Effect of ground insulation and feed stock on performance of fixed dome biogas digester

Nwoke Oji Achuka[1*], Okeke Chukwuka Paul[1], Chukwuma Chibundo Emmanuel[2], Ime Chukwuemeka[1], Ulasi Ginika Frances[1], Echiegu Emmanuel Amagu[1], Omah Augustine Dinobi[3]

(1. Department of Agricultural and Bioresources Engineering University of Nigeria Nsukka, Enugu State, 410001, Nigeria;
2. Department of Agricultural and Bioresources Engineering, Nnamdi Azikiwe University Awka, Anambra State, 420007, Nigeria;
3. Department of Metallurgical and Materials Engineering, University of Nigeria Nsukka, Enugu State, 410001, Nigeria)

Abstract: Digester temperature, the type and composition of material fed into the digester are key requirements for every productive biogas plant, thus their optimization is essential for biogas recovery and sustainability. The aim of the study is to determine the effect of ground insulation and feedstock on performance of fixed dome biogas digester. To achieve this 32-liter fixed dome biogas digester was developed, fed with three feedstocks namely cow abdominal waste (CAW), poultry droppings (PD) and 1:1 mixture of cow abdominal waste and poultry droppings (1:1CAW&PD) and buried underground for insulation before anaerobic digestion process at 30 days hydraulic retention time. The ANOVA result showed that there were significant differences in the slurry temperature, volume of biogas produced and slurry pH respectively at 5% significant levels The TS, VS, protein contents, crude fat, BOD5, C, COD, P, K, TVC and Calorific Value of ground insulated digester were higher than that of uninsulated surface digesters for the three different feedstocks at the end of the 30 Days digestion. GC analysis of biogas showed that the percentage compositions of methane produced were 68.39%, 64.33%, 66.41%, 61.79%, 57.74%, and 59.24% for underground with CAW, underground with PD, underground with 1:1CAW&PD, uninsulated with CAW, uninsulated with PD, and uninsulated with 1:1CAW&PD, respectively. The underground insulated biogas digester produced more methane than their counterpart uninsulated digesters containing the same feedstock signifying the importance of temperature regulation through insulation. In terms of the feedstock, the CAW performed better than the PD in both the underground and uninsulated digesters. They mixture of 1:1CAW&PD also showed better performance in methane production than the single anaerobic digestion of poultry dropping alone indicating efficiency and importance of co-digestion of feedstocks. The study has shown that underground insulation of the fixed dome biogas digesters improved biogas production. We therefore recommend its application by the biogas industry because is cost-effective and will help to reduce the effects of economic barriers to investment in biogas systems.

Keywords: fixed dome digester, biogas, ground insulation, feedstock, cow abdominal waste, poultry droppings

Citation: Nwoke, O. A., C. P. Okeke, E. C.Chukwuma, C. Ime, G. F.Ulasi, E. A. Echiegu, and A. D.Omah. 2023. Effect of ground insulation and feed stock on performance of fixed dome biogas digester. Agricultural Engineering International: CIGR Journal, 25(2): 145-171.

1 Introduction

Nigeria's energy scenario, like that of many other emerging countries, is dominated by non-renewable and environmentally harmful fossil fuels (Makamure et al., 2021; Oyedepo, 2012; Onyebuchi, 1989; Akinbami et al., 2001; Okafor and Joe-Uzuegbu, 2010; Famuyide et al., 2011; Ajayi and Ajanaku, 2009; Ohunakin, 2010; Ibitoye and Adenikinju, 2007; Sambo, 2009). This necessitates the efficient generation of renewable energy, including biogas in the country. Biogas technology is especially appealing in rural regions because of its low cost of raw materials, renewable nature, environmental friendliness,

Received date: 2022-06-05 **Accepted date:** 2023-01-06

***Corresponding author: Nwoke Oji Achuka,PhD**., Associate Professor Department of Agricultural and Bioresources Engineering University of Nigeria Nsukka, Enugu State Nigeria. Tel: +2348038299006. Email: nwoke.oji@unn.edu.ng.

and ability to be used for cooking, heating, and lighting (Park et al., 2019).The majority of Nigerians in rural areas produce cattle, sheep, goats, and poultry, all of which can be used as biogas substrate, thanks to their manure and kitchen waste (Mukumba et al., 2019).Many of the basic materials required to manufacture biogas can be found in rural schools, restaurants, hospitals, and other organizations (Sichilalu et al., 2017). Biogas is a combustible combination of gases formed by the anaerobic digestion of organic constituents such as sewage waste, animal waste, green waste, energy crops and food waste (Noraini et al., 2017; Ilaboya et al., 2010). Many parameters affect the generation of biogas in anaerobic digesters, including the carbon to nitrogen ratio(C/N), pH value, biological oxygen demand (BOD), existence of volatile compounds, chemical oxygen demand (COD), temperature, rate of substrate loading, and biodegradability of substrate (Mahanta et al., 2005; Niselow, 2019; Cioabla et al., 2012).

To ensure consistent biogas generation from any anaerobic digester, the well-being of the microorganisms surviving in the environment of the digester must be guaranteed, which includes providing a favored substrate, maintaining a suitable temperature, and maintaining a favorable pH. Digester temperature is one of the key influence parameters for optimal biogas recovery, and thus its optimization and stability are key requirements for every productive biogas plant. Research has shown that temperature fluctuations significantly affect the gas production (Tumusiime et al., 2020). When developing anaerobic digesters, temperature regulation is a critical design criterion (Nielsen et al., 2017). Unfortunately, most residential bio-digesters in Nigeria and many other emerging nations lack systems for heating or other means of maintaining a constant temperature within the digester (Makamure et al., 2021). As a result, biogas generation from such digesters will fluctuate during the day as a result of temperature changes, with biogas production dropping drastically at night and during the winter.

The rate of reaction and proliferation of the microorganisms responsible for gas generation are both influenced by the temperature inside the digester (Teleszewski and Żukowski, 2018). Every 5 ℃ increase in temperature up to 35 ℃ increases biogas yield rate by roughly double (Karimov and Abid, 2012). In the mesophilic temperature range (30^{o}C–40^{o}C), this suggests that the multiplication of methanogenic bacteria rises with temperature (Buan, 2018).Moreover, fluctuation in digester temperature affects the performance of methane forming bacteria (Fu et al., 2015).

