# Impact of Leachate Recirculation on the Stabilization of Municipal Solid Waste in Anaerobic Bioreactors of Different Compositions

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## ABSTRACT

**The aim of the current study is to determine the impacts of leachate recirculation on the degradation of three compositions of municipal solid waste in anaerobic bioreactors. The study was completed by using six columns with equal volume (0.042m$^3$) containing different densities and compositions of solid waste, in order to follow waste degradation over a limited time. Three compositions of waste were studied: simulated fresh waste of standard composition, simulated fresh waste of fermentable composition, and actual aged waste. Measurements of the significant parameters including pH, leachate conductivity, Chemical Oxygen Demand (COD), and waste settlement, were carried out. The quantity of oxidized organic matter was increased by the leachate recirculation, and the degradation period was reduced by using leachate recirculation. After 300, 150, and 480 days, waste stabilization seemed to be reached for fresh, aged, and fermentable waste, whereas the organic content decreased to 650, 480, and 4000mg COD/L, respectively.**

***Keywords-solid waste stabilization; leachate recirculation; bioreactor; chemical oxygen demand***

## I. INTRODUCTION

The quantity of domestic waste has increased along with population density [1]. Municipal Solid Waste (MSW) generation increases gradually as the commercial and industrial activities extend [2]. The percentages of green and food waste in MSW for middle- and low-income countries are very high [3], whereas landfilling is the most common option of waste disposal. However, during the landfilling process, the high organics amount in MSW often leads to leachate generation [4, 5]. Appropriate landfill management is required globally, especially in developing countries. Early landfill site stabilization and environmental pollution reduction caused by leachates are commonly recognized as important issues. In most developing countries, landfill leachates are treated in stabilization ponds [6], or are collected for further treatment [7]. The leachates are generated either from external water or from within the waste mass [8]. Overflow of untreated leachates or leakage into the environment is a problem because large amounts of landfill leachates are produced by landfill sites with high seasonal rainfalls. Recirculation of leachates in landfills is an attractive technology that can reduce the amount of leachates and limit the decomposition of pollutants in landfills [9, 10]. Leachate recycling is a proven on-site leachate treatment method. It has been shown that leachate recirculation improves biogas production and final leachate quality and reduces waste stabilization time [11]. Bioreactor landfills are designed to address the shortcomings of conventional landfills and reduce long stabilization times [12]. Bioreactor landfills are categorized as aerobic, anaerobic, semi-aerobic, and hybrid, depending on their operational characteristics [13].

Many researchers had applied such or similar techniques to show the impact of leachate recirculation on the stabilization of MSW. Authors in [14] used untreated leachates for liquid recycling and added water to investigate the effect on the anaerobic digestion of food waste. They combined batch analysis of mesophilic Biochemical Methane Potential (BMP) with a cyclical water reuse operation. Cyclic BMP assays showed that using an appropriate proportion of recycled leachates along with fresh water can stimulate the methanogenic activity and promote biogas production. Authors in [15] studied the impact of different leachate recirculation strategies on the discontinuous anaerobic digestion of solid organic waste. Many leachate recirculation strategies have been used in digestion systems of batch solid-phase in laboratoryscales experiments. Comparative studies with intermittent and continuous return of exudate showed no improvement of continuous flow. Authors in [16] used landfill leachates and gases to predict the moisture distribution and the water and gas pores of typical bioreactor landfills as the leachate recirculation or injection system. The effects of the unsaturated hydraulic conductivity and the anisotropic nature and heterogeneity of MSW, the geometry of vertical wells on pore water, moisture distribution, and gas pressure were tested. The unsaturated hydraulic properties of MSW have significant impact on the wetted area and pore water pressure during the initial stage of leachate injection and subsequent gravity drainage. Authors in [17] investigated the combination of a vertical well and a spray recirculation system simultaneously, and stated the impact of their synchronized application on landfill leachates. Authors in [18] investigated the impact of aeration on leachate recycling and waste decomposition rates using leachate quality and quantity. This study investigated the stabilization of MSW in different bioreactor landfills (anaerobic, semi-aerobic, aerobic, and recirculating anaerobic leachate landfills) in terms of leachate characteristics. The results noted that leachate recycling appeared to be a good solution to deliver in-situ treatment and minimize time of leachate stabilization when an aerobic landfill is not applicable. Authors in [19] investigated the effect of a semi-aerobic bioreactor landfill and the co-treatment of leachate recirculation and pre-aeration on landfill stabilization. The results proved high removal rates for COD and ammonia nitrogen, reaching 97% and 88%, respectively. The current research mainly addresses the determination of the effects of leachate recirculation on solid waste stabilization and settlement at different degradation stages and for different compositions (fresh, aged, and fermentable MSW) collected from different locations in Baghdad, Iraq to eliminate the risk of waste contamination in the long term.

