SECTION 8. LIFE SAFETY

DOI: 10.46299/ISG.2024.MONO.TECH.2.8.1

8.1 Prospective technologies of water purification and disinfection for safe human consumption

Introduction. The quality of surface water sources has significantly deteriorated in many regions, mainly due to pollution from industrial activities, agricultural runoff, and, most of all, the Russian invasion of the territory of Ukraine. The impact of such factors on water quality can be severe, leading to several harmful chemical and biological contaminants being introduced into the water supply system.

A comprehensive study by the World Health Organization (WHO) highlights the seriousness of the situation, as approximately 30% of the world's population does not have access to safe drinking water services. Heavy metals such as lead and mercury are ten times higher than recommended safety standards in areas affected by industrial waste. Military operations, especially in conflict zones, significantly contribute to the pollution of surface sources due to the ingress of hazardous substances, such as fuel and organic residues, heavy metals [268]. Lack of access to safe water affects the quality of life of civilians who cannot use potable water for cooking, drinking, and domestic needs.

The health consequences of poor water quality are profound and far-reaching. Contaminated water is linked to diseases such as cholera, dysentery, typhoid, and hepatitis A. The WHO reports that unsafe water, sanitation and hygiene are responsible for about 485,000 deaths from diarrhea each year. In conflict zones, the risk of water-borne diseases is even higher due to sanitation and water supply system disruptions [269]. Long-term exposure to polluted water can lead to chronic diseases, including cardiovascular disease, kidney damage, and neurological disorders. Children are particularly vulnerable, as poor water quality is a significant contributor to child mortality in low- and middle-income countries.

According to studies [270-272], the deterioration of the quality of surface waters caused by military operations requires urgent measures to clean them in order to provide the population with safe drinking water. In this context, innovative water purification technologies that can be used in everyday life are of great importance.

The development and introduction of innovative technologies and methods of water purification to improve drinking quality play significant role in modern society. Their use helps reduce health risks from disinfection by-products such as trihalomethanes and other chemical compounds and effectively removes traces of organic pollutants. Therefore, a higher level of drinking water safety is ensured, the possibilities of obtaining it from various sources are expanded, and the reliability of the water supply is ensured in the conditions of possible emergencies. Scientific and technical achievements support sustainable development and environmental security, forming the basis for future water resources management initiatives [273].

8.1.1.1 Technologies of micro- and ultrafiltration for obtaining water of drinking quality.

Membrane filtration has become an integral part of modern water purification technologies. In recent years, the number of large water treatment plants dedicated to producing drinking water has increased significantly worldwide. Membrane filtration is divided into several types, each with its characteristics and applications: microfiltration, multimedia filtration, ultrafiltration and reverse osmosis. Membranes, especially ultrafiltration and microfiltration systems, are critical in these processes because they effectively purify water from contaminants.

Although membrane filtration is highly efficient, some disadvantages make it difficult to implement widely:

1) accumulation of contaminants on the membrane surface can significantly reduce filtration efficiency;

2) soluble organic compounds, disinfection by-products and algae are often difficult to remove with standard membrane techniques;

3) the water source must be free from heavy contamination for a membrane plant to efficiently produce potable water.

In modern conditions, micro- and ultrafiltration technologies are recognized as essential and influential means of water purification to ensure the safety and quality of drinking water. These technologies demonstrate high efficiency in removing disinfection by-products and organic pollutants, which ensures better water quality. Significant progress in the development of ultrathin membranes can be made with a new material such as graphene. Its use can ensure the effective removal of pollutants at lower energy costs [274]. However, the problem of membrane fouling reduces the efficiency and increases the operating costs of filtration, which remains an important challenge for society. Research focusing on the development of solutions has shown that pre-filtration treatments such as coagulation and adsorption can effectively reduce membrane fouling, thereby increasing their durability and reducing the frequency of their washing and replacement [275].

Microfiltration is characterized by the presence of larger membrane pores compared to ultrafiltration and reverse osmosis (pore sizes range from 0.1 to 0.45 μm). This makes it possible to effectively remove bacteria, the simplest microorganisms and large colloidal particles (Fig. 1) [276]. The advantage of microfiltration is the ability to pass gases through the larger pores of the membrane, which allows you to use air to clean the membrane. This feature makes it valuable for microfiltration in various applications that require the removal of larger particles and high water flow. Disadvantages include the inability to retain viruses and the smallest colloids. However, for a more thorough purification of water from smaller pollutants, it is necessary to use additional filtration methods, such as ultrafiltration or reverse osmosis.

