Reduction of Pollutants from RO Reject using Phytoremediation: Proposed Methodology

Shivali Chourasia[1], Isha Khanna[2], Nidhi Gera[3] and Sumanth Chinthala[4]

[1,2,3,4]*Environmental Engineering Section, Department of Civil Engineering, Indian Institute of Technology-Delhi, Hauz Khas, New Delhi – 110016*

Abstract: Excessive wastage of water in the Reverse Osmosis (RO) treatment systems has always been a concern for sustainable development planners. With the increasing demand for safe drinking water, the usage of the reverse osmosis systems has increased over the past decade; however, no sustainably feasible solution for RO reject has been identified. TDS, BOD, metals and chloride are the major components of the reject which make it unsuitable for secondary usage like irrigation. In order to address the problem of the disposal of the RO reject and reduce the load on the existing treatment plants, the effect of phytoremediation of the effluent using plants has been investigated in this review. This article discusses the background, concepts and future trends for the use of phytoremediation of RO reject. It is a relatively recent technology and is perceived as cost-effective, efficient, novel, eco-friendly, and solar-driven technology with good public acceptance; however, it is not so popular for RO reject treatment.

This article proposes the use of phytoremediation of RO reject using different emergent plant species like Typha sp., and floating plants like Lemna and Azolla. Various techniques to enhance phytoextraction and utilization of by-products have also been elaborated. Since lot of biomass is produced during this process, it needs proper disposal and management. Despite this potential, phytoremediation is yet to become a commercially available and viable remedial strategy for RO reject, for which there is a need to mitigate plant stress in contaminated soils. There is also a need to establish reliable monitoring methods and evaluation criteria for remediation in the field.

Keywords: Phytoremediation, RO reject, methodology, BOD, COD, TDS

1. INTRODUCTION

Reverse osmosis is the process of forcing a solvent from a region of high solute concentration through a semi-permeable membrane to a region of low solute concentration by applying a pressure in excess of the osmotic pressure. Residential and small-scale industrial reverse osmosis units generate significant amount of waste water due to low back pressure difference across the membrane in RO systems. As a result, they recover only 5 to 15% of the feed water entering the system and the remaining 85-90% is discharged as waste water or RO reject. This RO reject contains lots of contaminants and pollutants in the form of heavy metals, organic and inorganic compounds among others, energy-efficient and environmentally-sustainable methods to recover this water need to be investigated.

The term ‘‘phytoremediation’’ is a combination of two words: Greek phyto (meaning plant) and Latin remedium (meaning to correct or remove an evil). The concept of phytoremediation (as phytoextraction) was suggested by Chaney in 1983 [1]. Phytoremediation is the use of plants to partially or substantially remediate selected contaminants in contaminated soil, sludge, sediment, ground water, surface water, and waste water. It can be used for removal of heavy metals and radionuclides as well as for organic pollutants (such as, polynuclear aromatic hydrocarbons, polychlorinated biphenyls, and pesticides). It is a novel, cost-effective, efficient, environment- and eco-friendly, in situ applicable and solar-driven remediation strategy.

Phytoremediation can remove pollutants and contaminates including leachate, TDS, heavy metals, organic and inorganic compounds, hazardous materials etc from waste water and surface water using different types of plant species and their application [2,3,4]. Thus, a methodology has been proposed in this paper for the purification of RO reject to remove pollutants like TDS, heavy metals, BOD and COD.

2. RO REJECT PROPERTIES

On an average, a RO unit which delivers twenty litres/day of purified water may discharge between 70-340 litres/day of RO reject [2]. Thus, it is essential to assess the constituents of the reject to retard the effects of the present pollutants on the environment as well as human health. The rejection rate of RO is the percent removal of a particular contaminant by the membrane present. The rejection rate for various metals, organics, insecticides, BOD, COD, TDS, are very high (approx 90%) for each of the constituents of the feed water [3]. The concentration of the contaminants and pollutants in the RO reject will depend on the nature of the influent feed water and the membranes used in RO systems along with the applied pressure.

