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Biogas Production from Anaerobic Co-Digestion of Lignocellulosic Waste Material in Sugarcane Bagasse Sawdust and Groundnut Shell

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Abstract

In the present study, anaerobic co-digestion of lignocellulosic waste materials in sugarcane bagasse, groundnut shell and sawdust was investigated. The experiments were carried out in a batch reactor under ambient conditions in order to determine which of the substrates have more influence on biogas production. Sample AB, BC and AC were carried out at equal ration and sample AB with cumulative gas of 9050ml and 67% of methane content appeared to be the best combination and was chosen for the pilot scale set up. In the second phase of the experiments sample AB1, BC2, and AC1 with a total gas and methane content produced of 9700 ml and 66% CH_4, 7040 ml and 54% CH_4, 9980 ml and 70% CH_4 respectively gave the highest yield of gas and methane content; and were chosen as the perfect scale of experiments. In the third phase of experiments sample A'BC with a total gas production of 8830 ml and methane content of 69% CH_4 was chosen as a pilot scale set up. The short lag phase of the digestion process indicated that the microbes acclimatized quickly to the slurry environment. Both sugarcane bagasse, groundnut shell and sawdust substrates showed great potential for biogas production. However, sugarcane bagasse and sawdust have greater potential in term of the quantitative and percentage of methane content. In conclusion, biogas production can mitigate over-dependence on depleting fossil fuel/crude oil in Nigeria and Africa.

List of abbreviations

AB = Sugarcane bagasse+Groundnut shell at ratio 1:1; BC = Groundnut shell+ Sawdust at ratio 1:1; AC = sugarcane bagasse + Sawdust at ratio 1:1; AB1 = sugarcane bagasse +groundnut shell at ratio 3:2; AB2 = Sugarcane bagasse+ groundnut shell at ratio 2:3; BC1 = Groundnut shell + sawdut at ratio 3:2; BC2 = Groundnut shell + sawdust at ratio 2:3; AC1 = sugarcane bagasse +sawdust at ratio 3:2; AC2 = sugarcane bagasse +sawdust at ratio 2:3; ABC = sugarcane bagasse+ Groundnut shell+ Sawdust at ratio 1:1:1; A'BC = sugarcane bagasse+ Groundnut shell+ Sawdust at ratio 3:1:1; AB'C = sugarcane bagasse+ Groundnut shell+ Sawdust at ratio 1:3:1; ABC' =Sugarcane bagasse+ Groundnut shell+ Sawdust at ratio 1:1:3

Keywords: Anaerobic Co-digestion, Biogas, Bioreactor, Lignocellulosic, Quantitative analysis, Qualitative analysis Waste Materials.

Introduction

Sustainable ways to meet energy demands are crucial as the globe struggles with issues like climate change and energy security. According to numerous studies, fossil fuel supplies will last for up to 25 years worldwide; as a result, alternative energy sources like renewables are required [1]. One promising way to meet the demand for bioenergy is to use biowaste resources sustainably to produce biogas. An important source of organic material that can be transformed into biogas through anaerobic digestion is biowaste, which includes lignocellulosic waste materials, food waste, animal manure, and agricultural residues [2]. Rural communities frequently struggle to obtain dependable energy sources, which results in a significant reliance on conventional fuels like fossil fuels and firewood. In addition to being unsustainable for the environment, these energy sources also fuel air pollution, greenhouse gas emissions, and deforestation [3]. By turning it into a useful product through the anaerobic digestion process, these environmentally unsustainable issues can be lessened.

In the absence of oxygen, bacteria use a process called anaerobic digestion to break down organic materials like food waste, wastewater biosolids, and animal manure. The technology is an extremely valuable biochemical conversion process [4]. Anaerobic digestion for biogas production takes place in a sealed vessel called a reactor. Anaerobic digestion of organic waste materials which can be gotten from municipal solid waste, industrial waste, agricultural waste, and household waste can also provide enormous energy since it can serve as a renewable source of energy such as biogas [5]. Biogas is a cheap and reasonably priced renewable energy source that can largely satisfy the energy needs of rural communities. It is a colorless, flammable gas produced by the anaerobic digestion of organic waste. Due to the fact that it produces no smoke, it is more hygienic and convenient [6]. Biogas contains a mixture of several gases, which include; methane (50–72 Vol. %), nitrogen (> 2 Vol.%), carbon dioxide (25–45 Vol. %), hydrogen sulphide (> 1 vol%), water (2–7 Vol. %), oxygen (> 2 Vol. %), and several other gases, produced by anaerobic digestion [7,8] The production of biogas occurs via three major biochemical processes which include: hydrolysis, acidogenesis/acetogenesis, and methanogenesis as shown below [9]

$(C_6H_{10}O_5)n + nH_2O \rightarrow n(C_6H_{12}O_6)$ − Hydrolysis (1)

$n(C_6H_{12}O_6) \rightarrow nCH_3COOH$ − Acetogenesis/Acidogenesis (2)

$nCH_3COOH \rightarrow nCH_4 + CO_2$ − Methanogenesis (3)

Lignocellulosic Biomass (LCB)

LCB typically consists of lignin (15–25%), cellulose (38–50%), and hemicelluloses (23–32%) [10]. Cellulosic and hemicellulosic fractions contain polymeric sugars that must be hydrolyzed into monomeric fermentable sugars. The polyphenolic heteropolymer lignin, however, shields cellulose and hemicellulose from pathogenic attacks that occur naturally. Because of the enriched cellulosic and hemicellulosic fractions in lignocellulosic biomass, their monomeric hexose (glucose, galactose, mannose) and pentose (xylose, arabinose) sugars show promise for use in the production of biofuel. Examples of easily accessible LCBs include forestry residues, energy crops, and agricultural, industrial, and urban wastes. Researchers have thoroughly investigated the potential of various LCBs in the production of biogas. Cotton stalks, corn stover, sunflower stalks, sugarcane bagasse, rice husks, corn cobs, palm bagasse, wheat and barley barn, alfalfa fiber, groundnut shell, sunflower hulls, and paddy and wheat straw are examples of agricultural wastes [11;10]. Food processing waste, paper waste, vegetable and fruit processing waste, cotton linters, pulps, and household waste are typically among the wastes from industries and urban areas [12;13]. Dead tree branches, wood chips, hardwood, softwood, slashes, and prunings are examples of forestry wastes [14].

When it comes to economic viability, treatment performance, as well as process capacity to manage different kinds of biowaste, anaerobic co-digestion (ACoD) seems to be the most advantageous solution, relieving several environmental and energetic concerns. Mono-digestion is often prone to acidification, ammonia, and long-chain fatty acid inhibition; the selection of suitable co-substrates is considered a key factor enhancing the stability of the process [15;16]

Most of the existing literature focused on mono-digestion of these lignocellulosic materials (sugarcane bagasse, groundnut shell, and sawdust), as reported by [17], [18], [19]. On the other hand, the effect of co-substrate mixing ratios and loading rate variations on food and agricultural wastes anaerobic co-digestion, the research was designed to develop a technical concept on closed-cycle biowaste to bioenergy treating food waste through combined biological processes. semi-continuous anaerobic co-digestion of FW, wheat straw, and cattle manure were tested to investigate the relationship between the effect of the feedstock mixtures and C:N ratio on biogas and digestate generation at different organic rates as reported by [20]. The co-digestion of groundnut shell and sugarcane bagasse with cow manure has been studied [21]. In another literature, the production of biogas from co-digestion of cow dung, sawdust, and maize husk was studied as reported by [22]. However, no studies have considered the mixtures of the three substrates simultaneously by varying the mixture ratios; therefore, the current study focused on the mixture ratio of these three substrates and determined which of the substrates had more influence on the other in terms of bigas production and determined the quantitative and qualitative analysis of the process.

Materials and Methods

Source of the raw materials

The substrates used for this research are sugarcane bagasse, groundnut shell, sawdust, and chicken waste. The sugarcane bagasse was collected from Green House Natural Drinks, Katsina, Katsina State. The groundnut shell and sawdust were collected from the groundnut oil mill and wood mill, and chicken waste was collected from Hasaid Agro Tech Farms, all in the Faskari Local Government of Katsina State, Nigeria.

Fig. 1 Sugarcane Bagasse powder

Fig. 2 Groundnut Shell Powder

Fig. 3 Sawdust powder

Fig. 4 Chicken Droppings

Fig. 5 biogas analyzer set up

Fig. 6 water displacement set up

Substrate Treatment

Physical screening was carried out on the samples in order to remove unwanted materials present in the samples. 500 g of the sample was measured and mixed with hot water; the mixture was stirred vigorously and massaged. The wet sample was dried under the sun for 48 hours. The dried sample has been ground into a fine powder using a mortar and pestle. The substrates were sieved, homogenized, packed, and labeled in different plastic containers for further analysis [20; 23].

Experimental setup

A chisel machine was used to bore a hole in the can's lid of 4L capacity. The hole in the lid was inserted with one end of the hosepipe (which acts as a delivery tube for the gas). A&B gum was put around the hole in the lid to make sure that no air seeps in through the hole in the lid or out of the can digester. The digester (can) was then filled with the feedstock (slurry), and the lid, which is already attached to the hosepipe, was placed on top of the can. To create the airtight environment required for anaerobic digestion, A&B gum was applied all the way around the can lid. In order to prevent air bubbles.

In this study, the volume of the gas produced was measured by the water displacement method, which considers that plastic basins were half filled with water and the measuring cylinder of 1000 ml capacity was filled with water too and put upside down in the basin containing water. The measuring cylinder was supported vertically in the bowls by a retort stand. To collect the created gas, the other end of the hosepipe from the digester was inserted into the water basin and passed through the measuring cylinder. The amount of biogas produced is inversely related to the amount of water displaced [24].

To store the gas for qualitative analysis, the tapping method was involved; a urine bag of 2000 ml capacity was used. The pipe in the urine bag was inserted into the hosepipe of the digester; A&B gum was put in between the pipes to make sure that no air seeped into or out of the two pipes. After 2 days of retention, a reasonable amount of gas was stored in the urine bag. A biogas analyzer machine was used for the qualitative analysis. A pump was connected to the urine bag, which aimed at transporting the gas to the biogas analyzer, and the biogas analyzer determined the constituents of the produced biogas in percentage.