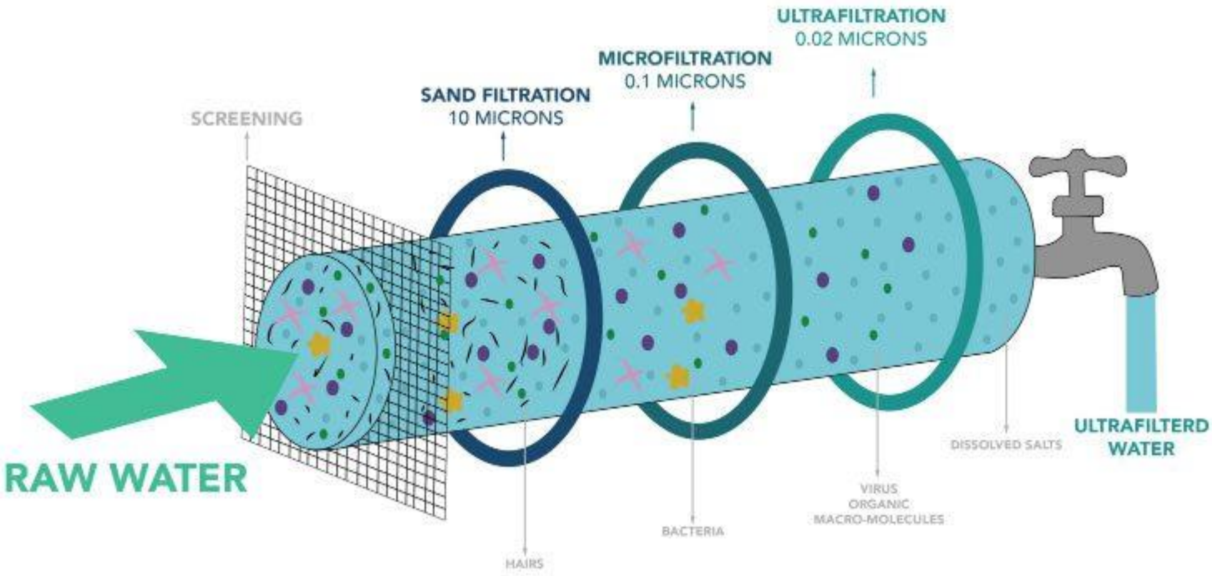

Figure 1. The scheme of retention of various pollutants from the degree of filtration

Microfiltration membranes are also manufactured as hollow fibers with an internal or external membrane, providing a high initial performance. Membrane configuration can vary from manufacturer to manufacturer, but the most common type is "hollow fiber". Usually, water is supplied from the outside of the fibers, and purified water is collected from the inside [275].

Microfiltration membranes, used to purify drinking water, usually work in "dead-end" flow. In this mode, all water supplied to the membrane is filtered through it, forming sediment on the surface of the membrane. This sediment must be washed off periodically to maintain filtration efficiency.

The recovery rate of water purification usually exceeds 90% in cases where the source water has high-quality indicators and low turbidity. This ensures efficient resource use and minimizes water loss during the filtration process.

A multimedia filter (MMF) typically contains three layers of media: anthracite coal, sand, and granite, with a supporting layer of gravel at the bottom. The larger but lighter anthracite is on top, and the heavier but smaller granite is below. This filter media configuration allows the largest particles of dirt to be removed near the top of the layer. In contrast, the smaller particles are retained deeper and deeper in the medium. This ensures efficient use of the entire bed as a filter, increasing the operating time between backwashes and particle removal efficiency [277].

The multimedia filter can remove particles up to 15-20 μm in size. When adding a coagulant, particles up to 5-10 μm in size can be removed. For comparison, the width of a human hair is approximately 50 μm.

Expanding on this information, multimedia filters can also be customized for specific needs. For example, adding layers with different properties can effectively allow the filter to remove specific contaminants. Regular maintenance and backwashing are vital to maintaining high performance and extending filter life. Backwashing removes accumulated sediment from the filter medium, restoring its throughput and efficiency [278].

Multimedia filters can be applied in various industries, including municipal water supply, industrial processes and water treatment for the food industry. Thanks to their versatility and efficiency, these filters are important to water purification systems, ensuring high-quality purified water.

Ultrafiltration technology is required for the complete removal of viruses. Ultrafiltration membranes have pores (Fig. 2) that can remove particles from 0.001 to 0.1 μm, effectively removing viruses, bacteria, and other small contaminants from liquids. All organic ultrafiltration membranes belong to the asymmetric type, while mineral membranes have a composite structure.

Features of ultrafiltration membranes:

1. Organic membranes. Organic ultrafiltration membranes usually have an asymmetric structure, with the active layer with the smallest pores on the surface and the substrate having larger pores. This ensures high filtration efficiency and membrane strength. The most commonly used polymers are polysulfone, polyvinylidene fluoride (PVDF), and others. These materials ensure the durability and chemical resistance of membranes.

2. Mineral membranes. Mineral ultrafiltration membranes consist of several layers, with the active layer made of materials such as metal oxides (for example,

aluminum oxide or zirconium oxide), which give the membranes high thermal resistance and mechanical strength. They are used in conditions where high heat resistance and resistance to aggressive chemical environments are required, for example, in the pharmaceutical and food industries.

