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Determination of optimum mixing ratio of cow dung and poultry droppings in biogas production under tropical condition

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There is urgent need for proper waste management and development of alternate energy using wastes in developing countries. Optimal digestion mixture of substrates ensures that waste products of animals, industries etc. are optimized. This study was designed to determine the optimal mixing ratio of cow dung and poultry droppings in biogas production under tropical condition. The mixing ratio used were 100:0, 75:25, 50:50, 25:75 and 0:100 for cow dung (CD) and poultry droppings (PYD), respectively. The fermentation was carried out in five 30 L digesters locally fabricated. The biogas yields obtained in the work for the cow dung and poultry dropping mixture were in the order of 25% CD + 75% PYD > 100% CD + 00% PYD > 50% CD + 50% PYD > 00% CD + 100% PYD > 75% CD + 25% PYD. The kinetics of anaerobic digestion process of the various digestion mixtures was successfully evaluated with modified first order model equation; the result shows that poultry dropping (alone) has the highest short term biodegradability index of 2.4 while the 50% CD+50% PYD digester has the highest removal rate of the biodegradable fractions (k) of -0.199 among all the substrates. Thus, optimum mixing ratio for cow dung and poultry dropping suggested by the study is 25% CD + 75% PYD mixing ratio which gave 16.35 L/total mass of slurry (TMS) within the period under study.

Key words: Waste management, energy, cow dung, poultry droppings, biogas.

INTRODUCTION

In any livestock production system, animal droppings constitute an unavoidable by-product. Globally, 998 million tons of agricultural waste is produced in a year (Agamuthu, 2009). These wastes can cause harm in many different ways via direct impairment of human health, damage to ecosystems and ecosystem functions or production of organisms that creates economic losses and loss in aesthetic value (Marchaim, 1992; Shih, 1993). Waste products from farms are highly contaminated with pathogenic microorganisms and are therefore hazardous to animals and humans. The conversion of these wastes to harmless and useful products can provide at least a partial answer to urban pollution, while at the same time relieving the pressure on ground water threatened by pollution (Marchaim, 1992).

Melford (2003) observed that management of Nigeria's environment is costing the nation roughly $5 billion annually as a result of poor agricultural practices, oil

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exploration, oil spills, grazing and habitat destruction. In Nigeria, water pollution and access to energy resources present challenges to human health, environmental health and economic development. The need for alternative renewable energy sources from locally available resources cannot be over emphasized. Appropriate and economically feasible technologies that combine solid waste and waste water treatment and energy production can simultaneously protect the surrounding water resources and enhance energy availability (Mshandete and Parawira, 2009). Biogas technology in which biogas is derived through anaerobic digestion of biomass, such as agricultural wastes, municipal and industrial waste (water) is one of such appropriate technology which could be adopted to ease environmental problems and enhance energy production. Biogas, which is bio-energy produced from biomass has several advantages over other forms of renewable energies (Sreenivas et al., 2009; Chae et al., 2002). The anaerobic fermentation of wastes for biogas production does not reduce its value as a fertilizer supplement, as available nitrogen and other substances remain in the treated sludge (Alvarez and Lide´n, 2008; Fiorese et al., 2008; Budiyono et al., 2010; John, 2010; Braun and Wellinger, 2002), and most of the pathogens destroyed in the process of anaerobic digestion (FAO, 1996). Several researches undertaken in anaerobic digestion of wastes in developed countries have shown technical feasibility of digestion of these wastes, however these studies which often involves regulation of temperature (Vindis et al., 2009), pH adjustment (Holubar et al., 2006), pretreatment of waste (Taherzadeh et al., 2011), use of sophisticated digesters, among others, in most cases, involve technicality and cost of operations quit expensive and difficult for rural settings in developing countries. Mshandete and Parawira (2009) noted that lack of basic and advanced technology by African scientists could be one of the factors contributing to poor biogas technology application in Africa; the authors recommended that relevant and appropriate research be carried out to adopt the biogas technology to the local conditions in African countries. Hence, there is need to research under the tropical environmental conditions faced by these rural populaces with simplified technology for waste management, affordable by local communities in Africa. Umeghalu et al. (2012) reported that about 15563 kg (15.6 tons) of fresh cow manure and about 2012 kg (2.01 tons) of poultry droppings are generated daily in Anambra State of Eastern Nigeria. The researchers also reported that only negligible proportion of these wastes are used as manure for vegetable crops and feed stock for fish farming. As a result of poor management of these animal wastes, various levels of environmental pollution have being reported by various researchers. Several researchers in Nigeria have emphasis the need to popularize biogas production because of its numerous benefits. The benefit of co-digestion of substrates usually outweighs that of single digestion because of synergistic effects (Braun and Wellinger, 2002). It is necessary in the face of energy challenges facing developing countries, and mismanagement of cow and poultry wastes in the study area (which has constituted environmental nuisances) to determine the optimum mixing ratio of these major animal wastes produced in the region under tropical conditions for biogas production.