Keeping the temperature in a digester constant is important for guaranteeing a regular supply of biogas and generating sufficient gas from the substrates. Maintaining a steady digester temperature helps in optimizing quantity and quality of biogas. As a result, it is necessary to evaluate and analyze various substrate heating methods in order to develop a recommended strategy that improves the homogeneity and uniformity of heat and profile temperature of the digester. The adjustment of digesters temperature can be done using different approaches, including adequate insulation of the digester, substrate heating using heat exchangers or heating elements, heating digesters in water baths or greenhouses, and steam blowing into the digester (Makamure et al., 2021).

Many investigations have been carried out to determine how best to maintain a constant anaerobic bio-digesters substrate temperature (Karimov and Abid, 2012; Sichilalu et al., 2017; Houngue et al., 2017). In all of these circumstances, biogas productivity rose, demonstrating that maintaining a steady temperature in a digester enhances efficiency and stability (Makamure et al., 2021). The temperature of the substrate in a digester is highly influenced by the ambient temperature, to the point where no amount of insulation may totally prevent temperature changes (Pham et al., 2014; Mukumba et al., 2015). If the stability of the digester is disrupted by temperature variations, the digester temperature must be quickly returned to the set point (Chapleur et al., 2016; Kim and Lee, 2016; Mukumba et al., 2017). The most laudable alternative for maintaining continuous temperature of digester and assuring stability of process and biogas yield is to heat the substrate in a controlled manner. To enhance efficiency in biogas production, even household digesters should be designed with some insulation and heating facility regardless of the intended use of the produced gas (Makamure et al., 2021).

Digester insulation and heating are necessary for high methane yield. The slurry can either be preheated or can be heated when already in the digester. Normally the cost of heating is the limiting factor (Moset et al., 2015; Meegoda et al., 2018). But even with introduction of subsidies such as custom duty waivers on imported biogas systems most biogas installations have not sustained gas production (Tumusiime et al., 2019; Nabuuma and Okure, 2006; Kariko-Buhwezi et al., 2011). This has partly been due to poor digester operating conditions such as low digester temperatures and poor quality of digester feed (Kariko-Buhwezi et al., 2011; Mwakaje, 2008). Most biogas digesters operate between 18^{o}C–25^{o}C (Kariko-Buhwezi et al., 2011), which is far below optimum of 30^{o}C–40^{o}C (Kumar et al., 2013; Al Seadi et al., 2008), with uncontrolled fluctuations which are inhibitory to biogas production. The ultimate goal of a productive biogas installation is to produce biogas for economic gain (Wehkamp, 2013), and thus, such a system must maximize energy outputs in order to realize high economic returns. Studies have described biogas production as a very intricate process with methanogesis; the stage responsible for methane generation, being the most affected by temperature fluctuations (Al Seadi et al., 2008; Athanasoulia et al., 2012; Nizami, 2012). According to Al Seadi et al. (2008), large temperature fluctuations lead to system imbalance with consequent low gas yield, and in worst cases to complete process failure. Low gas yield greatly derails expectations of biogas plant owners, and is a precursor to dis-adoption. In order to circumvent this, digester wall insulation is a necessary requirement. A study by Zhang et al. (2016) indicated that application of insulation mortar and glass fiber reinforced plastic (GRP) material on the outside walls of the digester, improved and maintained a stable digester slurry temperature with consequent increase in biogas production and economic benefits. However, GRP has a higher embodied energy and hence costly. Even though digester insulation provides material benefits, it must be undertaken at least cost in order to avoid accelerating the effects of economic barriers to investment in biogas system. Utilization of cost-effective approach for this purpose such as ground insulation, provides tangible benefits in this direction since it does not require extra cost other than cost of digging the trench for the biogas digester installation, thereby offsetting the importation and custom duty expenses on imported insulation materials.

Tumusiime et al. (2020) carried out Performance evaluation of cellulose fiber’s effectiveness as a thermal insulation material for productive biogas systems. The study concluded that CF is thus an effective insulation material for bio-digesters, but must be protected from hazard as might be caused by vermin and moisture penetration. Cellulose fiber insulation (CFI) is pulverized paper fibers, which are sometimes treated with organic additives for protection from fire and mold. Post-consumer newsprint and recycled paper form the main source materials for CFI. While cellulosic fibers have found application in the construction industry to provide wall and attic insulation in residential and commercial buildings, its widespread use is limited due to its inability to withstand high temperatures. Other factors that limit widespread application of CFI include its high hygroscopisity, and fungal growth (Hurtado et al., 2016). Because of these impediments, cellulose and other natural fibers only present a low percentage of total market share (Papadopoulos, 2005). Ground insulation has several advantages summarized as follows: perfect choice for any weather (protection from extreme weather due to thickness and characteristics of the soil), proof against flames of fire ,proof against extreme temperature fluctuation, provides strength to the digester walls, requires less maintenance, high load bearing capacity which discourages explosion of digesters, humidity controller, ambient temperature controller, economically feasible, ability to withstand high temperature and very low thermal conductivity. Hence the aim of the study is to determine the effect of ground insulation and feedstock on performance of fixed dome biogas digester. The specific objectives of this study are to: design and construct a batch biogas digester, determine the effect of ground insulation of the digester and feedstock on biogas yield, digester temperature, pH and other physicochemical properties during the anaerobic digestion.

2 Materials and methods

2.1 Collection and preparation of feedstock

Three feedstocks namely cow abdominal waste (CAW), poultry droppings (PD) and 1:1 mixture of cow abdominal waste and poultry droppings (1:1CAD&PD) were used for the anaerobic digestion. The cow abdominal waste (CAW) was obtained from abattoir in Ikpa Market Nsukka (latitude: 6^{o}51’33.41” and longitude: 7^{o}23’52.51”), Enugu state Nigeria while the poultry droppings(PD) was collected in bags from the National Centre for Energy Research and Development, University of Nigeria Nsukka (latitude: 6^{o}51’33.41” and longitude: 7^{o}23’52.51”). The feedstocks were mixed with water in the ratio of 1:2 (feedstock: water). The batch approach was used in the operational mode, with a working mesophilic temperature. These slurries were biomethanated in a fixed dome biogas digester for energy generation and cumulative biogas output; slurry temperatures were monitored throughout the period. To generate an anaerobic environment, the digester was tightly corked with a rubber stopper and linked to a gasometrical chamber.

2.2 Experimental set up

Household digesters design depends on climate conditions, available organic wastes, local materials and skills (Garf í et al., 2016). The fixed dome digester developed in China is one of the most common models implemented in rural areas of developing countries (Figure 1) (Rajendran et al., 2012; Shian et al., 1979). It consists of a cylindrical chamber, a feedstock inlet and an outlet, which also serves as a compensation tank (Nzila et al., 2012; Sasse et al., 1991). It is built completely underground of bricks and concrete. The system lacks proper mixing to avoid material sedimentation inside the digester and operates without heating. Biogas is accumulated in the upper part of the chamber. The level difference between the slurry inside the digester and the expansion chamber creates gas pressure. As biogas pressure builds-up, it pushes part of the substrate into the compensation tank (Rajendran et al., 2012; Nzila et al., 2012; Nazir, 1991). A pipeline transports biogas from the digester to a reservoir, where it is stored and then used for cooking, heating or lighting (Garf íet al., 2016).

