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Research Article

Reverse osmosis treatment system for landfill leachate: Operation conditions, advantages and challenges

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ABSTRACT

Landfill leachate treatment by Reverse Osmosis (RO) system was evaluated in this study. Operational conditions of sand filters, sulfuric acid dosing and pH adjustment, cartridge filters and cat pumps, and membrane modules were discussed in detail. Advantages and challenges of RO for leachate treatment in developing countries handled with sustainability logic. The system has been successfully applied in leachate treatment with high removal rates as 98% of COD, 99% of total Nitrogen and suspended solids and substantial heavy metal removal. However, high costly operating expenses, dependency on the manufacturers for membranes, chemicals and other materials indicated the system unsustainable. Especially high-strength characteristic of leachate, high energy consumption of RO process, difficulty to struggle with scaling problems, limited lifetime of membranes and management/treatment of concentrate were expressed as the constraints of the system.

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INTRODUCTION

Landfilling with the feature of being a short-term solution alternative is preferred widely by the municipalities for disposing the industrial and municipal solid wastes (MSW) owing to its low capital costs and minimum technology being practiced. A major issue arising from solid waste landfilling is intense impact of landfill leachates on the environment [1–3]. Leachates are high-strength wastewaters formed as a result of percolation of rainwater and moisture through waste in landfills [4, 5]. MSW landfill leachate varies widely in composition and needs to be treated effectively before being discharged into the environment. To maximise resources recycling with the least negative environmental impacts, regulations on both landfill management and leachate discharge are becoming more stringent throughout the world [6].

Landfill leachate must be appropriately treated and managed, maximizing the recovery and minimizing the waste disposals. In particular, standalone on-site treatments are more effective on unstable characteristics of leachate. Raw leachate from young landfills contains most of organic substances in biodegradable form thus can be easily treated by biological processes. For old landfills, most of the leached organic compounds are hardly or non-biodegradable forms and they should be treated by physico-chemical processes or a combination of biological and physico-chemical pro-

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Table 1. Specific parameters of leachate

Parameters	Quantity
Flowrate of leachate	180 m^3/day
Chemical oxygen demand (COD)	35.000 mg/L
Suspended solid	1.000 mg/L
Conductivity	30.0/cm

cesses [7]. On the other hand, the use of membrane technologies allows stable quality of the permeate that can be locally reused or discharged in water bodies. Reverse Osmosis (RO), as single post-treatment step has shown to be an indispensable means of achieving high purification, removal of hazardous metals and potential water recovery [8]. RO process was studied for treatment of landfill leachate within two decades from its discovery and was reported to be the most effective method for treating leachates [9–14]. By the mid-1980s, RO systems had already penetrated significantly into the market of leachate treatment [15]. However, RO concentrate is difficult to deal, the specific energy consumption of RO process is much higher than other treatments and it is difficult to struggle with significant scaling problems. Additionally, the frequent cleaning and strong demand of acid and alkali limits the continuous operation of the system and dramatically increases the running costs [6]. It is a controversial issue that the reverse osmosis system is a sustainable method in leachate treatment.

In this context, our study aims to evaluate the operational conditions of reverse osmosis system with interpreting its advantages and challenges for a landfill leachate treatment.

MATERIALS AND METHODS

Landfill Leachate

The amount of leachate is directly related to precipitation, population, features of the landfill and the waste source of the city where it is located. The amount of leachate is calculated by Equation 1.

$$C = Pr \times (1-R) - \Delta S - Ev \quad (1)$$

C is total amount of leachate (mm/year), Pr is precipitation (mm/year), R is runoff coefficient, ΔS is amount of accumulated water in landfill area and Ev is Evaporation from landfill surface (mm/year). Although the amount of leachate in landfills depends on many factors such as the rainfall in the region, the moisture content of the solid waste and the age of the landfill area, the daily amount of leachate from unit area of the landfill is generally considered to be 8.6 m^3/ha.day. Specific leachate parameters for study area are presented in Table 1.

