Optimization of the Seawater Desalination Method for a Certain Region

L. A. Nichkova\textsuperscript{1,a}, G. A. Sigora\textsuperscript{1,b}, T. Y. Khomenko\textsuperscript{1,c} and V.V. Biriuk\textsuperscript{2}

\textsuperscript{1}Federal State Autonomous Educational Institution of Higher Education "Sevastopol State University", Sevastopol, Russian Federation
\textsuperscript{2}Federal State Autonomous Educational Institution of Higher Education "The Samara National Research University named after the academic S. P. Korolev", Samara, Russian Federation

Email: \textsuperscript{a}prohvatilov12@mail.ru; \textsuperscript{b}sigora1@yandex.ru; \textsuperscript{c}tamara_homenko93@mail.ru

Abstract. The article deals with the problem of the shortage of fresh water and the desalination of sea water as one of the promising options for its solution. For the Crimean region the issue of desalination is the most urgent, taking into account its geographical peculiarities. The chemical composition and thermophysical properties of the Black Sea waters are presented. The technological scheme of the station for the preparation of drinking water from the waters of the Black Sea by the method of distillation desalination is presented and considered in detail. To ensure the manufacturability water must comply with the following requirements: the boundaries of the zones of the sanitary protection of water intake should be at least 200 m in all directions of the waters; water intake facilities should be equipped with a mesh filter to capture floating algae, water intake should include water treatment with biocidal agents (chlorine, copper sulphate etc.) with a view to their destruction and subsequent deposition, introduction of water in the chalk priming (with the value of the fraction 10-40 MK) at the rate of 8-15 kg/m3, water, polyphosphates up to 10 g/m3 of sulfuric acid 150 g/m3, organic antiscalers "Belgard EV" or PAF-13A - 10 g/m3; water should be subjected to deaeration. A water clarification station is necessary, as the evaporation plant should be feeding clarified water, containing dissolved oxygen and carbon dioxide, and not prone to scaling. Under the clarification of water, in the general sense, is understood the removal from it of suspended particles of organic and inorganic origin. The need for biocidal and antiscalers treatment is determined by experimental testing, but a good installation of clarification of sea water significantly reduces the need for this step.

1. Introduction

The problem of the lack of drinking water since the 20th century is regarded as a global problem of our time. The population of the planet is growing rapidly and at the same time there is a growing need for clean drinking water. According to www.worldometers.info, the population of the Earth in June 2018 exceeds 7.6 billion people, and the population growth for this half-year is about 44 million. The consumption of fresh water is growing dynamically as the number of people on the planet increases. Already today, the amount of water consumed in 2018 is 29 billion liters. Over the past 50 years, the withdrawal of fresh water has tripled. Fresh water costs vary considerably, depending on the specific geographic area of the world, with obvious large differences between, for example, the Sahara region in Africa and the Great Lakes region in North America.
According to experts, by 2040 the global demand for fresh water will be considerably higher. Of course, a future scenario such as this, requires thorough consideration and should be undertaken with all possible efforts to ensure the continued satisfaction of the needs for fresh water.

In connection with the increasing pollution of water sources, population growth, development of new territories, the challenge of artificial production of fresh water. Currently this is achieved via the next most common methods [1]:

- desalination of sea water;
- condensation of water vapour from the air, using deep-sea water;
- condensation of water vapor in daily cold accumulators, in particular of natural origin, such as the caves in cliffs.

One of the most promising solutions to meet the needs of drinking water on a world scale can be the proposed desalination of sea and brackish waters, as one of the sustainable options for the production of fresh water.

Desalination of sea water has established itself as a reliable and economically sustainable water resource since the second half of the 20th century. In the fresh water market, two technologies of water desalination - membrane (mechanical) and thermal (distillation) - have found wide industrial application.

In membrane technology, the method of desalinating water, called "reverse osmosis," is predominant. When water is desalinated by this method, seawater is passed through semipermeable membranes under the influence of pressure substantially exceeding the difference in the pressures of fresh and sea water (for sea water 25-50 atm.). Through the micropores of these membranes small molecules of water can freely penetrate, while larger ions of salt and other impurities are retained by the membrane. Such membranes are preferably made of polyamide or cellulose acetate and are available as hollow fibers or coils. The world's largest plant for membrane desalination Wonthaggi Desalination Plant is located in Melbourne and has a capacity of 440 thousand cubic meters of water per day. In Israel, in Ashkelon, there is a desalination plant using the reverse osmosis method, which produces 330 thousand cubic meters of water per day [1].

