Mesophilic Anaerobic Co-digestion of Cow dung, Chicken Droppings and Grass Clippings

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Abstract— **The main focus of this study was mesophilic anaerobic co-digestion of cow dung, chicken droppings and grass clippings using pilot bio-digesters. The biochemical methane potential (BMP) works under batch anaerobic digester operating in ambient mesophilic temperature of 35 ^{o}C and 37 ^{0}C and pH of 7 to generate biogas. The carbon/nitrogen (C/N) ratio for cow dung and chicken droppings was found to be 17.70 and 63.67 respectively and grass clippings to be 20.54. Through co-digestion in a ratio of 1:1, the C/N ratio for cow dung and grass clippings settled at 19.19 while that for chicken droppings and grass clippings settled at 20.49. The conversion rate of the reaction and biogas production increased with the increase in temperature and hydraulic retention time until an equilibrium state was achieved. At the temperature 37 ^{O}C, it was observed to be the suitable mesophilic temperature for anaerobic digestion due to high dissociation and collision leading to high rate of biogas production.**

Keywords— **Anaerobic digestion, Co-digestion, Mesophilic Temperature**

I. INTRODUCTION

THE energy consumption worldwide is spontaneously increasing due to industrialization, population growth, and state of development. The need for an alternative source of energy for centralized and decentralized power generation has led to researchers looking for alternative source of energy [1].

With the fast depletion of non-renewable energy sources such as fossil fuel and coal which has led to human health problems and global climate change and environmental degradation, the commercial production of biogas and other alternative energy source such as solar energy, hydropower, wind energy, bioenergy, geothermal will definitely give a drive for the development of the economy [2, 3]. Fig. 1 shows renewable energy conversion technologies. Energy derived from biogas is used in the form of fuel, heat, and electricity. It is desirable to create sustainable and with zero carbon emissions worldwide energy system [4, 5]. This results in resource conservation and environmental protection [5, 6].

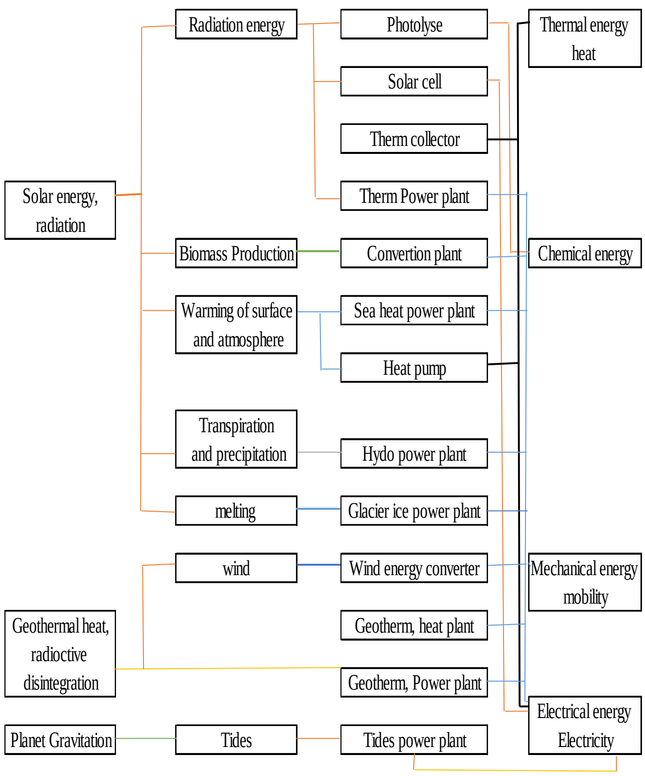

Fig I: Renewable energy conversion technologies

Biogas is produced by anaerobic decomposition process called Anaerobic Digestion (AD). It is the biological breakdown of organic matters in the absence of oxygen. The main product of biogas is methane and carbon dioxide [7, 8].

Biogas production follows four fundamentals processes. These processes include hydrolysis, acidogenesis,

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acetogenesis and methanogenesis [9]. Fig. 2 shows a simplified generic anaerobic digestion process [10].

