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INVESTIGATION OF ULTRASONIC MAGNETIC ADSORPTIVE SYSTEM OF WATER PURIFICATION

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Для зниження концентрації заліза у воді використовувалася ультразвукова магнітна адсорбційна система. Було встановлено оптимальний режим роботи системи при використанні різних її складових, а також оптимальний час роботи з регенерацією іоніту та без неї.

Ключові слова: очищення води, магнітна система, адсорбційний фільтр, генератор ультразвукових коливань.

Для снижения концентрации железа в воде использовалась ультразвуковая магнитная адсорбционная система. Были определены оптимальный режим работы системы при использовании разных ее составляющих, а также оптимальное время работы с регенерацией ионита и без нее.

Ключевые слова: очистка воды, магнитная система, адсорбционный фильтр, генератор ультразвуковых колебаний.

The ultrasonic magnetic adsorptive system was used to reduce the ferrum concentration in the water. The optimal working regime of system and optimal working time (with and without regeneration of ion exchanger) were determined.

Key words: water purification, magnetic system, adsorptive filter, ultrasonic oscillator.

Introduction. According to the Law of Ukraine "On the National program of water industry development for 2002–2011" (January 17, 2002 № 2988-III) the requirements of industry in water resources, which decreased by 41 % compared to 1990 and reached 49,3 km^3 in 1999, met water from surface sources – 14 %, underground sources – 3 %, sea sources – about 2 %, recycling and re-coherent water – almost 82 %. The industry owns about 99 % of reusable water capacity.

Mechanical and chemical (including biological) methods are usually used for water medium purification from bioactive and suspended substances. The physical methods like electromagnetic, acoustic, gravitational etc are more effective for admixtures reduction in the liquid composition.

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 effective, resource-saving, environmentally friendly system of water deferrization.

Along with the wide use of ultrasonic and magnetic treatment of water medium, there are no generally accepted and experimentally verified theoretical principles, which explain the physical and chemical processes occurred in such water treatment.

The two-level ultrasonic magnetic adsorptive system of water purification (UMASWP) 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 UMASWP;

to find out the optimal working time of UMASWP taking into consideration the regeneration of adsorptive unit – filter of adsorptive purification (FAP).

Ultrasonic methods. The liquid treatment by ultrasonic power streams provides the restructuring of medium by ultrasonic cavitations, which are obtained during the adiabatic compression of cavities and the formation of low-temperature plasma under flapping of cavitations bubbles. This regime promotes to destruction of macromolecules of impurities, which contaminate the liquid. The advantages of ultrasonic methods are the destruction of globules of impurities in working flow and the increasing of molecules chemical activity.

Magnetic methods. The magnetic treatment of water medium has a number of advantages relatively other physical methods [1]: it acts on all groups of admixtures; it acts both on chemical and physical processes in the liquid medium; it leads to the release of internal energy of medium in consequence of the destruction of electromagnetic connections between molecules of liquid and admixtures; it activates the water medium. The most important preference of magnetic treatment of water medium from ions of admixtures is possibility to handle the ions movement in the magnetic field, in other words, the possibility of direct removing of ions of admixtures from the flow. The devices of magnetic treatment of water medium have found a wide application in many branches of industry, this confirms their efficiency.

The combination of ultrasonic and magnetic treatment of water was chosen for further study. The ultrasonic treatment affects the macrostructure of impurities, magnetic – the microstructure. Thus, a wide range of impurities is treated according to their sizes.

Structure of UMASWP. UMASWP (Fig. 1) consists of ultrasonic oscillator (UO) and magnetic axially symmetric system (MASS) on the first level and filter of adsorptive purification (FAP) on the second level. The first level of UMASWP provides the activation of all range of admixtures structures for their following removal: UO restructures the macrostructures of admixtures, MASS – microstructures. As a filtration load natural zeolite of clinoptilolite type (K_2, Na_2, Ca) [$AI_2Si_{7,5\text{-}11,0}O_{19,0\text{-}26,0}$] (6–8)$H_2O$ was chosen.

At MASS the ferrum ions are 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 (CU FAP).

Planning of the experimental researches. The criterion of minimization the number of attempts was used for the research [2]. 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 neighbour-hood of an optimum point. The number of measurements in the one point was taken 1, and for guarantee of reliability P = 0,95 the Student's coefficient amounted to 12,706.

