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Effect of change in trans-membrane pressure differences on the efficiency of a thin film reverse osmosis membrane.

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Abstract: A spiral wound thin film composite reverse osmosis membrane was tested for its efficiency for the removal of certain water contaminants and its efficiency in terms of permeate generation. The experiment was performed using solutions of known concentrations of the contaminants at two trans membrane pressure differences. The synthetic solution concentrations used exceeded the permissible limits i.e., 100ppm of nitrate, 10ppm of fluoride, 1000ppm of chloride, 30ppm of iron, 25ppm of chromium, 5ppm of cadmium, and 25ppm of copper. The efficiency of membrane towards the removal of different contaminant from the feed solutions ranged from 88.8 to 99.8%. The contaminant concentrations in permeate were well below the standard limits for drinking water. The efficiency of permeate generation was low. However the efficiency of permeate generation increased at higher trans membrane pressure difference with no decline in removal efficiency of the contaminants, rather it improved. The type of the contaminants did not have a significant difference on the permeate recovery.

Keywords: Reverse osmosis, percentage removal, percentage recovery, fluoride, nitrate, cupper, iron, chloride, cadmium.

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I. INTRODUCTION

Contamination of drinking water may occur due to various sources like physical (sediment or organic material suspended in the water of lakes, rivers and streams from soil erosion). Other sources of of contamination are industrial discharge into river and canal, settling from the atmosphere, runoff from agricultural fields and urban area (Sorlini, et al., 2013). The quality of water is of vital concern for the mankind since it is directly linked with human welfare (Nagamani, 2015). The Joint Monitoring Programme (JMP) for Water Supply and Sanitation, implemented by the World Health Organisation (WHO) and UNICEF, reports that 783 million people in the world (11% of the total population) have no access to safe water, 84% of whom live in rural areas (WHO, 2012). Ground water is also contaminated due to percolation from municipal dumpsite, industrial discharge, agricultural waste, and naturally due to regional geology and geochemical process, landuse patterns (Liu et al., 2008; Saleem et al., 2016). Hence, the availability of potable water, apart from the above pathogenic contamination standards natural water which is fit for drinking is rarely available under the present scenario leading to deleterious health effects on both human and animals (Edokpayi et al., 2018; Ozden et al., 2018; Li et al., 2018). Some of them are discussed in Table-1. Pathogens can be killed by various disinfection methods and larger suspended matter can be filtered. However the inorganic and organic soluble components are hard to remove. There are different types of membrane filteration such as ultrafilteration, nanofilteration and reverse osmosis (Kurniawan et al., 2006; Barakat, 2011; Sung and Berrin, 2015). Membrane separation has been increasingly used recently for the treatment of inorganic effluent due to its convenient operation. Reverse osmosis (RO) is a pressure driven process similar to conventional filtration processes but using a much tighter filter or membrane. Reverse osmosis (RO) involves separating water from a solution of dissolved solids by forcing water through a semipermeable membrane (Sourirajan, 1970; Patrick, 1976; Fazilet, 2000; Nes et al., 2008). In the present study a commercial grade reserve osmosis membrane has been tested to determine its efficiency for removal of nitrate, Fluoride, Chloride, Iron, Chromium, Cadmium, and Copper from synthetic solutions.

Table 1: Standards (Bureau of Indian Standards (BIS) 1050 (2012)) and human health impact of selected water pollutants

Parameter	Limit (mg/l)	Permissible limit in absence of alternate source (mg/l)	Human health impact
Nitrate	45	No relaxation	• Methemoglobinemia in infant (Brender et al., 2013). • Cancer risk (Mirvish 1983, Forman and Al-Dabbagh., 1985). • Disruption of thyroid function (Ward et al., 2010). • Birth defect (Dorsch 1984; Knox, 1972; Super, 1981; Manassaram et al., 2006;Gupta, 2017)
Fluoride	1	1.5	• Crippling skeletal disease. • Severe dental flourosis. • Joint pain. • Osteoarthritis.
Chloride	250	1000	• Bladder and Rectal cancer
Iron	0.3	No relaxation	• Herediatry hemochromatosis (Pietrangelo, 2010). • Iron poisoning (Raynolds, and Klein, 1985; Chang and Rangan, 2011). • African iron overload (Gordevk, 2002).
Chromium	0.05	0.05	• Cr (VI) compounds which are powerful oxidizing agent which is more toxic than Cr (III) compounds. • Asthma, Chronic pharyngitis, congestion and hyperemia, traheobronchitis, lung cancer, nasal and Sinus cancer (ASTDR 2000). • Acute tubular necrosis and acute renal failure (Sharma Singhal et al, 1978). • Hepoctomegaly (Michie, Hayhurst et al., 1991); Meert, et al., 1994). • Hepatic failure (Loubieres, de Lassence et al., 1999; Stiff, Friedle et al., 2000).
Cadmium	0.003	No relaxation	• Lung disease (Mannino et al. 2004). • Itai-Itai disease (Ezaki et al., 2003; Kobayashi et al., 2006). • International Agency for Research on Cancer (IARC) classifies cadmium as a known human carcinogen.
Copper	0.05	1.5	• Gastrointestinal diseases. • Long term effect- Wilson diseases and other metabolic disorders of copper homeostasis.

