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ANAEROBIC DIGESTION OF COMPOST LEACHATE UNDER MESOPHILIC AND THERMOPHILIC CONDITIONS

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ABSTRACT

The objective of the present study was to examine the feasibility of biological treating of compost leachate in anaerobic digester. The experimental work was also carried out to evaluate the biodegradable potential of compost leachate at thermophilic and mesophilic conditions. The laboratory bench-scale biogas horizontal digester was used for batch anaerobic digestion system of 312 hours hydraulic retention time (HRT). The obtained results showed that there was an influence of digestion temperature, pH value and production of volatile fatty acids (VFA) on biogas and methane production. The methane yield was 8.3 L kg^{-1} volatile solids (VS) and 373 L kg^{-1} VS under mesophilic and thermophilic conditions, respectively. Under mesophilic conditions, the amounts of biogas and methane were very small as compared with thermophilic conditions. Under mesophilic treatment, the highest amount of biogas production was reached to 16.7 L after 48 h and decreased to 1.3 L after 144 h from hydraulic retention time. The same trend was similarly observed in methane production but the highest amount of methane production (1.3 L) was achieved after 96 h (HRT). On the other hand, the biogas production continuously increased during the anaerobic digestion in thermophilic conditions. The maximum biogas and methane yield were 41.5 L and 30.4 L, respectively, after 192 h (HRT). Effluent from mesophilic digester mainly contained acetic acid and propionic acid more than n-butyric acid. In contrast, acetic and propionic acids were found in little concentration under thermophilic digestion. The levels of volatile fatty acids and pH value can be used as an indicator of methane yield and methanogenic activity. It could be concluded from this study that there was a possibility of anaerobic digestion of compost leachate to produce biogas and methane. The biogas and methane production were positively correlated with the anaerobic digestion temperature. Therefore, the temperature of anaerobic digester is very necessity for optimization of anaerobic digestion process.

Keywords: Compost leachate, batch anaerobic, biogas, methane content, mesophilic, thermophilic, volatile fatty acids.

INTRODUCTION

Applications of anaerobic digestion have increased during the past 30 years. The process involves the treatment of agricultural and industrial wastes of varying types in order to utilization the production of biogas. Interest in the anaerobic treatment of agro-industry waste is increasing because it require low energy and is ecologically sound, among several other advantages, compared with aerobic treatment processes (Parawira *et al.,* 2006). Compost leachate is the liquid that drains out of compost when it is overly-moist (*i.e* at or above saturation). The leachate generated from a landfill site containing organic, inorganic and heavy metal compounds has a complex mixture with a foul odor. Lombardi and Carnevale (2005) found that, the leachate production was estimated assuming a generation of 0,067 liter per kg of landfill waste.

Leachate from landfill requires treatment before discharge into the environment to avoid surface and underground water contamination. Leachate recirculation is one option for inexpensive leachate disposal (Cureton *et al.,* 1991), in reducing the cost of post-closure care and long-term liability (Reinhart and Al-Yousfi, 1996). Other potential advantages of leachate recirculation include: (1) improvement in leachate quality; (2) reduction in volume of leachate to be treated by biochemical methods; (3) enhancement of gas production and (4) accelerated subsidence, permitting recovery of valuable landfill air space (Mostafa *et al.,* 1999 and Warith *et al.,* 1999).

Leachate treatment methods including anaerobic sequencing batch reactor and anaerobic hybrid bed filter have been investigated by several researchers (Timur *et al.,* 2000; Loukidou and Zouboulis, 2001). Filipkowska and Agopsowicz (2004) mentioned that, the landfill biogas is the result of the biochemical transformations of the organic fractions in the landfills. On the basis of theoretical considerations it is known that leachate recirculation has a positive effect on biochemical changes in landfill, including biogas production. The cumulative volume of methane and carbon dioxide production increased with leachate recirculation for about 1.7 to 2 times when compared with the reactors without leachate recirculation. However, the higher recirculation rate may cause the decreasing in cumulative methane production. It was possible that acidic conditions could inhibit the methanogenesis bacteria activity (Śan and Onay, 2001). Kuria (2008) reported that, the activity of methanogenic bacteria begins to become inhibited at a pH of 6.6 and pH values below 6 are clear indication that too much acid is being formed as a result of too few methanogenic bacteria. The volatile fatty acids are the main cause for a decrease in pH in anaerobic digesters. The optimum pH range for anaerobic digesters is from 6.6 to 7.4 (Moosbrugger *et al.,* 1992). The leachate pH ranged between 4.7-8.8 for conventional landfills (Kjeldsen *et al.,* 2002) and from 5.4-8.6 for bioreactor landfills (EPA, 2003). Leachate from young landfill can be characterized as high-strength wastewaters with 10-60 g/L COD, pH of 5-6 and several toxic/hazardous components (Gülşen and Turan, 2004). Tanticharoen *et al.* (1985) reported that solids degradation and biogas production were higher in thermophilic digester than that in mesophilic digester.

