

Treatment of Landfill Leachate using Reverse Osmosis and its Potential for Reuse

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ABSTRACT: An assessment of the treatment of sanitary landfill leachate with the help of reverse osmosis and potential of treated leachate for reuse was carried out at a sanitary landfill located in Srinagar city of Jammu and Kashmir. The untreated leachate contained high organic and inorganic load having high concentrations of BOD, COD, total nitrogen, ammonia, chloride and trace metals. Treatment plant operating on the principle of reverse osmosis indicated an overall removal efficiency of approx. 90%. Very high rejection rates were obtained for BOD (99.7%), COD (98%) and TDS (94%). The rejection rates of various trace metals ranged from 76% to 99.99%. The results revealed reverse osmosis as a promising technology for the treatment of landfill leachate and also the positive and productive potential of treated leachate for reuse.

KEYWORDS: Sanitary landfill, leachate, reverse osmosis, permeate, rejection rate.

I. INTRODUCTION

Millions of tons of municipal solid waste (MSW) are being dumped every day in thousands of landfills worldwide [1]. Although, alternative methods such as recycling, composting and incineration are nowadays very much encouraged for the effective management of solid waste, still large amount of waste from numerous sources and waste residues from waste treatment plants need to be landfilled ultimately. Sanitary landfills are modern engineered repositories which are designed to hold and enclose the municipal solid waste in such a manner that it remains separated from rest of the surroundings. Such engineered landfills control and minimize the risks to the environment to a fairly good extent. However, the inexorable generation of highly contaminated liquid called leachate continues to be a subject of debate. Leachate is generated when the precipitation (rain/snow) or surface runoff percolates down the waste bed and may continue to get released over decades even after the closure of landfill. Due to this reason, it is often considered as a long term pollutant [2] which can pollute all the three spheres of environment i.e., hydrosphere, lithosphere and atmosphere [3]. Leachates may also enter the food chains through contaminated water, soil and air and if left untreated it can act as a latent hazard to the environment and the living beings.

Leachate is typically composed of high concentration of organics, nitrogenous compounds, inorganic dissolved compounds, heavy metals and xenobiotics [4]. However, the characteristics of landfill leachate may vary depending upon various factors such as pH, age, precipitation, climate, waste type and composition, moisture within landfill and depth of waste bed [5], [6]. A combination of these factors in leachate makes it difficult to choose an appropriate treatment system. Virtually, various types of treatments have been explored including biological, physico-chemical and membrane separation techniques. Biological treatments for landfill leachates include activated sludge (AS), sequencing batch reactors (SBR), aerated lagoons (AL), and upflow anaerobic sludge blankets (UASB) [7]. Conventional physico-chemical techniques such as chemical precipitation [8]; adsorption [9]; coagulation/flocculation [10], chemical oxidation [11] may be used as co-treatment along with biological treatments. While as, membrane technologies include micro filtration, ultrafiltration, nanofiltration and reverse osmosis [12]. The choice of a particular treatment system mainly depends upon characteristics of leachate, cost and sustainability of treatment system and the regulation standards of a country. After proper treatment, leachate can be released safely into the environment. Moreover, recently

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possibilities of reusing municipal landfill leachate have been investigated by many researchers mostly exploring its potential as a source of fertilizer [13], [14]. This is particularly important for the sustainable management of leachate in many parts of the world where water resources are scarce.

However, because of the prevalence of organic and inorganic pollutants including pharmaceuticals and pesticides in leachate having potential adverse health effects makes it important to employ the suitable technique which can make leachate desirable for reuse. For this reason, membrane processes are often chosen for leachate treatment; since this technique can achieve high removals of constituents such as dissolved solids, organic carbon, inorganic ions, and regulated and unregulated organic compounds [15]. Among the membrane processes, reverse osmosis has been one of the most widely used methods for the last 20 years [16]. It is a pressure-driven process whereby a semi-permeable membrane rejects dissolved constituents present in the feed water. The treated leachate called permeate contains a very low concentration of dissolved solids [17]. Reverse osmosis (RO) is now the most widely used in many countries in western Europe (France, Germany, Italy, etc.), North America (United States, Canada) and Asia (China, Korea), for its good ability to retain both organic and inorganic contaminants [18]. This paper attempts to assess the ability of reverse osmosis for treatment of leachate at Achan sanitary landfill site in Srinagar city of Jammu and Kashmir in India and its potential for reuse.