Degradation rate measurement

The biodegradation rate is the speed at which a substance is broken down by microorganisms in the environment. It can vary depending on factors such as the type of material, environmental conditions (e.g., temperature, humidity), and the presence of specific microorganisms capable of decomposing the substance. Generally, materials with higher biodegradation rates break down more quickly, leading to reduced environmental impact and waste accumulation. Equation 4 is used to determine the degradation rate by measuring the total gas produced from a digester and dividing it by the amount of substrate loaded into the corresponding digester

$$\text{Degradation rate} = \frac{TAGPD}{TSL}$$

Where TAGPD = Total Amount Of Gas Produced From A Digester

TSL = Total Amount Of Substrate Loaded

Biogas production method

The method employed in this research is summarized in Table 1 as reported by [25]. And 2070ml of water where added in each digester

Table 1: Amount of substrates in different digester setups

Digester	Ratio (%)	Amount of Sugarcane Bagasse (gram)	Amount of groundnut shell (gram)	Amount of sawdust (gram)	Amount of chicken dropping (gram)
AB	1:1	50	50	-	150
BC	1:1	-	50	50	150
AC	1:1	50	-	50	150
AC1	3:2	60	-	40	150
AC2	2:3	40	-	60	150
BC1	3:2	-	60	40	150
BC2	2:3	-	40	60	150
AC1	3:2	60	-	40	150
AC2	2:3	40	-	60	150
ABC	1:1:1	33.33	33.33	33.33	150
A1BC	3:1:1	60	20	20	150
AB1C	1:3:1	20	60	20	150
ABC1	1:1:3	20	20	60	150

Results and Discussion

Biogas Produced From Sample AB, BC, AND AC

Figures 1 and 2 showed that the digesters AB and BC started production of biogas on the 2nd day of retention time, while Figure 3 shows that digester AC has started the generation of biogas on the first day of anaerobic digestion. A sudden increase in biogas production from both digesters was observed on the 5th day of digestion, which may have occurred as a result of an exponential increase in microorganisms, which leads to an increase in fermentation rate and a corresponding increase in biogas production. There was a decrease in biogas production in both digesters on the 7th day of retention time.

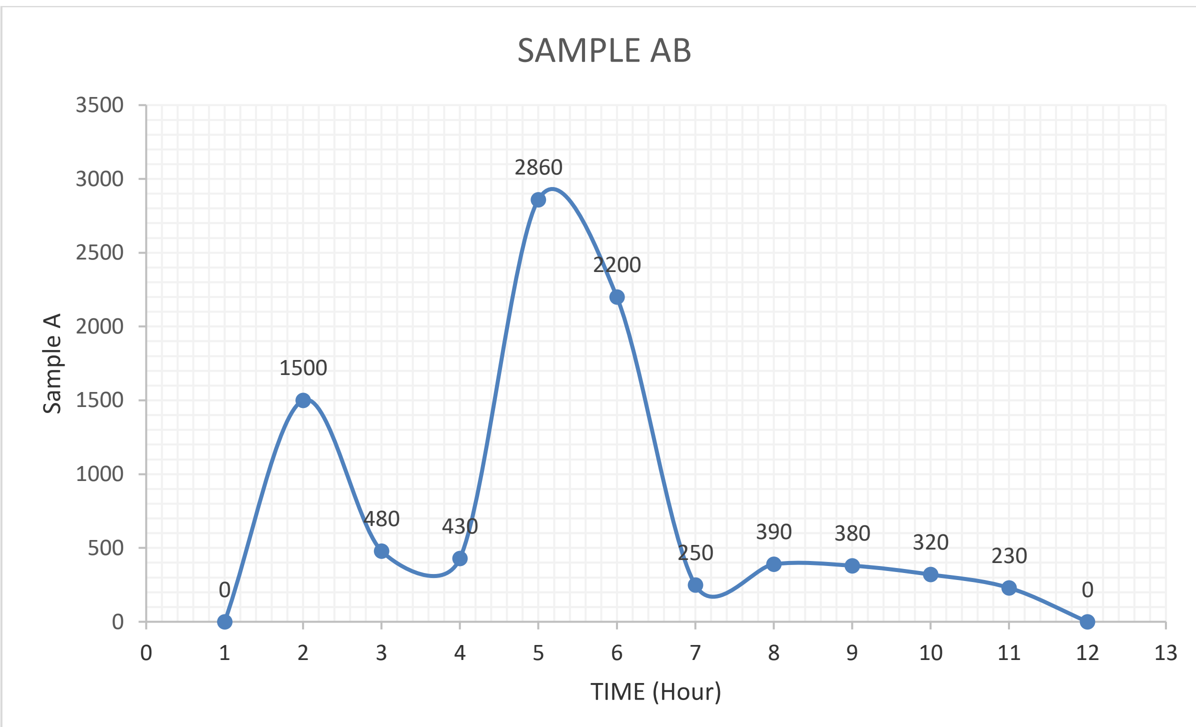


Fig. 6: Biogas production from sample AB

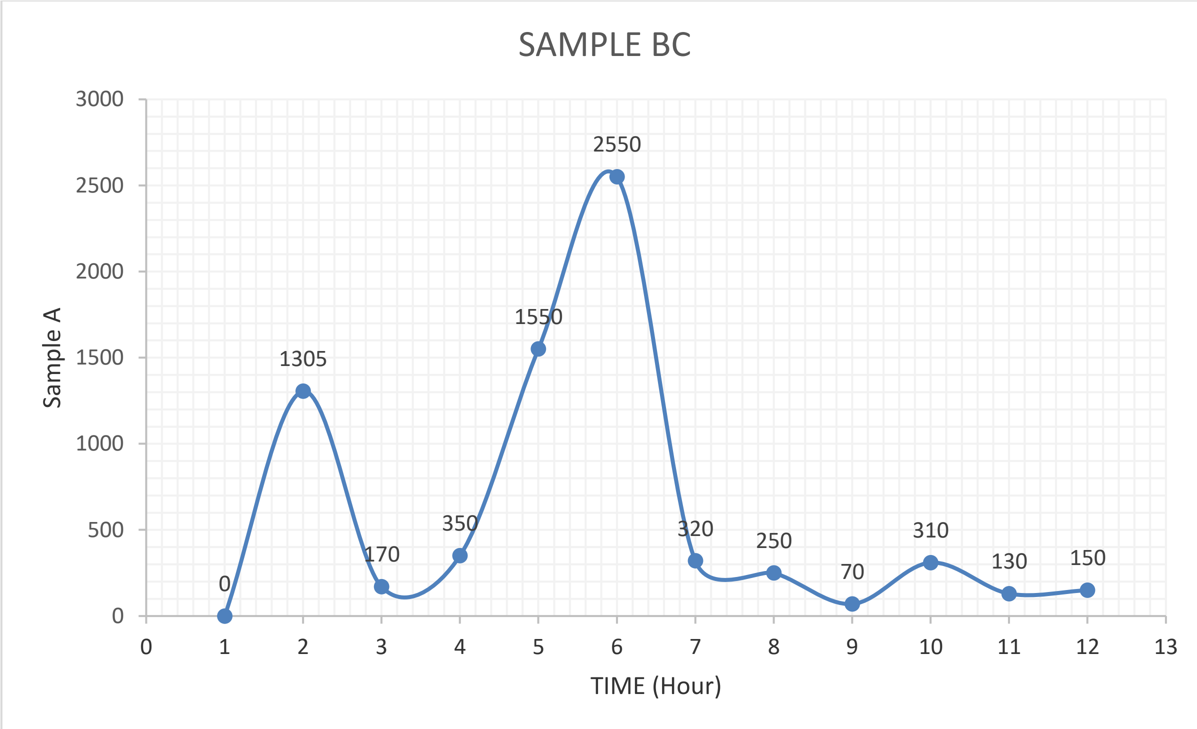


Fig. 7: Biogas production from sample BC

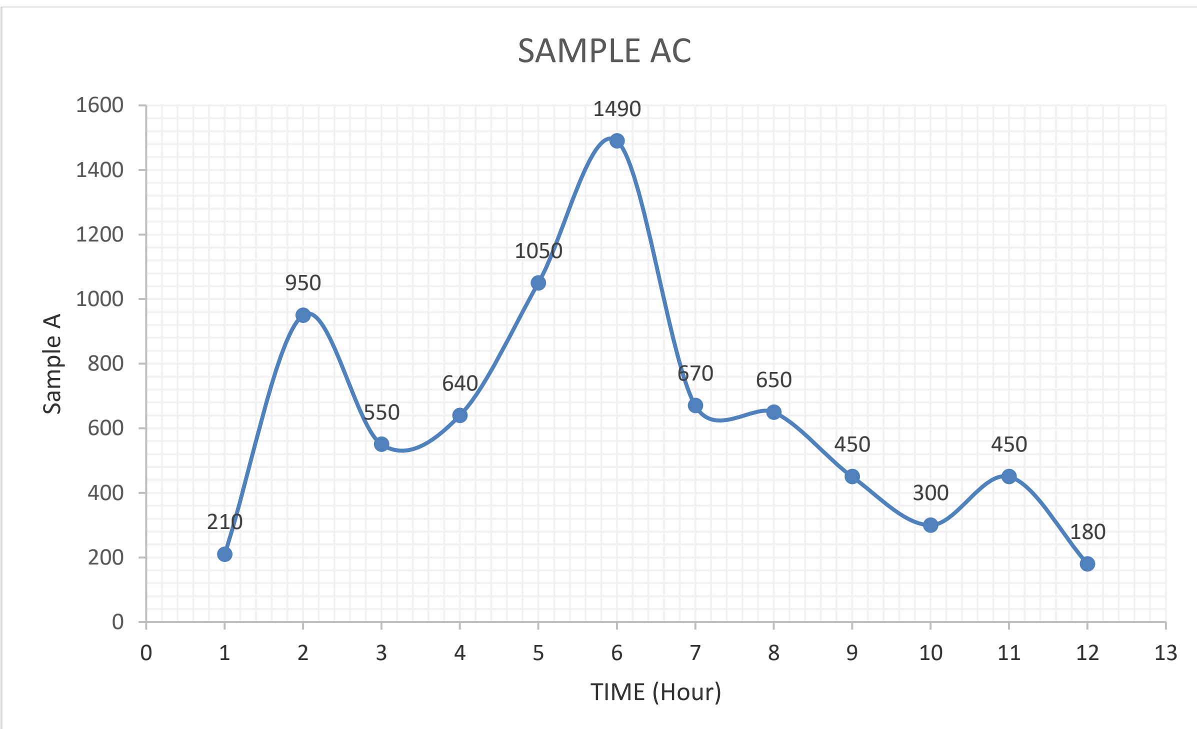


Figure 8: Biogas production from sample AC

Comparison between AB, BC, and AC

At a first glance, the comparison of gas production between AB, BC, and AC (see Fig. 4) displays that sample AB seemed like a much more effective combination as compared to BC and AC, as it first demonstrated peak production followed by AC and then BC. The cumulative gas produced and the methane content reached by AB were noticeably higher than BC and AC (see Figs. 5, 6, 7, and 8). It is imperative to note that the degradation rate of AB was also higher than the degradation rate of BC and AC (see table 1). This means that a combination of sugarcane bagasse and groundnut shell enables faster breakdown as compared to BC and AC. Based on that, AB was chosen for the pilot-scale setup.