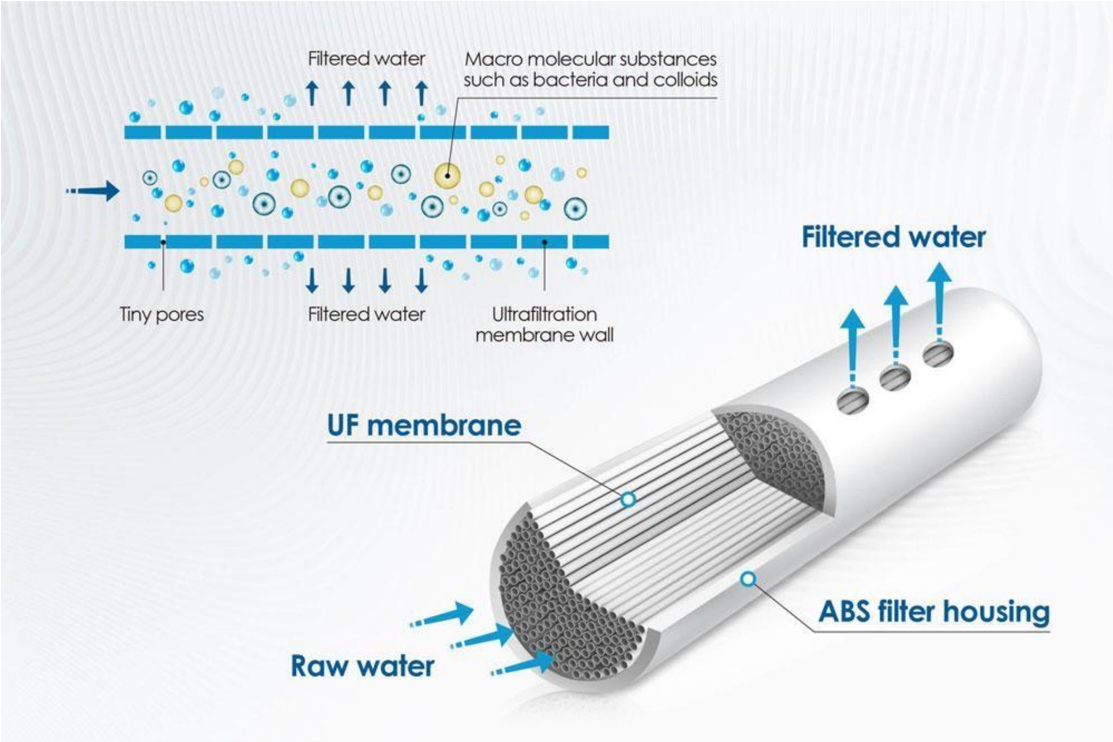

Figure 2. Membranes for ultrafiltration and the principle of their operation

Ultrafiltration membranes freely pass salts and retain only the most extensive dissolved forms, such as macromolecules and some specific particles, including viruses, bacteria, and colloids. They are characterized by a cut-off threshold of molecules of the most negligible molecular weight, which the membrane retains by more than 90%. The degree of contamination retention largely depends on the equipment's operation mode [279].

More extensive pore microfiltration membranes with a cut-off threshold of 0.03-0.1 μm are often used in water treatment. These membranes retain only some macromolecules, reducing the color of water-containing humic acids by 10-20%. The central role of these membranes is to remove substances suspended in water, which is reflected in their name - lightening membrane.

At the beginning of the operation of the new membrane, there is no effect on the maximum productivity. However, over time, the phenomenon of clogging of the membrane appears which becomes decisive for its operation. At constant concentrations and pressure, this phenomenon leads to a gradual decrease in filtrate flow up to the complete blocking of the membrane. Clogging is the result of forming sediment of colloidal particles on the surface of the membrane, as well as the adsorption of various dissolved forms in the membrane's pores [280].

In the first step of this process, backwashing can eliminate clogging, which consists of reversing the pressure to direct the treated water through the membrane to remove the accumulated sludge. However, adsorbed impurities are often not amenable to backwashing or increasing the washing rate, so a special chemical treatment is required to clean the membrane thoroughly.

Using ultrafiltration membranes allows you to achieve a high level of water purification, ensuring the safety and quality of purified water. Regular maintenance and chemical cleaning of membranes are necessary to maintain efficiency and extend their service life [278].

Experience with micro- and ultrafiltration is shown that where water resources were correctly conserved, the installations' efficiency was higher. However, if impurities such as algae and dissolved organic particles were present in the source water, a separate membrane process could not effectively purify the water to the drinking quality recommended for consumption by the WHO. As a result, the use of hybrid (or integrated) membrane processes was proposed.

Research combining various traditional treatment methods as pretreatment for a membrane filtration process has shown that overall performance is significantly improved. This includes increased production flow and membrane life (reduced membrane fouling) and improved fouling removal efficiency.

Hybrid membrane processes combine the advantages of several water treatment methods, effectively removing a wide range of contaminants. This ensures better water quality and stable system operation. For example, the combination of coagulation, settling, and filtration before membrane treatment can significantly reduce the load on membranes, reducing the frequency of backwashing and the need for chemical cleaning [271].

This approach provides a more economical and environmentally friendly solution for water treatment. The integration of various technologies allows the system to be adapted to specific conditions and types of pollution, ensuring high-quality purified water that follows international standards.

A study of the application of a hybrid combination of coagulation, sedimentation, filtration, and ultrafiltration was conducted on the source water of the Taihu River in China, which is characterized by high turbidity. This research used coagulation as a pretreatment before ultrafiltration membrane processes. The results revealed that the optimal dosage of ferric chloride as a coagulant made it possible to produce water that meets the drinking water standards in China. Coagulation has been found to significantly improve the removal of natural organic matter from water and reduce the fouling tendency of ultrafiltration membranes, thereby increasing their service life.

Also, a pilot test at the Gueui drinking water plant in Korea was implemented to evaluate the effectiveness of the hybrid ultrafiltration system in purifying river water. Precoagulation has been found to significantly improve system performance by reducing the susceptibility of a submerged hollow fiber ultrafiltration module to contamination [274].

Additional studies have confirmed that pre-coagulation treatment can significantly increase the efficiency of ultrafiltration membranes in removing dissolved organic contaminants that would otherwise be difficult to remove. Including coagulation before filtration helps form larger aggregates from small particles and organic molecules, which contributes to their more effective removal by ultrafiltration membranes.

In addition to coagulation, several other methods have been tried in water pretreatment, such as adsorption, peroxidation, ion exchange resins, and biological treatment. Studies have shown that using powdered activated carbon as an adsorbent significantly improves the removal of organic substances and membrane fouling, reducing the need for frequent and thorough membrane cleaning.

Peroxidation, a process using powerful oxidants such as ozone, chlorine, or permanganate, suppresses the growth of microorganisms and can modify the chemical properties of organic pollutants. One study analyzed the effect of ozonation on the performance of a hybrid ozonation and ultrafiltration system. The results showed that using ozone reduced the fouling of the membranes and significantly improved the filtrate quality due to a reduction in the total organic carbon level in the system.

It has also been found that ion exchange resins can effectively remove specific ions and some organic compounds, thereby improving the overall efficiency of the ultrafiltration system. On the other hand, biological treatment is beneficial for removing biodegradable pollutants and reducing biological load before membrane filtration [275].

It has been proven that the hybrid microfiltration system can effectively improve contaminant removal and cope with the impact load of solid particles. Coagulation significantly increased the retention of water-soluble substances and pollutants responsible for colloidal pollution. Pretreatment before membrane filtration protects the membranes against intensive contamination caused by particles in the water. In addition, a hybrid coagulation-micro/ultrafiltration system can remove viruses that cannot be achieved with either micro- or ultrafiltration alone. This highlights that combining membrane technologies with adequate pretreatment can be a powerful tool for removing viruses from drinking water [276].