II. MATERIALS AND METHODS

2.1. Study area description

The Achan sanitary landfill site (34°07'25'' N and 74°47'15'' E) in Srinagar city of Jammu and Kashmir, India has a surface area of 67.5 acre and is the sole waste disposal facility of the city. Reportedly [19], the average municipal solid waste (MSW) generation for the city is estimated to be 575 tons per day (TPD) with an average physical composition of 54% organic matter, 30% silt and about 16% other components. This waste disposal facility has been upgraded to a sanitary landfill which became operational since year 2012.

The sanitary landfill has a well designed multiliner system, leachate collection and management facility, a treatment plant of three units and a gas management system. The leachate released from the landfill is driven to the on-site treatment plant based on reverse osmosis technology having an installed capacity to treat 120000 litres per day.

2.2. Leachate sampling and physicochemical analysis

In an effort to assess the efficiency of treatment plant and to evaluate the potential of treated leachate for reuse, samples of raw (untreated) leachate and permeate (treated) were collected from the leachate collection system and the outlet of treatment plant, respectively, on seasonal basis for a period of one year and the samples were analyzed for relevant physico-chemical parameters and some trace metals. The analysis was started without any delay using the standard procedure prescribed by the American Public Health Association [20]. pH and total dissolved solids (TDS) were tested in situ using Oakton multi-parameter tester. For the analysis of other parameters, both raw leachate and permeate samples were collected in triplicates in clean polyethylene bottles and were immediately transferred to the laboratory and stored in refrigerator at 4°C. Estimation of COD for leachate was done by reflux titrimetry, while BOD was determined by Winkler titration. Total nitrogen was analyzed using automatic nitrogen analyzer (KEL Plus nitrogen analyzer), NH_4^+ was determined using phenate method and Cl^- by argentometric titration method. Prior to analysis, the samples for ammonia and chloride were filtered using 0.45 μm pore size filter paper. For the determination of trace metal content (zinc (Zn), nickel (Ni), mercury (Hg), lead (Pb), cadmium (Cd) and chromium (Cr)), samples were collected in separate sampling bottles and were acidified (pH 2) with the addition of 5 N HNO_3 and kept on 4°C until analysis. The concentrations of total metals were determined using Perkin Elmer Atomic Absorption Spectrometer (AAS). The data obtained were subjected to statistical analysis employing standard statistical procedures.

III. RESULTS AND DISCUSSION

3.1. Physico-chemical characteristics of raw leachate

The results of the study are depicted in Table I that displays the mean \pm SE of various physico-chemical parameters in raw leachate and permeate. In general, the major pollution parameters including TDS, Cl^- , BOD, COD, TN and NH_4^+ showed a well marked seasonal difference with higher concentrations in drier periods and lower concentrations in wet

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periods. This may be because the leachate concentrations of major cations and anions are generally higher in the dry season and tend to decrease by simple dilution during precipitation events [21].

Table I. Physico-chemical characteristics of raw and treated leachate with treatment efficiency of RO treatment plant (n= 12 for physico-chemical parameters; n=8 for trace metals)

