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A Short Review on Process and Applications of Reverse Osmosis

***Garud R. M., Kore S. V., Kore V. S., Kulkarni G. S.**

[1] Department of Environmental science and Technology, Shivaji University, Kolhapur (Maharashtra)

***Corresponding author: ravindragarud65@gmail.com**

Abstract:

Reverse Osmosis (RO) is a membrane based process technology to purify water by separating the dissolved solids from feed stream resulting in permeate and reject stream for a wide range of applications in domestic as well as industrial applications. It is seen from literature review that RO technology is used to remove dissolved solids, colour, organic contaminants, and nitrate from feed stream. Hence RO technology used in the treatment of water and hazardous waste, separation processes in the food, beverage and paper industry, as well as recovery of organic and inorganic materials from chemical processes as an alternative method . This paper intends to provide an overall vision of RO technology as an alternative method for treating wastewater in different Industrial applications. The present short review shows applicability of RO system for treating effluents from beverage industry, distillery spent wash, ground water treatment, recovery of phenol compounds, and reclamation of wastewater and sea water reverse osmosis (SWRO) treatment indicating efficiency and applicability of RO technology.

Keywords: Beverage Industry, Boiler Feed Water, Distillery Spent Wash, Recovery of Phenol Compounds, Reclamation of Wastewater, Sea Water Reverse Osmosis

1.0 Introduction:

Reverse Osmosis (RO) is a process that uses semi-permeable spiral wound membranes to separate and remove dissolved solids, organic, pyrogens, submicron colloidal matter, color, nitrate and bacteria from water. Feed water is delivered under pressure through the semi permeable membrane, where water permeates the minute pores of the membrane and is delivered as purified water called permeate water. Impurities in the water are concentrated in the reject stream and flushed to the drain is called reject water. These membranes are semi-permeable and reject the salt ions while letting the water molecules pass. The materials used for RO membranes are made of cellulose acetate, polyamides and other polymers. The membrane consists of hollow-fiber, spiral-wound used for treatment; depend on the feed water composition and the operation parameters of the plant. Reverse Osmosis (RO) is a membrane based process technology used for desalination. Membrane-based seawater desalination and wastewater reuse are widely considered as promising solutions to augment water supply and alleviate water scarcity (S. Lee *et al*., 2010). The most common membrane processes used are the reverse osmosis (RO) and the electro dialysis (ED) used for brackish water desalination, but only RO competes with distillation processes in seawater desalination (Kalogirou, 2005).

1.1 Scope of Reverse Osmosis:

The process has also been applied to treat municipal wastewater. Since conventional municipal treatment processes do not remove dissolved solids, but RO process is used for the removal of dissolved solids. RO is increasingly used as a separation technique in chemical and environmental engineering for the removal of organics and organic pollutants present in wastewater. It is seen from literature review that Reverse Osmosis (RO) processes have been widely used for separation and concentration (recovery) of solutes in many fields.

The use of RO in the treatment of various effluents of chemical (Bodalo-Santoyo *et al*.,2004; Bodalo-Santoyo *et al*., 2003), petrochemical, electrochemical, food, paper and tanning industries as well as in the treatment of municipal waste waters have been reported in the literature and were studied by many researcher (Schutte *et al*., 2003). Removal of organic contaminants by RO processes was first demonstrated by Chian *et al*. (1975). The presence of individual contaminants can cause problems, hence the removal of individual contaminants by RO has been studied by very few researchers (Murthy *et al*., 1999; Moresi *et al*., 2002; Arsuaga *et al*., 2006). Murthy and Choudhari (2008) studied the paper on "Treatment of Distillery Spent Wash where UF and RO membranes used for purification of the wastewater by removing the colour and the contaminants. A number of studies(Kimura *et al*.,2003; Bellona *et al*., 2004; Xu *et al*.,2005) have been reported on the application of RO for the removal of Organics such as endocrine disrupting chemicals, plastic additives, pesticides, pharmaceutically active compounds (PhaC's), benzene and toluene. Cellulose acetate and polyamide membrane has good salt rejection for inorganic salts like NaCl, $Na_2SO_4^-$. However, for organics, the rejection is reported to be lower and varies widely in the range of 0.3-0.96 (Pozderivic *et al*., 2006; Senthilmurugan and Gupta, (2006). RO process removes fluoride proportionately, if TDS is at tolerable level and fluoride content is high then one can use special alum-resin filter, works under gravitational force. (Krishnan S. *et al*., 2005).