The essence of the thermal method of distillation is that the seawater is heated to boiling point and the effluent vapor is collected and condensed. The formed fresh water is called distillate. Water can be evaporated either via boiling or without. In the latter case, seawater is heated at a higher pressure than the pressure in the evaporation chamber, where water is directed. For steam generation, the heat contained in the evaporated water itself is used, which is then cooled to the saturation temperature of the remaining brine. It is this method that allows one to obtain the largest volume of desalinated water per unit of time. For example, most of the Saudi Arabian state owned desalination plants use a multi-step, instantaneous evaporation method in which seawater evaporates sequentially through multiple chambers with a gradual decrease in pressure. Technology is considered more economical for larger volumes than reverse osmosis. Modern desalination plants in Saudi Arabia use a method of evaporation and reverse osmosis. The construction of 17 more desalination plants is planned. The main number of desalination facilities belong to the state, but there are private stations too.

A more detailed classification of the methods of the desalination of seawater and brackish waters, their advantages and disadvantages is given in [2].

2. Geographic analysis of desalination

According to the International Association for desalination Association (IDA) about 17000 plants are operating in 120 countries. According to experts, in the next 10 years the market of technologies of sea water desalination will increase by 60%: from the current $ 10 billion to $ 16 billion in 2020. The main drivers of growth will be Algeria, Spain and Australia. In addition, a growth in demand is expected in the emerging markets of China, India and the United States.

To date, of the sea water desalinate worldwide, Saudi Arabia accounts for 18%. According to waterworld.com it topped the list of the top 10 countries in terms of installed capacity of water desalination, the list also includes the UAE, USA, Spain and Kuwait.
The market of technologies of sea water desalination in the Russian Federation is poorly developed. The serial manufacture of desalination systems is not carried out. The latest installation with a capacity of 10 tons per hour was made at "Uralkhim mash" in 1988. Given that Russia has access to the Black, Azov and Caspian seas, these geographical features of the country should allow to widely apply methods of seawater desalination. The relevance of this problem affects the Crimean region, as on the Peninsula, in addition to the Black and Azov seas, there are many more salt lakes.

The problem of desalination requires an integrated and comprehensive analysis, it is necessary to consider the energy, technological, environmental and hygienic aspects.

Fresh water differs from seawater in the relative amounts of salts. Table 1 shows a simple classification of natural waters based on their salt content [3].

Table 1. Water classification based on salinity content

| Type            | Total dissolved solids (TDS) | Note                             |
|-----------------|------------------------------|---------------------------------|
| Freshwater      | Up to 1,500                  | Variable chemical composition   |
| Brackish water  | 1,500–10,000                 | Variable chemical composition   |
| Salt water      | > 10,000                     | Variable chemical composition   |
| Seawater        | 10,000–45,000                | Fixed chemical composition      |
| Standard seawater | 35,000                     | Fixed chemical composition      |

Freshwater water can have a salinity average of 0,146 ‰, brackish water shows a salinity of 1-10 ‰, whereas the salinity of seawater is usually between 10 ‰ (as in the case of the Baltic sea, the salinity which has an average size of 7 ‰) 45 ‰ (as in the Arabian Gulf, where the figure is about 40 ‰). Low salinity may be associated with the presence of inflow from rivers and melting glaciers, but also due to the abundance of precipitation. High salinity may be a result of the remoteness from land and high temperatures promoting evaporation.

The main chemical components found in sea water are sodium and chloride, they are, the common components of table salt, which account for 85 % of the total dissolved solids of sea water. Sulfate and magnesium are also plentiful, with nearly 8 % and 4 %, respectively. It should be noted that although the salinity of seawater can vary depending on the specific region, the percentage composition of the sea water is essentially constant throughout the world (i.e. the proportions of the main components are permanent) [3].

3. Seawater analysis

Special attention should be paid to the chemical composition of the Black Sea, as the waters of the Black Sea differ significantly from the waters of other seas. This is due to hydrological peculiarities of the Black sea, and features of the formation of its water mass, its structure and dynamics. Table 2 presents the chemical elements contained in the Black Sea waters.

