



Biogas Synthesis as Means of Solid Waste Management in Kampala, Uganda

Mukasa-Tebandeke I. Z.

Chemistry Department, Faculty of Science, Kabale University, Uganda

Karume I.*

Chemistry Department, School of Physical Sciences, Makerere University, Uganda

Mutesasira J.

External Studies Department, Institute of Distance Education, Makerere University, Uganda

Wasajja H. Z.

Departments of Earth Sciences, Wesleyan University, Connecticut USA

Nankinga R.

Departments of Earth Sciences, Wesleyan University, Connecticut USA

Abstract

Cattle dung, cooked food waste, and chicken droppings mixed with coffee husks have been used separately and also as mixtures to form anaerobic digestion slurries in a bid to treat to degrade the organic fractions of these wastes and recycle the bio-fertilizer after recovering biogas. Single and mixed substrate slurries evolved significant quantities of methane within 27 days together with reduced mass of soil conditioner. The volume of biogas formed in cogeneration mixtures were higher than for single substrate digestion due to the C/N ratio shifting to near 30:1 as a result of mixing. So degradation of organic pollutants was higher in mixed substrate digestion mixtures. Our study yielded average volumes ranging from 315 to 435+ 5.65 mL/L which was in agreement with what is in literature. Digestion of cattle dung, cooked waste foods, and droppings of chicken and mixed substrate slurries using sludge inoculums was very effective in degrading solid waste from homes, thus detoxifying it to bio-fertilizers. Although both single and mixed substrate digestion of waste yielded high enough volumes of biogas; digestion of slurry of mixed organic solid waste substrates is better method of waste management. Digestion of garbage from Kampala should be tested at macro levels at both ambient and mesophilic temperatures. There is need to try out the garbage digestion experiments in the semi-arid towns as well as very cold towns in Uganda.

Keywords: Biogas; Bio-fertilizer; Degradation; Cattle dung; Waste food; Chicken droppings; Sludge inoculums; Digester.



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1. Introduction

Ugandans rely on traditional energy sources like fossil fuels, wood and charcoal which are unsustainable because of ecological and environmental problems as well as rapid depletion [1] yet biogas cogeneration would supply the energy and also relieve environmental pollution through treatment of solid waste accumulated in homes, farms, or urban municipal councils [2]. A survey of 144 biogas plants in Uganda revealed they were run poorly or unmaintained and many were not functioning well [2]. The accumulation of solid organic waste at landfills is thought to be reaching critical levels in almost all regions of the world [3]. Removal of solid organic waste is now an ecological problem brought to light as a result of increase in concerns relation to public health and environment [4].

The estimated rate of generation of solid waste was reported to be 0.77 kg/person/day in developing countries [5] and is increasing and the municipal solid waste is about two billion tons per year and may reach three billion tons by 2025. The production of fruits and vegetables waste is very high and must be of a great concern in municipal landfills as it is readily decomposed [6]. It was demonstrated that household energy can be generated by digestion of sewage, food waste, cattle dung and energy crops and the same time overcome solid organic waste [7]. In Uganda, solid waste managements were tendered by Kampala Capital City Authority (KCCA) to three organizations, Nabugabo updeal, Homeklin and Solid waste consortium which ferry the solid wastes to Kiteezi landfill. The waste is graded before being loaded on trucks that ply the divisions of Kampala. Much of the waste is merely dropped at the landfill without further treatment which poses health hazards as it percolates in the nearby streams and underground waters in the area, let alone the off smell in the neighboring areas.

About a decade ago, fraction of solid organic waste was recognized as a valuable resource that can be converted to very useful products through microbial mediated transformation [8, 9]. Many methods are used to treat solid organic waste but anaerobic digestion was reported as most promising [10]. Anaerobiosis was shown to involve metabolic reactions like hydrolysis, acidogenesis and methanogenesis [11]. Anaerobic digestion of solid wastes at landfill releases gases including methane, and carbon dioxide that escape in air and pollute the environment [12]. Under controlled conditions, bio-digestion is used to provide biofuel and organic amendment or soil conditioner and the treatment system does not require oxygen supply [13, 14]. Anaerobiosis provides the opportunity to decrease

