Peculiarities of purification of natural water from iron compounds using ceramic membranes

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Abstract. The paper deals with the issues of natural water purification from iron compounds. A comparison of polymeric and ceramic membranes is given. During the experiments, ceramic membranes modified with titanium and completed in a filtering element were used. Experiments on filtration of simulated solutions of ferric iron have been carried out. The dependence of the permeate flux on time for various initial concentrations of ferric iron and the dependence of the working pressure on the volume of the filtrate for various initial concentrations of ferric iron, at a constant filtration rate is shown. It was found that the residual concentrations of iron (III) compounds, regardless of the experimental conditions, met the regulatory requirements and did not exceed 0.3 mg/l. Based on the results obtained, flow diagrams of ultrafiltration units based on ceramic membranes were proposed.

According to UNESCO, more than 80% of all diseases are associated with the use of poor-quality drinking water. It is with low-quality freshwater that pathogens, heavy metals, pesticides, and other harmful substances enter the human body. At present, the problem of providing the population with high-quality drinking water is a priority social task for any country in the world.

The world's experience in solving such problems has shown that one of the main problems associated with the use of artesian sources of drinking water is the multiple excesses of iron compounds of both natural and technogenic origin in it. In the main pressure water horizons, the total content of various forms of iron often exceeds the maximum permissible concentration (MPC = 0.3 mg/l) by 20 times, and for groundwater, this excess can be up to 40-60 times or more (up to 12-18 mg/l). The ingestion of significant amounts of iron compounds into the body leads to its accumulation in tissues. Given the almost uniform distribution of iron compounds in the body, a state of hemosiderosis may occur. With a total content of iron compounds in the body over 15 g, visceral injury (hemochromatosis) occur. Long-term use of "ferrous" water leads to hepatic injury, increases
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the risk of heart attacks, negatively affects the central nervous system and the reproductive function of the body. The increased iron content gives the water a brownish color, unpleasant taste, odor, causes clogging and corrosion of water supply networks, is the cause of defects in the textile, food, paint and varnish, paper, and cosmetic industries [1-5]. To prevent such negative consequences, various deferrization processes are used. At present, the specific daily water consumption in Russia per capita is 275-300 liters, and the task of providing the country's population with high-quality drinking water is named a priority by the government of the Russian Federation [6-9].

One of the most advanced technologies for treating both natural and wastewater is currently considered to be membrane technology, where polymeric or ceramic membranes can be used as a filter element. The table 1 below shows the comparative characteristics of various membrane elements, depending on the material of manufacture [10-14].

**Table 1.** Characteristics of membrane elements depending on the material of manufacture.

| Parameter                          | Polymeric membranes | Ceramic membranes |
|------------------------------------|----------------------|-------------------|
| **Operating parameters**           |                      |                   |
| Service life without replacement, years | 0.5-1               | up to 20          |
| Possibility of backwashing (purging) | -                   | +                 |
| Clean water requirement for backwashing, % | up to 10          | up to 2           |
| **Applications**                   |                      |                   |
| Water desalination:                | +                    | -                 |
| selectivity for desalting (by Na⁺), % | 98-99               | 0                 |
| Water softening:                   | +                    | -                 |
| selectivity for softening (by Ca²⁺), % | 95-98               | 0-0.5             |
| Water deferrization:               | -                    | +                 |
| selectivity for deferrization (by Fe³⁺), % | -                  | 99                |

The main objective of this work is to assess the possibility of using tubular ceramic filtration mullite-corundum membranes with an external working layer, which contain at least 85% aluminum oxide (Specification Requirements SP 5754-001-02066492-01). Such membrane elements have already confirmed their high performance and efficiency as components in ultra- and microfiltration units for the separation and purification of liquid media (suspensions and emulsions).

A key feature of such membrane elements is the possibility of additional surface modification with titanium compounds (Figure 1), which will effectively combine the processes of filtration and photocatalytic water decontamination.

**Figure 1.** Ceramic membrane modified with titanium, magnification 600 times.
Ceramic fine-pored tubular membranes were collected in a filter unit, which is a cassette consisting of a tube sheet, a filtrate cover, a bottom, and a central pipe. The cassette is located in a stainless-steel case, which is equipped with fittings for water drainage and supply [10-13]. Experiments on the study of selectivity were carried out on simulated solutions of bivalent and trivalent iron. Determination of the content of iron (III) compounds was carried out on a portable spectrophotometer DR 2800 (HACH USA) by the approved method.

The study of water filtration modes with a given content of iron (III) compounds was carried out over the entire range of permeate flux and working pressure of ceramic membrane elements. The data obtained as a result of the experiments are presented in Figures 2 and 3.

![Figure 2. Dependency graph of the filtrate permeate flux on time for various initial concentrations of trivalent iron at working pressure P = 3 atm.](image)

**Figure 2.** Dependency graph of the filtrate permeate flux on time for various initial concentrations of trivalent iron at working pressure P = 3 atm.

**Figures 2** and **3** show that, with an increase in the initial concentration of iron in the simulated solution and the duration of the experiment, the permeate flux of the membranes decreases, and the working pressure increases. In the process of filtration, the concentration of iron in the filtrate decreases, but the MPC required by Sanitary Regulations and Norms is never reached. This decrease in concentration over time during filtration is determined by the initial concentration and operating pressure. This may be due to the formation of a dynamic layer of oxidized forms of iron at the membrane surface. Further increases in filtration time and operating pressure will dramatically increase energy consumption. Residual concentrations of iron (III) compounds, regardless of the experimental conditions, met the requirements established by Sanitary Regulations and Norms 2.1.4.1074-01 (0.3 mg/l). Probably, the formed perimembrane layer of iron hydroxides will act as a kind of natural catalyst and will make it possible to remove iron compounds from water with high efficiency, and catalytic oxidation processes will take place for bivalent iron. It should be noted that taking into account the membrane material, iron compounds cannot damage the working structure, and the membrane itself can be efficiently regenerated during the backwashing process. Based on the data
obtained as a result of the experiments, the following flow diagrams of ultrafiltration units based on ceramic membranes were proposed (Figure 4).

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Innovative technologies for environmental protection in the modern world

As a result of the experiments, it was found that when filtering iron-containing simulated solutions through ceramic fine-pored tubular membranes at an iron (III) concentration in the simulated solution from 0 to 30 mg/l, a residual concentration of iron (III) compounds is achieved that meets the requirements of regulatory documents. Data on the change in the operating modes of the membrane elements depending on the volumes of the passed simulated solution, the initial concentrations of iron compounds, and the pressure at the inlet to the membrane element were obtained. The main concepts of the direction of integration of ceramic membrane elements into traditional technological flow diagrams of the processes of deferrization of various origins waters are proposed.
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