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# Comparative Evaluation of Membrane Bioreactor (MBR) and Sequencing Batch Reactor (SBR) Technologies for the Treatment of Landfill Leachate in Sri Lanka: Performance and Efficiency Analysis

*N.K.R.N. Jayawardena[1], L.M.L.K.B. Lindamulla[2]

[1]National Aquatic Resources Research and Development Agency, Sri Lanka
[2]School of Engineering, Royal Melbourne Institute of Technology, Australia

*ramodhj@nara.ac.lk

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**Abstract**— Production of leachate and contamination of water bodies is a major concern in solid waste landfills. The generated leachate must be appropriately treated before being discharged into the environment. It can be treated by different physico-chemical and biological methods and their combinations. In this study, the performance of the membrane bioreactor (MBR) and sequencing batch reactor (SBR) technologies are compared in treating landfill leachate. Lab scale models of MBR with working volume of 7.5 L and SBR with volume of 16.5 L were set up and fed with landfill leachate collected from Karadiyana dumpsite, Sri Lanka. The leachate fed to the reactors contained chemical oxygen demand (COD) and biochemical oxygen demand (BOD5) in the ranges of 2100 mg/L-2800 mg/L and 260 mg/L -320 mg/L, respectively. Two treatment systems were assessed for 60 days and analyzed for the performance of removing BOD5, COD, Total Carbon (TC), Total Nitrogen (TN), Sulphates and Phosphates. The MBR exhibited a superior performance with removal efficiencies exceeding 95% for BOD5, 77% for TC, and 80% for COD. In the case of SBR, the removal efficiencies of BOD5, COD and TC were 76%, 65%, and 51%, respectively. TN removals were below 60% in both the MBR and SBR. The Sulphate and Phosphate removal were 37% and 76% for MBR and 25% and 48% for SBR. The SBR technology offers flexibility in cycle time and sequence, however, its performance is constrained when considering landfill leachate associated with significant variations in quality and quantity. The MBR technology improved removal efficiencies significantly.

**Index Terms**— Landfill Leachate, Membrane Bioreactor, Sequencing Batch Reactor, Wastewater Treatment

## 1. INTRODUCTION

Municipal solid waste management is a significant challenge, with landfilling remaining as common approach despite various available techniques [1], [2]. Landfills can be classified as sanitary or open dump sites [3]. In many countries, both developed and developing, continue to practice open dump sites instead of sanitary landfills without concerning the environmental risks associated with landfills. These risks include the generation of toxic leachate, contamination of nearby water bodies such as groundwater and surface water [4], [5], [6], [7], and the release of methane into the atmosphere, contributing to greenhouse gas emissions, especially when methane recovery systems are absent [8].

Leachate is produced when rainwater percolates in a landfill and interacts with the decomposed waste. This is resulting in the various contaminants to be dissolved in the moisture [9], [10]. The composition and the volume of the leachate varies according to factors such as landfill age, climate, hydrogeology, and waste composition [11]. As a landfill is getting aged, the ammonia concentration of leachate increases while the organic matter decreases [12]. High ammonia levels in older landfills arise from the hydrolysis and fermentation of biodegradable waste [4], [13], [14]. The relationship between landfill age and leachate composition must be critically understood to determine the suitable treatment methods. Leachates typically contain high levels of organic matter, humic substances, ammonia-nitrogen, heavy metals, chlorinated organics, and inorganic salts [15], [16], [17]. The landfill lifecycle includes four phases: aerobic, acetogenic, methanogenic, and stabilization [18].

Traditional landfill leachate treatment methods fall into three main categories: (a) leachate transfer, (b) biodegradation, and (c) physical and chemical methods [19], [20]. Leachate transfer is generally paired with municipal sewage treatment due to its low cost and maintenance ease. Nevertheless, the presence of persistent organic compounds and heavy metals will hinder the treatment efficiency of this method [21]. Recirculating leachate back into the landfill is another cost-effective strategy [22], [23], enhancing moisture content and facilitating nutrient distribution among methanogens, ultimately reducing methane production and chemical oxygen demand (COD) [24]. Nonetheless, excessive leachate recirculation can inhibit methanogenesis due to the accumulation of toxic organic acids ($pH < 5$), leading to ponding and acidic conditions [16], [25].