MATERIALS AND METHODS

Substrates sources and characteristics

The study was carried out at Biotechnology Research Centre, Nnamdi Azikiwe University Awka, Anambra State Nigeria. Awka is the state capital of Anambra State and is located at latitude 6°20′N and longitude 7°00′E. Substrates utilized in this research were poultry droppings (PYD) and cow dung (CD). The poultry droppings were randomly collected from Buka-Chuks Poultry Farms in Amawbia, few kilometers from Awka, the state capital of Anambra State, Nigeria. While Cow dung (CD) were randomly collected from Amansi cattle ranch in Awka town. The fresh substrates were taken immediately to Spring Board Laboratories, Udoka Housing Estate, Awka for substrate analysis. The parameters determined include moisture content, total solid (TS), volatile solid (VS), total Kjeldahl nitrogen, carbon content and pH. The result of the analysis is shown in Table 1.

The pH measurements were taken with a pH meter (Fisher Scientific Accumet Basic, Model AB 15 pH meter). Total solids (TS) in samples were determined using Standard Method 2540 G; Volatile solids (VS) was measured using Standard Method 2540 E (APHA, 2005). Total Kjeldahl Nitrogen was measured using Standard Methods 4500-Norg C, (APHA, 2005) while carbon content was carried out using Walkley and Black (1934) method.

Experimental setup

7 kg of cow dung and poultry droppings were weighed and mixed in the ratio of 100% CD + 00% PYD, 75% CD + 25% PYD, 50% CD + 50% PYD and 25% CD + 75% PYD and 00% CD + 100% CD, 15 L of water was added to the waste, mixed properly and fed in five 30 L batch type digesters for a period of thirty days to determine the effect of mixture ratio. The 100 %CD + 00 %PYD and 00 %CD + 100 %PYD are single substrate digestions and are used as data baseline as recommended by Buendía et al. (2009). The prevailing temperature range was 24 to 34°C during the period of study. The experiment was conducted at suboptimum condition (ambient temperature without any form of temperature regulation, pH adjustment, pretreatment of substrates etc.). The bio-digester is divided into three main parts- the inlet chamber, the body, and the outlet chamber. The body of the digester contains a stirrer for the mixing of the substrate to enhance gas production. An exit pipe is provided at the top of the smaller cylindrical portion of the digester for biogas collection and measurement. The digesters used for the experiment was made of mild steel, which is durable and potable for waste management. Other materials used for the experiment include graduated transparent bucket and measuring cylinder for measuring the volume of gas production, hosepipe, thermometer, digital pH meter. Volume measurements of biogas produced was done by water displacement. The method used was adopted from Ezeoha and Idike (2007). Biogas production was monitored and measured for thirty days. The experiment was repeated twice, the average values obtained was used in the research work. The digesters used for the research is shown in Figure 1.

Table 1. The composition of the substrates.

Composition	Cow dung	Poultry dropping
Moisture content (%)	79	60
Total solid (%)	19	40
Volatile solid (%)	15	12.5
TKN (mg/g)	2.98	9.52
Carbon content (%)	9.8	5
pH	7.2	7.7

TKN = Total Kjeldahl nitrogen.

Figure 1. The metallic digesters used for the Research at Biotechnology Research Center, Nnamdi Azikiwe University Awka, Nigeria.

Table 2. The pH values of digestion and co-digestion of poultry droppings with cow dung on the 7th day of digestion period.

Digester	100:0	75:25	50:50	25:75	0: 100
pH	6.4	6.3	6.5	6.8	7.0

Statistical analysis

The data were statistically analysed using Microsoft Excel software; Matlab version 7.5 was used in fitting the first order kinetic model to experimental data.

