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REVIEW ARTICLE OPEN ACCESS

Analytical Review on Membrane Water Filter using Different Materials to Prevent Microbial Activities

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Abstract

Drinking water quality monitoring technologies have made significant progress in monitoring water resources and water treatment plants. This paper discusses the adverse effect of microbial contamination and also gives a brief description of the important parameters for drinking water and the technologies currently available used in this field. This paper is focused on studying the requirement for the development of low-cost filter materials that can be suitable as well as economical to be produced on a large-scale for real applications. There are several parameters such as porosity, contact angle, water flux, thickness, microbial activity needed to be focused on in the future to study the transformation of the hydrophilic property on the surface of the water.

Keywords: Water Filtration, Water Borne Disease, Membrane Filtration

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INTRODUCTION

Water is an essential component for the survival of an individual as well as daily essential work. To ensure the availability of water for specific purposes such as drinking water, there is a need to meet some conditions such as its availability, accessibility, and treated as well. In the current scenario with the increasing population, there is also an increase in demand for drinking water that must be fit for consuming. But it is also true that with the increasing population there is an increase in pollution level which ultimately also affects the pollution level in the water. The major cause of water contamination or pollution is human activities that result in decreased quality of water. Out of all, human activities such as improper disposal of sewage, failure of the septic system, animal wastes are a major source for water contamination.[1] The discharge of waste material into drinking water not only causes disbalance in nutrient content as well also increases the growth of microbes, such as viruses, bacteria, etc, that can cause various water-borne diseases. From the study of 2012, it is surveyed that about 25% of drinking water is contaminated with fecal or harmful materials which cause the growth of a large number of harmful pathogens.[2] Consumption of such contaminated water can cause different severe health issues such as diarrhea, hepatitis, meningitis, encephalitis, polio, etc. According to the World Health Organization (WHO) report issued in 2019, about 844 million people all over the world are underprivileged with drinking water. Out of them, 159 million people are dependent on surface water completely. The contaminated water or polluted water is considered to be a major reason for death. It has been reported that approx. 5,02,000 deaths per year all over the world are caused by drinking contaminated water.[3] In India, death due to contaminated drinking water has been reported that 6514 deaths over 5 years until 2017. Similarly, due to virus borne diseases such as hepatitis, 2143 people died and became the second most alarming water-borne disease.[4] Some of the water-borne diseases are discussed in Table 1.

Hence, it is required to provide provision for safe drinking water as a part of public health protection all over the world. Pretreatment and post-treatment techniques including distillation, treatment with chemical disinfectants, sand filtration, reverse osmosis, and membrane filtration are widely used technologies to purify water. There are many traditional methods to filter water contaminations. It has been observed that many conventional techniques are being used for the filtration and separation of pathogens from water, such as coagulation, deep bed filtration for particle separation, or chlorination. But chlorination is quite inexpensive and takes a long time for operation along with chlorination also causes adverse effects on human health. Further, iodine is used as a substitute for chlorine for purification of drinking water.

One of the simplest methods for water purification is boiling the water before using it for drinking purpose. However, this process consumes more fuels. Then come UV and RO filtration and purification techniques that are gaining popularity nowadays for their efficiency to purify the contaminated water and making it fit for drinking. Ultraviolet (UV) technique destroys the cell structure of pathogens and prevents them to grow. Whereas the reverse osmosis (RO) technique is used across a semi-permeable membrane to separate the contaminants from the drinking water.[5] But this technique is quite expensive, so, many researchers focus their work on this

Table 1. Water-borne diseases

Disease	Pathogens	Symptoms
Diarrhea	virus	abdominal cramps fever weakness
Cholera	Bacteria	Diarrhea
Typhoid	Bacteria	Fever Diarrhea Vomiting
Amoebiasis	Parasite	Fever Diarrhea Vomiting Loss of appetite
Hepatitis	Virus	Jaundice Diarrhea Vomiting
Giardia	Parasite	Diarrhea Vomiting Fatigue Abdominal pain
Salmonella	Bacteria	Blood in stool Diarrhea Headache

membrane filtration technique and researched many polymeric and ceramic membranes.

