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REVIEW ARTICLE

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Reverse Osmosis – A Unique Technique of Water Purification

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ABSTRACT

Water purification is the removal of contaminants from untreated water to produce drinking water that is pure enough for the most critical of its intended uses, usually for human consumption. Substances that are removed during the process of drinking water treatment include suspended solids, bacteria, algae, viruses, fungi, minerals such as iron, manganese and sulphur, and other chemical pollutants such as fertilizers. Water contains many types of dissolved salt (mainly NaCl) in it and the process which used to remove these salt and other minerals from water is called desalination. The amount of salt present in water is measured in term of salinity. Salinity measured in term of ppm. On the basis of salinity, water divided into three classes: Fresh water, brackish water and sea water. Only fresh water is fit for drinking and other purposes. Reverse Osmosis is best used method for conversion of brackish and sea water into fresh water i.e. for water purification. Reverse osmosis removes 96-99% of elemental ions, 99% of almost all other impurities.

Keywords: water purification, potable water, desalination, reverse osmosis, semi permeable membrane

INTRODUCTION

For the existence of all living beings (humans, animals or plants) water is very crucial. We need water to drink, to wash our hands, to cook, to water plants and many other things. Without water, the plants would die and people and animals would go thirsty. Hence, it is urgently required to use the available water most carefully and economically. It is a chemical substance with the chemical formula H_2O. A water molecule contains one oxygen and two hydrogen atoms connected by covalent bonds. Water is a liquid at ambient conditions, but it often co-exists on Earth with its solid state, ice, and gaseous state (water vapour or steam). Water also exists in a liquid crystal state and gaseous state (water vapour or steam). Water also exists in a liquid crystal state near hydrophilic surfaces (Pollack, 2012 and Bramer, 2012). Under nomenclature used to name chemical compounds, dihydrogen monoxide is the scientific name for water, though it is almost never used (M.D.G. report, 2008). Your body is made up of many bones. All these bones make up your skeleton. Like your body, water is made up of a skeleton of water molecules. Water contains many types of dissolved salt (mainly NaCl) in it and the process which used to remove these salt and other minerals from saline water (Review: NRC of National Academics, 2004) is called desalination. The amount of salt present in water is measured in term of salinity. Salinity measured in term of ppm. On the basis of salinity water divided three categories.

1. Fresh water: <1000 ppm
2. Brackish water: 1000-3500 ppm
3. Sea water: □3500 ppm

Only fresh water is fit for drinking and other domestic and industrial uses. Water covers 70.9% of the Earth's surface (Henniker, 1949) and is vital for all known forms of life (United Nations report, 2012). On Earth, 96.5% of the planet's water is found in oceans, 1.7% in groundwater, 1.7% in glaciers and the ice caps of Antarctica and Greenland, a small fraction in other large water bodies, and 0.001% in the air as vapor, clouds (formed of solid and liquid water particles suspended in air), and precipitation (Gleick, 1993 and Special report AGU, 1995). Only 2.5% of the Earth's water is fresh water, and 98.8% of that water is in ice and groundwater. Less than 0.3% of all freshwater is in rivers, lakes, and the atmosphere, and an even smaller amount of the Earth's freshwater (0.003%) is contained within biological bodies and manufactured products (Gleick, 1993). Reverse osmosis and electro dialysis are mainly used method for desalination i.e for the conversion of sea and brackish water into fresh water (Glueckstern and Priel, 2002).

According to a 2007 World Health Organization (WHO) report, 1.1 billion people lack access to an improved drinking water supply, 88 percent of the 4 billion annual cases of diarrheal disease are attributed to unsafe water and inadequate sanitation and hygiene, and 1.8 million people die from diarrheal diseases each year. The WHO estimates that 94 percent of these diarrheal cases are preventable through modifications to the environment, including access to safe water (Internet Report, www.who.int). Simple techniques for treating water at home, such as chlorination, filters, Reverse Osmosis (RO) and solar disinfection, and storing it in safe containers could save a huge number of lives each year (Internet Report, www.who.int). Reducing deaths from waterborne diseases is a major public health goal in developing countries. For water purification numbers of methods are used out of which RO is best method for purification of water at domestic level.

Advantages of RO system

1. It is simple and reliable process.
2. Capital and operating expenses are low.
3. Compact design requires less space for installation.
4. Fully automatic operation with auto-start and auto-off.
5. Suitable for raw water from all types of sources like bore well, overhead storage tanks, water tankers and even municipal taps.
6. Colloidal SiO_2 can be removed by R.O. which cannot be removed by other methods.
7. The life of semi-permeable membrane is about 2 years and it can be easily replace within few minutes, thereby nearly uninterrupted water supply can be provided.