3. TECHNIQUES/STRATEGIES OF PHYTOREMEDIATION

The pollutant that potentially can be managed using phytoremediation are quite diverse including heavy metals, metalloid, salts, nutrients, organic chemicals and air pollutants. Metal contaminated water with other impurities including TDS, BOD and COD can be remediated by chemical, physical and biological techniques. Phytoremediation techniques includes following processes which can be used in various stages of purification of RO reject:

Physical processes: Sedimentation, Filtration, Adsorption, Volatilization
Chemical processes: Precipitation, Hydrolysis reaction, Adsorption, Oxidation reaction

Biological Process: Plant metabolism, Plant absorption, Bacterial metabolism, Natural die-off

The presented article studies on the various techniques of phytoremediation for the management of pollutants and contaminants present in RO reject to remove different contaminants including TDS, BOD, COD and salts in Table 1. Main phytoremediation techniques are:

1. **Phytoextraction / phytoaccumulation.** In this phenomena heavy metals and contaminates of waste water or soil is up taken by plant root and converted into the harvestable biomass. Due to less and slow degradation of up taken contaminates an accumulation of contaminates occurs in the plant [4].
2. **Phytofiltration.** Phytofiltration is the process of removal of pollutants from contaminated surface water or waste water by plants. Phytofiltration may be rhizofiltration (use of plant roots) or blastofiltration (use of seedlings) or caulofiltration (use of excised plant shoots) [5].This process involves filtering water through a mass of roots to remove toxic substances or excess nutrients.
3. **Phytostabilization.** Phytostabilization focuses on long-term stabilization and immobilization of the pollutants and contaminants in soil through absorption and accumulation through nearby roots. Pollutants become less bio available for wildlife and human exposure [6].
4. **Phytovolatilization.** Phytovolatilization is the process of absorbing of pollutants and contaminants from soil by plants, and converting them into volatile form and subsequent release into the atmosphere. This technique can be used for organic pollutants and some heavy metals like Hg and Se.
5. **Phytodegradation.** Phytodegradation is the biological breakdown of organic pollutants in soil and water through microbial activity that is enhanced by the presence of the root zone. Yeast, fungi, bacteria and other microorganisms consume and digest organic substances like fuels and solvents [7].
6. **Phytohydraulics.** Phytohydraulics is a mechanism to control or minimize of migration of contaminants in groundwater. In this phenomenon plants behave as organic ‘pumps’ to pull-in large volumes of the contaminated water. The result is reduced migration of the contaminant in ground water [7].
7. **Vegetative Cover Systems.** Vegetative Cover Systems is a long-term and self sustaining process which can be used to retard the environmental risk of hazardous material by growing plants in and/or over the hazardous material. It controls the leaching of hazardous compounds from landfills and other storage

8. **Riparian Corridors/Buffer Strips.** Riparian corridors/buffer strips are generally applied along with streams and river banks to control and remediate surface runoff and groundwater contamination moving into the river. In other words it is a non point source control technique. This technique is mainly used for ground water and surface water.

