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IMPACT OF LEACHATE RECIRCULATION ON ORGANIC MATTER DEGRADATION AND LEACHATE STABILIZATION IN A SMALL-SCALE ANAEROBIC BIOREACTOR

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Abstract

In this study, a small-scale anaerobic bioreactor with a volume of 0.0742 m3 was employed to examine how the recirculation of leachate affects the breakdown of organic matter and the stabilization of the leachate. The reactor contained 34.10 kg of organic waste, and various parameters such as pH, alkalinity, conductivity, oxidation-reduction potential (ORP), biochemical oxygen demand (BOD3), chemical oxygen demand (COD), solids, total nitrogen, volatile fatty acids (VFA), sulphate, chloride, sodium, calcium, and potassium were regularly measured to monitor leachate quality. Additionally, physical observations including temperature, settlement, and the amount of leachate generated and recirculated were recorded. The findings highlighted the significance of pH in the anaerobic digestion process, and it was noted that a total settlement of 37.21% of the waste occurred. Over time, there was a gradual decline in the quality of the leachate. Leachate recirculation was found to maintain the optimum moisture content within the required range and to accelerate microbial activity, aiding in the degradation of organic matter. Notably, significant reductions in BOD3, COD, and volatile solids of the leachate were observed, amounting to 84.92%, 82.12%, and 76.90%, respectively. Leachate recirculation was also found to mitigate the need for post-treatment of the leachate.
Keywords: Leachate Recirculation, Organic Waste, Anaerobic Bioreactor

1. Introduction

Cities worldwide are experiencing a substantial surge in municipal solid waste (MSW) due to factors such as population growth, economic advancement, urban expansion, industrialization, and improved living standards. Landfilling has been a prevalent method for MSW disposal globally, particularly in developing nations where it is deemed reliable and cost-effective provided sufficient land is available. However, in India, the volume of waste has escalated due to a lack of control, limited treatment options, and ineffective enforcement of MSW regulations. The improper management and operation of landfills in India pose significant environmental risks, including groundwater contamination, frequent fires, and unpleasant odors. Much of the waste received at Indian landfills comprises organic matter from residential areas, markets, commercial zones, and food establishments, varying in composition and sometimes causing acidic conditions due to low-pH organic materials like lemons, onions, and pickles. To address these challenges, bioreactor landfills have emerged as a viable solution. These sites employ enhanced microbiological processes to accelerate the decomposition and stabilization of organic waste compared to traditional landfills. Leachate, the liquid produced from waste decomposition, is recirculated within the bioreactor landfill to maintain moisture, nutrients, and microbial activity.

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Given the prevalence of acidic conditions in Indian landfills, there is a pressing need to explore the impact of leachate recirculation on organic matter biodegradation under such conditions. Thus, this study investigated the effects of leachate recirculation on the breakdown of organic matter in acidic environments.

2. Materials And Methods

2.1 Experimental Setup

The laboratory-scale anaerobic bioreactor was constructed using synthetic materials, featuring an internal diameter of 0.3 meters and a height of 1.05 meters, resulting in a total volume of 0.0742 cubic meters or 74.22 liters, as illustrated in Figure 1. The cylinder had a thickness of 5 millimeters. Positioned at the center of the bottom, just above the leachate outlet, was a plastic ball measuring 70 millimeters in diameter, 4 millimeters thick, and containing 75 holes with a diameter of 5 millimeters. This ball served to prevent the clogging of the leachate outlet.To facilitate the drainage of leachate, a layer of coarse gravel, 10 millimeters thick, was placed at the bottom of the reactor. This gravel layer comprised particles of 12.5 millimeters at the bottom, with a layer of 10 millimeter-sized gravel placed on top of the 12.5 millimeter gravel layer.