Table 2. Chemical elements (by weight)

| Element | Percentage | Element | Percentage |
|---------|------------|---------|------------|
| Oxygen  | 85,7       | Sulfur  | 0,0885     |
| Hydrogen| 10,8       | Calcium | 0,04       |
| Chlorine| 1,9        | Potassium | 0,0380   |
| Sodium  | 1,05       | Bromine | 0,0065     |
| Magnesium | 0,1350    | Carbon  | 0,0026     |

As in all seas, the main component of the Black Sea is sodium chloride, as well as magnesium sulfate, calcium carbonate, etc. A distinctive feature of the deep Black Sea waters is the presence of hydrosulfides in them. The amount of hydrosulfide anion HS at maximum depths exceeds 0,01 g per 1 kg of water, which is due to the hydrogen sulphide content in water. For the Black Sea, there is naturally a relatively large amount of phosphate, compared to other seas, especially in the case of deep
waters. The predominant concentration of these substances in the upper layers with a thickness of 100 m is noticeable in the winter months, during this period there is an active mixing of sea water and phosphates coming from the lower layers.

The concentration of dissolved silicon in the surface layer is 1300 mg/l, while closer to the coast it is always high, unlike in open waters. The amount of iron in the waters of the Black Sea is approximately 20 mg/m³, about the same of zinc and aluminium and copper and of magnesium about 4-5 mg/m³ silver 0.1 mg/m³ of gold – 0.003 mg/m³.

The average alkalinity of surface waters in the Black Sea is of 3.33 mEq/l. pH in the surface Black Sea waters varies from 8.1 to 8.5. Of gases dissolved in water, the most common nitrogen (15.9 mg/l). There is less oxygen (in the surface layer contains 10 mg/l). The main feature of the water in the Black Sea, is the lack of oxygen from horizons of about 170 meters to the bottom. Another specific feature is the presence of hydrogen sulfide, distributed throughout the water column from the bottom oxygen layer (about 170-180 m) to the bottom.

In seawater organic matter is dissolved, colloidal or suspended. The surface layer of the Black Sea contains an average of 3-4 mg of dry substance per 1 liter of water.

The salinity of the Black Sea the average is 18 ppm (18 g sea salt per liter of water). Annual fluctuations in the concentration of salinity occur in the range of 17.5 to 18.6 ‰.

Seasonal differences in salinity fields in the surface layer are mainly of a quantitative nature. The maximum salinity of the surface layer is observed in the second half of the hydrological winter, i.e. in February—March. This is due to the intensification of the processes of convective and wind mixing. In the centers of Western and Eastern cyclonic circulations observed stable region with a salinity of 18.4 ‰. The intensive transformation of river waters, followed by a seasonal increase in runoff, resulting in the largest horizontal gradients in kalinago front in March, wellhead delineation of the Danube coast.

Producing fresh water and desalination of the Black Sea and brackish water to create highly efficient and economically viable units at the present level of technology to a large extent contribute to addressing the shortage of freshwater in the Crimean region.

4. Desalination method selection

The design and operation of desalination facilities requires solving a large number of very complex tasks: a preliminary assessment of water consumption and local conditions; the determination method depends on the composition of water and economic feasibility; the reduction of scale formation, with the exception of the corrosive wear of equipment; preparation of drinking water; reprocessing or disposal of residual brines.

During a comparative analysis of the methods and principles of unit operation for seawater desalination in the Crimean region in the study, it was shown [2] that for the desalination of the Black Sea, it is advisable to use a distillation desalination plant, given its: simple design; high productivity; good quality of the obtained distillate; simplicity and high reliability; low cost of producing water; the possibility for the complete automation of processes, possibility of using low-grade heat (including heat of secondary energy resources); the possibility of multipurpose use, including the recycling of brine.

The technological scheme of the station for the preparation of drinking desalinated water (SPPOV) from the waters of the Black Sea was developed by the method of distillation desalination, presented in Figure 1.
Figure 1. Technological scheme of station of preparation of drinking desalinated water (SPDDW)

The distillation method of desalination is among the cheapest large-scale methods of producing desalinated water, therefore, at the present time as the number of desalination plants and, especially, their overall performance this method of distillation has a dominant position in desalination technology.

Studies show that the method of diversion of water from the sea, as well as the type and design of sea water intake facilities is necessary to determine, subject to the following specific conditions and characteristics of the sea coast [4]:

a) fluctuations in the water level due to tides, waves, surges, and sea currents;
b) significant force of shock waves;
c) the geological structure of the sea coast, the pumping of pumps in the coastal zone, the formation of shallows, the washing of the shore, landslide phenomena;
d) presence in seawater of algae, mollusks and microflora;
e) corrosive properties of sea water;
f) the nature of the ice phenomena in the area of the water intake.