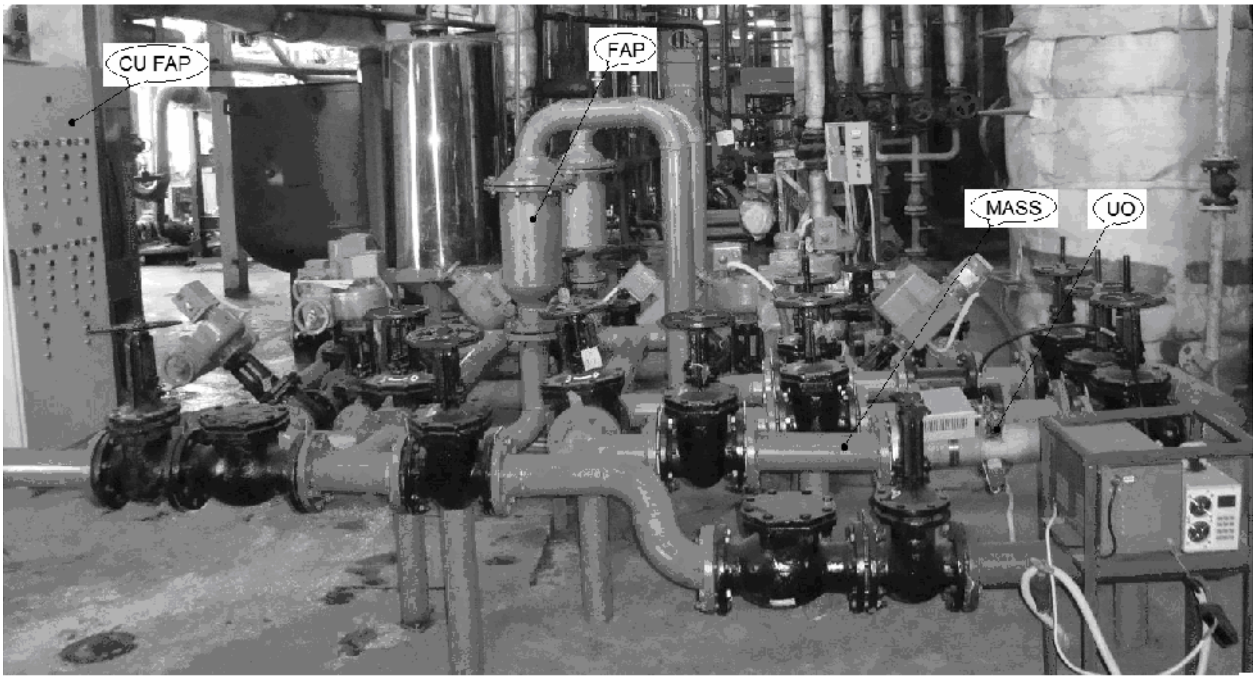

Fig. 1. The ultrasonic magnetic adsorptive system of water purification

The dependence of concentration of ferrum ions of water medium after UMASWP 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 (mode) 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.

Experimental stand and measurement tools. The hydraulic circuit of UMASWP is shown in the Fig. 2. The water was fed into UMASWP 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).

As an ultrasonic flowmeter (F) "ULTRAHEAT 2WR7" (type 2WR783, Germany) was used. The accuracy class of this flowmeter is 2 (SSTU 3339-97).

Pressure P (MPa) was measured by manometer (M) "DM 05100" State Standard 2405-88. Its range of pressure is from 0 MPa to 1,6 MPa. Its accuracy class is 1,5 (SSTU 3339-97).

Temperature T (K) was measured by bimetallic thermometer (T) "TB-100-50" (standard version with radial connection) TSU 33.2-14307481-033:2005. The temperature measurement range is 108-223 K. Accuracy class is 1,5 (SSTU 3339-97). Scale division is 0,5 K.

The FAP saturation time t (s) was measured by chronometer "Nitech" (Moldova).