Six identical fixed dome biogas digesters were designed and constructed for the study. The anaerobic experiment was in the premises of the National Centre for Energy Research and Development, University of Nigeria Nsukka. Three of the developed fixed dome biogas digesters were recharged with each of the three feedstocks respectively and were buried in the ground to insulate the digester while the remaining three digesters were also fed with the three feedstocks respectively and kept on the surface without insulation (Figure 1). The six digesters each with a volume of 32 liters were allowed to run concurrently under the same ambient temperature for a period of 30 days. To ascertain the performance of the digesters, physicochemical properties of the biogas production process were determined using standard procedures (APHA, 1995).

Each experimental digester received 8 kg of manure mixed with 16 liters tap water from the inlet, resulting in a slurry weight of 24 kg. Each of the feedstock was mixed with water in the ratio of 1:2 (Feedstock: water). The total volume of the digester is 32 liters. The digester was filled with the mixed feedstock (Slurry chamber) up to 75% volume (24 liters) with the remaining 25% volume (8 liters) left for biogas produced (gas Chamber). The ratio of 1:2 (Feedstock: water) is equivalent to 25%:50%

(Feedstock: Water). Given that 1 liter is equivalent to 1kg therefore 8 kg of each feedstock was mixed with 16 liters of water and the mixture was poured in the digesters for anaerobic digestion. Dung and water were mixed by hand in a water bath. FARMESA's technique was used to establish the loading rate (FARMESA, 1996). The inlets were tightly closed, and the entire digester assemblies were hauled and installed in 60cm depth trenches dug in an open space at the National Center for Energy Research and Development, University of Nigeria Nsukka, and natural conditions (NC) to accommodate them. Design criteria for the digester, trench and greenhouse depend on each location (Garf í et al., 2016). Facility for digester stirring was not provided because agitation has negligible effect on small scale digesters during anaerobic digestion (Barnet et al., 1978). After a specified hydraulic retention time, sludge was emptied through the input opening.

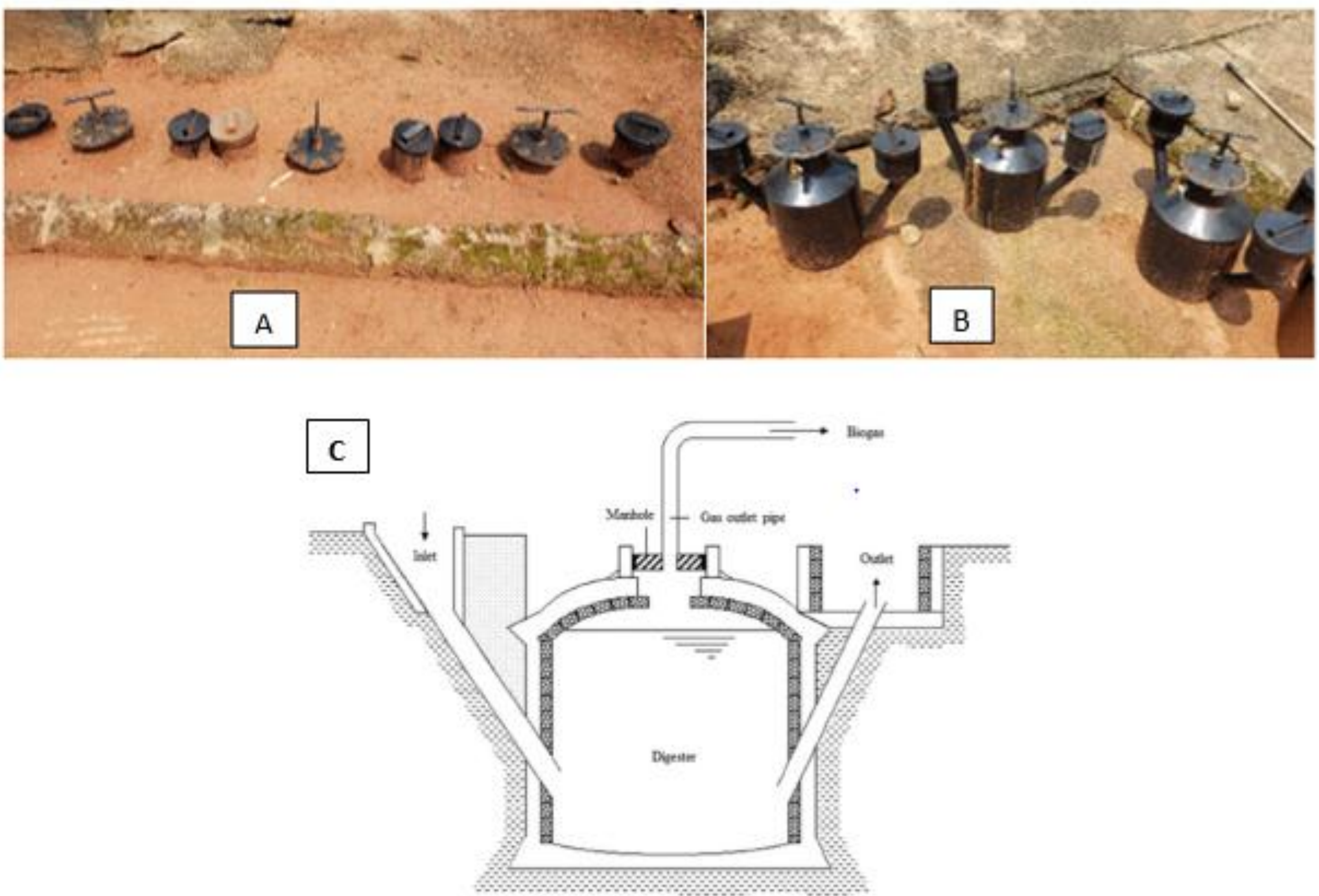


Figure 1 Experimental set up of fixed dome biogas digesters (A)buried underground (B) kept on the surface uninsulated (C) Schematic diagram of fixed dome digester – Chinese model (Gunnerson and Stuckey, 1986; Surendra et al., 2014; Garf íet al., 2016)

