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RANGING OF EFFECTIVENESS AND FORMALIZATION OF WORKING REGIMES OF COMPLEX SYSTEM FOR WATER DEFERRIZATION

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Abstract

The ultrasonic magnetic adsorptive system consisting of the ultrasonic oscillator, magnetic axially symmetric system and filter of adsorptive purification was used to reduce the ferrum concentration in the water. It was estimated that under the use of all units of such system the deferrization efficiency was 64.39%. The determined regression equation of change of ferrum concentration stated that efficiencies of each couple of units of system of water deferrization were not summed up, but superimposed, and the use of all units provided a synergistic action.

Introduction

The water deferrization is one of the most complicated problems of water conditioning. The single universal economically sound method of purification for any conditions and any fluid does not exist. That’s why it is important to develop the modern, effective, resource-saving, environmentally friendly system of water deferrization.

Mechanical and chemical methods are usually used for water medium purification from bioactive and suspended substances. High-molecular substances and electrolytes dissociated to ions in the liquid affect on the reliability and the durability of hydraulic equipment, and they give in to the traditional methods of refinement much more difficult. The physical methods like electromagnetic, acoustic, gravitational etc are more effective for admixtures reduction in the liquid composition [2, 3].

The two-level ultrasonic magnetic adsorptive system of water deferrization (UMASWD) was constructed in according with the analysis of methods and tools of treatment of fluids carried out by the authors.

The aims of the research:
- to find out the optimal regime of attraction of ultrasonic, magnetic and adsorptive units, which provides the minimal level of concentration of ferrum ions in the water medium.
- to carry out the formalization of this attraction for definition of interactions of units of UMASWD.

Materials and methods

The criterion of minimization the number of attempts was used for the research [1]. As a result, the complete-factor experiment of $2^k$ type was chosen. The quantity of levels of factor variations equalled 2, factors – 2, attempts – 8, that were quite enough for the attainment of neighbourhood of an optimum point. The number of measuring in the one point was taken 1, and for guarantee of reliability $P=0.95$ the Student's coefficient amounted to 12.706. The matrix of design of experiments is shown in the following section.

UMASWD (Fig. 1) consisted of ultrasonic oscillator (UO) and magnetic axially symmetric system (MASS) on the first level and filter of adsorptive purification (FAP) on the second level. At UO the treatment of liquid by ultrasonic power streams provided restructuring of medium by ultrasonic cavitations, which were obtained during the adiabatic compression of cavities and the formation of low-temperature plasma under flapping of cavitations bubbles. At MASS the ferrum ions were directed to the periphery of device by means of specific magnetic field. This allowed to move them out from the water flow to the external store. The turning on/off of UO was carried out by control console of UO, MASS – by removal of magnets, FAP – by switching of corresponding pipeline valve. These valves operated automatically and were controlled by control unit of filter of adsorptive purification. The water was fed into UMASWD by unregulated pump (UP) from reservoir (R) and was directed to necessary units by means of corresponding valves (V). The fluid consumption was measured by ultrasonic flowmeter (F), the pressure – by manometer (M). And the temperature was taken using the bimetal thermometer (T).
The water samples were taken from taps (Tp1) and (Tp2) in compliance with GOST 24481-80 “Drinking water. Sampling”. The chemical water analyses were carried out in compliance with GOST 4011-72 “Drinking water. Methods for determination of total iron” and GOST 4151-72 “Drinking water. Method for determination of total hardness”.

**Results and Discussion**

The dependence of concentration of ferrum ions of water medium after UMASWD and time of saturation of ion exchanger of FAP from the use of various combinations of UO, MASS and FAP was investigated. For such research main factors were assigned: the working regime of UO was marked as \( x_1 \), FAP – \( x_2 \), MASS – \( x_3 \). And the status variable was the change of ferrum concentration in the water.

