British Biotechnology Journal
11(3): 1-10, 2016, Article no.BBJ.22897
ISSN: 2231–2927, NLM ID: 101616695

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Biogas Production from Different Biomass Wastes with/without Leachate Recirculation

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

Article Information

DOI: 10.9734/BBJ/2016/22897
Editor(s):
(1) Standardi Alvaro, Department of Agricultural and Environmental Sciences, University of Perugia, Italy.
Reviewers:
(1) Dipak Kumar Sahoo, Iowa State University, USA.
(2) Roshanida A. Rahman, Universiti Teknologi Malaysia, Malaysia.
Complete Peer review History: http://sciencedomain.org/review-history/12744

Original Research Article

Received 4th November 2015
Accepted 3rd December 2015
Published 19th December 2015

ABSTRACT

This study attempts to determine the effect of leachate recirculation on biogas production. The study was carried out by using the co-disposal of three major wastes: municipal solid waste (MSW), sewage sludge and cow dung. Experiments are carried out in two stainless steel columns with daily feeding. The first reactor (R1: without leachate recirculation) and second reactor (R2: with leachate recirculation) both reactors compacted with 10% of cow dung + 70% of MSW and 20% sewage sludge by weight. Cow dung was added to facilitate the enzymatic hydrolysis or extracellular depolymerisation of polymers such as carbohydrate, fat and protein. The impact of leachate recirculation was investigated. Chemical parameters as pH, Chemical Oxygen Demand (COD), ammoniacal-N, total-P) and gas production (total volume, CH_4 and CO_2) were monitored for 12 weeks. The research demonstrated a dependency between recirculation of leachate and the volume and composition of biogas.

Keywords: Municipal solid waste; landfill capacity; leachate; anaerobic digestion; methane.

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1. INTRODUCTION

The anaerobic digestion of organic solid wastes is a process that has become a major focus of interest in waste management throughout the world. The untreated domestic sewage causes severe ecological harm to the area by polluting ground water and surface water, and it must be disposed safely. The amounts of MSW generated in the Irbed city in north of Jordan is around 1200 t/day, and contains more than 65% of organic wastes. The organic solid waste includes garbage, vegetable and food waste contains 52%, straw and wood contains 14%, clothes 3.1% and paper 3.5%. The present methods of disposal, like landfills are not suitable because in metropolitan cities , where the space is a constraint, valuable land that can be used for diverse purposes is wasted ,in other treatment methods, like incineration and pyrolysis, air pollution problems are predominant and initial investments are also usually too high. Anaerobic digestion processes has been demonstrated to be technically viable [1]. It's often been used to treat soluble and solid types of domestic and industrial wastes [2]. The organic solid waste can biologically be converted to methane and hydrogen by the anaerobic digestion process. There already exists recent literature about the applications and benefits of the anaerobic digestion process to produce renewable energy from various sources of organic solid waste [3,4,5,6]. On the other hand, for each particular biomass type to be used, without any manure or sludge addition, the effects of both operational and environmental parameters on the process performance of the anaerobic biogas digester have to be individually determined. This will help achieve a high conversion efficiency, since each substrate, even different harvests of the same substrate, has its unique characteristics. The biomass resources available in Jordan include sawmill residue, agricultural waste, animal waste, municipal waste and energy crops. Well tested applications for biomass-based technologies are cogeneration, biogas production from anaerobic digestion, and very recently bio-diesel production. Anaerobic digestion is a widely used method for the treatment of sewage sludge [7]. In addition, feedstock for anaerobic digestion include cattle dung and manure, goat dung, chicken droppings, abattoir byproducts, kitchen waste, food processing factory wastes and human excreta [8]. Typically biogas from digesters is composed of 55-75% methane, 30-45% carbon dioxide. Sanitation has become a major development issue in recent years. The increasing amount of organic waste material in both urban and rural communities and also the production of thousands of tonnes of sludge from sewage and wastewater from different agricultural and food industries lead to severe economic and environmental difficulties [9]. The gas yield of an organic material depends on the type of substrate and the Volatile Solids (VS). Other parameters such temperature, carbon-nitrogen (C/N) ratio, loading rate, Hydraulic Retention Time (HRT) also affect biogas yield of feedstock.

