Academic Journal of Chemistry
ISSN(e): 2519-7045, ISSN(p): 2521-0211
Vol. 3, Issue. 11, pp: 101-108, 2018
URL: https://arpgweb.com/journal/journal/20
DOI: https://doi.org/10.32861/ajc.311.101.108

Academic Research Publishing Group

Original Research Open Access

Assessing Performance of Cattle Dung and Waste Cooked Foods in Producing Biogas as Single Substrate and Mixed Substrates in Kampala Uganda

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Abstract

Biogas is anaerobic degradation product formed from aqueous slurry of organic waste in a digester. It can be produced from cattle dung, (cd)chicken droppings, decaying leaves, kitchen waste foods, (kwf), sewage sludge, slaughter house, goat, pig or sheep manure, Aqueous slurry of 200 g/L of mixed or single substrate of cattle dung or/and kitchen waste evolved up to 400mL of biogas at ambient temperatures. The rate of gas evolution reached 5 mL/day on the 15th day using 25 % cd mixed slurry. The overall rates of degradation attained in the mixtures were 1.42 + 0.26 mL/g for cd; 1.58+0.33 mL/g for kwf; 1.78+ 0.38 mL/g for 75 % cd mixed substrate; 1.78+ 0.29 mL/g for 50 % cd mixed substrate; 1.92+ 0.21 mL/g for 25 % cd mixed substrate slurries in the 200 g/L load. The comparative rate of biogas formation ranged from1.25 to 1.35 which was in agreement with the range published in literature of 0.8 to 5.5. Biogas can be synthesized efficiently at ambient temperature in Kampala as was done at mesophilic temperatures elsewhere. However, it may be necessary to attempt producing biogas at different pH and temperatures as well as using other substrates and inoculums.

Keywords: Co-generation; Digester; Cattle dung; Bio-waste; Kitchen waste.

1. Introduction

Biogas was defined as gas formed by biological decomposition of organic matter in absence of oxygen and it originates from biogenic materials so it is a biofuel. Interest in synthesis of gas formed by decomposing organic matter was first reported in the 17th century. Later it was found that gas produced from cattle manure and kitchen waste can be used for lighting and cooking in much the same as natural gas is used. It is now known that it contains up to 50 % methane, a renewable source of energy that can be used for heating, generating electricity and other operations based on internal combustion engines [1]. Biogas was reported as mixture of gases including methane, carbon dioxide, hydrogen and others [2-4]. Whereas kitchen waste is any substance raw or cooked which is discharged or remains after [5], cattle dung is black-greenish material that passes out of the rumen of herbivores after feeding on grass and other materials [6]. It was reported that digestion of kitchen waste as single substrate yielded 27 % of gas [7] yet cattle dung as single substrate yielded 17.9 % [8]. There are variations in quantities of gas formed when single or mixed substrates are digested [9].

The processes yielding biogas involve anaerobiosis whereby archaea bacteria, algae, fungi, protozoa and or viruses degrade organic matter. Bio digestion has been employed to treat organic wastes to recover renewable energy resource [10, 11]. Anaerobiosis involves a series of processes in which microbes biodegrade organic materials [1, 12]. Synthesis of biogas can be coupled to waste management because it produces bio residue which serves a s manure and a gas suitable to replace fossil fuels [13, 14]. The process of bio digestion starts with bacteria hydrolyzing organic matter placed in a digester to transform insoluble organic polymers like cellulose to soluble products, on which different protozoa act [13]. Acetogenic bacteria convert amino acids and sugars to methane, hydrogen, carbon dioxide and ammonia [15].

Flow diagram for biogas formation was summarized and shown to flow as follows [16] as follows;

