification without mixing [22]. Rmax is maximum radius, m.

In the research of Harris [24], based on the theory of M.S. Smolukhovsky, the ratio for rapid coagulation was obtained

$$\frac{n_0}{n_\tau} = \exp\left(KEGn_0\tau\right), \tag{7}$$

where n_0 is the numerical concentration of particles not coagulated by time τ, K is coagulation constant; E is experimentally determined parameter; G is the RMS velocity gradient.

Based on this ratio and the analysis of a number of other papers on this topic, it may be inferred that the product of C_oGT (C_o is the volume concentration of particles in the system, GT is the Camp criterion) can be used as a parameter that characterizes the conditions for water treatment with hydrolyzing coagulants. Again, it is to be noted that the backwash water is actually a product of coagulation of particles held in the layer of the filter and it contains known concentrations of coagulant (flocculant) (according to our experiment the reagent content is 0.02–0.23 mg/l) used for water treatment. Therefore, the use of the C_oGT product is acceptable even without the introduction of additional reagents, and when exposed to the backwash water exclusively by stirring. The volume concentration can be replaced by a weight concentration according to the ratio [15] $C_o = {C_w}/{\gamma_0}$, where γ_0 is the amount of solid phase by mass per unit volume of unconsolidated sediment.

The effect of temperature on the process of perikinetic coagulation consists of changes in the intensity of Brownian motion of particles, which, for example, E.F. Kurgaev proposed to express by means of the agglomeration coefficient [25]:

$$\alpha_t = 0.5 + 0.025T. \tag{8}$$

At the same time, a change in temperature entails a change in the viscosity of the medium, and hence the entire heterophase system, which affects both the particle sedimentation velocity and the stirring parameters, in particular, the value of the velocity gradient. Generalizing, we get:

$$Ef = f\left(C_w, GT, t, T, h\right), \tag{9}$$

where t is the sedimentation time, s; h is depth of the water layer, m.

While investigating natural water treatment of the river Don using WPK-402 (analog of PolyDADMAC) the staff of the Department of water supply and drainage of RISI (Rostov Civil Engineering Institute) obtained the following equation

$$Ef = const - e^{-kG}. \tag{10}$$

The aforementioned dependencies are involved in obtaining an equation for processing experimental results. The experimental results were processed using MS Excel (Microsoft Corporation) and STATISTICA (StatSoft Inc.) software products. The obtained dependences were checked for the reliability of the approximation using the value of the Pearson correlation squared.

3. Results and Discussion

The first group of experiments was conducted by clarification of wash water by sedimentation after hydrodynamic impact with RMS velocity gradients characteristic of water movement through the pipeline. The effect of the velocity gradient applied to backwash water on the subsequent process of water clarification by sedimentation under laboratory conditions at different sedimentation layer depths is shown in the diagrams (Fig. 3, 4). These results presented on these figures are obtained under the clarification of river water during the research. The results of experiments (measurements) were processed using MS Excel with the construction of a trend line using a polynomial equation.

At low values of the velocity gradient (with the Camp criterion GT from 1200 to 5100), the effect of clarification of backwash water slightly differs from the values obtained in experiments without stirring [23] and does not depend on the value of the Camp criterion (Fig. 3), even if the clarification time is relatively short. Considering the abovementioned results conducted by Baryshnikova [22], under such conditions, the destruction of flocs does not seem to occur, since shear stresses do not reach critical values and the coagulation process occurs with undisturbed partially destabilized suspended particles. It is also important to consider that the suspended solids in the backwash water has a zeta potential closer to the isoelectric point than in the reagentless feed water. Thus, these results prove this idea. This is indicated by No-Suk Parka and his colleagues [26], whose studies show a decrease (in modulus) of the zeta potential of the suspended solids from (–19) mV in the feed water to (–1.4) mV in the sediments of sedimentation tanks and in the backwash water up to (–4.3) mV.

Increasing GT values in the range from 10000 to 71000, the changes in the clarification effect is slightly increasing. This should be considered a feature for waters with reagent WPK-402 (or PolyDADMAC analog) for feed water treatment. This means that this flocculant was used for clarification river water during the research period (Fig. 4). Previously performed by other soviet scientists studies on river water clarification using WPK-402 as a reagent showed the need for long-term and (or) intensive stirring in order to intensify flocculation and improve the sedimentation properties of the suspended solids in sedimentation tanks.