2.3 Laboratory analysis of samples

Three digesters were charged and buried under ground for insulation while the remaining three were charged and kept on the surface uninsulated. The experiment lasted for 30 days. The laboratory analysis was based on standard procedures (APHA, 1995). The feedstock was mixed and fed into the digester for biogas production, the produced biogas was collected at the gas outlet. The hydraulic retention time (HRT) for this study was 30 days. The average time spent by the biomass inside a biogas digester before it comes out from the digester is known as the hydraulic retention time (HRT). The process of degradation of biomass requires at least 10-30 days in mesophilic condition while in thermophilic environment the HRT is usually less than ten days (Demetriades, 2008). At high altitude (i.e. psychrophilic conditions) long HRT of 60–90 days are needed (Ferrer et al., 2011) whereas in tropical regions (i.e. mesophilic conditions) lower HRT (20–60 days) are used (Garf íet al., 2016). The experimental digesters were turned off at this time, and their contents were emptied. The daily gas yields were calculated using the jar displacement method, and the temperature was recorded using a Delta-T logger Device. A hand-held pH meter was used to determine the pH.

Volatile solids (VS),Total solids (TS), proximate analysis (Protein content, Ash content, Moisture content, Crude Fiber, and crude Fat), total nitrogen (N), carbon content (C), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Phosphorous (P), Potassium (K), Total Viable Count (TVC), and Calorific Value were determined in the laboratory from samples of influent and effluent slurry. The sample was heated to 105 ℃ and 550 ℃ in order to determine the TS and VS. Total nitrogen was determined using the standard micro kjeldahl method provided by APHA (1995), whereas total carbon was determined using the Walkley-Black method described by Walkley (1947).

The daily gas yields were calculated using the jar displacement method, and the temperature was calculated using the Delta-T logger device. Standard GC methods outlined in APHA were used for the gas analysis (APHA, 1995). According to APHA (1995), the following were used to calculate the observed parameters:

(1) Total/volatile solids

$$Total\ Solid(\%) = \frac{x_{dm} \times 100}{g} \quad (1)$$

$$Volatile\ Solids(\%) = \frac{x_{dm} - y}{g} \times \frac{100}{1} \quad (2)$$

Where g = weight of sample(gram), x_{dm} =weight of dry matter(gram)

y = weight of residue(gram)

(2) Nitrogen/ protein

$$N(\%) = \frac{T \times M \times 0.014 \times DF \times 100}{g} \quad (3)$$

$$Protein(\%) = N(\%) \times 6.25 \quad (4)$$

Where M =molarity(mol L^{-1}), DF = Dilution factor(-)

g =weight of sample(gram), T =Titre value(mL)

(3) Ash content

$$Ash(\%) = \frac{x_{ash}}{g} \times \frac{100}{1} \quad (5)$$

Where (g) = weight of sample(gram), x_{ash} = weight of ash(gram)

(4) Moisture content

$$Moisture\ Content(\%) = \frac{g - x_{dm}}{g} \times \frac{100}{1} \quad (6)$$

Where g= Weight of sample(gram), x_{dm}=weight of dry matter, $(g - x_{dm})$ =loss in weight (gram)

(5) Crude fibre

$$Fibre(\%) = \frac{x_{dm} - y}{g} \times \frac{100}{1} \quad (7)$$

Where (g) = Weight of sample(gram), x_{dm}=Weight of dry matter(gram), (y) =Weight of residue(gram)

(6) Crude fat

$$Fat(\%) = \frac{x_{fat}}{g} \times \frac{100}{1} \quad (8)$$

g =weight of sample(gram), x_{fat}=weight of fat(gram)

(7) Carbon content

$$Carbon(\%) = \frac{(B-T) \times M \times 0.003 \times 1.33 \times 100}{g} \quad (9)$$

Where g = Weight of sample(gram), B = blank titre(mL), T = Sample titre(ml), M =molarity(mol L^{-1})

2.4 Statistical analysis

The effect of the treatment on the response of the biogas production parameters was determined using one way analysis of variance(ANOVA). Duncan Several Range Test at 5% Probability was used to compare multiple means. SPSS Version 21.0 was used for statistical analysis and graphical plots.