Physical and chemical treatments such as flotation, coagulation/flocculation, adsorption, chemical oxidation, and air stripping are being used in leachate treatment, which effectively remove suspended solids, color, colloidal particles, and toxicity. Nevertheless, these methods often come with obstacles such as high energy demands for equipment like ozonizers and UV lamps [26]. Biological treatments can be aerobic or anaerobic, depending on the presence of oxygen. In aerobic treatment, organic pollutants are converted into carbon dioxide and sludge, while anaerobic treatment produces biogas primarily composed of carbon dioxide and methane with minimal sludge. Biological processes effectively remove organic matter and nitrogen from young leachates with a high BOD/COD ratio ($> 0.5$), but their effectiveness reduces over time due to compounds like humic and fulvic acid [27].

Two advanced biological treatment technologies, Sequencing Batch Reactor (SBR) and Membrane Bioreactor (MBR), are commonly used for wastewater treatment. SBR operates as a fill-and-draw activated sludge system, where wastewater is treated in a single reactor that combines equalization, aeration, and clarification [28]. MBR systems integrate biological treatment with membrane separation, commonly used for municipal and industrial wastewater. The demand for high-quality effluent in municipal wastewater treatment has led to the adoption of MBRs, which effectively eliminate not just carbon and nutrients but also bacteria and viruses [29]. In MBR systems, microfiltration or ultrafiltration is used, with the membranes either placed inside or external to the bioreactor, often configured as flat sheets or hollow fibers [30].

Understanding leachate characteristics is vital for selecting appropriate treatment methods [31], [32]. Various biological and physical/chemical treatments have been developed for leachate, with biological methods targeting biodegradable fractions and physical/chemical methods used for pre- or post-treatment of persistent contaminants [33]. Treating landfill leachate biologically is particularly challenging for mature leachates [34]. Combined biological and physical/chemical processes, such as the MBR system, have gained recognition for treating high-strength wastewater with complex, recalcitrant compounds [35].

In the context of Sri Lanka, the implementation of MBR systems for leachate treatment is costly and lacks flexibility. This study investigates the feasibility of SBR and MBR for leachate treatment, aiming to evaluate if SBR could serve as a cost-effective alternative to MBR. Comparative research on SBR and MBR for local leachate treatment is rare in the Sri Lankan context.

## 2. MATERIALS AND METHODS

### 2.1 SBR Design

Fig. 1. (a) shows the cross-sectional view of the SBR reactor. The reactor model was made from a cylindrical Perspex tank where the bottom was modified to have a slope made of a 2 mm thick steel cone. This was to support the settling of solids during the setting phase. At the tip of the cone, a stop valve was fitted to extract samples. And the influence pipe was inserted to the tank from the top opening and the effluent motor was submerged in the tank at the level of 6.7 L. A mechanical agitator powered by an electrical motor was fixed at the top tank and the air was supplied by an aquatic air pump where the blowers are fixed at the bottom of the tank. After setting up the model, the operational phase was carried out. Initially the model was run by water to verify the system is watertight. Then the sludge from the wastewater treatment plant at Temple of Tooth Relic was introduced. Then sludge kept accumulating for four weeks.