When node 1 is placed in the bays of the coastal zone of the Crimean region, conditions a, b, c, e are not significant. Conditions g and d require certain actions: the water taken from the cove must pass through filters that are structurally represented by rotating screens and nets (diameter of holes 2 ... 4 mm.) Equipped with automatic rinsing devices. Then the water is pumped through the pipeline.

The tubing is manufactured from galvanized steel pipes. The choice of pipe materials and fittings must be made according to OST 5.5462-82 [5], with the exception of pipeline TDS and ozone treatment, to which pipes must be made of stainless steel grade 08KH22N6T GOST 9941-81 [6], the fittings - of brass, and gaskets for piping mineralization from food-grade rubber according to GOST 17133-83 [7], for piping ozone-air mixture from plastic on the other 6.05-1146-75 [8].

5. Conclusion

The process of preparing drinking water by distillation, determines a number of additional requirements to the quality of water supplied to the desalination plant. The pre-treatment of source water involves activities on its preliminary purification and giving the water the necessary technical properties. The filtration, settling, softening, deaeration, chemical treatment are the most widely used for these purposes.

To ensure the manufacturability of Presstime water must comply with the following requirements:

- as a distillation desalination plant (DDP), as a rule, is used to get large amounts of water and mainly surface waters (first of all sea water), the boundaries of the zones of the sanitary protection of water intake should be at least 200 m in all directions of the waters;
- water intake facilities should be equipped with a mesh filter to capture floating algae. If you have a large amount of algae in the city the water intake should include water treatment with biocidal agents (chlorine, copper sulphate etc.) with a view to their destruction and subsequent deposition;
- to reduce the intensity of the processes of scale formation at high temperatures in the evaporators due to high content in water of salts of rigidity, it is recommended that the preliminary introduction of water in the chalk priming (with the value of the fraction 10-40 MK) at the rate of 8-15 kg/m³ apresentamos water, polyphosphates up to 10 g/m³ of sulfuric acid 150 g/m³, organic antiscales "Belgard EV" or PAF-13A - 10 g/m³;
- method pre-treatment of source water should not lead to increased microbial contamination of water and deterioration in its organoleptic properties.

A water clarification station is necessary, as the evaporation plant should be feeding clarified water, containing dissolved oxygen and carbon dioxide, and not prone to scaling. Under the clarification of water, in the general sense, is understood the removal from it of suspended particles of organic and inorganic origin.

The need for biocidal and antiscaling treatment is determined by experimental testing, but a good installation of clarification of sea water significantly reduces the need for this step.

Acknowledgments
This work was carried out by lead performer of research and development effort with financial support of Russian Federation Ministry of Science and Education with the realization of Government decree №218 according to contract about providing and using subsidy № 02.G25.31.0150 from 01.12.2015.

References
[1] Slesarenko V.N. Modern methods of desalination of sea and solonchak waters. M. : Energia. 1973. - 248 p.
[2] Analysis of methods and principles of operation of sea water desalination plants in the Crimean region / Biryuk V.V., Blagin E.V., Gorshkalev A.A., Lukachev S.V., Nikchkova L.A., Sigora G.A., Khomenko T.Yu., Shimanova A..A.. // Newsletter of the BrSTU, 2016. No.4 (100). - P. 18-22.
[3] Cipollina A., Micale G., Rizzuti L. Seawater Desalination Conventional and Renewable Energy Processes. 2009. - 314 p.
[4] Abramov, N. N. Water supply / Textbook for high schools. Ed. 2 nd, revised. and additional. Moscow: Stroyizdat, 1974. - 480 p.
[5] OST5.5462-82. Ship systems and systems of ship power plants. Materials and test pressures. - Enter. 1983-01-07. - 17 p.
[6] GOST 9941-81. Seamless cold-and heat-deformed pipes of corrosion-resistant steel. Technical conditions (with Changes N 1-5, with the Amendment). - Enter. 1983-01-01. - Moscow: IPK Publishing House of Standards, 2004.
[7] GOST 17133-83. Rubber plates for products in contact with food. Technical conditions - Enter. 1984-01-01. - Moscow: IPK Publishing House of Standards, 1983.
[8] TU 6-05-1146-75. Film and sheet plastic formulations 57-40. - Enter. 1976-01-03.