Anaerobic digestion is a multi-stage process occurring in the absence of oxygen, where bacteria are the primary organisms involved [10]. The well-established digesters, pH of the fermenting mass are buffered between 6.8 and 7.4. Bacteria have limited range of temperature, in which they are active. Methanogens, in particular, are very sensitive to temperature changes. In this manner, the optimum temperature of anaerobic digestion ranges from 30 to 40ºC [11]. During fermentation of organic wastes, acetic acid is usually the main product. The excess production of Volatile Fatty Acids (VFA) may result in an inhibitory effect on the fermentation of organic wastes [12].The potential biochemical methane production yield from MSW and water can be as 0.2 m3/ kg of VS added [13]. The nitrogen and phosphorus contained in the MSW and domestic sewage are sufficient to satisfy the cell growth requirements during biogas production. The aim of the work was to investigate the possibilities for increasing the biogas production from MSW and swage sludge by study the effects of with/ without leachate recirculation on biogas generated.

2. MATERIALS AND METHODS

2.1 Materials

Samples of municipal solid waste (MSW), is obtained from refuse transfer station in Irbid city, The Organic wastes used in digestion experiments are collected separately, dried by natural methods and stored in a plastic container at room temperature prior to characterization. Cow manure was collected from breed plants in a suburban district in Irbid city. Municipal sewage sludge was sampled from the Foara-Irbid municipal wastewater treatment plant, a few kilometers at Irbid city (which receives both domestic sewage and industrial effluent) is used for seeding the digester. It is used in digestion experiments for diluting the feedstock to achieve the required total concentration of total solids TS. All samples were shredded to a maximum particle size of 3-5 mm prior to physicochemical analysis and the column study. The domestic sewage is added to MSW and cow dung, which is in the form of dry and shredded waste. Here all wastes are mixed so that it forms slurry. The sewage contains organic solids and methanogenic bacteria, which can be easily feed into the digester, which increase the concentration of the substrate. This mixed culture is developed outside the digester. Once the culture enters the digester directly the decomposition process starts and the gas production rate simultaneously increases.

2.2 Methods

Experiment are carried out in two stainless steel columns of 10 cm (diameter) 70 cm (length) , batch mode with daily feeding. The first reactor (R1: without leachate recirculation) and second reactor (R2: with leachate recirculation) both reactors compacted with 10% of cow dung + 70% of MSW and 20% sewage sludge by weight. Cow dung was added to facilitate the enzymatic hydrolysis or extracellular depolymerisation of polymers such as carbohydrate, fat and protein.

To study the influence of anaerobic degradation of a mixture composed of MSW, cow dung and sewage sludge (70:10:20), fresh weight basis, overall gas yield and CH_4 concentration, digester was placed in a laboratory at constant temperature 36ºC. Each digester is equipped with out lit valve in the base to drained and remove 180 mL of effluent leachate used for physicochemical property determination. For the recirculation treatment, the remaining leachate samples were re-applied to the columns. For columns without re-applied leachate, surplus leachate was drain. Two parts at the top of reactor, one for feeding (180 mL) substrate leachate and another for biogas line, which is connect to the calibrated measuring cylinders with water displacement arrangements to measure the volume of gas, collected. The concentrations of CH_4 and CO_2 in the gas samples were determined weekly using a gas chromatograph, (Hewlett Packard 5890 N Series).

2.3 Analytical Methods

The influent and effluent parameters, such as COD (Chemical Oxygen Demand), TS, and VS are measured using methods described in “Standard methods for the examination of water and wastewater”, published jointly by APHA, AWWA, WEF [14]. The biogas composition was confirmed by gas chromatograph. The available methane 67–70% and carbon dioxide 16-18% was present. Waste samples were employed for physicochemical analysis: pH (pH meter; Allen, 1989), total Kjeldahl N and P (determined using a QuikChem automated ion analyzer, Lachat Instruments, after sulfuric acid digestion [15]. For leachate samples, pH was measured by pH probe whereas COD was determined using the chromate reflux method (American Public Health Association, 1985) and the ammoniacal-N and total-P levels were detected by an automated ion analyzer (QuikChem AE, Lachat instruments) according to Chan and coll. [15] procedure.