(a) (b)

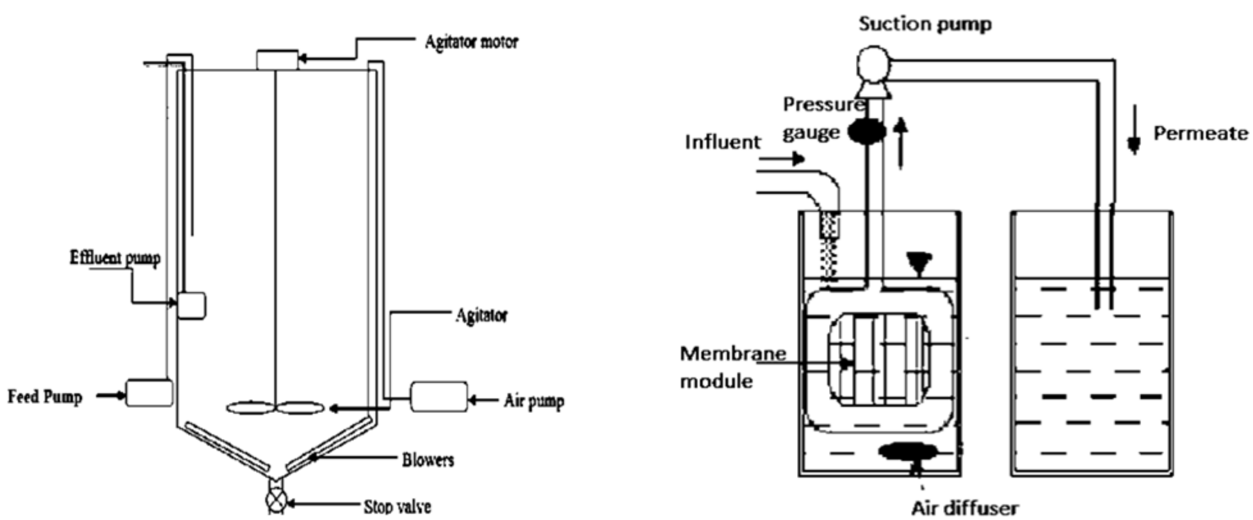



Fig. 1. The cross-sectional view of SBR (a) and MBR (b)

### 2.2 MBR Design

A laboratory scale MBR was set up in the laboratory. The treatment system was planned with an inlet tank and an aerobic MBR (Fig. 1. (b)). The working volume for aerobic tank was 7.5 L. A hollow fiber hydrophilic polyether sulfone microfiltration membrane module with pore size 0.1 µm and effective area of 0.012 $m^2$ is submerged in the aerobic reactor to separate the biomass from permeate. Aeration for the membrane surface scouring and biological aerobic digestion is supplied by a compressed air pump. The reactor was seeded with waste activated sludge from the leachate treatment plant of the temple of tooth relic in Kandy. Automatic backwashing is provided for 3 minutes after every 12 minute of permeating so that 15-minute cycles are continued. The SBR and the MBR model systems were run with natural leachate. The leachate collected from Karadiyana Dump Site was used to investigate the performance of SBR and MBR models. As per the research done by Hashemi, the COD loading rate of the influent was kept within the range of 0.75 g COD $L^{-1}day^{-1}$ to 1.5 g COD $L^{-1}day^{-1}$ [36]. The samples were taken from the inlet, SBR outlet and MBR outlet and investigated for the removal efficiencies for COD, $BOD_5$, TC, TN, Sulphates and Phosphates.

The operating conditions of the two systems are given in Table 1.

Table 1: Operational conditions of the treatment systems

| Operating Conditions | SBR | MBR |
|---|---|---|
| Reactor volume (L) | 16.7 | 7.5 |
| Feed rate (L/d) | 10 | 1.8 |
| HRT (Hours) | 40 | 96 |
| SRT (Days) | 30 | No removal |
| Organic loading rate | 1.5 | 0.5 |

**2.3 Analytical Method of Sample Analysis**

$BOD_5$ was measured after a 5-day incubation at 20°C in a BOD incubator using Winkler's titration method (APHA, 2017). The phosphate, sulphate and COD were analyzed using standard methods from APHA 2017. The TC and TN were analyzed using the TOC/TN Analyzer (Shimadzu, Japan).

