MAKERERE **UNIVERSITY**

INSTITUTE OF ADULT AND CONTINUING EDUCATION (I.A.C.E)

COLLEGE OF EDUCATION AND EXTERNAL STUDIES (CEES)

DEPARTMENT OF CHEMISTRY

CO-DIGESTION OF COW-DUNG WITH KITCHEN WASTE FOR BIOGAS PRODUCTION

BY

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A PROJECT REPORT SUBMITTED TO THE DEPARTMENT OF CHEMISTRY,
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DECLARATION

I Mutesasira Julius declare that this is my own original work and it has never been submitted for the same purpose in the university or any other institution of learning elsewhere.

Signed:......................   Date: ...20th /Nov / 2018...
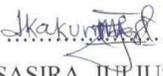
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This report has been submitted with my approval as the university supervisor.

Signed: ....   Date: 20/11/2018....
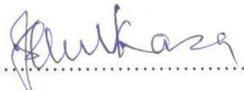
DR. ISHAKA ZUBAIR MUKASA-TEBANDEKE

Supervisor

DEDICATION

I dedicate this work to my entire family, thanks so much for your help. God bless you.

ACKNOWLEDGEMENT

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ABSTRACT

Kitchen waste, cow dung and a mixture of kitchen waste and cow dung were anaerobically digested. The performance of a single substrate and co-digestion of kitchen waste with cow dung were compared. The samples containing 400 grammes of the sample of kitchen waste, cow dung produced $55.0cm^3$ of gas after 18 days.

The results obtained on co-digestion of kitchen waste to cow dung in a ratio of 3:1 had produced $86cm^3$ yet that in a ratio of 1:1 formed $82.3cm^3$ and that in 1:3 produced $84cm^3$ by the 18th day. The increase was attributed to the synergistic effect of co-digestion process and the high nutrient contents in the kitchen waste (cellulose, carbohydrates, proteins, fats and oils among others). The results showed that co-digestion could obtain better and stable performances and might be one of the many options for efficient biogas production.

The kinetics of single substrate digestion closely followed the first order yet co-digestion deviated greatly from first order.

CHAPTER ONE

1.1 BACKGROUND

Scientific interest in manufacturing of bio gas produced by natural decomposition of organic matter was first reported in the seventh century. (Boyle 1701, Hale 1718). Later it was found out that biogas can be produced from cattle manure and kitchen waste (Alex 1779, Davy 1808).

Air tight tanks containing biomass waste have been used to transform waste materials to methane. Methane is now a renewable energy source that can be used for heating, generating electricity and other operations that use any variation of internal Combustion engine (Lowrey 2012).

Kitchen waste is defined as any substance, raw or cooked which is discharged or is intended or remains after eating. (Davidson et al, 2015).

Kitchen waste provides about 27% of bio gas if used alone. (Kentey, 2017). Cow dung is undigested residue of herbivores matter which has been passed through the animals gut (Robins et al 2014). Its colour ranges from greenish to black. (Kentins, 2016). It has been reported that the use of cow dung alone to produce bio gas can only give 17.9%. (Daybless, 2014).

The most common situation of biogas production is when a major amount of main basic substrates are mixed and digested together with main amounts of a single or a variety of additional substrates (Hey et al, 2016).

1.2 INTRODUCTION

Biogas refers to a gas produced by the biological break down of organic matter in absence of oxygen (Alfred 2015). It was reported that biogas originates from biogenic material and is a type of bio fuel. (Dictins, 2018).

Further reports show that   Biogas is a mixture of methane and carbon dioxide resulting from the anaerobic decomposition of such waste materials as domestic, industrial and agricultural wastes or residues (Roubik et al, 2016).

Anaerobic digestion is a process in which micro-organisms such as bacteria, archaea, fungi, protozoa, algae, and viruses breakdown bio degradable materials and can be used to treat various organic wastes and recover bio energy in the form of biogas. (Agdag et.al 2017, Chu, 2012, Cu et.al, 2012, 2015). Anaerobic digestion involves a series of processes in which micro-organisms break down biodegradable materials (Hale, 2014).

In the integrated waste management system anaerobic digestion is widely used as a renewable energy source because the process produces manure – rich biogas, suitable for energy production helping to replace fossil fuels (Vu et al, 2015). In addition, the nutrient- rich digester, (bioslurry) can be used as fertilizers (Silva et al, 2018). The digestion process begins with bacterial hydrolysis of the input materials in order to break down insoluble organic polymers such as carbohydrates and make them available for other bacteria (Dhung et. Al, 2012). It was published that acidogenic bacteria then convert the sugars and amino acids into carbondioxide, methane, hydrogen, ammonia and organic acids (Altherg et al, 2015). This is illustrated by the equations; Cellulose $(C_6H_{10}O_5)n + nH_2O \rightarrow 3nCH_4 + 3nCO_2$, Protein $2C5H_7NO_2 + 8H_2O \rightarrow 5CH_4 + 3CO_2 + 2(NH_4)(HCO_3)$, Fat[2)] $C_{57}H_{104}O_6 + 28H_2O \rightarrow 40CH_4 + 17CO_2$. A better schematic diagram for the processes is shown in the figure below;
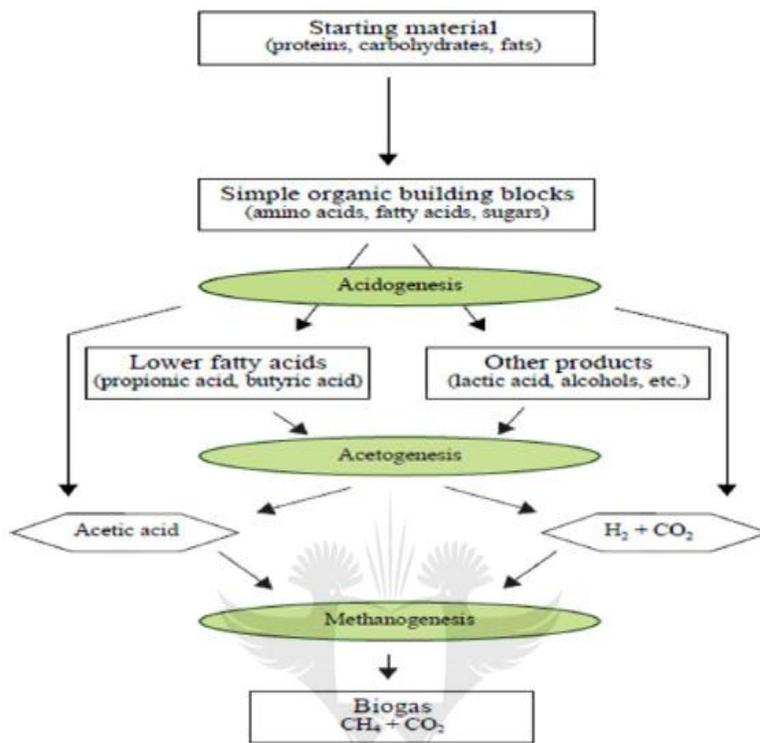