The membrane filters, made up of polymers have a low cost but due to lower thermal effect as well as the chemical effect with lower mechanical stability limits its usage as purification filter material. As compared to polymers ceramics provide these advantages as well as also protects from pathogens. The ceramic filter membrane provides lower membrane fouling.[6]

The membrane filtration process shows an advantage over other methods as it separates pathogens from water. This method can be used with a pretreatment process or without a pretreatment process. The conventional membrane water filtration process was successful for large-sized pathogens such as protozoa, bacteria, etc. But these membrane filters are not capable of removal of viruses as their size is very small, up to 20−100 nm. So, to remove viruses, nano-particle material, the adsorbing surface is

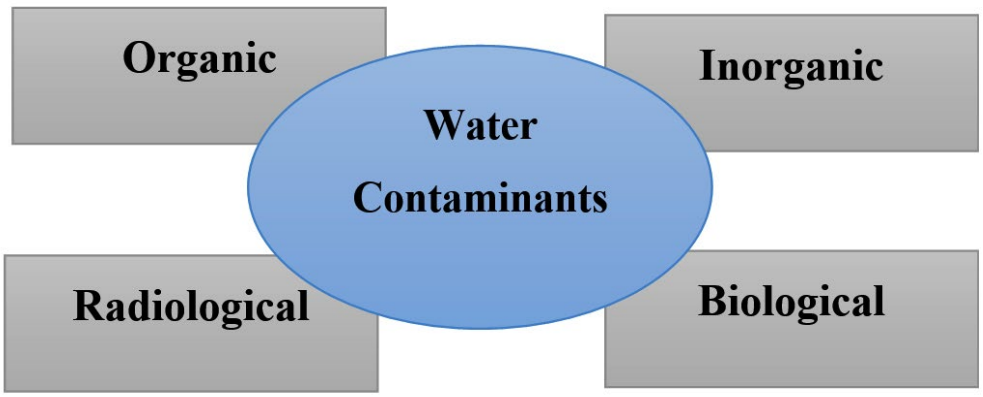

Figure 1. Types of Water Contamination

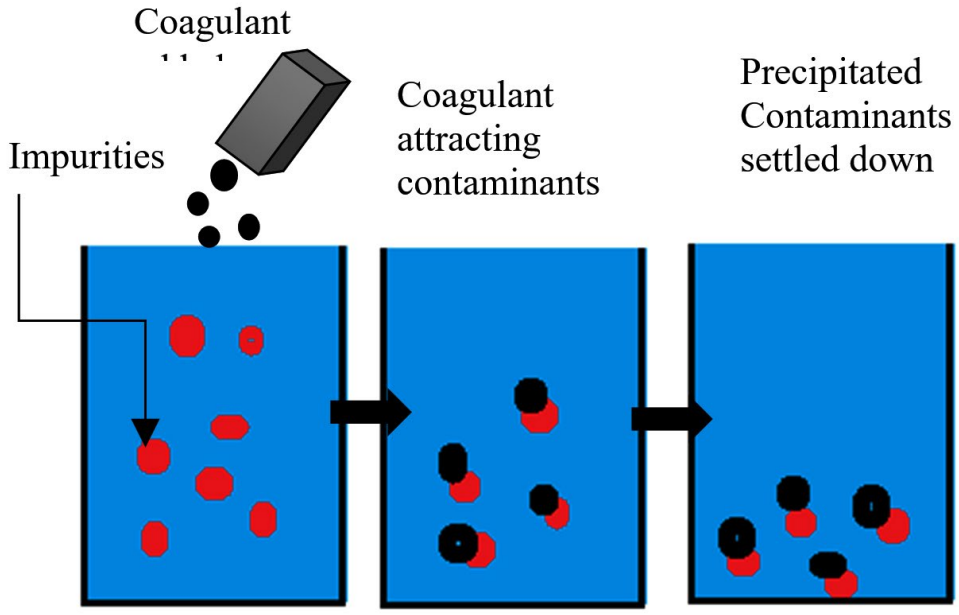

Figure 2. Precipitation and Coagulation Water Filtration

used to filter the contaminated water surface by applying forces such as van der Waals forces, electrostatic forces, and hydrophobic interactions. The literature reviews that recent research work that contributes to the adsorption process. In the adsorption process, electrostatic forces are applied.[7] Many water-borne diseases are caused by a virus. These viruses are negatively charged and it gets attracted by positively charged adsorption surface of the filter. In this way, contaminated water gets filtered.

This paper focuses on the usage of the membrane filtration method for the removal of microbes that contaminates water. Different membrane separation processes are also discussed with their limitations. In the further section of the paper different adsorption methods for the microbial removal process. In this article, a performance comparison is also discussed for the exploration of future scope.

Contaminants in water and its effects

