Civil Engineering Research Magazine
CERM
ISSN 1110-0990
Vol., 46, 2025.

Start Up Performance of Lab-Scale Bioreactor Landfills with Egypt Municipal Solid Waste Composition

M. A. Hussieny[a,b,*], M. H. Abdel Razik[a], S. Elagroudy[a,b], M. Abdelaziz[c]

a Public Works Department, Faculty of Engineering, Ain Shams University, 1 ElSarayat St., Abassia, Cairo, Egypt.
b Egypt Solid Waste Management Center of Excellence, Ain Shams University, 1 ElSarayat St., Abassia, Cairo, Egypt.
c Structural Engineering Department, Faculty of Engineering, Ain Shams University,1 ElSarayat St., Abassia, Cairo, Egypt.
*Correspondence: maged.abdallah@eng.asu.edu.eg

Abstract: Four lab scale bioreactor landfills with 250 liter each containing different composition of municipal solid waste was constructed and operated at the Egyptian solid waste center of excellence, Cairo, Egypt. Design of this lab-scale research included a temperature and humidity sensors, leachate collection system, and gas sampling vents, which provided for continuous temperature and humidity data and periodic measurements of both the quantity and composition of the leachate and gas produced. The data represents the lab scale bioreactors initial performance for the first two months. Temperature, humidity, and leachate characteristics (Ph, Alkalinity, Calcium, Magnesium, Sodium, Chloride, Sulfate, and Phosphate) are investigated.

Keywords: MSW Management – Landfill Leachates– Leachate Characterization – Bioreactor Landfill.

1. Introduction

In many developing countries, inadequate waste disposal systems result in municipal solid waste (MSW) from urban and rural areas being openly dumped. This issue of improper waste management is exacerbated by rapid population growth, leading to increased waste production. Without effective collection or treatment mechanisms, waste disposal methods become unsanitary and environmentally harmful, often resulting in waste being deposited near residential areas or in untreated open dumps. These waste dumps are significant public health hazards, fostering the spread of diseases and posing risks to both human and environmental health. To address these uncontrolled open dumps and transition towards sustainable waste collection and treatment, there is a need for increased research into technologies that enable effective and rapid waste degradation, as well as efficient leachate and by-product management. One promising technology is Bioreactor landfill which facilitates continuous biological degradation through leachate recirculation, leading to improved control and treatment of waste. Research on bioreactor landfills began in the early 1970s, and today, various laboratories in the United States, Australia, and Germany have conducted full-scale studies on this technology, demonstrating its benefits for waste stabilization, leachate management, and landfill gas (LFG) generation.

Managing landfills as bioreactors has been proposed as an environmentally sustainable alternative, with a few cells receiving regulatory approval on a case-by-case basis. Bioreactor landfills provide several environmental and financial advantages, such as faster waste stabilization that reduces long-term groundwater contamination risks and shortens post-closure care requirements. They also enable quicker methane production, making recovery more cost-effective, and allow for faster settlement, which increases the available volume for waste disposal during the landfill's operational period (EPA, 2007b; Pacey et al., 1999; Reinhart et al., 2002; Reinhart and Townsend, 1998). A few landfills or sections of landfills have been operated as bioreactors, and only a limited number of scientific studies have been conducted. Most of these studies have focused on increasing moisture levels through leachate recirculation and water addition to enhance bioactivity (Augenstein et al., 1997; Barry and Demme, 1997; Dahl, 1998; Maier et al., 1995; Moore et al., 1997; Pagano et al., 1998; Townsend et al., 1994; Warzinski et al., 2000; Wilson et al., 2000). Although these experiments have provided valuable insights, the overall knowledge remains limited, and many studies are constrained by the challenges of working within an existing cell. Currently, researchers and engineers lack a comprehensive scientific understanding of the key physical, chemical, and biological processes that influence bioreactor landfill performance. Additionally, there is no rigorous assessment of whether bioreactor landfills can achieve all the claimed benefits or if there might be unexpected negative consequences.