Reverse Osmosis System

Design criteria of RO system for the treatment of landfill leachate located in Gaziantep, Turkey was presented in Table 2. In the facility designed using reverse osmosis system,

Table 2. RO treatment design criteria for max and average annual flow rates

Rate (%)		Max annual value			Average annual value		
		L/h	m^3/day	m^3/year	L/h	m^3/day	m^3/year
Raw leachate	100.00	11.57	277.80	101.39	10.42	250.00	91.25
Concentrate	34.30	3.97	95.40	34.81	3.58	85.80	31.33
Permeate	65.70	7.60	182.40	66.70	6.84	164.20	59.92

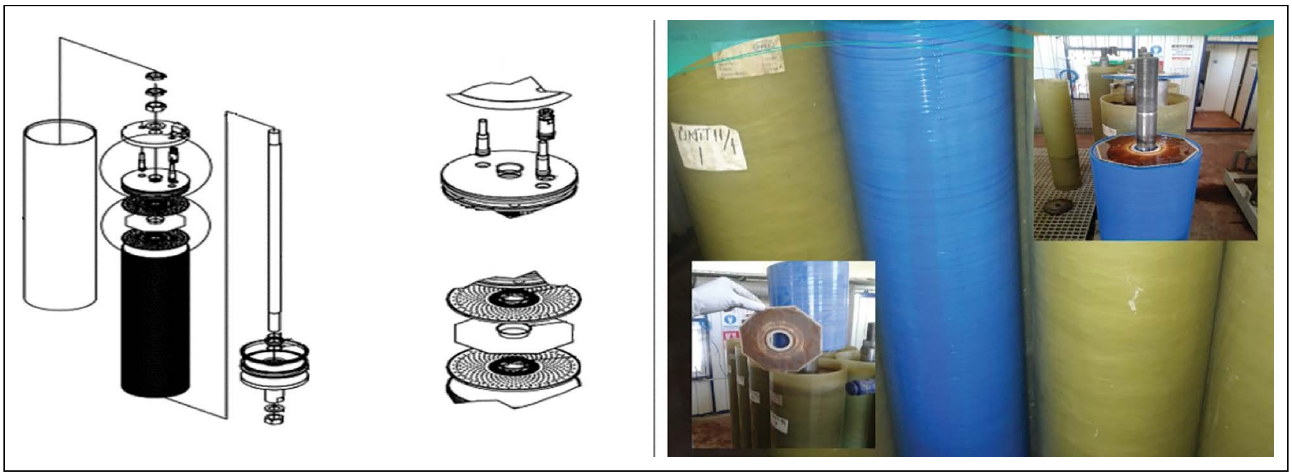

Figure 1. RO treatment plant membrane design and disc membranes.

