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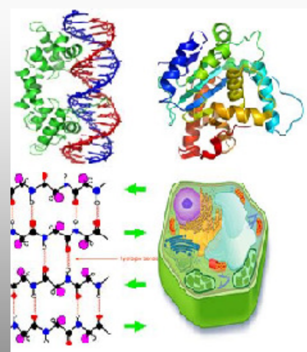

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REVIEW ARTICLE

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Reverse Osmosis: An Emerging Technology for the Production of Safe Water

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ABSTRACT

As the name suggests, reverse osmosis is the opposite phenomenon of osmosis. Osmosis describes the spontaneous flow of water from a dilute solution to a more concentrated solution, when separated from each other by a suitable membrane. As may be evident by now, the reverse osmosis process is best known for its use in desalination (removing the salts from seawater to get safe water), but also get to purified naturally occurring water for medical, industrial and other rinsing applications. In the production of bottled packaged drinking water, the water passes through a reverse osmosis water processor to remove contaminants and pathogens. Rain water collected from the sever drains is purified with reverse osmosis processor and used as tap water in some countries of the world, in case of water scarcities. In industry, reverse osmosis is used to remove minerals from boiler water. It also finds application in cleaning effluent and brackish groundwater.

Keywords: Groundwater, Brackish water, Semi permeable membrane, Toxicants, Reverse osmosis; Potable water.

INTRODUCTION

How did Reverse Osmosis (RO) technology get started? Let's begin with a close look into osmosis. One of the most interesting and fascinating natural phenomena, osmosis is the basis for the fastest growing desalination technology called RO. Natural osmosis governs how waters transfer between solutions with different concentrations.

It’s also the basis for the way in which human skin and organs function, and how flora and fauna maintain a water balance.
Due to the nature of the RO process it can’t be characterized as a filtration or as treatment.
As in natural process, water tends to flow from a solution with a lower concentration to a solution with a higher concentration (Henniker, 1949). As shown on figure 1, where there is a semi-permeable barrier such as a membrane, when pressure is applied to a concentrated solution that exceeds osmotic pressure, clean water will be displaced out of the concentrated solution while salts will remain in the concentrated solution. Theoretically, salts shouldn’t salts should not pass through the membrane, but in practice we observe salt leakages as a result of diffusion, despite the fact that membrane “openings” are much larger than the molecules of water (H_2O) and many other ions in the water that may pass the membrane (Polack, 2012).

REVERSE OSMOSIS TECHNOLOGY
This method was invented in 1959 by Professor Reid of the University of Florida and was into practical use by Sidney Loeb and Srinivasa Sourirajan. Reverse osmosis (Report on Industry Consortium........2004) is a mineralization process that relies on a semi permeable membrane to affect 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 polyamide polymers. Although many liquids (solvents) may be used, the primary application of RO is water-based systems (Model 1, 2&3). 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. (Scott, 2012). Osmosis is a natural process where water flows through a semi permeable membrane from a solution of low concentration of dissolved solid to a solution with 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 (salts). One compartment in the cell has a solution with a high 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. Now, there will not be more flow from one compartment to the other. However, the compartment that once contained the higher concentration solution now has a higher level than other compartment. The difference in height between the two compartments corresponds to osmotic pressure of the solution that is now at equilibrium, RO 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. This pressure forces water to pass through the membrane in the direction reverse to that of osmosis.