The objectives of this study were to characterize the anaerobic biodegradability potential of leachate with inoculum material (cattle dung) using experimental batch in horizontal digesters under mesophilic and thermophilic temperatures. The relationship between biogas production and volatile fatty acids was also determined.

MATERIALS AND METHODS

1. Bench-Scale Biogas Digester

A bench-scale of cylindrical biogas digester (horizontal type) was functioned during the experimental period as shown in Fig. (1). The digester was fabricated from galvanized steel sheet of 1.5 mm thick, 450 mm long and 250 mm diameter with total capacity of 22 liters and actual digestion volume of 17 liters. For feeding the organic wastes and rejecting the digested materials, galvanized steel inlet and PVC outlet tubes of 50.8 mm diameter were connected with the digester. To follow up the digestion processes, orifice for releasing the produced gas was located on the digester and another one for the pH-temperatures measurements. Released gas was collected in gasholder and its volume was also determined using the wetted displacement with a previously calibrated scale in liter.

Fig. (1): Schematic diagram of the horizontal bench-scale biogas digester.

The bench-scale digester horizontal type was used to measure and detected the suitable operating conditions. It was also employed to obtain the maximum possible biogas production with high methane percentage using leachate and inoculum (cattle dung). The characteristics of the input materials are summarized and listed in Table (1)

Table (1): Characteristics of the input materials (compost leachate and cattle dung) using in the experimental study.

Substance	Input Fresh [kg]	VS [%]	Input VS [kg]	pH
Leachate	16	2.71	0.434	5.92
Inoculum (Cattle dung)	1	2.46	0.025	8.3
Mixture	17	2.7	0.432	6.22

A hasp mixer was mounted with the biogas digester; and automatically adjusted at 2 minute each half on hour. A thermostatic heating unit (electric heater) was used with a water pump to adjust the temperature of the digester at the desired level. The temperature of mixture inside digester was adjusted at 34 ^{o}C (mesophilic) and at 54 ^{o}C (thermophilic phase). The batch experimental hydraulic retention time of 312 hours (13 days) was used to maximize the biogas and methane productions.

2. Analytical Methods and Instrumentation

2.1. Compost leachate

The compost leachate was analyzed for volatile solids (VS), volatile fatty acids (VFA), total solid (TS), chemical oxygen demand (COD), nitrogen and potassium. The determinations of TS and COD were executed using the standard methods (APHA, 1985). While the concentration of available nitrogen and potassium was determined using Kjaldhal nitrogen method and Flamephotometer, respectively (Sparks *et al.,* 1996). The characteristics of the compost leachate which during the experimental used.

Table (2): Characteristics of the compost leachate.

Parameter	Unit	Value
pH		5.92
Volatile solids (VS)	g L^{-1}	27.1
Volatile fatty acids (VFA)	g L^{-1}	10.09
Total solid (TS)	g L^{-1}	47.1
Ash	%	2.0
Total-N in fresh material	g kg^{-1}	1.30
Total-N in TS	g kg^{-1}	28.4
Available N in fresh material	g kg^{-1}	0.44
Available N in TS	g kg^{-1}	9.38
K in fresh material	g kg^{-1}	3.23
K in TS	g kg^{-1}	68.69
Chemical oxygen demand (COD)	g L^{-1}	43
Organic carbon (OC)	g L^{-1}	16.82
Organic carbon: Total nitrogen (C:N ratio)		12.9:1

2.2. Daily biogas production:

During the batch fermentation, the released gas volume in liter per day during the experimental period (13 days) was measured laboratory using the wetted displacement with a previously calibrated scale as shown in Fig. (1).