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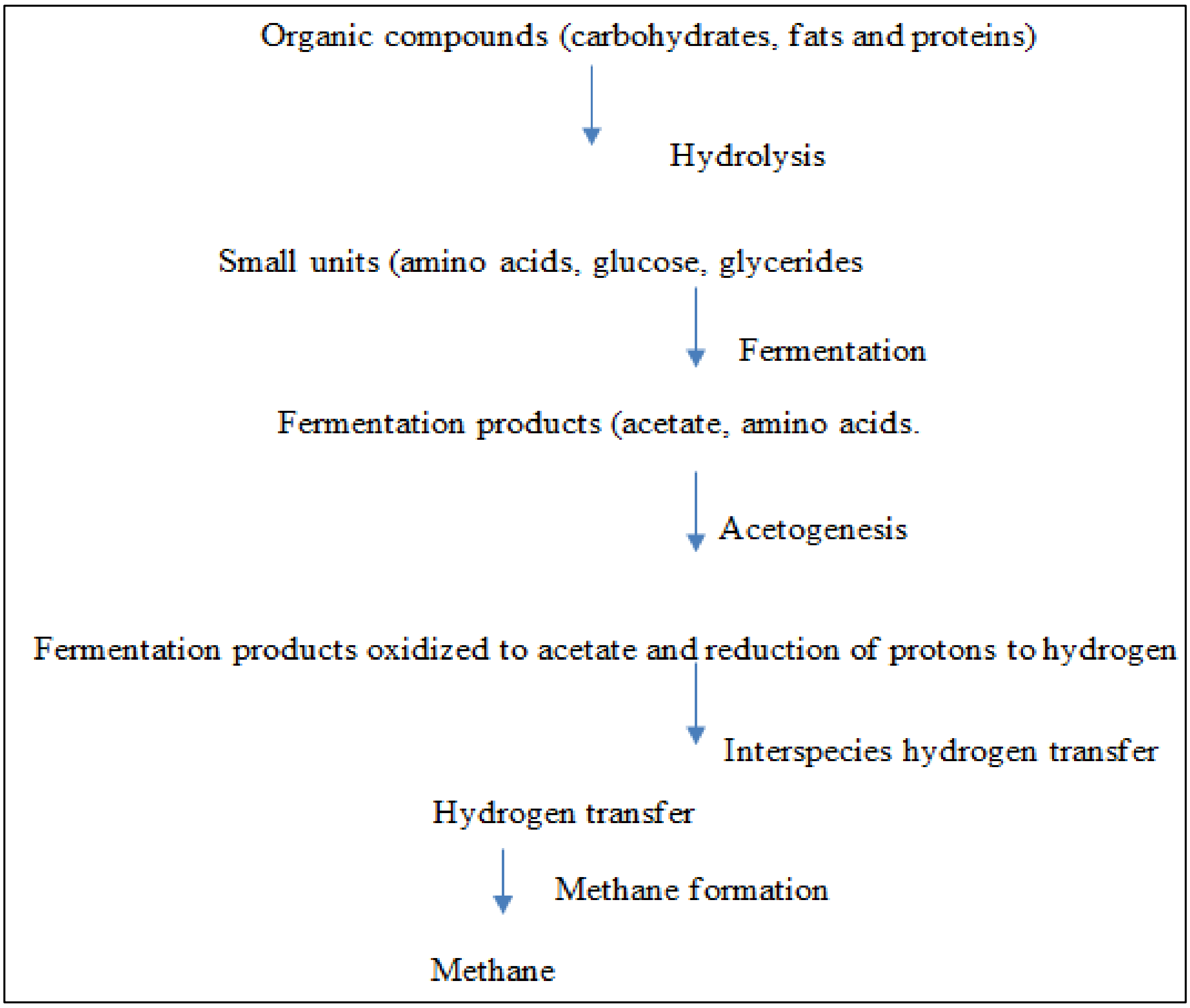


The two key processes in bio-digestion were reported to be mesophilic and thermophilic in nature. Further, it was shown that digesters that generate biogas from kitchen waste involve thermophilic microbes [17].

Cogeneration or co-digestion of biogas is simultaneous decomposition of homogeneous slurry of two or more substrates [11]. Cogeneration of biogas from mixed slurry of solid from slaughter house, manure, fruits and vegetables was reported to have increase the yield of methane by 44 % as compared to single substrate digestion of cattle dung or kitchen waste [18]. It was further reported that sodium hydroxide added to kitchen waste increased the yield of biogas formed [19]. Waste food materials were shown to have high potential for the production of methane because it can be digested rapidly [18]. Further food waste was shown to be highly desired substrate for anaerobic digestion because it accomplishes 80 % of the theoretical methane yield in 10 days of digestion [20]. It has been shown further that fats and oils produced higher volumes of gas than other organic wastes of different biochemical composition [21]. Fats and oils reduced organic wastes possessing higher gas potentials than sugars or alcohols [22].

