An Eco-Friendly Approach to Purify Reject Water from a Reverse Osmosis Treatment Plant

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Abstract
Purifying wastewater rejected from the Reverse Osmosis (RO) treatment plants is one of the challenges faced by industries. Wastewater consists of potential contaminants rejected from the RO treatment, referred as RO reject water. The study focuses phytoremediation technology where aquatic plants are used to absorb contaminants in RO reject water. The water hyacinth (Eichorrnia crassipes) and water lettuce (Pistia stratiotes) were selected as floating aquatic plants. Change in water quality before and after being exposed to plants and phytoaccumulation capacity of plants after eight weeks were investigated in the study. Contaminants of RO reject water were successfully removed by aquatic plants only within first four weeks (phase I). A higher reduction in concentration of total hardness, calcium hardness, alkalinity and ions was identified in the treatment tanks compared to control, filled with RO product. The removal of ions decreased with time within phase I, except for chloride and calcium hardness. Although the removal of total hardness, chloride, iron, magnesium, potassium and sodium in RO reject water was significantly ($p < 0.5$) greater in treatment tanks after first two weeks, only total hardness, alkalinity, iron and sulphate removal were significantly ($p < 0.5$) higher with time within phase I. Both aquatic plants accumulated ions in biomass especially with a higher accumulation for magnesium, sodium and potassium. Therefore, the proposed water treatment system can be used to treat RO reject water, with regular harvesting of plants and new replacement at every four weeks to maintain the effectiveness of phytoremediation process.

Keywords: *Reverse Osmosis, RO reject water, Phytoremediation, Phytoaccumulation capacity, Floating aquatic plants*

1. Introduction

Reverse Osmosis (RO) treatment plants purify water by filtrating and separating suspended solids, particle organic matter, microorganisms and dissolved ions passing through a membrane. Often, ground water is pumped as feed water into RO treatment plants to obtain good quality product water and the wastewater that contains almost all of the dissolved contaminants is referred to as RO reject water (Chourasia *et al*., 2015).

Good quality potable water, which is in accordance with the World Health Organization (WHO) drinking water quality standards, is essential for food manufacturing industries. The study is focused on one of the dairy industries in Sri Lanka which uses bore well water to supply large quantity of water for its process of manufacturing after desalination by the RO treatment. RO reject water cannot be directly discharged into surface water bodies as it may contain harmful contaminants that degrade the water quality of the environment.

As many research studies have focused on identifying appropriate methods to clean RO reject water using advanced techniques (Chourasia *et al*., 2009), a simpler method through phyto-remediation was investigated in this study. The specific objectives of the study were to determine the change in chemical parameters of RO reject water before and after being exposed to floating aquatic plants and to detect the phytoaccumulation capacity of aquatic plant bodies when exposed to contaminants. Phytoremediation is a relatively recent technology used in the treatment of wastewater using plants which are capable of absorbing environmental contaminants such as trace elements, organic compounds and inorganic ions. The phytoremediation treatment technology is an efficient, environment friendly, simple, in-situ applicable, aesthetically pleasing approach and cost-effective, hence suitable for many developing countries (Ghosh & Singh, 2005).

2. Materials and Methods

2.1. Experimental Design

Cylindrical five hundred liter, Polyvinyl Chloride (PVC) treatment tanks were used in duplicate to grow aquatic plants, E. *crassipes* and *P. stratiotes* in 2:1 ratio (fresh weight). A control was maintained using a similar PVC tank filled with tap water (RO product) in same ratio. Six hundred grams of *E. crassipes* and three hundred grams of *P. stratiotes* were maintained in each tank throughout the experiment. The treatment tanks were filled with RO reject water up to the volume of three hundred and fifty liters and the control also was filled up to the same volume with tap water which is the purified water released from the RO treatment plant. Water in control and both treatment tanks were tested for water quality parameters before initiation of the experiment. The water level was marked on the side of each tank. In treatment tanks, one liter of water was set to pass through the tank every hour through an inlet by adjusting the flow rate using flow meters and the rate of outflow was approximately the same as inlets.