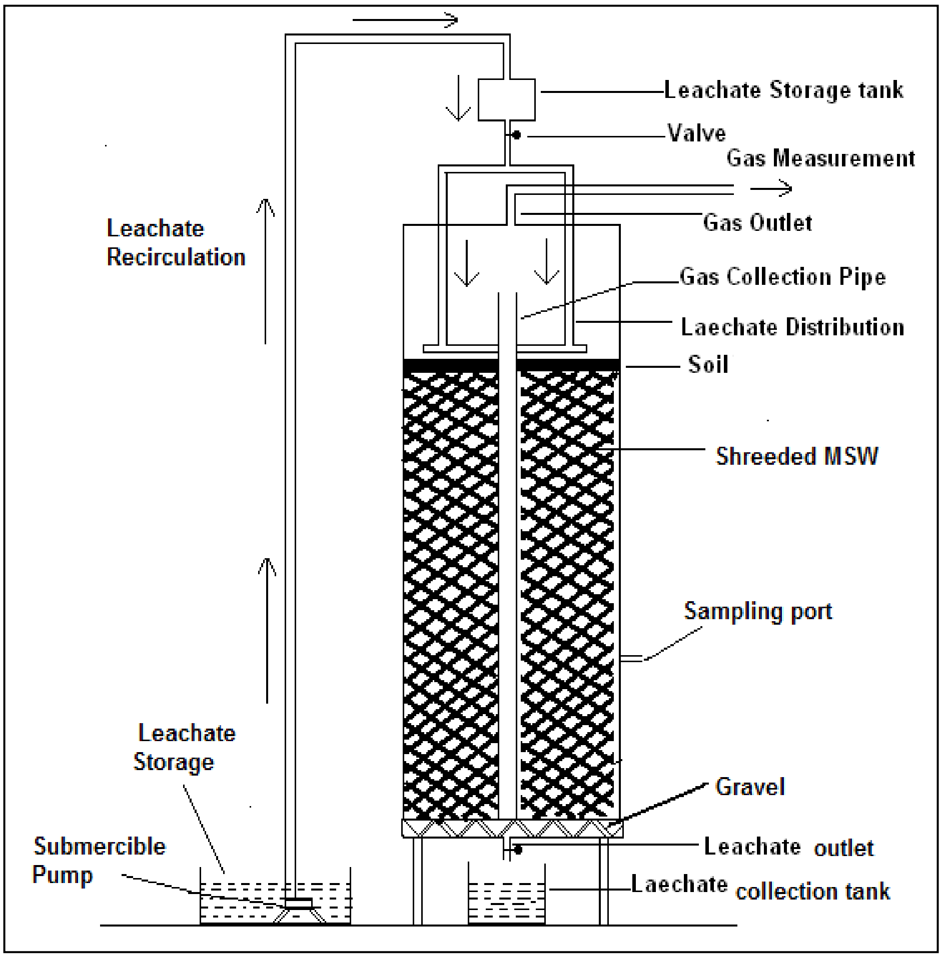

Figure 1 Schematic representation of lab scale anaerobic bioreactor

The waste, weighing 34.10 kilograms and with a density of 635 kilograms per cubic meter, was systematically filled into the bioreactor in layers. Each layer was manually compacted to a

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thickness of 100 to 150 millimeters. The total height of the waste reached 0.86 meters, with a freeboard of 0.19 meters. To ensure uniform moisture distribution throughout the waste mass, a 50-millimeter-thick layer of soil was placed on top of the waste. For gas collection, a pipe with a diameter of 40 millimeters and a height of 1 meter was installed in the middle of the waste mass. This pipe featured 430 holes, each with a diameter of 5 millimeters. Additionally, a sampling port, with a diameter of 25 millimeters and located 0.40 meters above the bottom, was provided for temperature measurement and sampling purposes. The bioreactor, situated on the terrace of the college building and exposed to atmospheric conditions, was covered from the top. Leachate was collected in a plastic bucket with a volume of 5 liters positioned at the bottom of the bioreactor. From there, the leachate was pumped through a submersible pump into a 20-liter leachate storage bucket for recirculation. The submersible pump, a model KR 1900 manufactured by Futura Industries in India, had a maximum head of 2.5 meters, operated at a voltage range of 165-250 volts and 50 hertz, with a power rating of 40 watts, and an output of 1800 liters per hour. Leachate was injected into the reactor through the upper soil layer using a perforated PVC pipe, with a control valve between the leachate storage bucket and the distribution system to regulate the flow rate. A water displacement assembly was set up for measuring gas production.

2.2 Preparation of Waste Sample

Organic waste was gathered from various sources including residential areas, vegetable markets, and the college mess to ensure a representative sample. Inorganic materials were meticulously separated from the waste. The waste was manually shredded to achieve a size range of 40 to 60 millimeters. To inoculate anaerobic microorganisms, a cow dung slurry of 10 liters was added and thoroughly mixed with the waste before filling the reactor. The characteristics of the waste feed supplied to the reactor are detailed in Table 1.

2.3 Analytical Method

Weekly analysis of the leachate included various chemical parameters such as pH, electrical conductivity, total solids (TS), total dissolved solids (TDS), total volatile solids (TVS), total fixed solids (TFS), chemical oxygen demand (COD), biochemical oxygen demand after 3 days (BOD3), total nitrogen (TN), chloride, oxidation-reduction potential (ORP), sulphate, sodium (Na), calcium (Ca), potassium (K), volatile fatty acids (VFA), and alkalinity. These analyses were conducted in accordance with Standard Methods (APHA AWWA, 1998).
Additionally, measurements of both atmospheric and reactor temperatures were recorded. The settlement of waste was initially measured before sealing the reactor and again at the conclusion of the experimentation period.

