Vol. 1, No. 1, 2016

# PREPARATION OF QUALITY DRINKING WATER AS A BASIS OF THE ENVIRONMETAL SAFETY AND HUMAN HEALTH

**Maryna Kravchenko**

*Kyiv National University of Construction and Architecture, Ukraine, Kyiv, marina-diek@ukr.net*

*Received: 29.09.2015*



**Abstract**. The problem of drinking water preparation with specified quantitative and qualitative composition is very acute today in various countries including Ukraine. The consequences of using the method of reverse osmosis at tap water purification using the equipment with the membrane element Filmtec XLE 440 (8"), produced by DOW Chemical (USA), have been reviewed. Positive characteristics as well as economical and technological shortcomings of reverse osmosis equipment have been proved.

**Key words**: drinking water; reverse osmosis; preparation of potable water.

## 1. Introduction

The uneven distribution of fresh water in different regions of the world, including separate countries, the growing consumption of fresh water by industrial and agricultural production, as well as residential areas against the background of continuous decline in the quality of water sources (natural water, mineral water, underground water), as a result of anthropogenic pollution, place the provision of the world's population with quality drinking water among the most important social and economic world’s problems [1].

“The lack of clean water causes more deaths worldwide than war. In some countries, half of the population has no access to safe drinking water and as a result, has poor health” [2].

Unimproved technologies of purification of polluted water that have not been significantly changed over the centuries, contribute to the problem of environmental safety and human health. Therefore, it is relevant today to search for new approaches and development of new effective technologies for drinking water, which are baromembrane methods.

## 2. Problem formulation

Today, centralized water supply stations in Ukraine use water purification system in three stages: coagulation, filtration and chlorination. These technologies are outdated and do not meet the DSanPiN 2.2.4-171-10 standards [3], adopted in Ukraine, not to mention the standards in force in European countries.

However, about 40 years ago a fundamentally different water treatment technology – baromembrane technology, started to develop. It is based on passing the water under pressure through a semi-permeable membrane and separating water into two streams, the filtrate (purified water) and concentrate (concentrated solution impurities) [4].

First baromembranes technologies were used only in the research areas, which is typical for the process of innovation. The volume of consumption was small, the cost was high and the range of consumers was narrow. Then, membrane technology was applied in space research and defense industries. The consumption increased, production became technological, the cost of the membranes decreased and it became possible to use the membranes in such industries as medicine, pharmacology and others. Reduced prices for membrane materials led to the increase in the production volume of these products and start of the use of its application in industries with significant production capacity, for example, food industry. Worsening of environmental problems and rising energy prices made it possible to use baromembrane technology in water preparation for power plants, water supply, and purification of industrial and household polluted water [5].

First of all, the advantages of baromembrane processes include the implementation of all these processes without changing the aggregation state of water which determines their economic attractiveness and technological efficiency, eliminating the competitors among the classical methods of water treatment [6–8].

Such features of the baromembrane processes are associated with the use of membranes whose properties are set during the design and synthesis of new polymers. For example, the selectivity of the membrane is set by creating new polymers with specified molecular weight, viscosity, concentration, mechanical properties, the structure of the polymer material that makes possible to use baromembrane methods for solution of a wide range of tasks in drinking water preparation.

Baromembrane processes, depending on the composition of the aqueous solution that is necessary to separate, are conventionally classified as follows: microfiltration, ultrafiltration, nanofiltration and reverse osmosis, which is the most popular today, particularly in drinking water preparation.

Reverse osmosis systems as water preparation equipment, since its inception, were developed not for centralized or autonomous (artesian well, well) water supply, but for desalination of salt and brackish water (salinity > 1000 mg / $dm^3$), wastewater purification, preparation of high purity water for industrial operations.

Over time, however, a number of large companies that are engaged in the development and delivery of water purification equipment began to produce both industrial reverse osmosis systems and household ones.

The positive characteristics of the household reverse osmosis systems include the following [9]:

- The possibility to purify water with various salt contents from different water sources including purification of the water that has been prepared at centralized treatment plants.
- Caring for a semi-permeable membrane, which is a key element of a reverse osmosis set, does not need the use of chemical reagents. Therefore, reverse osmosis equipment is considered to be environmentally safe for using.
- Duration of the membrane cartridge using (up to one year), that is profitable.
- Ability to accumulate about 12 liters of purified water in the set reservoir that is effective when cold water is disconnected.
- Simultaneous removal from water not only salts and other substances in the ionized state, but also organic substances, colloids, bacteria, viruses (particle size 0,001–0,0001 microns; operating pressure from 0,5 MPa).

