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**Improving the efficiency of reverse osmosis systems**

**Abstract**

**Relevance of the research.** Among all water desalination technologies, reverse osmosis has seen the fastest growth in productivity since the 1990s. This technology has become widespread due to its relatively low energy consumption compared to thermal desalination methods due to the absence of a phase change in the water and its resistance to contaminants, unlike electrodialysis. In 2019, reverse osmosis accounted for 69% (65.5 million m<sup>3</sup>/day) of the total volume of desalinated water worldwide.

Continuously improving wastewater disposal standards necessitate improving water use efficiency, reducing water consumption, and minimizing pollution of natural water bodies due to the discharge of mineral and thermally heated industrial wastewater.

Typically, in industrial reverse osmosis plants, the discharge flow of the first-stage concentrate accounts for 25-30% of the feedwater flow. Reducing water consumption for auxiliary needs is a pressing issue in newly designed and operating water treatment systems. A simple and effective method for reducing the amount of concentrate produced by continuous reverse osmosis systems is needed. This method is based on calculated and experimental data, defining the limits of the method's applicability, assessing the impact of the proposed method on the quality of the resulting filtrate, and developing compensating measures to improve permeate quality, along with a proper assessment of the feedwater suitability for reverse osmosis membranes (RO) and the operational characteristics of combined water desalination systems.

Currently, a significant amount of research exists on reducing the concentrate flow from reverse osmosis systems using a combination of reverse osmosis processes and chemical reactions to improve concentrate stability or modifications to the membrane process (OARO, CCRO, PFRO, VSEP, etc.). However, reducing the amount of concentrate for the most common continuous reverse osmosis systems without additional concentrate processing stages or complex process modifications, combined with compensating measures aimed at improving permeate quality, is a highly sought-after and understudied

area. Thus, research in this area meets current needs for improving water treatment systems and developing innovative, sustainable technologies.

**The purpose of work:** Developing a comprehensive approach to reducing the amount of reverse osmosis concentrate while simultaneously improving permeate quality, increasing reliability, and reducing operating costs of water desalination systems.

**Research Tasks:**

1. Identify and study the factors that determine the concentrate flow of reverse osmosis systems
2. Conduct a detailed analysis of the operation of combined water desalination systems based on a combination of reverse osmosis and ion exchange processes
3. To experimentally establish the effectiveness of a method for improving the quality of UOO permeate based on a two-stage removal of carbon dioxide by a physicochemical method
4. To develop and test a reliable and validated method for assessing the suitability of feed water for feeding RO membranes based on colloidal fouling.

**Scientific novelty of the work:**

1. A new integrated approach has been developed to minimize the concentrate flow in reverse osmosis units when treating water with a salinity of up to 2 g/l, based on maintaining the minimum required water flow over the membrane, assessing the maximum concentration of poorly soluble substances, and assessing the suitability of water based on colloidal load using a mathematically sound method.
2. For the first time, a mathematical model of the method for determining the colloidal index was developed, on the basis of which the concept of a generalized colloidal index was introduced
3. For combined water desalination systems that include reverse osmosis and counter-current ion exchange technology, non-obvious distinctive features of ion exchange filters for post-treatment of reverse osmosis permeate have been established
4. A new integrated approach to constructing a two-stage reverse osmosis system for permeate with two-stage carbon dioxide removal based on a combination of physical and chemical methods has been developed

**Theoretical and Practical Significance:**

1. A simple and cost-effective method has been developed to increase the filtrate recovery rate of continuous reverse osmosis systems of small and medium capacity (up to 10 m<sup>3</sup>/h); the factors limiting the filtrate recovery rate have been identified, and ways to overcome their influence have been defined.
2. A new method for determining the quality and suitability of source water for feeding to reverse osmosis membranes based on the content of colloidal particles in it has been developed and tested – the generalized colloidal index.
3. Important differences in the regeneration process of cation exchange filters, in which they are the second stage of water desalination after single-stage reverse osmosis units, have been established for the operation of water treatment systems, and recommendations for the operation of such water treatment systems have been developed.
4. A methodology has been developed and a highly effective method for improving the quality of the filtrate of two-stage reverse osmosis systems has been presented, based on the use of a combination of physical and chemical methods for removing carbon dioxide from water in membrane systems.

**Provisions for defense:**

1. A comprehensive approach that incorporates the influence of hydrodynamics, the tendency of membrane surfaces to foul with colloidal particles, and the dynamic factor of the formation of poorly soluble and insoluble minerals during the concentration of solutions on a reverse osmosis membrane. A method for increasing the efficiency of reverse osmosis processes is proposed, consisting of reducing the flow of the resulting concentrate and, as a result, more complete utilization of the feed water with an increased permeate yield.
2. Results of a computational and experimental study to determine the practical limits for each influencing factor on the possible increase in the degree of permeate recovery of a reverse osmosis system, taking into account the changing composition of the water.
3. Results of the computational and experimental study of the influence of the degree of permeate selection on the change in its composition, the dynamics of deposition

of poorly soluble compounds on the surface of the reverse osmosis membrane, the quality of the permeate of the second stage of reverse osmosis (by permeate).

4. Mathematical analysis of the method for determining the colloidal index and a qualitatively different method for assessing the suitability of source water based on the content of colloidal impurities, a mathematical model for describing the filtration kinetics of colloidal systems, limitations of the standard method for measuring the colloidal index (SDI) and a new method for determining the generalized colloidal index.
5. The results of testing the developed method for determining the generalized colloidal index on water after different stages of preliminary purification, the limits of practical application of the proposed method.
6. The effect of abnormally intense drop in water flow through a test membrane
7. A highly effective method for decarbonizing water with moderate to high carbonate hardness in multi-stage reverse osmosis units, based on a combination of physical and chemical methods for removing dissolved and undissolved carbon dioxide, and the results of testing the proposed method in industrial units.
8. Guidelines and conditions for the regeneration of cation-exchange filters in combined water desalination systems, the need to use step-by-step regeneration of the cation-exchange filter in such a system when using sulfuric acid as a regenerant.