WATER TREATMENT: EQUIPMENT AND PROCESSES

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Keywords: Quality of natural water. Purification. Water conditioning. Technological water purification layouts. Technical and economical basis. Optimization.

Contents

Summary

The article is devoted to the present situation and prospects of development of the methods and constructions for natural water purification for potable and technical purposes. The properties of natural water, requirements to its quality after purification, the fields of application and methodology of the selection of technological layouts of water purification are described. The modern approaches to the technical and economical substantiation of the water supply purification systems are denounced. The classification of the sources of water supply is proposed for the selection of the methods and constructions for water purification in dependence of the quality of the initial water, phase and disperse state of the admixtures, presence of human contaminants in it, time factor, and the requirements to the degree of its purification. The methodology and optimization of the technological complexes for water purification are enounced.

1. The requirements to the quality of the purified water

The basic characteristics determining water suitability for various categories of consumers are its composition and concentration of the admixtures. The water categories are differentiated along the specific requirements to its quality as follows: the water used for household and potable purposes, water for needs of food and fermentation industry, for stock and birds watering, for irrigation, for cooling of the elements of technological assemblages in thermal energy production and other branches of economics, for feeding boilers, for industrial technological purposes, for watering of oil beds, etc.

The hygienic requirements for water quality of the systems of centralized and local water supply as well the rules of quality control of the water supplied for consumers are established by World Health Organization and State Agencies for Sanitary and Epidemiological Control of the different countries. The norms and standards of the branch organizations are used in the technical water supply. These are established on the basis of the necessary quality of water for the manufactured production, requirements of the technical means to the utilized water, etc. The quality characteristics of the water in the water sources used for water supply without purification are established by the State Standards for water sources of centralized water supply systems.

The potable water should be safe as related to its epidemiological and radiation properties, harmless in its chemical composition, and adequate in its organoleptic characteristics. The safety of the water in relation of the epidemiological danger is determined in Russia by the norms presented in the Table 1.

Characteristics	Units of measuring	Norms
Thermoltolerant coli-form bacteria	Number of bacteria in 100 ml [1]	Absence
Total coli-form bacteria [2]	Number of bacteria in 100 ml [1]	Absence
Total microbial number [2]	Number of bacteria forming colonies in 1 ml	≤ 50
Coli-phages [3]	Number of shield-forming units (SFU) in 100 ml	Absence
Spores of the sulfite-reducing clostridia [4]	Spore number in 20 ml	Absence
Cysts of Giardia lamblia [3]	Cyst number in 50 ml	Absence

Notes:
[1] The investigation of three water samples (each in 100 ml) is carried out for the determination.
[2] The excess of this norm is prohibited in the 95% of the samples taken off in the water intake sites of the outer and inner water supply network in 12 months, if the number of the investigated samples is not less than 100 per annum.
[3] The determination is carried out only in the water supply systems fed from the surface sources before water feeding into the distributing network.
[4] The determination is carried out for estimation of the efficiency of the technology of water treatment.

Table 1. Norms for microbiological and parasitological characteristics of water

The safety of the potable water on the chemical composition is determined by its correspondence to the generalized norms and by the concentration of harmful chemical substances most frequently occurring on the territory of the Russian Federation (Table 2) and also by the concentration of substances of human origin that enter into the water or form in it in the processes of treatment (Table 3).

Characteristics	Units of measu-rement	Norms (maximum permissible concentration, MPC), not more than	Harmness charact-eristic [1]	Class of danger
Generalized characteristics				
Hydrogen index	Units of pH	6—9		
Total mineralization (dry residue)	mg l^{-1}	1000 (1500) [2]		
Hardness total	mmol l^{-1}	7.0 (10) [2]		