3. RESULTS AND DISCUSSION

3.1 Composition of Leachate and Municipal Solid Waste (MSW)

The present research was carried out to study the effect of leachate recirculation on Biogas generation from landfill co-disposal of municipal solid wastes with sewage sludge and cow dung in a lab scale anaerobic leachate recirculation reactor. The leachate samples were collected weekly to analyze pH, COD, TS, total N and total P. The physicochemical characteristics of municipal solid waste collected for the present study are shown in Tables 1, 2. The amount of food waste was the highest in general MSW. Soil has the lowest percentage in MSW. It shows that most of the waste dumped at solid waste dumping site consists of kitchen waste. The chemical characteristics of a typical leachate such as Biochemical Oxygen Demand (BOD), Total suspended solid (TSS) are presented in Table 3. In the leachate, reactor R2, there was a steady increase in leachate production rate to a maximum of 3 L in the first week while, the leachate production rate in R1 maintained a low level as shown in Fig. 1.

Table 1. Composition of municipal solid waste

Composition	Food wastes	Paper	Plastics	Cloth	Wood	Soil	Fine fraction
Weight percentages (%)	50.6	22.4	3.6	4.4	7.3	2.5	9.2

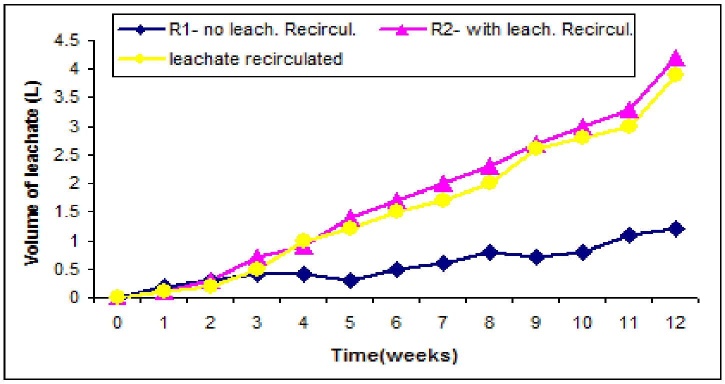

Fig. 1. Volume (L) of leachate collected from treatments with and without leachate recirculation and of leachate being circulated

3.2 Chemical Oxygen Demand (COD)

Since, the boundary between each stage of an anaerobic digestion could not be determined exactly, COD, BOD and methane production are used to depict. The results from many studies in laboratory indicated that the leachate recirculation showed exact advantage on COD removal. The reactors with leachate recirculation showed significantly rapid degradation and also reached stabilization more quickly than those without recirculation. This might be because the leachate recirculation could decrease acidogenesis and methanogenesis period [15,16]. Moreover, the effects of leachate recirculation are clearly more effective in anaerobic reaction [17].

Fig. 2 shows that the initial COD concentration in the leachate sample collected from both reactors (R1, R2) were around 6000 mg/L. The COD value in leachate in reactor R1 increased up to 10500 mg/L on the 6 th week and then started to decrease but in reactor R2 the COD value of leachate increased upto 9600 mg/L by the 4 th week and then started to decrease.