1.2 Treatment options for Reverse Osmosis:

In India, distillery uses various forms of primary, secondary and tertiary treatments of wastewater. The units processes used are screening and equalization, followed by biomethanation. Ferti-irrigation and biocomposting with sugarcane pressmud are the most widely used options for effluent disposal *(Ramana et al.*, 2002).In case of grain based distillery the treatment given is by way of DWGS separation, incineration and biomethanation. The process streams that can be recycled are namely, thin slop and process condensate. The effluent generated after removal of the solids. Thin slop contain high TDS, high temperature and contain carbohydrates, organic acids, dead yeast cells etc. which may have an impact on the fermentation process. The process condensate from the evaporator has high temperature, low pH, organic acids etc. This can be treated by RO system and used in the process or for utility operations.

1.3 Reverse Osmosis Process Description:

The RO process is simple in design consisting of feed, permeate and reject stream. For feed water it is necessary to provide pretreatment in order to remove inorganic solids and suspended solid and using high pressure pump given feed through semi permeable membrane. Depending upon the permeate where it is used necessary post treatment is given. A schematic diagram of the RO process is shown figure 1.

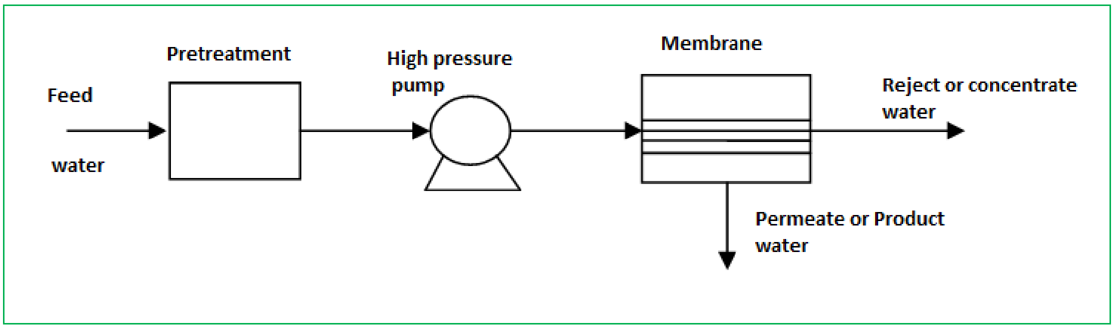

Figure1. Schematic Diagram of the RO Process

1.4 Reverse Osmosis Requisites:

An RO desalination plant essentially consists of four major systems: (a) Pretreatment system, (b) High-pressure pumps, (c) Membrane systems, and (d) Post-treatment. Pre-treatment system is provided to remove all suspended solids so that salt precipitation or microbial growth does not occur on the membranes. Pre-treatment may involve conventional methods like a chemical feed followed by coagulation/ flocculation/sedimentation, and sand filtration or membrane processes i.e micro filtration (MF) and ultra filtration (UF). High-pressure pumps supply the pressure needed to enable the water to pass through the membrane and have the salt rejected. The pressure ranges from 17 to 27 bar for brackish water, and from 52 to 69 bar for seawater. Membrane systems consist of a pressure vessel and a semi-permeable membrane inside that permits the feed water to pass through it. RO membranes for desalination generally come in two types: Spiral wound and Hollow fiber. Depending upon water quality of permeate and use of permeate; post treatment may consists of adjusting the pH and disinfection (Djebedjian *et al*, 2006).

1.5 Membrane Characteristics:

The membrane should be inexpensive, have longer and stable life. Membrane should be easily manufactured with good salt rejection i.e. slightly permeable to salt. They should have high water flux i.e highly permeable to water and less susceptible to fouling. They should permit the flow of large amounts of water through the membrane relative to the volume they occupy. The membrane should chemically, physically and thermally stable in saline waters. They need to be strong enough to withstand high pressures and variable feed water quality.