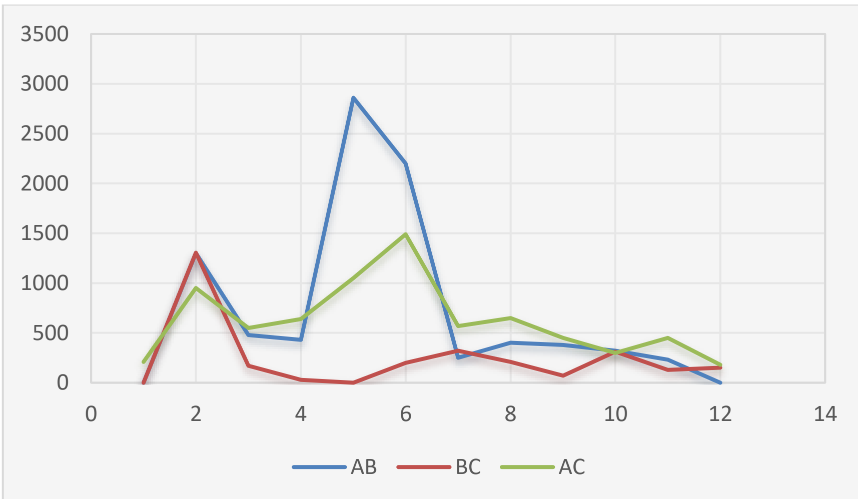


Figure 9: Line graph for sample AB, BC and AC

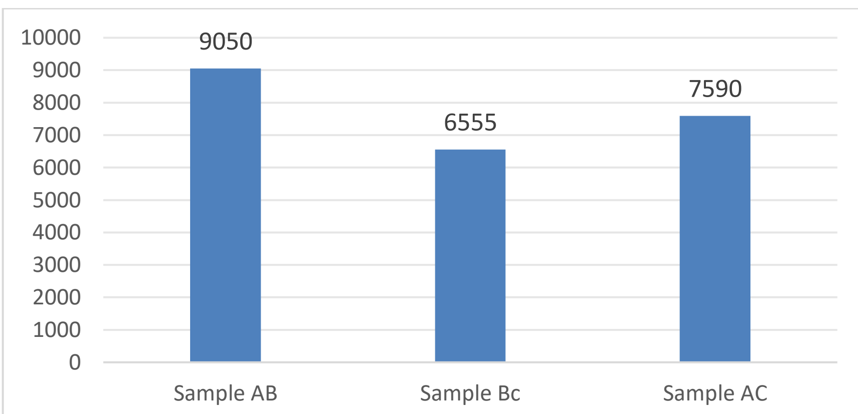


Figure 10: Cumulative gas produced for sample AB, BC and AC

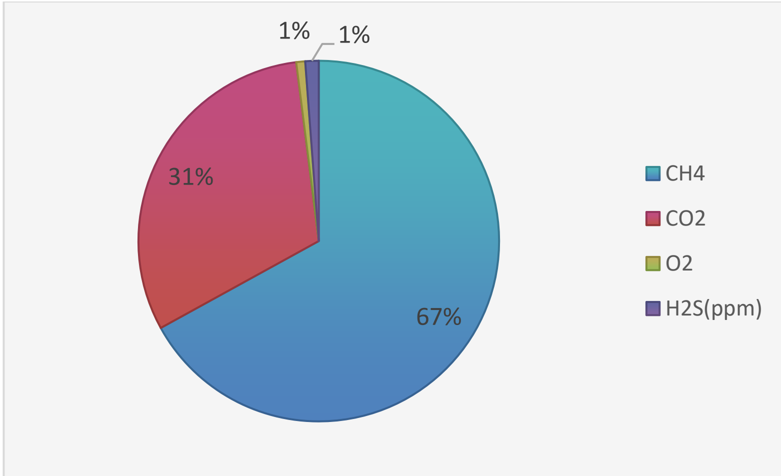


Figure 11: Compositional analysis in sample AB

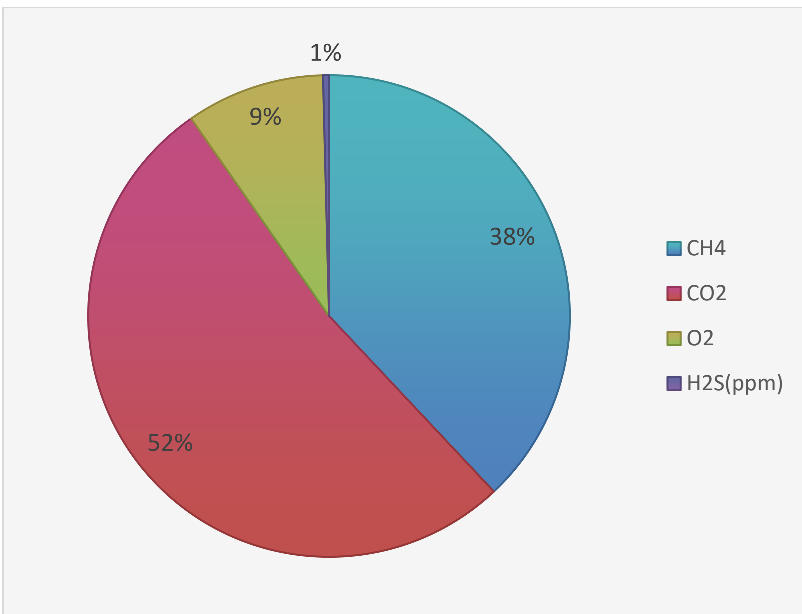


Fig. 12: Compositional analysis in sample BC

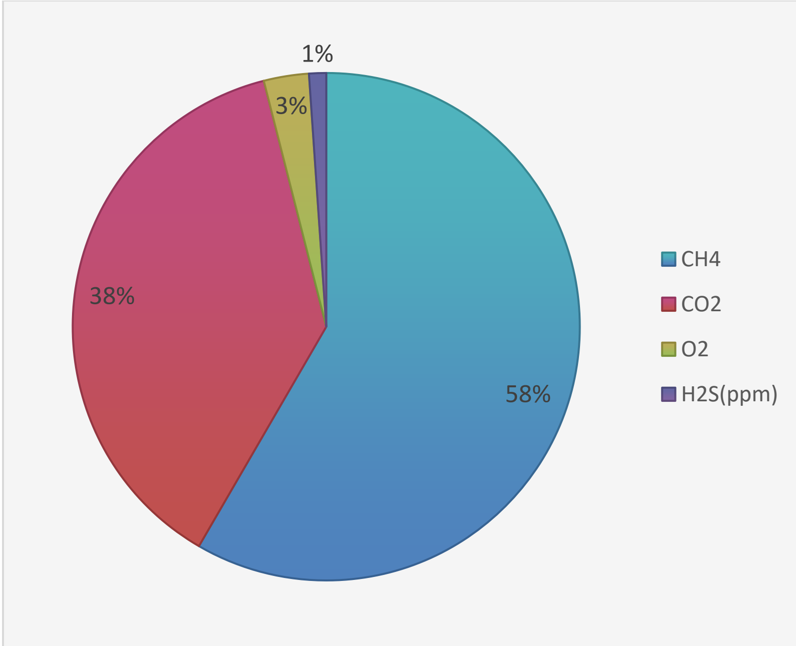


Figure 13: Compositional analysis in sample AC

Biogas produced from samples AB1 and AB2

It can be observed that sample AB1 has 60% sugarcane bagasse and 40% groundnut shell and its corresponding sample AB2 has 40% sugarcane bagasse and 60% groundnut shell. Fig. 9 showed that digester AB1 started production of biogas on the first day of retention time, while Fig. 10 shows that digester AB2 started the generation of gas on the 2nd day of digestion. A sudden increase in biogas production from both digesters was observed on day five of production, and the production started decreasing on the 8th day of digestion.