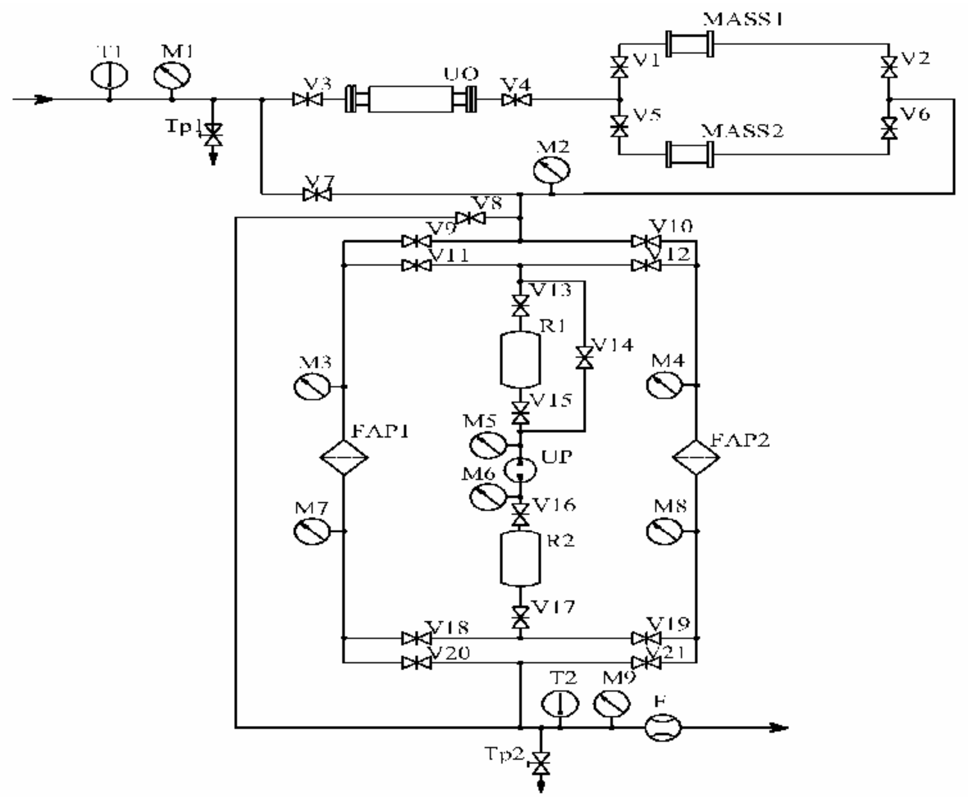

Fig. 2. Hydraulic circuit of ultrasonic magnetic adsorptive system of water purification

The induction of magnetic field *B* (Tl) in the ring gap of UMASWP was measured by teslameter "Mayak-3M". Its measurement range of magnetic induction is 0,01-2,00 Tl. Its accuracy class is 1,5 (SSTU 3339-97).

The variation of length distribution of the magnetic field was achieved by using different number of magnets (from 1 to 3). The length of the ring magnet was determined by using callipers "C-150-0,05" State Standard 166-89.

The water samples were taken from taps (Tp1) and (Tp2) in compliance with State Standard 24481-80 "Drinking water. Sampling". The chemical water analyses were carried out in compliance with State Standard 4011-72 "Drinking water. Methods for determination of total iron" and State Standard 4151-72 "Drinking water. Method for determination of total hardness".

The research of optimal regime of attraction units of UMASWP. The dependence of concentration of ferrum ions of water medium after UMASWP and time of saturation of ion exchanger of FAP from the use of various combinations of UO, MASS and FAP was investigated.

The working pressure was 0,1 MPa, the water flow – 28 m^3/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 UMASWP. 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 UMASWP. The initial concentration of ferrum was 1,32 mg/dm^3. The test log is shown in the Table 1.

The ferrum concentration in the water after the action of various units of UMASWP depending on working time is shown in the Fig. 3. It continuously decreases in case of use MASS and UO and decreases 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 gradually increases to initial.

Thus deferrization efficiency under the combined action of UMASWP 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 UMASWP 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 UMASWP