In order to get ground information, before introducing into the treatment system, feed water for the RO treatment plant was tested for twenty seven parameters to identify the level of existing ions. This helped the research to identify the possible contaminants of RO reject water. In addition, RO reject water was also tested to determine physicochemical parameters, existing ions and their concentrations for selection of plant species suitable for phytoremediation. Water sampling was carried out biweekly for two months (eight weeks) and samples were taken from both inlet and outlet of the treatment and control tanks in two phases, phase I - first four weeks when plants were healthy and phase II – five to eight weeks when chlorosis and necrosis of plant leaves were noticed. The aquatic plants were visually examined for changes in their shoot and root lengths. Also, any increase in leaf sizes and production of daughter plants were observed.

2.2. Analysis of Water Quality

The pH [Mettler Toledo Seven Plus compact pH meter], electrical conductivity (EC) [Thermo Scientific Orion four star conductivity meter] and Total Dissolved Solids (TDS) [Thermo Scientific Orion four star conductivity meter] of water samples were measured.

Physical and chemical characteristics of tap water in control and RO reject water in treatment tanks at the time of filling were tested initially. Water samples from inlet and outlet of tanks with exposure to plants were tested for ten chemical parameters. Chloride, calcium hardness, total hardness, alkalinity, iron and sulphate concentrations were tested according to the Operator's Manua of Palintest Automatic Wavelength selection Photometer (7100). Concentrations of nitrate, magnesium, potassium and sodium were determined using the standard procedures (Clesceri *et al*., 2012). The mean concentration and standard error of each characteristic of water were calculated for replicates of RO reject water outlets in phase I. The removals of components of water were calculated by subtracting outlet concentration from the concentration of inlets. Average percentage removal efficiencies of components of water were calculated.

2.3. Chemical Analysis of Dried Plant Matter

Before exposing and after the treatment, five plants from treatment and control were dried at 105ºC for 2 hours until constant weight was obtained and dry weight was obtained.

The plant tissues were analyzed for calcium, magnesium, sodium, potassium and total nitrogen contents in plant biomass using standard methods (Association of Analytical Communities International, 2012). The percentage of magnesium, sodium and magnesium was determined by the technique of inductively coupled plasma optical emission spectroscopy (ICP-OES) using inductively coupled plasma optical emission spectrophotometer (Varian720-ES). The calculation of Bio Concentration Factor (BCF) for each element separately for each plant type in control and treatment tanks was done using the following equation;

$$BCF = \frac{Metal\ in\ plant\ biomass\ (mgkg^{-1})}{Metal\ in\ solution\ (mgl^{-1})}$$

2.4. Statistical Analysis

One sample t-test was used to detect the significant differences in removal of each component of water in treatment tanks with control after 2 and 4 weeks from the commencement of experiment in phase I ($p < 0.5$).

3. Results and Discussion

The brackish groundwater which was used as feed water source to the RO treatment plant in this particular dairy industry had a higher concentration of total hardness, dissolved cations and anions, but not heavy metals. Magnesium, calcium, potassium, sodium, iron and manganese were identified as main dissolved ions in feed water, which could pass to the RO reject water. Common anions such as chloride, nitrate and sulphate were also available in feed water.

Common cations such as calcium, magnesium, potassium, sodium and common anions chloride, sulphate and nitrate were found in RO reject water. As shown by magnesium and calcium carbonate concentrations, total hardness was higher in RO reject water compared to feed water. Alkalinity was greater in RO reject water compared to feed water as a result of dissolved ions in the form of bases. The higher TDS was indicated by the higher electrical conductivity of RO reject water. RO reject water was with higher concentration of all tested water quality parameters compared to control.

According to the results, electrical conductivity was 20 times higher in RO reject water (2 g/l) compared to control (102 mg/l) possibly due to concentrated salts and contaminants dissolved in RO reject water.

The both aquatic plants revealed their phytoremediation potential in first four weeks (phase I). It is described that *E. crassipes* can phytoremediate metals such as calcium, magnesium, iron and potassium (Zhu *et al*., 1999). Furthermore, they have the capacity to absorb nitrogen and sodium from water (Sooknah & Wilkie, 2004). *P. stratiotes* has been well studied for the nitrogen removal from water (Aoi & Hayashi, 1996). Total hardness decreased compared to other tested chemical parameters in treatment tanks. A higher decrease of calcium hardness, total hardness, alkalinity, iron, sulphate, magnesium, potassium and sodium except chloride and nitrate-nitrogen was detected in treatment tanks than that of control during the first four weeks of treatment.