By accessing odor, color, turbidity, or taste are used to access or to determine the contamination level. This may cause severe health issues. However, sometimes contamination cannot be detected easily. In such a situation there is a requirement of the testing process. Types of contaminants are shown in Figure 1.

Chemical parameters of water determine its contamination level or contaminant composition. The hardness of water depends on the geographical location. Due to the presence of calcium or magnesium, water becomes hard and it is classified into two types such as carbonates (containing co_3^- ions) or non-carbonates. Generally, a hardness level that is considered to be fit is about 300–400 mg/L but its prolonged usage will cause stone formation in the kidney. Some other inorganic compounds such as fluoride, arsenic, lead, copper, chromium, mercury, antimony, cyanide, etc can also contaminate drinking water. Arsenic contamination is the main cause of water contamination all over the world and also in India.[8] Another contamination source is organic compounds such as pesticides, domestic waste, industrial waste, etc. Similarly, the presence of living organisms causes biological contamination in

Table 2. Different contaminants and their adverse effect[7-16]

Contaminants	Contaminants classification	Adverse effect
Cr	Inorganic	Toxic in nature Allergic
Hg	Inorganic	Alteration in the immune system Cardiovascular toxicity
Cd	Inorganic	Risk of cancer Damage to kidney
Pb	Inorganic	Hypertension
As	Inorganic	Risk of cancer
Mg	Inorganic	The risk to the brain or neurological disorder The risk to the endocrine system
Nitrogen	Inorganic	Blue-baby syndrome, breathing problem in infants
Sulfate	Inorganic	Diarrhea
Coliform	Biological	Diarrhea
Radium	Radiological	Risk of Cancer
Uranium	Radiological	Risk of Cancer
Pesticides	Organic	Damage liver and nervous system
Trichloroethylene	Organic	Risk of Cancer Nervous system and reproductive disorder Damage to liver or kidney
Vinyl chloride	Organic	Risk of Cancer Nervous system and reproductive disorder Damage to liver or kidney

Table 3. Advantages and disadvantages of different water decontamination methods[17]