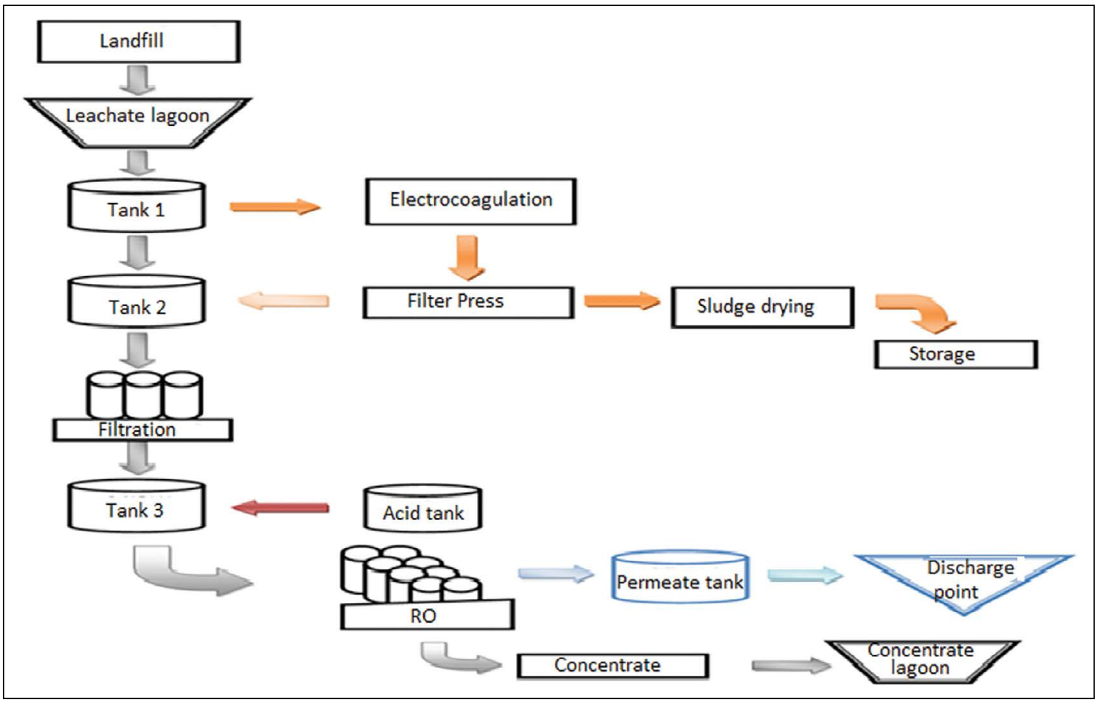

Figure 2. RO process flow chart.

Figure 3. Inlet unit-tank 1.

vertical modeling system and disc membranes were used. The manufacturer is PALL Company and it is located in Germany. The reverse osmosis is a 2-stage system operating for an average pressure of 75 bar. Disc membrane technology was preferred for the treatment (Fig. 1). The facility used 100 modules 21.000 disc membranes in the 1st stage, and 18 modules 3.780 disc membranes in the 2nd one. The system is completely assembled on a portable base. It can be easily commissioned with water and energy connections. The system is fully equipped with pH, conductivity, antiscalant dosage control and chemical cleaning equipment.

Analysis of Leachate Parameters

The leachate flow was measured continuously by the Burket brand flow meter at the entrance of the facility. Monitoring of conductivity and pH value was made with LTH conductivity/pH meter. Oil and grease were measured by the method of SM 5520 D. Total Cyanide and Fluoride (F) were analyzed by the methods of SM 4500 CN C E and SM 4500 F B D, respectively. Total Kjeldahl N, Total P, chemical oxygen demand (COD), and suspended solids (SS) were measured using SM 4500 Norg B, SM 4500 P B E, SM 5220 B, SM 2540 D, respectively. Cr, Cu, Zn, Fe, Cd, Pb were analyzed by EPA Method 200.7.

RESULTS AND DISCUSSION

Operation of RO Treatment System

The schematic figure for process flow chart is represented in Figure 2. A cartridge filtration is applied at the inlet of the system and pH adjusted pre-treated water is fed to the system with antiscalant dosage. The concentrate is taken to a lagoon to be used in order to humidify the landfill area. Excess water is transferred to lagoon 1. Permeate is taken to a tank with a volume of 15.000 L to be used for water utilization for afforestation and similar purposes (Fig. 2).

Figure 4. Sand filters in the system.

Figure 5. Tank 3 for pH adjustment.

Sand Filters

Leachate from the solid waste landfill enters the lagoon with its own attraction and passes to water intake structure to be stored in tanks. The leachate transmitted to the tank 1 must be delivered to the electrocoagulation (EC) unit positioned in the project. Due to the failure of the EC unit the tank 2 is used as a backup of the tank 1 (Fig. 3). The system has three sand filters (fiberglass reinforced PE filter) in series with 2.7 m^3. Average capacity is 13 m^3/h. Sand filters alleviate the load of leachate before the reverse osmosis and increase the membrane lifetime (Fig. 4). Since the system works continuously, both blower and backwash are applied to the sand filters in each shift to protect the sand filter environment life. However low pH in the concentrate due to returning of diluted leachate to the system with recirculating shortens the sand filter media life and causes encrustation problem.