The efficiency of reverse osmosis plants for a wide range of issues, including preparation of potable water, is determined by the quality of their basic element – membranes, represented at the world market in a wide range, which work at low (up to 1,5 MPa), medium (2,5–3,0 MPa) and high (more than 3,0 MPa) pressure and have different physicochemical and technical characteristics.

For reverse osmosis systems that are available today at the commercial market, the membrane elements (cartridges) are the basic elements, that are made from multilayer polymeric composite membranes, mainly produced by the USA (Hydranautics, Filmtec), Germany (Koch Membrane Systems), Korea (Saehan), Japan (Nitto Denko and Toray Inc.).

So the quality of the water, which passed through the preparation process by reverse osmosis, and the productivity of reverse osmosis set are determined directly by such physicochemical properties of the membrane as the structure of its pore size, selectivity and permeability.

The disadvantages of reverse osmosis domestic systems include [9]:

- The supplied to the reverse osmosis set water must be free from chlorine that needs an additional stage of water purification, for example, by carbon adsorption filter.
- The value of permanganate oxidation of water supplied to the reverse osmosis set must not exceed 3. 0 $mgO_2$ / $dm^3$, which needs an additional step to reduce the concentration of organic substances (ion exchange filters, filters based on the activated carbon).
- On average, the reverse osmosis system spends 3 liters of water to prepare 1 liter of purified water (permeate) that is technologically not profitable. Furthermore, the technology of concentrate recycling from the reverse osmosis set must be provided.
- As a result of contamination of the membrane surface by slightly soluble salts, suspended solids, microorganisms, that reduces the productivity of the plant, there is a need for periodic regeneration of membranes, which requires additional economic and technological costs.
- The level of water purification, which was prepared in the reverse osmosis set, reaches 99,8 %, which is the main drawback of reverse osmosis household equipment.

Reverse osmosis in the demineralization process divides tap water into two streams: demineralized water (permeate), which flows into the storage tank and water with high salt content (concentrate) which is discharged into the sewer.

Water that was cleaned by reverse osmosis becomes brackish. Its total mineralization is 3–100 mg/$dm^3$, depending on the physical and chemical characteristics of the membrane that is used in the set. For example, a mineralization of distilled water is up to 10 mg/$dm^3$, and water with salinity 1000 mg / $dm^3$ is recommended for permanent use [3].

## 3. An experimental part

Table 1 shows the experimental results of changes in the concentration of basic components of water, that was additionally cleaned in the reverse osmosis set with a capacity of 2,0–3,0 $m^3$ / h and Filmtec XLE membrane element 440 (8"), produced by DOW Chemical (USA) , with a working pressure of 18 atm [10, 11].

As it can be seen from these results, the value of the original color and turbidity of water changed after the reverse osmosis system to a zero value.

*Table 1*

**Changing the fundamentals of water over time (τ) after the reverse osmosis on the membrane of Filmtec type XLE 440 (8") at a pressure of P = 18 atm**

| Quality of water | Unit of measurement | Output water | Water after reverse osmosis P = 18 atm, the membrane Filmtec (USA) | Selectivity membrane φ, % |
|---|---|---|---|---|
| Turbidity | mg / dm$^3$ | 0,58 | 0 | 100 |
| Chromaticity | hail | 18,0 | 0 | 100 |
| Hydrogen pH | | 7,75 | 6,43 | - |
| Alkalinity ($HCO_3^-$) | mg / dm$^3$<br>(mg-eq / dm$^3$) | 244,0<br>(4,0) | 48,8<br>(0,8) | 80,0 |
| Sulfates ($SO_4^{2-}$) | mg / dm$^3$ | 18,47 | 13,85 | 25,0 |
| Chlorides ($Cl^-$) | mg / dm$^3$ | 20,0 | 10,2 | 50,0 |
| Hardness total | (mg-eq / dm$^3$) | 4,8 | 0,53 | 90,0 |
| Magnesium ($Mg^{2+}$) | mg / dm$^3$ | 13,38 | 3,3 | 75,0 |
| Calcium ($Ca^{2+}$) | mg / dm$^3$ | 74,15 | 4,0 | 94,5 |
| Iron ($Fe^{3+}$) | mg / dm$^3$ | 0,109 | 0,03 | 70,0 |
| Nitrate ($NO_3^-$) | mg / dm$^3$ | 11,07 | 8,85 | 20,0 |
| Nitrite ($NO_2^-$) | mg / dm$^3$ | 0,39 | 0,29 | 25,0 |
| Nitrogen ammonium ($NH_4^+$) | mg / dm$^3$ | 0,15 | 0,08 | 46,0 |
| Permanganate oxidation ($KMnO_4$) | mg / dm$^3$ | 5,04 | 6,24 | – |
| Sodium ($Na^+$) | mg / dm$^3$ | 12,7 | 0,13 | 99,0 |
| Potassium ($K^+$) | mg / dm$^3$ | 4,0 | 0,04 | 99,0 |
| Total mineralization | mg / dm$^3$ | 290,0 | 65,4 | 77,5 |