Table 1: An overview of phytoremediation techniques

Technique	Process Involved	Media	Contaminants	Plants
Phyto-extraction	Contaminant, extraction and capture	Soil, sediment, sludges	Ag, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, Zn, OC, radionuclides	Hyper Accumulators Indian Mustard, *Pennycress, Alyssum* Sunflowers
Phyto-filtration	Sorption of contaminants from aqueous solution into the roots. Filtration& absorption	GW, SW	Metals, radionuclides & hydrophobic OC	Water Hyacinth, Duckweed, Pennywort, Indian Mustard, Sunflowers
Phyto-stabilization	Stabilization of pollutants by binding, holding in soils or decreased leaching	Soil, sediment, sludge	Metals As, Cd, Cr, Cu, Hs, Pb & OC	Plants with deep and fibrous root *Indian* Mustard, Hybrid *Poplars*, Grasses
Phyto-volatilization	Contaminant extraction from media and release to air	GW, soil, sediment, sludge	Volatile OC, Chlorinated solvents	*Brassica,* Grasses, *Poplars, Alfalfa,* Black Locust
Phyto-degradation	Microbial degradation of pollutants	Soil, sludge, GW, SW	OC, Chlorinated solvents, phenols, herbicides, munitions	*Algae, Stonewort,* Hybrid Poplar, Black Willow, *Bald Cypress*
Phyto-hydraulics	Removal of large volume of water from aquifers by plants	GW, SW	Water-soluble organics and inorganics	Hybrid Poplar, Cottonwood, Willow
Vegetative Cover Systems	Erosion control, to retard leaching of hazardous compound using plant	Soil, sludge, sediments	Organic and inorganic compounds	*Poplars, Alfalfa,* Grasses
Riparian Corridors/Buffer Strips	Contaminant uptake and plant metabolism	SW, GW	Water-soluble organics and inorganics	*Poplars*

SW- Surface Water, GW- Ground Water, OC- Organic Compounds

4. METHODOLOGY

From the techniques and processes discussed in Table 1, it is evident that various phytoremediation techniques can be used to remove pollutants and contaminates from different types of waste water and effluents by the application of various plant species. These techniques involve basic purification processes of waste water like sedimentation, filtration, adsorption, volatilization, bacterial metabolism, precipitation, oxidation reaction. In case of RO reject, it has been observed that the pollutants are similar to other wastewater and industrial effluent, therefore, phytoremediation techniques can also be applied in case of RO reject treatment. Varieties of species, their removal capacity and time required to remove contaminants like TDS, BOD, and COD from different effluents have been elaborated in Table 2.

Table 2: List of plant species and techniques to remove RO reject contaminants by phytoremediation

Influent type	Species used	Techniques	Time taken	% Removal			Reference
				BOD	COD	TDS	
Zinc-plating effluent	*Azolla*	a	10	14.7	20.5	33.4	[8]
Sewage	Water Hyacinth	-	4-9 days	37-91	72.6	21-92	[9]
Simulated dyes mixture	*Petunia grandiflora*	e	36 hours	44	58	-	[10]
	Gailardia grandiflora	e	36 hours	31	37	-	[10]
	P. grandiflora, G. grandiflora	e	36 hours	69	73	-	[10]
Polluted river water	*Myriophyllum aquaticum*	-	30 days	75.4	67.4	-	[11]
Textile ind. Waste	Water Hyacinth	a	3 days	10	25	62.4	[12]
Domestic wastewater	*R. carnea*	a, c	10 days	80.66	78.72	-	[6]
	Acorus gramneus	a, c	10 days	84.08	84	-	[6]
	A. orientale	a,d	10 days	80.88	78.95	-	[6]
	A. calamus	b,d	10 days	81.73	79.51	-	[6]
	Iris pseudacorus	a,c	10 days	84.76	84.61	-	[6]
	L. salicaria	a,d	10 days	82.37	80.58	-	[6]
	Lotus	b,c	5.4 days	63	-	67	[13]
	Hydrilla	b,c	5.4 days	21	-	33	[13]
Hard water	*Lemon peel*	b,d	20 minutes	-	-	42	[14]
	Peanut husk	b,d	20 minutes	-	-	41.14	[14]

	Ind. Gooseberry bark	b,d	20 minutes	-	-	42.14	[14]
	Vetiver root	b,d	20 minutes	-	-	55.93	[14]

a- Phytoextraction, b- Phytofiltration, c- Phytostabilization, d- Phytovolatilization, e-Phytodegradation

It has been observed that the techniques required for efficient removal of BOD ad COD are quite similar, i.e., Phytoextraction, Phytofiltration, and Phytovolatilization. Thus, the application of these techniques can result in control of both BOD and COD. The most efficient species required for all three contaminants have been selected based on their percentage removal capacities which are given in Table 2.