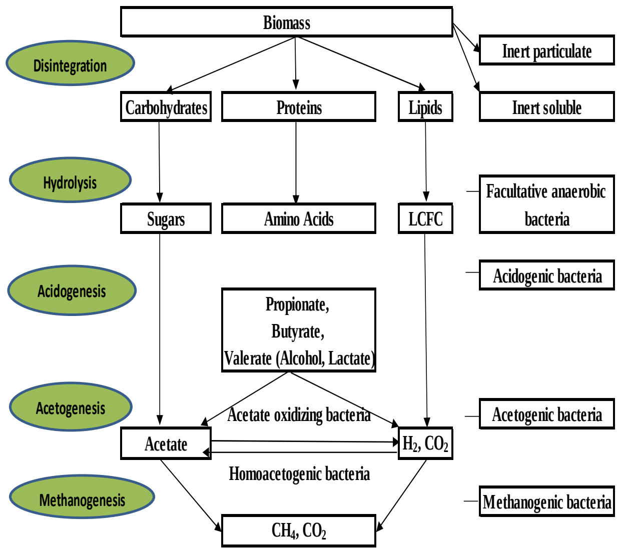

Fig 2: Degradation steps of the anaerobic digestion process.

Hydrolysis is theoretically the first step of anaerobic digestion, during which the complex organic matter (Polymers) are decomposed into smaller units (mono- and oligomers). During hydrolysis long-chain molecules, such as carbohydrate, protein, and fat polymers, are broken down to monomers (small molecules). Different specialized microbial produce a number of specific enzymes which catalyze the decomposition, and the process is extracellular. During hydrolysis, polymers like carbohydrates, proteins, lipids and nucleic acids are converted into glucose, glycerol, purines, and pyridines [11]. In the acidogenesis process, the acidogenic bacteria transform the products of the hydrolysis into short chain volatile acids, alcohol, ketones, carbon dioxide and hydrogen. Some of the major acidogenesis stage products are acetic acid, propionic acid, formic acid, butyric acid, lactic acid, ethanol, and methanol. From these products, the carbon dioxide, hydrogen, and acetic acid will skip the third stage, acetogenesis, and be utilized directly by the methanogenic bacteria in the final stage [12, 13]. The third stage is known as the acetogenesis stage, the rest of the acidogenesis products, i.e. the butyric acid, propionic acid and alcohols are transformed by acetogenic bacteria into hydrogen, carbon dioxide, and acetic acid. Hydrogen plays an important role in this process, as the reaction will only occur if the hydrogen partial pressure is low enough to thermodynamically allow the conversion of all compounds of acids. Such lowering of the partial pressure is carried out by hydrogen scavenging bacteria thus, the hydrogen concentration of a digester is an indicator of its health [14]. Methanogenesis is the final stage of the biogas production. The production of methane and carbon dioxide from intermediate products is carried out by Methanogenic bacteria. 70% of the formed methane during AD originates from acetate, while the remaining 30% is produced from the conversion of carbon dioxide (CO_2) and hydrogen (H_2) [11]. The methanogens bacteria have the slowest growth rate involved in the process; they also the limiting factor for how quickly the process can proceed and how much material can be digested in AD. The growth rate of the methanogens is only around one fifth of the acid-forming bacteria [15].

The activity of biogas production depends on various parameters like temperature, partial pressure, pH, hydraulic retention time, C/N ratio, pre-treatment of feedstock, trace of metals and concentration of substrate [5, 16-18]. Table I shows different thermal stages and typical hydraulic retention times for the AD process.

TABLE I:
THERMAL STAGES AND TYPICAL HYDRAULIC RETENTION TIMES [19].

Thermal stages	Process temperature (^{0}C)	HRT(days)
Psychrophilic	<20	From 70-80
Mesophilic	From 30-42	From 14-40
Thermophilic	From 43-55	From 14-20

Biogas can be produced from co-digestion of various substrates. In the present study, anaerobic digestion of co-digestion of cow dung/chicken droppings and grass clippings were studied in laboratory experiments in a 10 liters digester under a constant temperature of 35 ^oC and 37 ^0C.

II. METHODOLOGY

A. Substrate Collection

Cow dung and Chicken droppings were collected at the farm in Gauteng province while grass clippings were collected from the University of Johannesburg. Waste characterization was done to ascertain the composition. These included physical and chemical composition with regards to C/N ratio, total solids, volatile solids and elemental analysis for Carbon, Nitrogen, Sulphur and Hydrogen in accordance with the standard method (APHA 1995) [20].