RESULTS AND DISCUSSION

pH and alkalinity

Many research work on anaerobic digestion of waste has shown that pH of substrates has strong influence on the rate of production and yield of biogas by the substrate. The methanogenic bacteria are known to be very sensitive to pH. The pH of the substrates was measured on the seventh day of digestion in accordance to Chaiprasert et al. (2006), pH is an indicator of system process stability of anaerobic process, and this is shown in Table 2.

The values of the pH of the substrates determined in this research fall within the range of 6.3 to 7.0, which is optimum pH for anaerobic digestion. The digestion of these wastes was carried out progressively without any noticeable inhibition.

Digester performance and biogas production potentials of mixture

The 50% CD + 50% PYD digester started gas production on the first day; this is probable due to optimum composition of the substrate mixture. Poultry waste has

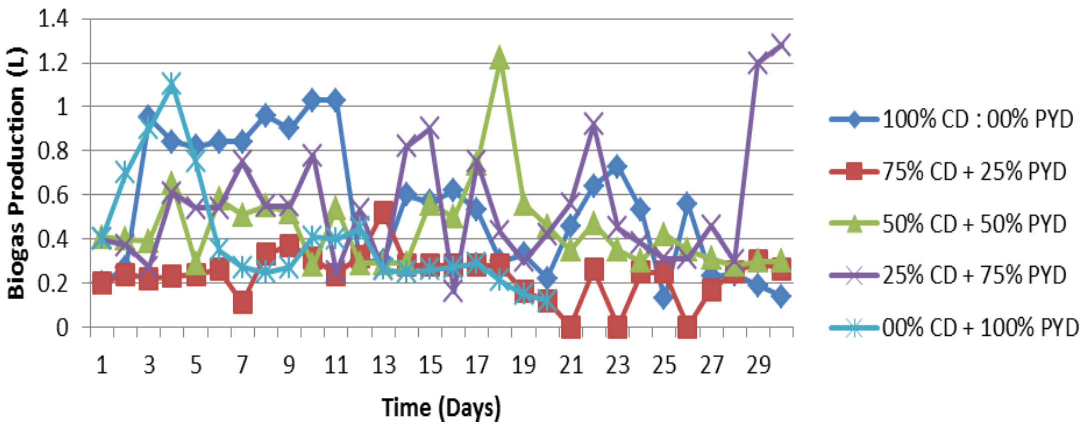

Figure 2. Daily biogas yield from digestion of cow dung and poultry droppings with their mixtures.

been reported to degrade faster than cow dung (Marchaim, 1992). However cow dung has been acclaimed to contain bacteria that kick starts anaerobic digestion (Nwaogazie and Momoh, 2008). This optimum condition must be responsible for the quick production of biogas by 50%CD + 50%PYD digester among the various mixtures. A plot of retention time versus the quantity of biogas produced daily is shown on Figure 2.

The daily biogas production varies from a minimum of 0 L/TMS for 75% CD + 25% PYD mixture to a maximum of 1.3 L/TMS for 25% CD + 75% PYD mixture. From Figure 2, several peaks were observed for both single digestions and co-digestions. The daily biogas trend of several peaks in this research work could be attributed to the effect of temperature fluctuations which is a major factor in biogas yield.

Biogas production yield seems to be lower at the beginning and at the end of digestions with the exception of 25% CD + 75% PYD digestion mixture, which had more yield towards the end of digestion period than at the beginning. The general trend is predicted due to the biogas production rate in batch condition directly corresponds to specific growth rate of methanogenic bacteria in the bio-digester (Gupta et al., 2009; Rabah et al., 2010). The daily biogas yield reached the peak value for 00%CD + 100% PYD mixture in the first week, while the daily biogas yield for 100% CD + 00% PYD and 75% CD + 25% PYD reached their peak value in the second week. On the week third week, the 50% CD + 50% PYD mixture reached its peak. The 25% CD + 75% PYD surprisingly, reach its peak at the last week.

