Clarifier with built-in prefilter for water treatment

Zhanna Govorova[1], *Uliana* Kanivets[1*], and *Anastasia* Govorova[1]

[1]Moscow State University of Civil Engineering, 26, Yaroslavskoe Shosse, Moscow, 129337, Russia

Abstract. Natural water sources in the Northern, Northwestern and other regions of Russia are characterized by increased color, the presence of organic pollutants of natural and anthropogenic origin, as well as often high bacterial contamination. The use in practice of a technological scheme with preliminary chlorination and purification of low-turbid colored waters in clarifiers with suspended sediment and filters during periods of low alkalinity and temperature is not always justified. The consequence is a decrease in the barrier role of structures for organochlorine contamination and residual aluminum. The intensification of the water purification process in clarifiers is achieved by adjusting the reagent treatment mode, artificially increasing the turbidity index of water, the device of flocculation chambers, thin-layer modules or sludge recirculators in the working chamber, as well as the device of a prefilter with floating loading. The description of an experimental stand simulating the operation of an industrial water supply station, parameters and operating modes of a clarifier model with a built-in prefilter is given. The experiments were carried out in different periods of the year on real water with permanganate oxidizability up to 22.3 mg/l, chromaticity – 55-81 degrees, turbidity – 2.8-25.6 FTU, pH from 7.52 to 8.04 and alkalinity 1.5-4.6 mg-eq/L. The results of the study showed that the device of a prefilter with a layer thickness of no more than 0.5 m from polystyrene granules at filtration rates from 1.2 to 1.7 m / h reduces turbidity to 7.9 FTU, chromaticity to 14.5 deg., and permanganate oxidizability by 5.4 mg/l, compared with a single clarifier. At the same time, the load on the second stage structures is reduced and the normative value of residual aluminum in drinking water is ensured.load on the second stage structures is reduced and the normative value of residual aluminum in drinking water is ensured.

1 Introduction

Providing the population with high-quality drinking water in the modern world is a priority.

The physico-chemical composition of natural surface waters of rivers, lakes, reservoirs differs in diversity and variability depending on various factors. The natural waters of the Northern and Northwestern regions of Russia, Siberia and the Far East are characterized by increased color, the presence of organic pollutants of natural and anthropogenic origin, as well as often high bacterial contamination. Table 1 shows, as an example, the physico-chemical and bacteriological composition of the Vologda River water by major pollutants

* Corresponding author: u.rudich@mail.ru

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over a 20-year observation period [1].

The constant deterioration of the quality of natural water and the tightening of sanitary and hygienic requirements during the long-term operation of existing water treatment complexes using chlorination at the preliminary stage leads to a decrease in the barrier role in preventing the entry of organochlorine compounds into drinking water [2-8]. The use of aluminum sulfate in the cold periods of the year is ineffective [9]. In addition, the insufficiently justified use of clarifiers with suspended sediment on such water sources as part of the technological scheme leads to unsatisfactory coagulation, an increase in the load on filters and does not always allow to ensure the required drinking water quality standards for residual aluminum with a low content of suspended substances during periods of low pH, alkalinity and water temperature [10].

Table 1. Water quality indicators in different years.

Indicators	1990-2000	2008-2022
Turbidity, mg / l (FTU)	19.6-0.6	(14.9-0.28)
Color, degrees platinum-cobalt scale	140-13	201-12
Permanganate oxidizability, mg / l	25.6-1.57	32-3.8
Ammonium salt, mg / l	1.38-0.01	0,97-0.02
COD, mgO_2 / l	63.6-14.79	83-8
BOD, mgO_2/ l	7.7-0.4	6,1-0,34
TMC, CFU/ml	1000-5	65600-20
Petroleum products, mg / l	0,45-0.001	0.095-0.002
Phenol, mg / l	7.07-0,0	0,27-0.001
Synthetic surfactants, mg / l	3.15-0.54	0.292-0.025

Note: the minimum and maximum values of the indicator are indicated.