The removal of ions decreased with time within phase I, except for chloride and calcium hardness in treatment tanks. As stated by Maine *et al*., (2004), the greater the initial concentration, the greater the rate of bioaccumulation.Therefore, treatment tanks may have showed a higher removal of components in water than that of the control in all tested parameters except for chloride and nitrate-nitrogen in phase I.

Although the removal of total hardness, chloride, magnesium, potassium and sodium ions in RO reject water was significantly ($p<0.5$) greater in treatment tanks after first two weeks with exposure to plants, only total hardness, alkalinity, iron and sulphate removal was significantly ($p<0.5$) higher in treatment tanks compared to control with the period of exposure to plants within phase I (Table 1 & 2).

Table 1: Removal of components of water after first two weeks of treatment by aquatic plants

Time of analysis	**Component (mg/l)**	**RO product (control)**	**RO reject water**		
			Tank1	**Tank2**	**Average tank (Mean ±S.E)**
After two weeks of Commencement of experiment (phase I)	Chloride	9.9	4	2	3 ± 1.0*(0.046)
	Calcium hardness	0.09	33	84	58.5 ± 25.5
	Total hardness	10	200	260	230± 30*(0.043)
	Alkalinity	0	15	25	20 ± 5.0
	Iron	0.1	0.37	0.43	0.4± 0.03*(0.032)
	Sulphate	4	27	40	33.5 ± 6.5
	Nitrate	4.4	2.2	1.1	1.65 ± 0.55
	Magnesium	7.34	42	44	43± 1.0*(0.009)
	Potassium	2.79	6	6	6± 0.001*(0.001)
	Sodium	30.3	151	160	155.5± 4.5*(0.012)

Data on average tank represents mean ± S.E.
Single asterisk (*) represents significantly different values at sig 1-tailed < 0.05, n=2.
Sig1-tailed value is indicated within parenthesis in case of 5% level of significance

Table 2: Removal of components of water after first four weeks of treatment by aquatic plants

Time of analysis	**Component (mg/l)**	**RO product (control)**	**RO reject water (Treatment)**		
			Tank 1	**Tank 2**	**Average tank (Mean ±S.E)**
After four weeks of Commencement of experiment (phase I)	Chloride	9.9	4	7	5.5 ± 1.5
	Calcium hardness	0.05	153	97	125 ± 28
	Total hardness	5	200	250	225 ± 25*(0.036)
	Alkalinity	1	70	65	67.5 ± 2.5*(0.012)
	Iron	0.09	0.26	0.25	0.255 ± 0.005*(0.010)
	Sulphate	0	20	22	21 ± 1.0*(0.015)
	Nitrate	1.8	1	0.68	0.84 ± 0.16
	Magnesium	0.01	16	11	13.5 ± 2.5
	Potassium	0.67	1	2	1.5 ± 0.5
	Sodium	4.5	51	70	60.5 ± 9.5

Data on average tank represents mean ± S.E.
Single asterisk (*) represents significantly different values at sig 1-tailed < 0.05

As stated by Carvalho and Martin (2001), the removal efficiency of metals greatly depends on the concentration of such metals in solution and the higher the metal concentration in solution, the lower the removal efficiency. Therefore, even though the removal was higher for the tested parameters except alkalinity when treated with RO reject water in phase I, the removal efficiency of each tested parameter wasless for treatment tanks compared to control. At the end of the first two weeks of treatment, removal efficiency was 85.1%, 57.33%, 50.49% and 46% for iron, magnesium, sodium and total hardness respectively.

Phytoremediation potential of plants was not observed in second four weeks of treatment according to the results. It is clear that the growth characteristics of both plants were more sensitive and severely affected by high concentrations of ions in RO reject water with increasing the time period. The surpassing of the ability of tolerance by aquatic plants may have released the stored elements to tanks by necrosis in addition to the ions in water.

