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The Use of Membrane Technologies of the CWTP to Obtain Quality Drinking Water

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ABSTRACT

The purpose of the study is a scientific and theoretical substantiation of the energy characteristics of ultra and nano filtration, which directly depend on the quality of the source water, to ensure reliable and uninterrupted operation of a combined water treatment plant (CWTP), to obtain high-quality drinking water in water supply systems intended for settlements and industrial facilities. The developed method of combined operation of a water treatment plant is based on membrane technology, the efficiency of which directly depends on the preliminary improvement of the quality of purified low-mineralized water using an energy-efficient membrane, post-treatment and subsequent disinfection. Indicators of the quality of treated water that meet regulatory requirements and indicators of improving the energy efficiency of the water treatment plant have been investigated and calculated on the basis of experimental data. The results of studies on low-mineralized water made it possible to obtain TDS (Total dissolved solids) with a total residual concentration of hardness and chlorides in the range of 0.77 mg/dm^3 without any problems. The proposed combined water treatment plant method is a priority among fundamental and applied works in the field of water treatment, it is intended for the purification of natural waters under conditions of increased anthropogenic loads on natural water sources.

Keywords: drinking water, ultrafiltration, nanofiltration, ultraviolet disinfection.

INTRODUCTION

The most important tasks in the field of water treatment are to increase energy efficiency, reliability, environmental friendliness and uninterrupted supply of high-quality drinking water to the population of the CIS countries, near and far abroad. A special place in solving these problems is given to the further processing of water from natural sources in water treatment systems.

Purpose of the study is to give a scientifically substantiated approach to a new nanomembrane technology, which is not widely used in the field of preparation of household drinking water.

In the work done, the technology of improving the quality of the preparation of household drinking water at a combined installation has been theoretically and experimentally substantiated. Ultrafiltration and nanomembrane installations, as well as an installation for ultraviolet water disinfection, showing high efficiency of water purification, have been developed and tested. Research is devoted to development of a technological scheme for the purification of highly mineralized surface and concentrated waters at a combined water treatment plant to obtain high-quality household drinking water that meets sanitary and hygienic standards.

One of the modern, effective ways of developing drinking water supply systems is the use of membrane technologies, the state of which on the market shows steady trends towards expansion in the field of their application.

Traditionally, the role of membrane technologies in drinking water supply was reduced to desalination of sea and ground water, mainly with the aim of reducing its salt content. However, the "versatility" of membranes, as well as their new quality (energy saving) due to operation at low pressures, made membranes an irreplaceable method of additional purification of water, capable of removing from it many impurities in the ionic form, which are beyond the power of other methods – fluorides, arsenic, strontium, ammonium, nitrates, and nitrites. The use of membranes for additional purification of water "at the tap" has led to a huge increase in membrane production, the pace of which is constantly increasing. According to data for 2016, in the USA alone, the annual production of small-sized membrane devices for mini-systems already exceeds $ 250 million, and according to the South Korean company Saikhan (SAEHAN), which ranks third in the world in the production of membranes, almost half of all membranes produced by this company go to the production of devices for mini-systems.

Many devices and large installations "work" for drinking water supply. The development of the nanofiltration method (a type of reverse osmosis with low mud-retaining capacity) makes it possible to use this method for the purification of surface and groundwater instead of traditional methods. This is due to the extremely high efficiency of nanofiltration membranes in reducing the concentration of organic contaminants, both high molecular weight (humic and fulvic acids that form color) and low molecular weight, including organochlorine substances, especially hazardous to human health. It is the nanofiltration process that can have a decisive influence on the formation of a new direction in drinking water supply - the creation of large stations for centralized drinking water supply. Such nanofiltration stations with a capacity of 10,000 m^3 of water per hour and more are already operating in several European cities (Paris, Amsterdam), the USA and Australia.

The high rates of membrane production and the constant appearance of new types of membranes with a steady decrease in their cost require the developers of water treatment equipment to know the capabilities of membranes and skills in using membrane processes in water treatment technologies. Here, the ability to correctly select the types of membrane equipment, technological scheme, reagents for operation, etc. is important. Membrane equipment manufacturers supply their customers with Software that allow them to calculate and design membrane water treatment systems and correctly use the characteristics of the membranes used.