*Corresponding Author

environment pollution, produce biogas and bio-fertilizer. Anaerobic treatment of organic waste is not widely used in Uganda and even elsewhere in the world probably due to the longer retention period required for the waste to achieve stabilization [4]. The process is also retarded by excessive evolution of ammonia formed by degradation of proteins or amino acids [15, 16]. However, metals and recalcitrant organic products which may be toxic may not breakdown and will become concentrated in residue [3]. A test involving different sizes of particles fed in bioreactor was performed using sisal fiber waste revealed smaller particles worked better than lamps [17]. Anaerobic digestion of solid organic waste receives worldwide attention today because several digester designs are on market [18]. Inside the bioreactor, a series of metabolic reactions were shown to occur [19, 20]. Anaerobiosis has been applied to municipal, agricultural and industrial wastes and plant residues [16] and it has the advantages of low energy requirements and low biomass production [21] as well as the simultaneous production of biofuel, a renewable resource [22, 23]. The sealed environment in the bioreactor prevents leakage of methane in the atmosphere, yet burning methane releases carbon neutral carbon dioxide [24].

The anaerobic process requires long retention times and has low removal efficiencies of organic compounds [19] because the chemical composition and structure of lignocellulosic materials retards the rate of biodegradation of solid organic wastes. So hydrolysis of complex organic matter is rate limiting step of anaerobic digestion of wastes with high solid content [10, 25]. To alleviate such, physical, chemical and enzymatic treatments are essential to increased substrate solubility and accelerated degradation to gas [20].

Co-digestion is a waste treatment method in which different waste materials are mixed and treated together [26]. Co-digestion brings advantages to waste management like dilution of toxic compounds; increased loading of biodegradable organic materials; improved balance of nutrients; synergistic effects of microorganism; higher biogas yields. Co-digestion also provides nutrients in excess [27] which accelerates biodegradation of solid organic wastes in addition to increased rate of digestion and stabilization [28, 29]. Co-digestion therefore facilitates a stable and reliable digestion performance and production of good quality and increased yield of biogas [28]. Backyard farmers in Kampala rear cattle, goats, sheep, chicken all of which excrete dung or droppings which pollute the environment when they are accumulate or dropped at garbage pits. KCCA charges residents for solid waste management reducing household income from rearing animals. It would be advantageous for farmers to utilize these waste resources in production of renewable energy biogas and bio-fertilizers if they invested in it. This study has targeted the use of cattle dung (cd), cooked food waste (cfws), and chicken dropping (dc) to produce biogas as means of treating organic solid wastes in homes. The process of generating biogas using anaerobes of organic matter is a technology which is popular and widely used and it arose from problems of day to day living like how to acquire sufficient energy and proper disposal of waste without harming man or changing the environment [30]. Anaerobic fermentation of domestic waste and weeds was found to produce methane for nearly 22days in the bioreactor [30]. Organic wastes are of plant and animal origin and are biodegradable and this was observed when organic waste composted, stabilized in ponds or digested anaerobically [31]. Dead animals and plants or their remains like leaves, roots, hair, feathers or blood as well as waste generated by animals like the dung are organic waste materials which are acted on by microorganisms to break them to smaller molecules [32]. Organic wastes are nuisance because of their odors, pH and they require treatment to reduce odor levels, the quality and stability before disposal using such methods like aerobic digestion, anaerobic digestion, composting, incineration and stabilization in a pond. When the above mentioned is not done properly municipalities or towns will have characteristics off odors resulting release of polluting gases in the entire environment.

2. Methodology and Sampling

2.1. Sampling

From kraal at Kibuli wet cattle dung, cd, (10kg) was collected. From same kraal cattle urine (10l) as also collected from garbage pit cooked waste food, cfws, (10kg) was collected from Wandegeya market. Chicken droppings mixed with coffee husks, dc, (10kg) was collected.

2.2. Methodology

2.2.1. Cattle Dung Digestion

Wet cattle dung (45g) was put in a can, cattle urine (200mL) and sludge inoculums (50mL) added. The mixture was stirred to obtain slurry; the slurry was fed in the digester. Carbon dioxide was bubbled in slurry loaded in the digester for 5 minutes to expel dissolved oxygen [33]. The gas formed was collected over dilute sodium hydroxide solution. The experiment was repeated three times.

2.2.2. Cooked Waste Food Digestion

Cooked waste food, cfws, (45g) was put in a can, cattle urine (200mL) and sludge inoculums (50mL) was added. The mixture a stirred in a can to form slurry, the slurry was fed in the digester. Carbon dioxide was bubbled in slurry loaded in the digester for 5 minutes to expel dissolved oxygen [33]. The gas formed was collected over dilute sodium hydroxide solution. The experiment was repeated three times.