Table 1 Characteristics of waste at starting and end of experimentation

	Total quantity of wet waste, kg	Total solids, %	Volatile solids, %	Fixed solids %	Organic Matter, %	Moisture content, %
At starting	34.10	21.119	85.414	14.586	94.473	45.97
At end	23.60	23.081	67.581	32.419	73.117	46.759

2.4 Operational Protocol

The experimentation period spanned from July 10, 2009, to September 7, 2009, totaling 90 days. Throughout this period, the generation and recirculation of leachate were consistently

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monitored. Periodically, the pH of the recirculated leachate was adjusted by introducing an alkaline solution (CaOH) to elevate the pH of the waste mass, ensuring the maintenance of anaerobic conditions.

Initially, the waste possessed adequate moisture content, allowing for leachate recirculation after 23 days. The volume of leachate recycled every 7 days ranged from 3 to 6% (v/v) of the waste in the reactor, equivalent to 2 to 3 liters. Over the entire experimentation period, a total of 32.30 liters of leachate were generated, with 21.9 liters being recirculated. Additionally, tap water was intermittently added to sustain a moisture content of 50%, with a total of 11.3 liters of tap water being introduced into the reactor. For analysis purposes, approximately 600 to 700 milliliters of leachate were sampled weekly.

3. Results and Discussion

3.1 Settlement and Degradation of Waste

The initial settlement of waste in the reactor was measured at 5.81%, which increased to 18.60% after 1 day and reached a total settlement of 37.21%. This settling was primarily attributed to the self-weight of the waste, with subsequent settlement occurring due to waste degradation, accounting for 19.61% of the total settlement. Settlement during actual landfill operations can significantly impact various factors including final surface grade, surface drainage, roads, gas collection piping systems, and leachate and air distribution piping systems (A. Suna Erses et al., 2008).

The initial weight of the wet waste was recorded as 34.10 kilograms, which reduced to 23.60 kilograms after 90 days, indicating a weight reduction of 30.79%. This reduction suggests that the time required for organic waste degradation was longer compared to composting methods. The anaerobic digestion process did not occur effectively, likely due to the waste being in an acidic condition.

Initially, the organic matter content was measured at 94.47%, which decreased to 73.11% over the experimental period. Similarly, the volatile solids decreased from 85.14% to 67.58%, further indicating the decomposition of organic matter.

3.2 BOD and COD

The biochemical oxygen demand (BOD) and chemical oxygen demand (COD) were measured as indicators of the organic strength of the leachate. The trend of leachate BOD and COD is illustrated in Figure 2. Initially, the COD value was 74,400 mg/L, which decreased to 20,600 mg/L after 46 days. Subsequently, the COD increased from 20,600 to 32,400 mg/L due to the acidogenic stage, during which volatile fatty acids (VFA) formation increased (see Fig.6). The COD concentration decreased to 12,000 mg/L on day 81 as a result of waste degradation. From day 67 onwards, the COD values began to decrease and eventually stabilized, indicating a reduction in the rate of COD removal.

The trend of BOD mirrors that of COD removal (see Fig.2). The BOD3 to COD ratio is often utilized to assess the biodegradability of organic matter in leachate (Alvarez Vazquez et al., 2004). In this study, the BOD3 to COD ratio decreased from 0.63 to 0.40, indicating a decrease in the biodegradability of the organic matter over time.

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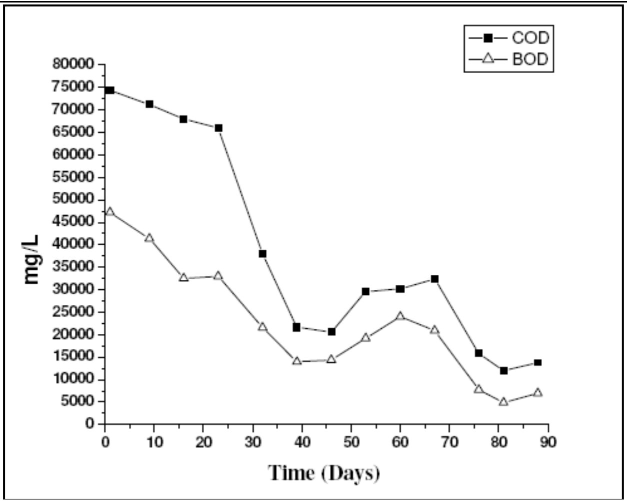

Figure 2 BOD and COD variation with time

3.3 Solids

Kylefors and Lagerkvist (1977) and S.T.S. Yuen (1999) both observed that the concentration of total solids (TS) is expected to decrease as leachate progresses from the acidogenic to the methanogenic stage. Similarly, they noted that dissolved solids concentrations do not undergo significant changes compared to total solids. In the anaerobic reactor, Figure 3 displays the results of all solids measurements. Total solids ranged from 53,800 to 17,520 mg/L, total dissolved solids (TDS) from 47,160 to 14,680 mg/L, and total volatile solids (TVS) from 40,520 to 9,360 mg/L. The percentage reductions in TS, TDS, and TVS were 67.43%, 68.87%, and 76.90% respectively.