Methods	Advantages	Disadvantages
Precipitation and coagulation	Simple Easy to implement Suitable for organic contaminants or dissolved organic compounds	Requires chemicals for this process Effect of by-products Sludge formation and their disposal
Distillation	Suitable for removal of inorganic and biological contaminants Doesn't require post-filtration methods Not much effective for organic contaminants	Consumes energy Requires maintenance
Adsorption (Activated Carbon)	Effective for removal of carbon impurities and chlorine impurities Cost-effective Durable High capacity	Filter replacement reduces efficiency Can generate carbon fines
Adsorption (Activated alumina)	Suitable for contaminants such as arsenic, chloride, fluoride	Not capable to remove other contaminants
Adsorption (Silica gel)	Non-toxic Non-corrosive High adsorption High porosity	Needed to be precise
Ion exchange resins	Simple and low cost Can handle hazardous water contaminants Long-lasting	Generation of sodium waste Don't remove organic or biological contaminants
Membrane Filtration (Reverse Osmosis)	Require low energy Environment friendly Don't produce harmful chemicals Suitable for all types of contaminates No taste or smell alteration	Require replacement of the membrane
Membrane Filtration (Electrodialysis)	Safe Non-polluting Reliability Effective for ionic particles and heavy metals	The requirement of a large area for membrane especially for low concentration of contaminants
UV Treatment	Easy to use Inexpensive Effective for biological contaminants No adverse effect on mineral contents of water.	Less effective on bacterial spores

water. The sources of radioactive material can also contaminate water as they emit radiations (like α, β). Each of these can cause distinctive problems in water as discussed in Table 2.

Water decontamination methods

Water decontamination is the removal or reduction of contaminants from water sources by physical, chemical, or other methods. There are many approaches developed that aims to decontaminate or disinfect the public water supplies especially for drinking. Contaminated water is a major source of water-borne diseases and also acts transmission medium of such diseases. Some of the processes and techniques in mitigating the contaminations are discussed below and their advantages and disadvantages are discussed in Table 3.

Precipitation and Coagulation

Precipitation and coagulation is a process to remove unwanted substances from the contaminated or polluted water by adding some reagents, as presented in Figure 2. This is based on 'solubility' rules and is considered to be one of the simplest methods for decontamination. These techniques are used to remove contaminants like phosphorus, fluoride, arsenic, ferrocyanide and heavy metals, etc.

Table 4. Comparison between ceramic and polymer membrane filters[20-23]

Features	Ceramic	Polymers
Thermal stability	High	Low
Mechanical stability	High	Low
Chemical stability	High	Low
Pathogenic Tolerance	High	Low
Weight	High	Low
Cost	Low	High

Distillation

In this technique, heat is applied to separate contaminants from water. The concept is based on the difference in boiling points of components of water, as presented in Figure 3. This technology was developed mainly for industrial as well as domestic purposes. This process is not effective for the removal of organic contaminants. As the distillation process is safe but cannot contains any nutrients or minerals. So, such a method cannot be recommended for drinking water filtration.