Figure 1: Schematic Figure of methane production via anaerobic digestion

Acetogenic bacteria then convert these resulting organic acids into methane along with ammonia hydrogen and carbon dioxide (Arison, 2014). This is illustrated by the equations; $CH_3\text{-}CH_2\text{-}CH_2\text{-}COOH \rightarrow CH_4 + CH_3\text{-}CH_2COOH$, $CH_3\text{-}CH_2\text{-}COOH \rightarrow CH_4 + CH_3\text{-}COOH$, $CH_3COOH \rightarrow CH_4 + CO_2$, $2CH_3\text{-}CH_2OH + CO_2 \rightarrow CH_4 + 2CH_3\text{-}COOH$, $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$. It was further reveled that anaerobic digestion is caused by the consortium of archae – bacteria belonging to the coccus group and these occur freely in the alimentary cannal of cows, goats, sheep, pigs among others (Davidson et al, 2018). This is illustrated by the equations; Hydrogen $4H_2 + CO_2 \rightarrow CH_4 + 2H_2O$, Formic acid $4HCOOH \rightarrow CH_4 + 3CO_2 + 2H_2O$, Methanol $4CH_3OH \rightarrow 3CH_4 + CO_2 + H_2O$, Acetic acid $CH_3COOH \rightarrow CH_4 + CO_2$. Co-digestion is the simultaneous digestion of a homogenous mixture of two or more substrates (Agdag et al, 2017).

Co-digestion of kitchen waste and cow dung increased the methane yield by 44% as compared to single co-digestion of cow – dung which produced 14% of biogas and kitchen waste which produce 18% of bio gas (Alvarez et al, 2018). Available report seen reveled that addition of sodium hydroxide to kitchen waste also increases bio gas production (Heys and Kent, 2016). Literature revealed that a 32% yield of bio gas was obtained from kitchen waste with sodium hydroxide than raw kitchen waste that yielded 19.7% and this was explained in terms of increased alkalinity and buffering effect (Heys et al, 2018). Available literature suggests that food waste has a high potential for methane production because it has a high carbon hydrogen content and can be digested rapidly making it a good source of material for anaerobic digestion (Alvarez et al, 2018). Food waste is a highly desirable substrate for anaerobic digesters accomplishing 80% of the theoretical methane yield in the 10 days digestion time (Clemens et al, 2014). Fats and oils have been reported to have produced high volume of bio gas compared to other organic wastes of different biochemical composition (Chu et al, 2017). Fats and oils are reduced organic materials and have a higher bio gas potential (Davidson et al, 2018). Fats from animals and vegetable origin were almost completely degraded in high percentages in co-digestion of fats and oils due to their bio chemical composition.

Fats and oils were almost completely degraded in the high percentages in co-digestion with simulated organic fractions of municipal solid waste, confirming that anaerobic digestion of liquids is possible (Fernandez et al, 2012, Nielson and Ahring, 2016, Pereira et al, 2013).

There are two key processes in the biogas production. Mesophilic and Thermophilic digestion. The plants that produce bio gas from kitchen waste use thermophilic micro-organisms that survive in extreme environment (Zhang, 2017). This is illustrated by the equations; $CH_3\text{-}CH_2\text{-}CH_2\text{-}COOH \rightarrow CH_4 + CH_3\text{-}CH_2COOH$, $CH_3\text{-}CH_2\text{-}COOH \rightarrow CH_4 + CH_3\text{-}COOH$, $CH_3COOH \rightarrow CH_4 + CO_2$, $2CH_3\text{-}CH_2OH + CO_2 \rightarrow CH_4 + 2CH_3\text{-}COOH$, $CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$. It was reported that thermophiles from the environment are the extremophiles that can survive under high temperatures (Hester, 2014). The other principle type of biogas is wood gas. It is created by gasification of wood or other biomass. This type of biogas is composed mainly of nitrogen, hydrogen and carbonmonoxide with trace amount of methane (Lui and Wang, 2012). Anaerobic digestion is attractive for treatment of organic wastes such as cow manure, since it produces biogas which is a renewable energy source and digester that can be used as organic fertilizer because bio gas plants are difficult to run (Rave, 2013 and Weiland, 2017).

1.3 PROBLEM STATEMENT

Production of biogas using co-digestion mixture of cow dung and kitchen waste remains in ratios which could lead to higher yield of biogas. It is the aim of the study to provide data in the report.

1.4 OBJECTIVES

1.4.1 General Objectives

To determine the yield of biogas using co- digestion mixture of cow manure with kitchen waste.

1.4.2 Specific Objectives

To determine volume of biogas formed when;
   (i) Cow dung is digested.
   (ii) Kitchen waste is digested.

To determine volume of biogas produced when co-digestion of cow dung and kitchen waste in ratios of; 1:1, 1:3 and 3:1.

1.5 JUSTIFICATION

The research seeks to study the behavior of co-digestion of cow dung with kitchen waste in order to increase the yield of biogas.
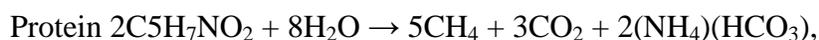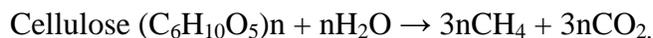
CHAPTER TWO

2.1 LITERATURE REVIEW

It was reported that anaerobic digestion of a single substrate yield 16% of biogas from cow dung and 18% of biogas from kitchen waste (Browel et al, 2015).

Recently, it has been reported that anaerobic digestion has become more stable when a variety of substrates applied at the same time in co-digestion produce more yield of biogas (Agdag et al, 2017).

Using sewage – sludge, it was found that a mixture of the same quantity when digested together with minor amount of a single or variety of additional substrates. (Brain et al, 2017). The use of co-substrates usually improves the yields from anaerobic digestion due to positive synergisms established in the digestion medium and the supply of missing nutrients by the co- substrates (Meta – Alverez et al, 2014). This is illustrated by the equations;

Cellulose $(C_6H_{10}O_5)n + nH_2O \rightarrow 3nCH_4 + 3nCO_2$

Protein $2C5H_7NO_2 + 8H_2O \rightarrow 5CH_4 + 3CO_2 + 2(NH_4)(HCO_3)$,

Fat[2)] $C_{57}H_{104}O_6 + 28H_2O \rightarrow 40CH_4 + 17CO_2$.

It was reported that co-digestion provide a better nutrient balance and high biogas yields (Desai et al, 2015). A combination of hey and poultry manure was found to be capable of maintaining the proper carbon: nitrogen ratio in the reaction (Desai et al, 2015). Revealed research shows that highly buffered systems are obtained by co-digestion of solid slaughter house waste manure, fruit and vegetable waste and the process work well with gas yields of $0.84m^3$/kg (Murto et al, 2016).