## 3. RESULTS AND DISCUSSION

**3.1 COD variation of the systems**

Fig. 2. (a) shows the system performance of SBR and MBR for the abatement of COD. The feed wastewater to both systems was maintained at a COD range of 2474 ± 183.12 mg/L. In the beginning, the SBR showed only a removal of 27 % where the COD reduced only to a value of 1865 mg/L. But the MBR exhibited a COD removal of 81.17 % reaching the value of 482 mg/L. After that the removal efficiency in SBR gradually increased up to 78 % with time. In MBR, the removal efficiency increased from 81 % to 90 % and the removal was stabilized with time. The SBR reached to a maximum reduction to a value of 458 mg/L while MBR reached to a COD value of 177 mg/L. When comparing the results with the previous researches, Kulikowska et al., obtained a removal efficiency of 76 % for COD in SBR for landfill leachate [12]. Furthermore, it has been found that the COD removal increases when the duration of aeration phase increased. And the higher HRT also helps to increase the COD removal in higher percentage [37], [38]. The SBR cycle is a 24-hour cycle and the length of the aeration period, and the higher HRT can be identified as the reasons for the COD removal in SBR. It is important to know if increasing cycle period and MLSS concentration significantly affected the SBR performance. It has been found that the MLSS concentration has no impact towards the improvement of SBR while increasing the cycle time from 12 hours to 24 hours, the removal of COD was increased. But increasing from 24 hours to 48 hours did not show in increase [39]. This indicates the most of the substrate degradation occurred during the first 12 hours and a smaller portion was degraded in the rest of the time [8], [39]. A wide range of COD removal efficiencies were reported for leachate treatment using MBRs, from as low as 23% to as high as above 90%. However, it is worth noting that COD removals greater than 75% were attained under optimal operating conditions in the majority of the previous studies [34]. More than 90 % of COD removal for leachate by MBR was obtained by other research as well [40], [41], [42], [43].

**$BOD_5$ variation of the systems**

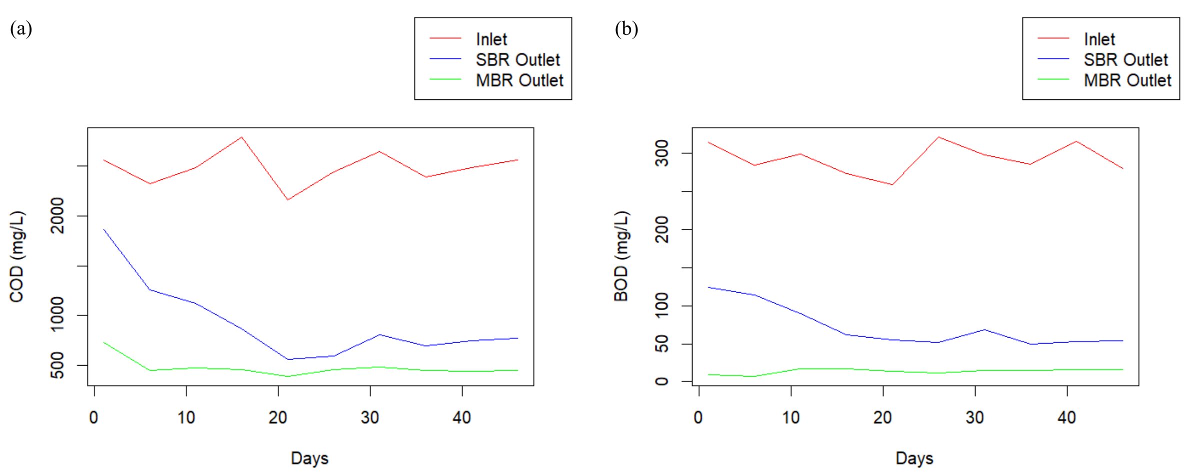
The performance of the SBR and MBR for $BOD_5$ removal is elaborated in Fig. 2. (b). The $BOD_5$ of the feed wastewater was 294 ± 20.7 mg/L. At first, the SBR showed a removal of 60 % which is higher compared to the COD removal percentage. After that the removal steadily increased up to 83%. But the removal decreased on $28^{th}$ day, increased and stabilized. The $BOD_5$ was reduced to a maximum value of 49.5 mg/L. When comparing the removal efficiency of MBR, the $BOD_5$ was reduced to 9.15 mg/L showing a removal of 97 % initially. Then the removal slowly decreased up to 94% and stabilized throughout the monitoring period. The removal of $BOD_5$ is easy for MBR. The average removal of $BOD_5$ is 97 % [44] which was very much similar to the results obtained by this experiment. These results can be obtained by the MBR regardless of the leachate age or the operating conditions used [45].