Applications of RO system

Reverse Osmosis is used in various applications such as water filters for refrigerators/fridge, RO water purifier for hemodialysis patients, RO water purifier for dialysis, reverse osmosis for fluoride removal, reverse osmosis for ship, reverse osmosis for boats, for beer brewing equipment, for hydroponics, reverse osmosis for fish tank, reverse osmosis for fluoride removal, reverse osmosis for milk reverse osmosis for plants, iron removal system, House Oxidation System, Manganese Removal, Sulfur removal, Ice flaker machine manufacturers, for Blood Dialysis, Medical water purifier, for Biochemistry Analyzer, For Pharmacy, for Hospital Central Sterilize Supply Department (CSSD), for Clinical Analysis, Laboratory Water Purification and Polysulfone filter.

Potable water and its characteristics:

Water suitable or safe for drinking is called potable water. World Health Organisation (WHO) guidelines (WHO report who.int, 2003) are generally followed throughout the world for drinking water quality requirements. In addition to the WHO guidelines, each country or territory or water supply body can have their own guidelines in order for consumers to have access to safe drinking water.

The common specifications or standards prescribed and recommended for drinking water are as follows (unitedutilities.com):

1. It should be colourless and odourless.
2. It should be good in taste.
3. It should not be hot i.e. less than 25^0c.
4. Its turbidity should be less than 10 ppm.
5. It should be free from objectionable gases like H_2S.
6. It should be free from objectionable minerals such as lead, arsenic, chromium and Manganese salts.
7. Its pH should be in the range of 6.6-8.5.
8. It should be soft. Its total hardness should be less than 500 ppm.
9. It should be free from algae, fungi, harmful bacteria and other micro-organisms.
10. The chloride, fluoride and sulphate contents should be less than 250, 1.5 and 250 ppm respectively.

Water Purification

Water purification is the removal of contaminants from untreated water to produce drinking water that is pure enough for the most critical of its intended uses, usually for human consumption (Wilson et.al., 2012). Substances that are removed during the process of drinking water treatment include suspended solids, bacteria, algae, viruses, fungi, minerals such as iron, manganese and sulphur, and other chemical pollutants such as fertilisers. The goal of all water purification process is to remove existing contaminants in the water, or reduce the concentration of such contaminants so the water becomes fit for domestic and industrial use, medical and many other uses (Kozisek, 2003). One such use is returning water that has been used back into the natural environment without adverse ecological impact. A combination selected from the following processes is used for municipal drinking water treatment worldwide:

Screening- removing floating matter like wood pieces leaves etc. from water.

Sedimentation - for solids separation, that is, removal of suspended solids
Coagulation - for flocculation i.e. for convert small particles to larger particle which easily removed by sedimentation. Coagulant aids, also known as polyelectrolyte - to improve coagulation and for thicker flocculate formation.
Filtration - removing micro-organisms, odour, colour, taste, finely divided suspended and colloidal impurities/ particles from water.
Desalination - removing dissolved salt from the water.
Disinfection - for killing bacteria
There is no unique solution (selection of processes) for any type of water. Also, it is difficult to standardize the solution in the form of processes for water from different sources. Treatability studies for each source of water in different seasons need to be carried out to arrive at most appropriate processes.

Reverse Osmosis (RO): This method was invented in 1959 by Prof Reid of the University of Florida, and was put into practical use by Sidney Loeb and Srinivasa Sourirajan. Reverse osmosis (Report on Industry Consortium......2004) is a demineralization process that relies on a semi permeable membrane to effect the separation of dissolved solids from a liquid. The semi permeable membrane allows liquid and some ions to pass, but retains the bulk of the dissolved solids. Semi permeable membrane (Suratt, 1995) made up of thin films of cellulose acetate, polymethyl methacrylate and polyamides polymers. Although many liquids (solvents) may be used, the primary application of RO is water-based systems. Hence, all subsequent discussion and examples will be based on the use of water as the liquid solvent. To understand how RO works, it is first necessary to understand the natural process of osmosis.
Osmosis is a natural process where water flows through a semi permeable membrane from a solution with a low concentration of dissolved solids to a solution with a high concentration of dissolved solids. Picture a cell divided into 2 compartments by a semi permeable membrane, as shown in *Figure 1*. This membrane allows water and some ions to pass through it, but is impermeable to most dissolved solids. One compartment in the cell has a solution with a high concentration of dissolved solids while the other compartment has a solution with a low concentration of dissolved solids. Water will continue to flow through the membrane until the concentration is equalized on both sides of the membrane. In equilibrium, the concentration of dissolved solids is the same in both compartments *Figure 2*, there is no more net flow from one compartment to the other. However, the compartment that once contained the higher concentration solution now has a higher water level than the other compartment. The difference in height between the two compartments corresponds to the osmotic pressure of the solution that is now at equilibrium.