The decrease in concentrations of all types of solids can be attributed to the consumption of organic matter in the leachate by bacteria to produce new cells and carbon dioxide. This indicates substantial degradation of solids in the leachate through the process of leachate recirculation. TVS exhibited a similar trend to COD concentration, as depicted in Figure 3. The increase in TVS observed after 60 days was due to the addition of cow dung slurry to the recirculated leachate, which aimed to enhance microbial activity. However, after 67 days, TVS concentration began to decrease due to the degradation of organic matter.

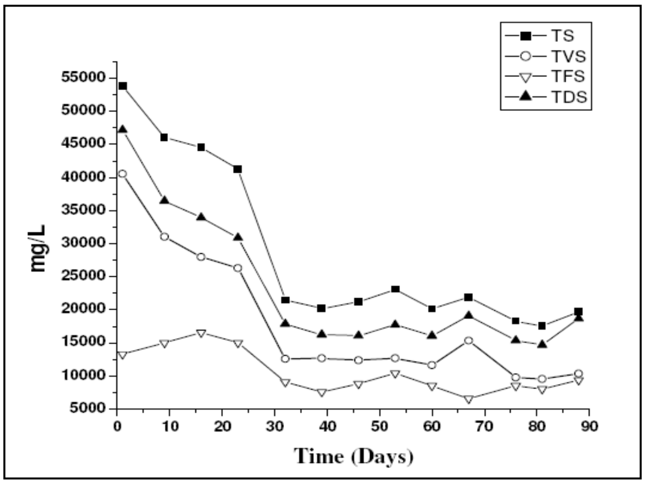

Figure 3 Solids variation with time

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3.4 pH and Alkalinity

Figure 4 illustrates the change in pH of the leachate within the reactor. On the first day, the pH of the leachate was measured at 3.37. To elevate the pH, alkaline solution (CaOH) was intermittently added to the recirculated leachate. After 81 days, the pH increased to 4.92. Observations indicate that the process of increasing pH within the reactor through leachate recirculation was slow.

During anaerobic digestion, the initial formation of volatile fatty acids can hinder pH increase. Therefore, it is essential to check the pH of the waste material at the time of feeding, aiming for a range of 6.5 to 7.5 for optimal anaerobic digestion. Adjusting the pH to the required range can be achieved by adding suitable acidic or alkaline solutions. In this study, the pH did not reach the desired level, likely due to the presence of substances such as lemon and onion in the waste, which inherently have low pH levels.

Throughout the experimentation period, no gas formation was observed due to the waste being in an acidic condition. For the methanogenesis stage to occur, the pH should ideally fall within the range of 6.8 to 7.4. The pH of the waste serves as a crucial operational parameter to maintain anaerobic conditions, as any deviation can significantly impact the entire process. This study suggests that the degradation rate of waste was hindered in acidic conditions, prolonging the treatment time without gas formation.

