

## PURIFICATION OF DRINKING WATER FROM ARSENIC (V) COMPOUNDS BY SORPTION HOUSEHOLD WATER TREATMENT DEVICES TYPE OF "JUG"

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### Abstract

The article reflects the problem of contamination of drinking water with arsenic (V) compounds. The purpose of the study is to develop a method for reducing the arsenic concentration in drinking water using sorption household water purification devices (HWPD) such as a "jug".

We have compiled 6 compositions of filter-sorbing mixtures, which differ in sorbents and its specific weight: granular activated carbon, cation exchange resin, selective anion exchange resin, hybrid iron-containing sorbent. The mixtures were placed in standard replaceable cartridges for HWPD type of "jug"; through these mixtures were passed 150 - 300 L of standard liquid solution, simulating tap water contaminated with arsenic compounds (0.05 mg/L  $\pm$  20%), chloroform (0.4 mg/L  $\pm$  20%), lead (0.06 mg/L  $\pm$  20%). All concentrations of pollutants were determined before and after water purification (arsenic and lead - by atomic absorption spectrometry, chloroform - by gas chromatography).

It has been proven by our experiment that the using of mixtures reduces effectively the concentration of arsenic (from 0.05 mg/L to 0.0008-0.013 mg/L). The most effective mixtures were established: of granular activates carbon (GAC) - 45%, hybrid sorbent (HS) - 20%, selective anion exchange resin (SAER) - 35%, and mixture of GAC - 30%, Canion exchange resin (CER) - 20%, HS - 16%, and SAER - 34%. This second mentioned mixture was determined as most universal and rational, along with arsenic removing: heavy metal ions, active chlorine,

and volatile organohalogen compounds. The effective resource of the cartridge is 150 L.

Cartridges with this mentioned mixture are recommended for mass production and it is proposed to purify water from arsenic compounds, "typical" pollutants, and characteristic of water from centralized sources of drinking water supply.

**Key words:** Household water filter, Drinking water, Arsenic purification.

### 1. Introduction

A man's health and long life expectancy depend on the quality of drinking water. Many people use tap water for drinking purposes, which they purify to enhance the aesthetic qualities and treating the pollutants with the help of the household purifying devices (HPD) [1]. However the produced HPD treat only the typical pollutants [2]. The problem of arsenic compounds in drinking water has come to a discussion in mass media over the last decade. The presence of arsenic compounds at a high concentration is fixed in: India, Bangladesh, Chile, Malaysia, Argentina, Mexico, Hungary, Vietnam, Romania, Cambodia, China, Korea, along with some areas in the USA, the United Kingdom, Germany [3, 4] and Russia [5]. It is most urgent in the countries of Asia. It was noted in the preamble to Taiwan declaration on the

issue of water quality and arsenic pollution that arsenic compounds are present in ground waters at a concentration dangerous for a human being in 12 countries of Asia (0.050 mg/L) and 50 millions of people consume such water. Nearly 35 millions of people drink water the arsenic concentration of which comes to 0.200 mg/L [6, 7, and 8]. Approximately 4 million of people living in rural areas in Latin America (Argentina, Cuba, Bolivia, Salvador, Mexico, Nicaragua and Peru) consume water out of wells with high arsenic substance [9].

The average arsenic substance in the Earth's crust is  $1.7 \times 10^{-4}\%$ . The arsenic Clark in grounds comes to 5.0 mg/kg on average, but it may vary depending on the geographic area, for example, in the USA it is 6.5 mg/kg.

Scientists have established more than 300 arsenate and minerals, which contain arsenic [10]. Arsenic appears in the underwater sources as a result of dissolution of minerals and ore, and it appears in the water sources with open mirror as a result of anthropogenic impact. Arsenic prevails in underground waters (III), and it prevails in the surface waters (V).