Parameter	Unit	Raw (untreated) leachate		Permeate (treated leachate)	
pH	Unitless	6.39-7.31	6.98±0.10	6.38-7.82	6.78±0.18
TDS	mg/l	6390-15910	11100±1065	481-766	645±35
BOD	mg/l	4000-12250	8063±825	21-29	25±0.93
COD	mg/l	5200-15400	10633±1088	70-240	163±19
Chloride	mg/l	1430-2899	2100±152	108-211	153±11
Ammonia	mg/l	326-911	616±63	10-15	13±0.51
Total nitrogen	mg/l	420-1470	957±100	34-104	67±7.07
Zinc	mg/l	8.32-11.56	9.69±0.34	1.98-2.33	2.11±0.04
Nickel	mg/l	0.63-0.90	0.807±0.031	0.04-0.09	0.064±0.006
Lead	µg/l	16-36	28±2.54	1-7	3.50±0.65
Mercury	µg/l	38-274	144±29	0-0.19	0.06±0.03
Cadmium	µg/l	49-65	55±1.83	12-13	13±0.25
Chromium	µg/l	806-1171	1998±45	163-269	193±12

pH of raw leachate was slightly acidic with a mean value of 6.98±0.10. This could be attributed to the decomposition of simple and complex organics into organic acids [22]. High TDS values indicated the presence of higher dissolved inorganic materials in raw leachate. Chloride was found in high concentrations owing to its conservative nature. TDS and chloride also showed maximum values in the driest season of summer and lowest in the autumn season which may be attributed to the dilution due to heavy downpour in autumn season (Fig. I).

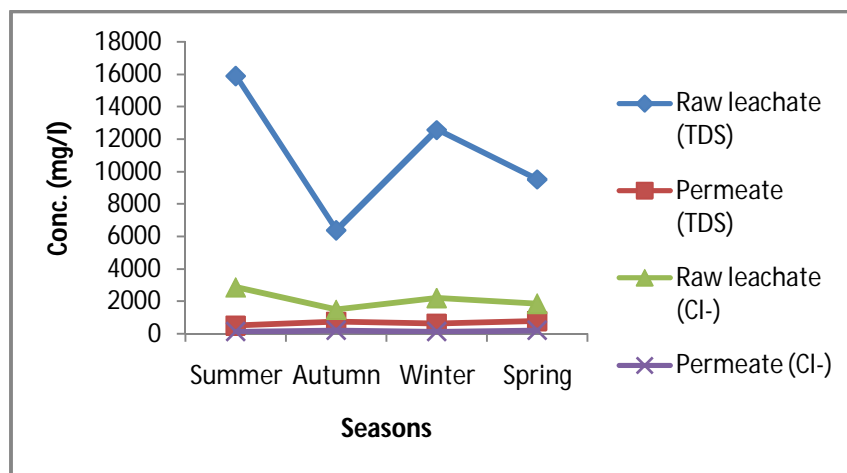


Fig. I Seasonal variation in the values of TDS and chloride of raw leachate and permeate

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The presence of high BOD and COD in fresh raw leachate is indicative of high organic strength in the raw leachate showing that the majority of the organic compounds are biodegradable [23]. The effect of seasons is well evident from BOD and COD concentrations of leachate resulting in higher values during summer (Fig. II). This may be due to the reason that during dry periods only a smaller volume of more concentrated leachate is produced because of the reduced rainfall and increased evaporation.

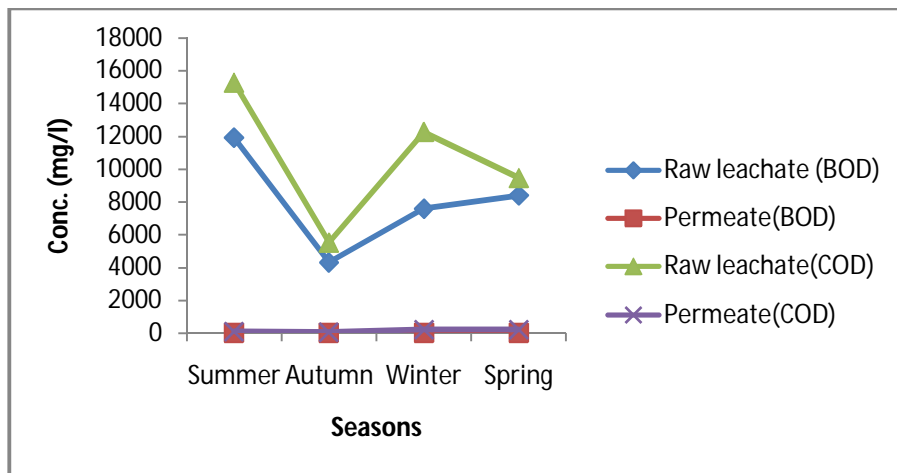


Fig. II Seasonal variation in the values of BOD and COD of raw leachate and permeate