1.6 Advantages of RO Process:

Following are the advantages of the RO process that make it attractive for dilute aqueous wastewater treatment include:

(1) RO systems are simple to design and operate, have low maintenance requirements, and are modular in nature, making expansion of the systems easy;

(2) Both inorganic and organic pollutants can be removed simultaneously by RO membrane processes;

(3) RO systems allow recovery/recycle of waste process streams with no effect on the material being recovered;

(4) RO systems require less energy as compared to other technology; and

(5) RO processes can considerably reduce the volume of waste streams so that these can be treated more efficiently and cost effectively by other processes such as incineration (Cartwright, 1985; Sinisgalli and McNutt, 1986; Cartwright, 1990; McCray *et al*., 1990; Cartwright, 1991; Williams *et al*., 1992).

(6) The RO plant is normally operated at ambient temperature which reduces the scale formation and corrosion problems, because of antiscalent and biodispersent use, which will reduce maintenance cost.

(7) The modular structure of the RO process increases flexibility in building desalination plants within a wide range of capacities.

(8) The specific energy requirement is significantly low 3- 9.4 kW h/m^3 product.

(9) The process is electrically driven hence it is readily adaptable to powering by solar panels.

In addition, RO systems can replace or be used in conjunction with others treatment processes such as oxidation, adsorption, stripping, or biological treatment (as well as many others) to produce high quality product water that can be reused or discharged.

2.0 Applications of Reverse Osmosis:

This technology has advantage of a membrane based process where concentration and separation is achieved without a change of state and without use of chemicals or thermal energy, thus making the process energy efficient and ideally suited for recovery applications. The bibliographic review shows applicability of RO system for treating effluents from beverage industry, distillery spent wash, ground water treatment, recovery of phenol compounds, and reclamation of wastewater and sea water reverse osmosis (SWRO) treatment indicating efficiency and applicability of RO technology.

2.1 Distillery Spent Wash:

The spent wash in distillery is acidic having pH 3.94 -4.30, dark brown liquid with high BOD 45000–100000 mg/ l and COD 90000 – 210000 mg/ l, and emits obnoxious odour but do not contain toxic substances, when discharged in water streams gives immediate discoloration and depletion of dissolved oxygen , posing serious threat to the aquatic flora and fauna (Mane *et al*., 2006). Membrane based separation processes like ultra filtration (UF), nano filtration (NF), reverse osmosis (RO) and membrane bioreactor (MBR) have been applied for treating distillery effluent (Nataraj *et al*., 2006; Couallier *et al*., 2006; Zhang *et al*., Murthy And Chaudhari;2006). Murthy and Choudhari (2008) studied the paper on “Treatment of Distillery Spent Wash where UF and RO membranes on pilot plant uses thin film composite membrane for purification of the wastewater for removal of colour and the contaminants. The result obtained which indicate suitability of RO for reducing freshwater consumption by recycling water which will minimize the waste disposal costs and reduction in regulatory pressure. The pilot plant gives removal of Total

Dissolved Solids (TDS), Chemical Oxygen Demand (COD), Biochemical Oxygen Demand (BOD), sulphate and potassium with the rejection efficiency of 97.9%, 96.8%, 97.9%, 99.7% and 94.65%, respectively. The above results were obtained for feed flow of 15 lit/min and feed pressure of 20 atm. They found TDS in permeate water less than 1000 ppm and COD 500 ppm i.e. within limits as per the guidelines of the World Health Organization(WHO) and the Central Pollution Control Board (CPCB) of India.

2.2 Ground Water Treatment:

Belkacem *et al*. (2006), studied ground water treatment in which two stage RO module was used in the beverage industry. The results of the physico-chemical analysis showed that the raw water taken from the groundwater contained significant amounts of solutes and suspended solids (TDS ranging from 757 mg/l to 964 mg/l). The Feed water composition shows that the raw water was rich in sulphate, chloride and calcium and highly furring. The quality of water produced from the pre-treatment demonstrates that turbidity underwent the strongest reduction 87% i.e. reduced from 1.3 NTU to 0.167 NTU. The rejection rate varied between 97% and 98% and remained stable during the RO operation which signified that the permeate quality was constant with total conductivity decreased from 1070 µs/cm to 33 µs/cm with larger rejection of 95 % ions. The bacteria removal efficiency of microorganisms decreased from 90 UFC/100 ml to 50 UFC/100 ml, which represents a total elimination of 44%. However, the rejection of nitrate was lowest i.e about 88.18%. Hence the obtained results showed applicability of RO for the ground water treatment.