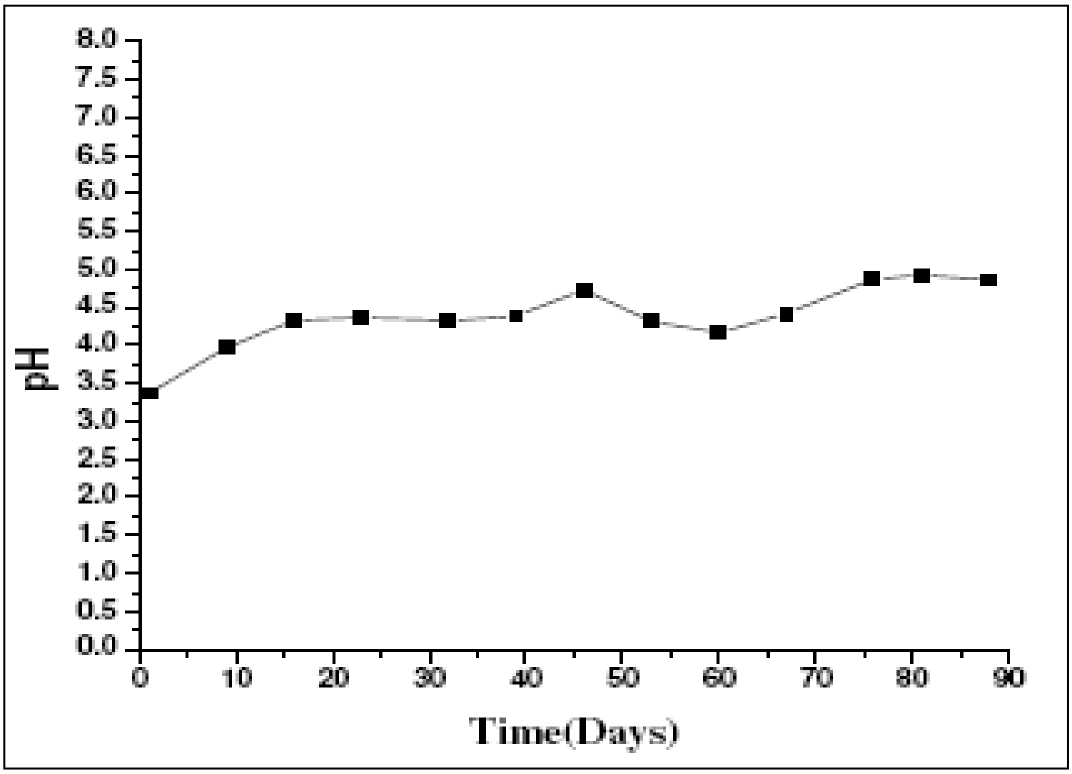

Figure 4 pH variation with time

Maintaining adequate alkalinity is crucial for stabilizing the pH within the reactor and ensuring optimal biological activity. G.J. Farquhar et al. (1973) and Tchbanoglous and Burton (1979) recommended an alkalinity range of 1000 to 5000 mg/L as CaCO3 for effective operation. Figure 5 depicts the variation of alkalinity in the leachate. Initially, the alkalinity was higher, gradually decreasing from 8480 to 3200 mg/L as CaCO3 over time.

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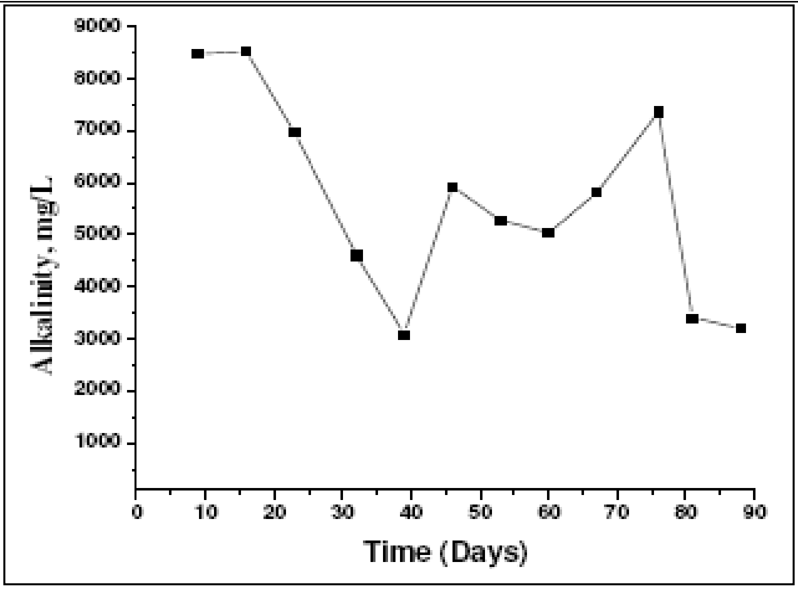

Fig. 5 Alkalinity variation with time

3.5 Volatile Fatty Acids (VFA)

In the anaerobic reactor, the organic waste undergoes hydrolysis initially, breaking down into aqueous organic acids, which are then consumed by acidogenic bacteria to produce volatile fatty acids (VFA) and carbon dioxide. Figure 6 illustrates the variation of VFA concentration over time. VFA concentration fluctuated with time due to variations in acid formation up to day 67, after which it gradually reduced. These fluctuations in VFA concentration corresponded to observations in COD.

Salem Alkaabi et al. (2009) noted that VFA concentration typically increases initially due to the accumulation of organic acids from the hydrolysis and acidogenic processes.

