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Justification of Material Requirements of Contact Clarifier Media on Water Treatment Plants in Shtykovo

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Abstract. In the course of this paper we examined an active clarifier unit with contact media on the hydroelectric complex in Artem, Primorskiy Kray, as well as conducted the assessment of filter media qualitative parameters on the facility. To intensify the operation of the facility, it has been proposed to replace the filter media by the sand from the Pavlovskiy opencast colliery. The assessment of qualitative characteristics of the Pavlovskiy opencast colliery sand material has been made with the justification of its possible use as a filter material on water treatment plants.

1. Introduction

The purpose of second stage facilities of water treatment plant of Artemovskiy hydroelectric complex is to supply Vladivostok with drinking water. According to the project, a single-stage technique of water conditioning is applied, during which, contact clarifiers of KO-1 type, with non-gravel contact media, are used as the main installations for water treatment. Contact media of clarifiers is an essential element of these installations as it is used for retention of contaminated substances that are present in feed water. Contact clarifiers unit of second stage facilities of water treatment plant of Artemovskiy hydroelectric complex includes 32 water treatment installations of KO-1 type with average useable surface area of 2335 m². Actual output during intensive water supply seasons exceeds 240000 – 250000 m³ per day.

Water, treated with the application of clarifiers with contact media, most of the time meets the requirements presented by Sanitary Regulations and Norms of the Russian Federation 2.1.4.1074-01, however depending on the quality of water in the storage reservoir the turbidity may increase up to 4,5 - 5.0 mg/dm³. Color of water may increase up to 30 degrees of platinum-cobalt scale and quite frequently, it is possible to notice an elevated level of total iron of 0,8 mg/dm³ [1]. These statistics reveals insufficiently high barrier functions of clarifiers, possessing quite a number of design defects and deviations from existing technical requirements, therefore it is necessary to assess the compliance with technical requirements during reconstruction in order to guarantee normal everyday conditions of facilities operation. Considering this, we identified that the purpose of this paper is to make an analysis and assessment of qualitative characteristics of filter media that are currently applied on the water treatment facility and of filter media that is proposed as the substation of the current one.
2. The examination of active clarifiers unit with contact media on the hydroelectric complex in Artem

Media for clarifiers is usually made of combination of gravel and sand (clarifiers of KO-3 type with gravel media) or of sand only (clarifiers of KO-1 type with non-gravel media) [2]. The sand that is used as a filler for water filtering installations must be prepared in accordance with requirements of Technical Specifications TS 5711 – 002 – 03987739 – 97 and technical documentation, adopted in accordance with the established procedure, which must be a guideline for the sand preparation. For preparation of media, it is preferable to use river gravel and river (quartz) sand. With proper justification, other filtering materials may be applied. These materials, however, must meet the requirements on mechanical strength, chemical durability, hydraulic exponents and technological parameters. It is also important to add that for household water supply systems only permitted materials must be used for filtering.

During the examination it was noticed that contact media in active clarifiers consisted of dissimilar materials such as quartz sand, clinoptilolite and granodiorite.

As the result of examination of active clarifiers unit with contact media we made an analysis of granulometric composition of media material, extracted from the open test pit at the depth of 0,5 m on the area with normal surface conditions and on the zones of surging. The results of the analysis (Table 1) demonstrated that from the point of fineness the content of fractions in the range that corresponds with the material of the third (upper) layer (0,7 – 1,2 mm) constituted 26 – 43%. Meanwhile, the amount of large fractions of “conditional” material constituted 35 – 43%. At the moment of loading of media into the contact clarifier the amount of these fractions accounted for no less than 71%.