The plot of the biogas cumulative yield is shown in Figure 3. Within the first few days of observation, biogas production was very low. From Figure 3, it could be seen that at the first 5 days of gas production for the different mixing ratio, the 00% CD + 100% PYD (poultry waste alone) digester had the highest biogas yield (3.85 L/MS) This agrees well with Marchaim (1992) report that poultry waste degrades faster than cow dung. Wilkie (2005) reported that zcattle manure is established to have low available volatile solids because ruminants extract much of the nutrients from the fodder and the leftover is rich in lignin complexes which were extensively exposed to enzyme action of the four chamber stomach of ruminants. This trend agrees well with Wilkie (2005) report. However, on the 10th day, the 100% CD + 00% PYD digester (cow dung alone) took the lead by producing a total yield of 7.85 L/TMS, a difference of 2.43 L/TMS in comparison to 00% CD + 100% PYD digester. This shows the ability of cow dung to produce more biogas than poultry dropping with respect to time from this research work. The 25% CD + 75% PYD digester produced the highest total volume of biogas of 16.35 L/TMS; this is slightly higher than the 16.30L/TMS of slurry produced by the 100% CD + 00% PYD digester. The 25% CD + 75% PYD digester produced more gas towards the end of the thirty days duration of the experiment, while the 100%CD + 00%PYD digester experienced a great decline in gas production towards the end of the experiment. This shows the tendency of the 25% CD + 75% PYD digester to produce more gas than the single substrate's digestion of cow dung given more time. The 75% CD + 25% PYD digester had the least gas yield of 7.01 L/TMS; this could be attributed to suboptimum substrate ratio. It was also observed that the 75% CD + 25% PYD digester failed to produce gas in some days during the experiment (around eighteen to twenty five days of gas production period). This could be attributed to low pressure within the digester. It is generally known that enough pressure must be built in digesters before the gas could escape from the exit pipe of the digesters. The digester with the maximum gas production per day is the 25% CD + 75% PYD digester, producing about 1.3 L/TMS of biogas. This is followed by the 100% CD + 00% PYD digester producing a maximum of 1.05 L/TMS biogas per day. Biogas yield was significantly ($P \leq 0.05$) influenced by co-digestion of the two substrates. The order of gas production is 25% CD + 75% PYD > 100% CD + 00% PYD > 50% CD + 50% PYD > 00% CD + 100% PYD > 75% CD + 25% PYD.

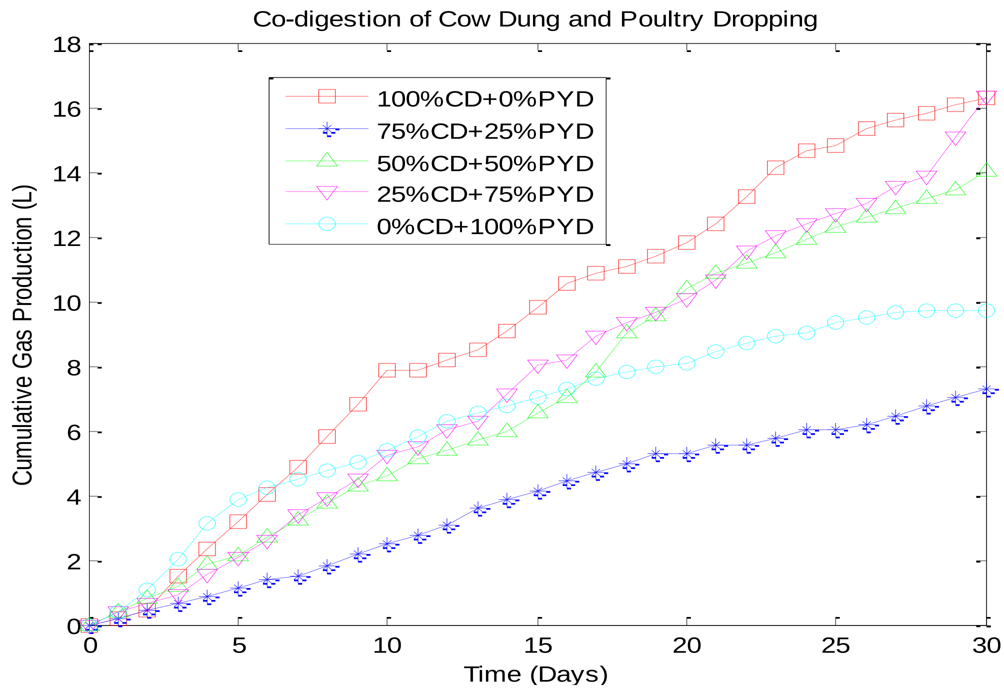

Figure 3. Cumulative biogas yield of cow dung with poultry dropping with their mixing ratio.