The choice of pretreatment method is not limited to coagulation. Other types of pretreatments, such as adsorption, oxidation, and biological filtration, have been considered. Each of these has been shown to be highly effective in improving system performance. Applying these methods makes it possible to achieve a significant increase in the quality of water purification, optimize the operating parameters of the system, and reduce costs for its maintenance and repair.

8.1.1.2 Reverse osmosis technology

Reverse osmosis effectively removes dissolved salts and minerals from water by applying pressure to a semi-permeable membrane through a pump. This method, together with an activated carbon filter, is integrated into a five-stage filtration system that helps remove bacteria, chlorine and minerals that contribute to water hardness. Highly efficient filters must be used to reject and recover salts to ensure optimal operation of the reverse osmosis system. Modern reverse osmosis filters use advanced membrane technologies to improve filtration and can even provide nanofiltration to remove the smallest contaminants (Fig.3).

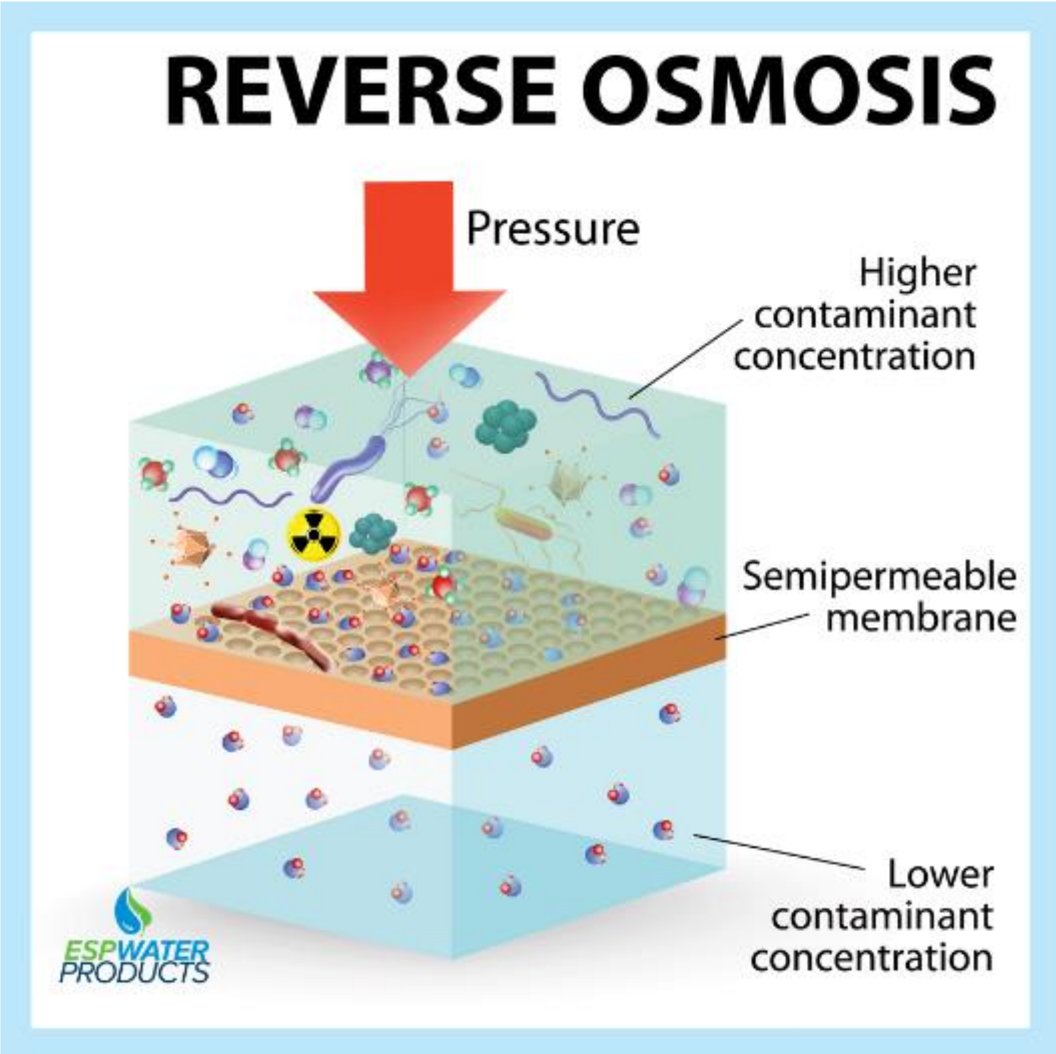

Figure 3. The scheme of operation of reverse osmosis [281]

The main elements of the reverse osmosis system consist of the following components:

1. Cold water line valve. The valve is placed on the cold water line and connects to the tube that supplies water to the pre-filter. This is the primary water source for the reverse osmosis system.

2. Pre-filter. The outlet water first enters a pre-filter, where several filters, such as sediment and carbon, can be installed. These filters not only remove coarse dirt but can also remove chlorine, which is harmful to membranes.

3. The reverse osmosis membrane is the central component of the system, responsible for removing the smallest impurities. Purified water after the membrane is stored in a tank.

4. Additional filter. Purified water passes through a final carbon filter before being fed through the tap, which removes any residual taste or odor.

5. Automatic shut-off valve that controls the water supply to the membrane and shuts it off when the tank is full, thereby saving water.

6. Non-return valve. This valve is located at the exit from the membrane body and prevents the reverse flow of water, protecting the membrane from damage.

7. Flow restrictor. This controls the flow rate through the membrane, ensuring high-quality water purification and maintaining the proper pressure at the membrane's entrance.

8. A storage tank that contains purified water under pressure ensures consistent water access.

9. Mixer. It is installed on the kitchen sink and can be standard or designer, depending on the user's requirements and taste.

10. Drainage line. This line removes filtered impurities from the membrane to the sewer, ensuring proper sludge disposal [282].