Table 2. Characteristics of municipal solid waste

Parameters	MWS	Sewage sludge	Cow dung
pH	8.7	8.2	8.5
Moisture content (%)	57.8	93.8	64.3
Volatile solid (%)	61.3	83.1	89.8
Fixed solid (%)	37.4	7.50	8.9
Total-N (mg g^{-1})	3.89	7.0	1.38
Total-P (mg g^{-1})	9.87	2.02	2.62

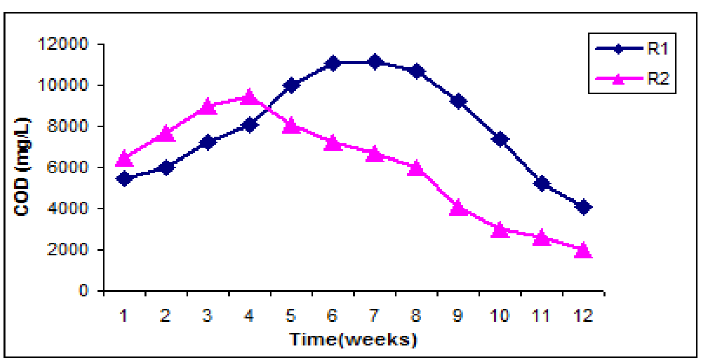

Fig. 2. Variation of chemical Oxygen Demand (COD) in reactor R1 and R2

Table 3. Typical leachate composition

Parameters	BOD	COD	TSS	pH	Total N	Total P
Mg/l	10.000	60.000	500	8.8	2915	30

The reason for this decrease in COD level may be the quick degradation of the solid wastes in the lab scale anaerobic MSW reactor [18]. The maximum value of COD reaches on 4 th week in reactor R2 as compared to reactor R1 in which maximum value reaches on 6 th week. This may be because of faster degradation of waste by microbes which were present in leachate recirculation of reactor R2. Percentage removal of COD in reactor R1 and R2 were observed 80 and 90% respectively. High COD removal in reactor R2 may be due to present more cow dung in leachate circulation which may result in easy and well developed microbial culture. The results of the present study are similar to those of Cossu and coll. [19] and clearly show that leachate recirculation has a positive effect on the rate of solid waste degradation in landfills. The ratio of measured COD to the maximum COD determined in each reactor is given in Fig. 2. It can be seen from the figure that, COD in reactor R2removal is realized more rapidly than reactor R1. Results indicate the positive effects of leachate recirculation on anaerobic degradation of municipal solid wastes clearly The COD level of leachate collected from R2 was lower than that from R1.

3.3 Ammonia and Phosphate

The evolution of ammonia concentration in anaerobic reactors are given in Figs. 3, 4. The highest ammonia concentrations were measured to be 1900 mg/L for R2,and 950 mg/l for R1 reactor, respectively. Ammonia concentrations were 1900 and 1200 mg/L for R2 and R1 reactors on 9th weeks. leachate treatment generally focuses on the removal of organic nitrogenous and carbonaceous matter and ammonia nitrogen. Most of the nitrogen in solid waste bioreactors is in the form of ammonia and is produced from the degradation of proteins and amino acids [20].

Several researchers have identified ammonia as the most significant long-term component of leachate [21,22], as there is no mechanism for its degradation in anaerobic MSW. The most of the nitrogen in the reactors is in the ammonia forms following the degradation of protein and amino acids [23,24].