There is a need to develop enhanced design parameters and operating guidelines for bioreactor landfills. These landfills will require methods to achieve and maintain higher moisture levels, efficiently collect increased gas production, address potential negative impacts from faster settlement, and evaluate different approaches to liner and cap construction. This study seeks to compare landfill leachate quality and gas emissions based on available data on the composition of municipal solid waste (MSW) in Egypt. The goal is to optimize the design of MSW landfills across different regions of Egypt, addressing potential threats to the sustainability of solid waste management (SWM) practices and developments, particularly in relation to landfill and leachate lining systems.

2. Materials and Methods

Synthetic solid waste was prepared and loaded into 4 bioreactors designated R1 to R4 based on the average MSW composition obtained from site visits to various locations in Greater Cairo (Hussieny et al., 2022). Bioreactors R1 and R2 represent waste from two distinct lifestyle areas in Cairo (northern & eastern Cairo and southern & western Cairo), while bioreactor R3 corresponds to the MSW composition at the Shabramant dumpsite in Giza. Bioreactor R4 reflects the MSW composition of Al-Obour and 15th May landfills, which are engineered landfills situated in northern & eastern Cairo and southern & western Cairo, respectively. R1 composition is 29.64% organics, 19.89% plastic, 2.86% paper, 0.46% metals, 0.69% glass, 19.05% textiles, and 27.41% other waste. R2 composition is 45.73% organics, 15.34% plastic, 2.21% paper, 0.36% metals, 0.53% glass, 14.69% textiles, and 21.14% other waste. R3 composition is 57.90% organics, 28.40% plastic, 3.20% paper, 0.60% metals, 2.70% glass, 4.20% textiles, and 3.0% other waste. R4 composition is 72.70% organics, 19.45% plastic, 5.70% textiles, and 2.15% other waste.

Four high-density polyethylene (HDPE) cylindrical containers, each with a capacity of 250 liters, 60 cm in diameter, and 90 cm in height, were used to simulate landfills. The design and setup of the bioreactors are illustrated in **Figure1.** Each bioreactor featured a 5 cm gravel layer at the bottom for leachate drainage, covered by two perforated low-density polyethylene (LDPE) sheets to prevent clogging and ensure uniform leachate flow. Perforated PVC pipes were installed vertically for gas collection, and a ½-inch ball valve was added at the bottom for leachate collection and sampling. MSW was loaded and compacted in layers using a rod. Each bioreactor had a separate gas collection system consisting of three 70 cm tall PVC perforated pipes embedded in the waste. A ½-inch nozzle on each cover facilitated gas transfer to a graduated transparent HDPE pipe half-filled with water, allowing gas volume measurement through water displacement. A ball valve controlled the release of collected gas. Settlement within each bioreactor was monitored using a graduated steel bar attached to a plate within the waste, which moved downward to capture changes in waste height.

Figure (1.a): HDPE Cylindrical Containers.

Figure (1.b): Leachate Collection Valve.

Figure (1.c): Gravel Layer with the Two LDPE Covering Sheets.

Figure (1.d): The Gas Collection System

Figure 1: The bioreactors configuration.

3. Results and Discussion

3.1. Temperature

The biological processes within the landfill generate heat, raising temperatures inside the bioreactor landfill. **Figure 2** shows the temperature inside the bioreactors vs. ambient temperature. The temperatures in all bioreactors are below 35 Co due to the MSW organic matter aerobic biodegradation, and the initial adjustment with ambient temperature.

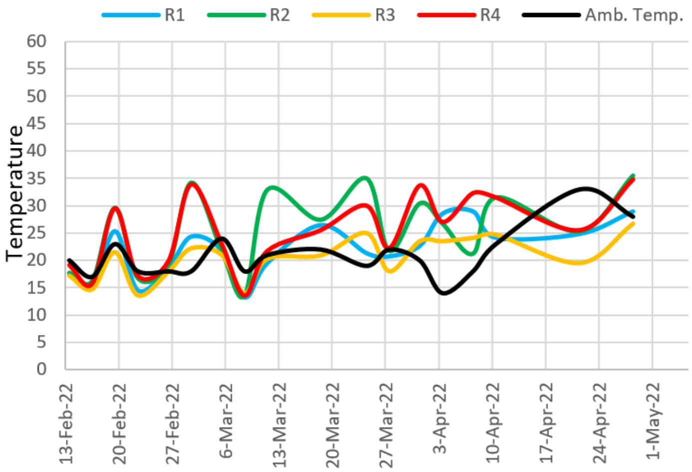

Figure 2: The Bioreactors Temperature vs. the Ambient Temperature.