Table 3. Antagonistic and synergistic effect of co-digestion of cow dung and poultry droppings.

Digesters	Co-digestion (kg)	Biogas performance			
		Cow dung (L)	Poultry droppings (L)	Increase (L)	Increase (%)
100:00	-	16.30	-		
75:25	7.01	12.225	2.02	-7.235	-50.58
50:50	13.46	8.15	4.04	1.27	10.4
25:75	16.35	4.075	6.06	6.215	61.3
00:100	-	-	8.08		

Co-digestion performance and antagonistic and synergistic effect

Table 3 illustrates the synergistic and antagonistic effect of co-digestion of cow dung with poultry droppings. The co-digestion improved the treatment efficiencies with higher cumulative biogas production for 50% CD + 50% PYD and 25% CD + 75% PYD mixtures, however the 75% CD + 25% PYD digestion mixture was less than both cow dung and poultry droppings single substrate digestion, this could be as a result of antagonistic effects. The synergistic mixture effects of the substrates is pronounced in the 50% CD+50% PYD digestion mixture; there was 10.4% improvement in biogas production in the 50% CD+50% PYD digester compared to the baseline digesters. There was also 61.3% increase in gas production for the 25% CD + 75% PYD mixtures which represent the optimum digestion mixture. Although there is a little difference of 0.5 L/TMS between this mixture and the baseline digester with respect to cow dung, the value increases to 7.46 L/TMS which represent 45.62% increase with respect to poultry baseline datum. Several researchers have reported on the synergistic effect of co-digestion of substrates in biogas production (Alvarez and Lide´n, 2008; Fiorese et al., 2008; Braun and Wellinger, 2002). However, the positive mixture effect of the substrates marked by increase in gas production in this research work is observed with increase in poultry droppings in the digestion mixtures. This showed that co-digestion significantly improved the biogas yield in this research work.

Kinetic modeling of the digesters

The first-order kinetic model use in assessing the degradation process of substrates is given as (Chen and Hashimoto, 1979):

$$\frac{dp}{dt} = -kp \quad (1)$$

Where p is the substrate concentration, T is the digestion time; K is the first order substrate decay rate constant. Integrating Equation (1)

$$\int_{p_0}^{p} \frac{dp}{p} = -k \int_0^t dt \quad (2)$$

$$\ln\left(\frac{p}{p_0}\right) = -kt \quad (3)$$

The gas production can also be correlated with substrate concentration (Adak et al., 2011):

$$\frac{Y_\beta - Y_t}{Y_\beta} = \frac{p}{p_0} \quad (4)$$

Y_β is the cumulative biogas production per unit mass of volatile solid converted over time (t); Y_t is the volume of biogas per unit of mass of volatile solids converted at time (t).

Substituting Equation (4) into Equation (3), we obtain

$$\frac{Y_\beta - Y_t}{Y_\beta} = \exp\,(-kt)$$

$$y_\beta\big(1 - \exp(-(kt))\big) = y_t \quad (5)$$

The rate constant associated with the degradation of the biodegradable fractions is represented by *k* (1/days), while the period of digestion is represented by *t* (in days). The application of Equation (5) in assessing substrate biodegradability and the rate constant was accomplished by attempting to linearize Equation (5) as shown below. By differentiating Equation (5), we obtain,

$$\frac{dy_t}{dt} = y_\beta k(\exp(-kt)) \quad (6)$$

Taking natural logarithm on both sides of the equation we obtain

$$ln\frac{dyt}{dt} = (lny_\beta + lnk) - \mathrm{kt}) \quad (7)$$

This equation can be reduced to the form

$$\frac{1}{t}ln\frac{dyt}{dt} = \frac{1}{t}(lny_\beta + lnk) - \mathrm{k}) \quad (8)$$