Anthropogenic sources of arsenic are: manufacture waste [11], pesticides (insecto-acaricides), and dumps of mines. For example, arsenic has accumulated up to 5,000 mg/kg in wastes of Californian gold mines [6], and it has accumulated 2,000 mg/kg on average in France in the wastes of the lead-zinc mines [12].

The main reason for arsenic to be present at such high concentrations in the waters of the above mentioned areas considered by specialists is low substance of iron hydroxide, which function as sorbents of arsenic in the water-bearing layers of these territories [7, 13]. Besides, the high substance of arsenic ions is often reasoned by the release of sorbed arsenic with the acting of competing anions; by the reduction of weakly absorbed arsenates to arsenides and reducing dissolution of iron hydroxide containing arsenic at a low redox potential [14, 15, and 16].

The officially published reports state that drinking water at a low concentration of arsenic is dangerous for human health [3, 5]. All arsenic compounds are highly toxic and highly biologically active [17]. Arsenic is related to toxic substances of the 1th dangerous class [18].

The majority of people consume water throughout their lives in the places of their constant living out of one and the same watercourse, which is why arsenic gets systematically into a body at a concentration, not causing any quick toxic effect, but reasoning a row of chronic diseases. The systematic consumption of food products and water with arsenic being than higher maximum acceptable concentration (MAC) results in a negative effect in 5 - 20 years [3].

Research proves that inorganic arsenic compounds have not only toxic but carcinogenic impact [19].

Death from oncological diseases caused by arsenic (at the concentration 0.05 mg/L) is no less than 10%.

A lot of research on the arsenic impact on a human is done in the USA. According to the results United States Environmental Protection Agency (US EPA) imposed stricter requirements to the maximum permissible concentration of arsenic: MCL - (maximum contamination level - maximum permissible level of polluting substances) is decreased from 0.050 mg/L to 0.010 mg/L [20].

World Health Organization (WHO) recommends the norms: the maximum consumption of arsenic daily (MCD) is no more than 0.05 mg/kg of the body mass, the maximum permissible arsenic concentration in drinking water is no more than 0.010 mg/L [21, 22].

The arsenic presence in tap water of the household-and drinking purpose in Russia regulated by SanPiN 2.1.4.1074-01 (Sanitary Rules and Regulations), MAC - no more than 0.050 mg/L [23]; in bottled water - SanPiN 2.1.4.1116-02, MAC - no more than 0.010 mg/L (first category), and no more than 0.006 mg/L (the highest category) [24].

The toxic degree of arsenic depends on the degree of oxidation and the composition of ligands. Within the composition of minerals of sulphides arsenic is relatively little toxic. Non-organic arms of arsenic (III) and (IV) are more toxic, than organoarsinate complexes. The toxicity of different degrees of oxidation is sharply different, for example, arsenic (III) is 2 - 3 times more toxic than arsenic (V). Both kinds form anions in water solutions, get adsorbed on minerals or get co-sedimented by trace elements, forming poorly soluble sediments. At this arsenic (V) is less mobile and is subject to desorbing, which is why less bioavailable [6].

The type of domineering form of arsenic depends on pH and Eh. At the neutral pH arsenate is represented as  $H_2AsO_3$  [25].

The negative arsenic (V) and (III) impact on a man's health has different mechanisms. Arsenic (III) reduces the synthesis of adenosine triphosphate (ATP), blocks the activity of a row of enzymes. The impact of arsenic (V) is less dangerous, than the impact of arsenic (III), but it can restore itself up to arsenic (III) in a man's body. The toxic impact of arsenic is related to sulphur, selenium and phosphorus exchange violation. The toxicity of arsenic depends on its chemical qualities and is reduced in the following order of the row: Arsine > nonorganic As (III) > organic As (III) > nonorganic As (III) > the compound of arsonium ( $AsH_4^+$ ) > elementary arsenic.

The mere toxic impact of arsenic (V) is revealed in the substitution of phosphorus by arsenic in biochemical processes, which is happening due to the similarity of the structure of these elements.