The developed Software are based on studies of the dependences of the characteristics of membranes on the composition of the source water, the set parameters of the installations, the conditions of their operation [1].

The experience of South Korea plays an important role in the formation of the modern market of membranes and membrane technologies, in particular the firm "Sayhan" – one of the world's largest manufacturers of reverse osmosis and nanofiltration membranes and water purifiers based on reverse osmosis membranes. The presence of a "market", ie, the need for membrane systems, created the largest membrane industry. Korean firms produce 2.5-3 million membrane water purifiers per year.

The creation of membrane production in Korea happened unexpectedly for everyone and quickly. Until 1996, water treatment specialists in the Research & Development department of "Samsung" company were involved in reverse osmosis technology in Korea. But even in early 1996, when R&D specialists demonstrated the operation of pilot lines for the production of membranes and devices, company's management was still skeptical about the possibility of creating a company that would meet the needs of the local market for competitive membrane products. However, the R&D department, having separated from "Samsung" and organized the SAIHAN company, then quickly established the production of world-class membranes, pushing out Japanese and American competitors not only in the Korean market, but also in the world market [2].

The goal of scientific substantiation of the energy characteristics of CWTP is set, to achieve which the following tasks are determined:

- to substantiate a method for improving the efficiency of CWTP through preliminary improvement of the quality of the initial and additional purification of the treated water;
- to propose a way to improve the quality of drinking water from a water supply source, based on the improvement of ultra- and nano- filtration;
- to calculate the energy performance of the CWTP, based on the data obtained experimentally.

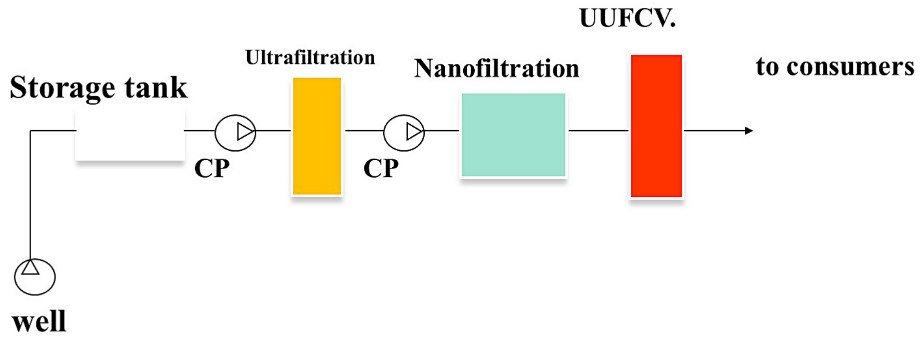

Figure 1. Technological block diagram of a combined water treatment plant (CWTP)

The growth in the introduction of membrane technologies based on ultra- and nano- filtration, reverse osmosis and electrodialysis, the prospects for the development of these membranes are explained by the enormous possibilities and versatility of this method, which provides a solution to various problems in drinking and technical water supply in scientific works [3].

There are a lot of researches in the fields of the use of membranes for water treatment in centralized water supply systems [4], for additional purification of tap water in city buildings, for water treatment at power facilities. Reverse osmosis and electrodialysis technologies are also acceptable for post-treatment of wastewater when used in the circulating system at industrial enterprises, as well as for the treatment and disposal of wastewater from city waterworks.

MATERIALS AND METHODS

Figure 1 shows the technological scheme of the CWTP, consisting of ultrafiltration water pretreatment (UFU) blocks, where the preliminary water softening is performed, and a nanofiltration unit (NFU). A water pretreatment block with such modules allows to work with a higher productivity. When working with water that has passed the stages of pre-filtration, the capital cost of building a water treatment plant is reduced, and at the same time, higher quality purified water can be obtained.

If it is necessary to empty water from the UFU unit, the discharge is carried out into the drainage system through the valve 9. For preliminary ultrafiltration, a roll element with ultrafiltration membranes based on cellulose acetate is used, which have a higher specific performance and hydrophilic properties. They are less susceptible to adsorption pollution by organic substances and allow to fully carry out preliminary water purification.