Equation (8) is of the form of a straight line equation *y* = *mx* + *c*, in which ($\ln y_\beta$ + ln*k*) represents the slope while, (–*k*) represents the intercept of $\frac{1}{t}\ln\left(\frac{dyt\left(\frac{l}{kgVS}\right)}{dt(day)}\right)$. The term ($\ln y_\beta$ + ln*k*) is a measure of the availability of readily and moderately degradable fractions of the substrates. Thus, the term can be used to select substrates with high biogas production potential. Higher values of this term depict substrate with the potential to produce high quantity of biogas under short retention periods and vice versa. The term (–*k*) is a measure of the rate of removal of the biodegradable fractions as the biogas yield increases with time (Yusuf et al., 2011). The more negative the value of (*k*), the faster the rates of removal of the biodegradable fractions while the more positive the value of (*k*), the slower the rate of removal of the biodegradable fractions. A plot of $\frac{1}{t}\ln\left(\frac{dyt\left(\frac{l}{kgVS}\right)}{dt(day)}\right)$ versus 1/t revealed that the modeled equation could suitably assess the ambient temperature short term biodegradability and removal rates of biodegradable fractions of substrates used in anaerobic digestion, linear polynomial was used to fit the experimental data as shown in Figures 4 to 9 using Matlab software version 7.5.

Kinetic parameters of the substrates

From Figure 4, the ambient temperature short term biodegradability of the substrate in digester 100% CD + 0% PYD for the period under study was observed to be 1.524 while the intercept, depicting the removal rate of biodegradable fractions was estimated to be -0.281. The model was able to fit the data set with a goodness of fit (R^2) of 0.785.

Similarly, digester 75% CD + 25% PYD had an ambient temperature short term biodegradability index of 0.958 with a removal rate constant of -0.205 and a goodness of fit (R^2) of 0.8535 as shown in Figure 5. The 75% CD + 25% PYD digester contains poultry droppings this probable resulted to more negative k value in comparison to the 100% CD + 00% PYD digester. This suggests that the 75%CD + 25%PYD digester has a faster removal rate of biodegradable fraction than the 100% CD + 00% PYD digester.

These trend agree with the research work of several researchers that asserts that cow dung is known to contain fibrous materials that are not easily degradable (Babatola, 2008; Taherzadeh et al., 2011). The digester 50% CD + 50% PYD had ambient temperature short term biodegradability index of 0.879 with a removal rate constant of -0.199 and a goodness of fit (R^2) of 0.7942 as shown in Figure 6.

The 50% CD + 50% PYD digester has the lowest removal rate constant (k). This could be attributed to the optimum C/N ratio in this digester; a combination of nitrogen rich substrate (poultry dropping) and cow dung that contains bacteria needed to kick start the anaerobic process. The 50% CD + 50% PYD digester was the first to start gas production within twenty four hours in the cow dung and poultry digestion mixtures. This resulted in a removal rate constant of -0.199, which is the least in all

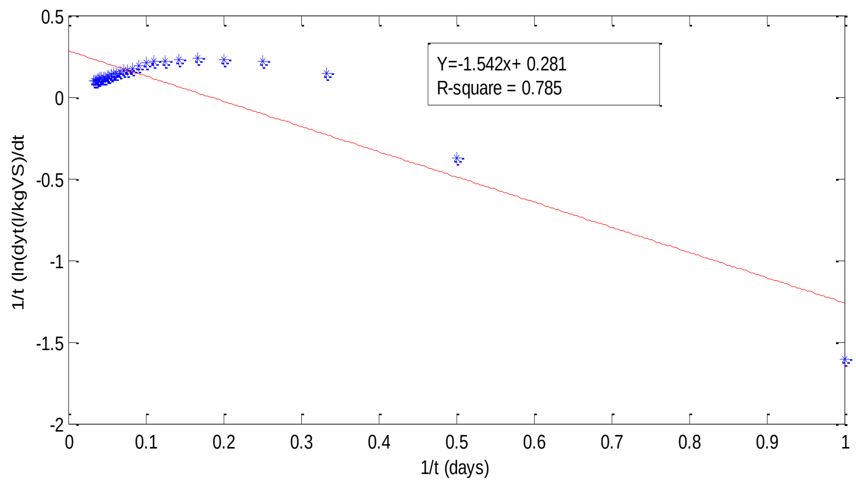

Figure 4. Plot of 1/t (ln(dyt(l/kgVS)/dt against 1/t for 100% CD + 00% PYD.