The pH water value after reverse osmosis has changed from 7,75 to the average 6,3, which describes the received water as acidic environment (pH < 7,0). This is also confirmed by the decrease in the total alkalinity ($HCO^{3-}$) from 4,0 mg-eq / dm$^3$ to the value received after reverse osmosis – 0,8 mg-eq / dm$^3$.

The organism balances the pH of the internal fluid, maintaining the value at some level. The acid-alkaline balance in the body is a certain ratio of acids and alkalis in it that supports its normal functioning. Acid-base balance depends on maintaining relatively constant proportions between the intracellular and intercellular water in body tissues. If the acid-alkaline balance of fluids in the body is not maintained constantly, the normal functioning and preservation of human life will be impossible [12].

The fundamental indicators such as $Ca^{2+}$ and $Mg^{2+}$ are important for human health. For the full physiological functioning of the human body $Ca^{2+}$ concentration in the water should be within the range of 25,0–75,0 mg/dm$^3$, $Mg^{2+}$ – within the range of 10,0–50,0 mg/dm$^3$ [3].

Considering the values obtained for the concentrations of these important parameters after the reverse osmosis, an important conclusion can be made that the selectivity of the membrane in reference to $Ca^{2+}$ is 94,5 %, and in reference to $Mg^{2+}$ it is 75 %.

The constant use of water with the lack of $Ca^{2+}$ and $Mg^{2+}$ has a negative effect on the bone strength, muscles work, especially the heart, causing blood pressure, seizures and risk of cancer, skin diseases, brain diseases, cardiovascular system and leukemia. Magnesium deficiency in children leads to serious diseases such as rickets, retardation [12].

The selectivity of the membrane relative to sulfates is 25 %. The selectivity of iron is 70 % [11].

The selectivity of the membrane towards chlorides is 50 %. This means that the membrane partially transmits molecules of $Cl^-$, because of approximately equal values of water molecules size (0,3 nm) and the molecules of chlorine $Cl^-$ (0.37 nm) (pore size is not larger than a water molecule (0,3 nm ), that leads to the detention of approximately equal size molecules and screening of larger size molecules).

An important result of this research is to increase the post-treatment values of permanganate oxidation of water at the set output. This phenomenon is a consequence of leaching of organics from the membrane layers included in the basis of its components (a membrane consists of layers of organic solvents such as aromatic polyamide (PA) and polysulfone (PS)). Also, the main disadvantage of polyamides is their sensitivity to free chlorine, which causes destruction of the amide groups. Thus, such membranes have a sufficiently large thickness (up to 150 micron), and thick membranes lead to a rapid decrease of mass transfer, i.e. to the reduction of reverse osmosis sets productivity [11].

Organic substances that contribute to the increased value of permanganate oxidation negatively affect liver, kidneys, reproductive function, as well as the central nervous and immune system of a person [12].

The membrane has a low selectivity for monovalent ions such as $NO_3^-$, $NO_2^-$, $NH_4^+$, as the size of a nitrogen molecule is 0,32 nm, which is close to the size of a water molecule.

The selectivity of the membrane relative to such water parameters as $NO_3^-$, $NO_2^-$, $NH_4^+$ is low and equals to 20,0; 25.0 and 46,0 %, respectively (Table 1).