3.2. Humidity

Initial humidity of all bioreactors was around 52% and then all bioreactors humidity dropped down gradually to 30% in R1, 25% in R2, 35% in R3, and 20% R4. After 70 day, all bioreactors tended to increase the humidity to the range of 40: 50 %. This increase in humidity is due to the waste microbial activity.

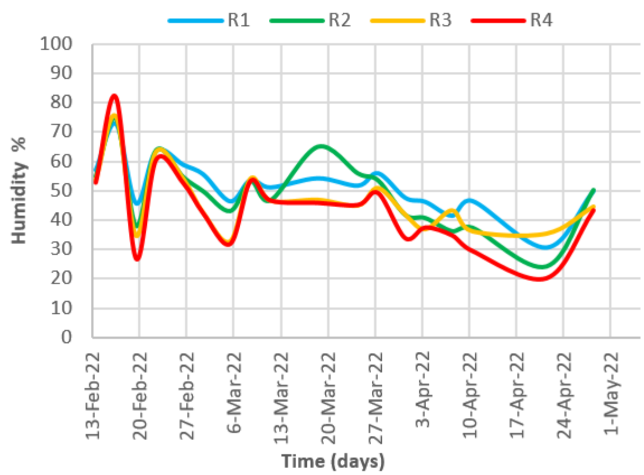

Figure 3: The Bioreactors Initial Humidity.

3.3. pH and Alkalinity

pH is a crucial factor affecting metal concentrations in landfill leachate, with lower pH levels enhancing metal dissolution, a characteristic of young landfill leachate (Kjeldsen et al., 2002). Initially, pH values were in the neutral range of 6.90-7.30 in all bioreactors. During the first three weeks, as MSW transitioned from aerobic to anaerobic degradation, pH dropped to the acidic range of 6.0 to 6.5. Subsequently, pH levels in R1, R2, and R3 increased to 8.0-9.0 by day 86, while in R4, pH decreased to a minimum of 5.80 by day 70.

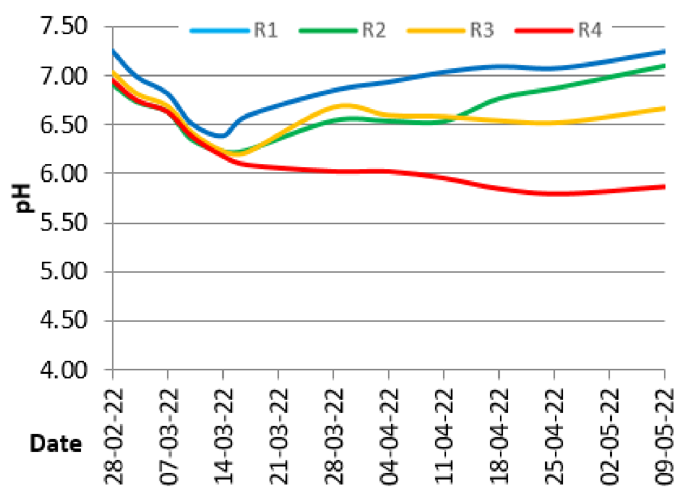

Figure 3: The Bioreactors Initial pH.

Alkalinity is essential for maintaining a stable pH, which is necessary for optimal biological activity in landfills (Vazquez and Varaldo, 2009). The initial alkalinity levels in R1, R2, R3, and R4 were 3891, 5490, 10100, and 12810 mg/L, respectively. In these bioreactors, alkalinity initially increased to its peak values of 9863, 12420, 25000, and 14983 mg/L on days 42, 86, 70, and 230, respectively.