2.2.3. Chicken Dropping Digestion

Mixture of chicken dropping and coffee husks, dc, (45g) was put in a can, cattle urine (200mL) and sludge inoculums (50mL) added. The mixture was starred to form slurry. The slurry was fed in a digester. Carbon dioxide

was bubbled in slurry loaded in the digester for 5 minutes to expel dissolved oxygen [33]. The gas formed was collected over dilute sodium hydroxide solution. The experiment was repeated three times.

2.3. Co Digestion of Cd, Cwfs, Dc.

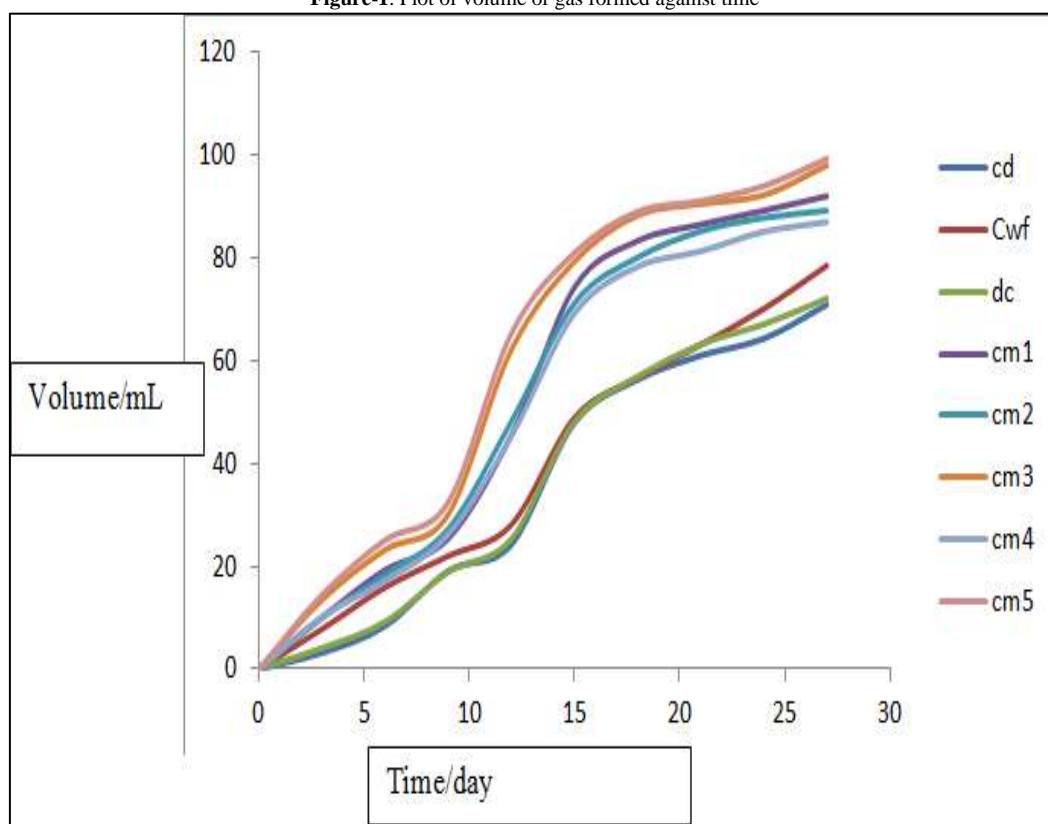
- A) cd (15g), cwfs, (15g) and dc (15g) was put in a can, cattle urine (200mL) and sludge inoculums (50mL) was added. The mixture was stirred to give slurry. The slurry was fed in digester. Carbon dioxide was bubbled through slurry loaded digester for 5 minutes. Coded as cm1. The gas formed was collected over dilute sodium hydroxide solution. The experiment was repeated three times.
- B) cd (7g), cwfs (23g) and dc (15g) was put in can, cattle urine (200mL) and sludge inoculum (50mL) was added. The mixture was stirred to give slurry. The slurry was fed in the digester. Carbon dioxide was bubbled through slurry loaded in the digester for 5 minutes. Coded as cm2. The gas formed was collected over dilute sodium hydroxide solution. The experiment was repeated three times.
- C) cd (7g), cwfs (15g) and dc (23g) was put in can, cattle urine (200mL) and sludge inoculum (50mL) was added. The mixture was stirred to give slurry and this slurry was fed in the digester. Carbon dioxide was bubbled through cold slurry loaded in the digester for 5 minutes. Coded as cm3. The gas formed was collected over dilute sodium hydroxide solution. The experiment was repeated three times.
- D) cd (15g), cwfs (7g), dc (23g) was put in can, cattle urine (200mL) and sludge inoculum (50mL), was added. The mixture stirred to slurry. The slurry was fed in digester. Carbon dioxide was bubbled through cold slurry loaded digester for 5 minutes. Coded as cm4. The gas formed was collected over dilute sodium hydroxide solution. The experiment was repeated three times.
- E) cd (23g), cwfs (15g), dc (7g) was put in can, cattle urine (200mL) and sludge inoculum (50ml) was added. The mixture was started to slurry. The slurry was fed in the digester. Carbon dioxide was bubbled through the cold slurry loaded in the digester for 5 minutes. Coded as cm5. The gas formed was collected over dilute sodium hydroxide solution. The experiment was repeated three times.