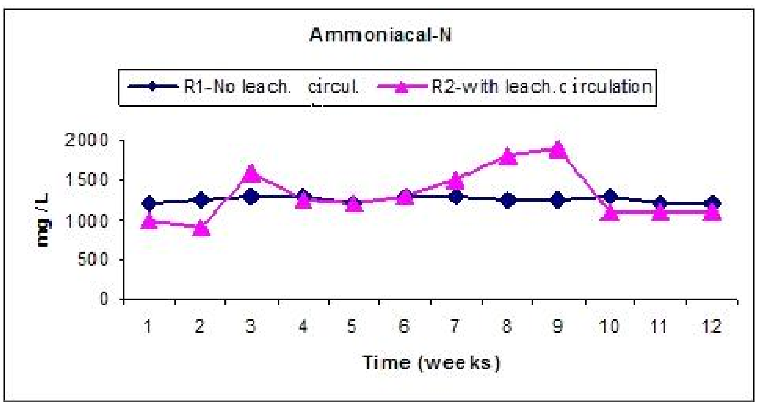

Fig. 3. Variation of total kjeldahl nitrogen (TKN) in reactor R1 and R2

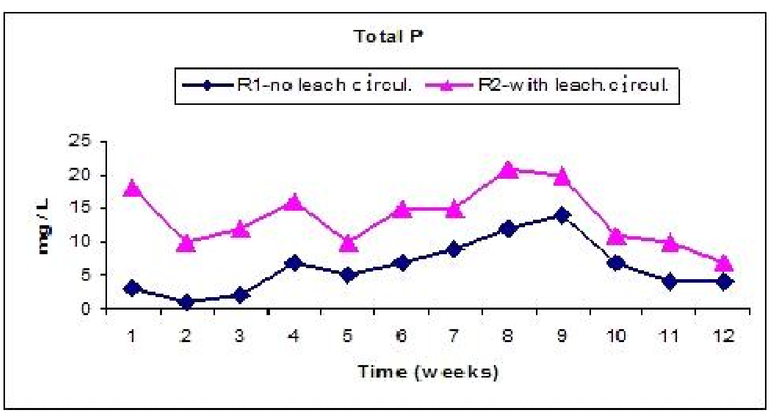

Fig. 4. Variation of phosphate in reactor R1 and R2

There circulation practice in the reactor R2 reintroduces ammonia to the system, keeping its value almost constant throughout experiment. The increase in removal efficiency in reactor R1 is due to bacterial synthesis and conversion of organic nitrogen compounds to NH4-N by nitrification [15]. The ammoniacal-N of leachate samples from both treatments fluctuated at approximately 1000 mg/l throughout the experimental period.

In the 6 th and 4 th week the maximum concentration of phosphate was found to be 15.2 mg/Land 18.4 mg/L in reactor R1 & R2 respectively. At the end of the experiment the phosphate concentration was found to be decreased and was 5.2 mg/L in case of reactor R1 and 4.0 mg/L in reactor R2 Fig. 4. The total P level in leachate samples collected from R2 was higher than that from R1 The decline in phosphate concentration may have been the results of phosphate assimilation by microorganisms in the reactors.

3.4 Conductivity and pH

The conductivity of a leachate reflects its total concentration of ionic solutes and is a measure of the solution's ability to convey an electric current. In both the reactors, the change in leachate conductivity with time followed a similar trend. This is because metals tend to form hydroxides or undergo sulfidation in the anaerobic phase and the majority of these compounds are not readily soluble [25]. All wastes were slightly alkaline with a pH range of 8.2–8.7, as shown in Table 2. The sewage sludge had the highest moisture content (94%) while MSW was relatively dry (58%). The variation of pH profile over time is provided in (Fig. 5). During the first two weeks pH levels were approximately 6.0, or on the acidic side of the pH scale. The observed pH values of leachate samples ranged from 6.2 to 5.8 in reactor R1 and 6.2 to 5.9 in reactor R2.

3.5 Biogas Production

In this study, enhanced gas production after leachate recirculation was observed at a relatively higher temperature of 36C. The experimental reactor were set to this temperature as higher temperature in landfill cell is generally expected due to endogenous heat release after anaerobic degradation. No significant differences in CH_4 and CO_2 compositions were observed between the two treatments. For R2, an average of 4 times the volume of waste input of gas was produced daily. For R1, the daily volume of gas produced was only 1.5 times the volume of input waste. The leachate samples from both treatments were slightly acidic, 5.8–6.5. Chadetrik and Arabinda [26], reported that it took a longer time to go through the initial adjustment, transition and acid formation stages before entering the methane production stages if the anaerobic degradation processes were not maximized in a landfill site. The cumulative volume of gas production in each reactor is given in Fig. 6, It can be seen from the figure that, the volume of gas production increased with leachate recirculation when compared with the reactors without leachate recirculation. Gas production rate in R2 increased steadily in the first 8 weeks and then started to decline; the peak gas production rate was 284L. For R1, gas production maintained a low level of 15–20 L. As shown in Figs. 7, 8, the proportion of methane in the gas is distinctly higher in recirculated reactors than those without recirculation. Comparing these values with those found in literature [18,26,28], it is apparent that, the gas production from reactor without leachate recirculation is lower than what was found with recirculated reactors. It is possible that the recirculation could increase methanogenesis bacteria activity. The leachate recirculation also could shorten the methanogenesis stage when MSW is co-digested with sewage sludge (8 weeks and 11 weeks respectively) [27,28].