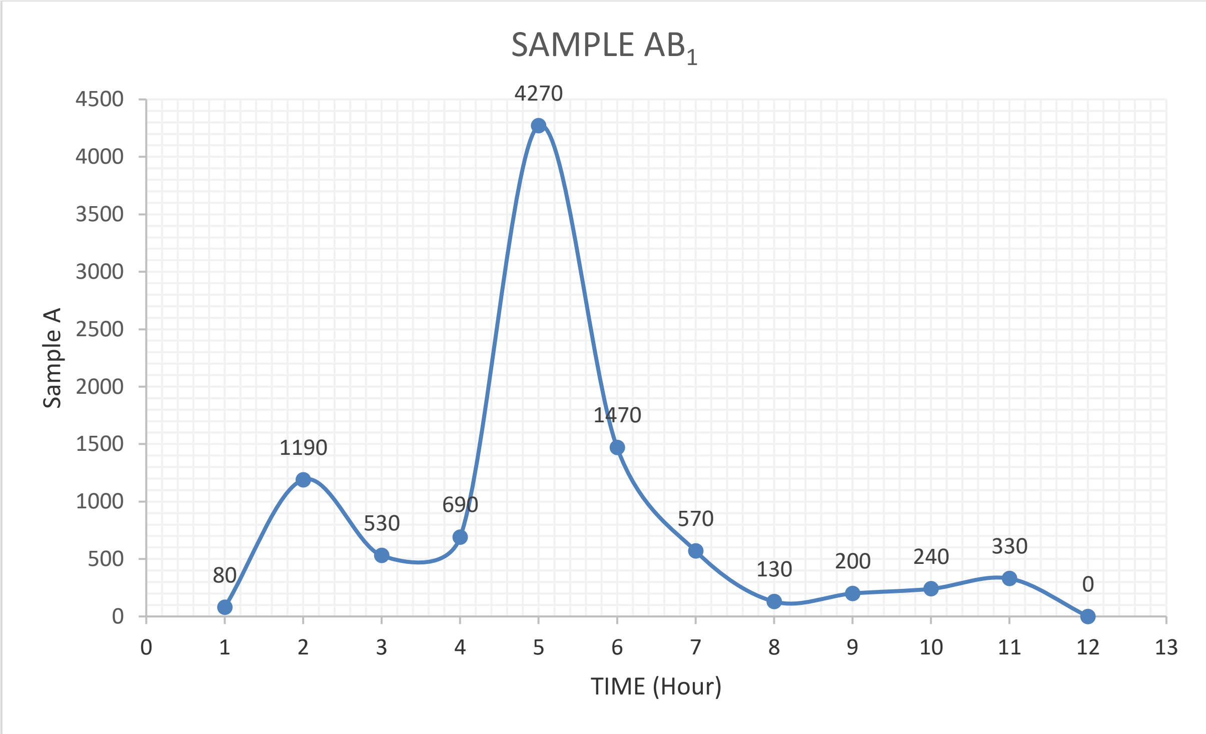


Figure 14: Biogas production from Sample AB1

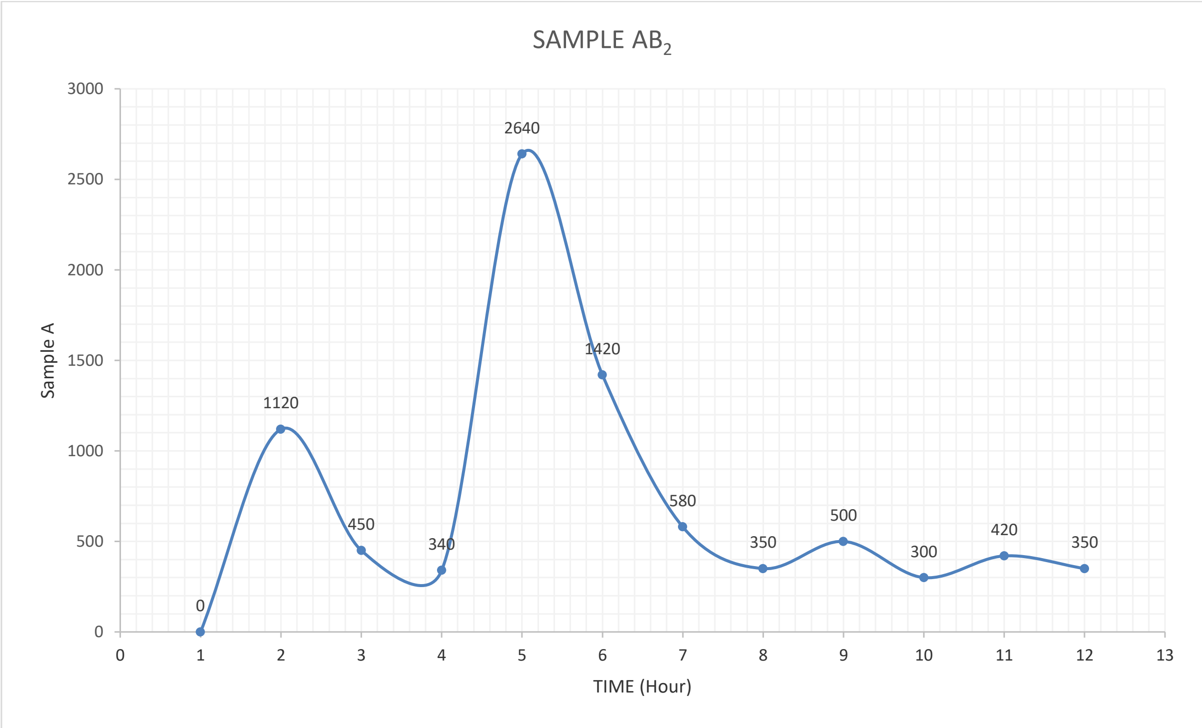


Figure 15: Biogas production from Sample AB2

Comparison of gas production in AB1 and AB2

The comparison of gas production between AB1 and AB2 (see Fig. 11) displays that sample AB1 seemed like a much more effective combination as compared to AB2 as it first demonstrated peak production. The cumulative gas produced and the methane content reached by AB1 were noticeably higher (see Figs. 12, 13, and 14). The degradation rate of AB1 was also higher than the degradation rate of AB2 (Table 1). This means that a combination of sugarcane bagasse and groundnut shell at a ratio of 3:2 enables the micrograms to act upon the substrates so easily compared to a 2:3 ratio of sugarcane bagasse and groundnut shell. Based on that, AB1 was chosen for the pilot-scale setup.

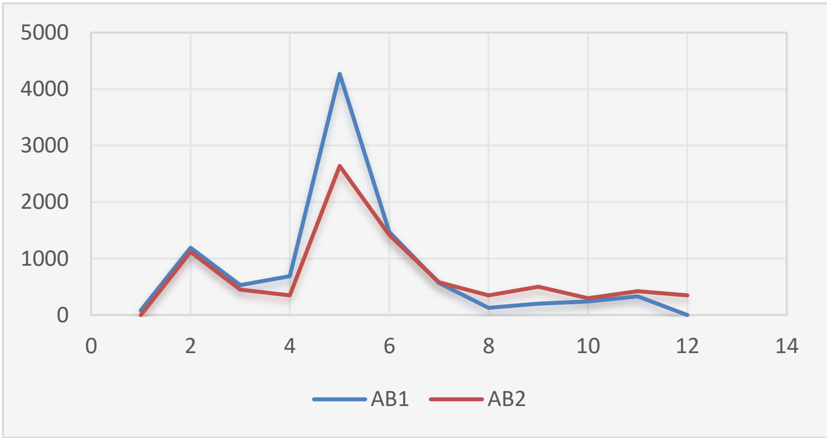


Figure 16: Line graph for Sample AB1 and AB2

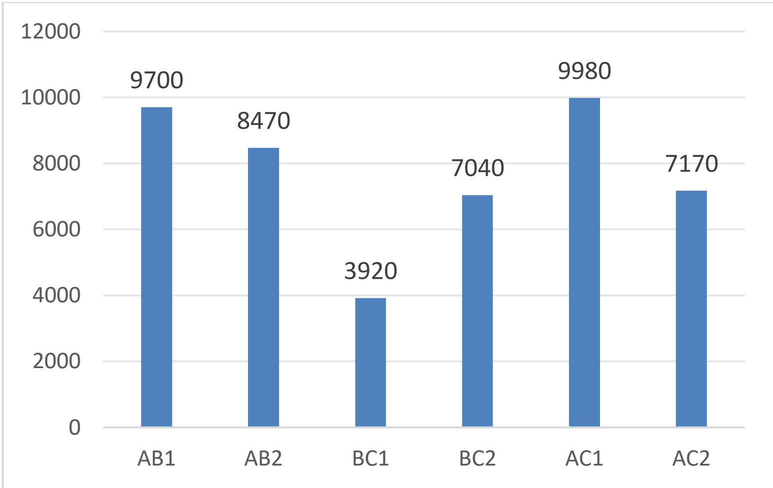


Figure 17: Cummulative gas produced from AB1, AB2, BC1, BC2, AC1 and AC2

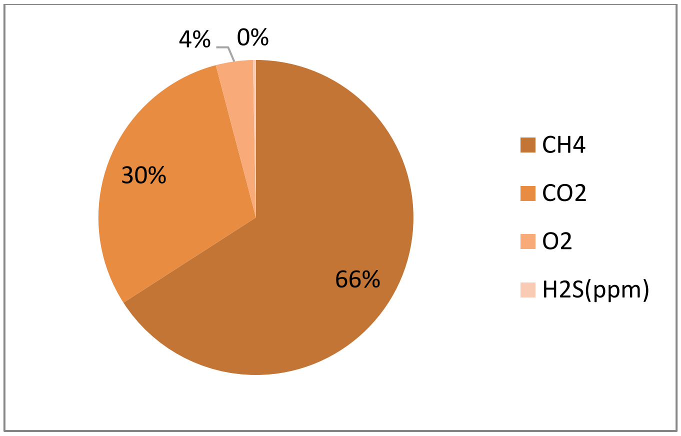


Figure 18: Compositional analysis in sample AB1

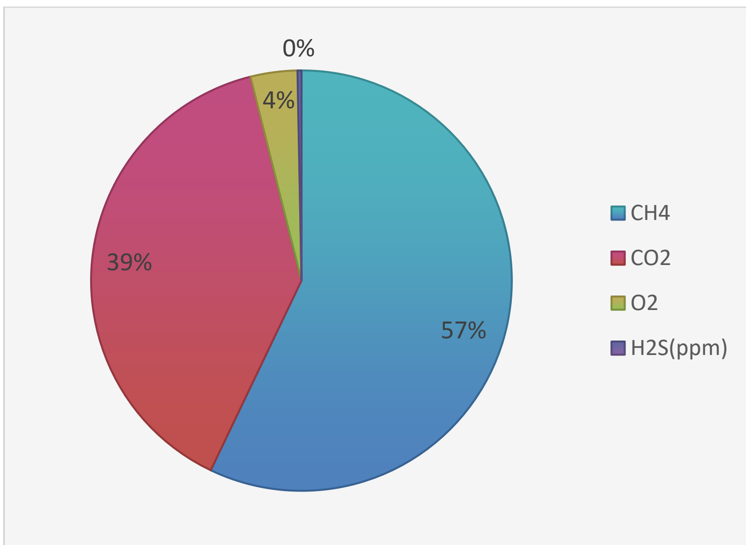


Figure 19: Compositional analysis in sample AB2

Biogas produced from samples BC1 and BC2

It can be observed that sample BC1 has 60% groundnut shell and 40% sawdust, while its corresponding pair, BC2, has 40% groundnut shell and 60% sawdust. Fig. 15 showed that digester BC1 started production of gas after the second day of retention time, while Fig. 16 shows that digester BC2 started the generation of gas on the first day of production. A sudden increase in biogas production from both digesters was observed on the 4th day, and the production started decreasing on the 9th day of production