№ test	№ in research program	Planning			FAP in work	Place of taking of water sample	Time t, min	Concentration		Turbidity, mg/dm^3
		UO (x_1)	FAP (x_2)	MASS (x_3)				Fe, mg/dm^3	Ca and Mg mmole/dm^3	
1	1	-1	-1	-1	FAP2	before UMASWP	0	1,32	6,90	2,90
2	2.1	+1	+1	+1	FAP2	after UMASWP	30	0,30	6,90	1,45
					FAP2	after UMASWP	60	0,52	7,00	2,03
					FAP1	after UMASWP	20	0,60	6,43	3,07
					FAP1	after UMASWP	40	0,48	6,63	1,33
					FAP1	after UMASWP	60	0,44	6,73	0,93
					FAP2	after MASS	30	0,72	6,70	2,09
3	2.2	-1	+1	+1	FAP2	after UMASWP	30	0,76	7,00	3,48
					FAP2	after UMASWP	60	0,64	6,70	2,32
					FAP2	after MASS	30	0,60	6,70	2,96
4	2.3	+1	-1	+1	FAP2	after UMASWP	60	0,44	6,90	1,62
					FAP2	after MASS	30	0,72	6,80	3,36
5	2.4	-1	-1	+1	FAP1	after MASS	30	0,88	6,42	2,61
6	2.5	-1	+1	-1	FAP1	after UMASWP	20	0,30	6,53	0,87
					FAP1	after UMASWP	40	0,44	6,43	0,70
					FAP1	after UMASWP	60	0,52	6,63	0,70

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).

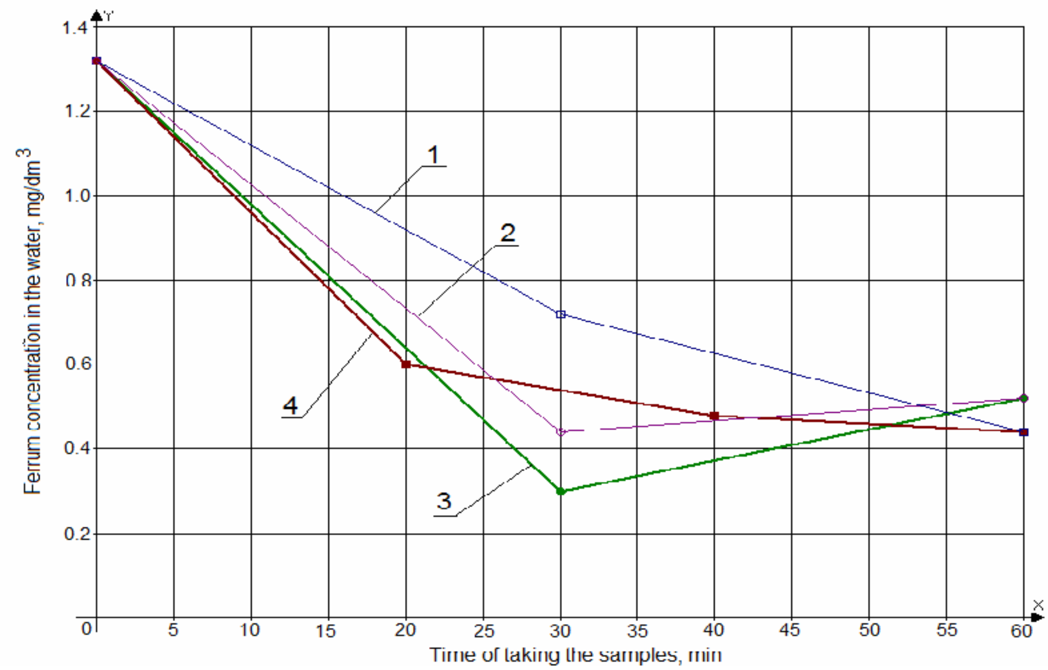

Fig. 3. The ferrum concentration in the water under the action of various units of UMASWP: 1 – MASS and UO; 2 – FAP1; 3 – MASS, UO, FAP2; 4 – MASS, UO, FAP1

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

№ test	x_0	Planning							
		x_1	x_2	x_3	$x_1\ x_2$	$x_1\ x_3$	$x_2\ x_3$	$x_1\ x_2\ x_3$	$\bar{y}_u$
1	1	1	1	1	1	1	1	1	0,47
2	1	–1	1	1	–1	–1	1	–1	0,70
3	1	1	–1	1	–1	1	–1	–1	0,72
4	1	–1	–1	1	1	–1	–1	1	0,88
5	1	1	1	–1	1	–1	–1	–1	0,72
6	1	–1	1	–1	–1	1	–1	1	0,52
7	1	1	–1	–1	–1	–1	1	1	0,72
8	1	–1	–1	–1	1	1	1	–1	1,32
	8	8	8	8	8	8	8	8	

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.