To determine biogas production rate, a batch digester was fed with the co-digested substrates and inoculum under pre-set conditions of 37 ^0C and pH of 7 as shown in Fig. 3. pH was neutralized by a solution of 8g NaOH in 100 ml and H_2SO4. The digester was flushed with Nitrogen gas to expel the oxygen and create an anaerobic process. It was then immersed in the water bath and kept under constant temperature. The liquid sample collected was analyzed using a spectrophotometer. The gas produced was measured using downwards displacement method on a daily basis until the end of retention time. The gas collected was sampled by extracting it from the digester using a gas syringe and was analyzed using gas chromatography instrument with flame- ionization detectors. The operating conditions were; helium was used as carrier gas at 20 ml/min, oven temperature 70 ^0C, detector temperature 150 ^0C and injector port at 80 ^0C.

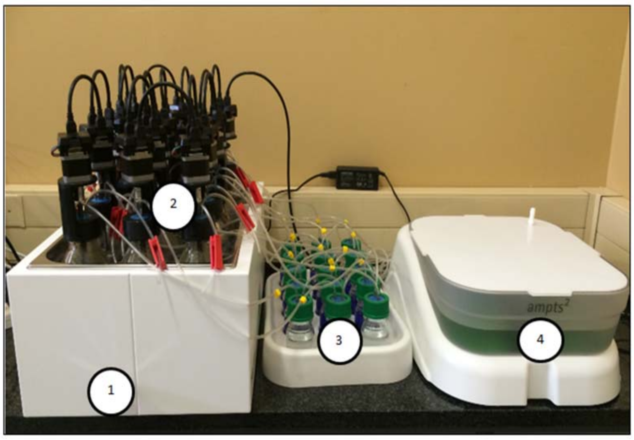

Fig 3: Biogas production setup.

Where: 1 – Thermostatic water bath, 2 - T-Glass bottle reactor, 3 – CO_2 fixing unit and 4 – Gas volume measuring device.

III. RESULTS AND DISCUSSION

The purpose of this experiment was to determine the efficiency of biogas production under mesophilic conditions. In this study, co-digestion of Cow dung/Chicken droppings and grass clippings were evaluated for the purpose of getting the bio-methane potentials and biochemical kinetics at optimum temperature 35 ^oC, 37 ^0C and initial pH of 7. Table II shows the substrate characterization. Cow dung and chicken droppings were found to contain more volatile solids compared to grass clippings which had more nutrients. The elemental analysis of cow dung indicated low C/N ratio compared to grass clippings. Through co-digestion, the C/N ratio increased to 19.19 while that one for co-digestion of chicken droppings and grass clippings the C/N ratio was 20.49.

TABLE II:
SUBSTRATE CHARACTERIZATION

Substra	C	H	N	S	VS (%)	TS (%)	C/N ratio
GC	19.10	1.04	0.93	0.00	64.08	87.88	20.54
CM	63.67	0.85	3.11	2.25	11.75	18.74	20.47
CD	14.87	1.65	0.84	3.66	78.72	91.55	17.70

Where: Substrate, GC-Grass clippings, CM-Chicken manure, CD-Cow dung, C – Carbon, H – Hydrogen, N – Nitrogen, S – Sulphur, TS – Total Solids, VS – Volatile Solids.

TS is the sum of dissolved solids and suspended solids. TS and pH are important to assess anaerobic digestion process efficiency [14, 19]. VS is the organic portion of TS that biodegrade in the anaerobic process. C/N ratio is an important factor in bacteria stability in the anaerobic process. The C/N ratio required for the production of biogas is from 15-30 [21, 22]. TS and VS are calculated using equation (1) and (2) respectively while C/N ratio is calculated using equation (3).

$$VS(\%) = \frac{M_{dried} - M_{burned}}{M_{wet}} \tag{1}$$

$$TS(\%) = \frac{M_{dried}}{M_{wet}} \tag{2}$$

Where:

M_{dried} = Amount dried sample (mg)

M_{wet} = Amount of wet sample (mg)

M_{burned} = Amount of burned sample (mg)

$$\frac{C}{N} = \frac{(F*C_F)+(S*S_f)}{(F*N_f)+(F*N_f)} \tag{3}$$

Where: F = First substrate, S = Second substrate, C_f = Carbon composition for the first substrate, C_s = Carbon composition for the second substrate, N_f = Nitrogen composition for the first substrate, N_s = Nitrogen composition for the second substrate.