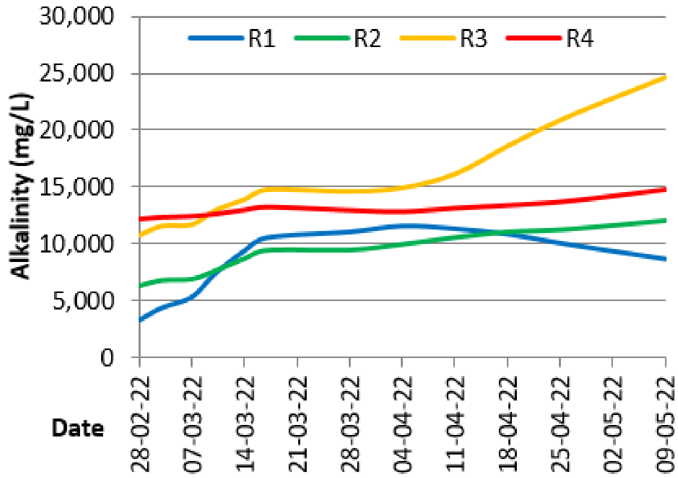

Figure 4: The Bioreactors Initial Alkalinity.

3.4. Calcium, Magnesium, and Sodium

Figure 5 shows the concentrations of Calcium (Ca) and Magnesium (Mg) in the four bioreactors. Initial Ca concentrations were 1100 mg/L in R1, 1000 mg/L in R2, 1,950 mg/L in R3, and 2,450 mg/L in R4. Each bioreactor then reached concentration of 8,400 mg/L in R1 and 4,950 mg/L in R2 by day 35 and 45 respectively, and 7,200 mg/L in R3 and 3,280 mg/L in R4 by day 70. Subsequently, the Ca concentrations stabilized at range of 2,500 to 3,500 mg/L in R1, R2, and R4 but R3 reached Ca concentration of 7,200 at day 70.

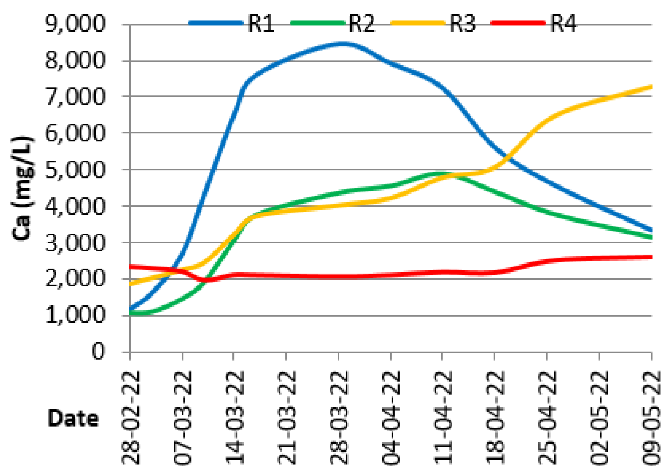

Figure 5: The Bioreactors Initial Calcium Concentrations.

The magnesium concentration values shown in **Figure (6)** varied from 165 to 326 mg/L in R1 and R2, from 200 to 842 mg/L in R3, and from 215 to 492 mg/L in R4. Afterwards, the Mg concentration in R2, R3, and R4 had an increasing trend in opposite to R1 which had a down trend.

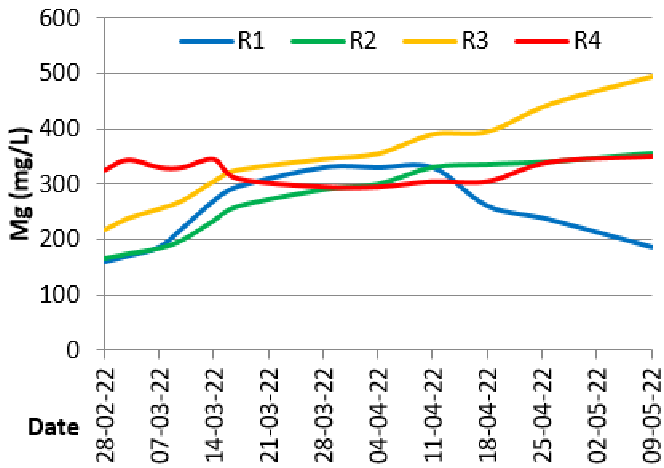

Figure 6: The Bioreactors Initial Magnesium Concentrations.

Sodium concentrations were gradually decreased from 900 to 550 mg/L in R1, increased from 500 to 790 mg/L, and from 500 to 1400 mg/L in R2 and R3 respectively, and decreased from 990 to 650 then increased again to 1050 mg/L in R4 respectively. **Figure (7)** shows up trend for R2, R3, and R4 in opposite to R1.

