Development of a technology for non-reagent deironing of water for power facilities

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Abstract. As part of the study of the possibility of using hydrodynamic water treatment for preliminary deferrization of artesian water before feeding it to a deep osmotic treatment unit. It was found that in the process of water treatment in a hydrodynamic device with constant air ejection, the complete oxidation of iron (II) compounds occurs. The influence of the volume of consumed air and the number of processing cycles on the efficiency of the deferrization process has been studied. Data were obtained on the distribution (size / ratio) of air bubbles in the fluid flow during its hydrodynamic treatment. Based on the results obtained, it was concluded that when hydrodynamic treatment is combined with ceramic ultra filtration membranes, the iron removal rate is 99%, while hardness salts, hydrogen sulfide and other pollutants are partially removed from the water, and complete disinfection occurs.

1. Introduction

The most widespread method of water treatment for the needs of energy facilities is reverse osmosis. Unfortunately, artesian or river water contains significant concentrations of iron compounds, which negatively affects the service life of reverse osmosis membranes. A prerequisite for the efficient operation of reverse osmosis post-treatment systems is the maximum removal of iron compounds from water [1].

One of the possible options for water purification from iron compounds is its reagent treatment with solutions of strong oxidants (hypochlorite, peroxide, potassium permanganate); however, the use of these reagents before the reverse osmosis system is undesirable due to the negative effect of the oxidant on the reverse osmosis membrane [2].

Today, the most common and at the same time simple, but not sufficiently effective method of purifying natural waters from ions of dissolved iron is based on simplified aeration and oxidation of iron by atmospheric air, followed by the removal of the formed insoluble iron compounds on mechanical filters (polymer, bulk, mechanical) [3].

The main disadvantage of this purification method is the low rate of the oxidation process and, as a consequence, an increase in the process time with a concomitant complication of the purification apparatus. The increase in contact time is due to the specificity of the interaction of iron ions with air oxygen dissolved in water. The oxidation reaction occurs at the interface between the air bubble and water, which means it, is limited by the contact area. The solubility of oxygen in water under normal conditions is about 9.0 mg/l [4], and, therefore, the maximum concentration is usually reached at the very beginning of the aeration process. In this regard, practically the only available way to intensify
the process of oxidation of iron ions with air oxygen is a significant increase in the contact surface of the phases at the water-air bubble interface.

In practice, a significant increase in the contact surface of the liquid-gas phases can be obtained either by creating sufficiently small liquid droplets (the so-called water fog), or by creating sufficiently small gas bubbles in the liquid. Taking into account the technological design of the process, as well as its economic component, saturation of the liquid with finely dispersed gas bubbles is more rational.

Methods such as air ejection or bubbling (for example, through finely porous ceramics) can further reduce the size of air bubbles in order to further increase the contact surface of the water-air phases, however, even for such methods there is a limitation on the attainable minimum bubble size (about 280 micrometer) [5].

To further increase the degree of dispersion of the gas in the liquid and reduce the bubble size, an effective way is the imposition of vibration influences or acoustic vibrations propagated in the processed multiphase system. In this case, the greatest effect can be achieved with a certain combination of parameters of the impact on the multiphase medium and the dynamic properties of the medium itself [6-7]. The optimal combination of the geometry of the reservoir, the physicochemical properties of the water-air mixture and the hydrodynamic parameters of the fluid movement provides a sharp increase in the degree of air dispersion, and, as a consequence, the intensification of the oxidation process of ferrous iron.

Literature sources [8] describe in detail methods for calculating the natural frequencies of a multiphase liquid-gas system in vessels of various shapes, when they coincide with the frequencies of an external influence, the rate of mass transfer processes increases significantly, dispersion increases, an intense directional movement of gas bubbles occurs, which outwardly resembles a violent "boiling" in the entire volume of the vessel.

2. Materials and methods
Determination of the content of iron (II) ions was carried out on a DR 2800 spectrophotometer (HACH USA), and the determination of the total content of metals on an atomic emission spectrometer with a magnetic plasma "SpectroSky" (Russia) [9].

To assess the degree of air dispersion and the possibility of oxidation of iron compounds in the process of hydrodynamic treatment, we used an installation (figure 1) assembled at the Department of Innovative Materials and Corrosion Protection of the Russian Chemical Technology University named after I. DI Mendeleev [10]. The hydrodynamic device is made of stainless steel 12X18H9T and allows air to be ejected directly into the working chamber by imparting a rotational velocity component to the flow, the presence of which leads to the emergence of centrifugal mass forces in the flow and the formation of a radial static pressure gradient. In this case, the velocity of the liquid at the wall of the working chamber significantly exceeds its average value, and at the axis, there is a sharp drop in pressure and the release of the smallest air bubbles from the liquid, caused by the cavitations phenomenon, contributing to the intensive dispersion of the gas. The flow rate of air ejected into the hydrodynamic device was controlled by rotameter.

