Conceptual design of water supply systems based on low-power nuclear desalination complex

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Abstract. The concept of environmentally friendly and energy-efficient water supply systems development on the basis of a desalination complex is considered to solve the problem of water deficiency, reduce the ecological load on the environment and provide fresh water to regions in which a lack of fresh water is found out. In the paper, a brand-new hybrid scheme of the water supply system is proposed, with the production of water containing reduced deuterium, based on desalination technology and recirculated water supply (recycling) with the help of membrane and distillation methods, as well as improved pretreatment and water purification technology.

1. Introduction
Nowadays water consumption is growing much faster than population. Russia is ranked 2th in the world for content of surface fresh water resources. However, only 20 percentages of fresh water sources are located in central and southern regions with a high population density, well-developed industry and agriculture. The lack of fresh water in these areas can be compensated by the desalination of salt seawater and brackish groundwater.

In order to solve the problem of water deficiency and to develop the desalination market in Russia, it is proposed to solve the global scientific and technical problem, in particular, to create environmentally-friendly water supply system which allows to obtain light water on the basis of desalination and recycling water technologies using membrane and distillation methods. This approach, from one hand, can solve the problem of water deficiency, and from another hand, will reduce the overall costs of water sector system operation in whole.

2. Conceptual design of water supply systems
Due to the high cost of desalination technology, technological scheme which will ensure the highest possible extraction by cheaper methods of purification before the desalination stage, should possess the significant advantage cause of reduction load on the desalination stage and also making it more efficient. Taking into account various groups of consumers of desalinated water (population, industry, agriculture) consuming water of different quality, it is advisable to use combined desalination schemes applying distillation, electrodialysis and low-pressure reverse osmosis (nanofiltration) technologies. In respond to different unit costs for the removal of various pollutant groups, the highest costs of which are salts, it’s advisable to use recycling methods – reuse of purified waste water produced by activities of water consumers and characterized by a lower salt content. The use of recycling methods allows to
reduce significantly the unit cost of different pollutants groups removal, satisfying the needs in the technical water for a wide range of consumers.

The daily human need for drinking water is 2-3 liters. Domestic water demand averages 100 liters per person daily. The proportion of fresh water used for industrial and agricultural needs is somewhat larger and averages 300 liters per person per day. Thus, for the water supply of a city with a population of 100 thousand people, about 0.85 m$^3$/s of water is needed, which is included in the most demanded range for the productivity of desalination plants, ranging from 50 to 200 thousand cubic meters per day (according to the IAEA) [1]. Table 1 shows the required amount of water used in various spheres of activity of the city, as well as the requirements for their quality and the recycling percentage, which reduces the required plant productivity.

Table 1. Calculation of the city water supply with a population of 100 thousand people.

| Water assignment | Quantity, m$^3$/s | Degree of purification from salts, % | Degree of purification from toxic substances, % | Deuterium content, ppm | % of Recycling |
|------------------|------------------|-------------------------------------|-----------------------------------------------|------------------------|---------------|
| Drinking         | 0.0035           | 94-96                               | in accordance with maximum permissible concentration (MPC) | 120                    | –             |
| Agricultural     | 0.35             | 94-96                               | in accordance with maximum permissible concentration (MPC) | 140                    | 50            |
| Domestic         | 0.116            | 99.9                                | 99.9                                          | 140                    | 80-90         |
| Own needs        | 0.00011          | 99.9                                | 99.9                                          | 155                    | 80-90         |
| Industrial       | 0.35             | 99.9                                | 99.9                                          | 155                    | 80-90         |

The total heat and electric power for obtaining of the water required amount for a city with a population of 100 thousand people is about 500 and 10.0 MW, respectively. Taking into account the recycling, this value is almost halved and amounts to 300 MW of thermal energy and 4 MW of electricity. Thereby, while developing a hybrid water supply system for the desalination complex, it is proposed to use low-power reactors [1] or power-generating gas turbines in which exhaust gases have significant thermal power.

The use of gas turbines as a source of energy in combination with recycling technology can successfully solve the problem of water deficit in Crimea. In addition, taking into account the relatively low salinity of the Black Sea (18 kg/m$^3$), there is a principal possibility of a significant reduction in energy consumption for desalination due to a partial recession from distillation technology and an increase of desalination influence on the process by the method of low-pressure reverse osmosis.

On the figure below one of the variable configurations of the technological scheme is presented.
Figure 1. Principle technological diagram of the water supply system on the basis on desalination complex: 1 - coarse filter; 2, 5, 12 – pump; 3 – pretreatment unit; 4 - sewage-sludge treatment unit; 6, 13 - tangential filter; 7 – nanofiltration unit; 8 - UV –treatment; 9 - drinking water tank; 10 – system of domestic water supply; 11, 20 – sewage system; 14 - distillation unit; 15 - light water obtainment unit; 16 - agricultural water supply system; 17 – electrodialysis unit; 18 - vapour source; 19 - industrial water supply system; 21 - water prepurification.

For the long-term operation of desalination plants, the quality of the source water should meet certain rigid requirements. So, there is the need to develop a pretreatment system, taking into account the data on the pollutants composition, salinity and water preparation system performance. It seems promising to use modules of reagent treatment and flotation dividing of phases in the pretreatment unit [2].