Reverse osmosis removes most dissolved salts and minerals from the water by applying pressure to the semi-permeable membrane using a pump. This process is very effective for water purification because the membrane allows only water molecules to pass through, trapping contaminants. Reverse osmosis and carbon filters are used in a five-stage system to remove bacteria, chlorine, and minerals that contribute to water hardness. This ensures clean and safe water for consumption.

A filter with high salt rejection and salt recovery is essential to achieve the best performance of a reverse osmosis system. The rejection rate indicates how well the filter removes salts and other dissolved substances, while the recovery rate indicates how much water can be recovered through filtration. A low recovery rate can be quite expensive, so aim for 75% to 85%.

Modern reverse osmosis filters use advanced membrane technology to perform their tasks. These membranes can have different pore sizes, allowing them to remove pollutants of different sizes. In particular, nanofiltration is possible for modern systems, which allows for the removal of even the smallest particles and pollutants. The smaller the membrane's pore size, the more thoroughly it cleans water [282].

Additionally, pre-filters that remove large particles and organic matter before the water passes through the reverse osmosis membrane can increase system efficiency. This reduces the load on the membrane and extends its service life. Regular maintenance and filter replacement are also important to ensure stable system operation.

Fouling occurs when deposits accumulate on the surface of the membrane, leading to its clogging. Spring water contains many impurities that are invisible to the human eye and harmless for consumption, but can easily contaminate (or clog) a reverse osmosis system. Fouling usually starts at the front of the membrane, leading to an increase in system pressure drop and a decrease in permeate flow. This increases operating costs and requires frequent cleaning or replacing reverse osmosis membranes. Despite proper pretreatment and regular cleaning, some degree of fouling is inevitable due to the microscopic pore size of the reverse osmosis membrane. However, by providing proper pretreatment, the need for frequent fouling problems can be minimized.

Fouling of membranes in reverse osmosis systems can be caused by various factors that contribute to the accumulation of deposits on the surface of the membranes. This reduces system efficiency and leads to increased operating costs. The main factors that can cause fouling are given in the Table.1.

Table 1. Factors that can cause fouling

Factor	Describing
Particles or colloidal substances	Dirt, silt, clay, etc. These particles can easily clog the membrane, reducing its efficiency
Organic substances	Humic/fulvic acids, etc. They can contribute to the formation of deposits on the surface of the membrane.
Microorganisms	Bacteria, etc. Bacteria can form biofilms that cover the membrane surface and lead to fouling.
Breakthrough of the filtering medium	A breach in the carbon layers and softener layers can lead to leakage down the drain, which can contaminate the RO system.

Various mechanical filtration methods are used to prevent contamination of reverse osmosis systems. The most popular of them are listed in the Table 2.

Table 2.Classification of filtering methods and their purpose

Method	Purpose
Multimedia filters (MMF)	Used for mechanical filtration to reduce the load on the reverse osmosis system.
Microfiltration (MF)	Provides an additional level of filtration to remove solid particles
Cartridge filtration	In some cases, it is enough to prevent fouling and extend the life of the membranes.

Analytical tests determine the potential for contamination of the water supplied to the reverse osmosis system. Mechanical filtration methods are used to prevent contamination of the reverse osmosis system. The most popular methods of pollution prevention are multimedia filters (MMF) or microfiltration (MF). In some cases, cartridge filtration is sufficient. Using these methods reduces the load on the reverse osmosis system and extends the membranes' service life.

Reverse osmosis has several advantages:

1. It can remove many contaminants, including salts, organic molecules, bacteria, and viruses, making it very effective in producing clean drinking water [276].

2. Unlike distillation, reverse osmosis does not require a phase change, which saves energy and avoids the complexities of handling steam and condensation.

3. A simple and compact system makes it suitable for small-scale and large-scale programs [278].

4. Modern advances in reverse osmosis technology, such as improved membrane materials and energy recovery devices, have significantly reduced the energy consumption associated with reverse osmosis, increasing its efficiency and sustainability [279].

5. Reverse osmosis is universal and can be used not only for the purification of drinking water but also in industries, such as the food industry and pharmaceuticals, where ultrapure water is required [280].

Disadvantages of technology include:

1. Reverse osmosis systems usually require significant energy, mainly due to the high pressure required to operate, which can be a severe drawback of sustainability and operating costs [282].

2. Significant water waste. For every unit of treated water produced, several units of water may be discharged as waste, which is a critical problem in areas facing water scarcity [283].

3. Membrane fouling by minerals, bacteria, and other contaminants is a common problem in reverse osmosis systems. This contamination can reduce system efficiency and increase maintenance costs due to the need for frequent cleaning or replacement of the membrane [284].

4. Disposing of brine (concentrated wastewater) produced by reverse osmosis systems can significantly impact the environment, especially in the marine environment, where it can negatively affect aquatic life [285].

5. Reverse osmosis systems often require significant and expensive pretreatment to protect the membranes from contamination and ensure efficient operation, increasing the overall water treatment cost [286].

In summary, although reverse osmosis is an effective method for removing a wide range of contaminants from water, it is also associated with high energy and water costs, potential environmental impacts from waste disposal, and issues related to membrane fouling and the need for pretreatment processing.

8.1.1.3 "Filtration-ozonation-UV-radiation" technology

All of the methods, as mentioned earlier, of preparing water for drinking quality can be used both at water treatment stations and as independent devices for additional water purification in private and public buildings. However, the disadvantages of micro- and ultrafiltration and reverse osmosis create certain limitations in their wide application.

A prospective direction of water purification for personal needs may be the use of devices or equipment that will have three methods of purification: filtration - ozonation - and ultraviolet disinfection (UV - radiation). The synergistic effect of filtration, ozonation and ultraviolet (UV) radiation is a powerful combination of methods in drinking water treatment systems. Each of these methods has its unique advantages, and their combination allows for achieving high efficiency in water purification.

Filtration is the essential and first step in water treatment systems. It removes solid particles, suspended matter, and some dissolved pollutants from water. Mechanical filters remove large particles such as sand, silt, and rust.