Oxidability (permanganate)	mg l^{-1}	5.0		
Petroleum products (sum)	mg l^{-1}	1.0		
Detergents, anionic	mg l^{-1}	0.5		
Phenol index	mg l^{-1}	0.25		
Inorganic substances				
Aluminum (Al^{3+})	mg l^{-1}	0.5	S.-t.	2
Barium (Ba^{2+})	mg l^{-1}	0.1	S.-t.	2
Berillium (Be^{2+})	mg l^{-1}	0.0002	S.-t.	1
Boron (B, total)	mg l^{-1}	0.5	S.-t.	2
Iron (Fe, total)	mg l^{-1}	0.3 (1.0) [2]	Org.	3
Cadmium (Cd, total)	mg l^{-1}	0.001	S.-t.	2
Manganese (Mn, total)	mg l^{-1}	0.1 (0.5) [2]	Org.	3
Copper (Cu, total)	mg l^{-1}	1.0	Org.	3
Molybdenum (Mo, total)	mg l^{-1}	0.25	S.-t.	2
Arsenic (As, total)	mg l^{-1}	0.05	S.-t.	2
Nickel (Ni, total)	mg l^{-1}	0.1	S.-t.	3
Nitrates (on NO_3^-)	mg l^{-1}	45	Org.	3
Mercury (Hg, total)	mg l^{-1}	0.0005	S.-t.	1
Lead (Pb, total)	mg l^{-1}	0.03	S.-t.	2
Selenium (Se, total)	mg l^{-1}	0.01	S.-t.	2
Strontium (Sr^{2+})	mg l^{-1}	7.0	S.-t.	2
Sulfates (SO_4^{2-})	mg l^{-1}	500	Org.	4
Fluorides (F^-) for climatic regions I and II III	mg l^{-1}	 1.5 1.2	 S.-t. S.-t.	 2 2
Chlorides (Cl^-)	mg l^{-1}	350	Org.	4
Chromium (Cr^{6+})	mg l^{-1}	0.05	S.-t.	3
Cyanides (CN^-)	mg l^{-1}	0.035	S.-t.	2
Zinc (Zn^{2+})	mg l^{-1}	5.0	Org.	3
Organic substances				
γ-Hexachlorocyclohexane (Lindane)	mg l^{-1}	0.002 [3]	S.-t.	1
DDT (sum of isomeres)	mg l^{-1}	0.002 [3]	S.-t.	2
2,4-D	mg l^{-1}	0.03 [3]	S.-t.	2

Notes:
[1] Limiting characteristic of substance harmfulness, on which the norm is established: “S.-t.” – sanitary–toxicological; “Org.” – organoleptic.
[2] The value indicated in the parentheses can be established on the decision of the Chief Sanitary Physician of the corresponding territory for particular water supply system on the basis of estimation of the sanitary-epidemiological situation in the settlement and employed technology of water treatment.
[3] The norm is established in correspondence with WHO recommendations.

Table 2. Norms and standards on the generalized characteristics of water and harmful chemical substances

Characteristic	Units of measu-rement	Norms (max-imum permis-sible concentr- ation, MPC), not more than	Harmness charact-eristic [1]	Class of danger
Chlorine [2] - residual free - residual combined	 mg l^{-1} mg l^{-1}	 0.3–0.5 0.8–1.2	 Org. Org.	 3 3
Chloroform (at water chlorination)	mg l^{-1}	0.2 [3]	S.-t.	2
Ozone residual [4]	mg l^{-1}	0.3	Org.	--
Formaldehyde (at water ozonation)	mg l^{-1}	0.05	S.-t.	2
Polyacrylamide	mg l^{-1}	2.0	S.-t.	2
Active silicic acid (on Si)	mg l^{-1}	10	S.-t.	2
Polyphosphates (on PO_4^{3--})	mg l^{-1}	3.5	Org.	3
Residual quantities of coagulants containing iron and aluminum	mg l^{-1}	See characteri-stics «alumin-um» and «iron» in the Table 2		

Notes:
[1] Limiting characteristic of substance harmfulness, on which the norm is established: "S.-t." – sanitary—toxicological; "Org." – organoleptic.
[2] When the water is disinfected with free chlorine, its contact time with water should be not less than 30 min. When the water is disinfected with combined chlorine, its contact time with water should be not less than 60 min. When the free chlorine and combined chlorine are present in water simultaneously, their total concentration should not be more than 1.2 mg l^{-1}.
[3] The norm is established in correspondence with WHO recommendations.
[4] The control of the residual ozone concentration is carried out after mixing chamber providing the time of contact not less than 12 min.