The working pressure was 0.1 MPa, the water flow – 28 m³/hour, the UO power – 750 Wt, the water temperature – 297 K (24 °C), the induction of magnetic field – 1.08 Tl. Accordingly to constructive features of FAP height of layer of ion exchanger amounted to 0.35 m, and the total mass of ion exchanger of one FAP – 14,341 kg.

During experiment the water cyclically passed through corresponding units of UMASWD. FAP1 and FAP2 were identical units, and just one of them was involved in the work. The effectiveness of water deferrization was determined as ratio of difference of final concentration of ferrum ions and initial (i.e. the part of ferrum ions trapped from water) to initial after 30 min of work of UMASWD. The initial concentration of ferrum was 1.32 mg/dm³. The test log is shown in the Table 1.

Thus deferrization efficiency under the combined action of UMASWD units was: MASS, UO, FAP – 64.39 %; MASS, FAP – 46.97 %; MASS, UO – 45.45 %; UO, FAP – 45.45 %; MASS – 33.33 %; UO – 45.45 %, FAP – 60.61 %. Under the use of all units of UMASWD the deferrization efficiency was a little more than efficiency of most effective unit of them (FAP). Under the use of MASS or UO together with FAP the deferrization efficiency was decreased below the deferrization level of FAP. It was explained by the increasing of internal energy of particles on the first stage of treatment and, as a consequence, their passing through the second stage.
### Table 1. Test log for determination of effectiveness of each unit of UMASWD

<table>
<thead>
<tr>
<th>№ test</th>
<th>Item of research program</th>
<th>Planning</th>
<th>FAP in work</th>
<th>Place of taking of water sample</th>
<th>Time $t$, min</th>
<th>Concentration</th>
<th>Turbidity, mg/dm$^3$</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fe, mg/dm$^3$</td>
<td>Ca and Mg mmole/dm$^3$</td>
</tr>
<tr>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fe: 1.32, Ca: 6.90, Mg: 2.9</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fe: 0.30, Ca: 6.90, Mg: 1.45</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fe: 0.52, Ca: 7.00, Mg: 2.03</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fe: 0.52, Ca: 6.90, Mg: 1.62</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fe: 0.44, Ca: 7.00, Mg: 2.61</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Fe: 0.72, Ca: 6.90, Mg: 3.36</td>
</tr>
</tbody>
</table>

The ferrum concentration in the water after the action of various units of UMASWD depending on working time was continuously decreased in case of use MASS and UO and was decreased to specific point concerned with the saturation of ion exchanger in case of use various combinations with FAP-unit. After this point the ferrum concentration was gradually increased to initial. The time of saturation of ion exchanger of FAP was 30 minutes.

The matrix of design of experiments with relative variables is shown in the Table 2 in columns 1-5. The regime of turning on of unit corresponded to high level (+1), and the regime of turning off – to lower level (-1).

### Table 2. Plan for calculation of regression equation of change of ferrum concentration

<table>
<thead>
<tr>
<th>№ test</th>
<th>$x_0$</th>
<th>$x_1$</th>
<th>$x_2$</th>
<th>$x_3$</th>
<th>$x_1 x_2$</th>
<th>$x_1 x_3$</th>
<th>$x_2 x_3$</th>
<th>$x_1 x_2 x_3$</th>
<th>$Y_u$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>0.47</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>-1</td>
<td>1</td>
<td>1</td>
<td>-1</td>
<td>-1</td>
<td>1</td>
<td>-1</td>
<td>0.70</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1</td>
<td>-1</td>
<td>1</td>
<td>-1</td>
<td>1</td>
<td>-1</td>
<td>-1</td>
<td>0.72</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>-1</td>
<td>-1</td>
<td>1</td>
<td>1</td>
<td>-1</td>
<td>1</td>
<td>1</td>
<td>0.88</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>1</td>
<td>-1</td>
<td>1</td>
<td>-1</td>
<td>1</td>
<td>-1</td>
<td>-1</td>
<td>0.72</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>-1</td>
<td>1</td>
<td>-1</td>
<td>1</td>
<td>-1</td>
<td>-1</td>
<td>1</td>
<td>0.52</td>
</tr>
<tr>
<td>7</td>
<td>1</td>
<td>1</td>
<td>-1</td>
<td>-1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>-1</td>
<td>0.72</td>
</tr>
<tr>
<td>8</td>
<td>1</td>
<td>-1</td>
<td>-1</td>
<td>-1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1.32</td>
</tr>
<tr>
<td>9</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1.32</td>
</tr>
</tbody>
</table>