Ultrafiltration unit – where the process of membrane separation of liquid mixtures under the action of a pressure of 0.3–0.8 MPa is carried out, based on the difference in molecular weights or molecular sizes of the components of the mixture to be separated (Fig. 2). Water treatment is conducted by ultrafiltration through a tubular apparatus with membranes, which are a vertical column consisting of several sections tightened in flanges with studs and nuts. Each section is a stack of membrane elements alternating with gaskets. The package is packed into a cylindrical shell. The gaskets ensure the tightness of the section and, when pressed by the pins, due to the frictional forces, transfer the force of the working pressure to the drainage material, which makes it possible to do without a special durable body in the case of the chosen design).

The ultrafiltration unit consists of two membranes laid on substrates made of fine-porous material, between which a drainage material is placed.

Figure 2. Experimental installation of the UFU ultrafiltration unit

Table 1. Technical characteristics of CWTP

UFU / NFU block characteristics	block / UFU	block / NFU
Water productivity, d^3/h	100	100
Number of membranes/cells, pcs	6	6
Electrode voltage limits, W	-	-
Weight of apparatus with valve block (with water), kg	35	60
Overall dimensions of the device, mm	330x330x450	530x530x450
Electricity consumption, kW	0.3–2.0	0.5–2.5

The membrane surface is cleaned without the use of reagents, using automatic hydraulic flushing. The pre-treatment unit retains all ions by 92–99%.

The ultrafiltration unit can effectively retain suspended solids and the smallest particles of colloidal iron, due to the size of membrane pores d = 30–1000 A, at an operating pressure of 0.2–1.0 MPa, particles up to 0.005 microns in size are removed.

The technical characteristics of the source water when filtered on the installation of the UFU ultrafiltration unit are given in Table 1.

Use of the UFU brings benefits of:

- flushing through the nozzles of the filtrate, concentrate and source water (simultaneously or sequentially);
- direct washing of UV fibers.
- operation in the mode of tangential filtration or with recirculation of source water;
- conducting backwashing with simultaneous supply of air to the inside of the fibers;
- carrying out enhanced chemical cleaning without dismantling membrane elements;
- testing the integrity of membranes using air;
- easy start-up and deaeration procedure of the installation;
- easy disconnection/replacement of any UV element without shutting down the entire installation and disassembling the cases.

All these advantages provide the possibility of increasing the specific removal of the filtrate up to 140 l/(m^2·h), low operating costs, the simplicity of operation and maintenance of the unit (Table 2). In addition, the use of the tangential filtration mode allows the treatment of source water with a high content of suspended matter (up to 1000 mg/l) and turbidity (up to 50 mm). The nano-membrane unit is shown on Figure 3 and the experimental data are in Table 3.

The choice of the type of membranes is determined by the requirements for the quality of the purified water and the compliance of the parameters of the purified water (the content of ions Ca^{2+}, F^-, NH_4^+, etc.) with the specified requirements. In this case, the optimal operating parameters of the membrane units are selected, corresponding to the values of the filtrate yield and operating pressure, at which the greatest cleaning effect is achieved for several specified components. Different types of membranes have different "resistance" to various pollution, which is also considered when designing water treatment systems.

RESULTS AND DISCUSSION

The results of the experimental study built the dependences of the quality indicators of purified drinking water are presented in Figure 4, 5.

The initial water from the pre-treatment ultrafiltration unit is fed by a centrifugal pump for additional treatment to the nano-membrane unit for additional treatment and then to the ultraviolet water disinfection unit.

Figure 3. Experimental installation of the NFU nanofiltration unit

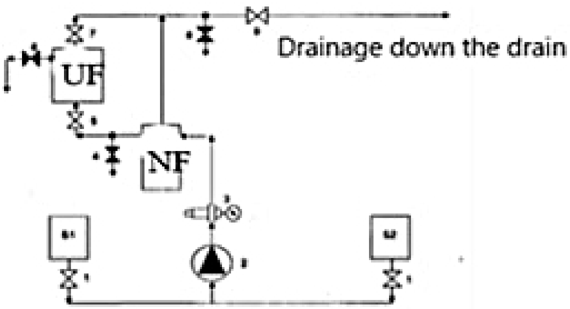

Figure 4. Schematic diagram of the operation of the UFU and NFU unit.
1 - valve at the outlet of the tank, 2 - pump, 3 - pressure reducer with a manometer, 4 - sampling valve, 5 - valve at the inlet to the ultrafiltration membrane, 6 - sampling valve at the outlet of the ultrafiltration membrane, 7 - valve on the drainage line of the ultrafiltration membrane membranes, 8 - sampling valve on the drain line, 9 - shut-off valve on the drain line

The measured characteristics of backwashing of the UFU ultrafiltration unit and the productivity of the total dissolved solids (TDS) of the combined water treatment process made it possible to determine the energy parameters of its operation, presented in the graphs (Fig. 6, 7).