Ozonation uses ozone (O_3), a powerful oxidizer, to disinfect water and oxidize organic and inorganic contaminants. The advantages of ozone include the destruction of bacteria, viruses, and other pathogens, the destruction of organic compounds (pesticides, phenols, and others), the elimination of unpleasant odors, the improvement of the taste of water, and the increase in the content of dissolved oxygen in water.

Ultraviolet radiation has a bactericidal effect and is used to disinfect water. It destroys bacteria, viruses, and parasite cysts without leaving any chemical by-products in the water. Processing speed: The process is instantaneous and does not require prolonged contact.

Ultraviolet (UV) rays are part of the light that comes from the sun. The ultraviolet spectrum has a higher frequency than visible light and a lower frequency than X-rays. This also means that the UV spectrum has a longer wavelength than X-rays and a shorter wavelength than visible light; the energy order, from low to high, is visible light, UV, than X-rays. It is known that UV water purification technology (Fig. 4) is an effective disinfectant due to its strong bactericidal (deactivating) ability;

Ultraviolet radiation (ionizing radiation) has enough energy to break chemical bonds, killing microbes. UV disinfects water-containing bacteria and viruses and can be effective against protozoa such as Giardia lamblia cysts or Cryptosporidium oocysts.

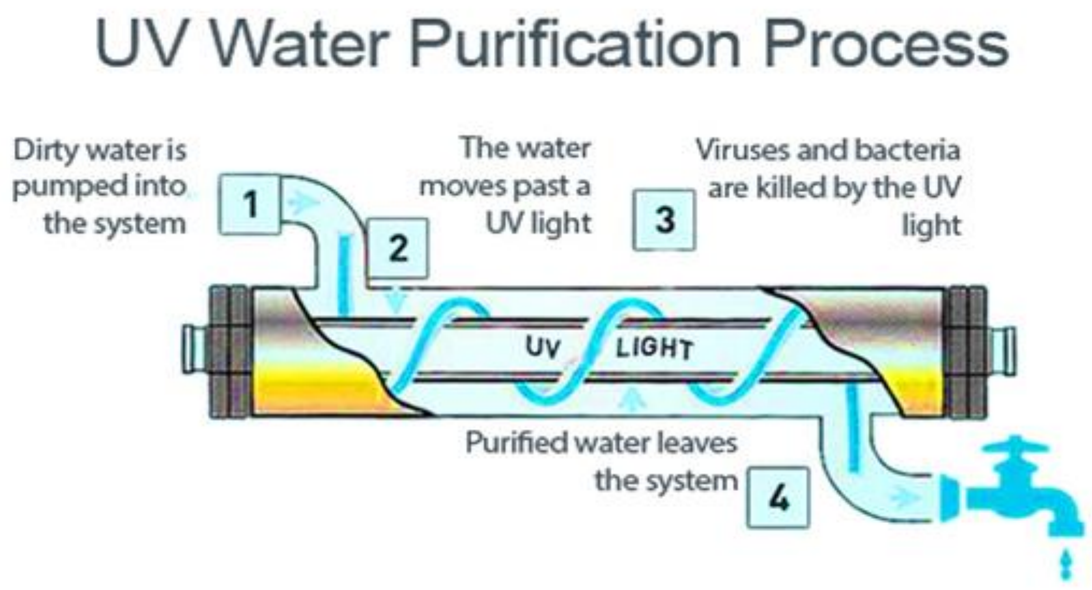

Figure 4. The scheme of water purification withUV rays

Due to safety concerns with chlorination and improvements in UV technology, UV disinfection has become increasingly common in municipal and household systems. There are only a few large UV water treatment plants in the United States, although there are over 2,000 in Europe. NSF certifies and classifies two classes of disinfection systems under Standard 55: Class A and Class B plants.

Type A - These UV water treatment systems must have an "intensity and saturation" rating of at least 40,000 $\mu s/cm^2$. Class A point-of-entry and point-of-use systems covered by this standard are designed to inactivate or remove from natural water microorganisms, including bacteria, viruses, Cryptosporidium oocysts, and Giardia cysts.

Type B - These UV water treatment systems must have an "intensity and saturation" rating of at least 16,000 μW-sec/cm^2 and be designed to provide additional bactericidal treatment to water already considered "safe." "Class B" UV systems are designed to operate at a minimum dose and are intended to "reduce the number of non-pathogenic or nuisance microorganisms only to the limit". "Class B" or similar UV systems are not intended to disinfect "microbiologically hazardous water".

Ultraviolet radiation has three wavelength zones: UV-A, UV-B, and UV-C, and this last region, short-wavelength UV-C, has bactericidal properties for disinfection. Like a fluorescent lamp, a low-pressure mercury arc lamp emits ultraviolet light in the 254 μm range. Nm is one billionth of a meter (10^-9 meters). These lamps (Fig. 5) contain elemental mercury and an inert gas, such as argon, in an ultraviolet-transmitting tube, usually quartz (which, unlike glass, is transparent to ultraviolet). Traditionally, most mercury arc UV lamps have been of the so-called "low pressure" type because they operate at relatively low mercury partial pressure, low total vapor pressure (about 2 mbar), low external temperature (50-100 °C) and low power. These lamps emit almost monochromatic UV radiation with a wavelength of 254 nm, which is in the optimal range for the absorption of UV energy by nucleic acids;

Since most microorganisms are affected by radiation around 260 nm, UV radiation is appropriate for bactericidal activity. UV lamps produce radiation in the 185 nm range, effectively against microorganisms and reducing total organic carbon (TOC) in water. For a typical UV system, approximately 95 percent of the radiation passes through the quartz sleeve and into the raw water. Water flows over the lamp in a thin film. The quartz sleeve is designed to maintain the ideal lamp temperature of approximately 104 °F.