Recent research show that using co-substrate in anaerobic digestion systems improves biogas yield. A yield of 26% of biogas was reported to come from co-digestion of bio wastes mixture through positive synergisms established in the digestion medium and the supply of missing nutrients by the co-systems. (Tand and Wong, 2017). It was reported that digestion of manure and organic waste in a well-established technology practice (Weiland, 2017). This process consists of combining several wastes with complimentary characteristics in order to improve the methane production. (Chu et al, 2014).

In many cases, the addition of co-substrates is however based on trial and error practice (Tzang et al, 2015). Biogas plant operators know well the effect of adding fat residue as food waste to biogas plants (Alves, 2013).

It was reported that food waste has a high potential for methane production and can be digested rapidly making it a good source of materials for anaerobic co-digestion in ratio of 1:1, 1:3 and 3:1 for cow dung to kitchen waste respectively. (Agdag et al, 2017).

It was reported that food waste is a good substrate for anaerobic digestion, accomplishing 80% of the theoretical methane yield in 10 days for the ratio of 3:1 (C.D:K.W) (Zhang et al, 2017). Among the co-digested wastes, fats and oils are also one of the most used (Fernandenz et al, 2012). Fats, oils and greases are one of the major organic matter found in the food waste and some industrial waste waters, such as slaughter house, dairy industries or fat refinaries (Li et al, 2012). When compared to other organic wastes of different biochemical composition, fats and oils are theoretically interesting for biogas production, since they are reduced organic materials and have a higher methane potential (Pereira et al, 2013). The research has investigated co-digestion of cow dung and kitchen waste in ratios of 1:1, 1:3 and 3:1respectively as well as separate digestion of cow dung and kitchen waste alone.

CHAPTER THREE

SAMPLING AND METHODOLOGY

3.1 SAMPLING

From a kraal in neighborhood, 2kg of cow dung was collected using a spade and a plastic basin.

From garbage dumpings, 2kg of kitchen waste were collected using hands worn of gloves in a plastic bucket.

3.2 METHODOLOGY

3.2.1 Cow dung digestion

Cow dung (400g) was put in an empty reactor and 200mls of urine was added and left to stand. At intervals of 3days volume of gas formed was measured (Prof. Danton, 2011).

3.2.2 Kitchen waste digestion

Kitchen waste (400g) was put in an empty reactor and 200m/s of urine was added and left to stand at intervals of 3days, volume of gas formed was measured (Cavalez, 2012).

3.2.3 Cow dung - Kitchen waste digestion (1:1)

Cow dung (200g) and kitchen waste (200g) were put in a reactor and 200m/s of urine was added and left to stand. At interval of 3days, volume of gas formed was measured (Ellis, 2014).

3.2.4 Cow dung - Kitchen waste digestion (1:3)

Cow dung (100g) and kitchen waste (300g) were put in a reactor and 200m/s of urine was added and left to stand. At intervals of 3days, volume of gas formed was measured (Cllanghan, 2016).

3.2.5 Cow dung - Kitchen waste digestion (3:1)

Cow dung (300g) and kitchen waste (100g) were put in reactor and 200m/s of water/ urine were added and left to stand. At intervals of 5 days volume of gas formed was measured (Frezzani, 2010).

In all the above five sets, each reactor containing the contents was connected to each empty reactor, thoroughly and tightly plugged so that they can be used to collect the gas given.

The experiment was allowed to run for 27 days and measurements were noted every after 3 days for 4 weeks (27days).

When the arrangements were left to stand for 27 days and readings taken very after 3 days, the setups are the ones shown in Figures 2 below. The collection of the gas was done by passing it through water and collecting in the gas jar.

The setup below is a modified to allow measurements of the gas to be taken. The system below was therefore used to collect and measure the gas evolved from the reactors.
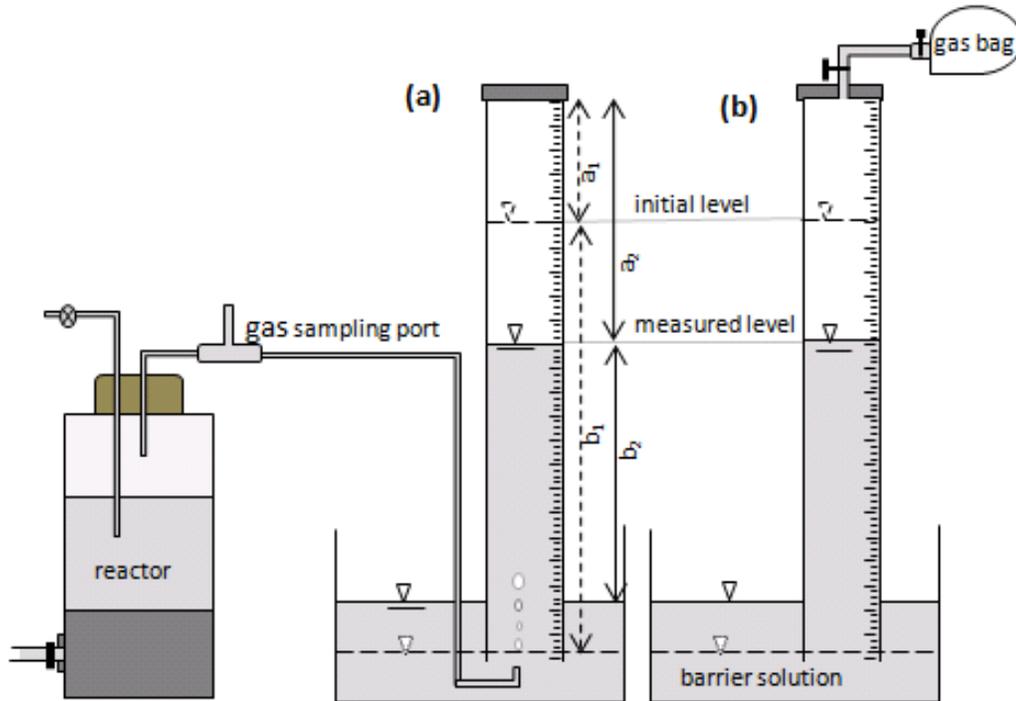

Figure 2: Measurement of gas a) direct from a reactor using cylinder meter b) indirectly by collecting in a gas bag using height meter

CHAPTER FOUR

RESULTS AND DISCUSSION

Using the setup in Figure 2, from the used methods, the experiments where left to run for 27 days, and readings were taken at an interval of 3 days from all the five step-ups. The results obtained are as shown in Table 1 below;

Table 1: Sample and Amount of Biogas produced (ml)

Days	Cow dung	Kitchen waste	K.W C.D 1.1	K.W C.D 1.3	K.W. C.W 3.1
0	0	0	0	0	0
3	3	8	9.6	10.7	12.7
6	8	16	18.5	19.6	21.8
9	19	21	24.5	26.2	28.4
12	24	27	43.2	49.3	57.8
15	48	49	71.8	69.3	76
18	55	55.7	82.3	84.4	86.3
21	60	62	85.4	86.2	89.4
24	64	69	88.3	88.7	91.2
27	71	78.5	89.7	88.9	96

Table 1 above shows the amount of biogas produced from 5 sets of digesters of different compositions.