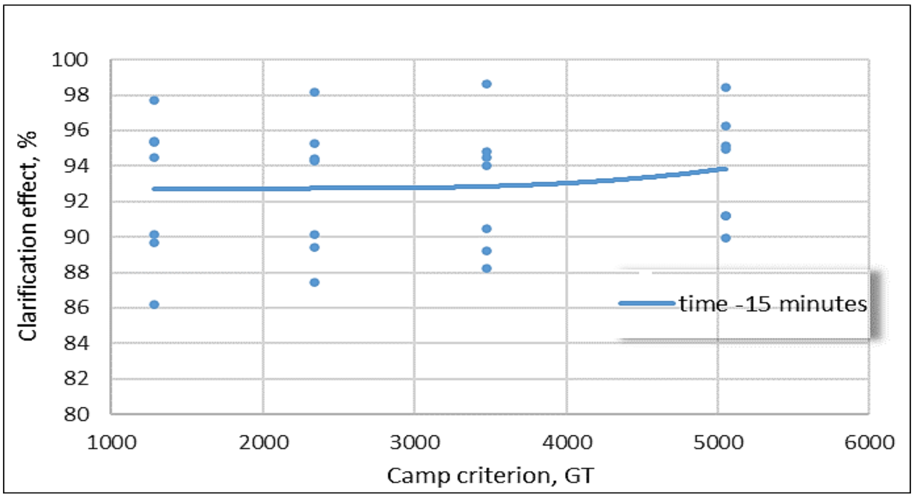

Figure 3. Change in the clarification effect depending on the GT values in the range of 1000÷5000 at the depth of the sedimentation layer of 0.32 m (stirring with a constant RMS velocity gradient).

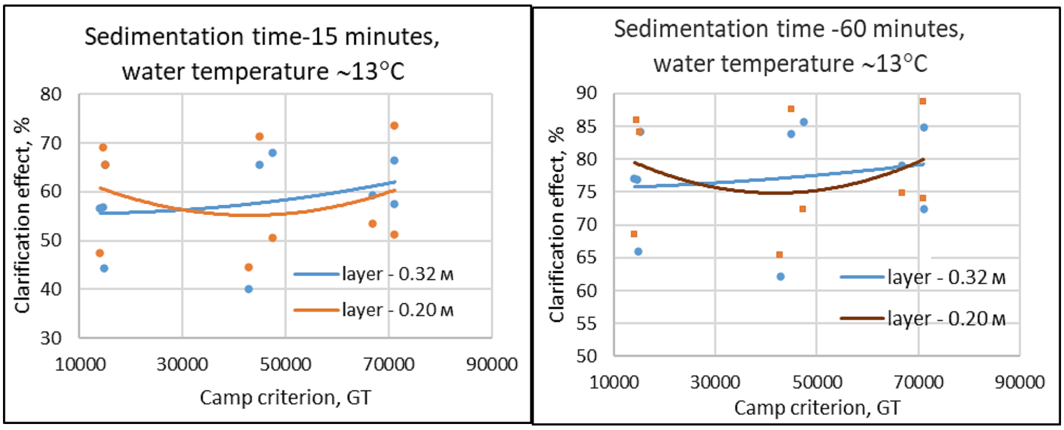

Figure 4. Change in the clarification effect depending on the GT values in the range of 10000÷71000 at the depth of the sedimentation layer of 0.20 and 0.32 m (stirring with a constant RMS velocity gradient).

The Fig. 5 presents the second group of experiments.The study of the treatment of backwash water with a variable velocity gradient was carried out according to the scheme: the first stage – rapid stirring while moving in the pipeline, the second stage – stirring in the flocculation basin. The results obtained in this experiment were different from the above. On the diagrams (Fig. 5) for the sedimentation time of 15 minutes and 60 minutes a minimum at GT value about 60000 is clearly expressed on the approximating curve. Comparison of the approximating curves in Fig. 4 and 5 shows that with the same sedimentation time, the use of a flocculation basin in a reuse constructions provides the best effect in the ranges of GT 20000÷40000 and 82000÷90000. If the water is stirred with a GT of 40000 to 82000 when moving through the pipeline, the use of flocculation basin reduces the efficiency of backwash water clarification.