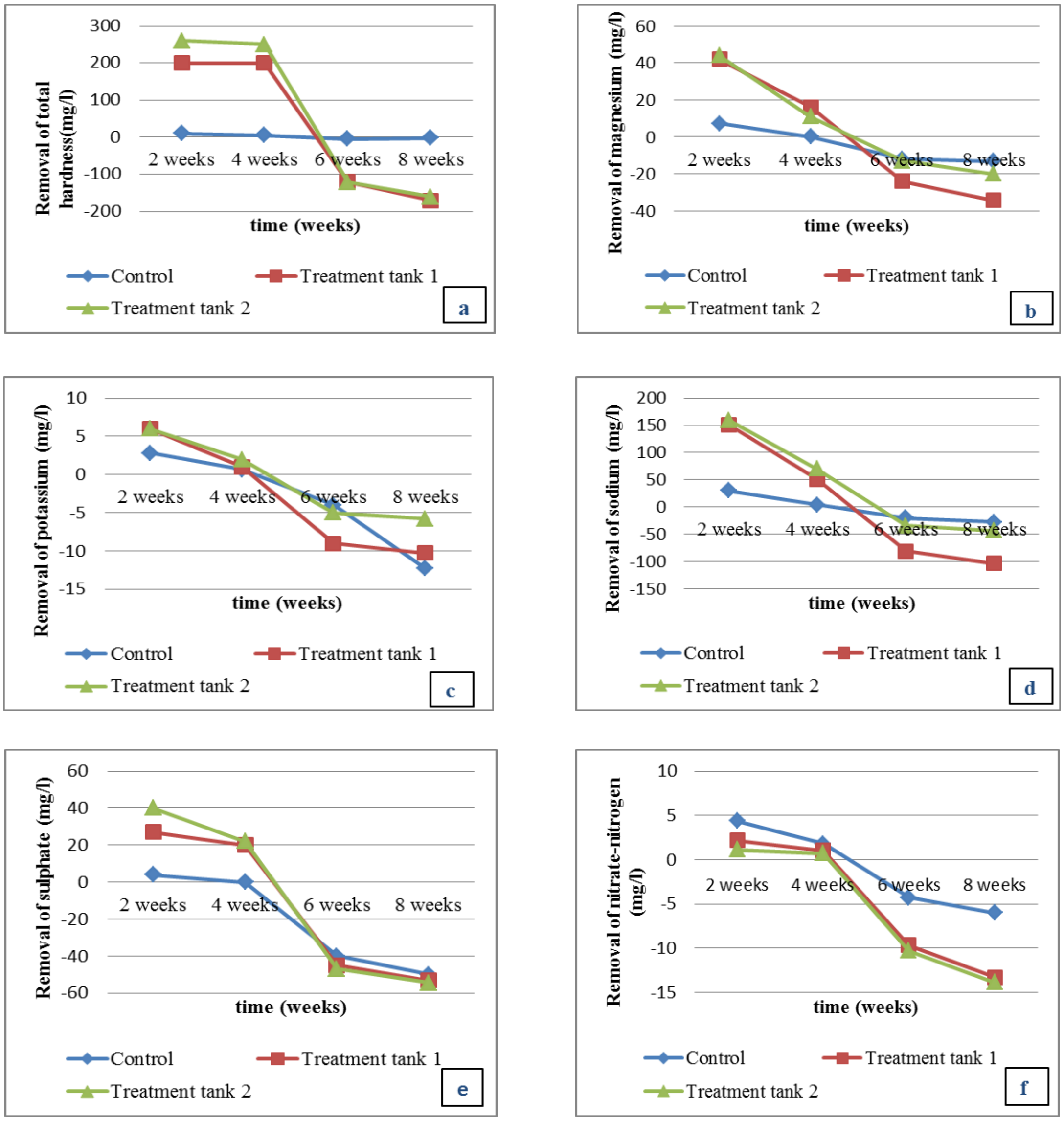

Figure 1: Changes in removal of components of water in the proposed treatment system containing floating aquatic plants with time; (a) Total hardness, (b) Magnesium, (c) Potassium, (d) Sodium, (e) Sulphate, (f) Nitrate-nitrogen