In blood arsenic gets concentrated in red blood cells, where it gets connected with a molecule of hemoglobin. Arsenic is known to be connecting with thiol groups of proteins, cysteine, glutathione, lipid acid. Arsenic influences oxidizing processes in mitochondria and takes part in many other important biochemical processes.

The toxic dose for a man: 5 - 50 mg, the lethal dose for a man 50 - 340 mg [26, 27]. The average presence of arsenic in a man's body is 0.08 - 0.20 mg/kg. Arsenic poisoning happens with the consumption of contaminated food and water, with breathing arsenic compounds as dust within manufacturing conditions, with taking some medical drugs. Arsenic is the reason many different diseases and pathological conditions. At the excess arsenic presence in a: man's body bone marrow, gastro-intestinal tract, skin, lungs and kidneys suffer most, the risk of developing cancer increases [19]. As some consequences of the arsenic impact are irreversible, the main health care measure is preventing the arsenic impact on a man's body [9].

The up-to-date task is to create the technology of additional purifying water, with would enable to eliminate arsenic effectively out of the water of the household and drinking purposes.

Arsenic is present in watering the form of arsenides and arsenates. In the natural conditions arsenic takes part in oxidative- and restoring reactions, coagulations, flocculation and adsorbing [17].

The majority of the technologies of the communal water preparation don't provide the elimination of arsenic compounds. Water purifying devices also don't reach the necessary effect should the given problem arise. The practice of water preparation a wide range of methods of purifying water, out of which the following may be applied to eliminate arsenic: sedimentation (coagulation with the further filtering), adsorbing, ion exchange on anion, reverse osmosis, nanofiltration, electrodialysis, distillation. However the more functionally acceptable, economically rational, effective is the usage of adsorbing methods, along with those on the selective hybrid sorbents, which include iron compounds [4, 17, 28, and 29].

## 2. Materials and Methods

The technology of eliminating arsenic out of drinking water must have the opportunity of additional purifying in compact HPD, which provide the security of the received water must obtain the functional efficiency and economical rationality. Meaning that the produced HPD and the cassettes must be affordable not only for rich, but also for low-income layers of the population.

Generally, HPD oriented for a mass consumption are packed with the cassettes, which are loaded with adsorbents and ion exchange materials. These components allow to manufacture inexpensive and effective devices.

For widening the functional qualities of these cassettes towards purifying water from arsenic we suggest that hybrid sorbents containing iron should be used.

The choice of filtering sorption load of hybrid sorbents containing iron as a component is reasoned by the following assumed qualities of sorbents:

1. Selectiveness in terms of arsenic.
2. Sufficient exchange capacity on arsenic.
3. Effective sorption in the necessary pH level, characteristic of the drinking water (6 - 9 pH units).
4. The opportunity of the usage in the combination with cation exchange resin, alkaline activated carbon depending on the accompanying pollutants of the initial water.

A recipe of filtering sorption load of exchange able cassettes for the HPD is elaborated. It allows to derive drinking water of high quality, which meets the security requirements. Aiming at enhancing the versatility the recipe includes activated carbon and cation exchanger apart from selective sorbents. These materials must ensure the elimination of volatile organohalogen compounds (granulated activated carbon) and ions of toxic metals along with other pollutants of different nature out of water of public sources of drinking water supply.

Six recipes were of filtering-sorption mixtures different in specific gravity of universal and selective components were composed by us (Table 1).

**Table 1. The recipe of filtering sorption mixture for eliminating arsenic compounds, volatile organohalogen compounds, ions of toxic metals out of drinking water**

Filtration-sorbition mixture components	Recipe «As № 1»	Recipe «As № 2»	Recipe «As № 3»	Recipe «As № 4»	Recipe «As № 5»	Recipe «As № 6»
Granular activated carbon (GAC), %	55	45	45	38	32	30
Cation exchange resin (CER), %	0	0	0	27	25	20
Hybrid sorbent (HS), %	0	0	20	8	18	16
Selective anion exchange (SAE), %	45	55	35	27	25	34

Legend: The recipe «As № 1» and «As № 2» included only granular activated carbon and selective anion exchange.