Gas production from anaerobic degradation depends mainly on the composition of the biodegradable fraction of a waste and its moisture content [29]. Nevertheless, the gas production depends on some factors such as pH, temperature, aeration, alkalinity, availability of nutrients, microbes and the absence of toxic compounds [15] Moreover, the increasing in gas generation has a relationship with the higher degree of stabilization and adding buffer solution before recirculation might accelerate methanogenic bacteria in waste degradation and could enhance gas production rate [28]. The organic content of MSW used in this study was high (61%), comparative to the high level in other temperate cities, such as the UK (30%). The organic contents in sewage sludge sample (82. %) were even higher [29]. In order to maximize the anaerobic degradation process, the pH of waste must be neutral or slightly acidic; otherwise the gas production will cease if pH drops below 5.5 [30]. As the individual pH of the three kinds of waste was slightly alkaline, pH 8.2–8.7, the mixture of them was highly susceptible to biodegradation. Leachate recirculation had further enhanced the degradation process as indicated by the improved rates in gas production and nutrient removal from test columns.

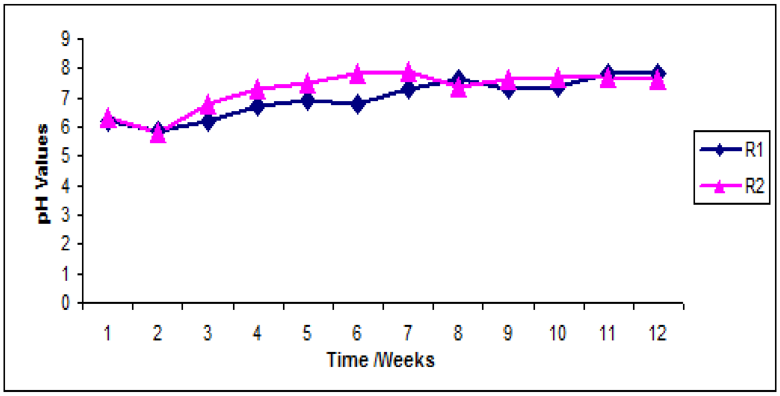

Fig. 5. Variation of pH in reactor R1 and R2

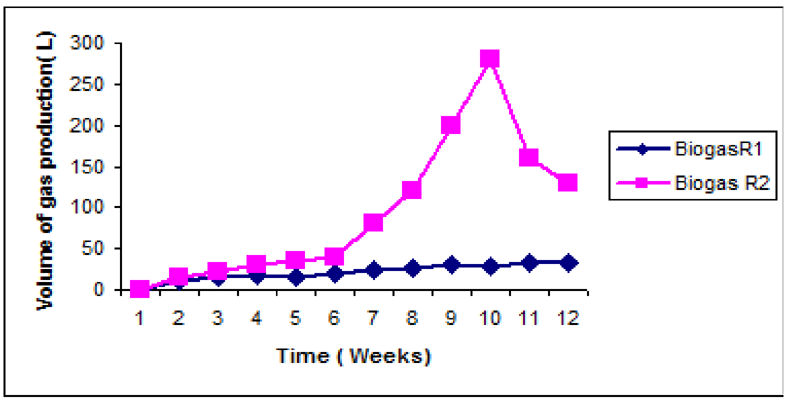

Fig. 6. Gas production (L) collected from treatments with and without leachate recirculation