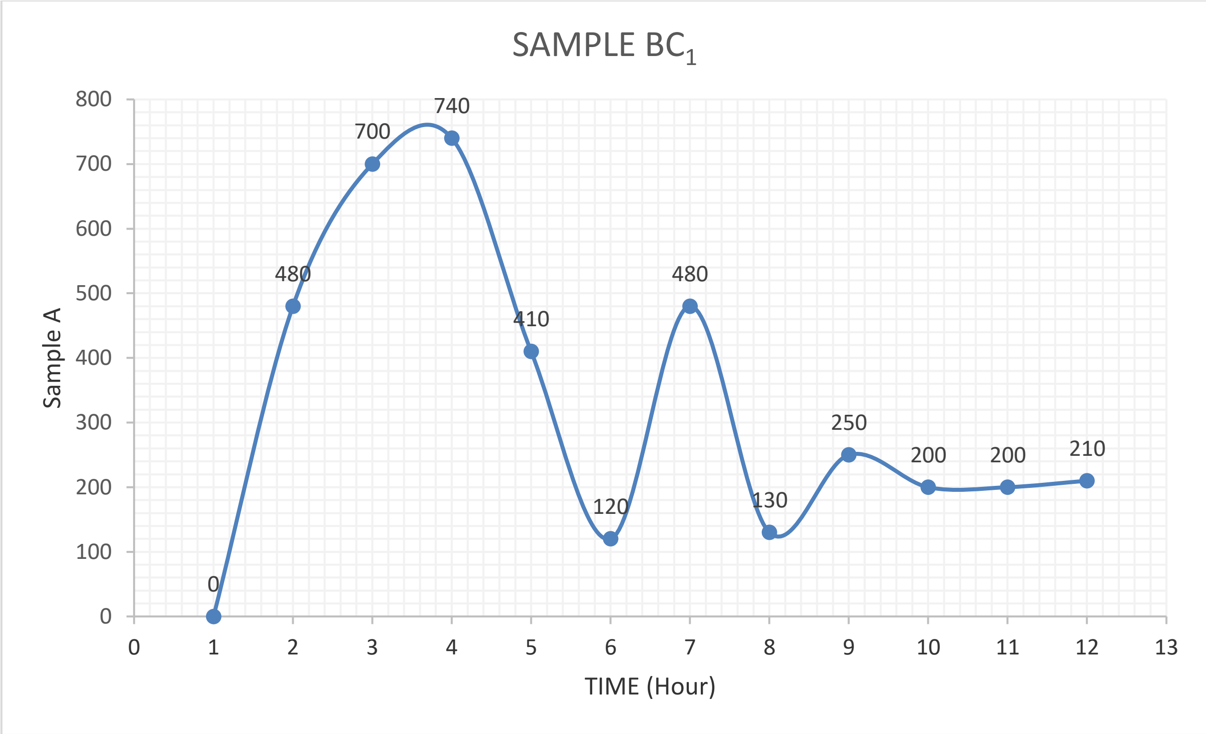


Figure 20: Biogas production from Sample BC1

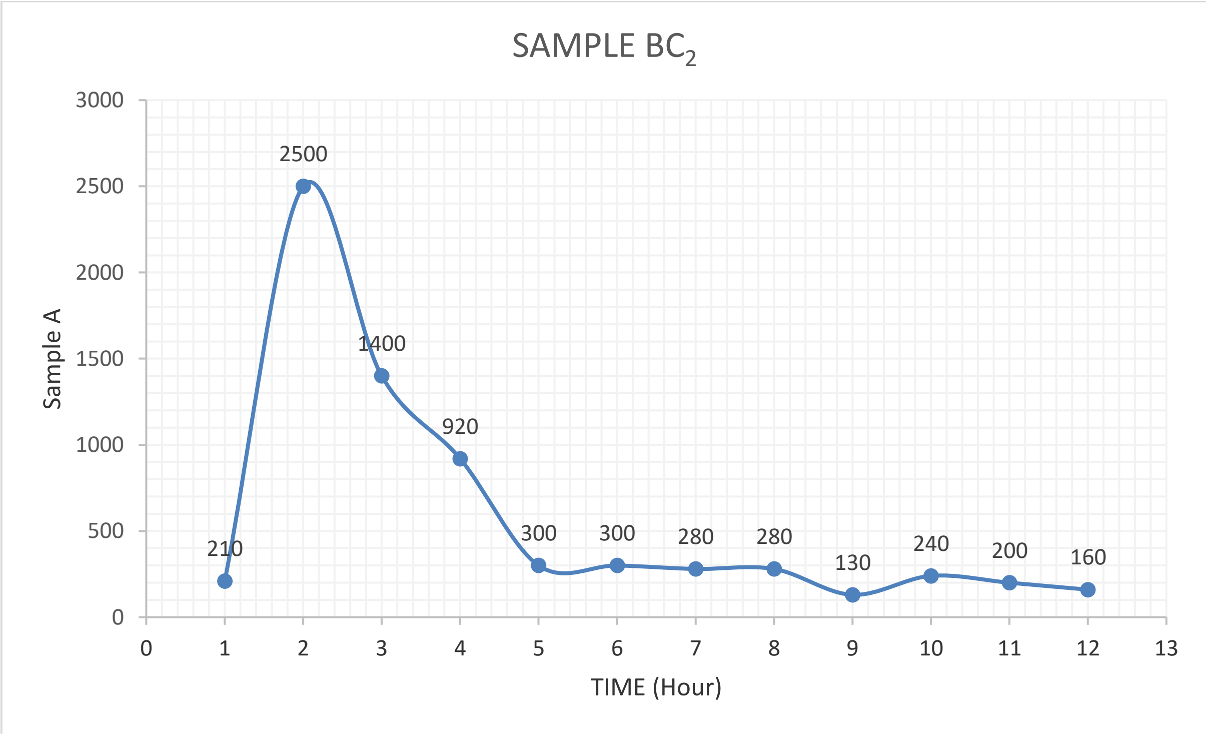


Figure 21: Biogas production from Sample BC2

Comparison of gas production in BC1 and BC2

The comparison of gas production between BC1 and BC2 (see Fig. 17) displays that sample BC2 seemed like a much more effective combination as compared to BC1 as it first demonstrated peak production. The cumulative gas produced and the methane content reached by BC2 were noticeably higher (see Figs. 12, 18, and 19). The degradation rate of BC2 was also higher than the degradation rate of BC1 (see Table 1). This means that a combination of groundnut shell and sawdust at a ratio of 2:3 enables faster breakdown of substrates as compared to a 3:2 ratio of the same substrate. Based on that, BC2 was chosen for the pilot-scale setup.

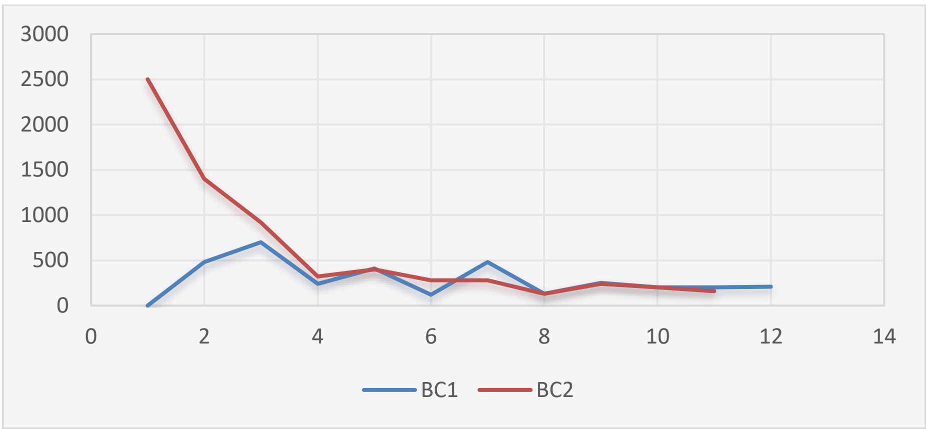


Figure 22: Gas production for Sample BC1 and BC2

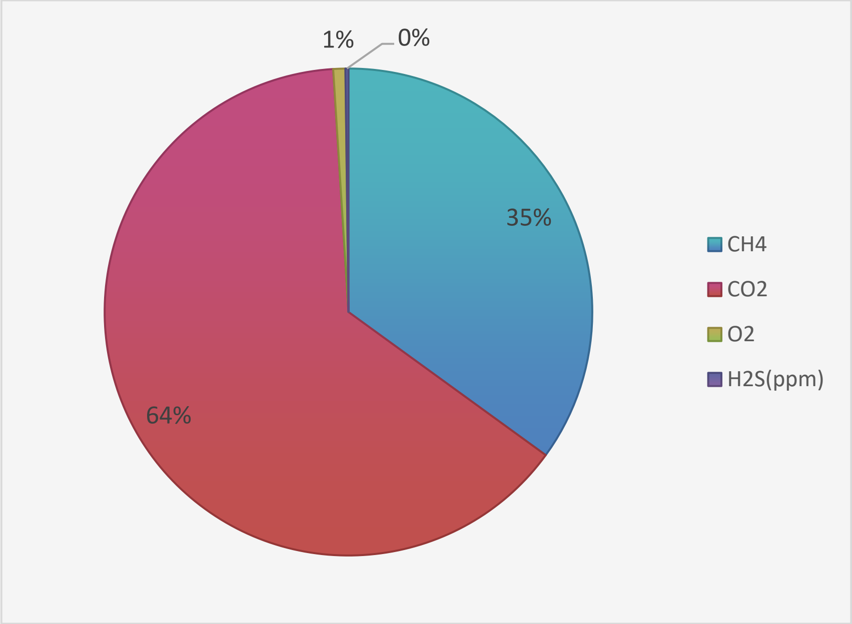


Figure 23: Compositional analysis in sample BC1

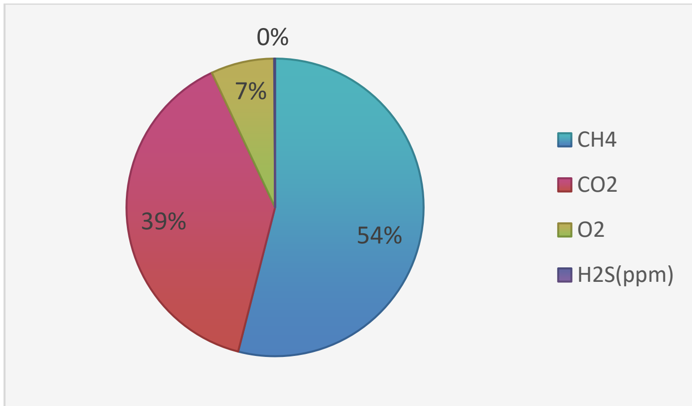


Figure 24: Compositional analysis in sample BC2

Biogas produced from samples AC1 and AC2

It can be observed that sample AC1 has 60% bagasse and 40% sawdust, and its corresponding pair, AC2, has 40% sugarcane bagasse and 60% sawdust.Fig. 20 showed that digester AC1 started production of gas on the 2nd day of retention time, while Fig. 21 shows that digester AC2 started the generation of gas on the first day of production. A sudden increase in biogas production from both digesters was observed on the 5th day, and the production started decreasing on day eight of production