## II. EXPERIMENTAL METHOD

### A. *Waste Samples*

The physical compositions of the MSW samples adopted in this study were manually adjusted to simulate the typical MSW compositions in Baghdad based on the average of 12 samples (Table I).

TABLE I. WASTE SAMPLE INGREDIENTS AND COLLECTION POINTS

| District | | Type and weight of waste (kg) | | | | | |
|---|---|---|---|---|---|---|---|
| | | Organic | Plastic | Paper | Metal | Glass | Other |
| **1** | **Al-Shaab** | 41 | 21 | 17 | 5 | 6 | 10 |
| **2** | **Al-Ghadeer** | 43 | 21 | 16 | 4 | 5 | 11 |
| **3** | **New Baghdad** | 42 | 22 | 17 | 4 | 6 | 8 |
| **4** | **Al-Sader1** | 44 | 19 | 16 | 4 | 4 | 13 |
| **5** | **Al-Sader2** | 43 | 20 | 17 | 4 | 5 | 11 |
| **6** | **Al-Adhamya** | 39 | 21 | 19 | 6 | 7 | 8 |
| **7** | **Al-Karada** | 39 | 21 | 20 | 5 | 6 | 9 |
| **8** | **Al-Rasafa** | 39 | 22 | 20 | 5 | 6 | 8 |
| **Average** | | 41.25 | 20.875 | 17.75 | 4.625 | 5.625 | 9.75 |

### B. *Experimental Work*

The experiment was conducted using 6 plastic columns of 750mm height and 300mm diameter, named C1-C6 (Figures 1-2). Each column has a cover and two perforated plastic plates, the first plate at a height of 5cm from the base of the reactor to ensure that the waste does not fall to the bottom during the decomposition process and thus clog the leachate collection valve, and the second plate at a distance of 5cm from the top of the reactor to distribute the recycled leachate and water simulating local seasonal rainfall rate. Finally, an external meter containing two sensors was inserted inside the columns to measure pH and moisture content during the bioreaction processes. Moisture content was maintained within the range of 40 to 60% by weight in order to prevent oxygen deficit due to void saturation from occurring. Table II shows the composition of MSW compacted in each column: fresh waste generated from households without sorting, waste that have been buried for several years from an aged sanitary landfill site, and fermentable only organic waste, which are represented by food waste, tree leaves, and garden waste.

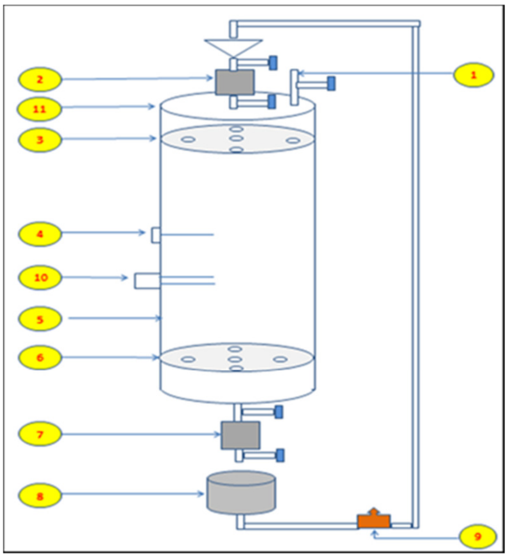

Fig. 1. Sketch of the anaerobic bioreactor. 1-Gas valve, 2-upper storage container for leachate recirculation, 3-upper perforated plate, 4-thermometer, 5-anaerobic biodegradation tank, 6-lower perforated plate, 7-leachate collection container, 8-extra leachate container, 9-pump, 10-pH and moisture content meter, 11-cover for waste feeding.