2.3 Recovery of Phenol Compounds:

Kurihara *et al*. (1981) uses Toray composite membrane PEC-1000 (polyfuran) and found several organic rejections with 97% for acetone and 99% for phenol. Koyama *et al*. (1982) and Koyama *et al*. (1984) reported separation results for several polar organic solutes (alcohols, phenols, carboxylic acids, amines, and ketones) and various phenolic derivatives for a composite membrane. They found that the main factors affecting rejection included molecular weight, molecular branching, polarity, and degree of dissociation for ionizable compounds.

Bhattacharyya *et al*. (1987) and Bhattacharyya and Madadi (1988) investigated rejection and flux characteristics of FT30 membranes for separating various pollutants (PAHs, chloro phenols, nitro phenols) and found membrane rejections were more than (>98%) for the organics under ionized conditions. They also found substantial water flux decline occurred even for dilute (< 50 mg/L) solutions of non ionized organics and observed significant organic adsorption on the membrane in some cases. Pusch *et al*. (1989) reported separation results for several different membranes (four composite and two asymmetric) for a variety of single and multi component organic solutions, including many organic pollutants. Rejections varied from only 25% up to >99% depending on the solute, but generally the composite membrane rejections were higher.

Srinivasan *et al*. (2010), conducted experiments for the recovery of phenol compounds on a laboratory scale on spiral wound polyamide RO module and parameter were studied. The Perma-TFC polyamide RO membrane in Spiral wound configuration (supplied by Permionics, Vadodara, India) were used in their study. It was found that the value of rejection increases with the increasing applied pressure. The maximum rejection obtained is around 90% for phenol.

2.4 Reclamation of wastewater:

The wastewaters contain organic contaminants, including pharmaceutical compounds, pathogens, disinfection by-products, and pesticides. They are less affected by biological degradation by bacteria in activated sludge process. Due to their water solubility, they are dissolved in water and not being removed in the sludge which will create problem to the safety of reclaimed water. Thus, use of RO process for separation is a key step in the safe recovery of water from wastewater source .The recent use of RO in reclamation of wastewater is done in GWR facility in Orange County for indirect potable use. It is used to produce 280,000 m^3/d of treated wastewater that is used to augment the groundwater in the region that supplies local municipalities with drinking water. (Franks 2004). RO plays an integral role in the advanced treatment process used at this plant. In this plant, low pressure, high rejection ESPA2 membranes are used to make RO permeate with less than 50 mg/l TDS which will make reclaimed water safe for potential potable reuse.

2.5 Seawater Reverse:

In SWRO (Sea water Reverse osmosis) unit, the operating conditions and performance of the HFF SWRO unit which received the NF product as feed. The SWRO unit consists of two vessel units, which are connected in series. During the test period, the operating pressure was maintained at 60 Kg/cm^2 and the temperature ranged from 23 to 34 ^oC. The average permeates recovery of the first and second vessels were around 30 and 21 percent respectively and the overall recovery of the integrated SWRO system was about 45%. Chemical analysis revealed that the majority of the hardness ions and other dissolved salts were concentrated in the brine reject. The study revealed that an increase of top Brine Temperature from 100^0C to 130 ^oC produces 48% increase in water production. (Hamed, 2005).

3.0 Conclusion:

Feed Water containing suspended particles, organic matter as well as inorganic salt may deposit on the membrane and fouling will occur or damage the membrane because of applied pressure and size of particles. Therefore the priority to remove these by way of pretreatment will determine the RO efficiency. Hence RO membrane performance can be checked to avoid the irreversible damages to the RO membrane. In fact success of RO system depends upon efficiency of the pre treatment. Post treatment of brine streams present a major problem with growing desalination capacity to minimize the damage on the ecology which depends upon the location of plant.

4.0 Future Scope:

Use of pre-heated feed water, operation at low pressure, advanced feed water pre-treatment, advanced energy recovery systems, site specific optimization and automatic real time plant management systems are the possible area where R&D is required with development of membrane material to sustain maximum temperature which will increase the productivity of plant thereby reduction of cost of treatment.

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