2.3. Methane concentration:

The percentage of methane in each sample was determined using a gas chromatography GC (Chrompack CP 9001) at a flow rate of 18 ml/min with helium as a carrier gas. The flame-ionization-detector (FID) was operated at a flow rate of H_2 24 ml/ min and make up N_2 of 30 ml/min.

2.4. pH value:

The pH values of the mixture (leachate and inoculum) solution inside the bench-scale digester were regularly measured every day using Jenway pH hand held meter (model 370 pH/mV).

RESULTS AND DISCUSSION

1. Biogas and methane yield

During the batch anaerobic digestion of compost leachate, biogas and methane yield were recorded. Intermediate compounds (VFA) were checked by removing effluent from mesophilic and thermophilic treatments at the end of the experiment (312 h). The production of biogas and methane under mesophilic and thermophilic phase are shown in Fig. (2). Under mesophilic conditions, the production of biogas and methane was lower than that under the thermophilic conditions. The highest amount of biogas production was 16.7 L which achieved after 48 h and decreased to 1.3 L after 144 h (HRT) under mesophilic phase. The same trend was similarly observed in the methane production but the highest amount of methane production (1.3 L) occurred after 96 h. On the other hand, the biogas and methane productions were not remained constant but varied with the period of digestion. Under thermophilic phase, the maximum biogas and methane yield were of 41.5 L and 30.4 L, respectively, which achieved after 192 h (HRT). After this stage, the biogas and methane productions were decreased to 2 L and 1.5 L, respectively, at the end of anaerobic digestion process as shown in Fig. (2).

Based on the previous results, the mixture temperature was found to be the prevalent parameter affecting the rates of anaerobic biodegradation, biogas and methane production of compost leachate. The obtained data also indicated that the biogas and methane yield was directly proportional to the temperature of anaerobic digester. The biogas and methane production at thermophilic process were two or three times greater than that at mesophilic process. This result is in agreement with the data published by Tanticharoen *et al.* (1985). Moreover, soluble organic materials in the thermophilic digester were also higher than that in the mesophilic digester. It was clarified that microbial activities between these two temperatures may differ in their ability to utilize complex substrate.

The total methane production by liter and methane yield (L kg^{-1} VS or fresh material added) is presented in Table (3). The total methane was reached 3.6 L and 161.3 L under mesophilic and thermophilic digestion, respectively. Therefore, the organic compounds in compost leachate were degraded; which faster in the thermophilic digester. On the other hand, the accumulation and degradation of these compounds were slower in the mesophilic digester. The amount of methane yield per VS added to digester was high (373 L) in thermophilic anaerobic digester compared with the mesophilic digester (8.3 L).

At both temperatures, methanogenesis was rapidly established within few hours from the retention time and was sustained until mixture was exhausted. Methanogenesis was more rapidly initiated in the thermophilic digester than in the mesophilic digester. In this regard, Hegde and Pullammanappallil (2007) found that 95% of the methane yield potential of the waste was produced in 11 days under thermophilic conditions as opposed to 27 days under mesophilic conditions.

Fig. (2): Production of biogas and methane (liter) under mesophilic and thermophilic anaerobic digesters at various time intervals (312 h).

Table (3): Total methane yield by liter and methane yield (L kg^{-1} VS or fresh materials added) of compost leachate under mesophilic (34 °C) and thermophilic (54 °C) conditions.

Treatment	Temperature (°C)	Input VS [kg]	Total Methane yield [L]	Methane average [%]	Methane yield [L kg^{-1} VS added]	Methane yield [L kg^{-1} Fresh added]
Mesophilic	34	0.432	3.6	17.1	8.3	0.2
Thermophilic	54	0.432	161.1	63	373	9.8

2. Methane and carbon dioxide concentrations

Methane and carbon dioxide concentrations characteristics of anaerobic decomposition of compost leachate are plotted in Fig. (3). The initial methane formation was low, due to the high concentration of volatile fatty acid in the early phase and not suitable for growing the methanogenic bacteria.

The obtained data indicated that, the methane formation was found to be more in the thermophilic than that in the mesophilic condition. It also shows that the maximum methane percentage was 76 and 40% occurred after 264 and 120 h (HRT) at thermophilic and mesophilic conditions, respectively.

Fig. (3): Methane and carbon dioxide percent under the mesophilic and thermophilic anaerobic digestion at various time intervals (312 h).