The recipe «As № 3» included granular activated carbon (45%), selective anion exchange resin (35%), and hybrid sorbent (20%). The recipe «As № 4», «As № 5», «As № 6» included granulated activated carbon, cation exchange resin, hybrid sorbent and selective anion exchange.

The recipes of filtering-sorption mixture removable cassette were tested at low and high indication of pH of the water, as the household drinking water may vary in quality indicators.

The quality of the drinking water derived from the purifying and the efficiency of purifying water was identified by passing the model solution through HPD with the standard constructive cassettes, filled with filtering-sorption mixtures «As № 1», «As № 2», «As № 3», «As № 4», «As № 5», «As № 6». The model solutions were imitating polluted water of the centralized sources of the drinking supply, had arsenic (V), and had a low and high level of pH. Cassettes with filtering-sorption mixtures «As № 4», «As № 5», «As № 6» were tested to efficiency lead and chloroform, chlorine reduction. The 2nd model solutions were imitating water with “typical” pollutants (lead as heavy metal marker, chloroform as volatile organohalogen compounds and sodium hypochlorite as active chlorine) of the centralized sources of the drinking supply (Table 2).

The resource testing resulted in establishing the necessary and sufficient volume of the selective sorbent in

a mixture at the preset resource (150 L). The recourse tests were carried out in accordance with the testing method, pointe in the standard NSF 53 2009 [30].

The model water was located into the receiving funnels of HPD; the capacity of the everyday portion of purified water was 15 L; the speed of the filtration was from 0.05 to 0.20 L/min.

The selection of samples of the model solutions with arsenic compounds and the purified water was carried out at the beginning of the tests (after going through the initial water at the quantity equal to 3, then to 10 capacities of the receiving funnel of the HPD) and after reaching: 25, 50, 75, 100, 125, 175, and 200% of the calculated resource of the filtering sorption mixture of the cassette of the HPD.

The concentration of the pollutant in the samples of the model solution and purified water was defined by the method of atomic-absorbing spectrometry (Tables 3 and 4) and atomic-absorbing spectrometry, gas by gas chromatography and titrimetric (Table 5).

Samples of the model solution with “typical” pollutants and purified drinking water were taken at the carried out at the beginning of the tests (after passing 5 L), and after reaching 50, 100% of the calculated resource of the filtering-sorption mixture of the cassette of the HPD.

**Table 2. The characteristic of testing method**

The pollutant/substance	Concentration In the model. solution, mg/L	MAC, mg/L (SanPin)	The initial water	pH of the model solution	The method of identifying the arsenic concentration and the regulatory document for identifying method
<b>Arsenic (V)</b> $H_3AsO_4$	0.050±20%	No more than 0.010 [24]	Water purified with the reverse osmosis with the brought pollutants characteristic of drinking water	6.50 ± 0.25 8.50 ± 0.25	Atomic-absorbing spectrometry ERD F 14.1:2:4.140-98 [31]
<b>Lead</b> $PbNO_3$	0.06±20%	No more than 0.3 [23]		Atomic-absorbing spectrometry ERD F 14.1:2:4.139-98 [32]	
<b>CHCl<sub>3</sub></b>	0.4±20%	No more than 0.2 [23]		Gas chromatography ERD F 14.1:2:7-95 [33]	
<b>NaOCl</b>	1.2±20%	No more than 0.6 [23]		Titrimetric ERD F 14.1:2:4.113-97 [34]	

### 3. Results and Discussion

We compare the concentration of the pollutant (arsenic) in the purified water to the requirements of the regulatory documents (Tables 3 and 4).