High TN (total nitrogen) in leachate could most probably be due to presence of high concentrations of ammonium and reduced nitrogen compounds [24]. Much of the nitrogen in solid waste was in the form of ammonia produced from the degradation of proteins and amino acids [25]. Like BOD and COD, the effect of dilution may be observed in total nitrogen and NH_4^+ as well (Fig. III).

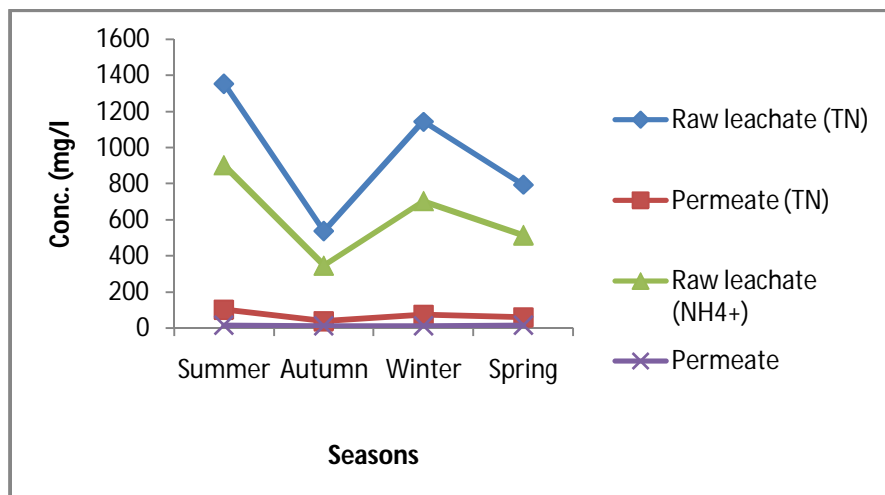


Fig. III Seasonal variation in the values of TN and NH_4^+ of raw leachate and permeate

Metals are inorganic compounds used in many industrial and manufacturing processes such as electroplating and the making of alloys and metal products that arrive at landfills because of the dumping of wastes containing such products [26]. In general, the concentrations of the metals including, Zn, Ni, Pb, Hg, Cd and Cr were higher in raw leachate which may be attributed to the solubility of metals in the acidogenic phase because of the production of acid in an anaerobic condition [27].

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3.2. Removal efficiency of RO

The removal rates of these parameters by RO treatment plant are displayed in Table II. Reverse osmosis seems to be one of the most promising and efficient methods among the new processes for landfill leachate treatment [28]. Acidic pH of permeate than raw leachate reflects the acidification during pre-treatment of leachate before the operation of RO process [29]. RO can be used for the removal of organic and inorganic contaminants, including heavy metals, suspended/colloidal materials and dissolved solids from landfill leachate with 98–99% rejection rate [30] which is quite evident from the results of this study. TDS and Cl⁻ were observed to be getting reduced by 94% and 93%, respectively which indicate that much of inorganic pollutants have been removed.