Fats and oils were degraded in high percentages in cogeneration with simulated organic fractions of municipal solid waste with result indicating anaerobic digestion of lipids [21, 23]. To alleviate expenditure on treating organic waste, it was necessary to use co-digestion to produce the renewable energy source in addition to manure [24]. The volume of gas formed from such digesters fluctuates, but can be stabilized by use a variety of substrates, including fruits, leaves, cooked food applied simultaneously in cogeneration processes [11]. Sewage sludge in mixture with other substrates yielded more gas than single substrate [14]. This has been associated with positive synergism established in the digestion medium together with supply of missing nutrients from the co-substrates [25]. In addition to synergism, cogeneration provides a better nutrient balance for the anaerobes, so it results in high yield of gas [2]. Thus slurry containing slaughter house manure, fruit and vegetable waste yielded even bigger volume of gas than slaughter house manure mixed with fruit waste [15]. Cogeneration was shown to increase yield of biogas to 26 % [26] because it supplied additional nutrients to the anaerobes. Digestion of mixed slurry of manure and organic waste consisted of combining several wastes with complimentary characteristics in order to improve production of the gas [27]. Cogeneration of biogas is based on trial and error practices so different yields are obtained with different substrates but gas operators need to know the effects of cogeneration [11]. Food residues from homes, restaurants or hotels serve as good substrate for anaerobiosis satisfying up to 80% of the theoretical yield of methane [17]. Cogeneration slurries containing fats, greases and oils, waste waters, manure from slaughter houses, diary industries and fat refineries have higher methane potential as fats and oils are reduced organic materials [13, 22, 23]. This study has targeted cogeneration of gas from cattle dung and kitchen waste in ratios of 1:1, 1: 3 and 3:1 in comparison to generation of gas using cattle dung and kitchen waste as single substrates.

The yield of biogas was shown to be affected by type and composition of the substrate, microbial composition, temperature, moisture, bioreactor design and pH [28]. Anaerobic digestion is catalyzed by microorganisms that convert macro molecules to low molar mass substances. The common sources of inoculums was sewage [29], however, all aggregates like flocs, biofilms, granules and mats may be used [30]. Heterotrophic organisms like *clostridium* species are common anaerobic digesters but a consortium of microbial like achtinmycytes, *Thermomonospis Ralslsttonia* [31, 32].

Low temperatures were reported to decrease microbial growth, rates, substrate utilization and rate of biogas formation [33, 34]. It also leads to exhaustion of cell energy and leaking of intra cellular substances [35]. High temperatures lower gas yield because volatile gases like ammonia are produced [36]. The best operating temperature is 35^{o}C, a mesophilic temperature [37]. Neutral to alkaline pH were reported suitable for anaerobiosis of organic waste [4, 38]. High moisture content facilitates anaerobiosis [39]. The availability and complexity of organic materials affect anaerobic digestion. The digester consists of pressure resistant container mounted with stirrer and reservoir. The volume of gas formed collected over sodium hydroxide solution was measured every after three-day interval for 28 days. On the 28th day, the digestion mixture was discharged. The digester was cleaned and used over again. This study has aimed at using cattle dung and cooked waste foods singly or mixed to produce biogas.

2. Materials and Methods

2.1 Sampling

From a kraal (zero-grazing facility), wet cattle dung (10 kg) was collected. From the same kraal, cattle urine (10L) was collected. From the garbage dumping site, cooked waste food materials (10 kg) from nearby restaurant at Wandegeya market was collected.

2.2. Cattle Dung Digestion

Wet cattle dung (50 g) was put in a can and cattle urine (200 mL) and sludge inoculum (50 mL) was added. The mixture was stirred to form slurry.

2.3. Kitchen Waste Digestion

Waste food materials (50 g) were put in a can and cattle urine (200 mL) and sludge inoculum (50 mL) was added. The mixture was stirred to form slurry. The slurry was fed in the digester.