Sulfuric Acid Dosing and pH Adjustment

Leachate after sand filters is taken into tank 3 for pH adjustment before its transferring to membranes. 98% pure

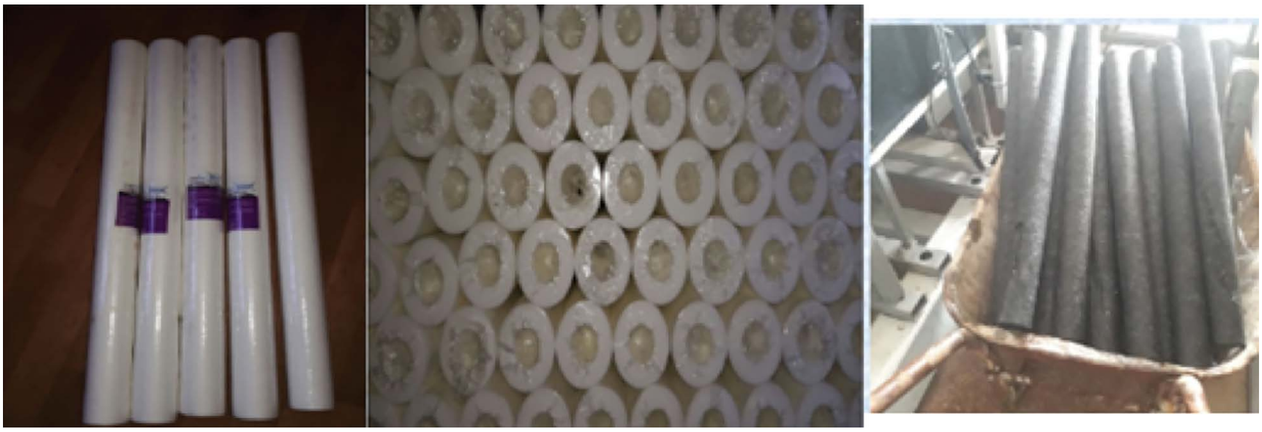

Figure 6. Cartridge filters for >10 μm particulates.

Figure 7. Pump center.

sulfuric acid is circulated with leachate in tank 3 to set pH as 6.4 (Fig. 5). Thus, desired pH value in membranes is achieved. The water that comes out of the tank 3 is delivered to the cartridge filters.

Cartridge Filters and Cat Pumps

Total of 21 cartridge filters consist of 3 modules and 7 in each module (Fig. 6). Cartridge filters prevent the entrance of >10 μm particulates to membrane filter. Andiscalant dosing is applied into the system to prevent any silica formation which causes calcification in the lines. Dydo et al. [16], have declared a similar problem on the examined leachate. They indicated that the wastewater was almost saturated with calcium sulfate, thus causing serious scaling problem. Furthermore, there was a large extent of sulfate ions over stechiometric CaSO4 composition. Also, they claimed that the large amount of magnesium ions could not be ignored for high pH conditions.

Pre-treated leachate from cartridges is transmitted to piston pumps called cat pump. Piston pumps raise the water to pressure of 65 bar. Since the basic logic of reverse osmosis is the pressure purification method, these pumps constitute the most important part of the system. In addition, these pumps require the most serious investment in maintenance and repair costs.

There are 3 cat pumps on the system. Two of them transmit the water to the 1st stage and one to the 2nd stage. Leachate pressurized by cat pump is transmitted to horizontal pumps ensuring the water access to modules (Fig. 7).

Membrane modules

Facility is operated as 2-stage system. 1st stage consists of 100 modules and 21.000 (100x210) disc membranes and it is divided into 4 sections as unit 11/1, 11/2, 11/3 and 11/4 (Fig. 8). The leachate is first taken to the membranes in unit 11/1. The water treated in unit 11/1 is transferred to unit 21 (Fig. 9), and the untreated part to unit 11/2 and this process continues until the 1st stage is completed. The treated leachate in 1st stage is filtered again in unit 21 to get a better-quality effluent (Fig. 10). Unit 21 contains 18 modules and 3.780 (18x210) disc membranes. In this way, permeate and concentrate are produced as a result of the treatment process. Membrane-based treatment processes, including reverse osmosis generate a large volume of membrane con-