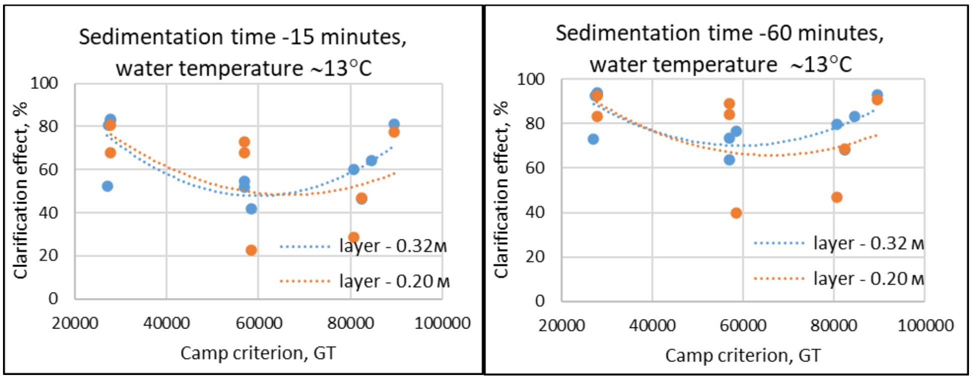

Figure 5. Change in the clarification effect when modelling the movement of water through a pipeline followed by stirring in the flocculation basin (stirring with a variable RMS velocity gradient).

Thanks to statistical processing of the results of experimental data obtained in laboratory conditions when modelling the movement of water through the pipeline to construction for reuse of backwash water we have gained an approximating dependence

$$Ef = 100 - t^{0.22} exp\left(\frac{t^{0.032}}{h^{0.004}}\left(0.04T - 5.97\right) - \left(C_w GT\right)^{0.007}\left(0.46ln\left(T\right) + 0.2\right) + 10.07\right), \quad (11)$$

where Ef is the clarification effect, %; t is the clarification time (precipitation), s; C_w is initial concentration of suspended substances in water, mg/dm^3; T is water temperature, °C; GT is Camp criterion.

Stirring with velocity gradients characteristic of flocculation basins for a sufficient duration in the aforementioned intervals of the Camp criterion will contribute to the recovery of flocs without the introduction of additional doses of reagents. As a result of experiments with modelling water stirring in a pipeline followed by stirring in a construction with a lower gradient, the dependence is obtained

$$Ef = 100 - exp\left(\left(\frac{0.17}{T^{0.03}}\right)^3 \frac{0.01GT + 13085}{(C_w h)^{0.02}}\left(\frac{0.23}{t^{0.03}} - 0.01\right) - 6.53\right). \quad (12)$$

Thus, using the obtained approximating equations, it is possible to calculate the clarification effect for various stirring options, both without the use of flocculation basins, and with flocculation basins built into constructions (or devices that restore the sedimentation properties of the suspended solids after the flocs are destroyed when moving through pipelines).

Based on the abovementioned results the most efficient construction for stirring with different velocity gradient should be mechanical stirring devices or air stirring tanks (airflocculators).

4. Conclusion

In order to organize reuse of backwash water from rapid filters on drinking water treatment plant the reagentless clarification of such water was studied. The research was conducted at the water treatment plant of the Central water supply system of Rostov-on-Don. Theoretical investigations and experimental results lead to the following conclusions.

1. The clarification of backwash water of water supply system rapid filters should be conducted considering the water removal from filters to the sedimentation facilities. When wash water moves through pipelines from rapid filters to reuse constructions, suspended particles are exposed to shear stresses caused by water stirring under certain conditions that exceed the limit values. Thus, at RMS velocity gradients from 50 to 800 s^{-1}, the formed flocs are destroyed and the clarification efficiency is reduced.

2. The authors studied the improving the flocculation properties of suspended particles of backwash water with extra stirring before the sedimentation in laboratories. Experimental studies have made it possible to determine the ranges of the Camp GT criterion, in which it is justified to use additional stirring in the flocculating chambers in reuse constructions (20.000 ÷ 40.000 and 82.000 ÷ 90.000) and the GT ranges in which additional stirring is impractical (from 40.000 to 82.000). Based on the designs of reuse constructions, which are most often used in natural water treatment facilities, we consider it acceptable to embed flocculation basin with mechanical stirring devices or air stirring tanks (airflocculators).