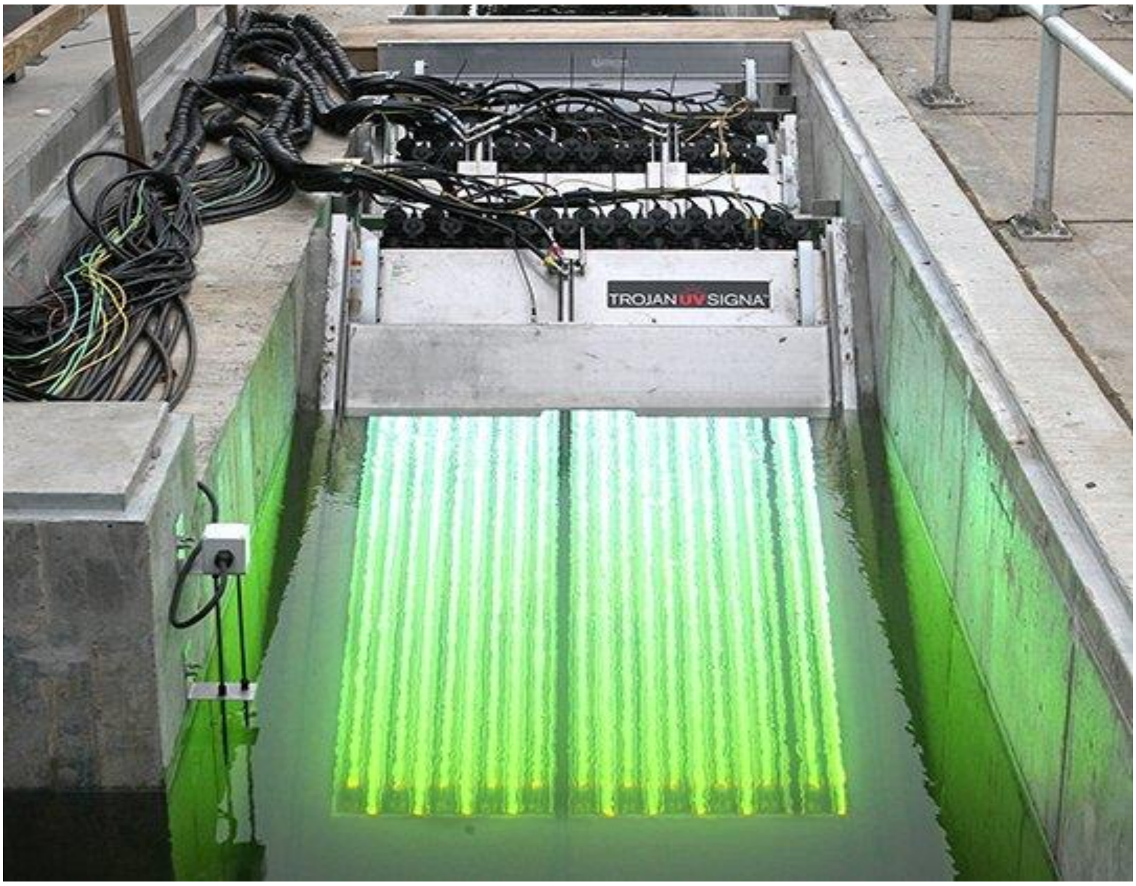

Figure 5. The example using of mercury lamps in UV disinfection

UV radiation affects microorganisms, changing the DNA in cells and preventing reproduction. UV treatment does not remove organisms from the water; it only inactivates them. The effectiveness of this process depends on exposure time, lamp intensity, and general water quality parameters. Exposure time is given as "microwatt seconds per square centimeter" ($\mu W \cdot s/cm^2$), and the US Department of Health and Human Services has set a minimum exposure of 16,000 $\mu W \cdot s/cm^2$ for UV disinfection systems. Most manufacturers provide a lamp intensity of 30,000-50,000 $\mu W \cdot sec/cm^2$. In general, E.coli bacteria, for example, are destroyed at 7000 $\mu W \cdot s/cm^2$. Because lamp intensity decreases over time with use, lamp replacement and proper pre-treatment are critical factors in the success of UV disinfection.

However, dissolved organic matter such as natural organic matter, certain inorganic pollutants such as iron, sulfites, and nitrites, and suspended solids (particulate matter or turbidity) will absorb UV radiation or shield microbes from UV radiation, resulting in lower doses of UV radiation and reduced microbial disinfection. Another concern with disinfecting microbes with lower doses of UV radiation is the ability of bacteria and other cellular microbes to repair UV-induced damage and regain infectivity, a phenomenon known as reactivation. Also, remember that unlike chlorination, there is no residual disinfectant in the water to deactivate bacteria that may survive or may be introduced after the water passes the UV source.

Literature analysis [287] shows that using ozonation and ultraviolet radiation for water purification in drinking water supply systems has a powerful effect. Thus, during the research, direct disinfection and indirect ozonation occurred in the tap water since the pH of the tap water was 7.66, which is in the range of pH 4-9. When disinfecting tap water, ozone and OH radicals play a role in the inactivation of Escherichia coli bacteria. The results show that in the process of disinfection using ozone, the optimal disinfection time is 3 minutes, according to the literature, which claims that the effective disinfection time is 2-10 minutes [288]. The synergy of ozone and UV rays is the most effective technology for disinfecting E. coli bacteria. For ozone disinfection processes, the lowest number of bacteria remaining at the 30th minute was 1.37×10^{4} CFU/ml.

When disinfecting using ultraviolet rays, the effective wavelength for inactivating bacteria was 254 μm. When UV rays come into contact with the deoxyribonucleic acid (DNA) of bacteria, it can cause DNA destruction and stop the reproduction of bacterial cells, and then the bacteria die. UV light resulted in the lowest number of bacteria remaining at 30 minutes, which was 60 CFU/mL. The percentage of bacterial decomposition in this disinfection process reaches 99.99%. This suggests that using ultraviolet light to disinfect a tap water sample containing E. coli is more significant in degrading the bacteria than using ozone. In this way, ultraviolet disinfection is more effective than ozone.