2.4. Co-Digestion of Cattle Dung and Food Waste

This was carried out in three different wats as shown below;

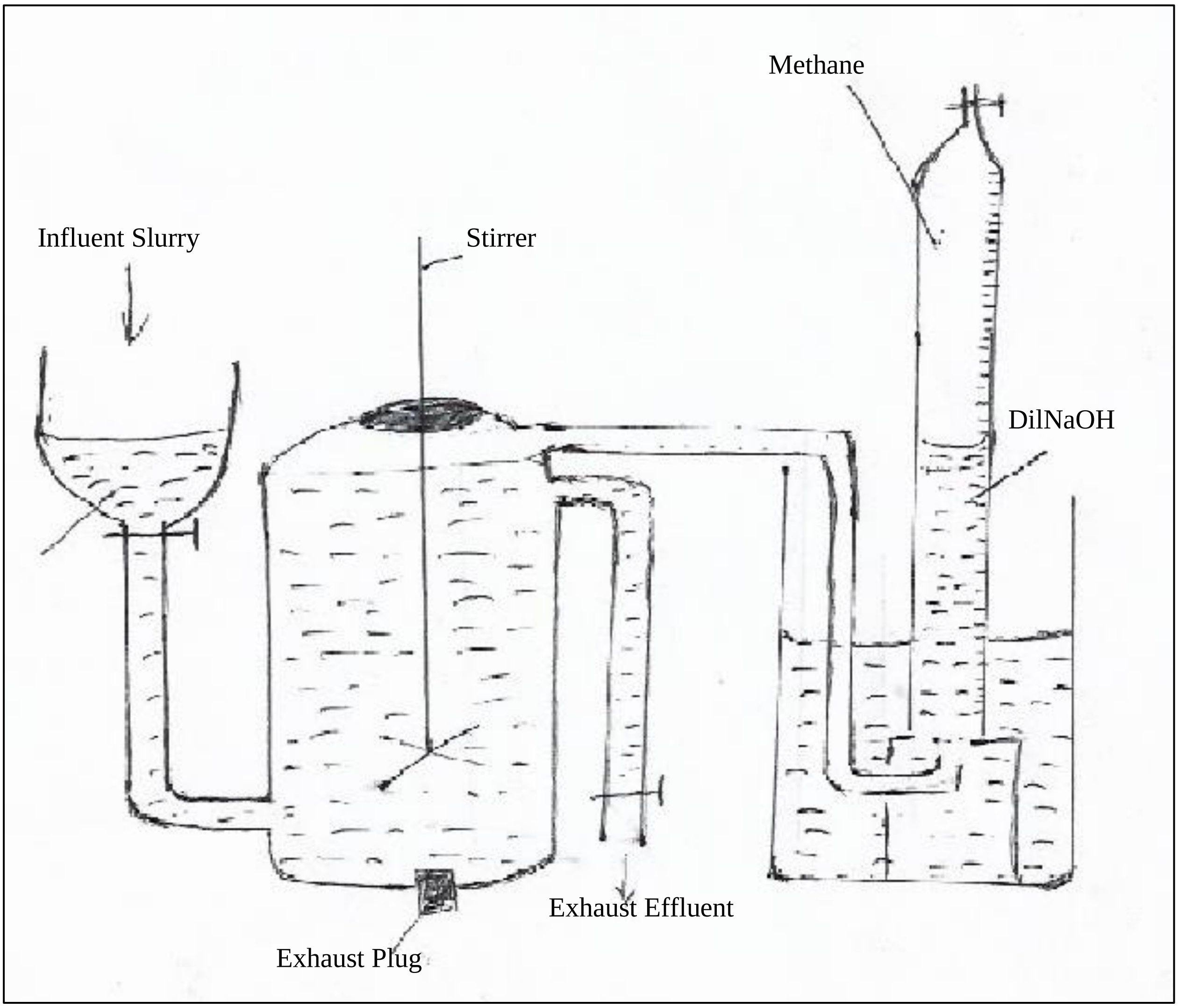
a. Wet cattle dung (25 g) and food waste (25 g) were put in a can and cattle urine (200 mL) and sludge inoculum (5 0mL) was added. The mixture was stirred to form slurry. The slurry was fed in the digester and carbon dioxide bubbled through slurry to eliminate oxygen.

b. Wet cattle dung (13 g) and waste food (37 g) were put in a can and cattle urine (200 mL) and sludge inoculum (50 mL) was added. The mixture was stirred to form a slurry. The slurry was fed in the digester and carbon dioxide bubbled through slurry to eliminate oxygen.

c. Wet cattle dung (37 g) and waste food (13 g) were put in a can and cattle urine (200 mL) and sludge inoculum (50 mL) was added. The mixture was stirred to form a slurry. The slurry was fed in the digester and carbon dioxide bubbled through slurry to eliminate oxygen.