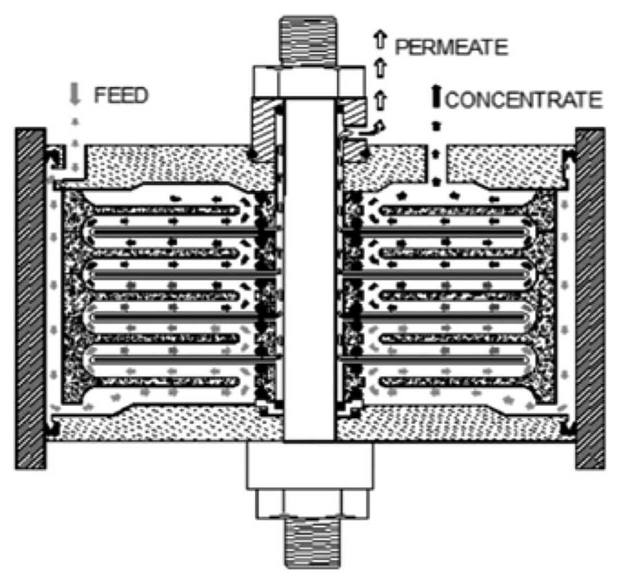

Figure 8. Schematic representation of modules and disc membranes.

centrate (MC) [17]. The concentrate that can no longer be treated in unit 11/4 is sent to concentrate lagoon. Leachate from lagoon is transferred back to the landfill through the pipes and the pumps to distribute the water with jets over the field as ensuring its evaporation and to dilute it by mixing with fresh leachate. The treated leachate from unit 21 is stored in permeate tanks. Caustic is dosed to permeate for a further pH adjustment as 6.9-7.0 and it is discharged into a stream bed by its own attraction.

Operating Problems/Challenges of Reverse Osmosis System for Leachate Treatment

The leachate has the potential to cause serious harm to human health and the environment. High removal of contaminants such as COD, SS, Total N, color, oil/grease, and heavy metal has been achieved using reverse osmosis process (Table 3). It is seen that the effluent discharge parameters are comply with the receiving environment discharge criteria. However, reverse osmosis is difficult process in terms of both operating cost and operating conditions.

Alkaline and acidic cleaning to protect the disc membranes increases the operating costs. Cartridge filter is a consumable with a certain lifetime. Time to change cartridge filter is monitored when the pressure difference reaches 1 bar in the scada system. In addition, andiscalant is dosed to prevent any silica formation in the system. Dydo et al. [16], concluded that the most reasonable method to mitigate scaling problem during reverse osmosis of the examined leachate is chemical softening pretreatment with sodium carbonate and sodium hydroxide mixture. Sodium carbonate will behave as the calcium while sodium hydroxide as magnesium precipitants. At the same time these precipitants will shift the examined leachate pH to the level desired for further treatment.

Figure 9. Unit 21 Disc membranes.

Figure 10. Raw leachate (on the left) and permeate (on the right).

Before the raw leachate is taken into the membranes, sulfuric acid is added to provide the desired pH value in the media. In order to meet the pH discharge criterion, caustic dosing is applied in permeate tank to increase the pH which is reduced at the beginning of the system. The disc membranes used in the system have also a limited lifetime and the membranes constitute approximately 50% of the

Table 3. 3-years (2016–2018 years) averages of influent and effluent parameters of leachate and removal rates by reverse osmosis system

Parameters	Influent water (mg/L)	Effluent water (mg/L)	Removal rate (%)
Chemical oxygen demand (COD)	6464.17	153.17	97.63
Suspended solids (SS)	429.43	<6	98.84
Total kjeldahl nitrogen	1495.90	17.87	98.81
Total phosphorus	10.71	6.00	43.98
Oil and grease	561.83	35.70	93.65
Color (Pt–Co)*	3355.04	142.09	95.76
Total chromium (Cr)	1.05	0.01	98.92
Chromium (Cr+6)	0.39	0.03	91.72
Fluoride (F)	3.04	0.48	84.20
Copper (Cu)	0.03	0.02	46.00
Zinc (Zn)	0.27	0.06	78.75
Iron (Fe)	2.33	0.25	89.43

*Unit of color is (Pt–Co).

