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Development of measures to reduce water consumption for own needs of waterworks

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Abstract. The article presents the designs developed by the authors: a tubular drainage distribution device and a device for water-air washing quick filters. As a result of studies carried out in real conditions at Sludinsk water supply station in N. Novgorod during 2017-2018, the effectiveness of the developed devices is proved which is achieved by increasing the degree of distribution of washing water in the filter as well as by reducing the number of washes which leads to decrease in the flow rate of wash water at the station. The proposed measures to reduce water consumption for its own needs are relevant for any water treatment plant, since they will improve environmental situation and reduce the amount of river water supplied for treatment, which will lead to energy savings in the pumps of the first lift pumping station.

1. Introduction

At any water supply station, a certain amount of water is required for the company's own needs, which is necessary to maintain water treatment facilities in working condition. In the classical two-stage scheme, every day additional water consumption reaches up to 20% of average productivity at the stations. Water is spent on technological work related to cleaning and repair of structures of the first, second stage and tanks but most of water is spent on washing (regenerating) fast filters [1,2].

The operation of fast filters largely depends on the efficiency of drainage distribution syste, as well as on regeneration method which should ensure completeness of washing the load from accumulated contaminants. The drainage system has two main functions: reception of filtered water as well as supply and distribution of wash water. Typical designs of drainage and distribution systems of any type of filter have a number of significant drawbacks, the main of which is uneven distribution of wash water over the filter area in the washing mode [3,4,5].

The main methods of quick filters regeneration which include water, air and air-flushing are constantly being improved but still they still have a number of disadvantages such as increased volumes of flushing water, reduced filter cycle, removal or mixing of filter material fractiona as a result of washing and etc [6].

This paper presents a series of measures aimed at reducing the cost of washing water of water treatment plants filter structures. This problem is an urgent environmental problem, since at many water supply stations the issue of treatment and disposal of washing and process water has not yet been resolved, therefore, decrease in their volume leads to decrease in anthropogenic load on water bodies [7].

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2. Research object

The studies were carried out from September 2017 to June 2018 at Sludinsk water supply station in N. Novgorod which is on the balance sheet of Nizhny Novgorod Vodokanal OJSC. The Oka River serves as a source of water supply. During the reporting period, the water quality in the water supply source - the Oka River, varied widely. Table 1 shows the main annual average indicators of the source. The average turbidity for months ranged from 2.35 to 16.89 mg/dm^3 (maximum value of 31.62 mg/dm^3). The average color for months ranged from 15 to 57 degrees (maximum value of 62 degrees). The average monthly oxidizability varied from 5.08 to 11.79 mgO/dm^3 (maximum value 13.44 mgO/dm^3). The average monthly alkalinity ranged from 2.21 to 3.92 mmol/dm^3 (maximum value of 4.08 mmol/dm^3). According to microbiological indicators, the water source had non-standard values: by the value of coliphages > 10 PFU in 100 cm^3 in March, April 2018; in terms of TCB > 100, the number of bacteria in 1 cm^3 in January 2018.

Table 1. Average annual quality indicators of the Oka for 2017-2018.

Year	Turbidity, mg/dm^3	Color, degrees	Alkalinity, mmol/dm^3	Oxidizability, mgO/dm^3	Sulphates mg/dm^3	Chlorides, mg/dm^3	Dry residue mg/dm^3	Total hardness, mmol/l	Ph, Unit ph
2017	8.40	33	3.39	8.19	69	24.3	335	2.4	8.0
2018	7.80	31	3.41	7.50	84	24.2	369	2.6	8.0

The actual capacity of the waterworks for the reporting period was on average 55970 m^3/day. The station uses a two-stage technological scheme of water treatment process which includes the following processes: preammonization, ozonation, disinfection with sodium hypochlorite (primary and secondary), reagent treatment (coagulation and flocculation), clarification and settling, filtration, ultraviolet disinfection. Water clarification is carried out on clarifiers with a layer of suspended sediment - II and III sections and horizontal settling tanks - IV sections. After water enters quick single-layer filters, it is filtered through a layer of sand loading from top to bottom collected by a cap system, slotted drainage and discharged into a clean water tank. A distribution channel passes through the center of the filters dividing the filter into two parts: the lower part of the channel serves to collect clean water and supply wash water to the filter; the upper part of the channel is meant for supplying clarified water and distributing it evenly over the surface of the filter using metal distribution trays as well as for collecting dirty water after washing the filters. Backwashing is carried out by a reverse current of water with an intensity of 14-16 l/s·m^2, for 6 minutes at least 1 time in two days according to the testimony of water quality.

The volume of water spent on the station's own needs for 2017-2018 was recorded. The volume of generated process water is 622-508 thousand m^3 per year. The volume of generated wash water is 1847-1906 thousand m^3 per year. The total volume of generated process and wash water is 10.6% of the total plant capacity.