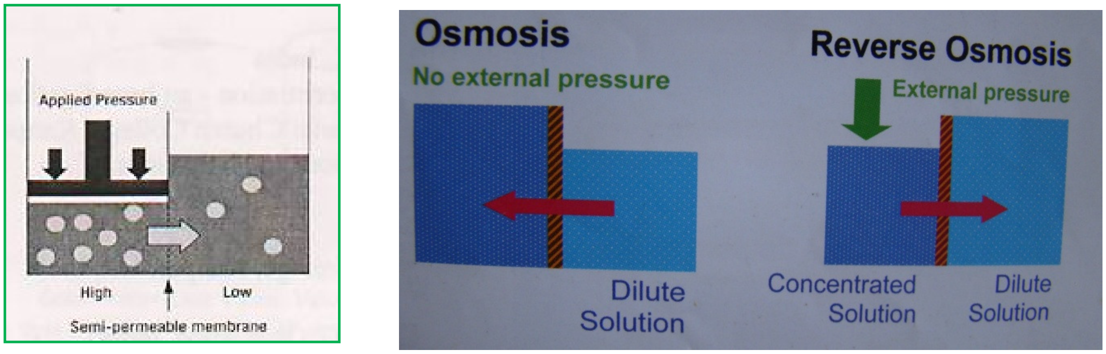


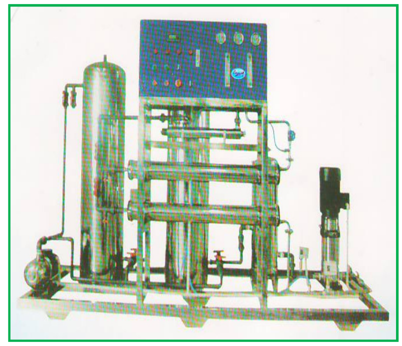
Figure 1. Schematic of Osmosis and Reverse osmosis

Water now moves from the compartment with the high concentration solution to that with the low concentration solution (Figure 1).

In this manner, relatively pure water passes through membrane into the one compartment while dissolved solids 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 (Scott, 2012). Due to added pressure of the membrane, the applied pressures required to achieve RO are significantly higher than the osmotic pressure. For example, for 1,500ppm TDS (Total Dissolved Solids) brackish water, RO operating pressure as high as 1,500 psi may be required. The factors that affect the performance of RO system are:

- Water temperature; Incoming water pressure
- Type and number of TDSs in the tap water
- The quality of 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 concentration 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 in Figure 2.



[Model of RO System: 1] **[Model of RO System: 2]** **[Model Industrial RO System: 3]**

- **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 RO pre-filter. This is the water source for the RO system.
- **Pre-filter (s):** Water from the cold water supply line enters the RO pre-filter first. There may be more than one pre-filter used. The most commonly used pre-filters are sediment filters. These are used to remove sand, silt, dirt and other sediments. Additionally, carbon filter may be used to remove chlorine, which can have a negative effect on TFC (Thin Film Composite) and TFM (Thin Film Material) membranes. Carbon pre-filters are not used in the RO system contains CTA (Cellulose Tri- Acetate) membranes.
- **Reverse Osmosis Membrane:** The reverse osmosis membrane is the central part (external kidney) of the system (Figure 3). The most commonly used is a spiral wound of which there are two options: the CTA, which is chlorine tolerant, and the TFC/TFM, which is not chlorine content. 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. The process achieves rejections of 99.9% of viruses, bacteria and pyrogens. A reverse osmosis will remove impurities and particles larger than 0.001µ (microns).
- **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.