3. pH value

The average of the leachate pH value in thermophilic and mesophilic digester is presented in Fig. (4). The initial pH value of the fresh mixture (leachate and inoculum) solution was 6.22 meanwhile the average pH value inside the bench-scale digester was 7.98 and 6.16 in thermophilic and mesophilic, respectively. The activity of methanogenic bacteria inhibited at mesophilic digester and limited the generation of significant amounts of methane (Fig. 2 and 3) due to the pH value (less than 6.6). Therefore the pH dropped slightly corresponding to the transient accumulation of volatile acids, there after it increased as the VFA were converted to methane. On the other hand the large amounts of organic fatty acids (Fig. 6) lead to decrease the pH value. This result is in agreement with the data published by Kuria (2008).

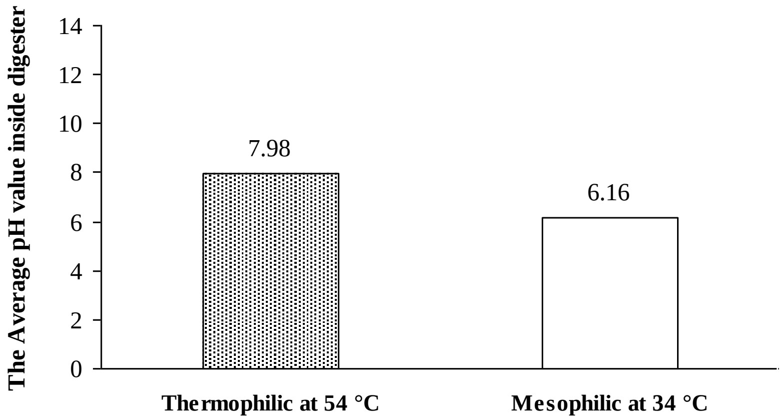

Fig. (4): The average pH value of compost leachate inside the digesters under mesophilic and thermophilic anaerobic digestion.

4. Degradation of organic carbon

The average of organic compounds degradation in compost leachate is shown in Fig. (5). The decomposition of organic carbon in compost leachate under thermophilic conditions was high compared with mesophilic conditions. As shown in Fig. (5) the degradation percentage of organic carbon was 48 and 7.6% under thermophilic and mesophilic conditions, respectively. Therefore, the decomposition of organic carbon in compost leachate under anaerobic digestion was highly response to temperature level.

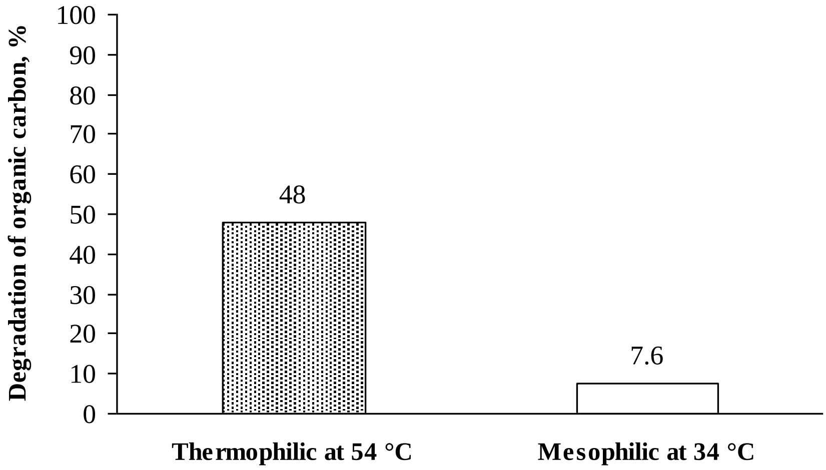

Fig. (5): The average degradation of organic carbon under mesophilic and thermophilic anaerobic digestion.

5. Volatile fatty acids

The production of intermediate compounds during anaerobic digestion of compost leachate is illustrated in Fig. (6). The results indicated that the predominated intermediate compounds were acetic and propionic acid followed by n-butyric and n-valeric acids in fresh compost leachate and leachate treated under mesophilic conditions. Under the mesophilic digestion, there was an increasing rate of acetic acid accumulation (160 g L^{-1}) followed by accumulation of propionic acids (140 g L^{-1}) as intermediates. Iso-butyric acid was found in very little concentration under the mesophilic digester. The same trends were observed in iso-valeric, n-valeric and caproic acids. Whereas, propionic acid was the only high intermediates found among the thermophilic digestion (Fig. 6). Effluent from mesophilic digester (34 ^{o}C) contained mainly acetic acid, propionic acid, and less in n-butyric acid (Fig. 6). In contrast, acetic and propionic acids were found in little concentration under the thermophilic digester (54 ^{o}C); only acetic acid, propionic, n- butyric and n-valeric acids were found as the major products. The result corresponds with the activity of microorganisms from thermophilic digester were little or unable to utilize propionic acid.

