Development of a mobile unit for purification of water from water dams

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Abstract. The article deals with the problem of pollution of water sources with substances such as phenols, formaldehydes, hydrogen sulphide, and ammonia as a result of the discharge of water from water-filled dams after their use. The elements of the mobile installation were also selected and calculated. Its 3D-model with the arrangement of equipment in a container has been developed.

1. Introduction
Floods cause significant material damage to residents of areas prone to flooding. For a long time, people have been fighting floods, but this fight has not been very successful. Various methods and structures are currently used for flood protection. Structures include, for example, dams, which are quite effective, but their use is limited by the terrain, the area of the site where construction is possible, as well as the level of water rise during the flood period. In conditions when it is impossible to build dams, such an installation as a water-filling dam has been developed and is widely used in practice (Fig. 1) [1, 2].

![Figure 1. Water filling dam.](image-url)

The water-filled dam is a closed shell elongated in length. The construction of such a structure is carried out by pumps. Water is pumped into the body of the dam from a surface source near the place of its construction. The injection is carried out without preliminary cleaning.
As a result, the following conditions are created inside the shell: a large number of microorganisms and organic matter, oxygen deficiency, and positive temperature. The latter is due to the use of dams in a warm climate. This leads to the formation of new intermediate compounds, which may include those that pose a threat to the inhabitants of the water source and humans. Under such conditions (under the influence of anaerobic microorganisms), phenols, formaldehydes, ammonia, and hydrogen sulphide are formed. Under normal conditions, they oxidize to form fewer toxic compounds. Based on the analysis of the studies, the excess of the initial concentrations of the maximal permissible concentration (MPC) standards for discharge into water bodies for household and drinking and cultural purposes was established (Table 1) [2-4], which indicates the need for water purification before discharge.

### Table 1. Concentrations of pollutants generated in the dam body.

| Name               | Hazard class | Initial concentration, mg/l | MPC, mg/l |
|--------------------|--------------|-----------------------------|-----------|
| Phenol             | 2            | 0.006                       | 0.001     |
| Hydrogen sulphide  | 2            | 0.31                        | 0.003     |
| Formaldehyde       | 2            | 0.07                        | 0.05      |
| Ammonia            | 4            | 0.107                       | 0.05      |

2. Methods
The work represents the development of a mobile installation. An analysis of the literature on substances formed in the absence of oxygen, the presence of a large number of microorganisms and a positive temperature was carried out. Based on this analysis, the main cleaning methods and requirements for the installation elements have been established, including mobility, since it must be delivered to the dam itself. Also, analysis of cleaning methods has shown that the most effective cleaning method is a combined scheme, consisting of: ozonation and adsorption on filtering installations. The efficiency of such a scheme can reach $\eta = 100\%$ [5].

As a result, the calculation and selection of equipment was made. The calculation was made on the basis of regulatory documents. After that, 3D models of all the elements were drawn, followed by their placement in the container. Thus, a 3D model of the installation was developed.

3. Modelling
The required flow rate is determined based on the volume of water injected into the dam. According to news sources, in most cases the volume of the installation does not exceed 6,000 m$^3$. For mobile units, we will assume a flow rate of 10 m$^3$/h. Then, in order to reduce the cleaning time, 2 cleaning units will be used. Each installation needs to be treated with 3000 m$^3$ of water. The cleaning time will then be approximately 12 days.

Before the main cleaning steps, it is necessary to precipitate suspended and colloidal particles to increase the ozonation efficiency and the filter life.

The main requirements for the equipment are small size and ease of use. All the requirements are met by a circuit consisting of sequential elements: a static mixer, a horizontal settler, a carbon filter, an ozonation unit, and an adsorption filter [5-8].

The analysis of coagulants has shown that the most suitable ones, based on their conditions of a large range of initial concentrations of the pollutant, are organic coagulants. Moreover, organic coagulants are much more effective than inorganic ones, they act faster and you need less of them to get optimal results. Organic matter fights well with chlorine and relieves water of unpleasant odours, for example, from hydrogen sulphide, and in the source water the concentration of hydrogen sulphide exceeds the MPC by tens of times [9-11].

Comparison of organic coagulants with each other allowed us to choose FLOQUAT FL28P1 as a coagulant for our case. It is an organic coagulant that works in a wide range of the initial composition of water supplied for treatment. The filter was loaded with "Sorbent MS" – a filter material based on
silicates of alkali and alkaline earth metals. It is used for the preparation of drinking water and physical and chemical purification of industrial circulating and waste water from iron, manganese, strontium, heavy non-ferrous metals, phosphates, oil products, phenol, and radionuclides. Hydrogen sulphide and manganese are also oxidized and retained in the feed layers with subsequent removal by backwashing [11-13].

“Sorbert MS” is regenerated by periodic water or water-air (which is more effective) washing. The active components enter the structure of the sorbent granule evenly, which ensures efficient operation even when the granule breaks. During operation “Sorbert MS” is practically not consumed, it is a very durable material. Thus, “MS sorbent” is relatively inexpensive and has a high efficiency of purification from hydrogen sulphide, a substance of hazard class 2, the concentration of which in the source water is exceeded by more than 100 times [12].

Based on the permissible cleaning speed, which according to SP 30.13330.2012 is 1.2 m/s. And at a flow rate of 10 m³/h, the diameter will be 55 mm. Pipes are selected in accordance with GOST 18599-2001. The inner diameter of the pipes determined according to the table is dtr = 57 mm. Then the speed will be 1.1 m/s. With a wall thickness of 3 mm, the outer diameter will be Dtr = 63 mm.