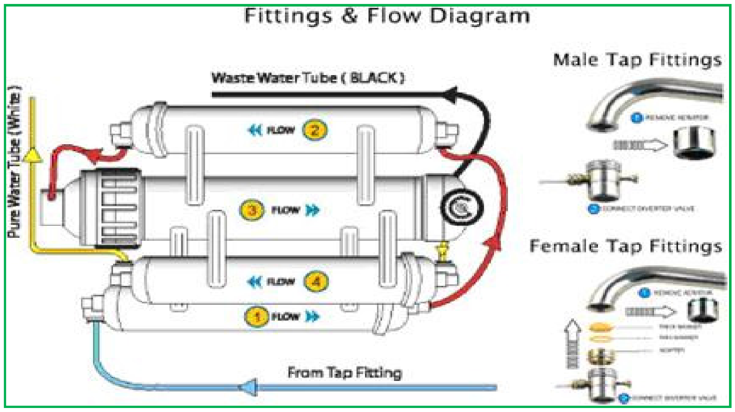


Figure 2. Major components of RO technology

- **Automotive Shut Off Valve:** 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 shutoff valve opens, allowing water to flow to the membrane and waste-water (water containing contaminants) to flow down the drain.
- **Check Valve:** A check valve is located in the outlet end of the RO membrane housing. The check valve prevents the back flow or product water from the RO storage tank. A backward flow could rupture the RO membrane.
- **Flow Restrictor:** Water flows through the RO membrane is regulated by a flow control. There are many different styles of flow controls. The 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 potable water would be produced because all the incoming tap water would take the path of at least resistance and simply flow down the drain line. The flow control is located in the RO drain line tubing.
- **Storage Tank:** The standard RO storage tank holds up to 2.5 gallons of water. A bladder inside the tank keeps water pressured in the tank when it is full.
- **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.
- **Drain Line:** The line runs from the outlet end of the RO membrane housing to the drain. This line is used to dispose of impurities and contaminants found in the incoming water source (tap water). The flow control is also installed in this line.

MEMBRANE CHARACTERISTICS AND CONTINUANCE

The material of the membrane has to be inert to the liquids, it is exposed to, at the same time having mechanical strength to withstand the high pressure of operation.

It should not support scale formation or organic growth, which will block the pores and reduce the performance of the unit. It should be resistant to acid and alkaline cleaning chemicals which are used to recover the membrane over a period of time. In the manufacture of RO membranes, Thin Film Composites (TFC) is used. These are semi permeable membranes manufactured principally for use in water purification. They also have use in chemical applications such as batteries and fuel cells. In essence a TFC material is a molecular sieve constructed in the form of a film from two or more layered materials. Membranes used in RO are in general, made out of Polyamide, chosen primarily for its permeability to water and relative impermeability to various dissolved impurities including salt ions and other small molecules that cannot be filtered (Table 3). It can withstand twice the temperature as compared to cellulose acetate membranes. The figure 5 shows a cutaway section of the modern RO membrane. Earlier versions of membranes were very different from the present cylindrical spirally wound membranes. They were flat sheets assembled with inter layers of collectors. But they were not as easy to install and maintain as the modern ones. Membranes formed from spiral wound layers of membranes/spacer/ collector comes in different sizes; the most popular sizes are the membranes of diameter 4 inches and 8 inches, with length of 40 inches. The effective area is 7 to 8m^2 for each module. Domestic models of RO plants use smaller membranes while larger diameter and length are made for special applications. Membranes are housed in pressure vessels with end connections for joining the inlet feed water, and outlets for the pure permeate and the concentrate. Housings come in different lengths to suit up to 8 membranes in a single housing. These are chosen depending on applications (Wilson et al., 2012; Kaushik, 2012).
It has become a practice to select RO plants as a commodity. Whereas, the membranes required for a specific application has to be selected based on several parameters, the most important being the quality of raw water, the flow rate, and its end use.

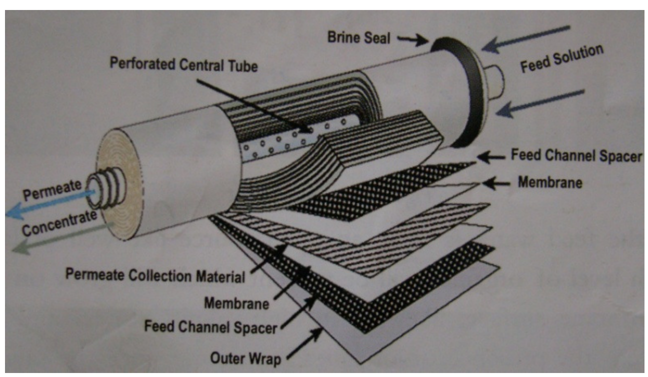


Figure 3. Cutaway Section of the modern RO membrane

Manufacturers of membranes have a fact sheet to be submitted to be submitted to them for specific applications, from which, data is used to run a software program which will specify among others, the number of membranes, its configuration, and the operating pressure, another factor to be considered is the utilisation of the reject stream.