Table 3. The norms on the harmful chemical substances entering and forming in the processes of water treatment

Table 4 represents the norms determining the favorable principal organoleptic water properties.

Characteristics	Units of measurements	Norms (not more than)
Odor	Points	2
Aftertaste	Points	2
Color index	Degrees	20 (35) [1]
Turbidity	Turbidity units on the formazine (TUF) or mg l^{-1} (on kaolin)	2.6 (3.5) [1] 1.5 (2.0) [1]

Note:[1] The value indicated in the parentheses can be established on the decision of the Chief Sanitary Physician of the corresponding territory for particular water supply system on the basis of estimation of the sanitary-epidemiological situation in the settlement and employed technology of water treatment.

Table 4. The norms on the organoleptic characteristics of water

The radiation safety of the potable water is determined by its correspondence with the norms of the characteristics of the total α– and β– radioactivity (Table 5).

Characteristics	Units of measurement	Norms	Harmfulness characteristic
Total α-radioactivity	Bk l^{-1}	0.1	Radiation
Total β-radioactivity	Bk l^{-1}	1.0	Radiation

Table 5. Norms on the radioactivity characteristics

The water quality control on the level of state, agency, or industry is realized in accordance with the requirements of the State Legislation.

The metrology certified methods by State Committee of Standards or by State Committee of Sanitary and Epidemiology of Russian Federation are admitted for laboratory investigations of potable water quality. The taking of water samples for analyses is carried out in correspondence with the requirements of the established procedures.

The analogous requirements (Tables 1 – 5) are demanded to the water used in the food industry. The individual branches of production establish its own additional requirements (connected with the specific technology of the manufacturing) to some components that can deteriorate the quality of the products or disturb the technological process.

The water that is used in the agriculture for watering livestock and birds should correspond to the quality requirements of water for household and potable purposes, but with little lower norms on color index, odor, and hardness. The temperature of water for these purposes is optimum in the limits +(8 – 15)^{0}C.

The norms for water for irrigation purposes are established mostly in dependence of the quality of water on the physiological development of the irrigated crops, on soil and climate properties of the irrigated territories, and on the requirements of the technical means of irrigation.

The water utilized for cooling the industrial units should not further the decrease of the heat conductance of the heat exchangers because of the sediments of carbonates and other salts or contribute in the contamination of moving parts of pumps, power drives, etc. by mechanical and organic admixtures.

When the water is utilized for technological purposes the following types of water are differentiated: water introduced into the product composition; water contacting with the row materials, water used for mining mineral resources and used for hydraulic transport, water used for treatment and cooling ready products.

The water quality should correspond to the branch norms and standards. The tentative requirements for principal types of contaminants and for their permissible concentrations are enounced in the integrated norms of water consumption for various branches and enterprises of the economic.

The water used for flooding oil beds and for supporting bed pressure has to contain less than 1 mg l^{-1} of the suspended matter, up to 0.2 mg l^{-1} of total iron, and up to 1 mg l^{-1} of petroleum. To prevent the decrease of porosity of oil containing strata, the concentration of the bicarbonates should be limited in the warmed water. Also, the oxygen concentration is to be limited, because it oxidizes the hydrogen sulfide and causes the corrosion of the casing and exploitation columns.

In the cases, when the direct norms and standards for the quality of the purified water for diverse specific production processes are absent, the designer should demand from the client the necessary data on the influence of the water quality on the production. These data can be obtained from the experience of the analogues production processes or from the results of specially performed tests on the concrete manufacture.

2. Field of application of the methods for water purification

There are two approaches for classification of the existing diversity of the methods for water purification in the solution of the technological problems on water purifying and conditioning for the needs of various consumers.

At first, it can be carried out on the basis of the achieved purpose of the purification connected with the quality standards of the purified water. The second approach is based on the characteristics of the phase and disperses composition of the admixtures separated from water in the processes of its treatment at the water purification and supply stations.