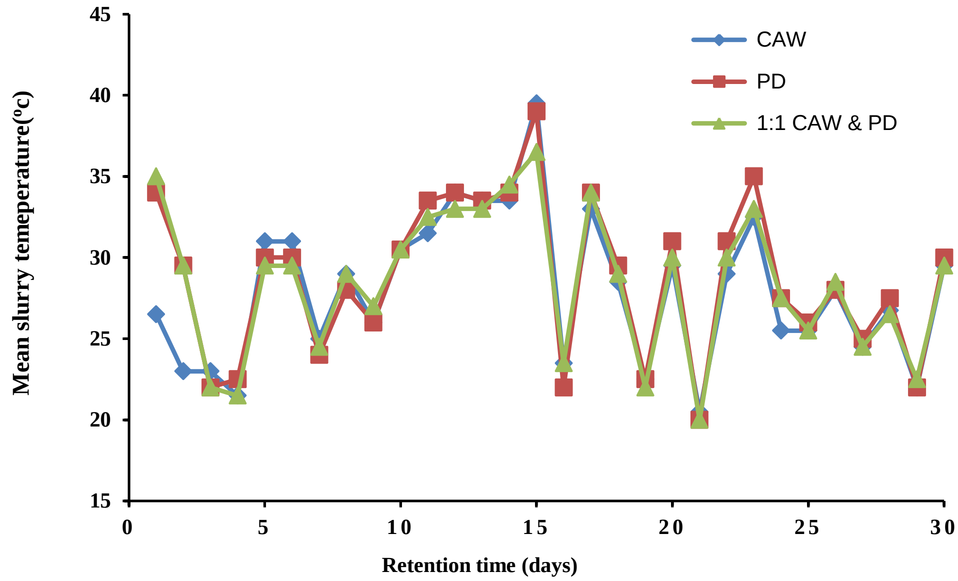
3 Results and discussion

3.1 Variation of slurry temperature, pH and volume of biogas produced in different feedstocks

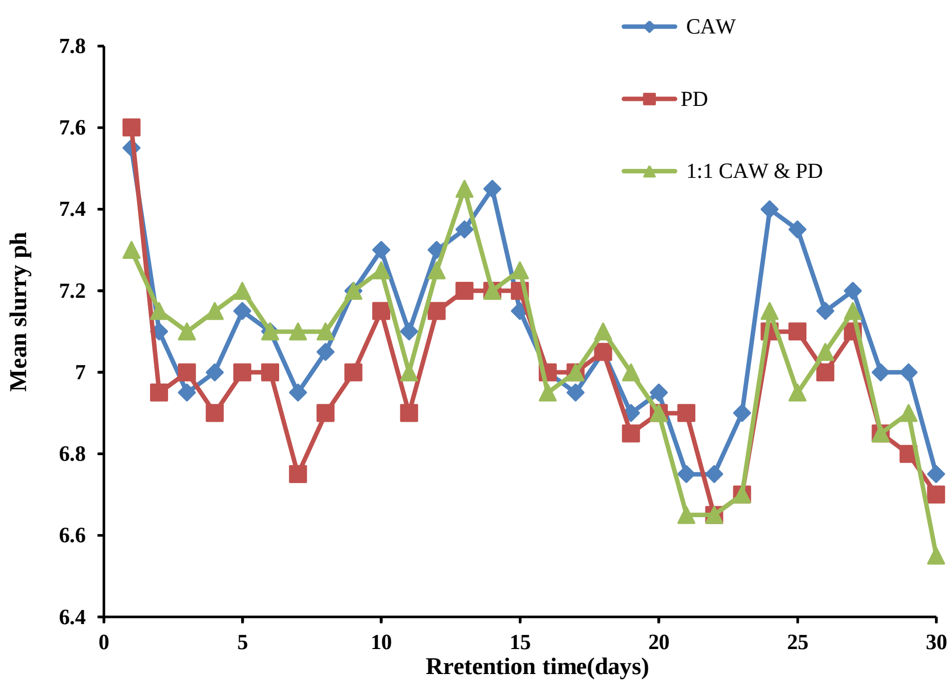
The variation of slurry temperature, pH and volume of biogas produced in different feedstocks during the 30 days anaerobic digestion is presented in Figure 2.

3.2 Graphical comparison of the effects of ground insulation of digester and feedstock on slurry temperature, pH and volume of biogas

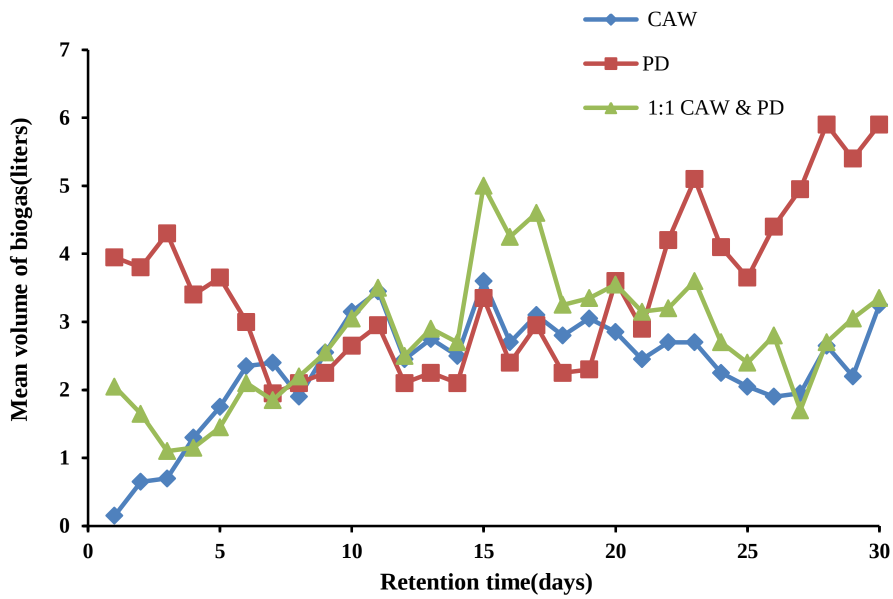
The comparison of the effects of ground insulation of digester and feedstock on slurry temperature, pH and volume of biogas produced are presented in Figure 3. The variation in the digester slurry temperature of the fixed dome biogas digester as affected by the mean ambient temperature during the 30 days of anaerobic digestion with the six digesters running concurrently is shown in Figure 3A. The six digesters slurry temperatures followed the same pattern as that of ambient temperature showing consistent rise and fall in the slurry temperature with consistent variation in the mean ambient temperature. The fall in the mean ambient temperature from 27 ℃ -21 ℃ from day 1 to day 4 resulted in lowering of the digesters temperatures from 27 ℃ -21 ℃, 32 ℃ -22 ℃, 37 ℃ -21 ℃, 26 ℃ -22 ℃, 36 ℃ -23 ℃ and 33 ℃ -22 ℃ for digesters 1, 2, 3, 4, 5 and 6 respectively.