| Fineness of media material, mm. | Content of media material of the third layer, | Place of gathering the sample of media material | | |
|---|---|---|---|---|
| Fineness | Content of media material in the zone of formation of hills of media materials washout | Content of media material out of the zone of formation of hills of media materials washout | sample № 1, % | sample № 3, % | sample № 2, % | sample № 4, % |
| 2,8 | 0,2 | 16,4 | 12,6 | 10,7 | 6,4 |
| 2,4 | 1,4 | 12,0 | 9,8 | 11,1 | 8,0 |
| 2,0 | 3,6 | 11,3 | 9,9 | 9,8 | 8,2 |
| 1,8 | 4,5 | 11,4 | 10,8 | 10,4 | 9,5 |
| 1,6 | 2,0 | 4,7 | 3,4 | 3,7 | 4,3 |
| 1,4 | 8,9 | 15,4 | 18,1 | 16,6 | 16,9 |
| 1,2 | 4,2 | 5,1 | 6,6 | 6,0 | 6,5 |
| 1,0 | 13,4 | 5,8 | 7,6 | 7,5 | 8,7 |
| 0,7 | 53,8 | 15,8 | 19,4 | 22,0 | 28,2 |
| 0,5 | 3,5 | 1,4 | 1,4 | 1,9 | 2,6 |
| 0,25 | 2,0 | 0,4 | 0,2 | 0,3 | 0,7 |
| <0,25 | 2,4 | 0,1 | 0,0 | 0,0 | 0,1 |

It is necessary to mention that media material samples, in comparison with their initial composition, possess significant amount of fractions larger than 1,2 mm. There were slightly more than 20% of these particles in the third layer of the initial material. After several filtration cycles their presence at the depth of 50 cm increased up to 50 – 70%. This is natural process; however, in a normal qualitative composition of the third layer the content of these fractions, even at the depth exceeding 70% of layer thickness, must not exceed 40%. Considerable amount of these fractions is related to washing of media during regeneration process and relocation of the particles with fineness of 0,7 – 1,2 mm and smaller closer to the surface. In the upper layer and on the surface of the media the amount of small fractions reaches 75 – 90%.
According to the conducted investigation the specification on fineness of grains have been made, following these specification it is necessary to state that media made of crushed granodiorite must be organized into three layers. The height of layers is selected in accordance with Technical Specifications of Academy of Communal Services named after K.D. Pamfilov [3] and Construction Norms and Regulations SNiP 2.04.02-84 [4]. The requirements constitute the following: for the first layer the fineness of grains is 5.0 – 3.0 mm with thickness of 500 mm; for the second layer the fineness of particles is 3.0 – 1.2 mm with height of layer of 1000 mm; for the third layer the fineness of particles is 1.2 – 0.7 mm with thickness of 1000 mm. Fractional composition, accepted on the basis of laboratory examination, for the first and second layers of media is slightly different from recommended one (5.0 – 2.0 mm and 2.0 – 1.2 mm respectfully), it is explained by insufficient resistance of material towards abradability, so during the operational process it is expected that the level of material crushing will be higher than normal.

As the result of examination we can conclude that the media that is currently used in the clarifiers with contact media does not meet necessary requirements and norms and needs to me replaced. The sand from Pavlovskiy opencast colliery is proposed as the substitution for current media.

3. Methods of identification of qualitative characteristics of media

While conducting sample tests of sand material it is necessary to apply normative techniques that are currently in force:

- Measurement Procedures of State Scientific Metrology Center “The Russian Scientific Research Institute of Physicotechnical and Radiotechnical Measurements” (MP SSMC VNIIFTRI), Mendeleev, 2004 "Methods of radionuclide activity measurement using scintillation beta-ray spectrometer with installed “Progress” software;
- State Standard of the Russian Federation (GOST) 18165-89 "Drinking water. Method of identification of aluminium mass concentration”;
- MP SSMC VNIIFTRI, Mendeleev, 2003 "Methods of radionuclide activity measurement using scintillation gamma-ray spectrometer with installed “Progress” software;
- Methodological Instructive Regulations (MU) 31-11/05 "Methods of measurement of mass concentrations of zinc, cadmium, lead, copper, manganese, arsenic and mercury using the approach of stripping voltammetry on analyzing devices of TA type”;
- MP SSMC VNIIFTRI, Mendeleev, 2005 “Methods of total alpha-activity measurement using scintillation alpha-ray radiometer with installed “Progress” software;
- Federal Environmental Standard Regulations (PND-F) 14.1:2:4.139-98 "Quantitative chemical analysis of waters. Methods of measurement of mass concentrations of iron, cobalt, manganese, copper, nickel, silver, chromium and zinc in the samples of drinking, natural and discharged waters using the atomic absorption spectrometry approach.