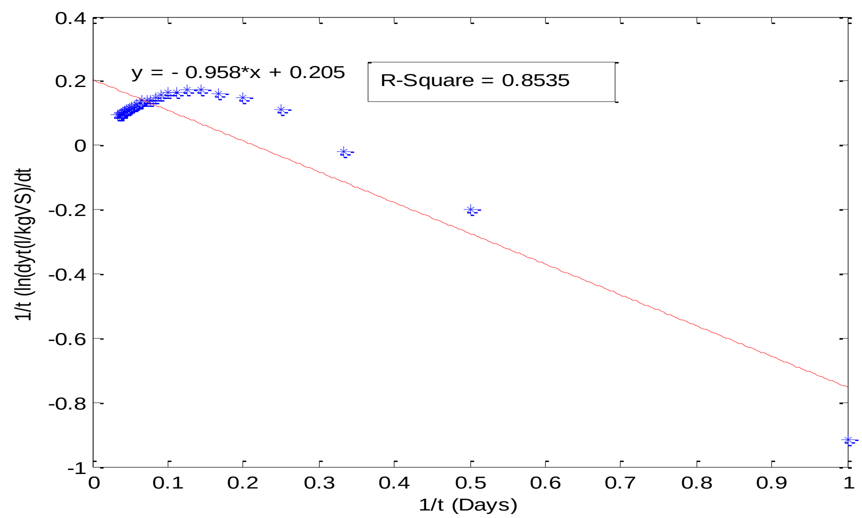

Figure 5. Plot of 1/t (ln(dyt(l/kgVS)/dt against 1/t for 75%CD+25%PYD.

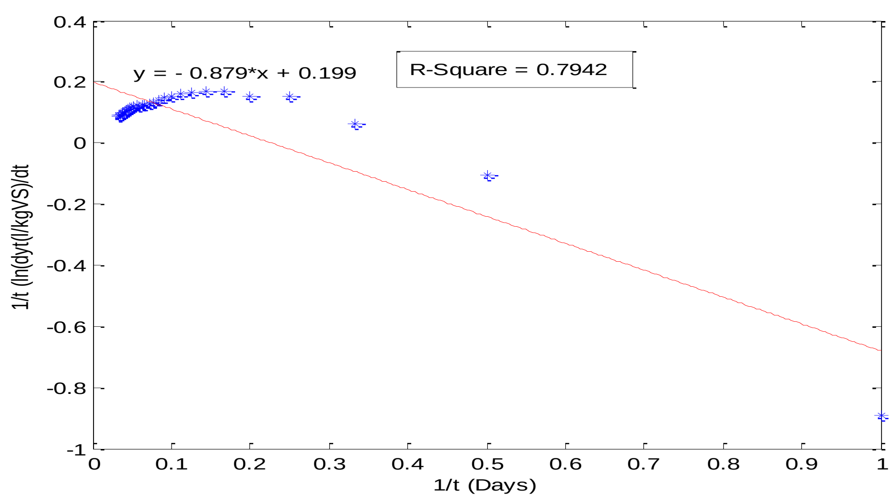

Figure 6. Plot of 1/t (ln(dyt(l/kgVS)/dt against 1/t for 50%CD+50%PYD.

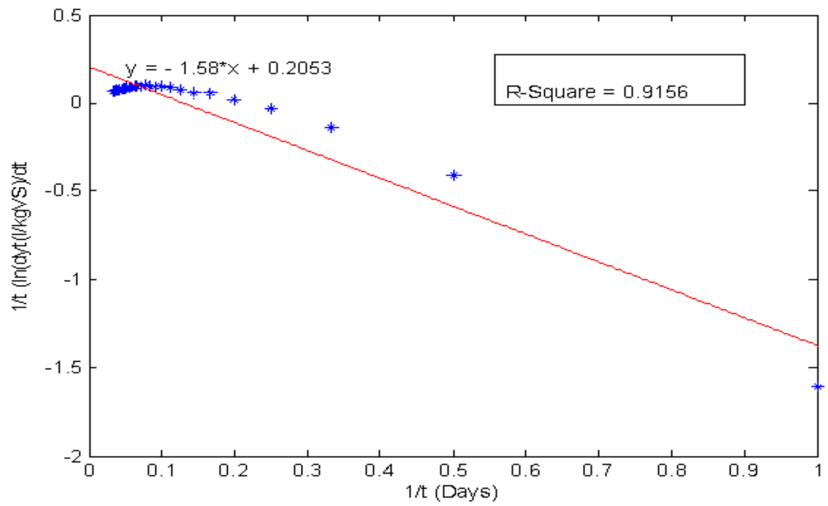

Figure 7. Plot of 1/t (ln(dyt(l/kgVS)/dt against 1/t for 25% CD+75% PYD.