A methodology using different species for different contaminants has been proposed in Figure 1. The purpose of phytoremediation can be in three stages: (a) risk control (phytostabilization); (b) phytoextraction of metals such as Ni, Ti and Au; (c) robust land management by which soil quality is improved gradually by phytoextraction [15]. The species selected in the proposed methodology can remove the contaminants in the range of 80-90%.

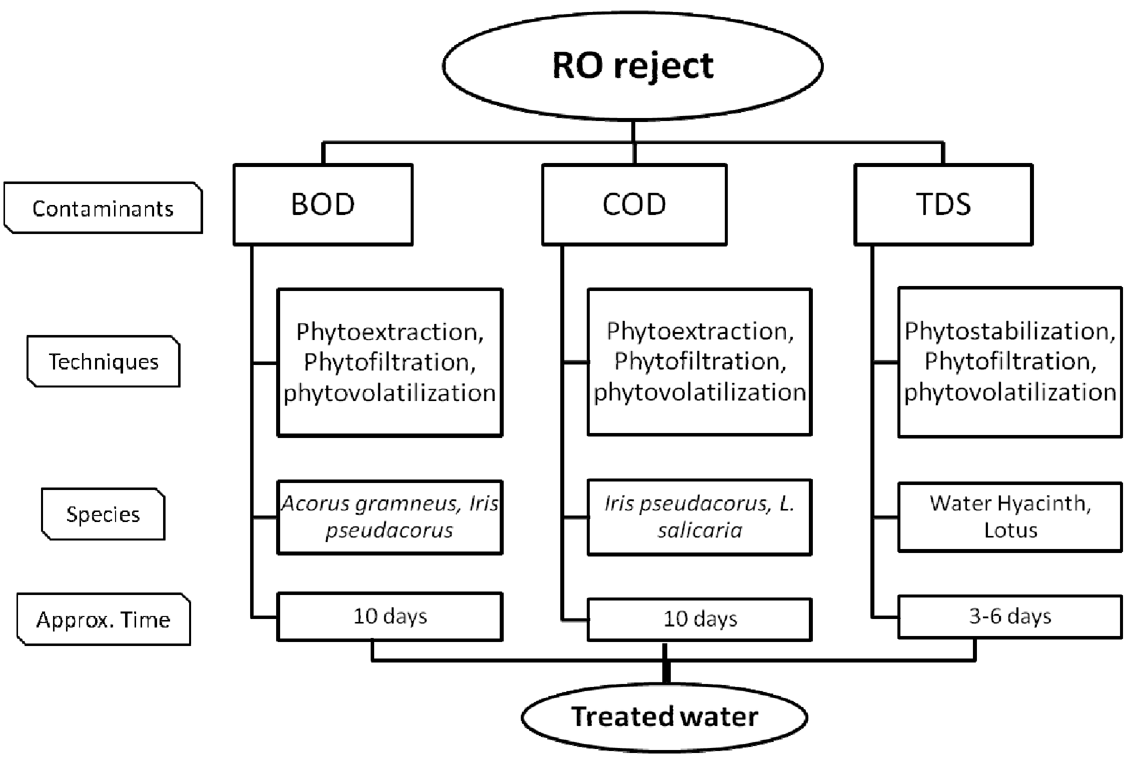

Figure 1: Proposed Methodology for treatment of RO reject using Phytoremediation

5. POTENTIAL AND CHALLENGES

The process of phytoremediation is relatively new technique but it has a lot of potential due to its environmentally sustainable nature and low maintenance alternative to more active and intrusive remedial methods. It is a low-cost technology as compared to other techniques which makes it all the more preferable, especially in developing countries, like India. A significant advantage is that a variety of organic (like Chlorinated solvents, pesticides, explosives, PCP and other PAHs) and inorganic compounds (like metals, radionuclides, etc.) are acquiescent to the phytoremediation process for RO reject [8,9,12]. This process would not have the destructive impact on soil fertility and structure that some more vigorous conventional technologies may have, such as acid extraction and soil washing. Instead, the presence of plants is likely to improve the overall condition of the soil, regardless of the degree of contaminant reduction.