An urgent issue for the station is to reduce the amount of water used for its own needs due to which the environmental situation will improve as well as the volume of river water flowing for treatment which will lead to decrease in the supply of the pumping station for the first lift and energy safety.

3. Development of a tubular drainage distribution device and a device for water-air washing of quick filters

To improve the operation of filtering device, the authors proposed the principles of designing a new type of drainage distribution device which is based on the principle of mutual compensation of changes in costs. A tubular-drainage filter distribution device has been developed and patented (Pat. RU No. 2625040 C1, IPC B01D 24/38, 2017) which consists of a common collector and two parallel lateral pipe branches connected by a diagonal pipe section using rounded bends. In this case, the parallel lateral branches consist of perforated pipes attached to them with holes attached through one to each of the parallel lateral branche. This ensures oncoming water movement and increases the degree of water distribution in the filter cavity [8].

The use of a tubular-drainage distribution device increases the filter efficiency, improves quality of the filtered water by increasing the degree of wash water distribution in the filter, and also reduces the amount of wash water.

It is known that water-air washing of filter structures has a more effective impact than water, and this makes it possible to obtain a high washing effect at lower rinsing water consumption [9]. The authors conducted a series of experiments, the purpose of which is a developed and patented device for air-water washing of quick filters (US Pat. RU No. 181329 U1, IPC B01D 24/46, 2018). The device consists of a drainage of high resistance, a pipe supplying wash water on which an additional bypass pipe with an ejector is installed. The suction air pipe is brought to the ejector on which the check and electromagnetic valves are placed as well as a pipe with a free end. Water flushing is proposed in two stages. At the first stage, the wash water with the wash water intensity I_{water} (1 et) = 3 $l/(s \cdot m^2)$ enters the pipe supplying the wash water, and due to presence of an additional bypass pipe, it is divided into two flows: the main one (moves through the pipe supplying the wash water) and auxiliary (moves through an additional bypass pipe). The auxiliary water flow passing through the additional bypass pipe with the help of an ejector, and it becomes saturated with atmospheric air while the air supply intensity is Iair. = 20 $l/(s \cdot m^2)$. Then the auxiliary water stream saturated with air is mixed with the main water stream to the quick filter, and the mixed stream enters the drainage of high resistance. The time of water-air washing at the first stage is 6 minutes, while loading is loosened and contaminants are washed off. Next comes the second stage of water-air washing, in which only the wash water with an intensity of I_{water} (2 et) = 6 $l/(s \cdot m^2)$ flows through the pipeline supplying the wash water for 5 minutes. The second stage is the final one and is carried out for the most complete washing away of pollution and displacement of trapped air [10].

The use of the proposed water-air washing device can increase the efficiency of quick filters which is achieved by reducing the cost of wash water simplifying the modes and reducing the stages of water-air washing as well as reducing energy costs due to the rejection of compressors.

4. Research results

In 2017-2018 the devices developed by the authors were investigated within the framework of Sludinskaya waterworks in N. Novgorod on the water of the Oka River. For testing, a semi-industrial fast filter installation No. 1 was installed with dimensions of 1x1 m and a height of 1.5 m. The quartz sand used at the station was also used as a quick filter load. The devices developed by the authors were used as a drainage and flushing method. A semi-industrial fast filter installation No. 2 was also mounted which imitated existing design of the station's quick filters.

The water that passed the first stage of purification on clarifiers with a layer of suspended sediment (pre-clarified) was subjected to a filtering process on existing station quick filters (with a filtering speed of 3.5 to 5.3 m/h) and on the above mentioned quick filters No. 1 and No. 2 (with a constant filtering speed of 5 m/h). The tests were carried out continuously in 4 stages, each for 2 months. The 2 phases of October-November 2017 and April-May 2018 (spring flood) were revealing.

During the flood (April-May 2018) the turbidity and color of the river reached their maximum values during the year (31 mg/dm^3 and 62 degrees) while the constructions of the first stage of clarifiers with a layer of suspended sediment showed good work and reached less than the turbidity 1.5 mg/dm^3 which meets the requirements for drinking water. At this stage, the filtering process on all designs of quick filters was approximately the same.

In the period from October to November 2017, the turbidity and color of the river were close to minimum values (5 mg/dm^3 and 20 degrees) while the constructions of the first stage of clarifiers with a layer of suspended sediment showed unsatisfactory work and the entire load fell on the constructions of the second stage filters. The performance indicators of the station's fast filters and the investigated semi-industrial units No. 1 and No. 2 for the period October-November 2017 are shown in Table 2.