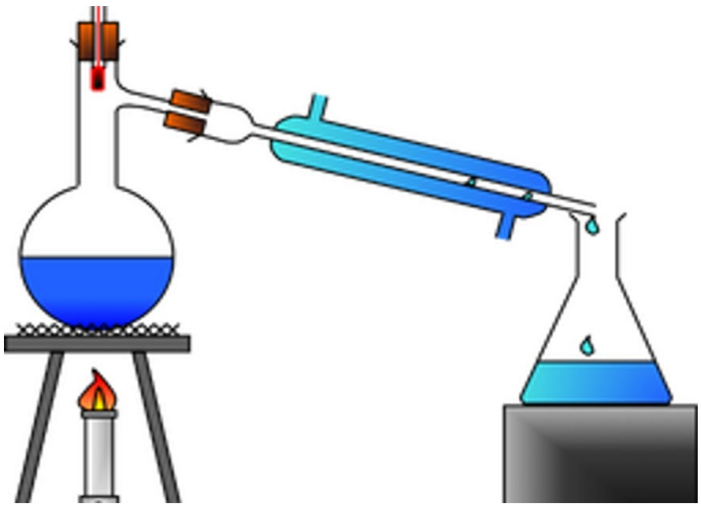

Figure 3. Distillation for Water Purification

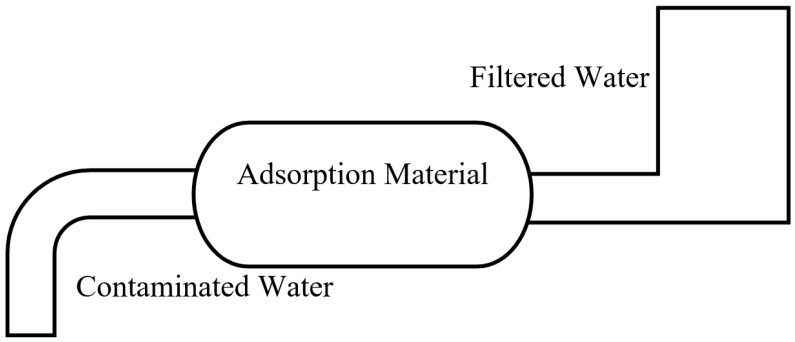

Figure 4. Adsorption Process for Water Filtration

Adsorption

In this process, a porous surface is provided to separate solid contaminants as they adhere to the surface, as presented in Figure 4. In this method, the adsorbent surface is directly added to the supply of water that combines physical and chemical processes to remove contaminants without altering the taste or mineral content of the water. All micro-porous or nano-porous materials can be used as adsorbent. Some of the porous solids such as activated carbon, activated alumina, silica gel, zeolite, etc can be used as adsorbent as they are porous and contains nano-sized surface pores.

Ion exchange

The ion exchange (as presented in Figure 5) filtration method uses the small polymer matrix having a diameter in millimeter (mm). Its structure is porous and contains gel. The ion exchange technology is based on the attraction of similar ions. Ions present in the water get exchanged with ions present in the polymer matrix. Common methods for the water filtration process are softening as well as deionization. The reduction of hardness level of water is performed by the process of softening which can also be used in the reverse osmosis technique.

Membrane Filtration

Another innovative idea for water filtration is membrane filtration in which a semi-permeable membrane is used for this purpose. Generally, there are two types of water treatment processes i.e. reverse osmosis (RO) and electro-membrane, as presented in Figure 6. Micro-membrane techniques are robust and efficient methods to remove contaminants. In this