The data obtained will allow:

- to avoid premature contamination of membranes and their failure.
- to achieve the best quality of drinking water without using reagents.
- to select the most optimal modes and types of membranes for different compositions of groundwater and the content of iron, sulfates, chlorides, bore and borates.
- based on theoretical and experimental studies, membrane technologies have been mastered and implemented in combined water treatment systems.

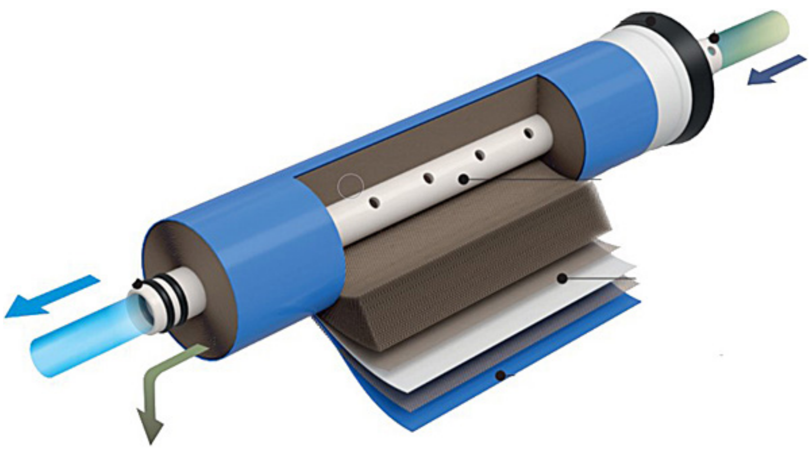

Figure 5. Construction and materials of membranes of ultra and nano filtration module

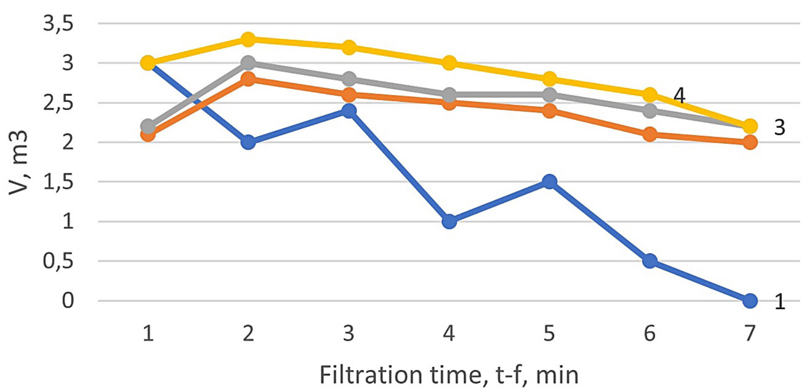

Figure 6. Duration of backwashing of UV and NF membranes in CWTP

Table 2. Indicators of the quality of source and drinking water

Name source	Indicator quality of source water, mg/d³			Indicators drinking water quality, mg/d³		
	TDS, mg/dm³	t,⁰C	pH	TDS, mg/dm³	t,⁰C	pH
Underground water	121.3	20	8.5 ÷ 9.5	0.77	22	8.5 ÷ 9..5

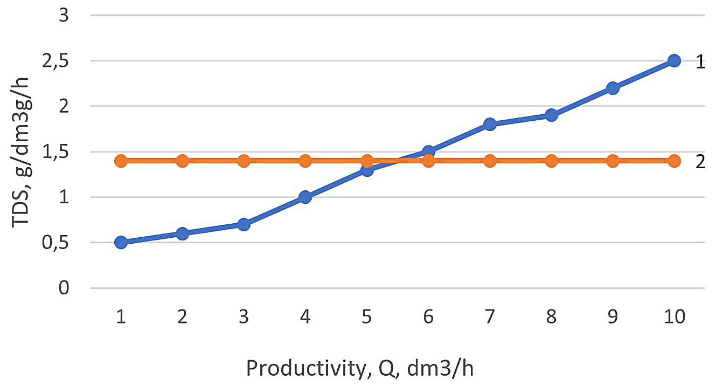

Figure 7. Productivity of CWTP from the total amount of dissolved substances TDS (Total dissolved solids)