Generally it can be seen that after a period of 9 days, the volume of gas formed from all a 5 setups kept on increasing but a remarkable increase was observed on day 15 across all the sets.

The highest value of gas produced was registered from a setup of kitchen waste to cow dung in a ratio of 3:1 and the lowest volume of gas produced was registered in the setup of cow dung alone.

The data in Table 1 was plotted in Figures 3-7. In these Figures, there was an increase in volume of gas evolved as time passed. The increase cannot be described as linear or exponential due to side reactions.
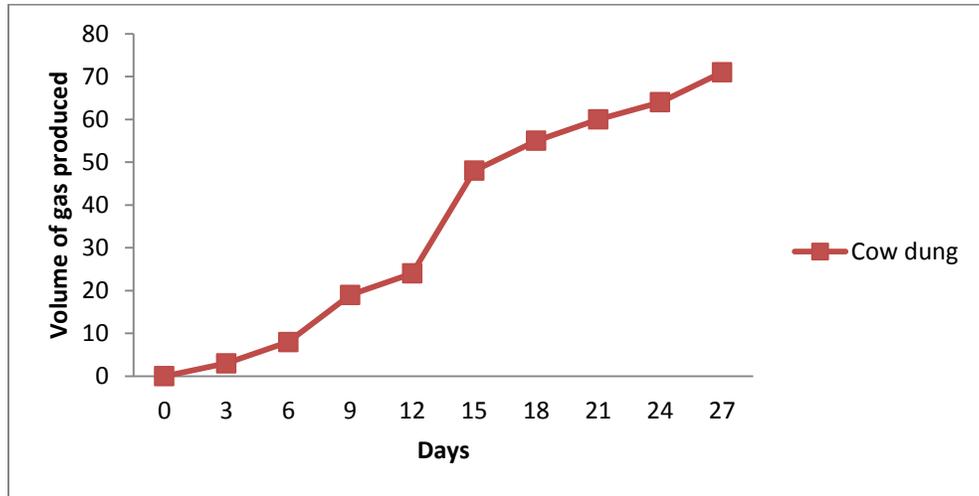
Figure 3: A plot of volume of gas formed by cow dung alone Vs time

As shown in Figure 3, the volume of gas formed at the beginning is low. This due to the fact that the number of anaerobes responsible for the anaerobic digestion was low. However, after 12days, the anaerobes multiplied in number, the volume of gas formed also increased. After day 15, the amount of gas produced started reducing due to the more acid concentration formed out of anaerobic biodegradation of the cow dung. (Jantch and Mathiason, 2004). The by products, fatty acids of anaerobic digestion of cow dung lower the pH and since these anaerobic bacteria cannot survive well in acidic medium, this became a limiting factor, thus the later gradual increase in the volume of biogas formed.

The results in Figure 4 indicate that the volume of gas produced initially is low but kept on increasing gradually, later drastically followed by the gradual increase in volume.
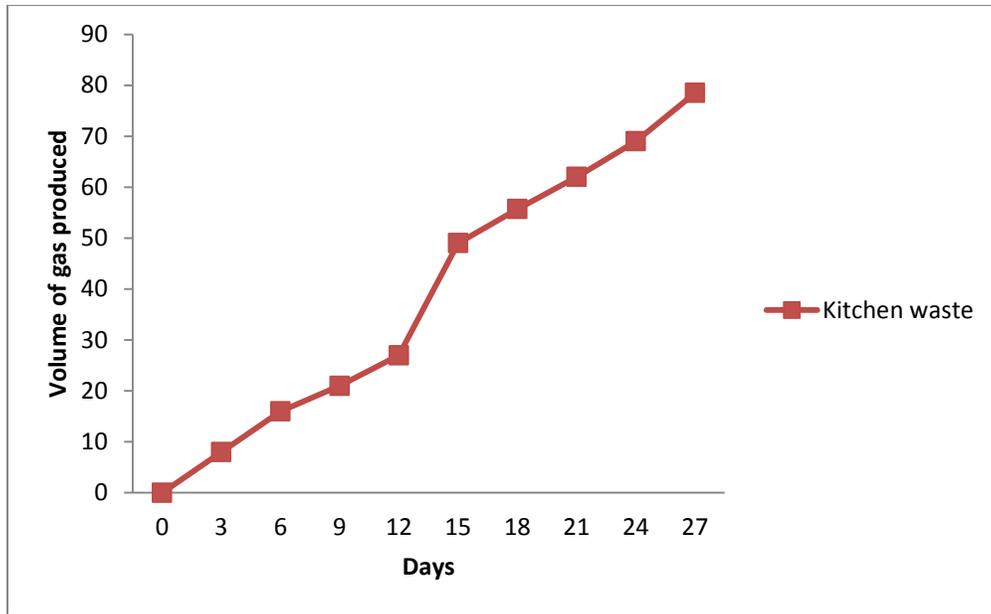
Figure 4: A plot of volume of gas formed from kitchen waste against time

When digesting mixture had stayed for some time that is to say 9 days, there was multiplication of anaerobes. So the volume of gas increased. Later the volume increased gradually because the medium was changing from neutral or alkaline to acidic due to formation of fatty acids. (Suyog, 2011). The curve for the mixture rises above the other curves for cow dung and kitchen waste alone. In all cases the curves follow an S-shaped curve. This indicates a closure to a first order kinetics.

Results comparing single substrate and co-digestion of cow dung and kitchen waste is given in Figure 5. The data in Figure 5 reveals that higher volumes of gas formed from co-digested mixture than from single substrate.

Figure 5: A plot of volume of gas formed by K.W: C.D in ratio of 1:1 against time