Table II. Treatment efficiency of RO leachate treatment plant in terms of pollution removal

Parameter	Treatment efficiency (%)
pH	-
TDS	94
BOD	99.7
COD	98
Chloride	93
Ammonia	98
Total nitrogen	83
Zinc	78
Nickel	92
Lead	89
Mercury	100
Cadmium	76
Chromium	80

BOD and COD reduced from very high concentrations of 8063±825 mg/l and 10633±1088 mg/l in raw leachate to fairly low concentrations of 25±0.93 mg/l and 163±19 mg/l in permeate, respectively having high removal rates of 99.7 and 98%. Total nitrogen and ammonical nitrogen also showed significantly higher removal rates of 83% and 98%, respectively. The results indicate that RO is a highly efficient technique that can remove both biodegradable as well as non-biodegradable organic compounds from landfill leachate. Very high rejection rates (96-100%) for the removal of COD and NH₃-N have been reported by other researches [31], [32], [33].

Trace metals including, Zn, Ni, Pb, Hg, Cd and Cr were also found to have reduced to non-toxic levels by the treatment process showing moderate to very high retention rates (76% for cadmium to 99.99% for mercury). Such rejection rates are in consistency with literature [34].

The small fluctuations in removal efficiency of permeates may be attributed to various factors which include leachate flow rate, operating pressure, pH, temperature, dissolved organic substances, particulate and colloidal matter that are responsible for fouling and polarization of membrane thereby reducing the performance of RO system [35], [36].

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3.3. Potential of permeate for reuse

In several parts of the world including India, it is not acceptable to release the raw leachate into the environment as it can cause several problems. So, any disposal of landfill leachate must be within the standards for treated leachate as prescribed by SWM rules, 2016 in India (Table III). In the present study, all the pollution parameters including the concentrations of trace heavy metals were found to be lower than the prescribed standards and did not exceed any of the disposal limits for treated leachate.

Table III. Quality of permeate (treated leachate) in comparison to maximum permissible limit for disposal standards for MSW landfill leachate in India (SWM rules, 2016)

Parameter	Standards (Mode of disposal)			Permeate (this study)	
	Inland Water	Surface	Public Sewers		Land Disposal
pH value	5.5 to 9.0		5.5 to 9.0	5.5 to 9.0	6.78
Dissolved solids mg/l, max.	2100		2100	2100	645
BOD (max, mg/l)	30		350	100	25
COD (mg/l, max)	250		-	-	163
Chloride (as Cl), mg/l, max	1000		1000	600	153
Ammonical nitrogen (as N), mg/l, max.	50		50	-	13
Total nitrogen (as N), mg/l, max	100		-	-	67
Zinc (as Zn), mg/l, max	5.0		15	-	2.11
Nickel (as Ni), mg/l, max	3.0		3.0	-	0.064
Lead (as Pb), mg/l, max	0.1		1.0		0.0035
Mercury (as Hg), mg/l, max	0.01		0.01		0.06
Cadmium (as Cd), mg/l, max	2.0		1.0	-	0.013
Total Chromium (as Cr), mg/l, max	2.0		2.0	-	0.19

Considerable reduction of organics (BOD and COD) and nitrogenous compounds (TN, NH₃-N) may prevent water pollution problems like eutrophication, algal blooms, foul odours, etc. Therefore, the treated leachate can be channelized to the inland surface water or safely disposed into the public sewers. Also, the modest concentration of nutrients present in permeate makes the treated leachate a source of fertilizer and more preferable for land disposal. Therefore, it may be wise to utilize the permeate for non- potable purposes like irrigation of land within and around the landfill or washing of vehicles that are used in various processes of waste management like carrying waste to the landfill, spreading and compaction of waste, etc.

IV. CONCLUSION

This study was conducted to assess the removal efficiency of landfill leachate by RO treatment plant and to evaluate the potential of permeate for reuse. The findings of study show that the RO process is fairly efficient in eliminating

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both organic and inorganic contaminants. The BOD and COD of the effluent were reduced by more than 99% and 98%, respectively. Also, the permeate was found to be in compliance with the SWM rules (2016) in India for disposal of treated leachate in the environment. It may also be concluded that the permeate bears a good potential for reuse and can be utilized for non-potable uses like cleaning of vehicles carrying waste to the landfill and irrigation of plantation within and around the landfill. However, for other purposes in depth investigation is needed.

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