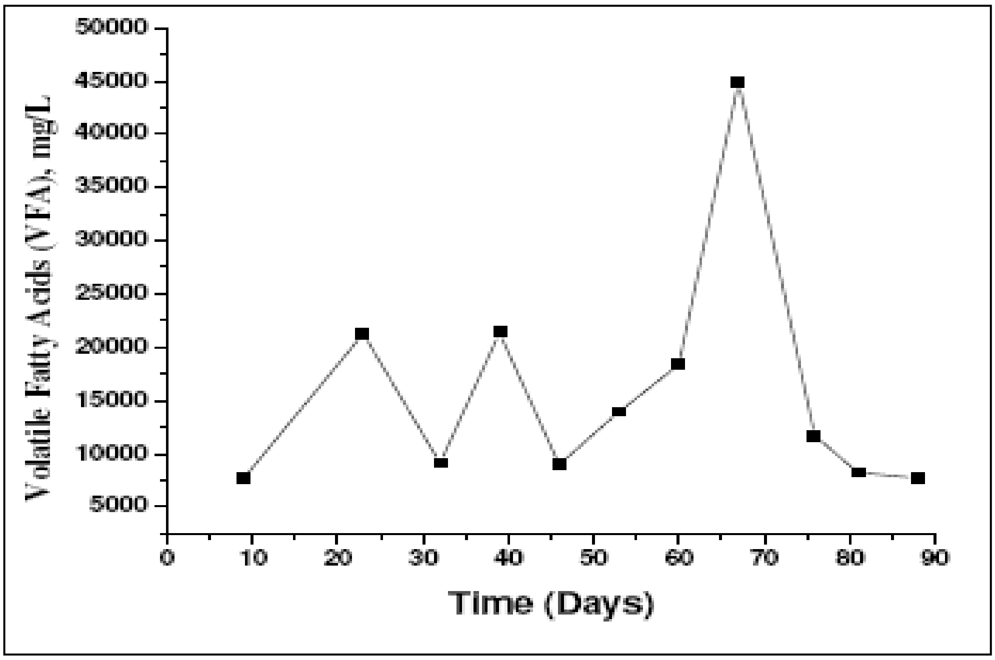

Figure 6 VFA variations with time

3.6 Conductivity

The conductivity of leachate serves as an indicator of its total concentration of ionic solutes and its ability to conduct electric current (A. Suna Erses et al., 2008). In the present study, the variation of conductivity ranged from 16.38 mS/cm to 18.5 mS/cm, as illustrated in Figure 7.

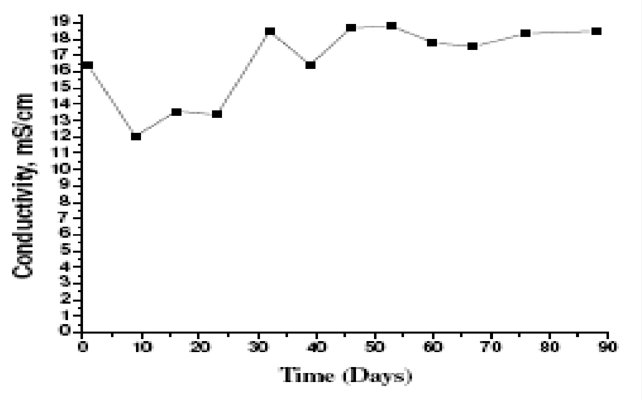

Figure 7 Conductivity Variation with Time

3.7 Oxidation Reduction Potential (ORP)

The redox potential (ORP) within a landfill plays a crucial role in determining the mechanism of waste degradation. Literature suggests that there is an optimum ORP requirement for methanogenesis, typically ranging from -100 to -300 mV (Farquhar et al., 1973, F.G. Pohland, 1975, G.J. T.H. Christensen et al., 1989). It's important to note that ORP tests are highly sensitive to sample storage time, with readings potentially rising fairly rapidly and becoming more positive if tested only hours after sampling (M. Sinan Bilgili et al., 2007). In this study, ORP tests were conducted immediately at the time of sampling.
Figure 8 illustrates that ORP values began to decrease after the initial consumption of available oxygen, indicating a shift in degradation from the acidogenic phase to the methanogenic phase. ORP values fluctuated between the initial period and day 67, after which they increased to approximately -45 mV.

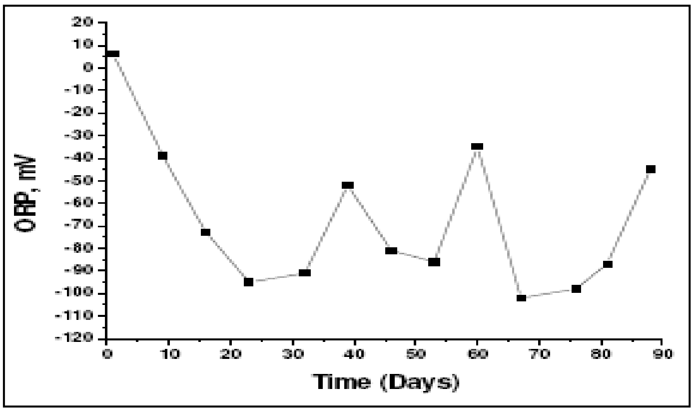

Figure 8 ORP Variation with Time

3.8 Nitrogen

The variation of total nitrogen (TN) in the leachate, as shown in Figure 9, is significant due to its potential contribution to soil and water pollution. Initially, the total nitrogen content was high, likely due to the mixture of organic matter and cow dung slurry. From day 39 onwards,

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the variation in TN value became minimal. This stabilization in TN value can be attributed to the reintroduction of ammonia into the system through the recirculation of leachate into the reactor, reaching a stable stage (A. Suna Erses et al., 2008).