**TC variation of the systems**

Fig. 2. (c) shows the removal of TC in SBR and MBR with the time. The feed wastewater had an initial TC of 499 mg/L and increased with time. The average TC concentration was 673 ± 148.5 mg/L. The same removal pattern can be observed in the TOC graph. The initial removal was 45 % in SBR and increased up to 62 %. After that it decreased and stabilized at the range of 47 % - 50 %. Initially, the SBR reactor is aerated to provide oxygen to the microorganisms. Aerobic bacteria, including heterotrophic bacteria, consume organic matter as a food source and biologically degrade it through the process of aerobic respiration. This leads to the conversion of complex organic compounds into simpler compounds such as carbon dioxide ($CO_2$), water ($H_2O$), and microbial biomass. Oxygen availability in this phase promotes the growth and activity of aerobic microorganisms. Following the aerobic phase, the aeration is stopped, and the settle phase begins. During this phase, the activated sludge, which consists of microorganisms and biomass, settles to the bottom of the reactor through gravity. The settle phase allows for solid-liquid separation and facilitates the removal of excess biomass from the treated leachate.

**TN variation of the systems**

TN removal in SBR and MBR is shown in Fig. 2. (d). The feed wastewater had a TN concentration of 475 ± 127.62 mg/L. Initially the SBR showed a removal of 34 % while MBR showed an 18 % removal. The removal was increased gradually in SBR and stabilized with time. But the removal of TN in MBR showed an irregular pattern. The SBR showed a maximum removal of 59 % and MBR 71 %. The nitrogen in wastewater is removed by the processes of nitrification and denitrification. In this process, nitrifiers, including ammonia-oxidizing bacteria (AOB) and nitrite-oxidizing bacteria (NOB), convert total ammonia (free ammonia and un-ionized ammonia) to nitrate. Denitrification happens in an anoxic environment in which denitrifies reduce nitrate and nitrite to nitrogen gas [46]. The nitrification is an aerobic process where the denitrification is an anaerobic/anoxic process [47]. During the react phase where aeration is supplied, nitrification would occur converting total nitrogen into nitrates. After the react phase, the aeration is stopped hence creating an anoxic phase where oxygen is limited. During the settling phase, the denitrification converted the nitrates into gaseous nitrogen and removed from the leachate effluent.