3. Instrumentation

The slurry was fed in the digester shown below through the reservoir while tap leading to out the effluent was open to allow air out of the reactor. Once the reservoir was nearly full, addition of slurry was stopped, carbon dioxide was bubbled through the slurry for five minutes and tap leading to the effluent was closed. The stirring started and slurry left to decompose while the electric stirrer was running. The gas formed was collected in graduated glass tube over sodium hydroxide solution to absorb carbon dioxide.

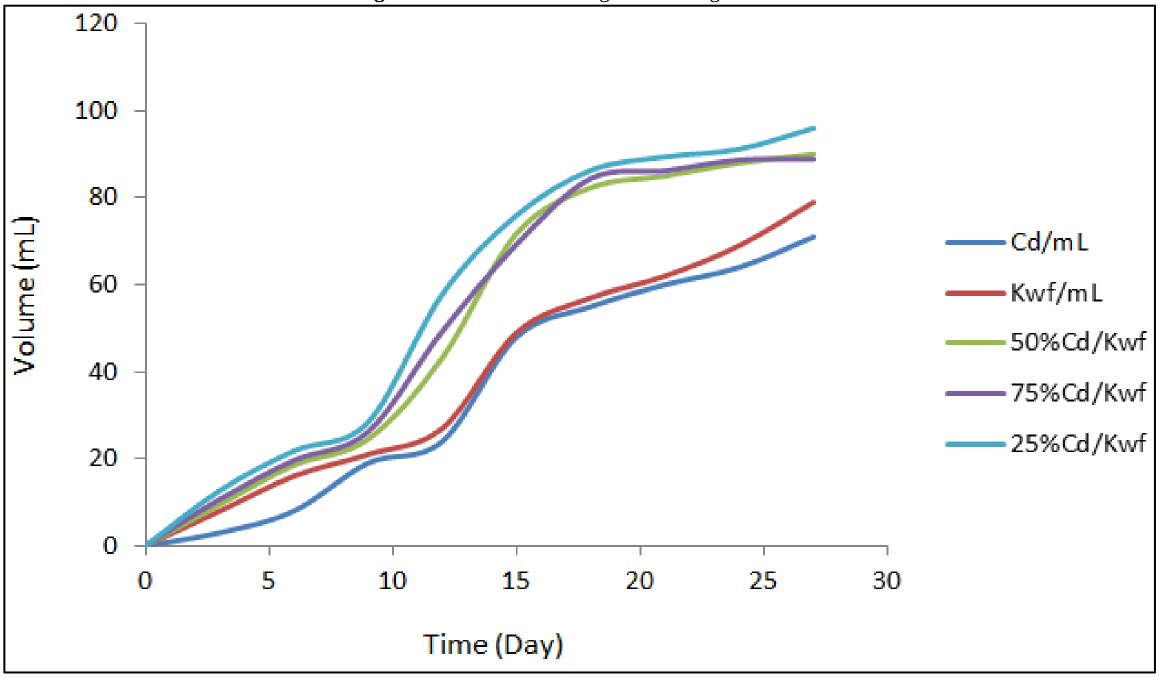


Instrumentationet cattle dung (37g) and waste food materials (13g) and cattle urine (200

4. Results and Discussion

The volume of biogas formed by degradation of cattle dung, kitchen waste and admixtures of these two were measured and recorded using the apparatus shown in Figure 2. Each experiment was repeated thrice and the average volume recorded over the 28 days' period was used to plot Figure2 below;

Figure-2. Plot of volume of gas formed against time



Production of gas from 50 g of cattle dung, 50 g of kitchen food waste and their admixtures in 50 %, 75 % and 25 % cattle dung in slurry with cattle urine (200 mL) and sludge inoculums yielded graphs in Figure 2.