The symptoms of stress on plants were observed within phase II after exposing to treatment. Growth of aquatic plants in treatment tanks was retarded and a significant chlorosis and at the end of four weeks (Fig. 3). However, the plants within the control did not show a significant chlorosis or necrosis compared with the treatment tanks (Fig. 2)

Figure 2: Aquatic plants after eight weeks of treatment in control

Figure 3: Aquatic plants after eight weeks of treatment with RO reject water

Both aquatic plants showed the capacity to accumulate ions in their biomass. The highest accumulation of ions per plant biomass was observed for calcium in aquatic plants treated with RO reject water. The amount of ion accumulation increases within plants with the concentration of dissolved ions in water used for treatment (Borker *et al*., 2013). They showed the capacity for higher accumulation of ions only for magnesium, sodium and potassium among tested parameters when treated with RO reject water compared to control.

After eight weeks of RO reject water exposure, dry tissues of *P. stratiotes* showed $11x10^3$ $mgkg^{-1}$ of maximum magnesium accumulation in treatment tanks filled with RO reject water compared to *E. crassipes*. The highest sodium accumulation ($14x10^3$ $mgkg^{-1}$) was by *E. crassipes* compared to *P. stratiotes* when it was treated with RO reject water. Potassium accumulation was maximum ($16x10^3$ $mgkg^{-1}$) by *P. stratiotes* in comparison with *E. crassipes* in treatment tanks, while the minimum was demonstrated by *E. crassipes* in control.

The use of Bio Concentration Factor (BCF) is more important compared to the amount of metallic ion accumulated in plants because it provides an index of the ability of the plants to accumulate ions with respect to the concentration of ion in water and as this value is calculated on a weight basis (Borker, *et al*., 2013).

According to Rivelli *et al*., (2012), larger BCF indicates better phytoaccumulation capacity and tissues with BCF greater than 1,000 are considered high, and less than 250 as low, with those between classified as moderate.

The BCF value for magnesium and potassium were detected to be at level moderate for *Pistia stratiotes* grown in tanks filled with RO reject water after 8 weeks. A moderate potassium BCF was detected for *E. crassipes* and sodium BCF value for both types of plants was low in treatment tanks at the 8 weeks of growth. *P. stratiotes* showed the highest magnesium BCF value (305.55) in treatment tanks filled with RO reject water compared to *E. crassipes.* The maximum sodium BCF value (106.06) was demonstrated by *E. crassipes* in treatment tanks at the end eight weeks of growth. However, the highest values (882.35 and 1000) were detected in *P. stratiotes* in considering the BCF for potassium within treatment tanks with RO reject water. Therefore, the values of ion accumulation and BCF values of each contaminant for both types of aquatic plants were same at the end of the experiment according to the results.

Limitations of the research study should be considered in enhancing the research work. It is very important to understand the edaphic factors such as temperature, light, nutrient conditions and their interaction to enhance the production ecology which leads to phytoremediation efficiency of both types of plants. The differentials in day/night temperature facilitate the biochemical reactions within plants which encourage the growth of plants by increasing the uptake of ions (Berry and Bjorknman, 1980; Fox, 2009). Therefore, the system is more successful when plants are used for remediation under optimal conditions and the conditions must be monitored when planning the phytoremediation of RO reject water for a better functioning model.

It is recommended to maintain harvesting intervals with maximum remedial potential to prevent the release of the filtered ions back to the tanks to make erroneous results. The disposal of aquatic plants must be done with caution and proper management practices are essential when they are composed of the possible content of toxic elements (Patil *et al*., 2011). The expansion of the proposed water treatment system would become a better management strategy that could be utilized alone or in combination with other management practices to reduce the water quality degradation caused by the flow of RO reject water into the surface water bodies.

4. Conclusions

The purification of RO reject water by phytoremediation is identified as efficient, cost-effective, flexible, and eco-friendly technology for its safe disposal. The floating aquatic plants of *E. crassipes* and *P. stratiotes* based water treatment system was effective only for a duration of four weeks without any replacement of plants. The removal efficiency of components of RO reject water can be enhanced with improvements such as introduction of the salt-tolerant plants, maintaining the regular flowing of water into treatment tanks, mechanical aeration of tanks, exposure of aquatic plants into different dilutions of RO reject water, etc.

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