(a)Slurry Temperature



(b) pH

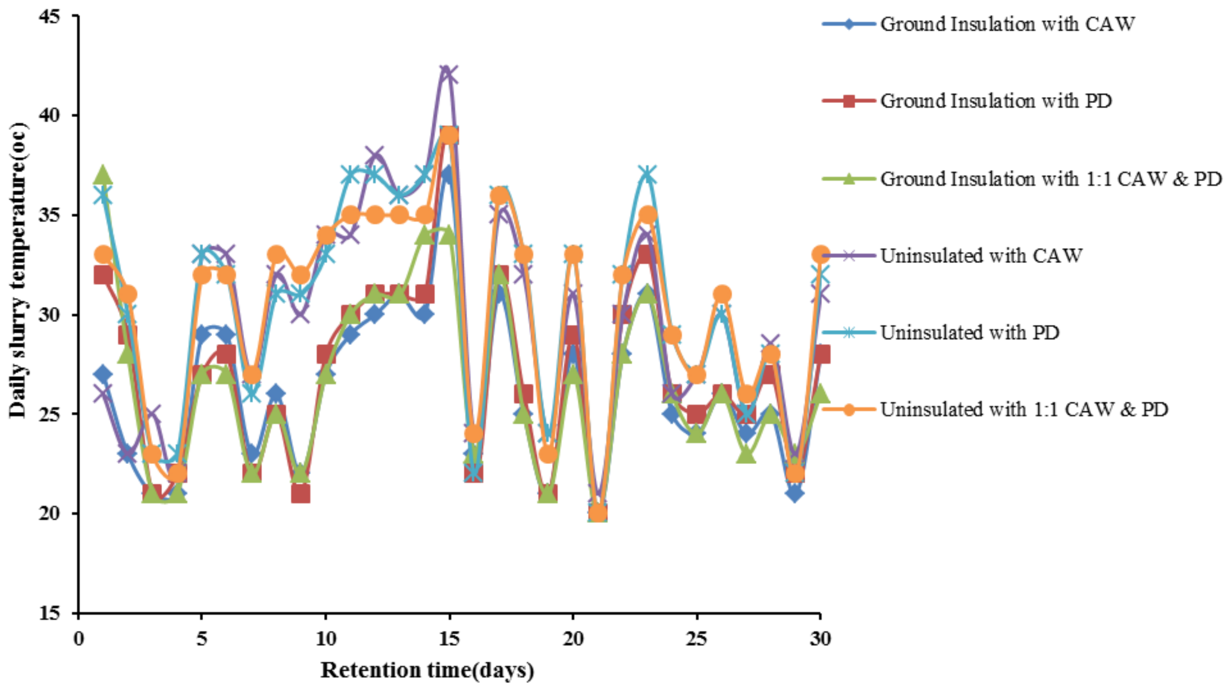


(c) volume of biogas

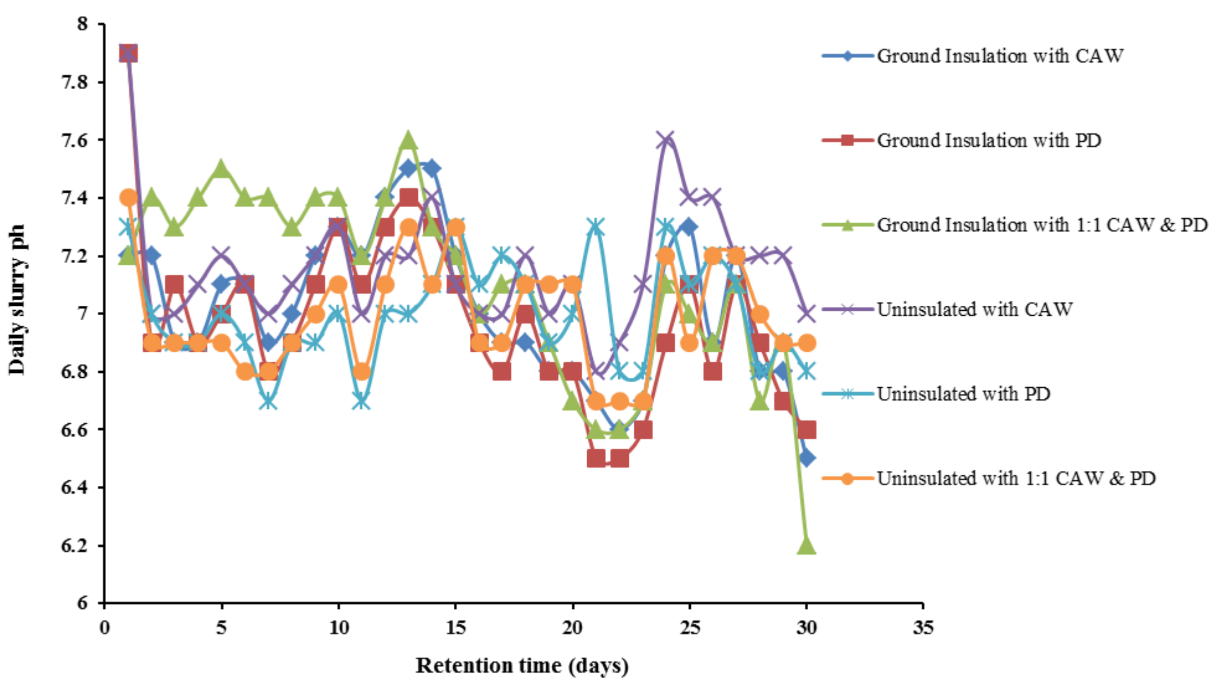
Figure 2 Variation of Slurry Temperature, pH and Volume of Biogas produced in different feedstocks

The rise in the mean ambient temperature from 26℃-31℃ between day 5 and day 15 resulted in increasing of the digesters slurry temperatures from 29℃-37℃, 27℃-39℃, 27℃-34℃, 33℃-42℃, 33℃-39℃ and 32℃-39℃ for digesters 1, 2, 3, 4, 5 and 6 respectively. Moreover, it was demonstrated that anaerobic digestion was sensitive to daily temperature fluctuation (from 26℃ to 31℃). However, the process responded immediately to temperature increase, suggesting that methanogenic bacteria activity was well preserved during the period at low temperature (Surendra et al., 2014). This is relevant, since temperature cycles (i.e. day–night) may occur in unheated biogas production systems (Garfí et al., 2016). The slurry temperatures in this study compares well with the value of 29℃-33℃ obtained by Mukumba et al. (2015) during an assessment of the performance of a biogas digester when insulated with sawdust. According to Mukumba et al. (2015), the temperature range 29℃-33℃ is the magnitude of temperature for optimum biogas production without any external heating required and this fell in the mesophilic range. The results showed that the digesters slurry temperatures reached the peak of 39℃-42℃ on day 15 of the anaerobic digestion and thereafter fluctuated between 23℃-28℃, 22℃-28℃, 23℃-26℃, 24℃-31℃, 22℃-32℃ and 24℃-33℃ for digesters 1, 2, 3, 4, 5 and 6 respectively from day 16 to 30. The ambient temperature also fluctuated between 20℃-26℃ from day 16 to 30.