The production of biogas started by day 3 of experiment showing that the time between set up of experiment and initial formation of gas was not utilized by the anaerobes to act on the slurry. This has been explained as time used by the anaerobes to use up oxygen present in the slurry; and after oxygen is depleted, acid forming anaerobes became active so gas production started [40].

Production of biogas increased steadily at first and then sharply after day 9 until it attained its peak on day 18. When gas production had just begun, the microbes in the slurry had just become active and began increasing their population [40]; and the microbes needed acclimatization period [41].. The steady increase in biogas was explained by the fact that the microbes' population was fully established in large enough numbers and were therefore progressively acting on more and more substrate as their numbers increased [40].

By the time the peak production was attained, the anaerobes were acting on maximum quantity of organic matter suspended in the slurry [28].

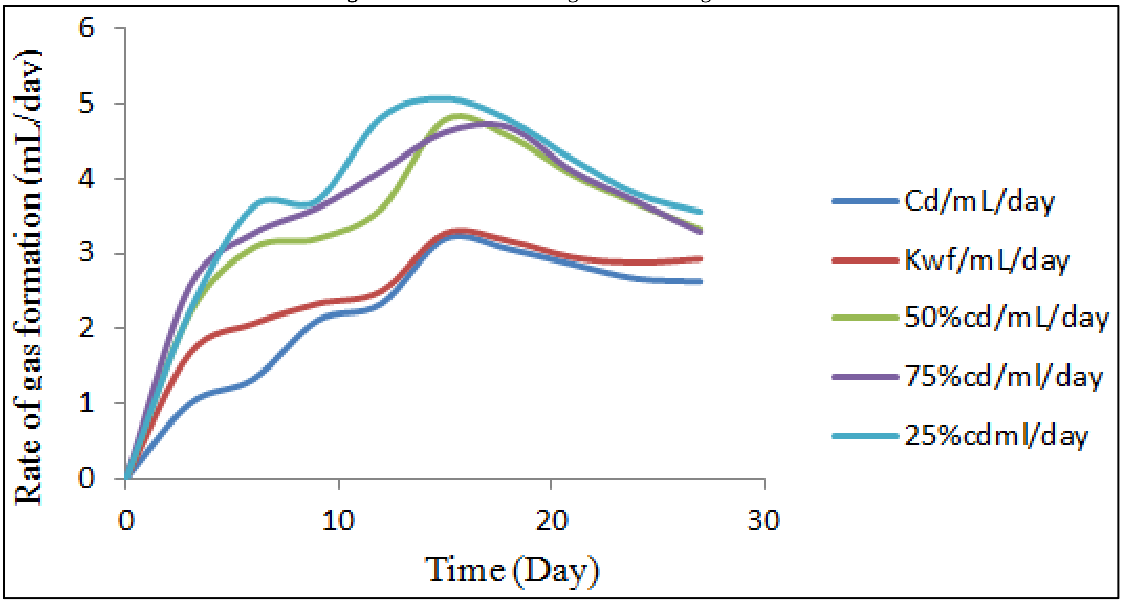
The drop in volume of gas formed beyond the peak may have resulted from decrease in quantity of substrate available to the microbes to act on or even shift in the balance of carbon to nitrogen ration available to the anaerobes to use [41]. The volume of gas formed from different generating substrates varied with cattle dung yielding least yet cogeneration mixture made of 50 % cattle dung produced highest volume. It was observed that after day 9, the volume of gas formed from all digestion mixtures kept increasing steadily.

The rate of change in volume with time in Figure 3 revealed that the higher the rate of evolution of gas was attained by the 15th day for single substrate and mixed substrate digestions. However, smaller rates of evolution of gas occurred for single substrate than for mixed substrates due to positive synergism brought about by balance of the carbon to nitrogen ratio getting closer to 30:1 [41]. After day 15, the rate of degradation decreased due to depletion suspended ingredients. It would therefore be recommendable that if biogas is generated for commercial needs, one needs six to seven digesters arranged in series such that thy are started one after the other after a day and left to run up to the 15th day the restarted on the 18th day by feeding the first in the same series as was done at the beginning.