Two main types of clarifiers have been used in domestic and foreign practice of water purification. They differ in the method of forming a layer of suspended sediment and its contact with the newly incoming water for cleaning [10]. In the first of them, the contact of water with sediment is achieved when it moves from bottom to top through the sediment layer at a speed υ_{up}, mm/s large enough to maintain the sediment in suspension, but less than the speed of free deposition of flakes in still water u, mm/s. In the second type of clarifiers, there is a special hydraulic or mechanical flocculation chamber in which water is continuously mixed with the sediment formed. In the first of them, the contact of water with sediment is achieved when it moves from bottom to top through the sediment layer at a speed large enough to maintain the sediment in suspension, but less than the speed of free deposition of flakes in still water. In the second type of clarifiers, there is a special hydraulic or mechanical flocculation chamber in which water is continuously mixed with the sediment formed. After that, the suspension enters the clarification zone, in which large flakes formed in the flocculation chamber are isolated from it. For hydraulic mixing of water with sediment and increasing the duration of the flocculation process, diffusers are arranged in the lower part of the clarifiers.

The disadvantages of corridor-type clarifiers and the absence of separate flocculation chambers in front of them are: high sensitivity of the suspended sediment layer to changes in the hydraulic load on water; the negative effect of changes in water temperature during one or several hours on the structural characteristics of the suspended layer and the stability of its operation; the complexity of controlling hydrodynamic processes in the zones of formation of the sediment layer and clarification of working chambers and in the sedimentation compactor with continuous removal of excess sediment.

The experience of long-term operation and adjustment of the technological process of purification of low-turbid colored waters on clarifiers shows that their use requires

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increased attention to the reagent pretreatment of water with oxidants, coagulants and flocculants, to the modes of their mixing and flocculation. As a result of water treatment with large doses of coagulant, the resulting sediment has a significantly lower density relative to natural water impurities. This, together with the carbon dioxide released during the reagent treatment, does not allow to increase the permissible speed of the upward flow of water in the clarification zone, even with the use of sludge recirculation over 0.5-0.6 mm/s.

The intensification of the work of clarifiers is currently achieved by the technological techniques discussed below [11-14].

In the entrance block of treatment facilities, which contain corridor-type clarifiers, or before each clarifier of this type, it is recommended to use a complex method for improving the properties of the suspension, which provides for rapid mixing of the coagulant with water with simultaneous blowing off of CO_2; intensive mixing, which prevents the formation of a loose structured system saturated with water and carbon dioxide at the initial moment of coagulation; removal of free carbon dioxide and the pH shift of the medium towards higher pH values. All these operations can be carried out in a recirculator-aerator equipped with an ejector device and a finely dispersed air distribution system.

A widespread method of intensifying water purification processes in the suspended sediment layer is to ensure sediment recirculation in the clarification corridors using small-sized devices characterized by about 4-5 times less metal consumption compared to other designs. Such recirculators allow to increase the productivity of structures while maintaining the stability of the suspended layer.

To intensify the processes of water purification directly in the suspended sediment layer, the method of recirculation of most of the sediment in the clarifier corridors themselves is also used.

The efficiency of water purification in the suspended layer is also enhanced by design improvements of individual elements of clarifiers aimed at ensuring the uniformity of mixing of newly incoming water with the working layers of suspended sediment at the lower boundaries of its formation and the removal of excess sediment into sedimentation tanks.

In special designs of clarifiers-pulsators, "accelerators", etc. several zones (primary and secondary) of mixing and flocculation are arranged, combined with zones of placement of the suspended layer and the sedimentary compactor.

According to some researchers, the device in the zone of functioning of the suspended layer of thin-layer modules, where a small amount of the largest and densest flakes removed from the sediment zone partially precipitates, allows increasing the specific load on the structure up to 30%. Thin-layer settling blocks are made of tubular or lamellar polymer materials and corrosion-resistant steel grades, which ensures a long service life. Thin-layer elements are also used for compaction of sediment in sediment compactors. The equipment of sediment compactors with thin-layer blocks creates good hydrodynamic conditions for gravitational compaction of sediment, which makes it possible to increase the period of its accumulation and reduce the amount of water discharged with it.

The creation of conditions for the formation of denser and heavier flakes in the suspended sediment layer can be achieved by the device in the working chambers of the clarifier of a combined suspended layer consisting of flakes of coagulated suspended particles and fine-grained material with inert or active sorption loading. In such clarifiers, the layer functions with a complete expansion of the granular material.

A type of creation of combined clarifiers with layers of dense granular layer and suspended sediment are clarifier reactors. According to the principle of operation, they are similar to the operation of a contact flocculation chamber with a partially dense layer of fine-grained loading (up to 80-90%) and partially with its fluidized upper part (10-12%).