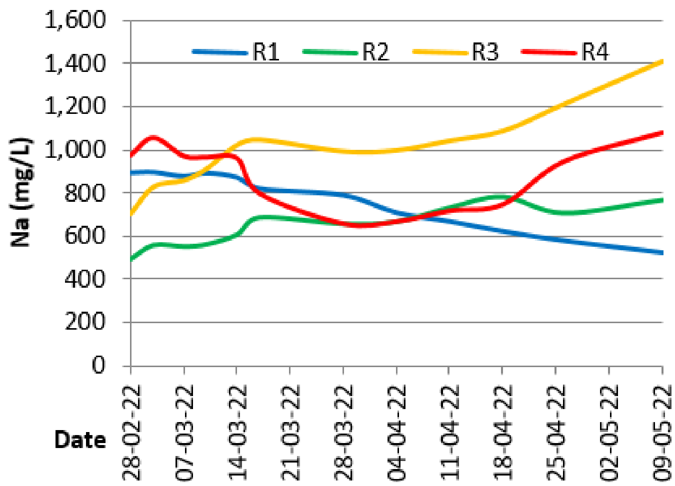

Figure 7: The Bioreactors Initial Sodium Concentrations.

3.5. Chloride, Sulfate, and Phosphate.

Figures (8, 9, 10) illustrate the variations in chloride, sulfate, and phosphate concentrations in the leachate from the bioreactors respectively. Chloride, a non-biodegradable component in leachate from MSW decomposition, is used to evaluate the dilution of the leachate (Bilgili et al., 2007). Cl initial concentrations in R1, R2, R3 and R4 were 1500, 900, 1510 and 1650 mg/L respectively at day 7. It is observed that there is an uptrend in R2, R3, and R4 reaching the range of 1500 to 2000 mg/L in opposite to R1 which has an obvious down trend reaching concentration of 1000 mg/L. According to Manning and Robinson (1999), the chloride concentration in landfill leachate was 1,488 mg/L at a pH of 5.9. When the pH rose to 7.4, the concentration increased to 2,397 mg/L. Thus, chloride concentration increases as pH rises. Chloride ions (Cl^-) are a significant contaminant in leachate resulting from municipal solid waste (MSW) decomposition. Because Cl^- is non-biodegradable, it either migrates into the leachate or adsorbs onto landfill materials. Additionally, Cl^- does not release as gas in the landfill environment. Therefore, most of the Cl^- produced from MSW decomposition is expected to end up in the leachate, with its concentration closely related to the extent of MSW decomposition and the leachate quality (Gu et al., 2020).

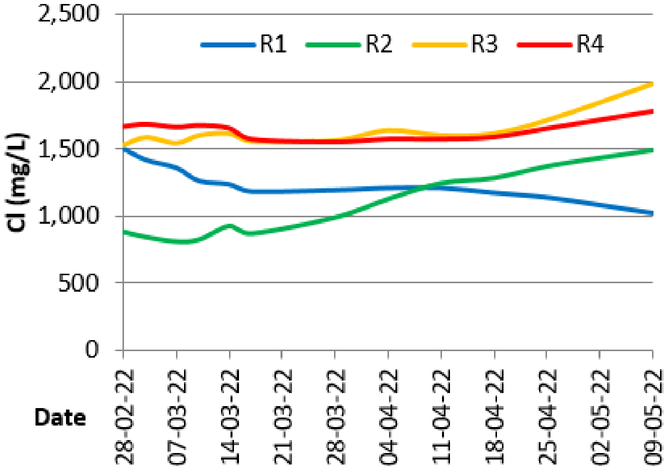

Figure 8: The Bioreactors Initial Chloride Concentrations.

Sulfate is an inorganic element in leachate, and its concentration tends to be lower during the methanogenic phase. During this phase, sulfate microbial reduction to sulfide occurs, often accompanied by higher pH levels. This reduction happens alongside with sorption and precipitation processes during periods of lower organic content (Kjeldsen et al., 2002). SO_4 concentrations were 680, 560, 680, and 810 mg/L in R1, R2, R3, and R4 respectively at day 7. The peak SO4 concentration were occurred at day 55 with 884, 985, and 997 mg/L in R2, R3, and R4, respectively. On the other hand R1 SO_4 peak concentration was occurred at day 10 with 800 mg/L.