Fig. 2. Six bioreactor columns.

TABLE II. SOLID WASTE CHARACTERISTICS ACCORDING TO COLUMNS

| Column's code | C6 | C5 | C4 | C3 | C2 | C1 |
|---|---|---|---|---|---|---|
| Waste type | Fermentable | Fermentable | Aged | Aged | Fresh | Fresh |
| Waste mass (kg) | 25 | 25 | 30 | 30 | 15 | 15 |
| Waste height (m) | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| Waste volume ($m^3$) | 0.042 | 0.042 | 0.042 | 0.042 | 0.042 | 0.042 |
| Waste density ($kg/m^3$) | 595.24 | 595.24 | 714.29 | 714.29 | 357.14 | 357.14 |
| Precipitation (L/week) | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| Leachate recirculation (flowrate) (L/day) | 0.03 | 0 | 0.1 | 0 | 0.06 | 0 |

### C. *Analysis Methods*

Leachate samples were analyzed for pH, Chemical Oxygen Demand (COD), and Electrical Conductivity (EC) on a monthly basis. All the parameters were measured according to standard methods [20].

## III. RESULTS AND DISCUSSION

### A. *pH Value*

The pH changes in the bioreactor leachates are depicted in Figure 3. The waste in reactors 1, 2, 5, 6 went through aerobic decomposition and produced a greater initial $CO_2$ concentration due to the tiny amount of air in the voids of the fresh waste after loading. As a result, the pH values decreased over the first 100 days. Leachate recharge has the ability to speed up the hydrolysis of organic matter [12, 21], and acidogens, which are rapidly growing bacteria, have the ability to quickly transform soluble organic waste into volatile fatty acids [22]. The pH levels of the 6 reactors gradually rose to above 8 after 100 days. The relatively lower pH level in the reactors over a longer period of time suggests that acidogenic and hydrolytic bacteria were predominant and that the accumulation of their degradation products, including small molecular organic acids and simple soluble organic matter, delayed the methanogenesis phase. Acidity is the primary inhibitor of methanogenesis under anaerobic conditions. A pH range of 6.5 to 8.0 is optimal for methanogenic bacteria, while a pH range of 5.5 to 6.5 promotes the hydrolysis and acidolysis processes [23]. After this period, the pH of all the reactors rapidly increased and then was maintained at steady state levels.

### B. *Electrical Conductivity Monitoring*

EC in the leachates varied for the 3 types of MSW. High values of EC indicate the presence of high dissolved inorganic materials in samples, yet conductivity values tended to decrease after the $90^{th}$ day, as shown in Figure 4. It should be noted that fermentable solid waste leachates have a higher EC value. This result is in accordance with the findings of [24], where it is reported that average EC declines with increasing landfill age. The loss of some easily mobilized ions, such as sulphate, metals, and chloride, among others are possible causes of the experiment's decreased EC. These factors would tend to remove the ionic strength from the solution.

(a)

(b)

(c)

