Study of the temperature requirements for ponds of treatment facilities for Eichhornia cultivation

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Abstract. The article shows the need for desalination of underground waters in the city of Shakhty pumped out from old mine workings. The existing scheme of purification of pumped underground waters from iron is presented. There is a high content of salts in the purified waters, which pollute the river. The positive qualities of phyto-purification with the use of water hyacinth - Eichhornia are considered. A model for predicting a decrease in temperature in the winter period, developed on basis of the results of studies of water temperature requirements in ponds of sedimentation tanks of mine water, is presented.

1 Introduction

Water on our planet is the most important component of life, therefore, the state of water resources largely determines the environmental safety of entire regions. Currently, in many places on the planet, there is a shortage of fresh water. The problem of water quality is no less acute. Human activities make a huge contribution to the deterioration of the state of water bodies. A special place in the violation of the ecological state of rivers and lakes is occupied by the mining industry, since its functioning is associated with the impact on the hydrogeological situation of vast territories [1-3].

In the process of mining operations, millions of tons of rocks and minerals are extracted [4-5]. After ore processing, tailings are stored in dumps, which are exposed to atmospheric precipitation [6-7]. Groundwater, which is the second largest in terms of volume after the world's oceans, is also subject to intense negative impact. Opening up and pumping out huge volumes of water to the surface of the earth during the long service life of mining enterprises is accompanied by the removal of large amounts of solid particles and dissolved salts, since water is an excellent solvent. Pumping volumes often do not allow to fully ensure high-quality purification of groundwater from salts, which leads to pollution of water bodies [8].

2 Significance of the problem

Unfortunately, with the end of operation of mining enterprises, the degree of negative impact does not decrease. The development of fields of mineral resources in vast territories is

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accompanied by the disturbance of mountain ranges and the formation of a hydraulic connection between aquifers and a deep layer discharge. This brought about an increase in the volume of mine water pumping. During the operation of mines and ore mines, water was purified at each enterprise.

On the territory of the Eastern Donbass, after the closure of mines, the flooding of rock mass began, which required arrangement of dewatering to prevent flooding of residential areas. For this, in the City of Shakhty, on the territory of former mines, three sections had been created for pumping underground water from old mine workings. The volume of pumped water in the section of Glubokaya mine reached 930 m^3/hour, and the wastewater consumption of the entire city was 750 - 920 m^3/hour. With a dry residue of up to 9 kg in 1 m^3 of groundwater, the iron content reached 0.3 kg. Since old treatment facilities were designed for a much lower water consumption, at the initial stage of the drainage operation, pollution of the Kadamovka River was catastrophic (Fig. 1).

Fig. 1. Pollution of the Kadamovka River

In the waters of Glubokaya mine, iron is contained in a mixed sulfate and hydrocarbonate bivalent forms Fe_2SO_4 and $Fe(HCO_3)_2$ with a small content of a highly soluble trivalent form $Fe(SO_4)_3$. In view of the acidic reaction of groundwater, water purification from iron compounds represented mainly by Fe^{2+} ions is a very difficult task [8]. However, with the new treatment facilities including an aerator, a sectional sedimentation tank and four shallow ponds, the issue of iron removal was effectively resolved. With the passage of mine water enriched with air oxygen through a cascade of ponds, the iron content decreased by almost 1000 times, and suspended particles - by half. Nevertheless, a significant reduction in the salt content was not observed.

The large amount of calcium and magnesium salts remaining in the water currently creates a salinity threat, since pollution of small rivers during operation of the mines reached such a level that they have practically lost the ability to self-purify. Analysis of modern desalination systems shows that with such a volume of treatment, capital and operating costs can reach very high values, therefore, the task of purifying wastewater from salts has not lost its relevance.

Due to the increase in the proportion of nitrogen- and phosphorus-containing organic substances in urban wastewater, phyto-purification methods are increasingly used for disinfection. In this case, a fairly high efficiency is shown by the use of macrophytes (higher aquatic vegetation), which are capable of accumulating, utilizing and transforming many pollutants, contributing to the process of self-purification of water bodies [9-12]. However, these plants require disposal, which is associated with high costs.