This method was used in the development of technology for surface water treatment facilities of The Moscow International Business Centre (MIBC), also known as "Moscow City", with a capacity of 1.39 m$^3$/s. As the main reagent is used a low selective (removing a wide range of contaminants) mineral composite reagent, obtained by sulfuric acid decomposition of cheap aluminosilicate raw materials [3]. As a result of the use of this reagent, the concentration of heavy metals and oil products in water is reduced by 99%, the concentration of the hardness salts is 96%, and the residual aluminum content in the purified water is one order less than in the initial.

After the pretreatment unit, the salt water enters the desalination unit, which, as a rule, is very energy-intensive. In order to reduce the energy intensity of the desalination process, it is assumed to develop hybrid desalination schemes (collaborative use of distillation and membrane desalination
methods) based on nuclear desalination, and these schemes make it possible to obtain drinking, technical and light water.

The part of the water from the pretreatment unit is directed to the distillation unit. The salt content of the desalinated water at the outlet (in the permeate flow) is minimal (<25 mg / l), so it is possible to use this water as a technical one for various industrial, domestic and own needs. The retentate section with high salt content is directed to the electrodialysis unit, afterwards it is entered the special evaporator in a form of brine in order to obtain leach, or is used for mineralization of agricultural water. In addition, the developed scheme has provision for the recycling of waste water, which after preliminary cleaning can enter to the input of the system or be used for agricultural purposes (Figure 1). The share of industrial water recycling is about 80-90%. The usage of the recycling scheme allows to reduce the salt content and consumption of the initial water and, consequently, to reduce the load on the desalination stage, which makes it more efficient.

Among other things, the scheme provides for the production of light water depleted heavy hydrogen isotope - deuterium. As known, the content of deuterium in seawater is about 155 ppm. For the production of light water, some of the desalted (technical) water is fed to the input of the deuterium removal unit. Depending on the application, there are various restrictions on the permissible content of deuterium in the water. For example, for drinking, it is sufficient to reduce the deuterium content to 120 ppm, which is somewhat lower than the corresponding level for fresh water reservoirs (Lake Baikal - 135 ppm). For irrigation waters of agricultural and household purposes, it is sufficient to reduce the deuterium content up to 140 ppm.

As known, total mineralization of drinking water should be 0.5-1.0 kg/m³. In this case, the content of toxic ions in water should not exceed the MPC level. In order to obtain high-quality drinking water, another part of the water from the pretreatment unit, if necessary, is additionally purified from the toxic elements remaining in the water, after which it is fed to the nanofiltration and UV-treatment units. It is commonly known that nanofiltration membranes have reduced selectivity and increased permeability in comparison with reverse osmosis membranes. The operating pressure in nanofiltration processes is usually in the range from 0.3 to 1.0 MPa, which is much less than the operating pressure of the reverse osmosis process. In this case, the selectivity of nanofiltration membranes to the cations of Ca²⁺ and Mg²⁺ is different and depends on the composition of the water. In any case, the extraction degree of salts with nanofiltration is lower than with reverse osmosis. It affords an opportunity to obtain mineralized water used for drinking purposes at the outlet of the permeate flow. It is important to notice that it is necessary to dilute this water additionally with a depleted flow, entered from the deuterium removal unit, in which the deuterium content was reduced to a level of 100 ppm. The total content of deuterium in drinking water will be approximately 120 ppm. The concentrate from the nanofiltration membrane can be used for water mineralization of agricultural purposes.

It should be noted that the lowest percentage of recycling is provided by agricultural water, as about 50% of this water are irretrievably lost. The construction of the desalination system requires optimization taking into account all the technological processes taking place inside the system. There is a variant of the technological scheme in which water of agricultural purpose is obtained with the help of a nanofiltration unit. In this case, the share of electricity consumed for desalination process increases, and the share of thermal energy decreases.

The unit for sludge drying and compaction is designed for harvesting and subsequent dehydration of coagulated suspensions and concentrates. Pollutant concentrates enter the sludge treatment unit for dehydration, after this they can be used in the manufacture of concrete and asphalt in order to increase the dispersion of the product. The leach obtained after evaporation in the electrodialysis unit can be used in the production of fertilizers, as well as a source for the microelements production.

3. Conclusions

The concept of environmentally friendly and energy-efficient water supply systems development on the basis of a desalination complex is considered to solve the problem of water deficiency, reduce the ecological load on the environment and provide fresh water to regions in which a lack of fresh water is
found out. In the paper, a brand-new hybrid scheme of the water supply system is proposed, with the production of water containing reduced deuterium, based on desalination technology and recirculated water supply (recycling) with the help of membrane and distillation methods, as well as improved pretreatment and water purification technology. The problem of concentrating brines and sediments to a level ensuring their utilization is considered. For example, providing a small city with a population up to one hundred thousand people with the fresh water, the possibility of using a low-power nuclear reactor or gaseous turbine as an energy source, is considered.

Thereby, developed scheme of the water supply system is economically-viable, environmentally-friendly, can successfully solve the problem of water deficit and provide high-quality water to regions with water deficiency, including Crimea.

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