Due to the established low flow rate and the absence of the need to raise water to a height, it is advisable to use a surface pump for optimal operation. The surface pump PEDROLLOHFm 5 BM was selected for the given parameters.

Calculation of a washer static mixer was made according to the following method [14].

Initial data: Q = 10 m³/h = 0,003 m³/h – flow rate of incoming water; h = 3 m – mixer head loss.

1) Pipeline diameter, mm:

\[ d = \sqrt[\frac{4}{3\pi \cdot v}} = \sqrt[\frac{0,003 \cdot 4}{3,14 \cdot 1,2}} = 0,065 \text{ m} = 65 \text{ mm}, \]  

(1)

where \( v \) – incoming water speed.

Since the speed of the treated water should be in the range of 1 ... 1.5 m/s, we take \( v = 1.2 \text{ m/s} \).

Then:

\[ d = \sqrt[\frac{0,003 \cdot 4}{3,14 \cdot 1,2}} = 0.065 \text{ m} = 65 \text{ mm}. \]  

(2)

The outer diameter of the pipe is 73 mm, the inner diameter is 65 mm. Seamless hot-worked pipe, GOST 8732-78.

2) Selection of the compression ratio of the jet and the ratio of the areas of the washer and the pipeline:

\[ \varepsilon \cdot \frac{\omega_0}{\omega} = \frac{1}{\sqrt{2g \cdot h}} = \frac{1}{\sqrt{2 \cdot 9,81 \cdot 0,3}} = 0.381, \]  

(3)

where \( \varepsilon \) – jet compression ratio, which depends on the ratio \( \omega_0/\omega \) and is determined by the tables [14], \( \omega_0 \) – washer hole area, \( \omega \) – free area of the pipeline.

When \( \omega_0/\omega = 0.6, \varepsilon = 0.656, \varepsilon \cdot \omega_0/\omega = 0.656 \cdot 0.6 = 0.394. \)

When \( \omega_0/\omega = 0.5, \varepsilon = 0.642, \varepsilon \cdot \omega_0/\omega = 0.642 \cdot 0.5 = 0.322. \)

Let us accept \( \omega_0/\omega = 0.59 \varepsilon = 0.646, \) then \( \varepsilon \cdot \omega_0/\omega = 0.646 \cdot 0.59 = 0.381. \)

4) Washer hole diameter, mm:

\[ d_0 = d \cdot \sqrt{\omega_0/\omega} = 60 \cdot \sqrt{0.59} = 46 \text{ mm} \]  

(4)

Sump OGT-10 St3 was selected for the specified parameters (Fig. 2) [15].
After the sedimentation tank, fast filters with coal backfill are used for post-treatment. Filters will reduce the content of suspended and colloidal particles, since sedimentation tanks have low efficiency. For the flow rate of water entering the filter equal to 10 m$^3$/h, the CAS 4278 filter was chosen [16].

Calculation of the ozonation plant was made as follows [17].

Initial data: $Q_h = 10$ m$^3$/h or $Q_{day} = 240$ m$^3$/day – estimated consumption of ozonized water; $q_{oz}^{max} = 0.5$ g/m$^3$ – ozone dose according to [18].

1) Maximum design ozone consumption:

$$G_{oz} = \frac{Q_{day}q_{oz}^{max}}{1000} = \frac{240 \cdot 0.5}{1000} = 0.12 \text{ kg/day} = 0.005 \text{ kg/h}$$

2) Duration of contact with ozone $t = 6$ min.

OZO-B5 ozonizer with a capacity of $G_{oz} = 5$ g/h [19]. Since the volume of water supplied for treatment is 10 m$^3$/h, 2 units are required.

According to the specified ND, the calculated amount of the fine is about 1.07 million roubles [20]. The cost of the two installations is 7.09 million roubles, taking into account the overhead costs. The useful life of the installation is 10 years. The cost of operating two units per year will amount to 709.423 thousand roubles. The total cost of operating two installations per year, taking into account that one flood will occur during this period, is $SE = 738.673$ thousand roubles. Money saved for the year, thousand roubles: $Savings = W - SE = 1070.873 - 738.673 = 332.2$ thousand roubles.

4. Results

An installation has been developed to purify water from a water-filling dam after its downtime. It consists of the following elements: static mixer NSM-65-H, which mixes the FL28P1 reagent with purified water, OGT-10 St3 settler, KAS 4278 carbon filter, OZO-B5 ozonizer (2 pieces), and filter with granular filling "Sorbent MS".
The elements of the installation are proposed to be mounted in a container of the 1AAA type, with overall dimensions LxWxH, m: 12192 x 2438 x 2896. The elements were placed using a 3D model in a CAD program (Fig. 3). Savings of the unit are about 332.2 thousand roubles.

5. Conclusion
The article presents an installation that allows reducing the concentration of the original pollutants formed in the body of the water-filling dam to the MPC standards for discharge. The installation consists of the following elements: a reagent tank, a static mixer, a horizontal settler, a coal filter, an ozonation station, and a filter with a sorbent load "Sorbent MS". All elements are mounted in a 1AAA container, which allows the unit to be moved to the dam construction site. The container is fixed on special supports for trucks trailers. In addition to treating water from water-filled dams, this installation will allow cleaning surface runoff. For example, runoff from the territory of enterprises or storm drains from urban areas.

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