In accordance with Technical Conditions 5711–002–03987739–97 [5] granulometric size composition of sand is identified by sizing analysis of average sample after its drying out in thermostat under the temperature of 150°C. It is necessary to mention that requirements on mechanical strength and abradability for media material of contact clarifiers must be significantly higher than for filtering material, such as high-rate trickling filters, for instance. As it is generally known, mechanical strength characteristics of filtering materials are standardized particularly for high-rate trickling filters [6]. Physical and chemical properties of grained filtering materials are determined by their mechanical strength and chemical durability. Those materials in which an adhering of solids in different water environment does not exceed 20 mg/dm³ and growth of oxidability is lower than 10 mg/dm³ are considered chemically durable.

In accordance with existing regulations for filtering media of high-rate trickling filters the abradability must not be higher than 0.5% from total weight and grindability must be less than 4.0% from total weight.

Total specific activity of natural radionuclides (A_{\text{rad}}), which are present in the sand-filler, must meet the requirements of timing criteria limiting the exposure to radiation by population from natural
sources of ionizing emission, adopted by Ministry of Health of the USSR for 1 class construction materials. It must also satisfy the requirement provided by Regulations of Radiation Safety [7] and comply with provisions of Principal Sanitary Rules [8]. Total specific activity of natural radionuclides is identified by specialized institutions of radiation safety.

4. Qualitative indicators of media characteristics, revealed as the result of laboratory research

As the result of the research, the following indicators were revealed:

- granulometric texture;
- content of slime and clay particles, revealed by the levigation method;
- sanitary characteristic, which includes radionuclides specific activity, volumetrical total radioactivity in the aqueous extract, metals migration into the aqueous extract;
- mechanical strength, characterized by the abradability and the detachability;
- chemical durability;
- average density and apparent density, according to the Building Standards 528-80;
- porosity;
- mineralogical and petrographic composition;
- content of main chemical components.

While defining the granulometric composition it was identified that the amount of fractions less than 0,5 mm in the sand samples from Pavlovskiy opencast colliery was less than 20%. According to the current Standards, the content of slime and clay particles, revealed by the levigation method, must be not higher than 0,5% above the whole sand-filler quantity. The heterogeneity coefficient (C_h) without preliminary extraction of minor particles and silt accounts for 0,12, and the equivalent diameter (D_e) makes up 0,9 mm. Without presorting of natural sand in a current condition, the usage of it for the filter media is unacceptable.

The sanitary characteristics of sand-filler, which were received from Pavlovskiy opencast colliery, were defined according to the samples, which had been previously prepared by washing-off the minor fractions of slime and clay particles. This method of the sand washing-off is used due to the fact, that, while loading of media into the filtering facilities, the particles of filler of abovementioned fractions must be removed. It is done because those particles do not participate in the operational process of water treatment.

According to the radionuclide research (Table 2), sand from Pavlovskiy opencast colliery generally corresponds with the radiation safety.

| No | Radioactivity indicators | Sanitary – hygienic standard | Actual value |
|----|--------------------------|-----------------------------|--------------|
| 1. | Effective specific activity of radionuclides in a sample, Bg/kg | Up to 370 | 85,6±15,7 |
| 2. | Volumetrical total radioactivity in the aqueous extract: | | |
|    | Alpha-activity, Bg/kg | 0,2 | less than 0,011 |
|    | Beta-activity, Bg/kg | 1,0 | less than 0,230 |

Current research of chemical resistance has shown that oxidability accession and concentrated silicic acid accession of the sand material, taken from Pavlovskiy opencast colliery, both have augmented stability to disruption. The indicators shown above are almost 10 times better than permissible ones.

Due to the solid residue accession, the chemical resistance of this sand also corresponds with standardize limits. The indicators for aluminum oxide and ferrous oxide accession of studied material are twice or more better than standardized ones, which also determines its augmented stability.
The grindability of sand material, taken from Pavlovskiy opencast colliery, doesn’t exceed 0.5 – 0.9%, which is 4 – 8 times better than permissible levels. The wear capacity of material is 25 – 50 times better, which proves that this sand is more stable to disruption in different environments that are specific for the work of filtering facilities.

The average density of sand-filler (ration of sand mass to total occupied volume, including pores and openings in the sand, counted as a specific weight) must be between 2.6 – 2.7 t/m³ [9]. For the studied sand material from Pavlovskiy opencast colliery this indicator states for 2.67 t/m³.

The apparent density of sand-filler of medium fraction in state of natural humidity constitutes for 1.5 g/sm³, which totally corresponds with the standardized levels. Natural humidity of sand-filler ranges from 3 to 5% of its mass.