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By means the data from Table 1 and the plan for calculation (Table 2) the coefficients in the regression equation of change of ferrum concentration were determined. The results of calculation of coefficients of regression equation are shown in Table 3.

Table 3. Calculation of regression equation of change of ferrum concentration

<table>
<thead>
<tr>
<th></th>
<th>Calculation</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>b0 0,470</td>
</tr>
<tr>
<td>1</td>
<td>b1 -0,700</td>
</tr>
<tr>
<td>2</td>
<td>b2 0,720</td>
</tr>
<tr>
<td>3</td>
<td>b3 -0,720</td>
</tr>
<tr>
<td>4</td>
<td>b12 0,720</td>
</tr>
<tr>
<td>5</td>
<td>b13 -0,720</td>
</tr>
<tr>
<td>6</td>
<td>b23 0,720</td>
</tr>
<tr>
<td>7</td>
<td>b123 0,720</td>
</tr>
<tr>
<td>8</td>
<td>0,756 -0,099</td>
</tr>
<tr>
<td>9</td>
<td>-0,154 -0,064</td>
</tr>
<tr>
<td>10</td>
<td>0,091 0,001</td>
</tr>
<tr>
<td>11</td>
<td>0,046 -0,109</td>
</tr>
</tbody>
</table>

Thus the regression equation of change of ferrum concentration was:

\[
\min \bar{y}_i = 0,756 - 0,099 \cdot x_1 - 0,154 \cdot x_2 - 0,064 \cdot x_3 + \\
+ 0,091 \cdot x_1 \cdot x_2 + 0,001 \cdot x_1 \cdot x_3 + 0,046 \cdot x_2 \cdot x_3 - 0,109 \cdot x_1 \cdot x_2 \cdot x_3
\]

In the equation the coefficients near members \(x_1, x_2, x_3\) showed that efficiencies of each couple of units of UMASWD were not summed up, but superimposed. And the coefficient near member \(x_1 \cdot x_2 \cdot x_3\) meant the synergistic action of all units of UMASWD. Comparing coefficients near members \(x_1, x_2, x_3\) it was obvious that FAP exerted the most influence on the change of ferrum concentration, consequently, it was the most effective unit.

**Conclusions**

1. The deferrization efficiency under the combined action of UMASWD units: MASS, UO, FAP – 64,39 %; MASS, FAP – 46,97 %; MASS, UO – 45,45 %; UO, FAP – 45,45 %; MASS – 33,33 %; UO – 45,45 %; FAP – 60,61 % with the working pressure 0,1 MPa, the water flow – 28 m³/hour, the UO power – 750 Wt, the water temperature – 297 K (24 °C), the induction of magnetic field – 1,08 Tl.
2. Under the use of all units of UMASWD the deferrization efficiency was a little more than efficiency of most effective unit of them (FAP). Under the use of MASS or UO together with FAP the deferrization efficiency was decreased below the deferrization level of FAP. It was explained by the increasing of internal energy of particles on the first stage of treatment and, as a consequence, their passing through the second stage of purification.
3. From the determined regression equation of change of ferrum concentration it was stated that efficiencies of each couple of units of UMASWD were not summed up, but superimposed, and the use of all units provided a synergistic action.
4. The optimal regime of UMASWD functioning is regime with the attraction of MASS, UO and FAP units. It provided the reduction of ferrum concentration in the water from 1,32 mg/dm³ to 0,47 mg/dm³.

**References**