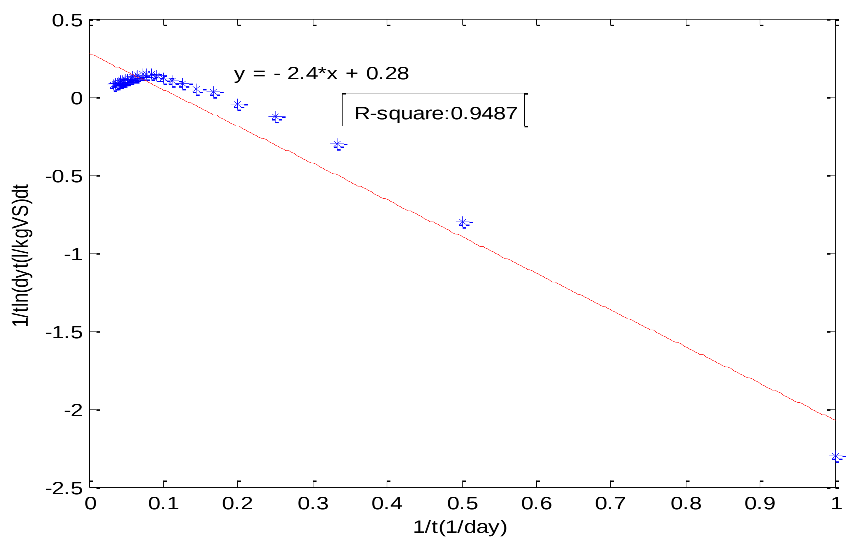

Figure 8. Plot of 1/t (ln(dyt(l/kgVS)/dt against 1/t for 00%CD + 100%PYD.

the digesters. The 25% CD + 75% PYD digester had ambient temperature short term biodegradability index of 1.58 with a removal rate constant of -0.2053 and a goodness of fit (R^2) of 0.9156 as shown in Figure 7.

The 25% CD + 75% PYD digester has more of poultry dropping content compare to cow dung. Thus the removal constant of -0.205 was less than the cow dung removal rate constant of -0.281. This shows the readily removal rate of protein rich substrate in waste compare to carbon rich substrates. The 00% CD + 100% PYD digester had ambient temperature short term biodegradability of -2.4 with a removal rate constant of -0.28 and a goodness of fit (R^2) of 0.9487 as shown in Figure 8. The ambient temperature short term biodegradability index of 2.4 of the 00% CD + 100% PYD digester is the highest. This shows the potential of poultry droppings to degrade faster than all other digesters within the period of experimentation.

Thus, the first order kinetics with the modeled equation successfully assessed the ambient temperature short term biodegradability and removal rates of biodegradable fractions of substrates used in anaerobic digestion in this research work. The linear polynomial was able to fit the experimental data as shown in figures above.

Conclusions

The maximum biogas production potential for the cow dung and poultry dropping mixture is in the order of 25% CD + 75% PYD > 100% CD + 00% PYD > 50% CD + 50% PYD > 00% CD + 100% PYD > 75% CD + 25% PYD. This shows that the optimum mixture ratio is the 25% CD + 75% PYD mixture ratio with 16.35 L/TMS within the period under study. However, a longer digestion detention period may be required because gas production has not ceased for the digesters especially for the 25% CD + 75% PYD digester. The kinetics of anaerobic digestion process of the various digestion mixtures evaluated with modified first order model equation shows that poultry dropping alone has the highest short term biodegradability index of 2.4 while the 50% CD+50% PYD digester has the highest removal rate of the biodegradable fractions (k) of -0.199 among all the substrates, this agrees well with the experimental observation. Successful digestion of these substrates at suboptimum condition is a means of providing environmental friendly waste management system which will go a long way in providing bio-fertilizers, clean environment, renewable energy, and reduction in flies, odor and pathogen transfer in rural communities, abattoirs and farms etc. This will also reduce the demand for wood from forest and the impact of deforestation on developing countries.

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