Model and real artesian treated in a hydroacoustic device and assessed the size of the formed dispersed air bubbles in distilled water, and also measured the sizes of Fe (II) and Fe (III) forms during hydrodynamic treatment and after filtration through a ceramic membrane filter with a pore size 0.05-0.5 micrometer.

The bubble size was determined using the "Imagescope" software by analyzing photographs obtained with a microscope.

3. Results
At the exit from the hydrodynamic device, it was possible to achieve a sharp increase in the specific surface area of phase contact and a high degree of homogenization due to the impact on the gas-liquid mixture of the field of centrifugal forces, which contribute to the intensive fragmentation of gas bubbles and renewal of the interphase surface (figure 2).
Figure 1. Schematic diagram of the operation of the hydrodynamic device: d - diameter of the inlet channel cameras (RK); R is the radius of the RK; L is the length of the RK.

Figure 2. Dispersed air bubble size distribution.

From the data in figure 2, it can be seen that the sizes of air bubbles at the outlet from the hydrodynamic device are in the range of 2.4-10.0 microns. Most of the bubbles (up to 40% of the total) had a size of 5 microns; the average size is 5 microns. The calculated average bubble ascent velocity was approximately 0.1 mm/s. Based on these data, it can be assumed that the processes of heterogeneous oxidation of iron compounds at the air bubble - water phase boundary will occur much faster due to an increase in the contact area.

The effect of the number of water treatment cycles without oxygen ejection is shown in table 1. From the data in table 1, it can be seen that a single passage of water through a hydrodynamic device allows a 68% decrease in the concentration of dissolved iron (II), the second cycle of treatment reduces the concentration of iron (II) to the MPC standard, the third cycle reduces the concentration of iron (II) to the level of the detection limit techniques. It should be noted that the residence time of the
treated water in the hydrodynamic device is 1-3 seconds, and the linear velocity of the water is in the range of 25-32 m/s.

Table 2 shows the dependence of the residual content of iron (II) ions depending on the volume of ejected air into the working chamber.

Table 1. Efficiency of removal of iron and manganese compounds from the model water solution.

| Index        | Feed water | Cycle 1 | Cycle 2 | Cycle 3 | Cycle 4 | Cycle 5 |
|--------------|------------|---------|---------|---------|---------|---------|
| Iron (II)    | 0.65       | 0.21    | 0.09    | 0.01    | 0.00    | 0.00    |

Table 2. Efficiency of removal of iron and manganese compounds from the model water solution.

| About air, Vg/Vzh, % | Source water | 0.0 | 1.5 | 3.0 | 4.5 | 6.0 | 7.5 | 9.0 | 10.5 |
|---------------------|--------------|-----|-----|-----|-----|-----|-----|-----|------|
| Iron content, mg/l  | 0.65         | 0.21| 0.13| 0.09| 0.05| 0.18| 0.23| 0.31| 0.37 |

From the data in table 2 it can be seen that with a volume of ejected air equal to 4.5%, the maximum possible oxidation efficiency of iron (II) compounds is achieved. An increase in the volume of ejected air in excess of this amount leads to a sharp change in the hydrodynamic treatment of the water flow, which in turn significantly reduces the efficiency of oxidation of iron (II) ions.

4. Conclusion

According to the results of the experiments, it was found that the use of hydrodynamic treatment of natural water makes it possible not only to increase the degree of air dispersion, which is confirmed by a significant decrease in the size of the formed dispersed air bubbles, but also to lead to a significant intensification of the process of heterogeneous oxidation at the bubble-water interface. This process is due to the formation of cavitations phenomena in the processed natural water during its processing.

The characteristics of the air dispersion process have been studied - in particular, data on the size distribution of dispersed air bubbles formed as a result of hydrodynamic treatment have been obtained. It was found that most of the air bubbles formed during the treatment of water have a size of 2.5 to 6 microns, which, on average, is an order of magnitude smaller than when bubbling through fine-porous ceramic membranes is used [11].

It was found that for the complete oxidation of iron compounds in water, only 3 processing cycles are sufficient, while the optimal volume of ejected air was determined - 4.5 deironing percent. Taking into account the design features of the hydrodynamic device, it is possible to replace the air ejection with ozone, which will not only further increase the cleaning efficiency, but also enhance the disinfecting effect.

The data obtained will further expand the scope of application of hydrodynamic treatment, which has recently been gaining more and more popularity, in view of the fact that hydrodynamic treatment of natural waters does not require additional use of chemical reagents, and, therefore, the absence of additional effluents, and at the same time has a fairly simple and reliable hardware design [12-16]. The above factors, in turn, contribute to the improvement of the ecological component of the water treatment process as a whole.

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