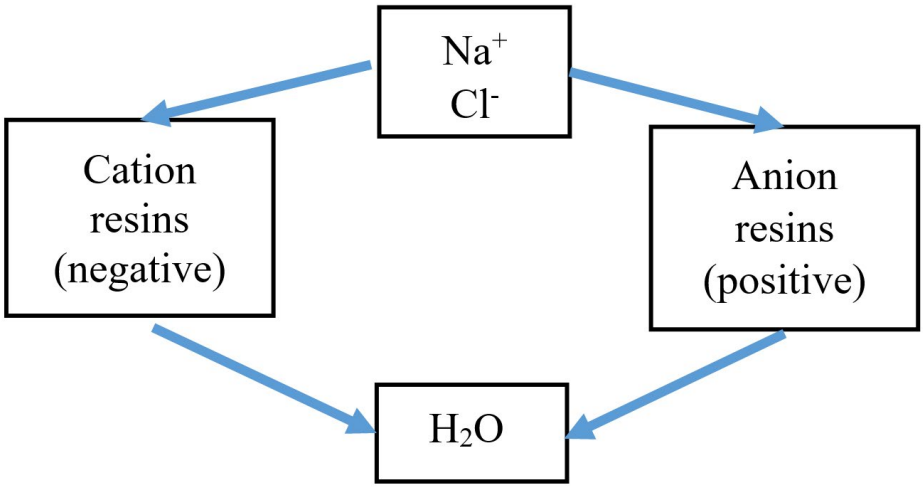

Figure 5. Ion Exchange Resin Water Filtration

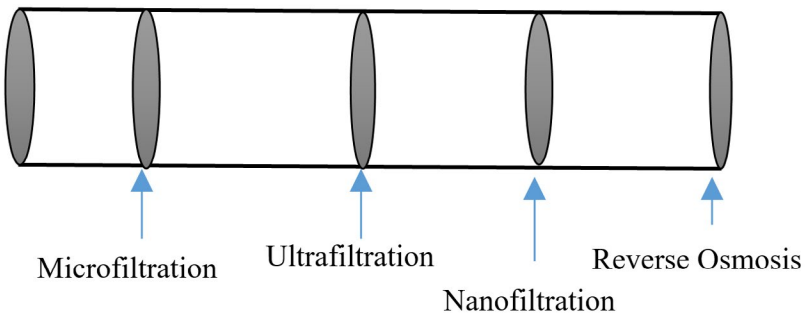

Figure 6. Membrane Water Filtration

Table 5. Comparative performance of different membrane filters

Membrane	Porosity	Wall Thickness or Crystal size	Water contact angle	Water Flux (L/m^2h)	Ref.
Zr-based hollow fiber membrane	81.51%	0.18 mm	62.06o	50.68	[28]
Green silica based ceramic hollow fiber membrane	70%	902 µm	-	130	[29]
PP/TiO_2 membrane	-	2.38 nm	91.8o	-	[30]
PVDF-PVP-TiO_2-$FeCl_3$ ultrafiltration membranes	43%	200nm	16o	~200	[31]
Gravity-driven membrane	-	-	37o	52	[32]
3-layer polyacrylonitrile membrane	-	~10 µm	-	~100	[33]
Polyvinylpyrrolidone membrane	-	~0.3mm	-	~200	[34]

Table 6. Membrane materials and their key features[35-41]

Materials	Type	Features
TiO_2	Inorganic	Photocatalytic under UV. Anti-fouling. Applicable to MF and UF.
Ag/TiO_2	Inorganic	Applicable in UF. Bacterial inactivation.
TiO2–SiO2/ Al2O3	Inorganic	Photocatalytic under UV. Applicable to UF.
Graphene	Inorganic	Applicable to NF. High retention for dyes and ions.
Polyvinyl Alcohol (PVA)/ Polypropylene (PP)	Organic	Applicable to MF. Achieve smaller as well as average pore size. High fouling tendency High operation cost and shorter lifetime
Cellulose Acetate (CA)	Organic	Applicable to UF. High flux and lack long term stability
Polyvinyl chloride (PVC) and polyvinyl formal (PVF)	Organic	Applicable to UF. Enhanced anti-fouling property.
Polysulfone (PSU)	Organic	Applicable to NF. Improved hydrophilicity
Polyisoprene (PI)	Organic-Inorganic	Applicable to MF. Improved porosity.
AgNPs/ polysulfone(PSU)	Organic-Inorganic	Applicable to UF Improved anti-bacterial effect and fouling strength.
ZnO/PES	Organic-Inorganic	Applicable to NF Improved permeability and fouling resistance

technique, the pressure-driven separation process is performed that can separate contaminants from water chemically as well as mechanically.

UV Treatment

In the UV filtration process, the ultraviolet (UV) light is allowed to pass through the contaminated/polluted water, as presented in Figure 7. Bypassing UV light through water, it breaks the genetic structure of microbial contaminants present in the water get damaged and, in this way, microbes get killed. But this method is not effective for the treatment of chemicals or other organic/ inorganic contaminants.

Membrane based filtration method

The membrane filtration method is considered to be one of the safer and cleaner as

compared to other filtration methods in terms of health issues. As the membrane filtration method is best suited for microbes' filtration of macro to nano size. Bacteria, macro in size, can be completely removed by membrane technology. This technology when implemented in industries can be better in respect of cost as compared to conventional water treatment processes.