Large amounts of nitrates ($NO^{3-}$) that get into a body can cause pulmonary edema, chronic nephritis and hepatitis. Long-term consumption of drinking water that contains nitrates causes the increase of methemoglobin, worsening of the blood function, especially concerning children. A direct relationship between the occurrence of malignant tumors and the intensity of the inflow of nitrates has been found out.

Nitrites ($NO_2^-$) in the human body are converted into nitroso-compounds – carcinogens that lead to the progress of liver cancer and lung cancer.

The constant water consumption with a high level of ammonia nitrogen ($NH_4^+$) causes changes in the tissues [12].

Such water components as sodium and potassium are important to maintain an appropriate level of environmental safety and human health. The recommended value of their concentration varies from 2,0 to 20,0 mg / $dm^3$ for the maintenance of the body physiological completeness. It is very important for these components to be in the ratio of 1:1 that makes a sodium-potassium pump in the human body, which provides transport of glucose and amino acids through biological cell membranes. It is necessary for normal functioning of nerve endings, nerve impulse transmission and muscle activity, as well as for the assimilation of the relevant nutrients by the human body [12].

The reverse osmosis membranes selectivity relative to $Na^+$ and $K^+$ is significantly high and amounts approximately 99 % that confirms almost complete removal of these important for human body components.

## 4. Conclusions

1. After purification of tap water with salt content of 300.0 mg / $dm^3$ by a reverse osmosis set, water has a total mineralization value up to 70 mg / $dm^3$, but all the vital for human health components (calcium, magnesium, sodium, potassium) are almost removed. Therefore, the phases of water enrichment by the minerals (e.g. phase of the energy fields and minerals impact to the quality of drinking water, as well as the phase of biological adaptation of water) must be provided, that makes additional economic and technological costs.

2. During the process of tap water reverse osmosis treatment the pH value and total water alkalinity are reduced, that characterizes the environment of water as an acid.

3. It was confirmed that during the process of reverse osmosis the organic substances, which are formed from organic polymers (polyamide, polysulfone), are vanished from the membrane layers and then these organic substances get directly into the drinking water which is consumed.

4. Reverse osmosis membrane has low selectivity to the singly charged ions, such as nitrates, nitrites, ammonia nitrogen and chlorine (which is typical for tap water), which badly influence the vital activity and human health.

Having considered the disadvantages of the reverse osmosis, it can be concluded that the method of reverse osmosis has no competitors in the area of water treatment at the demineralization of marine or brackish water or preparation of service water.

As for the post-treatment of tap water in the household reverse osmosis sets, this leads to a range of negative and important consequences, that must be considered both in terms of environmental safety and human health and technological and economic aspects.

## References

[1] Bryk M. T. Naukovy zapiski, 2000, **18**, 4.

[2] Mark R. Riley, Charles P. Gerba, Menachem Elimelech: Journal of Biological Engineering, 2011, **5**: 2.

[3] Derzhavni sanitarni pravyla i normy gigienychnih vymoh do vody pitnoi, priznachenoi dlya spojivannya lyudinoyu: DSanPin 2.2.4-171-10, K.: MOZ Ukrainy – 2010. – 18 p.

[4] Ditnerskiy Y. I. Baromembrannie procesy. Himiya. Moscva, 1986, 272.

[5] Ditnerskiy Y. I. Membrannie processi razdeleniya zhydkyh smesey. Himiya. Moscva 1975, 232.

[6] Plate N. A. Criticheskie technologgii. Membrani, 1999, **1**, 4.

[7] Karelin Y. V. Criticheskie technologgii. Membrani, 2001, **12**, 3.

[8] Svyttsov A. A. Vvedenie v membrannuyu technologiyu. RHTU im. D. I. Mendeleeva, Moscva, 2006, 170.

[9] Kravchenko M. V. Ecologichna bezpeka ta prirodo-koristuvannya, 2015, **17**, 74.

[10] Kravchenko M. V., Zagray Y. M. Problemi vodopos-tachannya, vodovidvedennta ta hydravlici, 2011, **18**, 6.

[11] Kravchenko M. V. Rozrobka funkcionalnoyi tehnologii pidgotovki pitnoi vodi na osnovi vdoskonalennya baromembrannih procesiv: diss. ... cand. Tech. Sc.: 21.06.01 / Marina Vasylivna Kravchenko, K., 2012. – 190 p.

[12] Spolniy A. V. Himicheskie elementi v fyzyolohii i ecologii cheloveka. Mir. Moscva, 2004, 216.