The field of application of the numerous methods of water treatment depends at the first case on the purposeful influence of these methods on the following epidemiological, chemical and organoleptic characteristics of the purified water:

- improvement of the organoleptic properties of water – clarifying, discoloration, deodoration;
- providing of the epidemiological safety – chlorination, ozonation, treatment by electric pulses, UV-irradiation, etc.;
- alteration of the mineral composition of water – removing iron, manganese, and silicon salts, desalination, softening, fluorination, silicon salts removing, etc.;
- extraction and improvement of the gas composition – removing hydrogen sulfide, oxygen, methane, free carbon dioxide, etc.;
- extraction of hardly oxidative organic substances and harmful products, forming at the same time in the processes of water treatment – reverse osmosis, biosorption, nanofiltration, etc.

The selection of one or another method of water purification is carried out on the basis of the comparative analysis of the quality of initial water and required degree of its purification, technological possibilities of one or another method available, and specific features of the design of constructions and installations, on which these methods are realized, and also on the basis of results of technical and economical substantiation.

The general specific characteristics of the substances contaminating natural water are the forms, in which they are present in the water. The idea of the phase state in water and aggregate and kinetic stability of the particles of the colloidal dispersion was used as the basis for differentiation on the groups of the whole multiplicity of the admixtures. Phase and dispersion state of the water admixtures together with their chemical specific features determine the behavior of these substances in the aqueous medium and their response on the reagents and ancillary disperse materials introduces into the water in the processes of its treatment. The required quality of the water in the processes of its purification or conditioning (altering its one or other quality characteristic in the necessary direction) can be achieved only in the case, when the proper combination of the corresponding methods of action (water treatment) would be selected. Academician Kul'skii proposed to unite the multiplicity of the contaminations of natural and industrial waters into the four groups on the basis of this principle. In so doing, the common combination of the methods of water purification can be applied for each of these groups. The classifying water admixtures on its phase and dispersion state and recommended processes of these admixtures removing are presented in the Table 6.

Heterogeneous systems		Homogenous systems	
Dispersions (suspensions, emulsions, microorganisms and plankton)	Colloidal solutions, high molecular weight com-pounds and viruses	Molecular solutions (gases, dissoluble organic substances)	Ionic solutions (salts, acids, bases)
Group I (10^{-2} – 10^{-5} cm)	Group II (10^{-5} – 10^{-6} cm)	Group III (10^{-6} – 10^{-7} cm)	Group IV (10^{-7} – 10^{-8} cm)
Mechanical reagentless separation	Membrane separation	Adsorption of gases and volatile organic compounds	Separation of water and ions by membrane methods
Oxidizing by chlorine, ozone, etc.	Oxidizing by chlorine, ozone, etc.	Oxidizing by chlorine, chlorine dioxide, ozone, potassium permanganate	Transforming ions into the hardly soluble compounds by different methods including oxidation
Flotation of suspensions and emulsions	Coagulation of the colloidal admixtures	Extraction by organic solvents	Ion separation in various phase status of water
Adhesion on the hydroxides of iron and aluminum and on the high dispersion materials	Adhesion on the hydroxides of iron and aluminum and on the clay materials	Adsorption on the active carbon and on other adsorbents	Ion retention on the solid phase ionites
Aggregation with the help of flocculants	Aggregation with the help of flocculants of cationic type	Association of molecules	Ion transforming into the low dissociated compounds
Electrofiltration of suspensions and electrical retention of microorganisms	Electrophoresis and electrodialysis	Molecule polarization in the electrical field	Utilization of ion mobility in the electrical field
Bactericide act-ion on the pathogenic microorganisms and spores	Virus disinfecting action	Biochemical destruction	Microbial isolation of the metal ions

Table 6. Classification of the water admixtures on their phase and dispersion state and processes used for their removal

The capability of numerous admixtures to change its phase and dispersion state under action of physical and chemical factors, in the first turn such as salt composition, temperature, pH value of the medium, etc. make possible to vary in large limits the procedures and methods of water treatment processes.

The utilizing this methodology in the designing the water purification stations allows to validate the applied water treatment layouts to the first approximation. As regards to the validation of the technological complex of consequently operating purification constructions and its economical substantiation, the designer needs the information about phase and dispersion composition of the admixtures, the information about range of concentrations of the components of natural and human origin, which are extracted by these construction from the initial water. Also, the information about the technological characteristics of the particular water purification constructions is necessary.

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