As shown in Figure 5, the volume of gas produced initially is low, since the amount of anaerobes is low. After 9 days, the num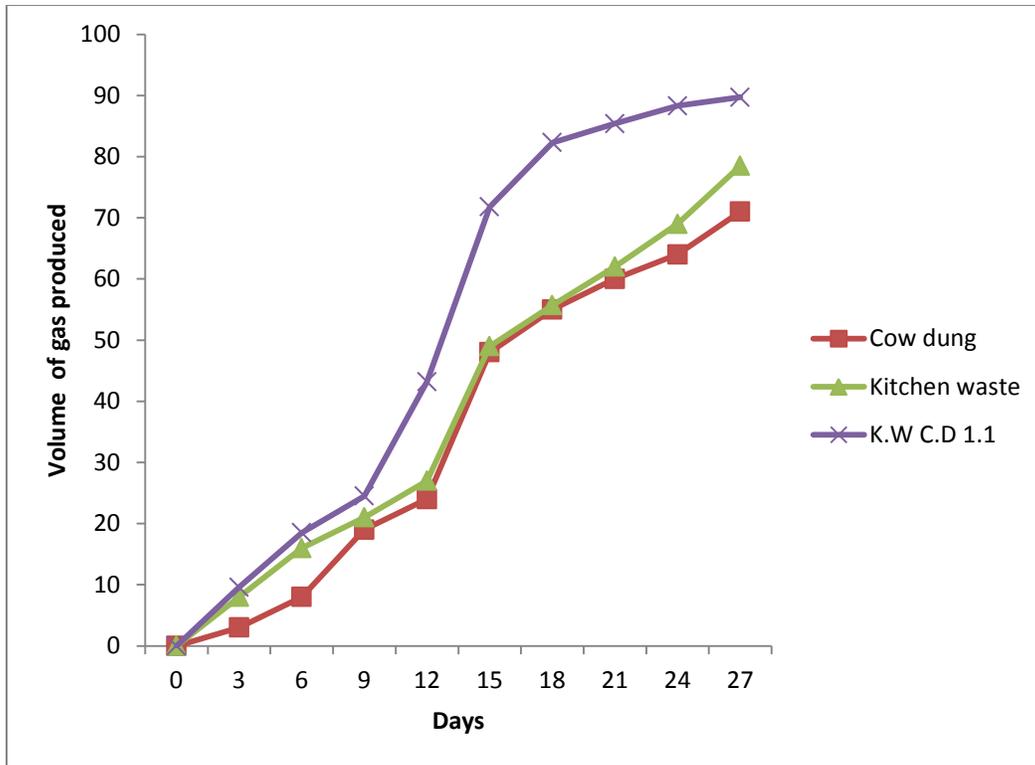ber of anaerobes kept on multiplying. From day 9 to day 18, there is a drastic increase in the volume of gas formed. This is explained by two factors that the anaerobic bacteria kept on multiplying and also that the kitchen waste contain nutrients like cellulose, carbohydrates, proteins, lipids among others for biogas compared to cow dung which is large cellulose so, co-digestion resulted in larger increase in the volume of gas formed than single substrates. (Zhang et al, 2015).

However after day 18, the rate of gas production kept on increasing gradually. This was due to the fatty acids formed. Acids lower the pH of the reactants medium and thus play a limiting role for anaerobic digestion since it retards the rate of reaction. (Szafnick, 2004).

The results on digestion of single substrates and co-digestion of 1:3 kitchen waste to cow dung shown in Figure 6.
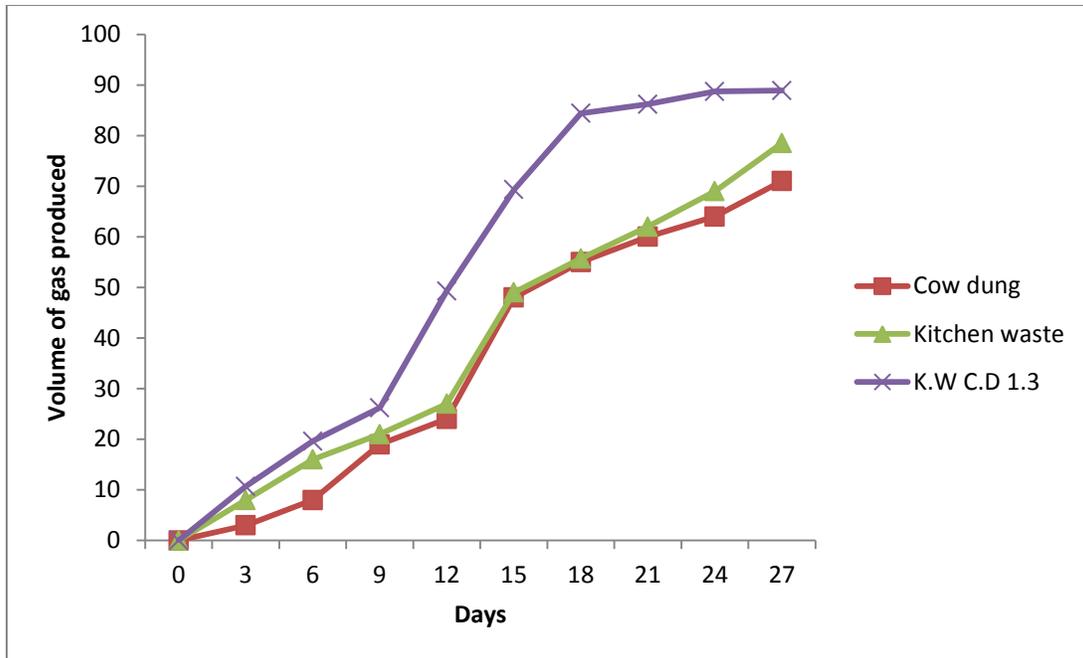
Figure 6: A plot of volume of bio gas formed by Kitchen Waste: Cow Dung (1:3) against time

As seen in Figure 6, single substrates and co-digestion mixtures produced very low volumes of gas at the beginning of the process due to scarcity of microbes. Between day 9 and 18, the increase in volume of gas formed was drastic as the number of anaerobes had increased.

However, the increase in volume for co-digestion mixture was by far higher than for single substrate.

This rise is explained by the fact that cow dung has got a high hydrolysis rate than kitchen waste and thus, after its hydrolysis, the anaerobes which kept on multiplying as time passed acted on the hydrolyzed cow dung mixed with kitchen waste. A combination of these two factors led to a drastic raise in the volume of gas produced. Though the kitchen waste is in small amount of (1:3) in respect to cow dung, it can be stated that since its nutrient content is high, it offers the more substrates for the anaerobic digestion which contributes to the high rate of volume of gas production than in single substrate digestion.

After 18th day, the volume of gas produced rose gradually due to fatty acids produced. (Lissens, 2004).

A comparison of single substrate and co-digestion of 3:1 kitchen waste to cow dung is shown in Figure 7. The volume of gas formed from co-digestion mixture was higher than that for single substrate digestion due to presence of mixed ingredients for gas formation.
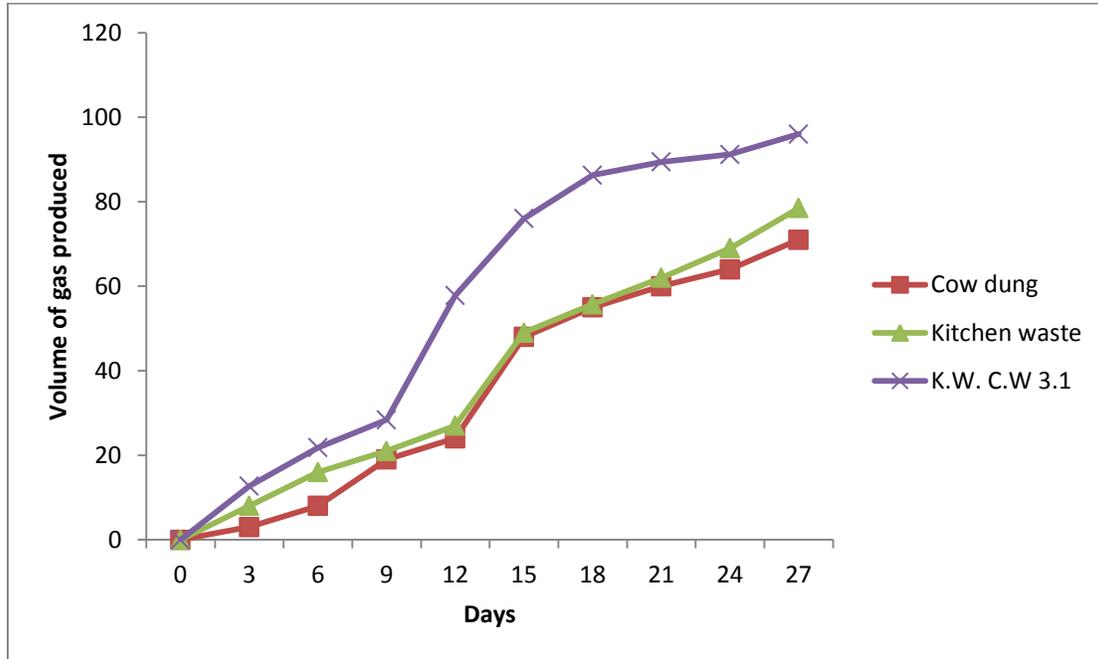