Thus the regression equation of change of ferrum concentration was:

$$\min\ \bar{y}_1 = 0{,}756 - 0{,}099 \cdot x_1 - 0{,}154 \cdot x_2 - 0{,}064 \cdot x_3 + 0{,}091 \cdot x_1 \cdot x_2 + 0{,}001 \cdot x_1 \cdot x_3 + $$
$$+ 0{,}046 \cdot x_2 \cdot x_3 - 0{,}109 \cdot x_1 \cdot x_2 \cdot x_3.$$

The coefficients near members $x_1 \cdot x_2$, $x_2 \cdot x_3$, $x_1 \cdot x_3$ showed that efficiencies of each couple of units of UMASWP were not summed up, but superimposed.

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

№ test	Calculation							
	*b*0	*b*1	*b*2	*b*3	*b*12	*b*13	*b*23	*b*123
1	0,470	0,470	0,470	0,470	0,470	0,470	0,470	0,470
2	0,700	–0,700	0,700	0,700	–0,700	–0,700	0,700	–0,700
3	0,720	0,720	–0,720	0,720	–0,720	0,720	–0,720	–0,720
4	0,880	–0,880	–0,880	0,880	0,880	–0,880	–0,880	0,880
5	0,720	0,720	0,720	–0,720	0,720	–0,720	–0,720	–0,720
6	0,520	–0,520	0,520	–0,520	–0,520	0,520	–0,520	0,520
7	0,720	0,720	–0,720	–0,720	–0,720	–0,720	0,720	0,720
8	1,320	–1,320	–1,320	–1,320	1,320	1,320	1,320	–1,320
	0,756	–0,099	–0,154	–0,064	0,091	0,001	0,046	–0,109

The coefficient near member $x_1 \cdot x_2 \cdot x_3$ meant the synergistic action of all units of UMASWP. 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.

The time of saturation of ion exchanger of FAP was 30 minutes.

The research of optimal working time of UMASWP taking into consideration the regeneration of FAP. Optimal working time of UMASWP was concerned with the saturation of ion exchanger of FAP.

The working pressure was 0,12 MPa, the water flow – 10 m^3/hour, the UO power – 750 Wt, the water temperature – 288 K (15 °C), the induction of magnetic field – 1,08 Tl. The height of layer of ion exchanger amounted to 0,35 m, and the total mass of ion exchanger of one FAP – 14,341 kg. The initial concentration of ferrum was 0,83 mg/dm^3.

The investigation of saturation time of ion exchanger of FAP was carried out by water sampling every 10 minutes within the bounds of 60 minutes. The data of chemical analyses of water samples from UMASWP with/without the regeneration are listed in the Table 4 and pictured in the Fig. 4.

In the regime without regeneration the saturation time of FAP amounted to 50 minutes, and the ferrum concentration was 0,52 mg/dm^3. After regeneration the saturation time of FAP amounted to 60 minutes, and the ferrum concentration was 0,28 mg/dm^3. After the saturation point the ferrum concentration increased to initial in both cases. But in the regime with regeneration this process was much longer.

According to the Table 4 the regression equation of change of ferrum concentration depending on time:

$$\min \bar{y} = 1{,}69 \cdot 10^{-4} \cdot t^2 – 0{,}019375 \cdot t + 0{,}832.$$

The optimal time of working regime of UMASWP was determined by path-of-steepest-ascent method. The step of convergence was chosen as 10 minutes.

Table 4. Test log for determination of effectiveness of UMASWP with/without regeneration of FAP

№	Water sample №	Operating FAP	Place of taking water samples	Time *t*, min	Concentration		Turbidity, mg/dm^3
					Fe, mg/dm^3	Ca & Mg, mmole/dm^3	
1	11	FAP	Before UMASWP	0	5,92	6,02	22,61
2	1	FAP	Before UMASWP	20	0,80	6,12	2,11
3	2	FAP	Before UMASWP	40	0,96	6,02	3,56
4	12	FAP	Before UMASWP	60	0,88	6,07	3,21
5	13	FAP	Before UMASWP	80	0,68	6,12	2,38
6	8	FAP 1	After UMASWP	20	0,56	6,22	2,14
7	6	FAP 1	After UMASWP	40	0,52	6,12	1,91
8	7	FAP 1	After UMASWP	60	0,56	6,17	2,03
9	22	FAP 1	After UMASWP	80	0,64	6,22	2,06
10	21	FAP 2	After UMASWP	20	0,64	6,17	1,94
11	15	FAP 2	After UMASWP	40	0,52	6,22	1,97
12	20	FAP 2	After UMASWP	60	0,56	6,12	2,06
13	23	FAP 2	After UMASWP	80	0,60	6,22	1,94
14	4	FAP1 (reg)	After UMASWP	20	0,52	5,91	1,88
15	3	FAP1 (reg)	After UMASWP	40	0,32	3,36	1,13
16	5	FAP1 (reg)	After UMASWP	60	0,28	3,06	1,07