However, there are a few challenges in this process which need to be taken care of like a longer time period, dependence on plant growth rates, affected food chain, lower effectiveness during winter or other changes in weather, disease, or pests. High initial contaminant concentrations can be phytotoxic, and prevent plant growth. These conditions need to be monitored while planning the phytoremediation of RO reject for a better functioning model.

6. CONCLUSION

This article discusses the background, concepts and future trends for the use of phytoremediation of RO reject. It is perceived as cost-effective, efficient, novel, eco-friendly, and solar-driven technology; however, it is not so popular for RO reject treatment. For the purification of RO reject, a methodology has been proposed to use phytoextraction, phytofiltration, phytodegradation and phytostabilization techniques to remove pollutants like TDS, BOD, and COD in desired time and domain. Despite this potential, phytoremediation is yet to become a commercially available and viable remedial strategy for RO reject, for which there is a need to mitigate plant stress in contaminated soils.

REFERENCES

[1] Chaney RL. 1983. *Plant uptake of inorganic waste*. Land treat. of hazard. waste 1983; 50–76.

[2] Information on http://www.ag.ndsu.edu/pubs/h2oqual/watsys/ae1031.pdf

[3] Information on http://www.purewaterproducts.com/articles/ro-rejection-rates

[4] Rulkens WH, Tichy R, Grotenhuis, JTC. *Remediation of polluted soil and sediment: perspectives and failures.* Water Sci. Technol. 1998; 37:27-35.

[5] Mukhopadhyay S, Maiti SK. *Phytoremediation of metal enriched mine waste: a review.* Global J. Environ. Res. 2010; 4:135–150.

[6] Zhang XB, Liu P, Yang YS, Chen WR. *Phytoremediation of urban wastewater by model wetlands with ornamental hydrophytes.* J. Environ. Sc. 2007; 19:902–909.

[7] Sridhar S, Victor FM, Steven CMC. *Phytoremediation: An ecological solution to organic chemical contamination.* Ecological Engineering 2002; 18:647–658.

[8] Deval CG, Mane AV, Joshi NP, Saratale, GD. *Phytoremediation potential of aquatic macrophyte Azolla caroliniana with references to zinc plating effluent*. Emir. J. Food Agric. 2012; 24 (3): 208-223.

[9] Zimmels Y, Kirzhner F, Malkovskaja, A. *Application of Eichhornia crassipes and Pistia stratiotes for treatment of urban sewage in Israel.* J. Environ. Mngt. 2006; 81:420–428.

[10] Watharkar AD, Jadhav JP. *Detoxification and decolorization of a simulated textile dye mixture by phytoremediation using Petunia grandiflora and, Gailardia grandiflora: A plant–plant consortial strategy*. Ecotoxicol. & Environ. Safety 2014; 103:1–8.

[11] Souza FA, Dziedzic M, Cubas SA, Maranho LT. *Restoration of polluted waters by phytoremediation using Myriophyllum aquaticum (Vell.) Verdc., Haloragaceae.* J. Environ. Mngt. 2013; 120:5-9.

[12] Trivedy PK, Gudekar VR. *Treatment of Textile Industry Waste Using Water Hyacinth.* Water Sci & Tech. 1987; 19(10):103–107.

[13] Kanabkaew T, Puetpaiboon U. *Aquatic plants for domestic wastewater treatment:Lotus (Nelumbo nucifera) and Hydrilla (Hydrillaverticillata) systems*. Songklanakarin J. Sci. Technol. 2004; 26(5): 749-756.

[14] Ebrahim A, Ali M, Gautham, Jawahar N, Hariram S. *A preliminary attempt to reduce total dissolved solids in Ground water using different plant parts.* Intl. J. Pharma Bio Sci. 2011; 2:B414-422.

[15] Ali H, Khan E, Sajad MA. *Phytoremediation of heavy metals – Concepts and applications.* Chemosphere 2013; 91:869–881.

[16]