3. Results and Discussion

The average volumes of methane formed has been plotted in Figure 1 for single and mixed substrates digestion of various organic waste at 225g/L loading at ambient temperatures in Laboratory setting in Kampala.

Among single substrate digestion mixtures, cwfs underwent degradation more. Efficiently than cd or dc possibly because cwfs were cooked and so nutrients in the organic waste are easily degraded.

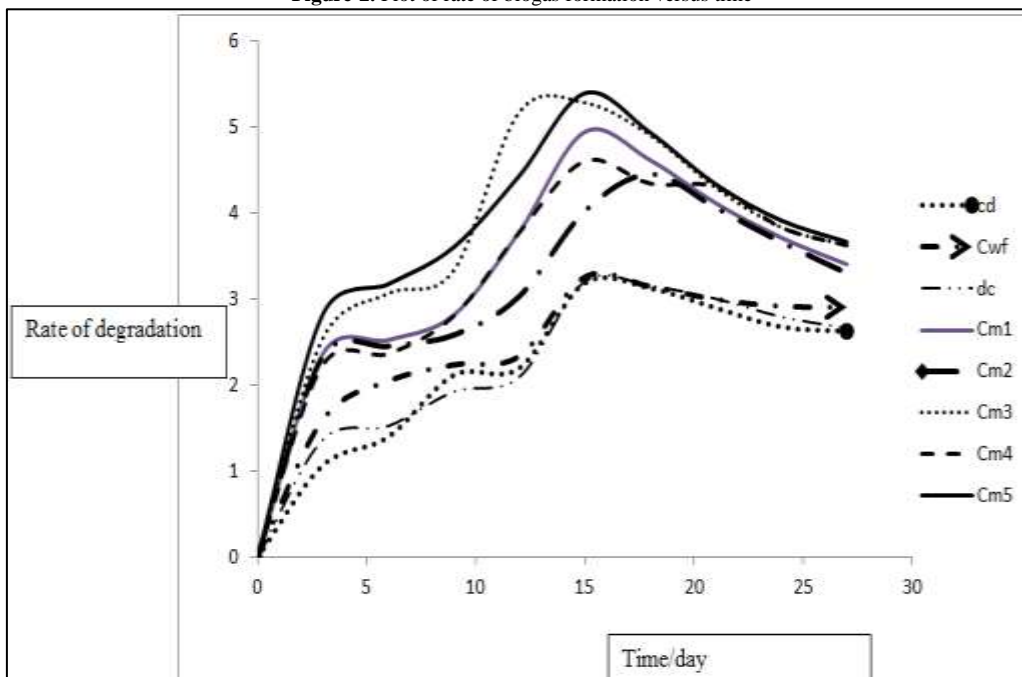
Figure-1. Plot of volume of gas formed against time



Of the co-digestion mixtures cm1, cm2, cm3, cm4, cm5; the cm5 produced biggest volume of biogas because the microbes had all nutrients needed and there could have been a balance of nutrients in cm5.

The least performance was observed for cm4 probably due to presence of dc in bigger quantities than in other experiment. dc constituted 50% of the mixture, this could have led to presence of excess nitrogen in feed and consequently may have produced excess ammonia which inhibited multiplication of microbes in mixture [34].