By comparison, the volume of biogas formed from slurry of cattle dung was less than that formed from kitchen food waste in cattle urine probably due to kitchen food waste providing a better nutrient balance for carbon to nitrogen than cattle dung which was largely lignified cellulose [40]. The microbes survive better in media containing more nitrogen than those containing less because nitrogen is an essential element for their life. The anaerobes metabolize organic matter with aid of enzymes reducing carbohydrates, proteins and fats to methane. There is dependency of quantity of gas formed on the carbon to nitrogen (C/N) ratio of the slurry digested [42]. The optimum ratio of C/N is 30:1 was reported. The anaerobes consume carbon 30 times faster than nitrogen [41] to convert organic waste to a renewable energy source, biogas. The chemical composition and structure of lingo-cellulosic materials hinders the rate of bio-digestion of slurry as hydrolysis of complex matter to soluble compounds must be the are determining or limiting step for the decomposition of the slurry with high solid content like cattle dung slurry [28, 43].

Cogeneration is simultaneous generation of biogas using homogeneous slurry of two or more substrates, each of which can produce the gas if digested singly. The results on cogeneration of biogas using slurries containing cattle dung cd and kitchen food wastes kwf in a laboratory scale digester at ambient temperatures is shown in Figure 3.

Figure-3. Plot of rate of biogas formation against time



As shown on Figure 3, the rate of evolution of biogas from mixed aqueous slurry of cd and kwf was higher than single substrate because the combination brought together the positive characteristic of feed stocks and potentially bringing better digestion performance as well as more rapid growth of microbial population in the mixed substrate than in the single substrate [40, 44].

It can be observed that very significant evolution of gas started after day 3. Evolution of biogas was slower for cd than kwf because cd slurry had higher content of lignified cellulose than kwf. Cellulose requires more time and adverse conditions to hydrolyze than ordinary carbohydrates in present kwfs. Additionally, cooking could have weakened bonds in kwfs. So the retention time for cd was higher than for kwf [45]. The maximum rate of volume increase biogas formed was for mixture made of 25 % cd on the 15th day. This was interpreted as showing that the slurry contained the best C/N ratio of all the samples tested [41]. So this mixed substrate slurry containing cd and kwf approached the optimum C/N ratio of 30:1 [46].

The rate of decomposition expresses volume of gas formed per gram of substrate digested is shown in Figure 4 below for cd, kwf and mixtures cd and kwfs.

Figure 4. Rate of degradation in slurries containing 200 g/L at ambient temperatures