It can be seen out of the given tables that at the pH  $8.50 \pm 0.25$  the efficiency of eliminating arsenic out of water is lower. The samples of the purified water after being treated by mixtures «As № 1», «As № 2», «As № 3», «As № 4», «As № 5» the concentration of arsenic is 1.7 - 2.6 times on average higher, then in the samples of drinking purified water at the pH  $6.50 \pm 0.25$ .

The samples of purified water at the pH  $8.50 \pm 0.25$  after being treated by mixtures «As № 3», «As № 6» the concentration of arsenic is on average by 31 - 34% lower, then in the samples of the drinking water at the pH  $6.50 \pm 0.25$ .

The concentration of arsenic in the water purified by mixtures «As № 1», «As № 2», «As № 3», «As № 4», «As № 5», «As № 6» is lower than MCL SanPiN 2.1.4.1074-01 (no more than 0.050 mg/L). However the arsenic concentration in the samples if drinking water received after passing 100 L through the mixtures «As № 1» and

**Table 3. The concentration of arsenic in the purified water at the pH of the model solution  $6.50 \pm 0.25$**

Volume <sup>1</sup>	C <sub>initial</sub> <sup>2</sup>	The arsenic (V) concentration in the purified water, mg/L/ The reduction of arsenic (V) concentration compared to the initial, %											
		«As № 1»		«As № 2»		«As № 3»		«As № 4»		«As № 5»		«As № 6»	
5	0.047	0.0033	93	0.0040	91	0.0009	98	0.0060	87	0.0020	96	0.0010	98
18	0.055	0.0047	91	0.0032	94	0.0030	95	0.0070	87	0.0060	89	0.0027	95
50	0.055	0.0035	94	0.0032	94	0.0010	98	0.0070	87	0.0020	96	0.0030	95
100	0.050	0.0051	90	0.0031	94	0.0020	96	0.0010	98	0.0008	98	0.0020	96
150	0.048	0.0072	85	0.0069	86	0.0060	88	0.0030	94	0.0010	98	0.0019	96
200	0.055	0.0091	83	0.0070	87	0.0015	97	0.0044	92	0.0032	94	0.0036	94
250	0.050	0.0110	78	0.0035	93	0.0027	95	0.0046	91	0.0024	95	0.0046	91
300	0.052	0.0130	75	0.0090	83	0.0011	98	0.0029	94	0.0019	96	0.0015	97
Average efficiency level	-	-	86	-	90	-	96	-	91	-	95	-	95

Legend: 1. Volume - the capacity of the purified water, L; 2. C - the arsenic (V) concentration in the model solution, mg/L.

**Table 4. The concentration of arsenic in the purified water at the pH of the model solution  $8.50 \pm 0.25$**

Volume <sup>1</sup>	C <sub>initial</sub> <sup>2</sup>	The arsenic (V) concentration in the purified water, mg/L/ The reduction of arsenic (V) concentration compared to the initial, %											
		«As № 1»		«As № 2»		«As № 3»		«As № 4»		«As № 5»		«As № 6»	
5	0.055	0.0045	92	0.0055	90	0.0002	99	0.0060	89	0.0020	96	0.0001	99
18	0.056	0.0040	93	0.0034	94	0.0003	99	0.0091	84	0.0007	99	0.0004	99
50	0.053	0.0040	92	0.0039	93	0.0030	94	0.0089	83	0.0051	91	0.0018	96
100	0.049	0.0230	53	0.0103	79	0.0002	99	0.0020	96	0.0010	98	0.0007	99
150	0.047	0.0290	38	0.0214	54	0.0007	99	0.0081	83	0.0061	87	0.0022	96
200	0.055	0.0260	53	0.0128	77	0.0011	98	0.0057	90	0.0029	95	0.0014	97
250	0.052	0.0370	29	0.0180	65	0.0021	96	0.0092	82	0.0051	90	0.0019	96
300	0.053	0.0140	74	0.0226	57	0.0017	97	0.0083	84	0.0060	89	0.0017	97
Average efficiency level	-	-	66	-	76	-	98	-	86	-	93	-	97

Legend: 1. Volume - the capacity of the purified water, L; 2. C - the arsenic (V) concentration in the model solution, mg/L.