The disadvantage of such structures is the limitation of the useful area, the conditions for washing the load without taking it outside the body, the lack of a system for continuous removal of excess sediment from the clarification zones.

An important technological parameter during operation is the low hydraulic resistance of the suspended layer itself and the water pressure above it. The increase in the magnitude of pressure losses in the suspended sediment layer in the operating mode does not exceed 0.5-2 cm / h [10]. With fragile light flakes of sediment, it is difficult only due to the device of thin-layer modules with low resistance to prevent the removal of part of the sediment into the water clarification zone. However, such resistance, which will contribute to a greater concentration of sediment in the area of the bypass windows, is easy to create using a device in the upper part of the clarifier floating filter layer consisting of light polystyrene granules.

Thus, increasing the efficiency of water purification at existing facilities on the basis of an integrated approach to solving the task by: the use of chlorammonization, reagent pretreatment of water with the selection of more optimal types of coagulants and flocculants, improving the design of the clarifier by placing a prefilter of large-granule floating loading in the clarification zone in order to bring its quality up to regulatory requirements [15, 16] is relevant and requires experimental verification and study.

2 Materials and methods

The results of experimental studies of the process of chlorammonization and coagulation of treated water are given in our early works [7, 17]. At this stage, the goal was to investigate the process of water purification in a clarifier with a medium-granule load placed in the clarification zone of the working chamber.

The research was carried out on an experimental stand (Figure 1) in different periods of the year. The experimental stand included consumable containers with working solutions of reagents, a mechanical mixer, a working chamber and a clarifier sediment thickener, a quick filter with a granular load, a booster pump and dosing pumps, shut-off and control valves and piping.

The clarifier was supplied with water treated with reagents in a certain sequence and at different time intervals. In experiments with chlorammonization, ammonium sulfate was supplied 1-2 minutes before the introduction of chlorine water. The doses of reagents, depending on the quality of river water, were 1.2 and 4.8 mg/l, respectively. In experiments without ammonification, the chlorine dose did not exceed 3-3.5 mg/l. Aluminum sulfate with a dose of 45-50 $Al_2(SO_4)_3$ was used as a coagulant, polyacrylamide with a dose of 0.2–0.35 mg/l was used as a flocculant. The flocculant was fed into the water by a dosing pump 1.3-1.6 min after the coagulant.

Mixing of the treated water with coagulant and flocculant was carried out in a mechanical flocculation chamber. Camp's criterion in the experiments was 14.9×10^3-30.3×10^3.

The clarifier model, made of translucent pipes, consisted of a connected working chamber with a diameter of 250 mm and a sedimentation compactor with a diameter of 90 mm and a height of 5.6 m each. The velocity of the upward flow in the suspended sediment layer was regulated by a valve on the supply pipeline and varied from 0.4 to 1.2 mm/s. A prefilter was placed in the clarification zone of the working chamber and the sedimentation tank. The prefilter was a loading layer of expanded polystyrene grade PSV [18, 19] with a thickness of no more than 0.5 m. To prevent floating loading of the prefilter from surfacing, a grid with a cell size smaller than the size of granules was arranged. The filtration rate in the experiments varied from 1.2 to 1.7 m/h.