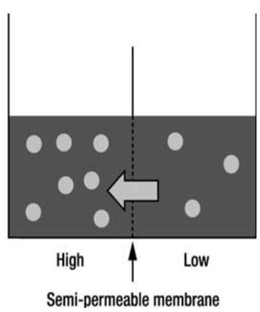

Figure 1

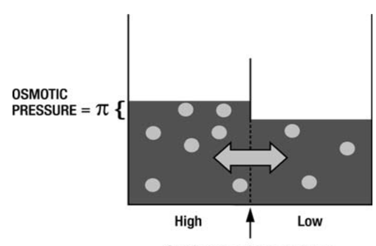

Figure 2

Reverse osmosis is the process by which an applied pressure, greater than the osmotic pressure, is exerted on the compartment that once contained the high-concentration solution, forcing water to move through the semi permeable membrane in the reverse direction of osmosis. Once contained the high-concentration solution (*Figure 3*). This pressure forces water to pass through the membrane in the direction reverse to that of osmosis. Water now moves from the compartment with the high-concentration solution to that with the low concentration solution. Reverse osmosis take place in reverse osmosis cell as in *Figure 4*.

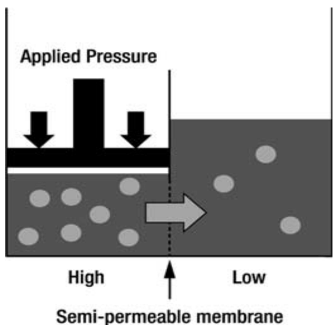

Figure 3

Figure 4

In this manner, relatively pure water passes through membrane into the one compartment while dissolved solids are retained in the other compartment. Hence, the water in the one compartment is purified or "de mineralized," and the solids in the other compartment are concentrated or dewatered. Due to the added resistance of the membrane, the applied pressures required to achieve RO are significantly higher than the osmotic pressure. For example, for 1,500 ppm TDS brackish water, RO operating pressures can range from about 150 psi to 400 psi. For seawater at 35,000 ppm TDS, RO operating pressures as high as 1,500 psi may be required. The factors that affect the performance of a RO System are:

- Water Temperature
- Incoming water pressure
- Type and number of total dissolved solids (TDS) in the tap water
- The quality of the filters and membranes used in the RO System

This process which removes both dissolved organics and salts. Feed water is pressurized and flows across a membrane, with a portion of the feed permeating the membrane. The balance of the feed sweeps parallel to the surface of the membrane to exit the system without being filtered. The filtered stream is permeating because it has permeated the membrane. The second stream is the concentrate because it carries off the concentrated contaminants, rejected by the membrane. Because the feed and concentrate flow parallel to the membrane and not perpendicular to it, the process is called "cross flow filtration". Depending on the size of the pores engineered into the membrane, cross flow filters are effective in the classes of separation known as RO, nano filtration, ultra filtration and microfiltration. Basic components of a RO System are shown as in *Figure 5*:

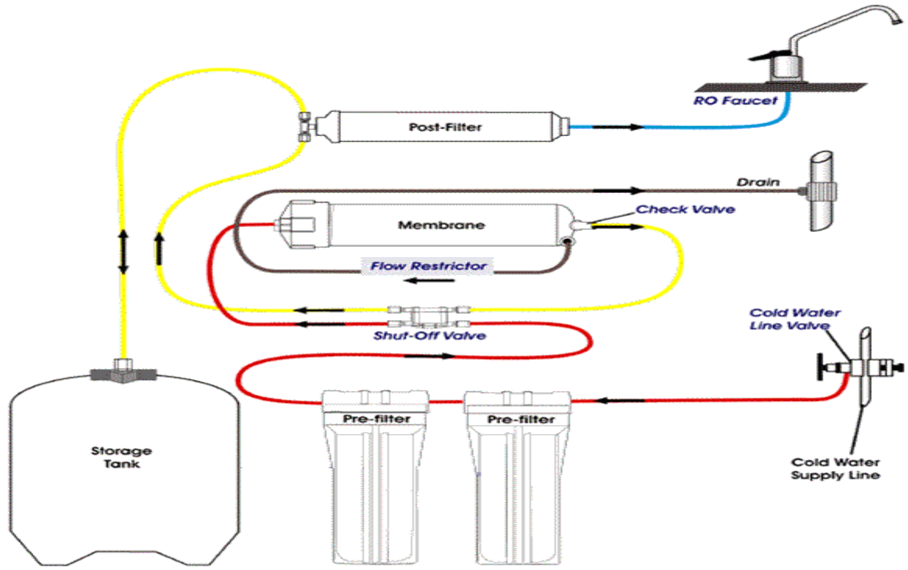

Figure 5

1. Cold Water Line Valve: Valve that fits onto the cold water supply line. The valve has a tube that attaches to the inlet side of the RO pre filter. This is the water source for the RO system.
2. Pre-Filter (s): Water from the cold water supply line enters the Reverse Osmosis Pre Filter first. There may be more than one pre-filter used in a Reverse Osmosis system. The most commonly used pre-filters are sediment filters. These are used to remove sand silt, dirt and other sediment. Additionally, carbon filters may be used to remove chlorine, which can have a negative effect on TFC (thin film composite) & TFM (thin film material) membranes. Carbon pre filters are not used if the RO system contains a CTA (cellulose tri-acetate) membrane.
3. Reverse Osmosis Membrane: The Reverse Osmosis Membrane is the heart of the system (*Figure 6*). The most commonly used is a spiral wound of which there are two options: the CTA (cellulose tri-acetate), which is chlorine tolerant, and the TFC/TFM (thin film composite/material), which is not chlorine tolerant. A selection of RO membranes can be used to treat different feed water scenarios. It can meet almost all water standards with a single pass system and all water standards with a double pass system.

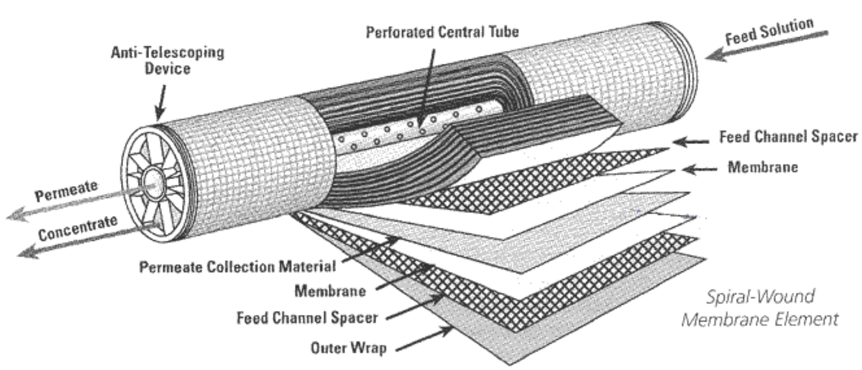

Figure 6

The process achieves rejections of 99.9% of viruses, bacteria and pyrogens. A reverse osmosis membrane will remove impurities and particles larger than 0.001 microns.

4. Post filter (s): After the water leaves the RO storage tank, but before going to the RO faucet, the product water goes through the post filter (s). The post filter (s) is generally carbon (either in granular or carbon blocks form). Any remaining tastes and odours are removed from the product water by post filtration.

5. Automatic Shut Off Valve (SOV): To conserve water, the RO system has an automatic shutoff valve. When the storage tank is full (this may vary based upon the incoming water pressure) this valve stops any further water from entering the membrane, thereby stopping water production. By shutting off the flow this valve also stops water from flowing to the drain. Once water is drawn from the RO drinking water faucet, the pressure in the tank drops and the shut off valves opens, allowing water to flow to the membrane and waste-water (water containing contaminants) to flow down the drain.

6. Check Valve: A check valve is located in the outlet end of the RO membrane housing. The check valve prevents the backward flow or product water from the RO storage tank. A backward flow could rupture the RO membrane.

Table 1. Rejection Percentage of RO membrane as per element.

S. No.	Element	%Rejection
1	Arsenic	96%
2	Barium	95%
3	Cadmium	95 %
4	Calcium	98%
5	Chloride	92%
6	Cyanide	84%
7	Fluoride	85%
8	Iron	98%
9	Lead	98%
10	Magnesium	98%
11	Manganese	98%
12	Mercury	95%
13	Nickel	98%
14	Nitrate	75%
15	Phosphate	96%
16	Potassium	95%
17	Selenium	96%
18	Sodium	94%
19	Sulfate	96%
20	Zinc	98%

7. Flow Restrictor: Water flow through the RO membrane is regulated by a flow control. There are many different styles of flow controls. This device maintains the flow rate required to obtain the highest quality drinking water (based on the gallon capacity of the membrane). It also helps maintain pressure on the inlet side of the membrane. Without the flow control very little drinking water would be produced because all the incoming tap water would take the path of least resistance and simply flow down the drain line. The flow control is located in the RO drain line tubing.
8. Storage Tank: The standard RO storage tank holds up to 2.5 gallons of water. A bladder inside the tank keeps water pressurized in the tank when it is full.
9. Faucet: The RO unit uses its own faucet, which is usually installed on the kitchen sink. In areas where required by plumbing codes an air-gap faucet is generally used.
10. Drain line: This line runs from the outlet end of the Reverse Osmosis membrane housing to the drain. This line is used to dispose of the impurities and contaminants found in the incoming water source (tap water). The flow control is also installed in this line.

CONCLUSION

From the study of RO system for domestic water purification rejection characteristics of RO membrane as per element in percentage is given in Table 1.

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