3 Discussion of research results

Analysis of world and domestic experience in phyto-purification of wastewater shows that a floating aquatic plant - Eichhornia - which can oxidize and break down industrial and organic wastewater into simple elements using them as food [13] deserves special attention. Moreover, oxygen acts as an oxidizer, which it produces itself. This plant grows at a high speed, cleaning household and industrial wastewater from almost all harmful impurities, including poisons and bacteria. Moreover, the dirtier the reservoir, the faster the eichhornia (water hyacinth) grows and reproduces.

This aquatic plant is thermophilic and has spread in fresh water bodies of all tropical countries as a malicious aquatic weed, and now it is used to cleanse lakes listed in the list of the dead, small rivers and reservoirs, and all kinds of dirty drains [13]. Numerous studies abroad and in our country indicate that Eichhornia very effectively cleans waste water from chlorides, sulfates, nitrates, ammonium nitrogen and pathogenic microorganisms, while COD is significantly reduced (five-fold) and BOD is reduced two-fold. Eichhornia is also able to clarify, deodorize wastewater, cause death of E. coli, salmonella, enterococcus and other pathogenic bacteria, absorb nutrient compounds, accelerate the process of nitrification, mineralize oil products and neutralize many toxins [14].

The most favorable for vegetation of Eichhornia are air temperatures above + 18 °C and water temperatures from + 22 °C. At temperatures below + 8 °C, water hyacinth reduces its wastewater treatment ability, and with a prolonged decrease in air temperature below + 6 °C, plants die off [15]. However, the experience of cultivating this plant in Russia shows that in the summer it is capable of vegetating up to the latitude of Arkhangelsk.

Studies of the temperature in the Rostov region over the past three years show that under the most favorable conditions, the growing season of Eichhornia in open water bodies is no more than 9 months, therefore, it cannot be used for sewage treatment in our region without interruption.

A study of the operating modes of drainage plants at Glubokaya former mine shows that year-round, when pumping from a hundred-meter depth of 930 m^3/h, the water temperature is 19.1 °C. Therefore, to determine the possibility of cultivating water hyacinth in the winter period, the temperature regime of the cascade of settling ponds of treatment facilities was studied.

With regard to sedimentation ponds, the basis for calculating heat losses from open water bodies is the heat balance equation (1), in which the following factors must be taken into account [16]: total heat supplied as a result of the discharge of pumped water; total (direct and scattered) solar radiation; effective radiation of the water surface; heat exchange with the atmosphere due to evaporation and convection.

$$\frac{c \cdot \rho \cdot H \cdot dT_s}{k \cdot dt} + \alpha_e (e_m - e) + \alpha_c (T_s - T_a) - R - \frac{\Delta S}{\omega} = 0 \qquad (1)$$

This equation contains 9 variables characterizing climatic parameters and 6 characteristics of drainage and sedimentation ponds. It is solved by one of the numerical methods for integrating differential equations. That is, the process of data preparation and solution is quite time consuming. Therefore, it was decided to draw up a regression model based on the observations made to predict the thermal regime of sediment ponds.

The model development algorithm is as follows.

For specific meteorological indicators observed during winter periods of 2017 - 2019, and measurements of water temperature in ponds, a sample of 39 positions was compiled at different periods of time. The air temperature and humidity were measured with an MG4+ electronic thermohygrometer. The wind speed was measured with a vane anemometer, and the water temperature was measured with a UT71C multimeter with a TK thermocouple.

Temperature measurements on the pond mirror were made using a telescopic pole considering temperature measurements and calculations of average values of each pond. The total calculated sample was 156 positions. The results obtained were processed in Statistika program, which made it possible to obtain equation (2).

An analysis of statistical indicators (Fig. 2 - 3) shows that a standard error of the equation is 0.073, and the level of adequacy is 0.99.