Figure-2. Plot of rate of biogas formation versus time



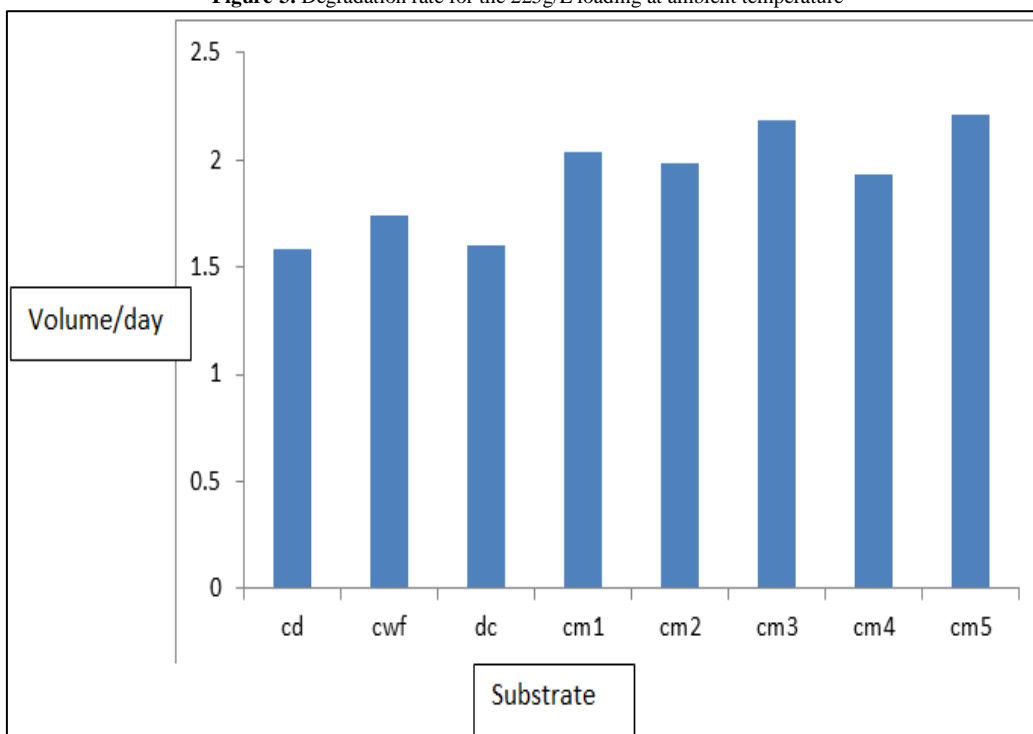
In all experiments done the rate was highest at day 15 because microbes were most active then, and the ingredients were in large enough supply [35]. For single substrate digestion, cwfs showed better performance and cd showed worst.

For multiple substrate cm3 showed highest rate of gas evolve due to C/N balance and being the 30:1 ratio for optimum yield [34]; cm2 had least performance to retardation effects of urea in high concentration.

The rates of decomposition for the single and mixed substrate digestion slurries were computed and presented in Figure 2. Single substrate slurries shown the lowest rates of degradation yet mixed substrates were more rapid indicating synergistic tendencies were brought the mixture when different substrates were put in one reactor.

The overall rate of degradation at ambient temp was highest for co-digestion mixture cm5 due to balance of C to N ratio 30 to 1 [30] as shown in Figure 3.

Figure-3. Degradation rate for the 225g/L loading at ambient temperature



And lowest rate of degradation was exhibited in mixture cm4 probably due to excess nitrogen introduced by the excess chicken dropping used in that experiment. Evolution of ammonia may have retarded the microbes producing the biogas [33]. The highest rate of degradation for single substrate digestion was observed using cwfs because cooked food is more readily hydrolysable than lignified cellulose in grass remains and coffee husks [36].

As co-digestion mixtures cm1, cm2, cm3, cm4 and cm5 showed average rates greater than 2.0 at ambient temperature yet single substrate slurries decomposed at lower rates, it would be advisable that waste management in homes, factories, municipal works or towns utilize co-digestion to facilitate the rate of decomposition of garbage in anaerobic digesters because at the end of the process the bio-fertilizer formed will be smaller if co-digestion is employed than when single substrate is digested. Additionally, the retention time for the digestion process will be less for co-digestion in mixtures than for single substrate and the volume of biogas formed is much higher. So co-digestion of multiple substrates is better choice in waste management [3]. So bio-waste accumulated in Municipal and Town can be treated as bulk without sorting if nutrient balance is checked to be 30:1 for the Carbon to Nitrogen content in the waste.