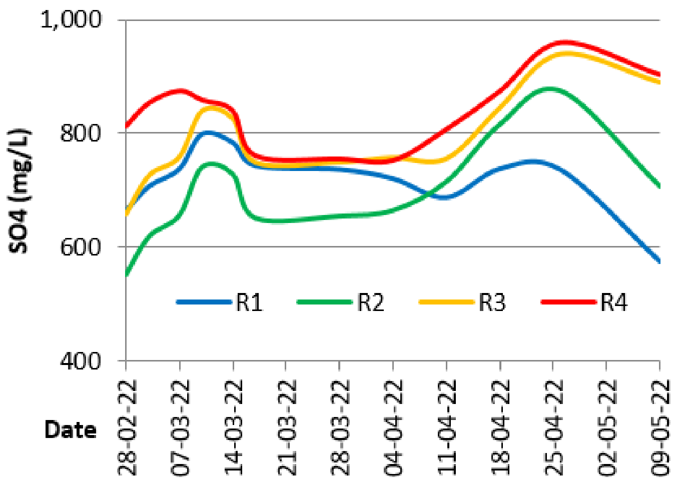

Figure 9: The Bioreactors Initial Sulphate Concentrations.

Figure (10) shows phosphate in the four bioreactors leachate samples which were not detected until day 14 in R1 and R2, and then it was detected in R3, and R4 with initial concentrations of 1.2, and 1.9 mg/L respectively. R3 and R4 reached the PO4 peak concentration of 305 mg/L at day 55 and R4 reached its peak concentration of 310 mg/L at day 58 mg/L.

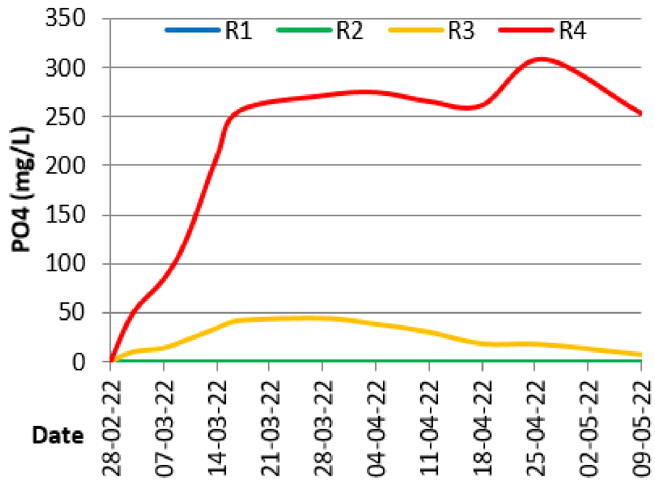

Figure 10: The Bioreactors Initial Phosphate Concentrations.

4. Conclusion

The present study investigated the initial performance of four lab scale bioreactor landfill with different Egyptian MSW composition. Temperature was in the same range in four bioreactors, and humidity at the beginning was high then a down trend was observed in four bioreactors. pH initial values were in the neutral range of 6.90-7.30 in all bioreactors. During the first three weeks, pH dropped to the acidic range of 6.0 to 6.5. Afterward, pH levels in R1, R2, and R3 increased to 8.0-9.0 by day 86, while in R4, pH decreased to a minimum of 5.80 by day 70. The initial alkalinity levels in R1, R2, R3, and R4 were 3891, 5490, 10100, and 12810 mg/L and then increased to its peak values of 9863, 12420, 25000, and 14983 mg/L on days 42, 86, 70, and 230, respectively. Initial Ca concentrations were 1100 mg/L in R1, 1000 mg/L in R2, 1,950 mg/L in R3, and 2,450 mg/L in R4. Mg concentration values varied from 165 to 326 mg/L in R1 and R2, from 200 to 842 mg/L in R3, and from 215 to 492 mg/L in R4. Na concentration in all bioreactors were in range of 450 to 1400 mg/L. Cl initial concentrations in R1, R2, R3 and R4 were 1500, 900, 1510 and 1650 mg/L respectively at day 7. SO4 concentrations were 680, 560, 680, and 810 mg/L in R1, R2, R3, and R4 respectively at day 7. PO4 in the four bioreactors leachate samples were not detected until day 14 in R1 and R2, and then it was detected in R3, and R4 with initial concentrations of 1.2, and 1.9 mg/L respectively.