II. MATERIAL AND METHODS

The Schematic diagram of the assembly of components used in the experimental setups is given in Figure 1.

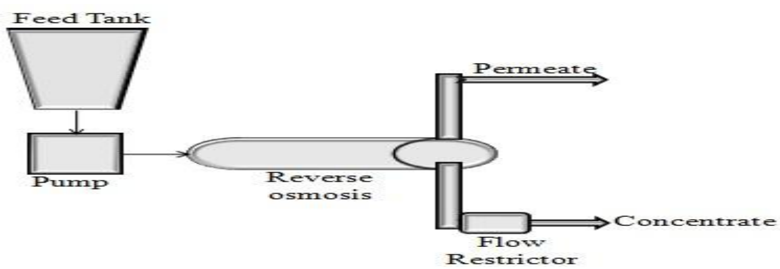

Figure-1. Schematic diagram of reverse osmosis.

1. Membrane- Spiral-wound thin film composite reverse osmosis membrane of 80 Gallons/Day (GPD) .Commercially available membrane of Vontron make was used.
2. Pump- Reverse osmosis rotary booster pump. Hi-Tech make model PL-GY-100A with the following specifications- operating pressure 70PSI, Working flow 100 ml/min.
3. Power supply 24 Volt DC, Working current with 1.2 A.
4. Flow Restrictor (FR)-Two restrictor No.500 (500 ml/min) and No.300 (300 ml/min) were used to create two pressure differences in the membrane.

Synthetic solution of known concentrations of the elements using different salts were made i.e 100 ppm of nitrate, 10 ppm of Fluoride and 1000 ppm of Chloride solution were made by salt using Potassium nitrate, Sodium fluoride, and potassium chloride respectively, 30 ppm of Iron, 25 ppm of Chromium and 5 ppm of Cadmium solution were made from 1000 ppm of stock solution from Hi-media respectively. These solutions were pumped into the RO membrane at high pressure. Pressure difference in RO membrane is created using a restrictor installed in line at the concentrate output. Two type of constrictors of different flow rate were used to create two pressure differences in the membrane. Restrictor No. 300 produced more pressure than restrictor No. 500. Permeate and concentrates were collected from respective outlets, measured and analyzed for qualification of the contaminants.

Contaminants removal percentage - The percent removal (Equation 1) describes the quantity of heavy metals removed from the reverse osmosis feed water stream as a percentage (Aljendeel, 2011).

$$R_p = \frac{\alpha - \beta}{\alpha} \times 100 \qquad (1)$$

Where: R_p = Percentage in Removal. α = Concentration in feed water. β = Concentration in permeate.
Permeate recovery percentage - The recovery is the amount of water permeated produced per unit feed water. The design recovery is calculated as given in equation 2-

$$\text{Percentage Recovery} = \frac{Ff - Cf}{Ff} \times 100 \qquad (2)$$

Where : Ff = Feed flow (ml), Cf = Concentrate flow (ml).

III. RESULT

For nitrate the quantity of contaminant in permeate was 8.1 ppm, for 500 flow restrictor (FR) and 7.6 ppm for 300 FR. The percentage removal is higher in 300 FR as compared to 500 FR which were 92.48% and 91.99% respectively. The same trend was observed in case of other contaminants. In case of fluoride, the permeate values for 500FR and 300FR were collected 1.15 ppm and 1.06 ppm . Percentage removal for 300 RP was 89.81% whereas, in case of 500 FR it was 88.85%. For chloride there was 95.59% removal for 300 FR and 95.1% removal for 500 FR from 1001 ppm synthetic solution of chloride. In case of Iron from 30.21 ppm synthetic solution of iron, 300 FR have more removal efficiency with percent removal of 95.59% whereas, for 500 FR it was 95.1%. Cadmium and copper also follows the same trend as discussed above, the percent removal for 500 and 300 FR for cadmium and copper were 99.44%, 99.95%, 99.08%, and 99.14% respectively. For chromium there was no significance difference in removal efficiency of the restrictors. In 500 FR permeate concentration of chromium was 0.05 ppm and for 300 FR it was 0.046 ppm. Due to little difference the percentage removal for both FR were 99.8%. According to result presented in Table-2 the percentage removal was significantly high and it increased further with the increasing transmembrane pressure. The range of percentage removal of contaminants ranged from 68.55 to 99.8 for 500 FR and 71.27 to 99.8% for 300 FR.