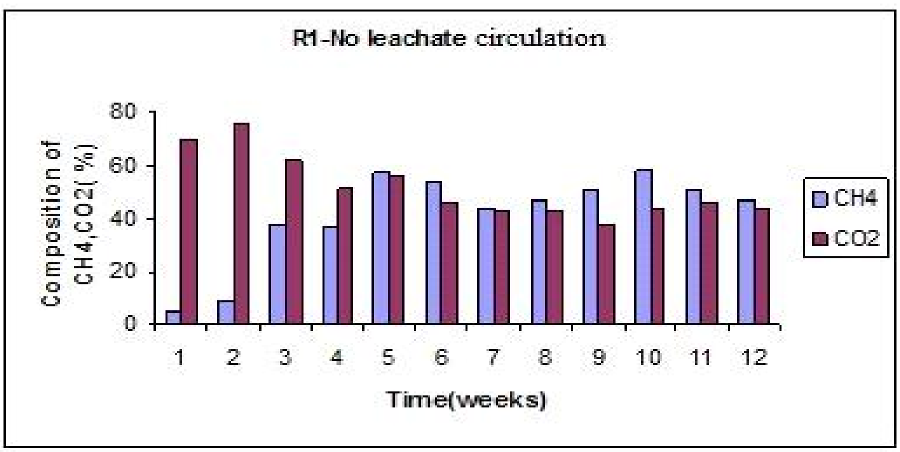

Fig. 7. Compositions of methane and carbon dioxide (%) collected from treatments without leachate recirculation

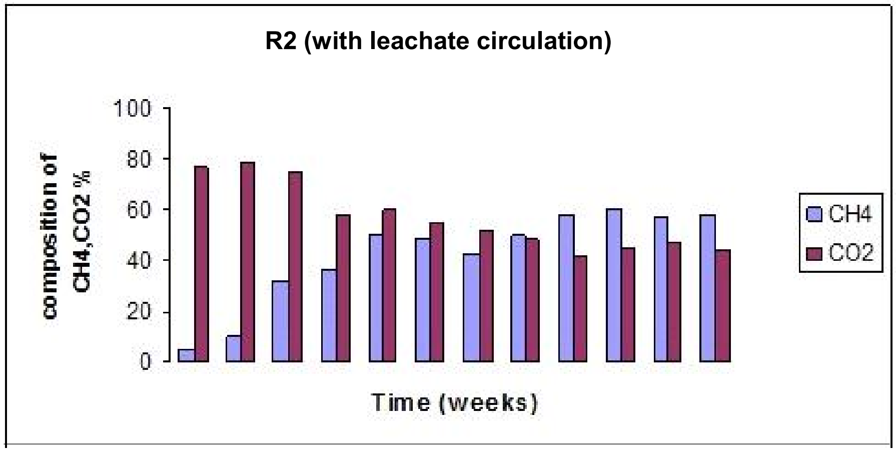

Fig. 8. Compositions of methane and carbon dioxide (%) collected from treatments with leachate recirculation

The results from this study indicated a range of methane production of 33 to 125 L CH4/ kg VS for cattail mixed with manure and a range of 9 to 104 L CH4/ kg VS for cattail only. Comparing these values with those found in literature (Table 1), it is apparent that and the yields from this trial are lower that what others have found for cattails in a LSAD system (Mshandete, 2009).

4. CONCLUSION

The leachate recirculation is a feasible way for in situ leachate treatment. It is one of the important problems in engineering landfills process because it has high concentration of toxic compound and could contaminate ground water. The leachate recirculation is one of the suitable methods to solve these problems. The recirculation shows a lot of benefits on anaerobic degradation of MSW and swage sludge in present cow dung as accelerating the degradation, increasing in gas production and reducing metal concentration in leachate. From those advantages and disadvantages, the leachate recirculation tends to be one of the most appropriate methods to apply in anaerobic co-disposable wastes in landfills. Cow dung addition will generate methane (CH_4) results in faster and more stabilization of solid waste as COD removal in case of reactor R2 was reported higher. The results of the present study demonstrated the feasibility of leachate recirculation in reducing the overall leachate loading for treatment and in enhancing the degradation rate of waste. Further more, leachate recirculation is projected to be an effective measure in increasing the potential filling capacity of a landfill site .

COMPETING INTERESTS

Author has declared that no competing interests exist.

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