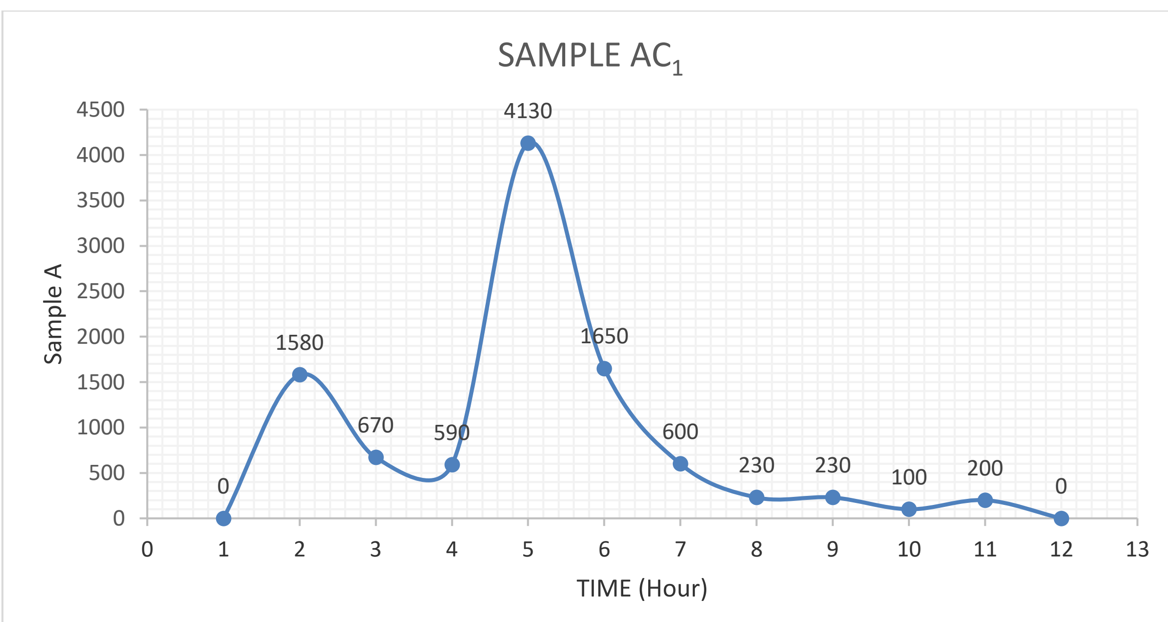


Figure 25: Biogas production from AC_1

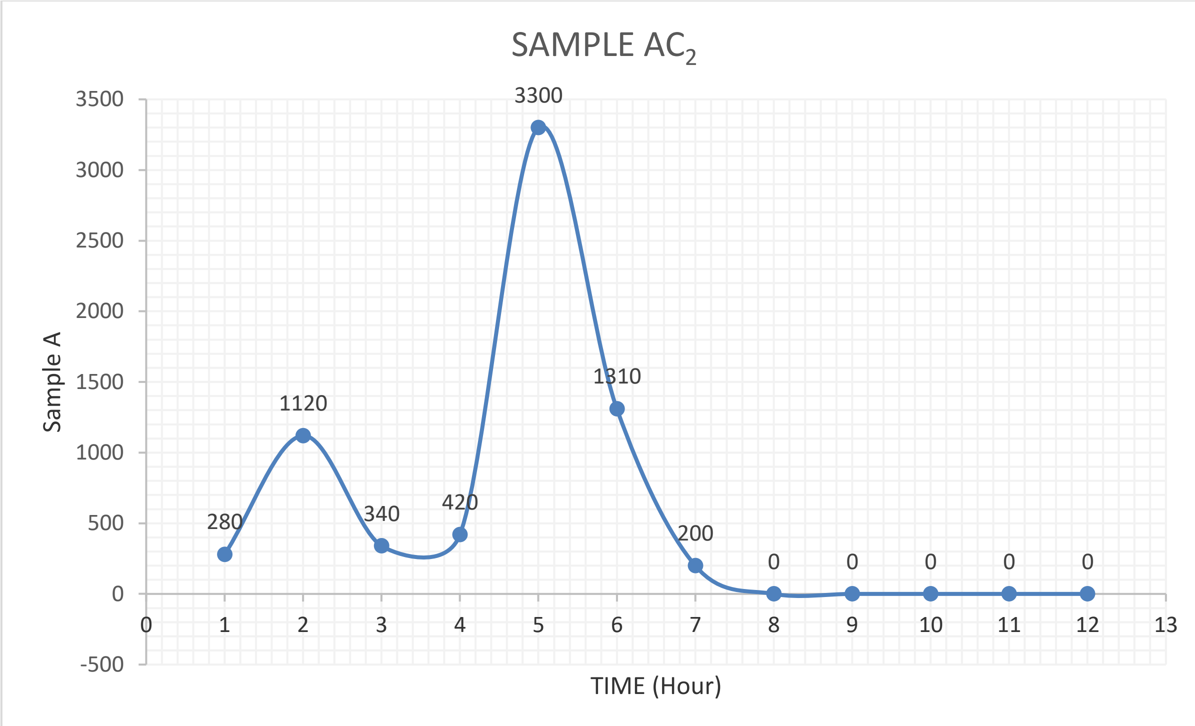


Figure 26: Biogas production from AC2

Comparison of gas production in AC1 and AC2

The comparison of gas production between AC1 and AC2 (see Fig. 22) displays that sample AC1 seemed like a much more effective combination as compared to AC2, as it first demonstrated peak production. The cumulative gas produced and the methane content reached by AC1 were noticeably higher (Figs. 12, 23, and 24). The degradation rate of AC1 was also higher than the degradation rate of AC2 (Table 1). This means that a combination of sugarcane bagasse and sawdust at a ratio of 3:2 enables faster breakdown as compared to a 2:3 ratio of the same substrate. Based on that, AC1 was chosen for the pilot-scale setup.