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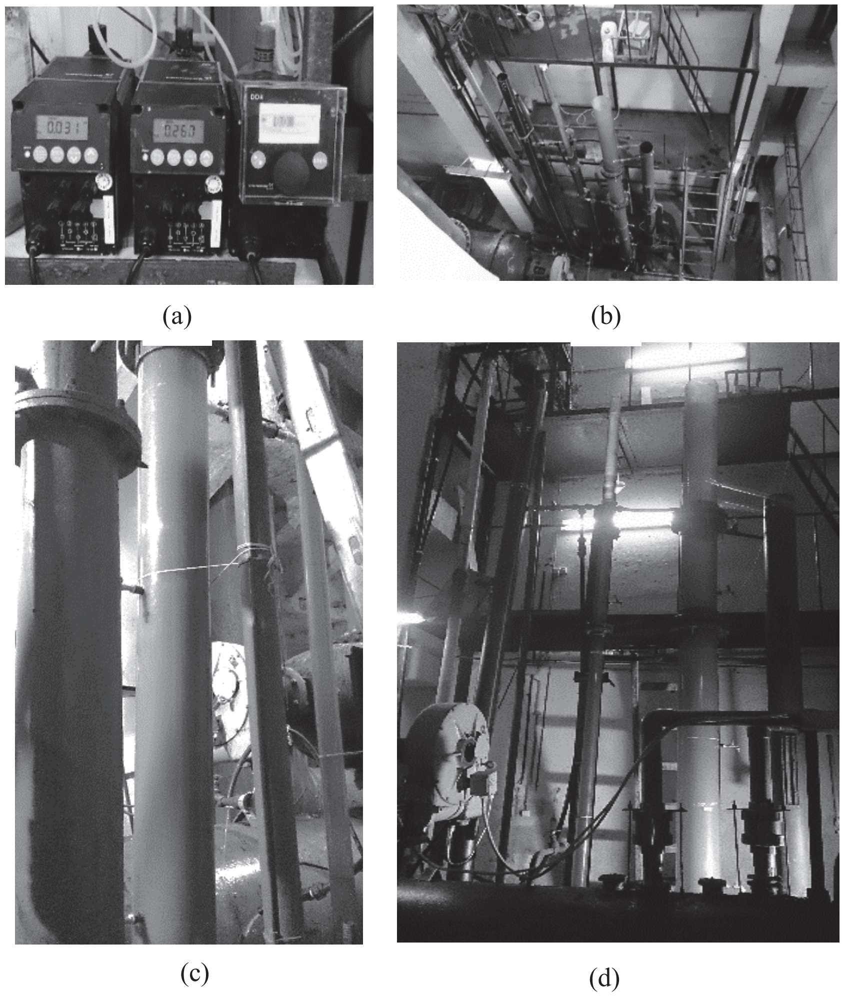

Fig. 1. Experimental stand: a - containers with working solutions of reagents and dosing pumps; b, c - main elements of the stand; d - fragment of the working chamber of the clarifier model.

After the clarifier, water was supplied to the model of a rapid filter loaded with quartz sand with a grain size of 0.7-1.2 mm or floating polystyrene foam loading. The filtration rate in the experiments ranged from 4.5 to 5.8 m/h. The duration of the filter cycle was taken from 8 to 12 hours. The washing of the filter load was adopted by water with an intensity of 14-16 $l/s \cdot m^2$.

The efficiency of the water purification process in the clarifier model with a built-in prefilter was controlled by turbidity, chromaticity, permanganate oxidability, alkalinity, pH and residual aluminum. The work used standard research methods and analyzes, as well as certified laboratory equipment.

Quantitative assessment of the efficiency of ammonization and coagulation was carried out, respectively, by residual chlorine, ammonium and chloroform and pH, alkalinity, turbidity and color.

3 Results

The analysis of long-term observations of the work of industrial corridor-type clarifiers with vertical sedimentation tanks on the Vologda River water showed the following. During reagent treatment in the most unfavorable periods of the year, a loose, low–concentrated phase is formed in the clarifier, the coagulation process proceeds sluggishly, the load of suspended substances on the second stage - filters increases, and the concentration of residual aluminum in purified water increases [20], exceeding the maximum permissible value according to [16]. Thus, during the research period (December), the concentration of residual aluminum in the water at the outlet of the station was 0.22-0.32 mg/l.

It was proposed to place a floating loading layer in the upper part of the clarifier directly in the clarification zone. The efficiency of the lightening and discoloration process was studied in different periods of the year under different hydraulic loads and operating modes of the experimental stand. Some results are presented in Tables 2-4.

Table 2. Water quality indicators before and after purification in a clarifier with a built-in prefilter (December).

Indicators	Source water	Before the prefilter	After the prefilter
Turbidity, FTU	5.0-12.6	7.9-15.6	5.1-6.8
Color, deg.	55-65	8-14	6.7-9.6
Permanganate oxidizability, mg/l	8.9-10.7	3.9-6.9	3.1-4.6
pH	7.9-8.04	7.22-7.26	nd
Alkalinity, mg-eq/l	2.9-4.2	1.9-3.4	nd

Table 3. Water quality indicators before and after purification in a clarifier with a built-in prefilter (January-February).

Indicators	Source water	Before the prefilter	After the prefilter
Turbidity, FTU	2.8-6.2	3.6-19.8	2.6-7.9
Color, deg.	59-76	10-22	7.6-14.5
Permanganate oxidizability, mg/l	10.0-11.8	4-7.5	3.4-6.4
pH	7.64-8.02	7.18-7.27	nd
Alkalinity, mg-eq/l	4.3-4.6	2.9-3.7	nd

Table 4. Water quality indicators before and after purification in a clarifier with a built-in prefilter (April).