The ideal situation would be one where the reject could be put to alternate use. But given the rate of depletion of groundwater, the available water already has a high concentration of salts, resulting in the reject being hardly useable. High recovery plants will produce reject water which cannot be discharged as per pollution norms. They have to be evaporated by approved means. However, higher recoveries also mean the plant will operate at greater pressures, incur higher operating cost, become service and power intensive. Hence a holistic approach is needed to get an optimum water balance over the different conditions. In order to maximize the performance of the RO membranes, pre-treatment of the feed water is done. Physical impurities are removed by sand filters. If the feed water has been chlorinated at the source, the chlorine has to be 'leached', since the membranes are sensitive to chlorine. High amount of dissolved iron has to be removed by oxidation. Likewise, colloidal silica causes fouling of the membrane which is difficult to remove by simple means. Nevertheless, it has to be tackled. Dosing pumps are used to dose various chemical formulations which aid in the pre-treatment of feed water (Kozisel, 2003).

If the feed water is from an open source like well or lake, higher level of organics will be present which will grow on the membrane surface, likewise, in high salinity waters and sea water, the presence of organics is extreme since the salinity sustains it. To overcome this, special formulations called antiscalents are dosed before the water enters the membranes. Sometimes post-treatment is done depending on the end use of the water. In drinking water applications, if the output water has the low pH, the taste may not be palatable. Here again dosing is done to bring the pH to 7. Water treatment plants which use RO membranes systems need to be regularly monitored, and preventive maintenance systems should be in place from day 1 of the operations. As the chemicals filtered out are the main source of damage to the membrane, an ideal plant with the raw water within the membrane is a major hazard for the plant. There are many cases where procrastination to rectify small effects have lead to major replacements – a perfect example of the adage, "A stitch in time saves nine". For cleaning of membranes, the RO plant is provided with Clean-in-place (CIP) systems; this helps to bypass the normal flow pattern of the plant and circulates under low pressure, a mild alkaline solution. In certain cases, this may be followed by acidic cleaning; the procedure may be repeated to achieve desired results with adequate flushing between every change. Organic fouling is also removed in a similar fashion. The sourcing of membranes is as equally important factor. In any case, the users are expected to monitor and maintain the operating records of the RO plant with respect to pressures and flow rates of the equipment, along with the details of cleaning cycles. Reject streams of large plants discharge water at almost the operating pressure. Hence is a source of energy. Today large plants are built with patented energy recovery systems. So, that part of the wasted energy is used to run the plant and reduces the overall power consumption. Very large plants are complex in design and operation but in the long run are more economical as the unit cost of treated water could be attractive. If the plant is not going to be used the membranes have to be de-watered and preserved with chemicals. Otherwise the permeability of the membrane is lost irreversibly.

Despite the fact that RO system is composed from a number of RO membrane elements properties, there are a number of design and operation techniques that can make RO system design and operation extremely flexible (Table 1 and 2).
The RO process attracted the attention of many researchers in middle of the twentieth century; however efforts to develop a commercial RO membrane were unsuccessful until the late 1950s. In 1959, a group of researchers at the University of California Los Angeles (UCLA) led by Sidney Loeb and Srinivasa Sourirajal demonstrated an RO membrane that worked. The asymmetric or anisotropic cellulose acetate membrane demonstrated by the researchers provided adequate salt rejection at that time. This was the beginning of desalination by RO membrane. Besides membrane desalination, this was also the beginning of the commercial development of membrane technologies for solid-liquid separation. The RO separation process can be shown in the simple diagram in figure 4.
The RO process has three major streams: a) Feed; b) Permeate (product water); c) Concentrate (reject or brine).