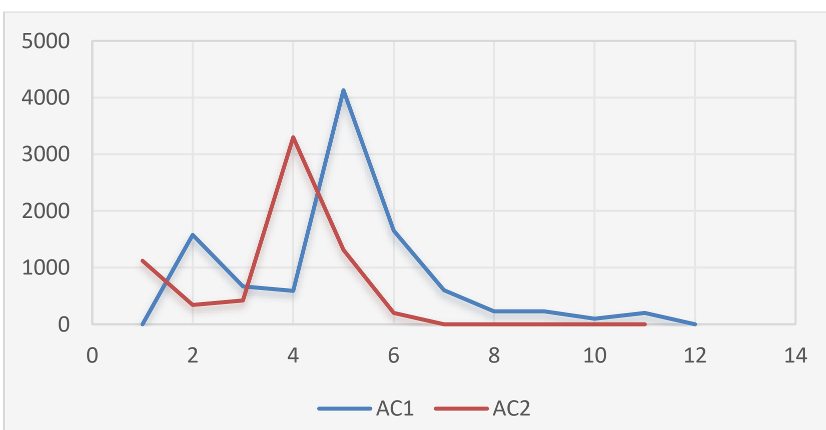


Figure 27: Gas production for Sample AC1 and AC2

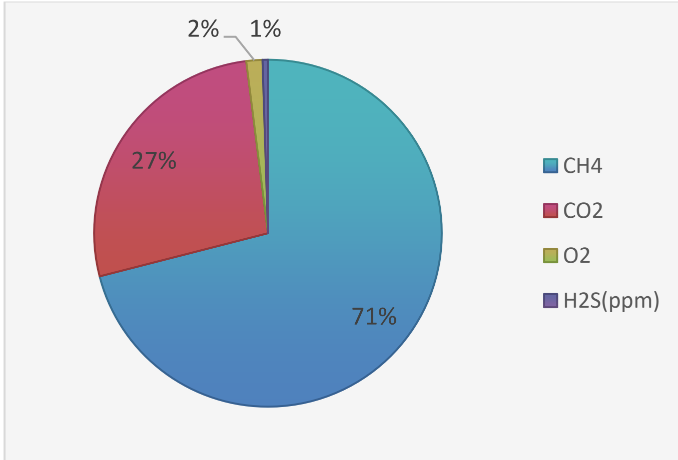


Figure 28: Compositional analysis in sample AC1

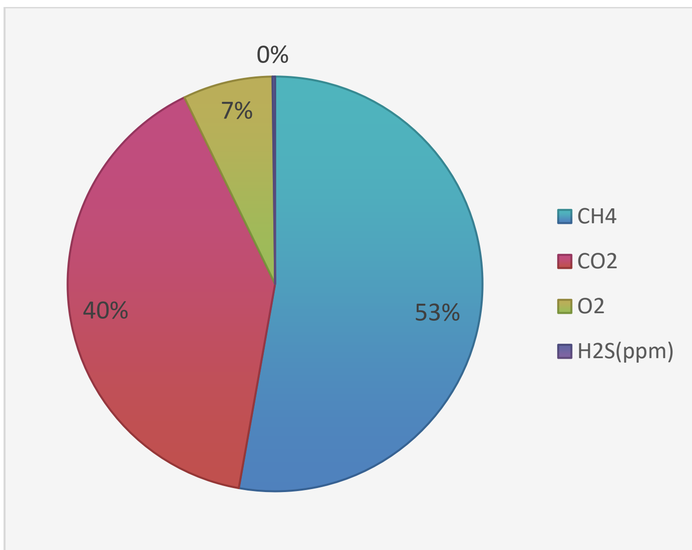
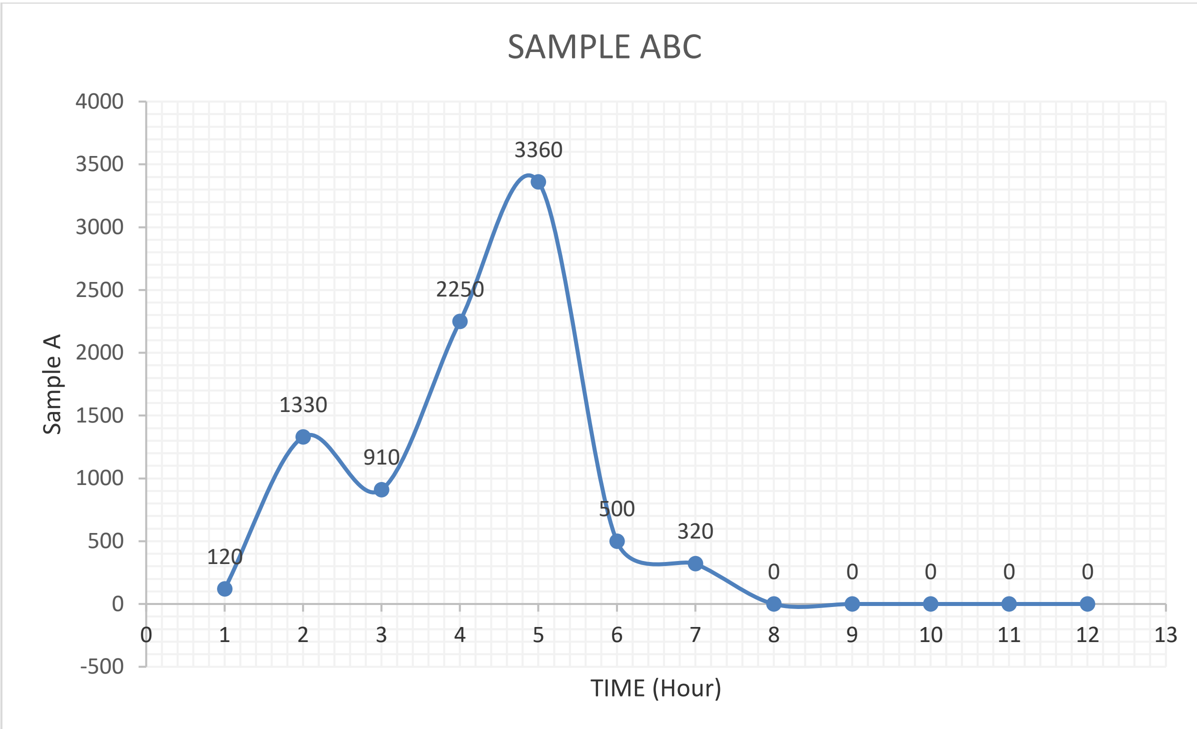


Figure 29: Compositional analysis in sample AC2

Biogas produced from samples ABC, A1BC, AB1C, and ABC1

It can be observed that sample ABC has an equal ratio of 33.333% for the substrates (sugarcane bagasse, groundnut shell, and sawdust), while sample A1BC has 60% sugarcane bagasse, 20% groundnut shells, and 20% sawdust. Sample AB1C has 20% bagasse, 60% groundnut shell, and 20% sawdust. while Sample ABC1 has 20% bagasse, 20% groundnut shell, and 60% sawdust. Figs. 25, 26, 27, and 28 show that both digesters started producing gas on the first day of anaerobic digestion. A sudden increase in production was recorded on day five for ABC, while for sample A'BC, the increase in gas production was recorded on day six. The sudden increase in samples AB'C and ABC' was noticed on the third day of production. This increase may have occurred as a result of an exponential increase in microorganisms in the bio digester.