Pohland et al. (1987) indicated that TN concentrations ranging from 200 to 1500 mg/L have shown no adverse effects on the anaerobic process. Concentrations ranging from 1500 to 3000 mg/L exhibited inhibitory effects at higher pH levels, while concentrations above 3000 mg/L were deemed very toxic.

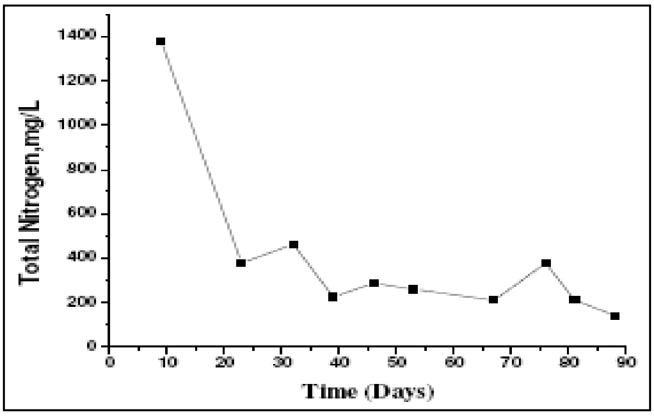

Figure 9 Total nitrogen Variations with Time

3.9 Chloride and Sulphate

Chloride was monitored as a conservative tracer to estimate dilution and washout effects (A. Suna Erses et al., 2008). Initially, the chloride value decreased from 4763 to 1617 mg/L after 32 days, likely due to dilution effects. However, it then increased continuously, possibly as a result of the recirculation of leachate (Figure 10).

Similarly, the sulphate concentration varied over time, as depicted in Figure 13. At the beginning, the sulphate concentration was measured at 2695 mg/L, which increased to 6131 mg/L by day 60 before gradually decreasing.

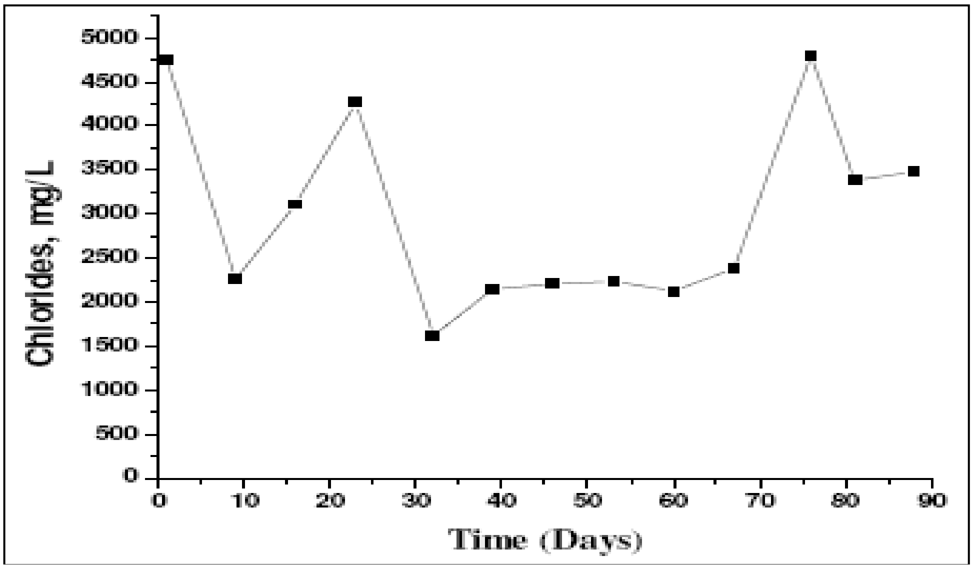

Figure 10 Chloride variations with time

3.10 NA, CA and K

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Figure 11 illustrates the change in alkali metals (Na, Ca, and K) over the experimental period. Initially, the values of alkali metals were higher and declined until day 39. This decrease may be attributed to the recirculation of diluted leachate before day 39. Subsequently, the concentrations of alkali metals increased continuously until day 90.

3.11 Temperature

Figure 13 displays the variations in temperature, which ranged from 22.9 to 32.2°C over the course of the experiment. According to Mehta et al. (2002), observations suggest that leachate recirculation accelerates anaerobic reactions in landfills, leading to increased temperatures within the bioreactor landfill. Rees (1980) noted that the optimum temperature for methane production from domestic refuse in a conventional anaerobic digester is around 40°C.