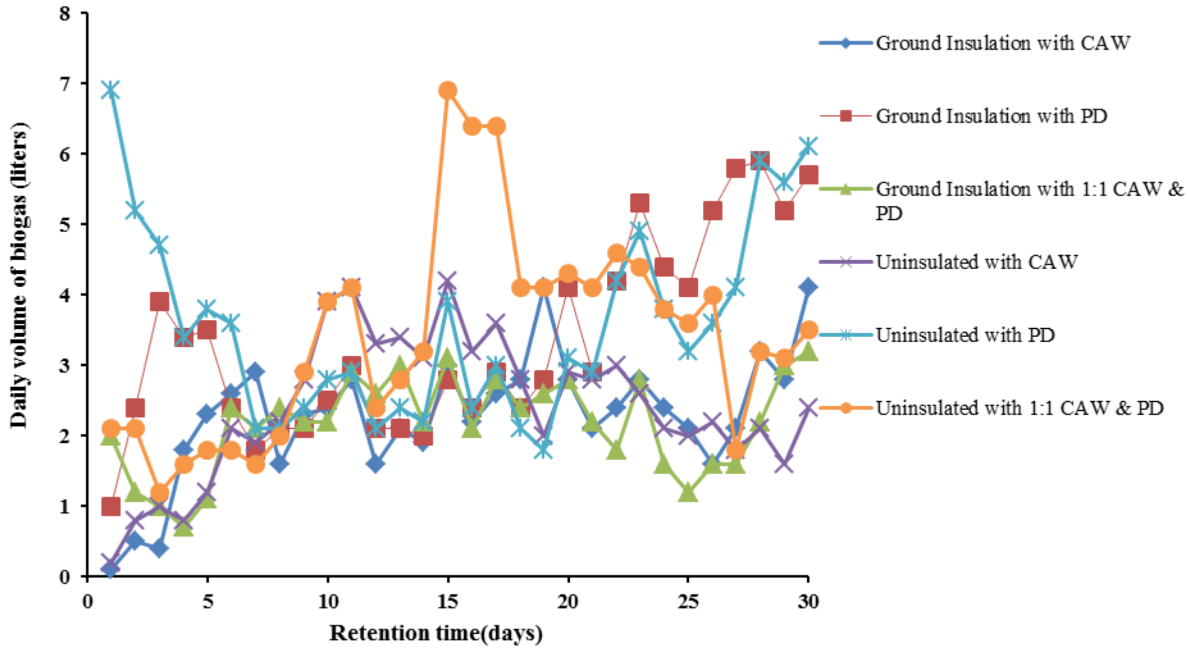
A similar observation of rise and fall in slurry temperature resulting from fluctuation in ambient temperature was reported by Kalia and Kanwar (1998) for a 3 m^3 fixed dome Janata biogas plant installed in the hilly conditions of Himachal Pradesh and also by Mukumba et al. (2015) during an assessment of the performance of a biogas digester when insulated with sawdust. The result showed that the fluctuation of all the digesters slurry temperature between day 1-4 and between day 16 and 30 where greater than 5˚C. According to Zhang et al. (2011) the fluctuations of digestion temperature ought not to surpass 2℃~3˚C per period. If the fluctuations of digestion temperature surpass 5˚C during a short time, biogas production (BP) could lower considerably, therefore a constant digestion temperature is needed (Zhang et al., 2011). The results also indicates that the digester slurry temperatures operated within the range of optimum temperature (35℃-37℃) required for maximum gas production by animal waste from day 5 to 15 according to Sakar et al. (2009). The anaerobic digestion (AD) in this study took place under the temperature ranges: psychrophilic (10 ℃– 27 ℃), low-mesophilic (30 ℃± 3 ℃), and mesophilic digestion (35 ℃± 3 ℃) (Deublein and Steinhauser, 2011; El-Mashad et al., 2004). None of the six digesters operated at thermophilic temperature range (55 ℃± 3 ℃) (Deublein and Steinhauser, 2011; El-Mashad et al., 2004). The results indicates that all the six digesters operated above the prevailing ambient temperature during the anaerobic digestion process.



(a) Slurry Temperature



(B) slurry pH



(C) volume of biogas produced

Figure 3 Comparison of the effects of ground insulation of digester and feedstock on measured parameters during the 30 days anaerobic digestion

The lowering of the digester temperature between day 1 and day 4 from 37℃ -21℃, 36℃ -23℃ and 33℃ -22℃ for digesters 3, 4, 5 and 6 respectively(Figure 3A), resulted in lowering of the gas produced during this period from 2 - 0.7 liters, 6.9-3.4 liters, and 2.1-1.6 liters for digesters 3, 5 and 6 respectively (Figure 3C). The lowering of temperature of digesters 1, 2 and 4 from 27℃ -21℃, 32℃ -22℃, 26℃ -22℃ respectively did not result to decrease in volume of biogas produced between day 1 and 4. A similar observation was reported by Mukumba et al. (2015) and this was attributed to temperature fluctuations that made some of the methanogenic bacteria to stop producing biogas. This inhibition that occurred in digesters 3, 5 and 6 resulted in a loss of activity of the methanogenic bacteria and hence low biogas yield. Literature had confirmed that a 10℃ temperature increase or decrease in the digester can stop methane forming bacterial activities (Gerardi, 2003).

3.3 Statistical analysis results

3.3.1 The ANOVA results of the effect of ground insulation and feedstock on fixed dome biogas digester performance

The ANOVA table of the effect of ground insulation and feedstock on fixed dome biogas digester performance at 5% significant level is also presented in Table 1. Table 1 showed that ground insulation of digester and feedstock have significant effect on the performance of the fixed dome biogas digesters. Table 1 indicates that there are significant differences in the slurry temperature, volume of biogas produced and slurry pH respectively at 5% significant levels.

3.3.2 Multiple comparison of the mean of measured digester parameters using Duncan multiple range test (DMRT)

The multiple comparison of the mean of measured digester parameters using Duncan Multiple Range Test at 5% significant level is presented in Table 2.

3.3.3 The mean plots of volume of biogas produced, slurry temperature and pH for the six different digesters

The mean plots of volume of biogas produced, slurry temperature and pH for the six different digesters studied are presented in Figure 4. The descriptive statistics of the performance of the ground insulated and uninsulated fixed dome biogas digesters with different feedstocks showed that the range of values for pH, volume of biogas and slurry temperature were 6.973-7.163, 2.167-3.573

litres and 26.167^{o}C -30.467^{o}C, respectively. The pH values obtained in this study are within the range of 6.6-7.6 suggested by Rittmann and McCarty (2001) and Tchobanoglus et al. (2003) as optimum pH for Biogas production for rural developing world applications in biogas digester systems. An optimum pH value for anaerobic digestion lies between 6.4 and 7.2 (Chugh et al., 1999). The mean slurry temperature also falls within the mesophilic range of 0^{o}C -30^{o}C suggested by Rittmann and McCarty (2001). Above 40 ℃, enzyme denaturation is a concern (Rittmann and McCarty, 2001). The highest volume of biogas and slurry temperature were produced by digester 5 (Figure 4A and Figure 4B), indicating that the highest volume of biogas and slurry temperature were produced by uninsulated fixed dome biogas digester with poultry droppings feedstock. The highest slurry pH was produced by digester 4 (Figure 4C), indicating that the highest pH evolution was from uninsulated fixed dome biogas digester with cow abdominal waste feedstock. The results generally indicate that the uninsulated fixed dome biogas digester performed better than the ground insulated fixed dome biogas digester with respect to the volume of gas produced, pH and Temperature evolution.