Figur 30: Biogas production from ABC

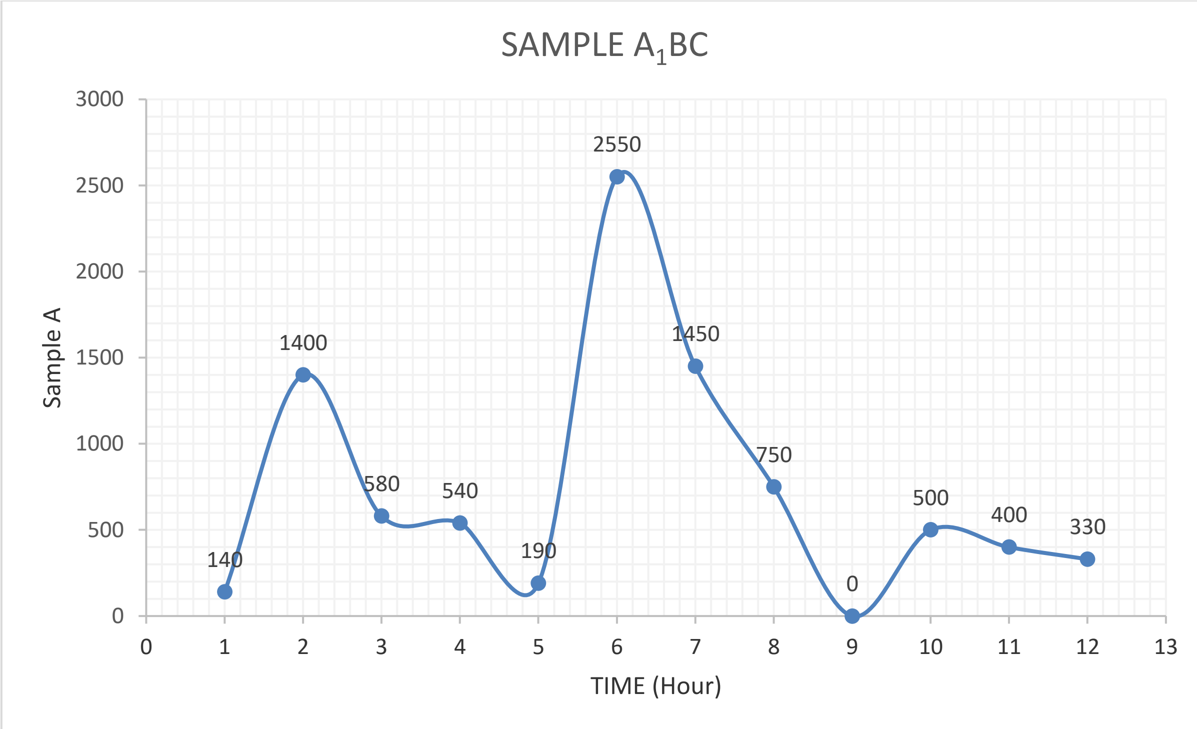


Figure 31: Biogas production from A1BC

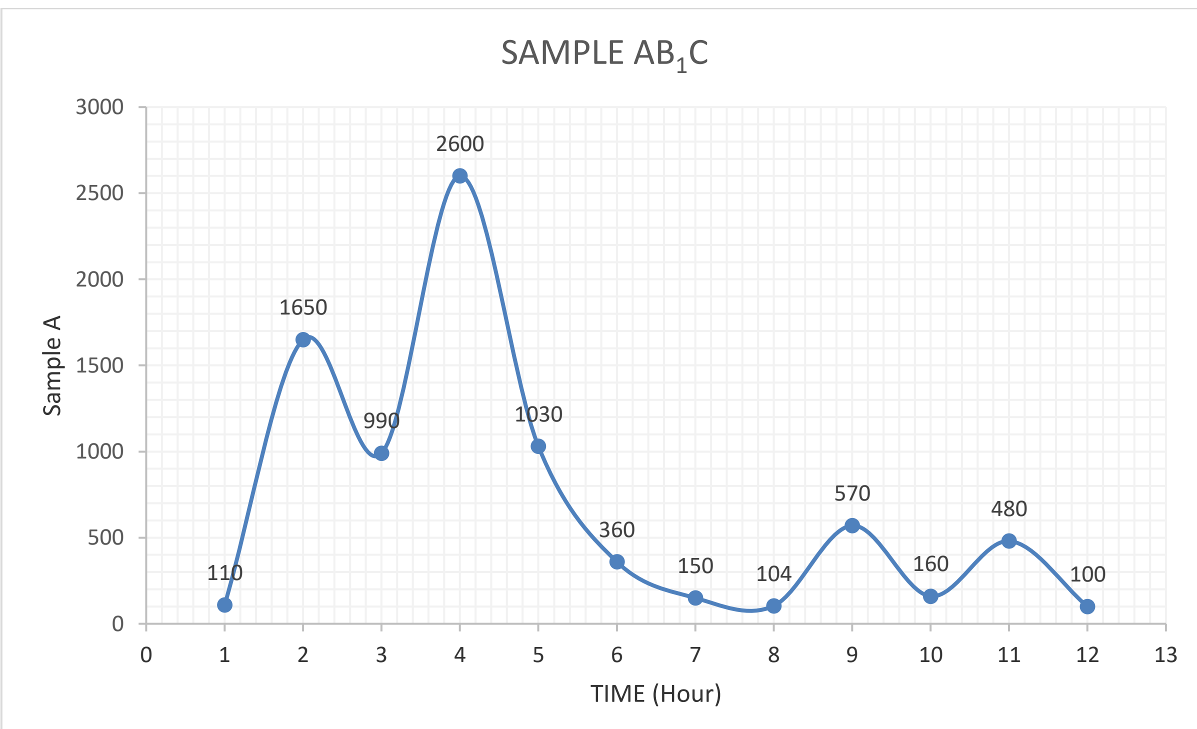


Figure 32: Biogas production from AB1C

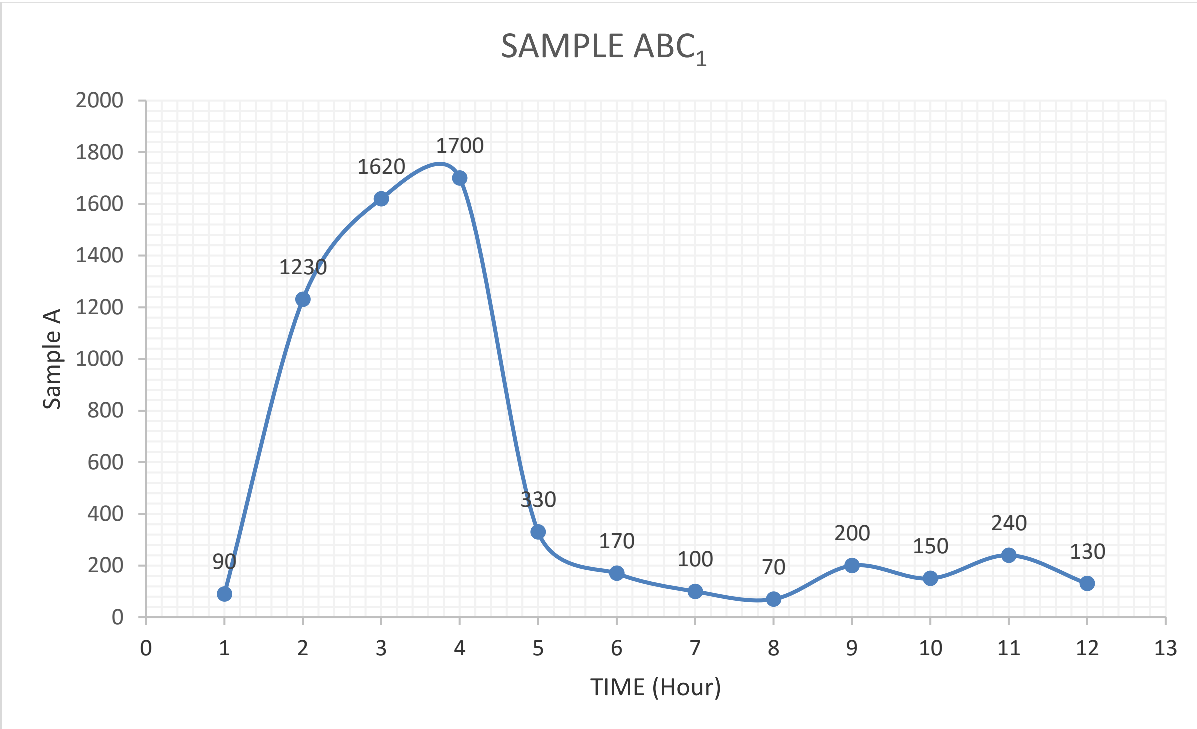


Figure 33: Biogas production from ABC1

Comparison between sample ABC, A'BC, AB'C, and ABC'

The comparison of gas produced between ABC, A'BC, AB'C, and ABC' (Figure 29) displays that sample A'BC seemed like a much more effective combination as compared to ABC, AB'C, and ABC', even though sample ABC first demonstrated peak production, followed by A'BC and then AB'C and ABC. However, the cumulative gas produced and the methane content reached by A'BC were noticeably higher (Figure 30, 31, 32, 33, and 34). It is imperative to note that the degradation rate of A'BC was also higher (Table 1); this means that a combination of sugarcane bagasse and groundnut shell and sawdust at a ratio of 3:1:1 enables faster breakdown of the substrates as compared to ABC, AB'C, and ABC'. Based on that, ABC was chosen for the pilot-scale setup.

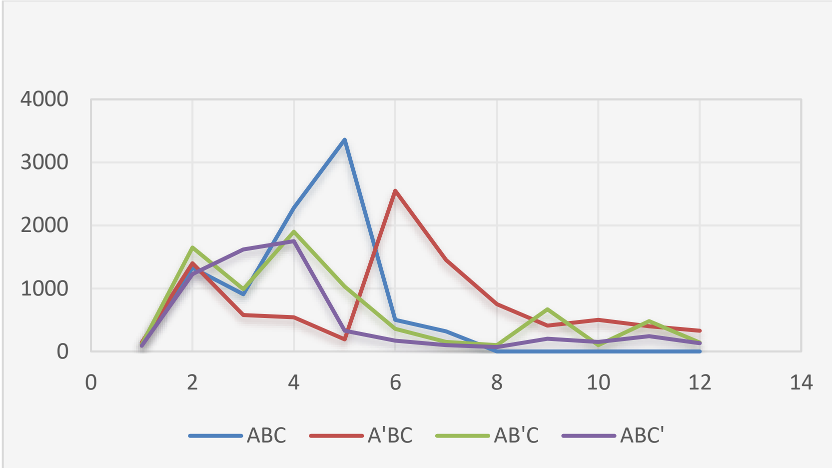


Figure 34: Line graph for the gas production with time

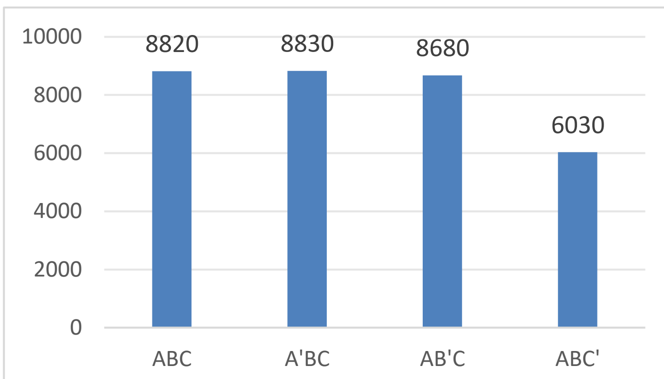


Figure 35: Bar chart for the cumulative gas produced for sample ABC, A^1BC, AB^1C, and ABC^1

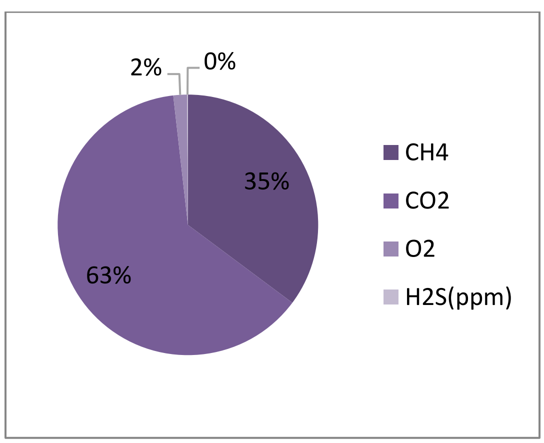


Figure 36: Compositional analysis in sample ABC

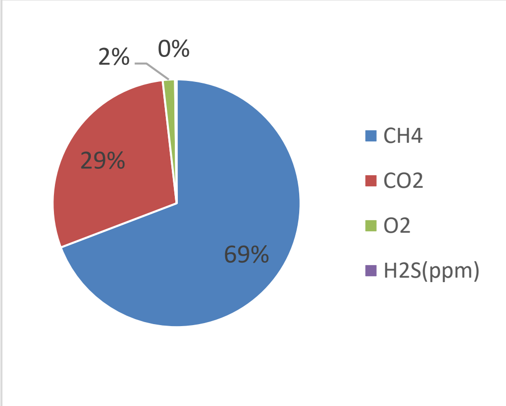


Figure 37: Compositional analysis in sample A[1]BC

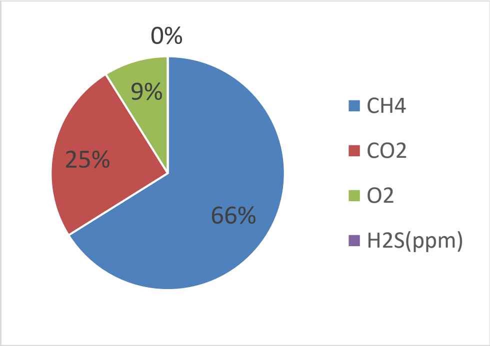


Figure 38: Compositional analysis in sample AB[1]C

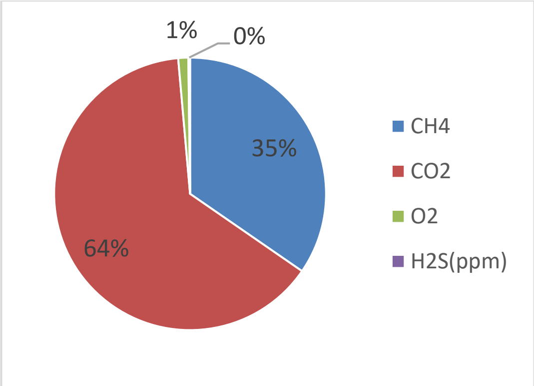


Figure 39: Compositional analysis in sample ABC[1]

Table 2: Data table for biogas production per gram of biomass (degradation rate) after 12 days.

Substrates	Loading (gil) rate	Biogas Production in (ML)	Degradation rate (ml/g)
A(100%)	250	12,500	50
B(100%)	250	9,110	36.44
C(100%)	250	8,135	32.54
AB(50-50%)	250	9,050	36.2
BC(50-50%)	250	6,555	26.22
AC(50-50%)	250	7,590	30.36
AB1(60-40%)	250	9,700	38.8
AB2(40-60%)	250	8,470	33.88
BC1(60-40%)	250	3,920	15.68
BC2(40-60%)	250	7,040	28.16
AC1(60-40%)	250	9,980	39.92
AC2(40-60%)	250	7,170	28.68

Conclusion

The energy crisis should be resolved by prioritizing research on biomass as a fuel. Development of sustainable bioenergy could lower increased levels of runoff from agricultural chemicals, net greenhouse gas emissions, and deforestation. From the preceding discussion, in the case of sample AB1 & AB2, sugarcane bagasse has demonstrated significant influence in gas production, while for sample BC1 & BC2 and sample AC1 & AC2, sawdust appears to have more influence in gas production than groundnut shell and sugarcane bagasse, respectively. In the condition where the three substrates mixed, sugarcane bagasse appeared to have more influence on gas production and methane level than the groundnut shell and sawdust. It can be said that sugarcane bagasse and sawdust have bigger potential in biogas production than groundnut shell. It is necessary to test other waste material combinations, paying particular attention to sugarcane bagasse and sawdust as the best options for producing biogas. It is thought that better results can be achieved by applying efficient waste material combinations and appropriately adjusting the environment.

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