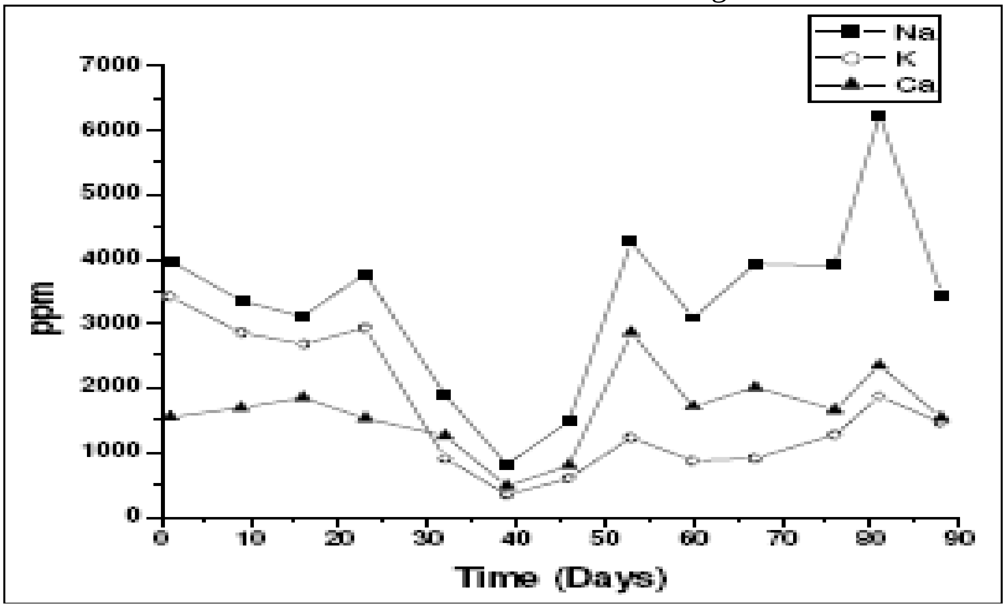

Figure 11 Na, K and Ca variation with time

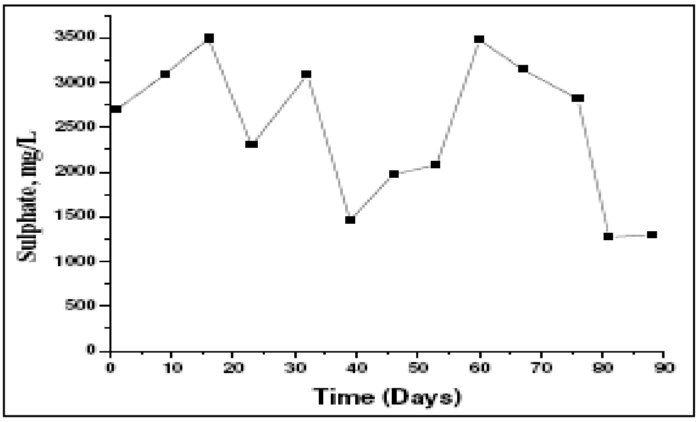

Figure 12 Sulphate variation with time

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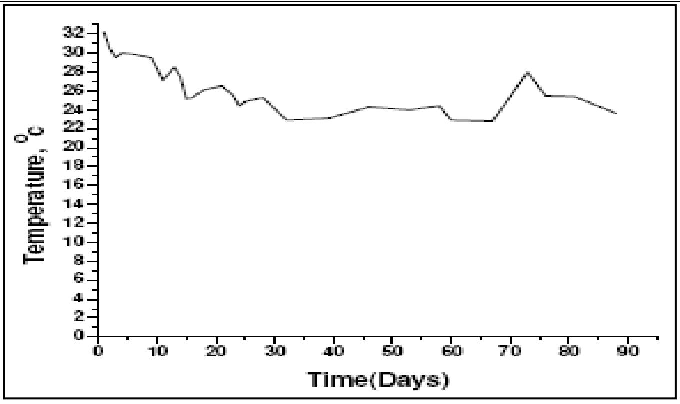

Figure 13 Temperature variations with time

4. Conclusion

In the present study, the influence of leachate recirculation on the biodegradation of organic matter and the stabilization of leachate was investigated using a laboratory-scale anaerobic bioreactor. Leachate recirculation played a crucial role in maintaining the optimum moisture content within the required range, thus accelerating microbial activity and enhancing the degradation of organic matter. However, the presence of organic matter in an acidic condition posed challenges to the anaerobic digestion process. The waste mass exhibited a lower pH value (3.37) at the beginning of the experimentation, and efforts to increase the pH value through the addition of alkaline solutions proved difficult.

Despite the reduction in biochemical oxygen demand (BOD3), chemical oxygen demand (COD), and volatile solids of leachate by 84.92%, 82.12%, and 76.90%, respectively, it was observed that the chemical characteristics of the leachate decreased over time during the acidic condition. However, achieving higher removal efficiency within a shorter timeframe proved challenging. Therefore, it is essential to maintain operational parameters for anaerobic digestion processes or anaerobic bioreactor landfills to ensure better performance of the reactors.

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