Indicators	Source water	Before the prefilter	After the prefilter
Turbidity, FTU	14.8- 25.6	7.4-11.3	2.3-4.1
Color, deg.	70-81	12-17	7.5-8.3
Permanganate oxidizability, mg/l	11.8-22.3	4.7-5.3	3.7-4.4
pH	7.52-7.56	7.04-7.12	nd
Alkalinity, mg-eq/l	1.5-2.0	1.1-1.2	nd

Doses and concentrations of reagent solutions were determined by trial coagulation. The operating parameters of the clarifier and filter models were assumed to be as close as possible to the parameters of industrial structures.

As the data of the tables show, water during the research period (December and January) was characterized by a constant composition, relatively low turbidity up to 12.6 FTU, color 55-76 degrees, permanganate oxidizability up to 11.8 mg/l, high pH up to 8.04 and alkalinity up to 4.6 mg-eq/l. The water temperature was 0.5-0.8 ^{o}C. April was the beginning of the flood. The number of suspended solids and organic pollutants gradually increased, while the alkalinity of the water decreased by 2 times, and the water temperature remained at the same level.

The efficiency of water purification in the suspended sediment layer after pretreatment with reagents varied in a wide range and was: in color – 71-85% and oxidizability – 36-60%. As for turbidity, in some experiments, after a layer of suspended sediment, it reached 19.8 FTU, while the removal of light flakes of sediment into the prefilter zone was observed (Table 2-3).

Experimentally, it was found that when water passed through the prefilter with an ascending velocity from 1.2 to 1.7 m / h, the turbidity of water decreased decreased to 2.3-7.9 FTU, chromaticity – 8.3-14.5 deg., permanganate oxidizability to 4.4-5.4 mg/l. Residual aluminum in the loading layers decreased by 37-73% at its concentration in water after a layer of suspended sediment of 1.38-2.5 mg/l.

When cleaning low–turbid colored waters, the head loss in the suspended sediment layer at an upward flow rate of 0.8 mm/s did not exceed 22 cm in 5 hours in experiments, and at 0.4 mm/s - 12 cm in 20 hours. The pressure losses in the pre-filter loading layer at a filtration rate of 1.1-2.3 m/h were similar.

The use of a small thickness of the filter layers of the load placed in the clarification zones of the working chamber and the sedimentation compactor (less than 0.5 m) and relatively large granules (2-3 mm) is caused by the need to ensure the ratio of the available pressures in the mixer and the existing clarifiers of the existing water supply station. The main purpose of these layers is to prevent the removal of flakes that have not settled in the sediment layer and to achieve a decrease in turbidity – up to 5-10 mg / l and chromaticity up to ~ 10-15 degrees. At the same time, the reduction of the mud load on the fast filters will be ensured.

Another important indicator of the joint work of the clarifier and the filter is the duration of the floating load until it is flushed. With the correctly selected distribution of hydraulic loads between the working chamber and the sedimentation compactor, ensuring their uniformity during the filter cycle and air separation with an increase in alkalinity to 1.4-2.5 mg-eq / l and a decrease in pH from 7.8-7.9 to 6.76-5.4, the efficiency of both the suspended sediment layer and filter loadings increases.

4 Conclusion

The analysis of literature data and experience of operation of clarifiers on low-turbid colored waters showed that in unfavorable periods of the year the barrier role of structures in relation to the intake of organochlorine compounds and aluminum into drinking water decreases.

A brief overview of technological techniques aimed at intensifying the work of clarifiers is performed. It was revealed that in order to increase the efficiency of low-turbidity water purification in the suspended sediment layer, it is necessary to prevent the removal of light flakes that have not settled on the filters and to create additional hydraulic resistance in order to concentrate the sediment in the area of the bypass windows and the verified removal of its excess.

The results of the study of the water purification process in the conditions of an operating station on a clarifier model with a built-in prefilter in the upper part are presented. It has been established that the use of such a technological technique allows to achieve a significant reduction in turbidity, color and oxidizability by an average of 15-35%, to reduce the mud load on fast filters and thereby prevent the entry of contaminants into drinking water.

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