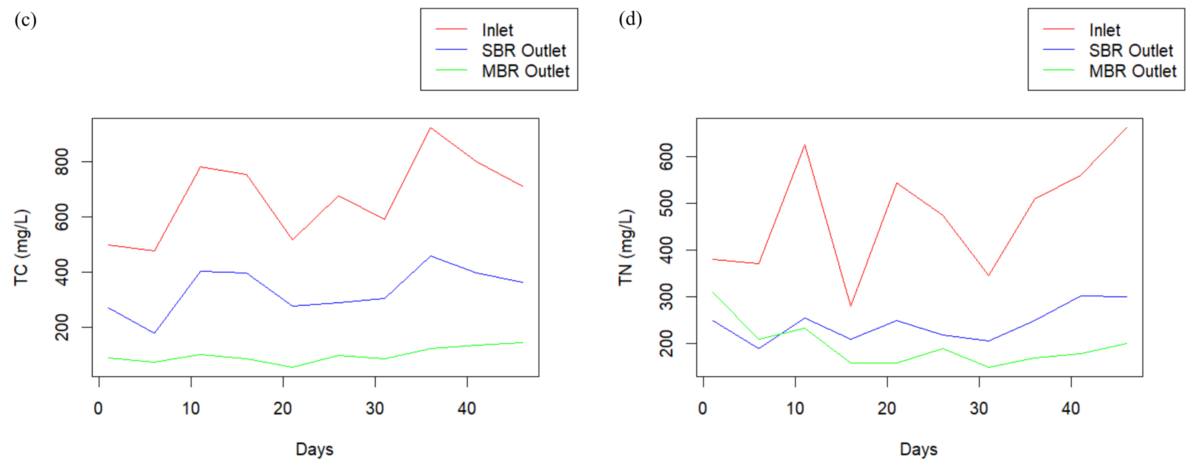



Fig. 1. The variation of COD (a), BOD (b), TC (c) and TN (d)

**Sulphate variation of the systems**

The Sulphate removal by SBR and MBR within the monitoring period is expressed by Fig. 3. (a). The feed wastewater had a Sulphate concentration of 281.2 ± 47.57 mg/L. Initially, the SBR and MBR showed higher removal efficiency. But the removal efficiency has been reduced with the time in both SBR and MBR. At first, the SBR showed a removal of 56 % and MBR a 95 %. The reduction of Sulphate gradually decreased in the SBR. But in MBR, the abatement was drastically reduced to 7 % after 12$^{th}$ day. With time, the removal was reduced in both SBR and MBR and stabilized in a percentage of 13 % and 7 % respectively. When comparing the results with previous researches, Mohan et al achieved 8.3 % of Sulphate removal by SBR which quite similar to the results obtained by this research [48]. A conventional aerobic system cannot reduce sulphates, because conversion involves an anoxic / anaerobic environment. During the sequence activity, sulphate transformation in the SBR reactor may be due to the prevalent anoxic zone in the internal layers of the suspended biofilm and to the induced anoxic conditions. The size of the biofilm flock affected significantly the degree and nature of the anoxic environment. Normally, the particle size of the biofilm was 10–110 µm in the ASP plant. The 200 µm and above biofilm flock should have an anoxic microinch in the inner part of thick flocks [48]. In this study the biofilms larger than 200 µm may induced an anoxic phase, which lead to sulphate transformation.

**Phosphate variation of the systems**

The feed wastewater had a Phosphate concentration of 23.7 ± 4.96 mg/L. The SBR showed a 47 % of initial removal, increased up to 55 %, decreased to 46 % and stabilized. The MBR showed a removal of 76 % at first. After that the removal was increased and decreased to 61 %. Then the removal was stabilized at 78 % for the removal of Phosphates in MBR. When comparing the results, the SBR showed a removal efficiency within the range of 32 % to 50 % for the feed wastewater having 30 mg/L [49]. In this research also the phosphate concentration was within the range of 17 mg/L to 32 mg/L and showed a removal of 47 % which was like the previous research results. The microorganisms that could accumulate phosphorus within their cells are known as polyphosphate-accumulating organisms (PAOs). In SBR, filling without aeration was used which created favorable conditions for PAOs to take up phosphorus. During the subsequent aerobic phase, the PAOs release phosphorus as orthophosphate [50]. This can be identified as the theory behind the removal of phosphorous in SBR.