Table 4. Consumable quantities reflected in operating expenses

Consumption during the operation	Consumable amount
Sulfuric acid	1872 kg/day
Andiscalant	3.12 L/day
Caustic	156 L/day
Alkaline cleaning chemical	125 L/per cleaning
Acidic cleaning chemical	75 L/per cleaning
Used cartridge filters	21 cartridges/per change

plant investment cost. Due to the sensitivity of the membrane structure and in case of insufficient pre-treatment processes, the membrane life will be completed in a short time. Renou et al. [18], argued that there were important limitations to this process. They stated that high salinities of the leachates caused high osmotic pressures, which required working at high pressures and low conversion rates. Chemical consumption is presented in Table 4 considering the facility as operating at full capacity for 312 m^3/day. The RO process is also strongly limited by the irreversible membrane fouling, which requires frequent chemical cleaning of the membranes [18].

Among the constant problems encountered in the system, there is also the corrosion problem of electronic equipment caused by the H_2S in the leachate content. To prevent corrosion, the facility should be located away from lagoons. In this case, the pump and the electricity cost of the equipment will also create a disadvantage for the system. While making cost calculations at the project stage of the reverse osmosis system, operating expenses should also be taken into account in this direction. Operation of more costly filtration technologies is more complex and requires the experienced teams. That's why problems occur in the leachate treatment plants due to the lack of trained personnel and an efficient treatment process cannot be provided.

The most important factors affecting the feasibility of membrane applications are formation, management, and treatment of the concentrate. Li et al. [11], Liu et al. [12], Renou et al. [18, 19], and Talalaj and Biedka [20], expressed the recirculation of concentrated leachate as one of the most debated options for RO treatment. Especially concentrate removal expenses constitute a significant part of the operating cost of the membrane processes. The rejection of the membrane processes generates a significant volume of membrane concentrate (MC) [21]. The MC is enriched with large quantities of refractory organics and salinity from leachate and is a particularly problematic issue in waste management. Therefore, there is a clear need to explore a scientific and rational route for MC, preventing it from severe environmental contamination.

Although good quality effluent is obtained in the leachate treatment; high costly operating expenses suggest the system is unsustainable. Once the reverse osmosis system is established, municipalities are financially dependent on the manufacturers for membranes, chemicals and other materials that are consumable during operation. Therefore, it is not an acceptable way for developed countries to exploit the financial resources of developing countries to sell their technologies with high operating costs. Similar approaches should be avoided in order to consider the savings and to offer more scientific solutions. For sustainable leachate treatment solutions, methods with lower initial investment and operating costs and, processes requiring a small number of technical staff support should be investigated in developing countries.

CONCLUSIONS

Leachate treatment is one of the most crucial tasks in municipal solid waste management. Reverse osmosis was assigned as an effective method for treating leachate in this study. The RO system has been successfully applied in leachate treatment with high removal rates as 98% of COD, 99% of total Nitrogen, 99% of suspended solids, 94% of oil/grease, 96% of color and substantial heavy metal removal, respectively. The system has sand filters which reduced the load of leachate before the reverse osmosis and increased the membrane lifetime. pH adjustment on leachate was performed before its transferring to membranes. A cartridge filtration was applied at the inlet of the system and pH adjusted pre-treated water was fed to the system with antiscalant dosage. The leachate was taken to the membranes that was operated as 2-stage system. 1st and 2nd stages consisted of 100 modules and 21.000 and 18 modules and 3.780 disc membranes, respectively. Permeate and concentrate were taken to a lagoon to be used in order to humidify the landfill area and for afforestation, respectively. Despite the advantages of system, challenges such as high costly operating expenses, dependency on the manufacturers for membranes, difficulty to struggle with scaling problems, high energy consumption, limited lifetime of membranes and management/treatment of concentrate were clarified as the constraints of reverse osmosis.

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DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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