The openness of sand-filler exceed required level for 40%.

According to the operational exploration data, the mineralogical and petrographic composition of sand-filler should have at least 40-60% of quartz, 5-22% of field spar, 22-26% of rock fragments (chert, mica schist, gneiss, granitic rock parts, pegmatite). Ore minerals can be presented by limonite, ilmenite, hematite, pyrite, chromite – from 0,5 to 0,8%. The presence of main chemical particles in sand-filler is evaluated according to the quantity of silicon dioxide (SiO₂), aluminum oxide (Al₂O₃), ferrous oxide (Fe₂O₃), the sum of potassium oxide and sodium oxide (K₂O + Na₂O). Judging by the chemical particles of sand material from Pavlovskiy opencast colliery, it has sufficient number of quartz – more than 80% (Table 3).

| No | Chemical compound                                      | Presence in % due to the mass by analysis | standardized levels |
|----|--------------------------------------------------------|------------------------------------------|---------------------|
| 1  | Silicon dioxide (SiO₂)                                 | 81.95                                    | 76-84%              |
| 2  | Aluminum oxide (Al₂O₃)                                 | 7.67                                     | 8-12%               |
| 3  | Ferrous oxide (Fe₂O₃)                                  | 1.57                                     | 2-4%                |
| 4  | The sum of potassium oxide and sodium oxide (K₂O + Na₂O) | 4.55                                     | 5-10%               |

During the research it was discovered that the amount of semi-stable rock material is quite low. In particular, there is less than 1.2% of feldspar due to the fact that it is contained in the fine fractions structure (up to 0.3 mm), with the amount of 5%. The sand contains 15.4% of metamorphosed rocks in average, up to 6.2% of sedimentary rocks, 2.8% of effusive rocks.

The results of research about main chemical components contain are presented in the table 4.

| Substances, indicators (factors)   | Sanitary – hygienic standard | Analysis result | Analysis method |
|-----------------------------------|-----------------------------|----------------|----------------|
| Aluminum, mg/dm³                 | Up to 0.2                   | <0.040         | GOST 18165-89  |
| Ferrum, mg/dm³                   | Up to 0.3                   | 0.084          | GOST 4011-72   |
| Arsenicum, mg/dm³                | Up to 0.05                  | <0.010         | GOST 4152-89   |
| Plumb, mg/dm³                    | Up to 0.03                  | <0.0010        | GOST P 51309-99|
| Cadmium, mg/dm³                  | Up to 0.001                 | <0.000100      | GOST P 51309-99|
| Cuprum, mg/dm³                   | Up to 1.0                   | <0.0010        | GOST P 51309-99|
| Manganese, mg/dm³                | Up to 0.1                   | <0.0010        | GOST P 51309-99|
| Nickel, mg/dm³                   | Up to 0.1                   | <0.0010        | GOST P 51309-99|
According to the results of laboratory analysis, content of toxic elements in aqueous extract is considerably less than sanitary – hygienic standards require. These results correspond with the safety conditions of usage of sand from Pavlovskiy opencast colliery as a filter material of media loaded into the filtering facilities.

5. Results discussion
During the laboratory research it was ascertained that sand material from Pavlovskiy opencast colliery has quartz type of the mineralogical and petrographic composition. The content of quartz is no less than 73 – 82%, quantity of relatively fragile rocks is in small amounts, which defines high resistance qualities of material and contributes to applicability of sand in clearing agents with contact filter media. However, it is necessary to consider that before loading sand from Pavlovskiy opencast colliery into high capacity filters or clearing agents with contact filter media, it is required to perform preliminary material fractionation by dry selection and removal of fine fractions and silty fractions (up to 20%). The removal of these fractions from sand can also be done by the backwash of water directly in filter facilities, in compliance with the conditions of layer-by-layer washing off.

6. Conclusion
The laboratory research presented above proves that sand from Pavlovskiy opencast colliery satisfy requirements of materials, which are used as filter facilities media. This sand is suitable for usage in clearing agents with contact filter media in Artyom hydro system after the removal of fine fractions and silty fractions. The presented method of reconstruction of clearing agents with contact filter media of Artyom hydro system by sand from Pavlovskiy opencast colliery is the most acceptable way. This method was accepted to be implemented in frames of reconstruction project.

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