References

1. Augenstein, D., Yazdani, R., Moore, R., Dahl, K., 1997. Yolo county-controlled landfill demonstration project, pp. 43–83.
2. Barry, R.M., Demme, D.C., 1997. Design innovations at the DSWA's latest landfill expansion project. In: WASTECON Proceedings.
3. Bilgili, Mehmet & Demir, Ahmet & İnce, Mahir & Ozkaya, Bestamin. (2007). Metal concentrations of simulated aerobic and anaerobic pilot scale landfill reactors. Journal of Hazardous Materials. 145. 186-194. 10.1016/j.jhazmat.2006.11.014.
4. Dahl, K., 1998. Reuse of shredded waste tires for landfill gas collection and leachate injection systems in Yolo County's landfill bioreactor demonstration project. In: Proceedings from SWANA's 21st Annual Landfill gas symposium. March 1998, Yolo county, California, pp. 103–117.
5. Gu Z, Chen W, Wang F, Li Q. A pilot-scale comparative study of bioreactor landfills for leachate decontamination and municipal solid waste stabilization. Waste Manag. 2020 Feb 15;103:113-121. doi: 10.1016/j.wasman.2019.12.023. Epub 2019 Dec 20. PMID: 31869722.
6. Hussieny, M. A., Morsy, M. S., Ahmed, M., Elagroudy, S., & Abdel-Razik, M. (2022b). Municipal solid waste and leachate characterization in the Cairo Metropolitan Area. *Resources*, 11(11), 102. https://doi.org/10.3390/resources11110102
7. Kjeldsen, P., Barlaz, M. A., Rooker, A. P., Baun, A., Ledin, A., & Christensen, T. H. (2002). Present and long-term composition of MSW landfill leachate: a review. *Critical reviews in environmental science and technology*, 32(4), 297-336.

8. Maier, T.B.e.a., Steinhauser, E.S., Vasuki, N.C., Pohland, F.G., (1995). Integrated leachate and landfill gas management, Sardinia 95. In: Fifth International Landfill Symposium, Sardinia, Italy, p. 16.
9. Manning D. A. C., N. Robinson. 1999. Leachate-mineral reactions: implications for drainage system stability and clogging. Proceedings of the Seventh International Waste Management and Landfill Symposium, 4–8 October 1999. Cagliari, Italy.
10. Moore, R., Karina, D., Yazdani, R., 1997. Hydraulic characteristics of municipal solid waste: finding of the Yolo county bioreactor landfill project. In: The Thirteen International Conference on Solid Waste Technology and Management, Philadelphia, PA.
11. Pacey, J., Reinhart, D.R., Hansen, D.L., Townsend, G.T., Johnson, W.H., 1999. Landfill bioreactor – an innovation in solid waste management. In: SWANA 22nd Annual LFG Symposium.
12. Pagano, J.J., Scrudato, R.J., Summer, G.M., 1998. Leachate recirculation at the Nanticoke Sanitary Landfill using a bioreactor trench. NYSERDA report 98-6.
13. Reinhart, D., McCreanor, P.T., Townsend, G.T., 2002. The bioreactor landfill: its status and future. Waste Management & Research 20, 172–186.
14. Reinhart, D.R., Townsend, G.T., 1998. Landfill Bioreactor Design and Operation. Lewis Publishers, Boca Raton, Florida.
15. Townsend, T.G., Miller, W.L., Bishop, R.A., Carter, J.H., 1994. Combining systems for leachate recirculation and landfill gas collection. Solid Waste Technologies, 18–24.
16. Vazquez IV, Varaldo HMG (2009) Alkalinity and high total solids affecting H2 production from organic solid waste by anaerobic consortia. Int J Hydrogen Energy 34:3639–3646
17. Warzinski, J., Watermolen, B.T., Genthe, D.R., 2000. A superior approach to recirculation. Waste Age.
18. Wilson, V.L., Evans, W.D., Stark, T.D., c/o Repa, E., 2000. An interim slope failure involving leachate recirculation. In: Municipal and Industrial Solid Waste Disposal Technology Waste Tech 2000, Orlando, Florida.