3. Based on the theory of coagulation by M.S. Smolukhovsky and following papers developing its concept, factors affecting the efficiency of clarification in sedimentation constructions are identified and mathematical dependences of the clarification effect are obtained when stirring in the pipeline and in the pipeline with followed by processing in the flocculation basin. The use of the presented mathematical dependencies will make it possible to regulate the effect of backwash water clarification in construction for reuse of wash water at the design stage or during operation, optimizing it in terms of later use of clarified water.

References

1. Gosudarstvenny doklad «O sostoyanii i ob ochrane okrugayuschei sredy Rossiiskoy federacii v 2017 godu [State report "on the state and protection of the environment in the Russian Federation in 2017"]. [Online] URL: https://gosdoklad-ecology.ru/2017/ RU (reference date: 31.08.2020) (rus)
2. Draginsky, V.L., Alekseeva, L.P. Obrabotka promywnych wod filtrow wodoochistnych stanzii [Treatment of wash water from water treatment facilities filters]. Water Supply and Sanitary Engineering. 2005. 8. Pp. 25–32. (rus)
3. Kuznesow, W.N. Woswrat promywnoy wody i obrabotka osadkow Zapadnoi filtrowalnoy stancii Ekaterinburga [Return of filter washings and sludge treatment at the western filtration plant of Ekaterinburg]. Water Supply and Sanitary Engineering. 2015. 11. Pp. 28–32. (rus)
4. Urvantseva, M.I. Obrabotka promywnych wod i osadkow wodoprowodnych stahcii, raspologennych na istochnikach maloy i sredney mutnosti i cwetnosti [Treatment of wash water and precipitation from water supply stations located on sources of low and medium turbidity and color]: awtoreferat dis. cand.techn.nauk. [Online] URL: https://static.freereferats.ru/_avtorefe-rats/01005111383.pdf RU (reference date: 31.08.2020). (rus)
5. Urvantseva, M.I., Artemenok, N.D. Compleksnaya ocenka processow ochistky promywnych wod wodoprowodnich stanciy v zapadnoy sibiri [Complex assessment of processes of wash water treatment at water supply stations of the western Siberia]. Water Supply and Sanitary Engineering. 2011. 2. Pp. 25a–29. (rus)
6. Vigneswaran, S., Boonthanon, S., Prasanthi, H. Filter backwash water recycling using crossflow microfiltration. Desalination. 1996. 106(1–3). Pp. 31–38. DOI: 10.1016/S0011-9164(96)00089-6
7. Raj, C.B.C., Kwong, T.E., Cheng, W.W., Fong, L.M., Tiong, S.H., Klose, P.S. Wash water in waterworks: contaminants and process options for reclamation. Journal of Environmental Sciences. 2008. 20(11). Pp. 1300–1305. DOI: 10.1016/S1001-0742(08)62225-1. URL: http://dx.doi.org/10.1016/S1001-0742(08)62225-1
8. Brügger, A. Reuse of filter backwash water using ultrafiltration technology. Filtration and Separation. 2000. 37(1). Pp. 22–26. DOI: 10.1016/S0015-1882(00)87607-7
9. Bourgeois, J.C., Walsh, M.E., Gagnon, G.A. Treatment of drinking water residuals: Comparing sedimentation and dissolved air flotation performance with optimal cation ratios. Water Research. 2004. 38(5). Pp. 1173–1182. DOI: 10.1016/j.wat-res.2003.11.018