Table 2: Percentage removal of contaminant through Reverse osmosis unit.

S.No	Parameters	Feed water (ppm)	Permeate (ppm)		Concentrate (ppm)		% removal	
			500*	300**	500*	300**	500	300
1	Nitrate (100ppm)	100.7	8.1±0.4	7.6±0.2	91.3±0.5	96.9±0.1	91.9	92.5
2	Fluoride (10ppm)	10.4	1.2±0.7	1.1±0.6	8.8±0.8	9.6±0.5	88.9	89.8
3	Chloride (1000 ppm)	1001	49.0±0.8	44.2±0.1	936.1±07	956.9±0.5	95.1	95.6
4	Iron (30ppm)	30.2	9.5±0.1	8.7±0.1	17.6±0.4	21.5±0.6	68.6	71.3
5	Chromium (25ppm)	25.2	0.05±0.1	0.05±0.2	23.8±0.4	25.1±0.7	99.8	99.8
6	Cadmium (5ppm)	5.4	0.03±0.1	0.03±0.6	3.4±0.8	5.4±0.7	99.4	99.9

7	Copper (25 ppm)	24.9	0.23±0.2	0.21±0.5	22.3±0.4	24.7±0.5	99.1	99.1

*flow restrictor in 500 ml/min; ** flow restrictor in 300 ml/min.

The quantity of permeate recovery is also important, shown in Table-3 is the percentage recovery for 500 FR ranged between 32.2%-36.28% whereas, for 300FR it was better 34.8%-39.9%. Percentage recovery for nitrate for 500 FR and 300 FR is 33.8% and 37.2%., the corresponding values for fluoride was 36.2% and 39.9%, for chloride was 32.4% and 35.6%, for Iron was 34% and 37.7%, for chromium was 34% and 36.9%, for cadmium was 32.2% and 34.8% and for copper was 32.4% and 35.8%. The percentage recovery of the permeate was more at higher trans membrane pressure difference with no decline in removal efficiency of the contaminants, rather it improved. The type of the contaminants did not have a significant difference on the permeate recovery.

Table 3: Percentage recovery of contaminant through Reverse osmosis unit.

S.No	Parameters	Feed water (ml)	Permeate (ml)		Concentrate (ml)		% recovery	
			500	300	500	300	500	300
1	Nitrate (100ppm)	680±2.0	230±2.0	253±3.0	450±7.0	427±2.0	33.8	37.2
2	Fluoride (10ppm)	705±5.00	255±3.0	281±2.0	450±8.0	424±3.0	36.2	39.9
3	Chloride (1000 ppm)	725±7.0	235±6.0	258±9.0	490±5.0	467±8.0	32.4	35.6
4	Iron (30ppm)	705±4.0	240±5.0	266±4.0	465±4.0	439±3.0	34	37.7
5	Chromium (25ppm)	735±3.0	250±4.0	271±9.0	485±3.0	464±2.0	34	36.9
6	Cadmium (5ppm)	730±3.0	235±7.0	254±5.0	495±5.0	476±4.0	32.2	34.8
7	Copper (25 ppm)	695±8.0	225±9.0	249±8.0	470±5.0	446±5.0	32.4	35.8

IV. DISCUSSION

The contaminant removal efficiency was high reaching upto 99.8% for chromium .This efficiency increased with transmembrane pressure difference. The amount of the contaminants persisting in the permeate was less than the quantity prescribed in the standards given by BIS for drinking water. The efficiency of permeate recovery was poor. However, the concentrate produced can be put to other non-dietary used and the efficiency of recovery can be increased by increasing the pressure difference within the reverse osmosis membrane. Similar results has been reported by Bakalar, et al., 2009; Sudilovskiy, et al., 2008; Barakat, 2011; Aljendeel, 2011; liu et al., 2008.

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