The use of ultrafiltration or microfiltration in place of conventional methods reduced the cost of refinement for the same capacity plant. Technological advancement is shown by the fabrication of thin-film nanocomposite material, metal-organic material, carbon nanotubes. This technologically advanced nano-tube offers 2–3 times higher permeability along with salt rejection than conventional membrane technology, especially for industrial usage.[18,19] While designing the cost-effective membrane filters following factors must be considered:

- Membrane materials
- Water flux
- Wall thickness
- Water contact angle
- Mechanical/Chemical/Thermal Stability
- Operation cost

The membrane filtration process is mainly affected by the material and structure of the pores as well as its chemical and physical properties also shows impact. Many research works have been incorporated for exploring new membrane materials or design modifications for increasing its performance level. The most commonly used materials for ultrafiltration (UF), microfiltration (MF), or nanofiltration (NF) are synthetic polymers or ceramics. In the table 4 feature comparison is presented which will help in deciding material for the membrane.

Hence, the membrane filtration method shows its supremacy over conventional processes but every technology have some disadvantages. Some of the work contributing membrane technology are discussed in table 5. The preparation material for UF and MF membranes is almost the same but their preparation methods are different which results in different sized pores. As stated earlier these membranes can also be made from inorganic materials such as ceramics or zeolites.[24,25] But due to high operational cost and mechanical fragility, these materials are not much effective for large-scale applications. In the below section some of the research improvements are also discussed. The ceramic membranes exhibit high fouling-resistance and chemical stability as compared to current polymeric membranes. Some of the porous ceramics are such as Al_2O_3, TiO_2, ZrO_2, ZnO, and SiO_2 or their composites. These materials are actively studied due to their widespread applications.[26] These materials also exhibit photocatalytic ability for the decomposition of organic substances/ biological species which reduces unwanted adsorption on the membrane surface.[27] Although inorganic membranes are gaining more attention, the majority of membranes are made of polymeric materials as they provide a wide variety of structures and properties. Some of the common organic and inorganic materials are discussed in table 6 with their key features and drawbacks.

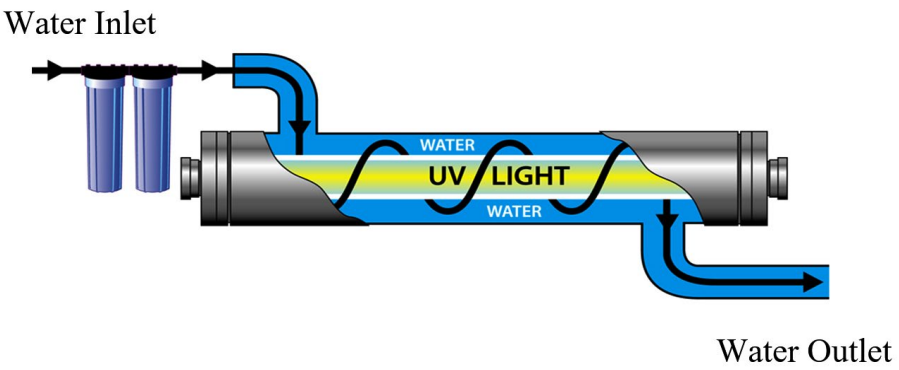

Figure 7. UV Treatment Water Filtration

CONCLUSION

Water is the source of life and its safety is fundamental. Since WDS systems are complex systems and the quality of drinking water is influenced by many factors, it is difficult to guarantee the safety of drinking water. The current water treatment & distribution system has a lot of drawbacks. Membrane filtration is considered to be one of the methods that are capable to meet the standards for safe drinking water either in a stand-alone unit or as a hybrid unit. The performance of the membrane-based filtration method is depending on many factors such as the number of pores and thickness of coatings. Nanotechnology has the potential to replace them and increase efficiency to prevent microbial activities. Nano-technology could potentially lead to more effective means of filtration that not only remove more impurities than current methods but do so faster, more economically, and more selectively. So, in the future design of the membrane would direct research work for the development of cost-effective with proven nontoxicity effects on the environment that could revolutionize the water treatment domain and prevention of microbes.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHORS' CONTRIBUTION

Both the authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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ETHICS STATEMENT

Not applicable.

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