10. Hou, B., Lin, T., Chen, W. Evaluation of a drinking water treatment process involving directly recycling filter backwash water using physico-chemical analysis and toxicity assay. RSC Advances. 2016. 6(80). Pp. 76922–76932. DOI: 10.1039/c6ra14912j. URL: http://dx.doi.org/10.1039/C6RA14912J
11. Ebrahimi, A., Amin, M.M., Pourzamani, H., Hajizadeh, Y., Mahvi, A.H., Mahdavi, M., Rad, M.H.R. Hybrid coagulation-UF processes for spent filter backwash water treatment: a comparison studies for PAFCl and FeCl3 as a pre-treatment. Environmental Monitoring and Assessment. 2017. 189(8). DOI: 10.1007/s10661-017-6091-3
12. Reissmann, F.G., Uhl, W. Ultrafiltration for the reuse of spent filter backwash water from drinking water treatment. Desalination. 2006. 198(1–3). Pp. 225–235. DOI: 10.1016/j.desal.2006.03.517
13. Zhang, J., Lin, T., Chen, W. Micro-flocculation/sedimentation and ozonation for controlling ultrafiltration membrane fouling in recycling of activated carbon filter backwash water. Chemical Engineering Journal. 2017. 325. Pp. 160–168. DOI: 10.1016/j.cej.2017.05.077
14. Sardari, R., Osouleddini, N. Data in Brief The data on the removal of turbidity and biological agents in spent fi lter backwash by bed ceramic in water treatment process. Data in Brief. 2018. Pp. 2–6. DOI: 10.1016/j.dib.2018.06.037.
15. Shafiquzzaman, M., Al-Mahmud, A., Al-Saleem, S., Haider, H. Application of a low cost ceramic filter for recycling sand filter backwash water. Water (Switzerland). 2018. 10(2). DOI: 10.3390/w10020150
16. Mahdavi, M., Amin, M.M., Mahvi, A.H., Pourzamani, H., Ebrahimi, A. Metals, heavy metals and microorganism removal from spent filter backwash water by hybrid coagulation-uf processes. Journal of Water Reuse and Desalination. 2018. 8(2). Pp. 225–233. DOI: 10.2166/wrd.2017.148
17. Skolubovich, Y., Voytov, E., Skolubovich, A., Ilyina, L. Cleaning and reusing backwash water of water treatment plants. IOP Conference Series: Earth and Environmental Science. 2017. 90(1). DOI: 10.1088/1755-1315/90/1/012035
18. Kachalova, G.S. Modern coagulants and flocculants in the cleaning of washing waters of water treatment plants. IOP Conference Series: Materials Science and Engineering. 2018. 451(1). DOI: 10.1088/1757-899X/451/1/012226
19. Mazari, L., Abdessemed, D. Feasibility of Reuse Filter Backwash Water as Primary/Aid Coagulant in Coagulation–Sedimentation Process for Tertiary Wastewater Treatment. Arabian Journal for Science and Engineering. 2020. (June). DOI: 10.1007/s13369-020-04597-1.
20. Bourgeois, J.C., Walsh, M.E., Gagnon, G.A. Comparison of process options for treatment of water treatment residual streams. 2005. 4(January).
21. Arora, H., Giovanni, G.D.I., Lechevallier, M. Spent filter backwash water contaminants and treatment strategies. Journal AWWA. 2001. (May) (90832). DOI: 10.1002/j.1551-8833.2001.tb09211.x
22. Babenkow, E.D. Ochistka wody coagulyantami [Water treatment with coagulants]. Moskwa: Nauka, 1977. 356 p.
23. Butko, D.A. Promywnye wody skorych filtrow i ich powtornoe ispolzovanie [Fast filter wash water and reuse]. Rostow-na-Donu: RGSU. 2009. 122 p. (rus)
24. Harris, H.F., Kaufman, W.J., Krone, R.B. Orthokinect flocculation in water purification. J. Sanit. Eng. Div. (1966) Proc. ASCE 92 (SA6) 95-111. (rus)
25. Kurgaew, E.F. Oswetliteli wody [Water clarifiers]. Moskwa: Stroyisdat, 1977. 192 p. (rus)
26. Park, N.S., Kang, M.S., Jeong, W., Kim, J.O. Experimental determination of the characteristics of physico-chemical particles in air-scouring-membrane (microfiltration) backwash water produced during drinking water treatment. Chemical Engineering Research and Design. 2015. 94(October). Pp. 714–720. DOI: 10.1016/j.cherd.2014.10.012. (rus)

Information about authors:

Denis Butko, *PhD inTechnical Science*
ORCID: https://orcid.org/0000-0002-3792-7198
E-mail: den_111@mail.ru

Marina Volodina, *PhD in Philology*
ORCID: https://orcid.org/0000-0002-3853-2796
E-mail: mclavender1984@gmail.com

Received 13.10.2020. Approved after reviewing 12.07.2021. Accepted 13.07.2021.