In emergency situations and military operations, water for economic and household needs is mostly taken from surface sources, where suspended substances limit the synergistic effect of ozonation and UV radiation.

Therefore, we developed a scheme (Fig. 6) for obtaining safe water in extreme conditions based on preliminary filtering through a coarse filter followed by ozonation and UV disinfection. After the completion of the first stage, the water is sent to the tank, from where it is then sent through a smaller fraction of a filter to the second stage of purification - ozonation and UV disinfection. In ozonation and UV disinfection, water is purified from organic and microbiological impurities, and some soluble metals are converted into insoluble ones. Purified and disinfected water is sent to the tank, where it can then be taken for domestic and drinking purposes.

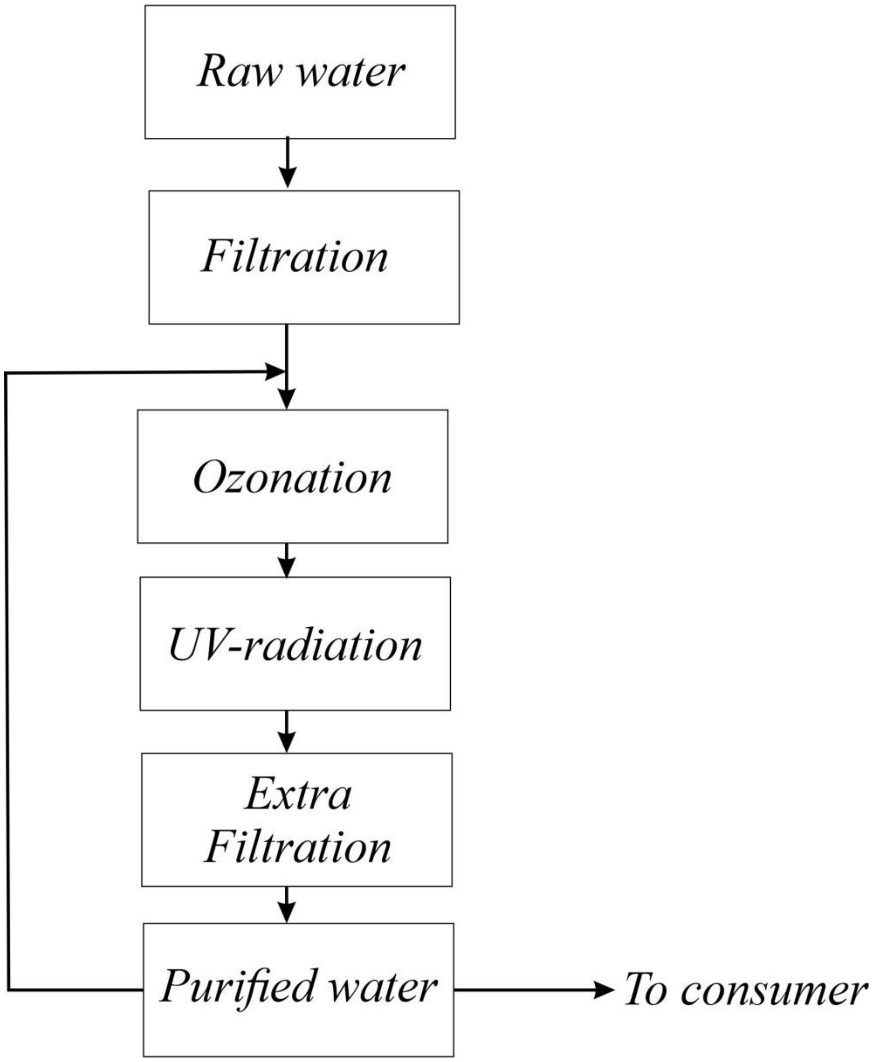

Figure 6. The proposed scheme of purification raw water

The combination of filtration, ozonation and UV-radiation provides the following synergistic effects:

1. Increased disinfection efficiency: Filtration removes solid particles that can protect microorganisms from ozone and UV light. Ozonation disinfects and destroys organic compounds that can absorb UV light, thereby increasing the effectiveness of UV radiation.

2. Reduction of chemical by-products: Combining these methods reduces the need to use chlorine and other chemical disinfectants that can produce harmful by-products.

Conclusion

The quality of surface water sources has significantly declined due to various factors such as industrial pollution, agricultural runoff, and notably, military conflicts like the Russian invasion of Ukraine. This degradation poses severe risks to public health, contributing to the prevalence of waterborne diseases and chronic health conditions. Approximately 30% of the global population lacks access to safe drinking water, with heavy metals and hazardous substances contaminating water supplies, especially in conflict zones. This underscores the urgent need for effective water purification technologies.

Prospective technologies for water purification are:

1. Microfiltration: effective for removing bacteria and large colloidal particles but cannot filter out viruses and the smallest colloids.

2. Ultrafiltration: capable of removing viruses, bacteria, and small contaminants. The use of organic and mineral membranes in ultrafiltration ensures high filtration efficiency, though membrane fouling remains a challenge.

3. Reverse Osmosis: removes dissolved salts and minerals by applying pressure through a semi-permeable membrane. This method is highly effective but requires significant energy and can result in water waste. Advances in membrane technology and pre-treatment methods like multimedia filters help mitigate these issues.

Combining filtration – ozonation - UV-radiation offers a synergistic effect, significantly enhancing water purification efficiency. Filtration removes particles that could shield microorganisms from ozonation and UV light, while ozonation deactivates organic compounds that could absorb UV radiation, increasing the effectiveness of UV disinfection. This multi-barrier approach reduces reliance on chemical disinfectants, minimizing harmful by-products.

A proposed scheme for emergencies and military operations includes preliminary coarse filtration followed by ozonation and UV disinfection. This process ensures the removal of organic and microbiological impurities, converting some soluble metals into insoluble forms, resulting in safe, potable water.

This integrated method provides a robust solution to water purification challenges, ensuring high-quality drinking water and addressing the limitations of individual purification technologies.