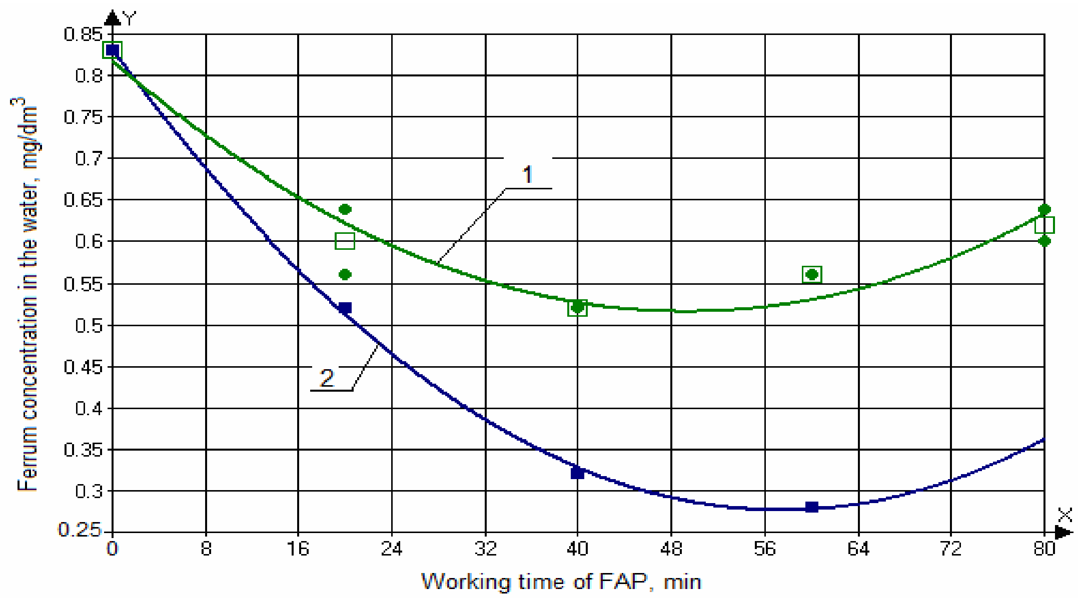

Fig. 4. The ferrum concentration in the water according to the action period of UMASWP: *1* – UMASWP without regeneration of FAP; *2* – UMASWP after regeneration of FAP

Table 5 shows a calculation of the steep ascent. Thus, according to Table 5 saturation time of ion exchanger met the experiment number 20, which corresponded to the ferrum concentration 0,58 mg/dm^3 and it took 100 minutes. Further time expansion increased the concentration to the initial value.

Table 5. Calculation of the steep ascent for *y*

Experiment №	*t*	*y*	Experiment №	*t*	*y*
17	70	0,30	19	90	0,46
18	80	0,36	20	100	0,58

Without the FAP regeneration UMASWP decreased the ferrum concentration from 0,83 mg/dm^3 to 0,52 mg/dm^3. After the the FAP regeneration UMASWP reduced the ferrum concentration from 0,83 mg/dm^3 to 0,28 mg/dm^3. After calculation the optimal working time of UMASWP amounted to 100 minutes. Thus, the optimal working time of UMASWP with regeneration of ion exchanger of FAP was twice longer than one without regeneration.

Conclusions

1. The deferrization efficiency under the combined action of UMASWP 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 m^3/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 UMASWP 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 UMASWP were not summed up, but superimposed, and the use of all units provided a synergistic action.

4. The optimal regime of UMASWP 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/dm^3 to 0,47 mg/dm^3.

5. After the the FAP regeneration UMASWP reduced the ferrum concentration from 0,83 mg/dm^3 to 0,28 mg/dm^3. Without the FAP regeneration UMASWP decreased the ferrum concentration from 0,83 mg/dm^3 to 0,52 mg/dm^3. This decrease of effectiveness was explained by saturation of adsorbent. The optimal working time of UMASWP amounted to 100 minutes with regeneration of ion exchanger of FAP and 50 minutes without.

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