Figure 7: A plot of Volume of gas formed by K.W:C.D in ratio of (3:1) against time

As seen from Figure 7, the volume of gas in the first 6 days is low for single and co-digestion mixtures, but later increases because at first the anaerobes were few in number. After day 9, the number of anaerobes had multiplied, which led to an increase in the volume of gas produced till day 18 and later the increase was gradual. (Meres, 2004). This was explained in terms of cow dung having higher rate of hydrolysis than kitchen waste. This tremendously increased the volume of biogas formed. It should also be noted that since kitchen waste was present in large ratio (3:1), it offered a high nutrient content (carbohydrates, proteins, lipids, fats, oils among others) for anaerobic digestion. So co-digestion mixture was more readily acted by the micro-organisms which caused a high yield of biogas. (Shekda et al, 2004).

From day 18, the volume of biogas formed increased gradually. This was caused by the fatty acids produced as by products that lowered pH and thus limiting the micro-organisms to act on the substrates to produce biogas (Thermson, 2014).

The data in Table 1 was used to obtain data in Tables 2-6 with the interest to deduce the kinetics of the generation of biogas. To achieve this, a quantity of reactants was expressed by $V\infty - Vo$ and quantity reacted away was deduced from $V\infty - Vo - Vt$. The differences in volumes have been put in Tables 2,3,4,5 and 6.

Cow dung

Table 2: Cow dung

Days	Cow dung	$(V \propto -Vo) - Vt$	Ln $(V \propto -Vo - Vt)$
0	0	71	4.2626
3	3	68	4.2195
6	8	63	4.1431
9	19	52	3.9512
12	24	47	3.8501
15	48	23	3.1354
18	55	16	2.7726
21	60	11	2.3979
24	64	7	1.9460

As observed in Table 2, quantity of reactants decreased as time passed. To test on whether the decrease was exponential, a plot of Ln $(V \propto -Vo - Vt)$ against time was mamde as shown in Figures 8-11.
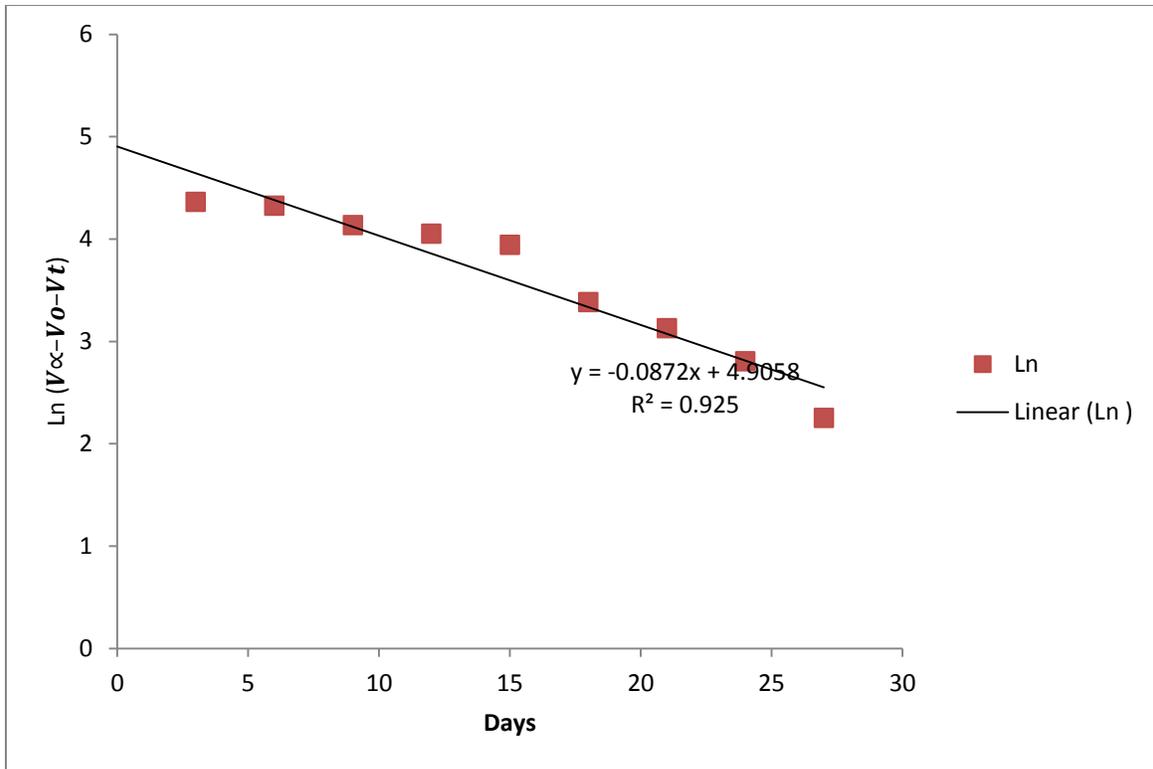
Figure 8: A plot of Ln $(V \propto -Vo - Vt)$ against time (Cow dung)

Figure 8 above reveals that the reaction follows a first order reaction kinetics closely. The rate constant is 0.0872 per day and linearity coefficient is 0.925. High deviation of co-efficient and linearity may have arisen from side reactions.