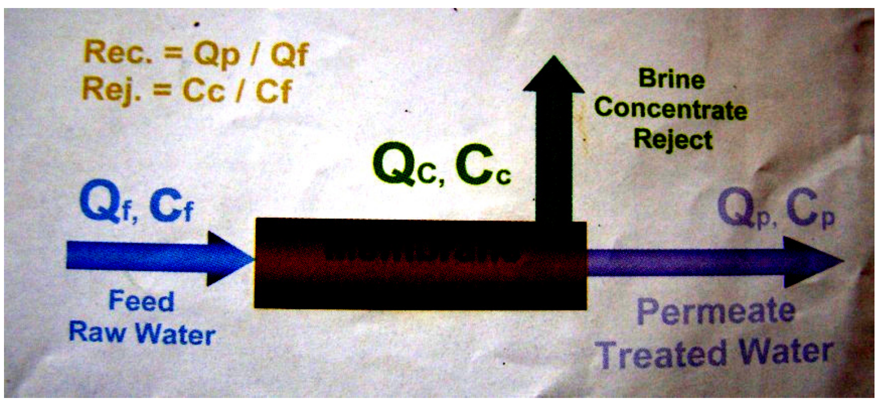


Figure 4. Schematic of major Reverse Osmosis stream

The mass balance for the entire system can be represented as follows:
$Q_f \times C_f = Q_c \times C_c + Q_p \times C_p$
Where: Q_f - feed flow (m^3/hr); C_f - salt concentration in feed water (ppm); Q_c – concentrate flow (m^3/hr); C_c – salt concentration in concentrate (ppm); Q_p – product flow (m^3/hr); C_p - salt concentration in product water (ppm).
The smallest module of the RO system of the RO system is the RO membrane element. As RO technology developed, the industry came to a consensus on manufacturing standard size RO membrane elements. The major diameters of the spiral – wound elements are 2.5”, 4” and 8” with the standard length of single elements at 40” and 60”.

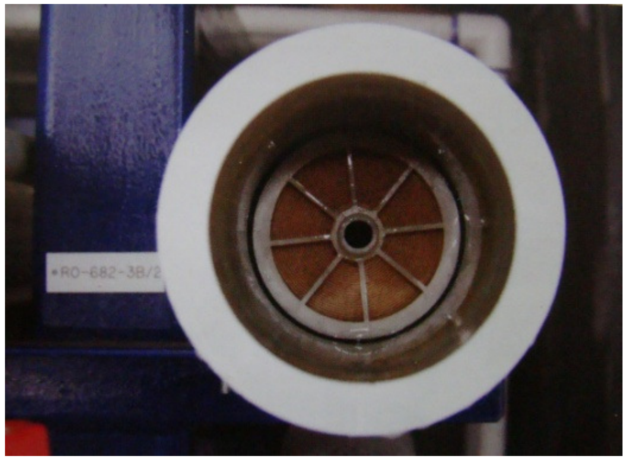


Figure 5. RO membrane inside the pressure vessel

More recently, the RO industry has developed larger RO elements with diameters o 16”, 17”, 18”, and 18.5”. While there is currently no consensus on a standard for large diameter RO, each supplies produces a different size, this situation may change as time passes. Each model of the RO element has certain “fixed” properties that are described and can be found in the element’s specification sheet. Little variation is allowed from the membrane element specification when each element is subjected to factory wet seta e.g., the produced elements must meet the specification. In a full scale system the RO elements are encapsulated in pressure vessels that can hold from one single element up to 8 elements in single vessel as shown on figure 5.
A number of vessels are mounted on the RO rack and can be operated in parallel or in series as shown on figure 6.

Figure 6. RO Rack

Table 1. Potable water and its essential characteristics (*bis standards*).

ESSENTIAL CHARACTERISTICS	IS REQUIREMENT LIMIT	IS PERMISSIBLE LIMIT	WHO GUIDELINES	US EPA LIMIT
Colour (in Hazen units)	5	25	15	15
ODOUR	UNOBJECTIONABLE	-	-	-
TASTE	AGREEABLE	- -	-	
TURBITY (in NTU)	5	10	5	-
pH	6.5 – 8.5	6.5 – 8.5	-	6.5 -8.5
TOTAL HARDNESS ((as $CaCO_3$)	300	600	-	-
IRON	0.2	1.0	0.3	0.3
CHLORIDE	250	1000	250	250
RESIDUAL FREE CHLORINE	0.2	-	-	-

Table 2. Potable water and its desirable characteristics (*bis standards*).