Table 3. Results of the quality of treated water by steps in CWTP

Indicator	Ref. water	MF	UFU	NFU	UUFCV
Total hardness, mg-eq/dm^3	2.8	2.8	1.0	0.7	-0.02
Total alkalinity, mg-eq/dm^3	2.7	2.7	0.012	-	-
Concentration of bicarbonates, mg/dm^3	1.35	1.35	0.7	0.04	-
Oxidability, mg 0_2/dm^3	14.8	14.8	9.2	-	-
Chloride concentration, mg/dm^3	19.0	19.0	16	0.03	-
Iron content (total), mg/dm^3	2.0	0.085	0.05	-	-
Aluminum content, mg/dm^3	0.016	0.016	0.016	-	-
Chromaticity	>80	40	-	-	-
TDS	121.3	80.4	25.9	0.77	-

- on the basis of the studies carried out, the work of a combined water treatment plant with membrane and filtration plants was designed and adjusted, effectively desalting sources of natural, groundwater and sewage;
- developed an engineering methodology for calculating and optimizing the parameters of a combined water treatment plant for heat supply systems based on membrane and filtration devices.

The proposed energy-saving membrane technologies make it possible to design autonomous heat supply systems and heating boilers with increased energy efficiency, with low consumption of chemicals and a decrease in sewage:
- allows to reduce the risk of exposure to corrosion processes in the steam-water path and to ensure uninterrupted operation of heat installations of HPP and autonomous heating systems;
- to increase technological efficiency, economic reliability, and environmental safety at industrial facilities in the conditions of the region of Central Asia and Kazakhstan.

The materials of this research work have been implemented into the practice of industrial enterprises, heating boilers, autonomous heating systems in Kazakhstan city Karaganda.

CONCLUSIONS

From the point of view of ensuring the minimum consumption of reagents and the highest environmental friendliness with high quality drinking water, the proposed CWTP method has the greatest efficiency, consisting of membrane blocks – modules for the various purposes.

We have proposed an improved scheme based on a combination of ultra- and nano-membrane technologies for enhancement of of drinking water properties.

After carrying out a multi-stage purification using the proposed method for purifying natural waters, they have final data that correspond to the hygienic standards for the content of harmful substances in drinking water.

Thus, the quality of the treated water in all respects meets the requirements for the quality of drinking water regulated by «Sanitary and epidemiological requirements for water sources, household and drinking water supply, places of cultural and domestic water use and safety of water bodies» legilsation.

The source water supplied to the installation must meet the requirements, if the source water does not meet the listed requirements, then its appropriate pretreatment should be provided (mechanical cleaning from suspensions, removal of excess iron, etc.). Thus, applying the method of purifying natural water using these devices to obtain water corresponding to the standard allows to reduce the cost and simplify the process and increase the degree of purification of natural waters.

The advantage of simplicity and easy adjustment of the process, low energy consumption and low cost of devices promising a huge benefit in the future. This solution made it possible to reduce the load on the filters, excluding the use of chemical reagents used in classical CWTP circuits.

The values of the CWTP KPI obtained in the course of the experiments and determined by calculation are consistent with each other within the experimental errors with the regulation of the performance of the membrane blocks.

The obtained experimental results made it possible to determine the dependences of the main characteristics of the UFU and NFU block CWTP, TDS, time of filtration and productivity (Tf, Q), the possible range of its regulation (50–180%), will improve the scheme in the design of the CWTP with the provision of deeper water quality to reduce the costs of desalination, water purification, the cost-effectiveness of the operation of the water supply system.

In addition, its use will prevent the further formation of toxic bottom sediments in open water intakes, and also - will significantly reduce the cost of water in comparison with traditional structures using coagulation, sedimentation, filtration and chlorination, and it is possible to achieve an economic effect from the introduction of the proposed technology at small facilities with water consumption. All this determines the ways of further continuation of the research work.

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