Table 3: Kitchen waste

Days	Kitchen waste	$(V \propto -Vo) - Vt$	Ln $(V \propto -Vo - Vt)$
0	0	78.5	4.3631
3	3	75.5	4.3241
6	16	62.5	4.1352
9	21	57.5	4.0518
12	27	51.5	3.9416
15	49	29.5	3.3844
18	55.7	22.8	3.1268
21	62	16.5	2.8034
24	69	9.5	2.2513

Figure 9: A plot of Ln $(V \propto -Vo - Vt)$ against time (Kitchen waste)
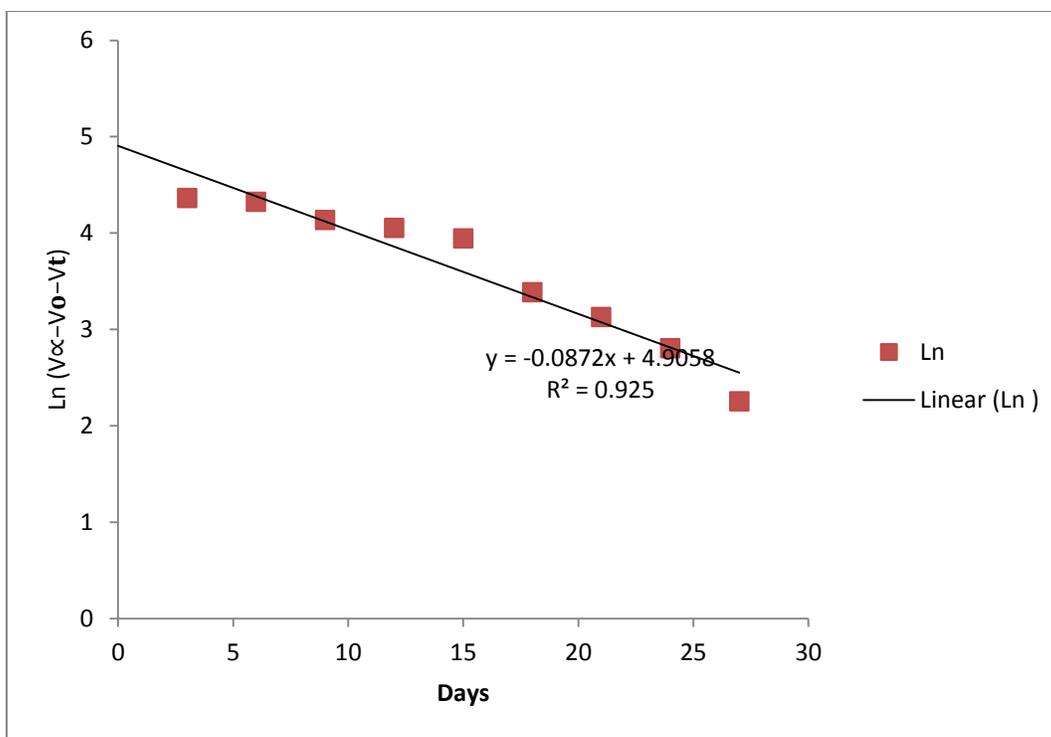
The plot in Figure 9 yielded a rate constant of 0.0872 per day with co-efficient of linearity $R^2 = 0.925$ decomposition, consecutive or parallel reactions, linearity deviated greatly.

Table 4: K.W: C.D (1:1)

Days	K.W: C.D (1:1)	$(V \propto -Vo) - Vt$	Ln $(V \propto -Vo - Vt)$
0	0	89.7	4.4965
3	9.6	80.1	4.3833
6	18.5	71.2	4.2655
9	24.5	65.2	4.1775
12	43.2	46.5	3.8395
15	71.8	17.9	2.8848
18	82.3	7.4	2.0045
21	85.4	4.3	1.4586
24	88.3	1.4	0.3365

In Figure 10 and 11, is shown the plot of kinetic data for a co-digested mixture of cow dung and kitchen waste. The plot is not linear and the reaction may not conform to first order kinetics because co-digestion generates more other gases than methane. And evolution of additional gases to methane alters mechanism of reaction, hence order changes.
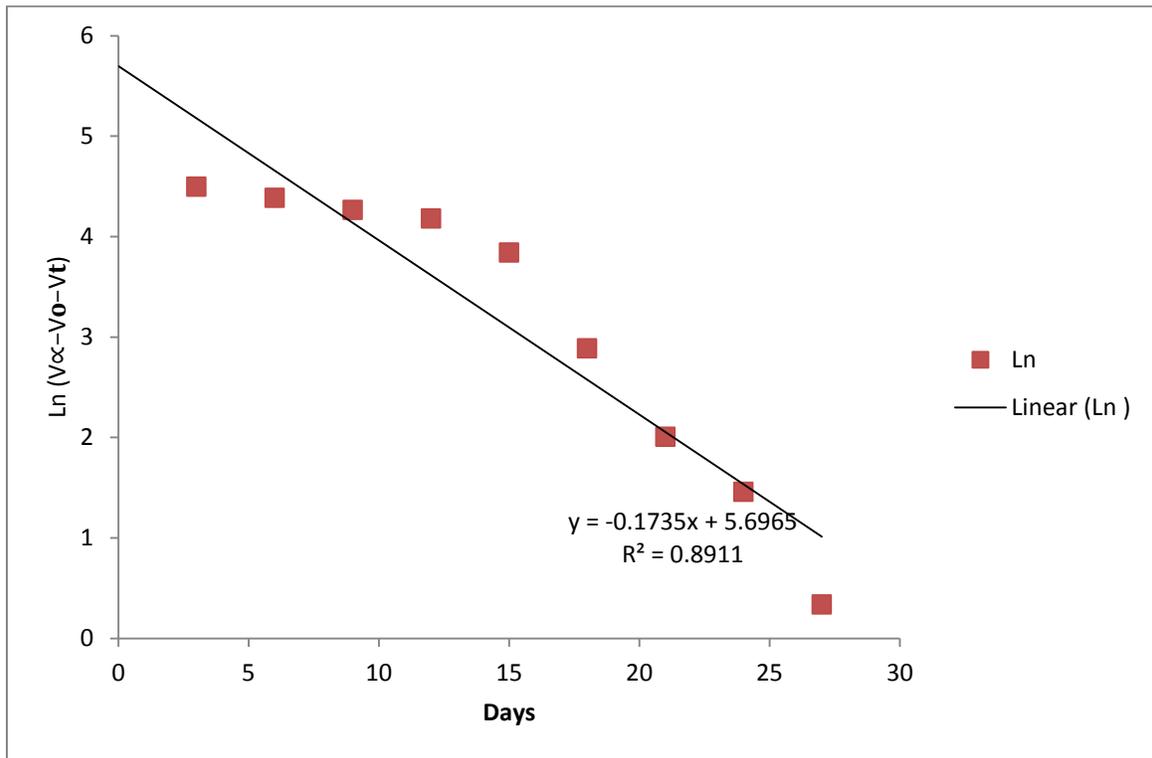
Figure 10: A plot of Ln ($V \propto -Vo - Vt$) against time (K.W: C.D (1:1))

Table 5: K.W:C.D (1:3)

Days	K.W:C.D (1:3)	$(V \propto -Vo) - Vt$	Ln $(V \propto -Vo - Vt)$
0	0	88.9	4.4875
3	10.7	78.2	4.3593
6	19.6	69.3	4.2385
9	26.2	62.7	4.1384
12	49.3	39.6	3.6788
15	69.3	19.6	2.9755
18	84.4	4.5	1.5040
21	86.2	2.7	0.9933
24	88.7	0.2	-1.6094

Figure 11: A plot of Ln $(V \propto -Vo - Vt)$ against time (K.W:C.D (1:3))