DESIRABLE CHARACTERISTICS	IS REQUIREMENT LIMIT	IS PERMISSIBLE LIMIT	WHO GUIDELINES	US EPA LIMIT
DISSSOLVED SOILDS	**500**	**2000**	**1000**	**500**
CALCIUM	**75**	**200**	**-**	**-**
COPPER	**0.05**	**1.5**	**2**	**1.3**
MANAGENESE	**0.1**	**0.3**	**0.5.**	**0.05**
SULPHATE	**200**	**400**	**200**	**200**
NITRATE	**45**	**100**	**50**	**10**
FLUORIDE	**1.0**	**1.5**	**1.5**	**4**
PHENOLIC COMPOUNDS	**0.001**	**0.002**	**-**	**-**
MERCURY	**0.001**	**0.002**	**0.001**	**0.001**
CADMIUM	**0.01**	**0.001**	**0.001**	**0.002**
SELENIU,	**0.01**	**0.001**	**0.001**	**0.002**
ARSEMIC	**0.05**	**0.05**	**0.01**	**-**
CYANIDE	**0.05**	**0.05**	**0/07**	**0.2**
LEAD	**0.05**	**0.05**	**0.01**	**0.0**
ZINC	**5**	**15**	**3**	**5**
ANIONIC DETERGENTS	**0.2**	**1.0**	**-**	**-**
CHROMIUM	**0.05**	**0.05**	**0.05**	**0.1**
POLY NUCLEAR HYDROCARBONS	**-**	**-**	**-**	**-**
MINERAL OIL	**0.01**	**0.03**	**-**	**-**
ALKALINITY	**0200**	**600**	**-**	**-**
ALUMINIUM	**0.03**	**0.2**	**0,2**	**0,05 – 0.2**
PESTICIDES	0.0	0.001	-	-

All units in mg/litres unless mentioned otherwise.
US EPA standards are Maximum Contaminants Level Goals (MCLG) and are non-enforceable public health goals.

Table 3. Typical rejection characteristics of RO membranes.

Typical Rejection Characteristics of RO Membranes	
Contaminant	% Normal Rejection
Sodium	85 – 94
Sulphate	96 – 98
Calcium	94 – 98
Potassium	85 – 95
Nitrate	90 – 95
Iron	94 – 98
Zinc	95 – 98
Mercury	95 – 98
Selenium	94 – 96
Phosphate	96 – 98
Lead	95 – 98
Arsenic	92 – 96
Magnesium	94 -98
Nickel	96 – 98
Fluoride	92 – 95
Manganese	94 – 98
Cadmium	95 – 98
Barium	95 – 98
Cyanide	84 – 92
Chloride	85-92
% may vary based on membrane type, water pressure, temperature and TDS	

ADVANTAGES OF RO SYSTEM

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

MAJOR IMPROVEMENTS IN REVERSE OSMOSIS TECHNOLOGY

Three major improvements in the technology can be identified.

1. Improvements of the RO technologies and RO process: membrane materials, energy optimization, large scale plants, design optimization, construction and procurement optimization
2. Nano materials and nano particles: modification of the RO materials utilizing nano materials and nano particles to achieve lower energy demand for the process and higher permeability of the membranes while keeping membrane fouling low or comparable to the existing commercial RO membrane materials.
3. Forward Osmosis (FO) utilizing draw solution with high osmotic pressure when utilizing Ammonia and Carbon dioxide or other ingredients for the draw solution.

CONCLUSION

Water purification is the removal contaminants from untreated water to produce potable 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 potable water treatment include suspended particles, pathogens, fertilizers, pesticides, algae, fungi, minerals and other chemical pollutants.. 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. One 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 flocculation, that is, removal of suspended solids; Coagulation- for flocculation i.e. to convert small particles to larger particles which are easily removed by sedimentation. Coagulation 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; Disinfection-for killing bacteria.

There is no unique solution (selection of the 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 process. Reverse osmosis has become one of the key technologies for desalinating water. RO is one of the fastest growing technologies spreading around the globe due to its advanced features and reduction in cost as technology develops. It has become cost effective for many water and wastewater treatment and desalination applications, replacing conventional processes while providing benefits for new construction, upgrades, and retrofits of existing facilities. RO also offers the advantage of high effluent water quality, a compact foot-print, and often times simpler operation as compared to conventional treatment processes.

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