The accumulation and degradation of these acids were slower under the mesophilic digester. The volatile organic acids concentration in the leachate increased during the first 6 days of the run and then they decreased till the end of the run to be less than 100 mg/L. Volatile organic acids levels of less than 500 mg/L are indicative of stable performance (Chynoweth and Pullammanappallil, 1996).

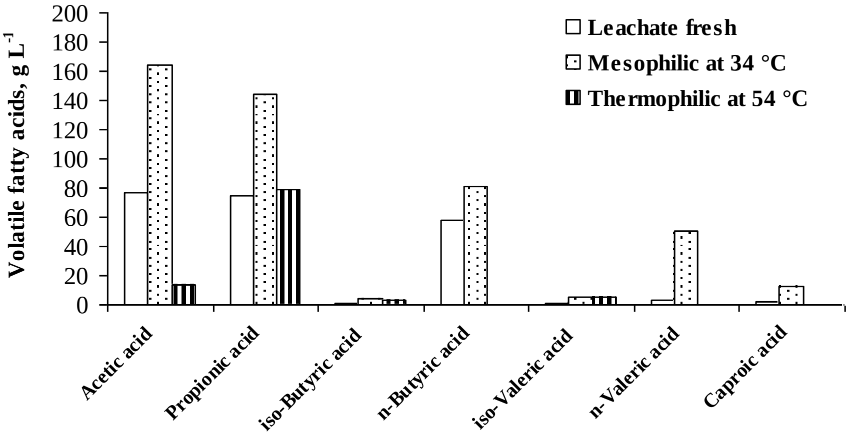

Fig. (6): Production of volatile fatty acids (g L^{-1}) under the mesophilic and thermophilic digesters during anaerobic digestion of compost leachate.

Throughout the study, the concentration of all the important fatty acids (acetic, propionic, iso- and n-butyric, iso- and n-valeric, and caproic acids) in the digester under the thermophilic (54 ^oC) was lower than that under the mesophilic temperature (34 ^oC). This is indicative of a high methanogenic bacteria activity under the thermophilic temperature, which produces more biogas and methane than that under the mesophilic temperature.

CONCLUSIONS

The leachate has a high-strength wastewaters with 47.1 g L^{-1} TS, 27.1 g L^{-1} VS, 10.09 g L^{-1} VFA, 43 g L^{-1} COD and several toxic or hazardous components. Therefore, this leachate requires treatment before discharge into the environment to avoid surface and underground water contamination. The present study had shown that leachate can produce significant amount of methane when digested under anaerobic conditions. The present study also showed that anaerobic digestion of leachate had high effect on degradation rate. The results of the present study demonstrated that the anaerobic digestion was evidently best started by thermophilic temperature (54 ^oC) compared with the mesophilic temperature (34 ^oC). The methane yield was high under the thermophilic anaerobic compared with the mesophilic anaerobic conditions. The methane production was influenced by VFA concentration. The degradation percentage of organic carbon increased from 7.6 under the mesophilic to 48% under the thermophilic temperature. Furthermore, temperature significantly influences anaerobic digestion process, especially in methanogenesis stages.

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التخمر اللاهوائي لراشح الكمبوست تحت تأثير درجة حرارة التخمر المتوسطة والعالية

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يتميز راشح الكمبوست الناتج من مصفوفات إنتاج سماد الكمبوست باحتوائه علي مواد عضوية وغير عضوية وعناصر ثقيلة وروائح كريهة مما يؤدي الي تلوث الهواء والماء والتربة. تخزين ومعالجة راشح الكمبوست الناتج يعتبر مكلف أقتصادياً وتعد تكنولوجيا التخمر اللاهوائي لإنتاج الغاز الحيوي أحد طرق معالجة المخلفات العضوية ذات المردود الأقتصادي والأثر البيئي الجيد.

