Development of a mobile membrane water treatment installation in emergency situations

R. A. Aleksandrov

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Relevance of the research topic. Water is one of the most important and valuable resources and one of the most consumed reserves of the earth by humans. Every year, from 4,500 to more than 6,000 km^3 of water are consumed in the world for domestic, industrial and agricultural water supply. At the same time, water consumption in the world is only increasing every year. Today, an urgent problem obtains pure water, including drinking water, in the context of increasingly frequent emergency situations of various types, such as floods, oil spills, and destruction of centralized water treatment infrastructure. A striking example is the flood in the Orenburg region in 2024, caused by a high water and a break in the protective dam, as a result of which thousands of houses in the cities of Orenburg and Orsk were flooded. Another example is the leakage of diesel fuel in Norilsk in 2020, as a result of which about 15 thousand tons of fuel fell into the nearby Ambarnaya River. At the same time, according to The Federal Service for Supervision of Natural Resources, the maximum permissible concentrations (MPC) of harmful substances in the water of the Ambarnaya River exceeded the norm tens of thousands times.

To obtain pure water in these conditions, it is necessary to create mobile small-sized treatment installations capable of easy transportation to the desired location with a quick access to the operating mode. In addition, taking into account that the composition of the water is very difficult to predict in advance, mobile installations must ensure effective treatment of water of various, the highest degrees of contamination, up to the production of pure water that meets the requirements of sanitary rules and regulations for drinking water.

The goal of the work is to develop a mobile installation for the treatment of surface water with a complex composition of pollutants based on a combination of reagent and membrane methods, with high efficiency in terms of the degree of purification, reagent and energy consumption.

The tasks of the work.

To achieve this goal, the following tasks were solved:

- A new method for producing a hybrid alumina-silicon reagent, which simultaneously has the properties of a coagulant, flocculant and sorbent, has been developed and research has been carried out.

- Experimental studies of the purification processes of model solutions containing the most common pollutants (heavy metals, petroleum products, suspended solids) using composite alumina-silicon flocculants-coagulants to identify the most effective reagent samples were performed.

- A device for dosing and mixing reagents has been developed, including jet ejection mixers, providing hydrodynamic intensification of the process of reagent pre-treatment of water.

- The basic hydraulic scheme of the pre-treatment unit and the membrane purification unit has been developed, and the selected technical solutions have been justified.

- An experimental sample of a mobile treatment installation has been developed and manufactured, and tests on model solutions and real polluted waters have been carried out.

The scientific novelty of the work:

1. A new method for producing a hybrid alumina-silicon reagent has been developed and optimal reagent doses and pH values have been determined for the purification of model aqueous solutions based on the results of mathematical modeling and experimental studies.

2. For the first time, the effect of reducing the concentration of residual aluminum in water after treatment with an aluminum-containing reagent was discovered, and a hypothesis about the formation of alumina-silicon zeolite-like structures with a sorbing effect during the purification process was proposed.

3. A new combined reagent-membrane water treatment system has been developed. The system consists of a pre-treatment unit with a device for ejection dosing and mixing reagents and a membrane purification unit based on a microfiltration device using a membrane made of porous titanium carbide and a reverse osmosis device.

Theoretical and practical significance of the work:

1. It is shown that the use of hybrid alumina-silicon reagent allows reducing the concentration of toxic residual aluminum in treated water by more than an order of magnitude (up to 0.02-0.05 mg/l) in comparison with other aluminum-containing reagents due to the formation of alumina-silicon zeolite-like structures in the process of purification, which have the effect of volumetric sorption in the pH range from 6.0 to 8.0. The efficiency of the hybrid alumina-silicon reagent in comparison with industrial analogue (prototype) at treatment of model solutions is shown. The degree of treatment from copper is 15% higher than that of the industrial analogue, the ASFC reagent, and the degree of clarification of water containing Fe(III) and suspended solids is 13.5% and 14% higher, respectively.

2. A new device for dosing and mixing reagents has been developed based on jet mixers – water-water and water-air ejectors, with the aim of intensifying treatment processes and increasing the degree of water treatment by mixing reagents in intense hydrodynamic fields at $Re>>Re_{cr}$ and creating the effect of hydrodynamic cavitation.

3. It has been established that the use of a water pre-treatment unit based on a device for ejection dosing and mixing reagents can increase the specific productivity of a microfiltration device up to 3.7 times when purifying water from petroleum products and hardness salts and up to 4.3 times when purifying heavy metals (copper).

4. An experimental sample of a mobile water treatment installation with reagent pre-treatment and membrane purification units has been developed, which provides a

predetermined degree of treatment of highly polluted wastewater for the main pollutants with the lowest specific energy consumption among analogues – 2.6 kWh/m^3. It is shown that the degree of wastewater treatment after the microfiltration device is more than 99% in all indicators, after the reverse osmosis device it reaches 99.9% for heavy metals and 99.7% of petroleum products.

The main provisions for the defense:

1. The results of an experimental study of the processes of model solutions treatment from major pollutants (heavy metals, petroleum products, residual aluminum, hardness salts, suspended substances) using composite alumina-silicon reagents.

2. The results of application of a new device for dosing and mixing reagents in the water pre-treatment process before the membrane purification unit.

3. The results of research test of an experimental sample of a mobile membrane water treatment installation on model solutions and real polluted waters.