«As № 2» is higher than the maximum arsenic concentration in drinking water, recommended by WHO (no more than 0.010 mg/L).

The efficiency of purifying water by filtering sorption mixtures was calculated by us based on the results of the testes (Figures 1 and 2).

The results of the tests bear witness to the fact that the efficiency of arsenic extraction from all the mixture recipes during the resource is at a high level and is reduces with the bigger capacity of the purified water, that is the exhausting of the sorption capacity.

The efficiency of eliminating arsenic is proved to be depending from pH of the water being purified. Filtering sorption mixtures «As № 1», «As № 2», «As № 3», «As № 4», «As № 5», «As № 6» in weak acid environment secure stable efficiency (90 - 99%). After purifying of 200 L of the model water there was some increase of purifying efficiency related to speed reduction of solution passing through the mixture. The high efficiency of purifying is conditioned by the presence of hybrid sorbent and selective anion exchange in the recipe.

Mixtures «As № 1», «As № 2» provide less stable bur sufficient efficiency (76 - 99 and 83 - 99%, accordingly), which is conditioned by the presence of only selective material and absence of hybrid sorbent in the recipe.

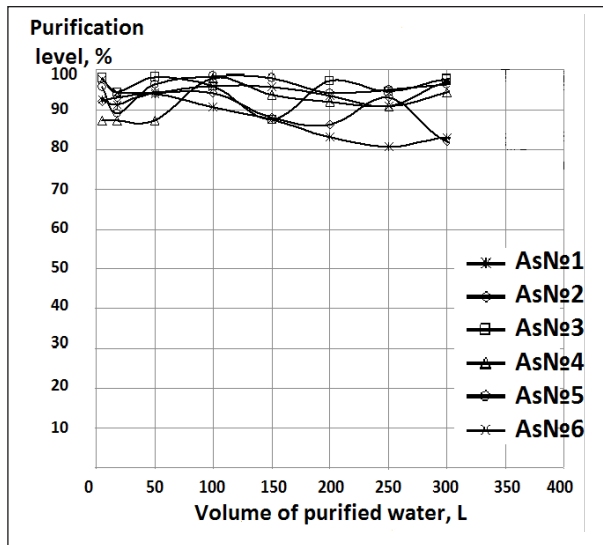


Figure 1. The efficiency of purifying arsenic by the cassettes HPD with different mixtures of filtering sorption mixtures at pH of the video solution  $6.50 \pm 0.25$

Filtering sorption mixtures «As № 3», «As № 4», «As № 5», «As № 6» in the alkaline environment ( $\text{pH } 8.50 \pm 0.25$ ) have less stable but high enough efficiency (82 - 99%).

Introduction of hybrid sorbent into the recipe of filtering-sorption mixture along with selective anion exchange allows to receive maximum efficiency of purifying from arsenic ions, and it allows the mixture of cation exchange resin and activated carbon to widen the range of pollutants being eliminated («As № 4», «As № 5», «As № 6») because of loss in the efficiency of the target component.

The cassettes with mixtures «As № 4», «As № 5», «As № 6» were tested by us to assess the effectiveness of removal of Pb,  $\text{CHCl}_3$ , and Cl from model solutions, and it shows that the level of purification from ions of Pb was more than 98% at the start of resource, more than 65% - at the end of resource; the level of purification from  $\text{CHCl}_3$  was 98% at the start of resource (5 L), more than 80% - at the end of resource (150 L); the level of purification from Cl was more than 95% at the start of resource (5 L), more than 50% - at the end of resource (150 L) (Table 5). It means that our mixtures are effective for the purification of 150 L water from "typical" pollutants at their initial concentration in water:  $\text{CHCl}_3$  - 0.4 mg/L, Pb - 0.06 mg/L, Cl - 1.2 mg/L.