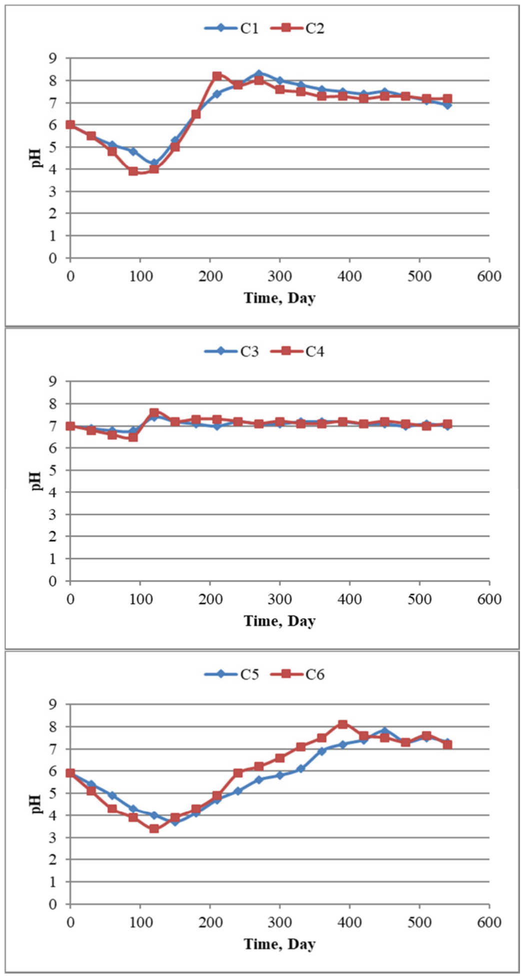


Fig. 3. pH profile of (a) fresh, (b) aged, and (c) fermentable waste.

### C. *Removal of Organic Content*

The primary indication of the impact of contaminants in bioreactors is COD. All of the bioreactors' COD patterns were virtually comparable, and the COD concentration increased significantly throughout the first 100 days (Figure 5). One possible reason for this could be that the generated leachates were produced in an unusually tiny amount, making it impossible for the COD to accurately reflect the concentration of organic matter in the waste leachates. Afterwards, as leachates were recirculated, hydraulic loading was increased accordingly providing additional nutrients and sufficient moisture to accelerate the rates of biodegradation [25]. Moreover, food waste is a component that degrades quickly [26]. Because there were not enough microbes to completely break down all the soluble organic waste, the concentration of COD was likely higher [27]. In recirculation reactors, COD concentrations rose quickly to maximum levels for both fresh and aged waste after around 90 days of operation, whereas this was accomplished after 120 days for fermentable waste. These findings demonstrate that leachates might leak more organics if the amount of leachate recirculation is increased within a specific range. The COD concentrations in all the reactors rapidly dropped when the bacteria gradually adjusted to the conditions in the reactor. These results are marginally better than those found in [28], despite the fact that their work involved more frequent leachate recirculation and utilized significantly more biodegradable materials.

(a)

(b)

(c)

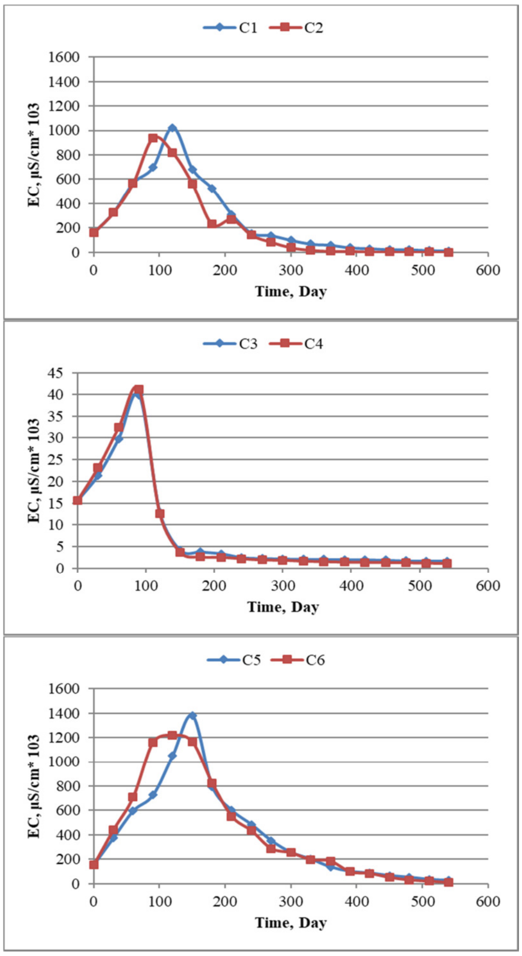


Fig. 4. Profile of electrical conductivity.

## D. Settlement of Solid Waste in Columns

One important criterion that makes anaerobic bioreactor landfills identifiable is the settlement of MSW, is settlement [29]. Following the end of the operation time, all bioreactors had a large settlement, as indicated in Table III, primarily as a result of the waste's gravity-induced settling. The anaerobic treatment showed a higher degree of settlement, indicating that the voids accelerated the rate and amount of subsidence. In [30] and over a 400-day testing period, the settlement in aerobic, anaerobic, and dry anaerobic reactors was 32%, 20%, and 7%, respectively, which are lower than the values acquired during the current study. This may be due to the biological decomposition of organic materials, which is influenced by humidity and the amount of organic material in the waste and partially determines the degree of settlement [31, 32]. The low aeration rates for the anaerobic reactors in this experiment could lead to high moisture content in waste, which has a visible effect on the biodegradation of organic matter. Moisture content is also essential for microbial activity.