أجريت دراسة معملية لإنتاج الغاز الحيوي علي خليط من راشح الكمبوست وروث الماشية كمادة لقاح بنسبة ١٦ : ١ بالحجم علي التوالي وبنسبة مادة جافة كلية في الخليط (TS) ٤,٧% بالوحدة التجريبية للغاز الحيوي بقسم الهندسة الزراعية - كلية الزراعة - جامعة قناة السويس في عدد أثنين مخمر أفقي والمخمر مصنع من الحديد المجلفن سمك ١,٥ مم و قطر و طول ٢٥٠ ، ٤٥٠ مم علي التوالي وبحجم كلي ٢٢ لتر وحجم تخمرللمادة ١٧ لتر.

تم تغذية الخليط في المخمرين نظام تغذية مرة واحدة تحت عوامل التشغيل من درجة حرارة ٣٤ ، ٥٤ م° في مدي حرارة التخمر المتوسطة والعالية علي التوالي والتقليب لمدة دقيقتين كل نصف ساعة. تم تقدير النسبة المئوية للمادة الجافة العضوية VS معملياً في المادة المتخمرة

للخليط لحساب نسبة تحلل المادة العضوية خلال وقت الاستبقاء ٣١٢ ساعة (١٣ يوم) كما تم تقدير الأحماض الدهنية الطيارة وقياس رقم الأس الهيدروجيني pH ودرجة الحرارة في المعاملات تحت الدراسة.

تم قياس كمية الغاز الحيوي باللتر ونسبة محتوي الميثان كل يوم علي أمتداد التجربة للمعاملات المختلفة وتم حساب كمية الغاز الحيوي و الميثان باللتر المتحصل عليها من كل واحد كيلو جرام مادة عضوية جافة.

وقد توصلت النتائج إلي:

- راشح الكمبوست الناتج من مصفوفات إنتاج سماد الكمبوست يحتوي علي ٤٧,١ جرام في اللتر مادة صلبة، ٢٧,١ جرام مادة عضوية طيارة، نسبة الكربون الي النيتروجين C:N ١٣:١ ، الأحماض الدهنية الطيارة ١٠,٠٩ جرام في اللتر، ٥,٩٢ تركيز رقم الأس الأيدروجيني ومواد اخري.
- التخمر اللاهوائي كان أفضل بصورة واضحة في مدي حرارة التخمر العالية ٥٤ م بالمقارنة مع مدي حرارة التخمر المتوسطة ٣٤ م°. فكانت كمية الميثان ٣٧٣ لتر لكل كيلو جرام مادة عضوية طيارة في مدي حرارة التخمر العالية ٥٤ م° بينما كانت ٨,٣ لتر لكل كيلو جرام مادة عضوية طيارة في مدي حرارة التخمر المتوسطة ٣٤ م° علي التوالي.
- إنتاج الميثان يتناسب عكسياً مع الأحماض الدهنية الطيارة في المخمر فكان ٣٧٣ لتر ميثان لكل كيلو جرام مادة عضوية طيارة عند مستوي ١٠٢ جرام أحماض دهنية طيارة في اللتر بينما كان ٨,٣ لتر ميثان لكل كيلو جرام مادة عضوية طيارة عند مستوي ٤٦٢ جرام أحماض دهنية طيارة في اللتر
- رقم الأس الأيدروجني يتأثر بتركيز الأحماض الدهنية الطيارة فكان ٦,١٦ عند مستوي ٤٦٢ جرام أحماض دهنية طيارة في اللتر في حالة التخمر علي درجة الحرارة المتوسطة ٣٤ م بينما كان ٧,٩٨ عند مستوي ١٠٢ جرام أحماض دهنية طيارة في اللتر في حالة التخمر علي درجة الحرارة العالية ٥٤ م° علي التوالي.
- نسبة الهضم تتناسب طردياً مع درجة الحرارة فكانت ٧,٦% مع درجة حرارة التخمر المتوسطة ٣٤ م° بينما كانت ٤٨% مع درجة حرارة التخمر العالية ٥٤ م°علي التوالي.

مما سبق يتضح أنه يمكن استخدام راشح الكمبوست الناتج من مصفوفات إنتاج سماد الكمبوست كمادة عضوية لإنتاج الغاز الحيوي حيث انه غني بالمواد العضوية القابلة للتحلل مع مراعاة ظروف التشغيل من درجة حرارة التخمر واضافة مادة مثل روث المواشي كلقاح مساعد في عملية التخمر.