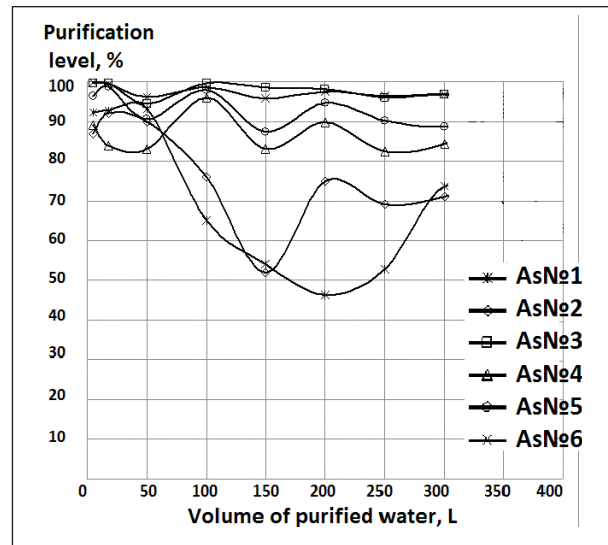


Figure 2. The efficiency of purifying arsenic by the cassettes HPD with different mixtures of filtering sorption mixtures at pH of the video solution  $8.50 \pm 0.25$

Table 5. Grade of water purification from "typical" pollutants with «As № 4», «As № 5», «As № 6» filter-sorbing mixture cassettes

Volume, L	Efficiency level, %								
	«As № 4»			«As № 5»			«As № 6»		
	Pb	$\text{CHCl}_3$	Chlorine	Pb	$\text{CHCl}_3$	Chlorine	Pb	$\text{CHCl}_3$	Chlorine
5	>99	>99	98	98	>99	97	98	>99	96
75	89	90	77	79	93	81	76	79	72
150	66	85	51	75	84	58	71	80	54
Average efficiency level	85	92	75	84	92	79	82	86	74

The comparative analysis of our tests results for the removal of arsenic (at 6.5 and 8.5 pH), lead, chloroform and chlorine from the model solutions shows that the most universal and rational for use in HPD cassettes is the filtering-sorption mixture «As № 6» because of its effective removal of arsenic and the “typical” pollutants of the treated water.

#### 4. Conclusions

- The toxic admixtures present in the plumbing water bear the risk of harming a man's health, which conditions the necessity of applying the household devices in order to provide the security of the drinking water consumed.

- Along with the typical pollutants there are arsenic compounds in water sources in many countries of the world.

- Arsenic eliminating is possible by using HPD with arsenic-selective loading.

- Recipes of loading filtering-sorption mixtures «As № 1», «As № 2», «As № 3», «As № 4», «As № 5», «As № 6» based on granulated activated carbon, ion exchange in combination with hybrid sorbents, selective anion exchange are elaborated.

- The tests have shown that mixtures eliminate arsenic most effectively at the low acid pH of water ( $6.50 \pm 0.25$ ). The increase of specific gravity of hybrid sorbent and selective anion exchange in the mixture increase the efficiency at the alkaline pH of the water too ( $8.50 \pm 0.25$ ). Cassettes with mixtures «As № 3», «As № 5», «As № 6» are most effective, as they have both hybrid sorbent and selective anion exchange.

- The most effective for eliminating arsenic are the mixtures «As № 3» (GAC 45; HS 20; SAE 35%) and «As № 6» (GAC 60; CER 20; HS 16; SAE 34%). The most universal and rational is the recipe of filtering sorption mixtures «As № 6» as it allows to eliminate ions of the heavy metals, active chlorine, volatile organohalogen compounds along with arsenic. The efficiency of eliminating the «typical pollutants is provided by cation exchange resin and granulated activated carbon without losing the eliminating efficiency of the target component. The effective resource of cassettes is 150 L. This given mixture may be used in mass production of the removable cassettes of HPD for purifying water from the arsenic compounds, along with other pollutants, characteristic of the public sources of drinking water supply.

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