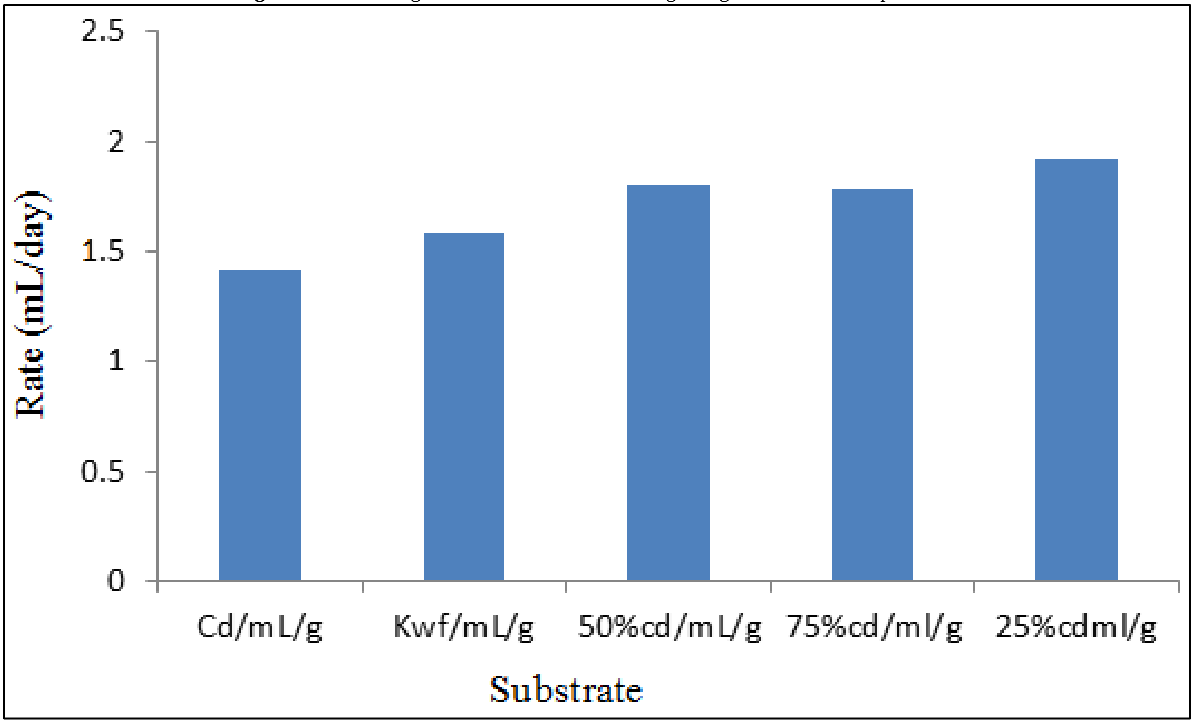


Figure 4 above illustrates that when equal total masses of substrates were fed in the digesters at ambient temperatures differing rates of decomposition resulted because the volumes of biogas registered were different. The cogeneration slurries showed higher average rates of decomposition than single substrate slurries of cd or kwf. The average rate of decomposition for cd was1.42 mL/g that for kwf was 1.58 mL/g that made of 75 % cd was 1.78 mL/g; for 50 % cd was 1.80 mL/g and for 25 % cd was 1.92 mL/g.

The rate of biogas formation for the cogeneration slurries containing cd and kwfs was obtained to be higher than for cd by the respective factors of 1.254 for 75 % cd; 1.268 for 75 % cd and 1.352 for 25 % cd and these values lie within the range of values of enhancement that were reported to lie between 0.8 to 5.5 as compared to single substrate digestion slurries alone [40, 44] and this brought about by synergistic tendencies whereby carbohydrates, fats and proteins simultaneously contribute to formation of biogas.

5. Conclusions

Optimum amount of biogas was produced by anaerobic digestion of cd and kwf in a period of 18 days, the slurry of cd 50 g/200 mL yielded 275$\pm$ 2.03 mL ; kwf 50g/200 mL yielded 329.2$\pm$ 5.77 mL/L; 50% cd yielded329.2$\pm$ 3.10 mL/L; 75% cd yielded 422.0$\pm$ 3.56 mL/L; 25% yielded 431.5$\pm$ 4.65 mL/L.

The average rate of degradation for cd was1.42$\pm$ 0.29 mL/g that for kwf was 1.58$\pm$ 0.21 mL/g that made of 75 % cd was 1.78$\pm$ 0.35 mL/g; for 50 % cd was 1.80$\pm$ 0.37 mL/g and for 25 % cd was 1.92$\pm$ 0.40 mL/g.

The rate of gas evolution reached 5 mL/day on the 15th day using 25 % cd mixed slurry. The overall rates of degradation attained in the mixtures were 1.42 $\pm$ 0.26 mL/g for cd; 1.58$\pm$0.33mL/g for kwf; 1.78$\pm$ 0.38mL/g for 75% cd mixed substrate; 1.78$\pm$ 0.29 mL/g for 50 % cd mixed substrate; 1.92$\pm$ 0.21 mL/g for 25 % cd mixed substrate slurries in the 200g/L load. The comparative rate of biogas formation ranged from1.25 to 1.35 which was in agreement with the range published in literature of 0.8 to 5.5.

Biogas can be synthesized efficiently at ambient temperatures in Kampala as was done at mesophilic temperatures elsewhere.

Cd and kwf can produce significant quantities of biogas if digested anaerobically.

Recommendation

The digestion of slurry of single cd, kwf and mixed substrates of cd, kwf should be tested for evolution of gas at 37^{o}C, the reported optimum temperatures.

Attempts to test on the effect of pH on yield of biogas need be determined.

Studies on C/N ratios for cd and kwf should be documented to assert the nutrient balance levels.

However, it may be necessary to attempt producing biogas at different pH and temperatures as well as using other substrates and inoculums.

Acknowledgement

We are indebted to Prof G.W. Nyakairu and Mr. Moses Mutenyo for the design and technical advice on the design of the bio-digester.

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