Table 2. Performance indicators of the station's fast filters and investigated semi-industrial units No. 1 and No. 2 for the period October-November 2017

Date	Turbidity (T) of the river, mg/dm^3	The river color, degree	T of clarified water, mg/dm^3	Existing Quick Filters		Quick Filter №1		Quick Filter №2	
				T f, mg/dm^3	Number of rinses	T f, mg/dm^3	Number of rinses	T f, mg/dm^3	Number of rinses
21.10	5.20	20	1.47	0.57	2	**0.48**	2	0.56	2
22.10	5.60	20	1.68	0.60	2	**0.47**	2	0.58	2
23.10	8.10	20	1.17	0.56	2	**0.48**	2	0.56	2
24.10	4.70	20	1.90	0.62	2	**0.48**	2	0.60	2
25.10	4.50	21	2.11	0.70	2	**0.50**	2	0.68	2
26.10	4.20	20	2.40	0.71	2	**0.50**	2	0.70	2
27.10	4.30	20	1.61	0.65	2	**0.49**	2	0.63	2
28.10	4.40	20	3.15	0.98	2	**0.53**	2	0.95	2
29.10	4.90	21	2.33	0.86	2	**0.51**	2	0.83	2
30.10	4.20	22	3.41	0.89	2	**0.54**	2	0.87	2
31.10	4.90	20	2.04	0.77	2	**0.50**	2	0.70	2
1.11	5.80	22	4.83	1.16	2	**0.58**	2	1.03	2
2.11	6.10	22	4.41	1.12	2	**0.55**	2	1.10	2
3.11	4.50	22	4.00	1.12	2	**0.56**	2	1.06	2
4.11	4.50	22	3.20	0.63	2	**0.50**	2	0.64	2
5.11	3.90	22	4.09	1.15	2	**0.52**	2	1.08	2
6.11	5.10	21	4.09	1.14	2	**0.50**	2	1.11	2
7.11	4.70	22	5.11	1.13	2	**0.54**	2	1.10	2
8.11	6.70	22	2.28	0.88	2	**0.48**	2	0.88	2
9.11	6.10	24	3.24	0.92	2	**0.48**	2	0.90	2
10.11	5.70	27	1.70	0.71	2	**0.49**	2	0.70	2
11.11	4.80	39	3.25	1.08	2	**0.54**	2	1.06	2
12.11	5.20	26	2.38	1.00	2	**0.50**	2	0.89	2
13.11	6.90	31	3.88	1.06	2	**0.51**	2	1.02	2
14.11	7.30	29	3.41	0.63	2	**0.48**	2	0.96	2
15.11	6.40	29	3.21	0.88	2	**0.49**	2	0.90	2
16.11	5.40	27	1.78	0.58	2	**0.47**	2	0.55	2

Other things being equal, the operation of all filter structures and observing the number of leaks per day according to the station's regulations, fast filter No. 1 showed more stable results on the turbidity of the filtrate. It is proved that the proposed design of the quick filter allows achieving more effective indicators of water purification.

In order to confirm the theory of washing water saving, the authors conducted an experiment to establish the effective time of fast filters No. 1 and No. 2. For this, pre-clarified water with a constant turbidity of 3.5 mg/dm^3 was subjected to the filtering process for 6 days, at a filtration rate of 5 m/h, the filter cycle was 24 hours. On the 7th day of the facilities operation, the time of effective quick filters operation to the next flushing mode was measured. The experimental results are summarized in table 3.

Table 3. Experiment results to establish the effective time of fast filters No. 1 and No. 2.

Time, hours	4	8	12	16	24	28	32	36	48
Turbidity of the filtrate after quick filter No. 1, mg/dm^3	0.50	0.50	0.53	0.68	0.75	0.77	0.99	1.14	1.52
Turbidity of the filtrate after quick filter No. 2, mg/dm^3	0.87	0.94	0.95	1.08	1.32	1.59	-	-	-

It was revealed that the semi-industrial installation of the fast filter No. 1 proposed by the authors produced non-standard water in accordance with SanPiN 2.1.4.1074-01 "Drinking water" for 48 hours of operation, and fast filter No. 2 for 28 hours of operation. This is due to the fact that in the fast filter No. 2 with washing inefficiency residual pollution accumulated over the previous day.

5. Conclusion

It was proved in the course of the experimental work that a number of measures to improve the design of the quick filter proposed by the authors, ceteris paribus, can improve the quality of filtered water by increasing the degree of wash water distribution in the filter, as well as reducing the number of rinses per day which leads to reducing the flow rate of flushing water at the station.

It was confirmed in real conditions that the filter cycle of structures, through the use of developed devices, increases from 24 hours to 36 hours. At the same time, the saving of wash water at the water treatment station will amount to 30-40% per day.

It is recommended to use the measures described for implementation at water treatment plants that operate on a similar technology with Sludinsk water supply station in N. Novgorod.

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