In order for a chemical reaction to take place, the ions or particles, which are reactants, must physically come into contact with one another. Anything that increased the frequency of these encounters increased the rate at which products were formed. The rate of a chemical reaction can be increased by increasing the temperature at which the reaction occurs. Temperature affects the chemical properties of the components in the substrates and the growth rate and metabolism of the micro-organisms as reported by Fogler (2010) [23]. High temperature kills the microorganisms and thus decreasing methane produced. It affects the population dynamics in the digester. The temperature sensitivity and classification can be divided into psychrophilic, mesophilic and thermophilic. Acetotrophic methanogens and degradation of butyrate and propionate are sensitive to high temperatures. Temperature also affects the partial pressure of H_2 in the digesters and thus the movements of the syntrophic metabolism. High temperature mesophilic 30-40 ^0C favored the production of acetate, carbon dioxide and hydrogen from propionate. It was desirable to keep the operating temperature stable so as to avoid disturbing the livelihood of the bacteria, especially the methanogens.

Fig. 4 and 5 shows the effect of mesophilic temperature on AD 35 ^0C and 37 ^0C. Between 1-10 days the rate of conversion increased with retention time. This was because, with time, the conversion rate/percent of reactants to products increased. Temperature played an important role in dissociating reactant particles to form new species. The conversion rate of the reaction and biogas production increased with the increase in temperature and hydraulic retention time until an equilibrium state was achieved.

The average CH_4 and CO_2 contents for Cow dung and Chicken droppings co-digested with Grass clippings were reported as 60 %, 58 % and 35 %, 38 % respectively. From the analysis using gas chromatography instrument (GC), CH_4 was observed to contain 60 % and 58 % in biogas. According to the literature, the energy content of biogas is directly proportional to CH_4 concentration. 1 m^3 of CH_4 has a calorific value of around 9.81 kWh, while CO_2 had zero [24]. The biogas generated can be used to generate renewable (green) energy in the form of electricity and heat using combined heat and power (CHP) engine.

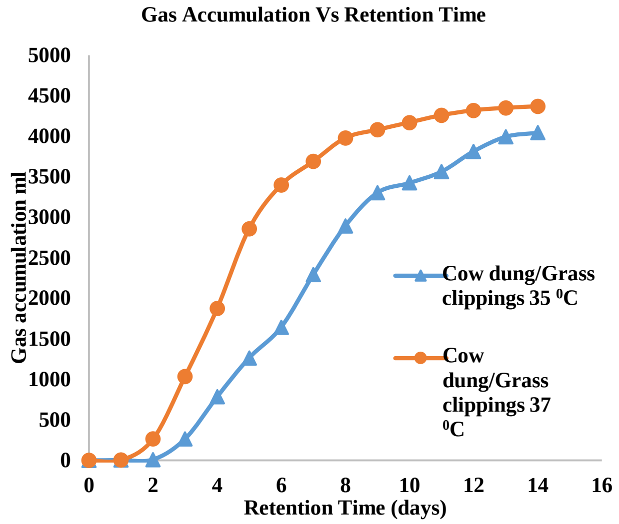

Fig 4: Effect of different temperature constant on rate of conversion with co-digestion of cow dung and grass clippings

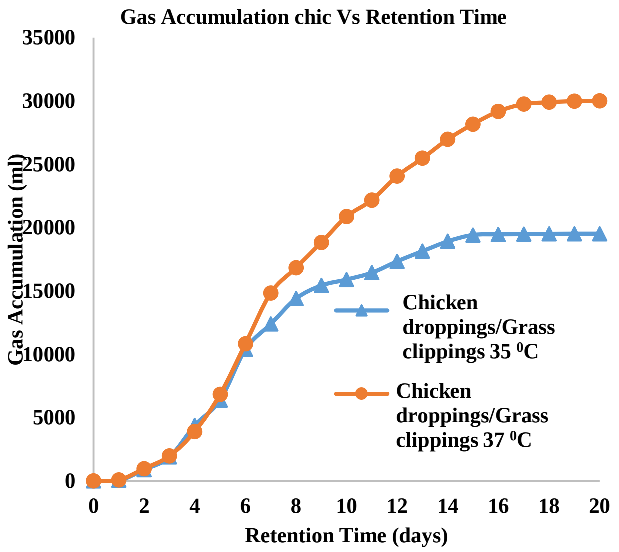

Fig 5: Effect of different temperature constant on the rate of conversion with co-digestion of chicken dropping and grass clippings.

IV.CONCLUSION

Biogas production from co-digestion of cow dung and grass clippings was established to be feasible at a temperature of 37 ^{0}C. All co-digestion in a ratio of 1:1 showed a good productivity of methane indicated as 58-60 %.

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