Although factors like type and composition of substrate, microbial composition, temperature, moisture and bioreactor design were shown to affect yield of biogas [37]. The results obtained from co-digestion of cd, cwf and dc revealed nearly equal volumes of gas formed at ambient temperatures in this study using sludge inoculum and the time taken to achieve the high yield was 15-21 days instead 63days as reported [3]. So digestion of mixed substrates can easily afford solid organic wastes treatment in 21days of incubation a biogas digester plant at ambient temperatures and overcome the high pollution levels caused to pilling the non-hazardous solid waste at landfills. The bio-fertilizers formed in shorter period than 60days as was earlier published would add revenue to the gas generated. Thus industrial facilities treating solid organic waste can be instrumental in treating solid wastes.

Whereas the respective volumes/kg of methane produced from mixed solid waste substrates published were 380mL from municipal solid waste [38], 530mL from municipal solid waste [39], 200mL for municipal solid waste [40], 294mL from food waste leachate [41] 390mL from house hold waste [42] and 396mL from food waste [43], our study yielded up 315 ± 2.03 mL from cd, 348.5 ± 3.10 mL from cwf 320.1 ± 4.65 mL from dc, as single substrate sludge were digested and 408.5 ± 4.55 mL from cm1, 396.45 ± 3.10 mL from cm2, 435.3 ± 3.65 mL from cm3, 386.2 ± 3.56 mL from cm4 and 432.1 ± 5.70 mL from cm5 at 225g/L loading at ambient temperature. The values adduced in this study compare very well with what was found in literature; but our study lasted 27 days instead of 60 or 90 days as was reported in literature.

Just as production of methane from food waste leachate in simulated landfill bioreactors (lysimeters) [41] using different inoculum. Substrate ratios yielded maximum yield of methane in 90 days; cd, cwfs, dc, cm1, cm2, cm3, cm4 and cm5 attained maximum methane production with 27 days. This showed that slurries of solid waste can effectively be degraded using sludge inoculum in shorter period of time than was presented. So anaerobic digestion of slurry of cattle dung, cooked food waste, chicken dropping and their mixed substrate mixtures turns to bio-fertilizers in a short period of time in addition to generating comparable volumes of biogas to those done elsewhere.

As it was reported that the rate of anaerobiosis is affected by type, availability and complexity of the substrate [44, 45] our experiment results revealed this through volumes of gas formed and rate of degradation of slurries used. While among single substrate slurries the volumes of methane formed increased in order of magnitude as $cd < dc < cwf$; because cd contained largely undigested lignified cellulose for which the retention time must be longer in addition to higher C/N ratio than 30: 1. So total volume of methane generated within the time frame of experiment was less. Similarly, mixture of chicken droppings with coffee husks dc either contained excess nitrogen and lead to evolution of ammonia which retarded evolution of ammonia which retarded evolution of biogas [46] or the coffee husks had a very high C/N ratio greater than 30 to 1 needed for optimum decomposition of organic waste yielding biogas. Cooked food waste evolved the largest volume of gas because the slurry enriched with urea from cattle attained the favorable C/N ratio near the optimum ratio of 30 to 1 for rapid evolution of biogas.

The volume of biogas formed in cogeneration mixtures varied in order of magnitude in order $cm3 > cm5 > cm1 > cm2 > cm4$ due conditions related to nearness of the C/N ratio to 30 to 1 the ideal [10, 14, 47].

However, all co-digestion experiments yielded volumes in the range of 400mL which is high enough and thus favored recommending the use of mixed substrate slurries in the treatment of organic solid wastes from homesteads or municipals.

4. Conclusions

Digestion of cd, cwfs, dc and mixed substrate slurries using sludge inoculums was very effective in degrading solid waste from homes, thus detoxifying it to bio-fertilizers. Solid single substrate and mixed substrate digestion of waste yielded high enough volumes of biogas for energy and bio-fertilizer.

Digestion of slurry of mixed organic solid waste substrates is better method of waste management than single substrate digestion because of positive synergism which enabled rapid decomposition.

Organic solid waste with little or no nitrogen content does not degrade as easily as that having significant nitrogen content. Likewise, highly nitrogenous materials will have retarded anaerobiosis.

The laboratory scale co-digestion experiments at ambient temperatures worked with efficiency nearly equal that of mesophilic digesters.

Recommendations

Garbage collected from Kampala contains numerous solids like bananas, banana peelings, cassava, potatoes, grass, shrubs, etc. There is need to test for degradation of such raw materials in digesters running at ambient temperatures.

Utilization of gas formed at ambient temperatures for generating electricity a cleaner energy needs to be tested.

Co-digestion of garbage from Kampala should be tested at macro levels at both ambient and mesophilic temperatures.

There is need to try out the garbage digestion experiments in the semi- arid towns as well as very cold towns in Uganda.

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