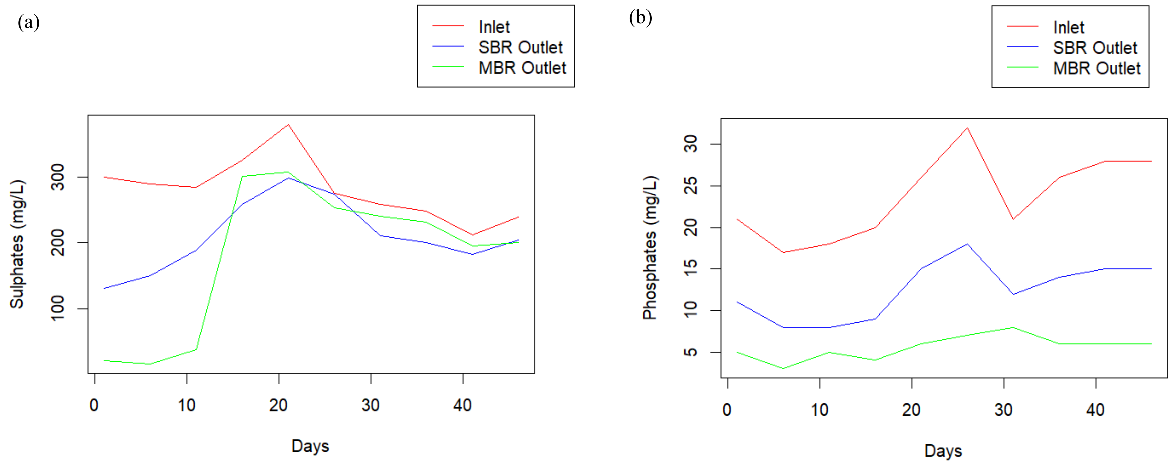



Fig. 2. The variation of Sulphates (a) and Phosphates (b)

**Paired T-Test**

The paired t-test was done to compare the inlet vs. outlet (SBR and MBR) values for each parameter to find whether there is a significant reduction in pollutants. The obtained results are tabulated in Table 2.

Table 2: Paired t-test results

| Parameter | Inlet and Outlet of SBR | | | Inlet and Outlet of MBR | | |
|---|---|---|---|---|---|---|
| | t value | p value | 95% Confidence Interval | t value | p value | 95% Confidence Interval |
| COD | 12.347 | 6.04E-07 | 1552.2 | 37.938 | 3.05E-11 | 2003 |
| BOD | 22.875 | 2.77E-09 | 220.5 | 41.906 | 1.25E-11 | 278.8 |
| TN | 7.3813 | 4.19E-05 | 233.3 | 6.6271 | 9.62E-05 | 280.5 |
| TC | 14.398 | 1.61E-07 | 339.7 | 8.0842 | 2.04E-05 | 514.9 |
| Sulphates | 4.3424 | 0.001871 | 71.3 | 2.741 | 0.02281 | 100.6 |
| Phosphates | 20.225 | 8.23E-09 | 11.2 | 13.454 | 2.89E-07 | 18.1 |

When looking at the values obtained, both SBR and MBR show significant reductions in all the measured water quality parameters (COD, BOD, TN, TC, Sulphates, Phosphates), but MBR consistently outperforms SBR in terms of mean difference, indicating it is more effective in reducing pollutants. The p-values for all tests are extremely small (well below 0.05), confirming that the differences between the inlet and outlet values are statistically significant.

## 4. CONCLUSION

In this study, the performance of the MBR and SBR technologies are compared in treating landfill leachate. Two treatment systems were assessed for 60 days and analyzed for the performance of removing $BOD_5$, COD, TOC and TN. The MBR exhibited a superior performance with removal efficiencies exceeding 95% for $BOD_5$, 88% for TOC, and 80% for COD. In the case of SBR, the removal efficiencies of $BOD_5$, COD and TOC were 76%, 65%, and 59%, respectively. TN removals were below 60% in both the MBR and SBR. Nevertheless, this research was conducted for the COD loading rate of 1.5 kg COD/m$^3$/day and obtained removal efficiencies. The removal efficiencies of each parameter would be varied with changing the COD loading rate. When the leachate has a COD concentration of 2500 mg/L and a $BOD_5$

concentration of 300 mg/L, the MBR and SBR can achieve the efficiencies. The SBR technology offers flexibility in cycle time and sequence, however, its performance is constrained when considering landfill leachate associated with significant variations in quality and quantity. The MBR technology improved removal efficiencies significantly.

## 5. ACKNOWLEDGMENT

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