(a)

(b)

(c)

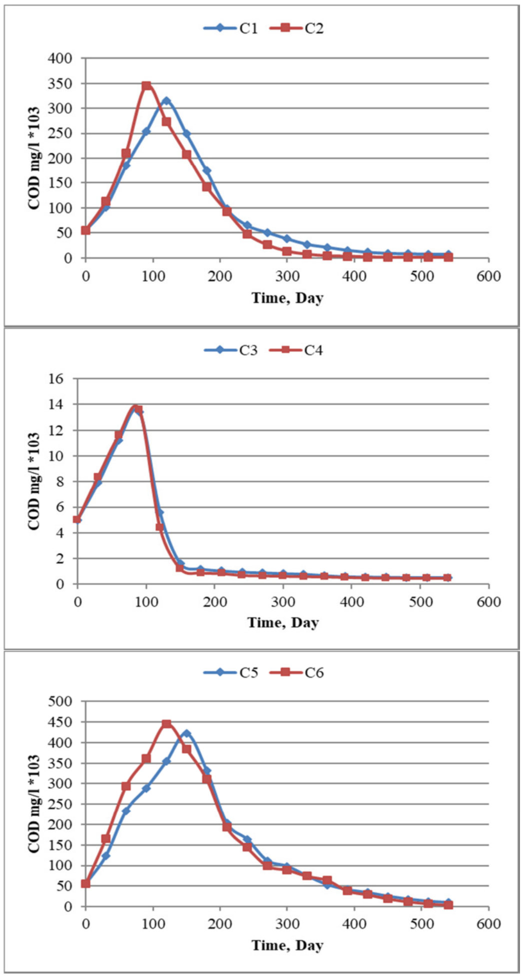


Fig. 5. Profile of organic content removal

TABLE III. WASTE SETTLEMENT INFORMATION

| Code | C6 | C5 | C4 | C3 | C2 | C1 |
|---|---|---|---|---|---|---|
| **Total height (cm)** | 60 | 60 | 60 | 60 | 60 | 60 |
| **Original colume ($cm^3$)** | 42412 | 42412 | 42412 | 42412 | 42412 | 42412 |
| **Final height (cm)** | 5 | 17 | 44 | 45 | 29 | 34 |
| **Final height (%)** | 8.33 | 28.3 | 73.3 | 75 | 48.3 | 56.6 |
| **Remaining volume ($cm^3$)** | 3534 | 12017 | 31102 | 31809 | 20499 | 24033 |
| **Removed height %** | 91.67 | 71.7 | 26.7 | 25 | 51.7 | 43.4 |
| **Removal ratio difference** | 6C&5C | | C3&C4 | | C1&C2 | |
| **Percentage%** | 20% | | 1.7% | | 8.3% | |

## IV. CONCLUSION

The usage of different solid waste columns allowed characterizing the main stages of waste decomposition in a limited period of time and highlighting the main disadvantages and advantages of leachates recycling for waste decomposition. Waste composition and degradation rate have a significant impact on the duration of the degradation process. Recirculating the leachate can reduce the time it takes fresh and old waste columns to reach the methanogenic stage.

Recirculation appeared to limit the risk of waste contamination in the long run. The amount of oxidizable substances co-released into the leachates was even more significant for columns in circulation. The quality of the recycled leachates and the quality of the leachates released from the waste appeared to be similar. After 450 days of recirculation, injecting the still-contaminated leachates appeared to mask contamination that could still be released by the waste.

This study has shown interest in the application of leachate recirculation due to advantages such as the shortening of the deterioration period. The quality of the recirculating leachates and the type of waste (composition and degradation state) are the parameters that determine the impact of recirculation on emissions. The waste settlements increased the leachate recirculation up to 20, 1.7 and 8.3% for fresh, aged, and fermentable waste, respectively.

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