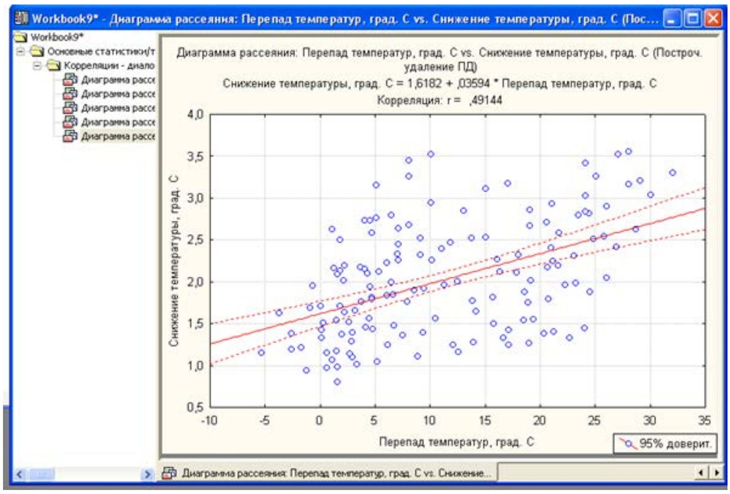

Fig. 2. Scatter plot of an array of meteorological observations.

$$\Delta T = 0{,}1365 \cdot t + 0{,}1785 \cdot W + 0{,}00027 \cdot \varphi + 0{,}000045 \cdot S + 0{,}1686 \cdot \Delta t - 1{,}777 \qquad (2)$$

where: ΔT – decrease in water temperature, °C; t – outdoor temperature, °C; W - wind speed, m/s; φ – relative humidity, %; S – sediment pond area, m^2; Δt – temperature difference between the average surface temperature of the pond mirror and the outside air, °C.

Comparison of the observation results and the calculated values of the temperature decrease made it possible to note that the maximum deviation in one sample position was 18.2%.

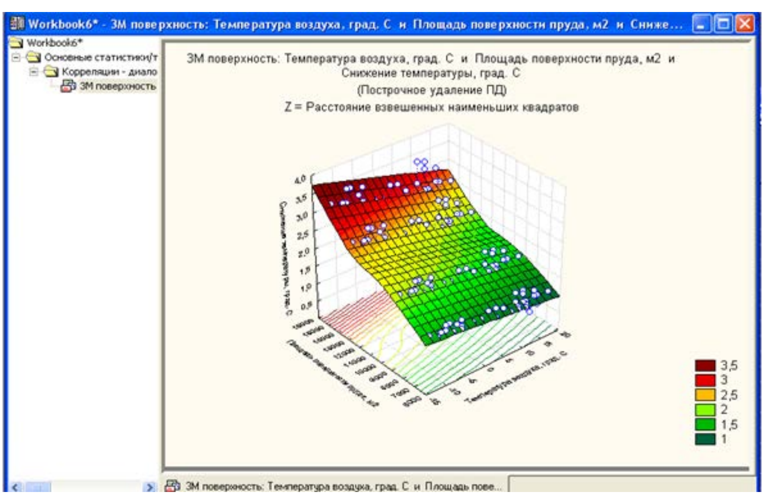

Fig. 3. Influence of air temperature and surface area of the pond on water temperature reduction.

During the five-day observation period in January 2018, at the exit from the fourth pond of the sedimentation tank, at an average air temperature of 9 °C, the water had a temperature from +8.9 °C to 17.2 °C. During the relatively long cold period of January - February 2019, outside the sedimentation tanks, the water temperature did not drop below 11.4 °C.

The given equation will allow, according to the data of meteorological observations and the temperature of the wastewater entering sedimentation ponds, to predict feasibility and period of productive vegetation of Eichhornia at various treatment facilities.

After determining the influence of the growing season temperature on the productivity of purification with Eichhornia, it will become possible to regulate the performance of phyto purification.

The research results show that the temperature requirements of treatment facilities makes it possible to cultivate Eikhhornia almost all year round, if the ponds are protected from wind, at a distance of 0.2 m from the water surface the average air temperature is lower than the water temperature by 2.3 °C, with a wind speed of no more than 3 m/s.

4 Conclusions

The water pumped out of old underground workings at the outlet of treatment facilities contains a large amount of salts and is considered insufficiently treated, which requires development of engineering solutions for additional treatment.

The world experience of phyto-purification testifies to the effectiveness of Eichhornia, which can be cultivated in the summer even in the northern regions of Russia, while removing most of the pollutants.

The study of the temperature regime of sedimentation ponds on the territory of the former Glubokaya mine enables to ensure a relatively favorable vegetation regime of Eikhhornia for 9-11 months a year.

The developed regression equation (2) will make it possible to predict feasibility and period of productive vegetation of Eichhornia at various treatment facilities using the data of meteorological observations and the temperature of wastewater entering sedimentation ponds.

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