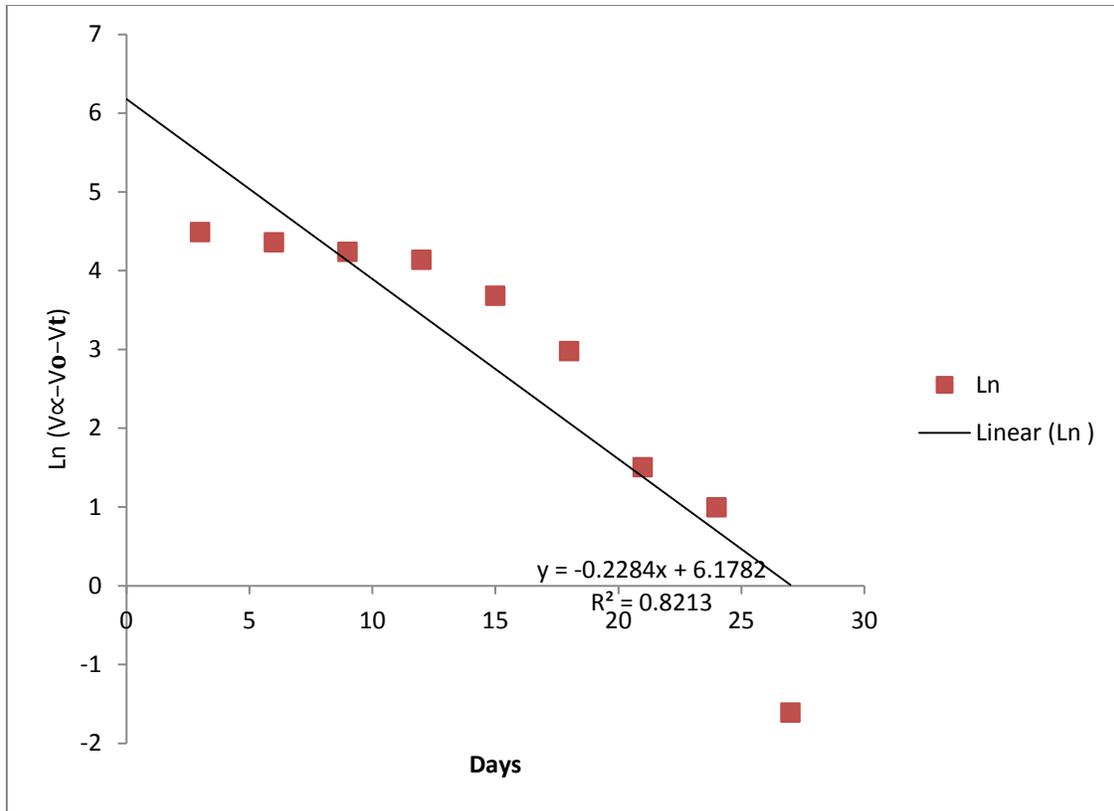The rate constant obtained from Figures 10, 11 and 12 are 0.173, 0.228 and 0.134 per day respectively with co-efficient of linearity of 0.891, 0.821 and 0.901 which are far below acceptable values for line graphs. So this study reveals that co-digestion may not follow simple first order kinetics.

Table 6: K.W:C.D (3:1)

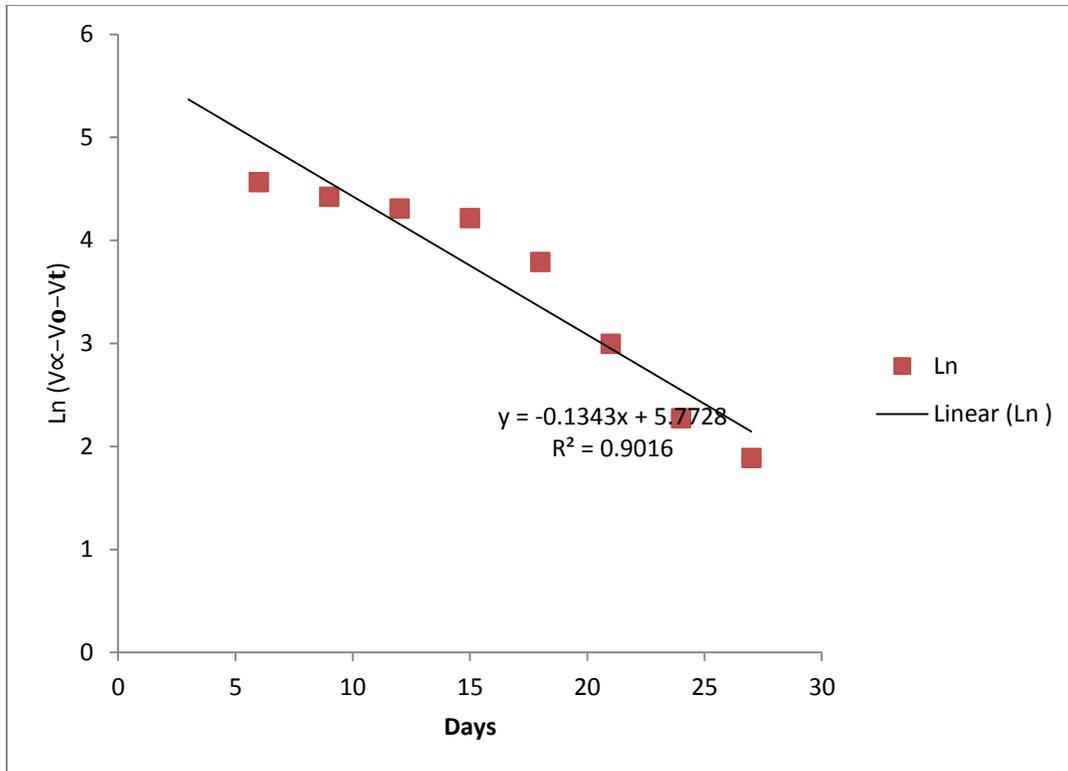| Days	K.W:C.D (3:1)	$(V \propto -Vo) - Vt$	Ln $(V \propto -Vo - Vt)$
0	0	96	4.5644
3	12.7	83.3	4.42244
6	21.8	74.2	4.3068
9	28.4	67.6	4.2136
12	51.8	44.2	3.7887
15	76	22.0	2.9957
18	86.3	9.7	2.2721
21	89.4	6.6	1.8871
24	91.2	4.8	1.5686

Figure 12: A plot of Ln $(V \propto -Vo - Vt)$ against time (K.W:C.D (3:1))

4.1 CONCLUSION

From the results obtained in the study, it can be concluded that co-digestion of cow dung and kitchen waste yields more gas than digestion of single substitute.

4.2 RECOMMENDATIONS

There should be further study to determine the kinetics of co-digestion mixtures of cow dung and kitchen waste.

Digestion of single substrate cow dung or kitchen waste alone more closely follows first order kinetics than co-digestion of cow dung and kitchen waste.

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