Table 1 ANOVA of the effect of ground insulation and feedstock on fixed dome biogas digester performance at 5% significant Level

		Sum of Squares	**df**	Mean Square	F	Sig.
pH	Between Groups	.829	5	.166	2.672	.024*
	Within Groups	10.789	174	.062		
	Total	11.618	179			
Volume	Between Groups	61.674	5	12.335	9.126	.000*
	Within Groups	235.176	174	1.352		
	Total	296.850	179			
ST	Between Groups	609.707	5	121.941	5.349	.000*
	Within Groups	3966.475	174	22.796		
	Total	4576.182	179			

Note: *=Statistically significant at 5% probability (α=0.05)

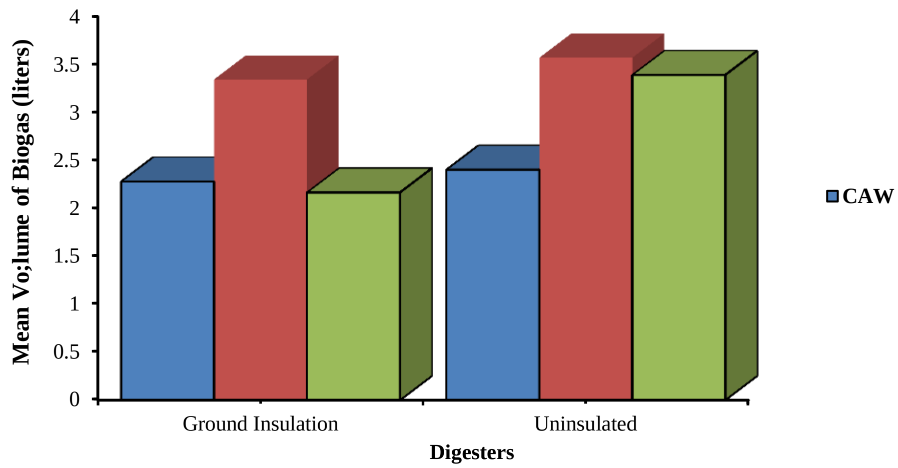
Table 2 Multiple comparison of the mean of measured digester parameters using Duncan multiple range test at 5% significant level

S/No.	Insulation	Feedstock	pH	Volume of Biogas (Litres)	Slurry Temperature (^{O}C)
1	Ground Insulation	Cow Abdominal waste	7.023a	2.280a	26.167a
2	Ground Insulation	Poultry Droppings	6.973a	3.347b	26.967a
3	Ground Insulation	1:1 Mixture of Cow Abdominal Waste and Poultry Droppings	7.100ab	2.167a	26.567a
4	Uninsulated	Cow abdominal Waste	7.163b	2.403a	29.783b
5	Uninsulated	Poultry Droppings	7.000a	3.573b	30.467b
6	Uninsulated	1:1 Mixture of Cow Abdominal Waste and Poultry Droppings	6.990a	3.393b	30.333b

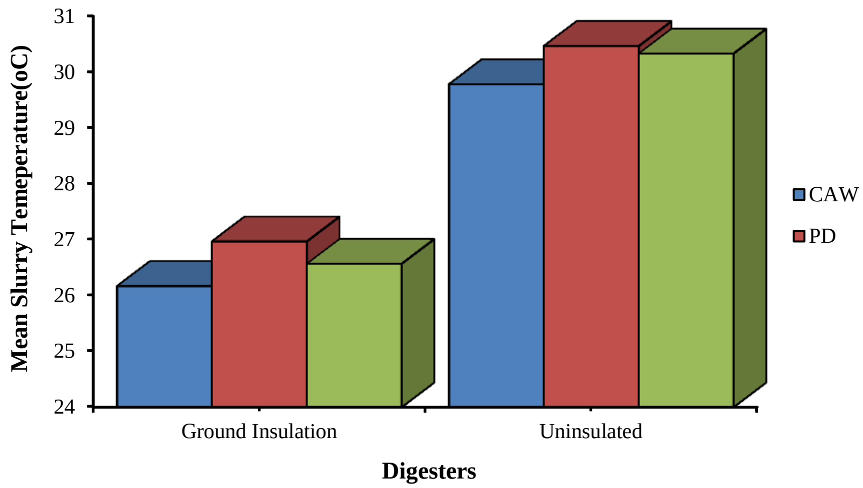
Note: Mean values followed by the same lower-case letters are significantly the same at 5% probability level.

3.3.4 The ANOVA of the effect of feedstock on fixed dome biogas digester performance at 5% significant level

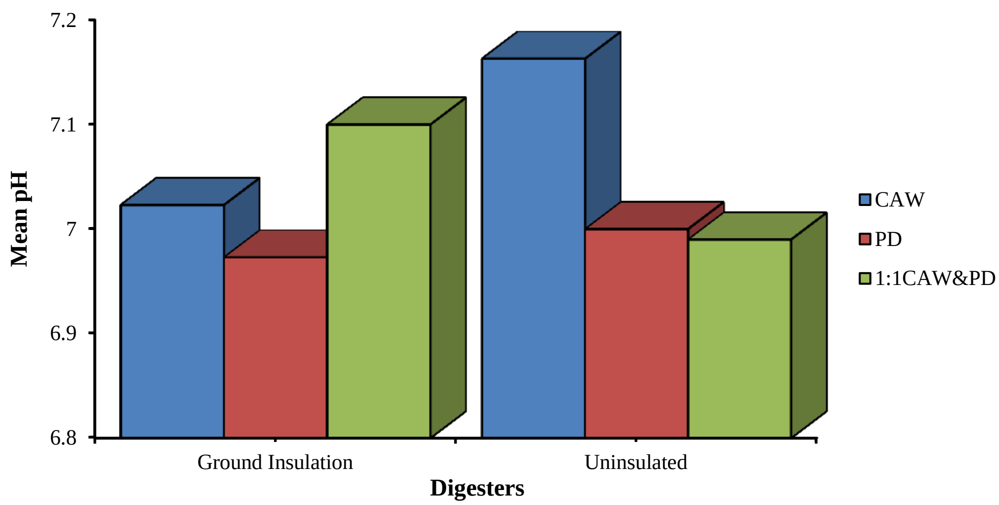
The ANOVA of the effect of feedstock on fixed dome biogas digester performance at 5% significant level is presented in Table 3. Table 3 indicates that feedstock has significant effect on volume of biogas produced by the fixed dome biogas digester (α=0.05) but has no effect on both pH and slurry temperature at 5% significant levels. Garf í et al. (2016) also reported that feedstock composition had a strong influence on the specific biogas production in a research carried out in Latin America using different animal manure.



(A)Volume of Bioga



(B) Slurry Temperature



(C) pH

Figure4 Mean plots of parameters for the six different digesters studied (A) volume of biogas produced (B) slurry temperature evolution (C) pH evolution

Table 3 ANOVA Table of the effect of feedstock on fixed dome biogas digester performance at 5% significant level

		Sum of Squares	df	Mean Square	F	Sig.
pH	Between Groups	.342	2	.171	2.687	.071^{NS}
	Within Groups	11.275	177	.064		
	Total	11.618	179			
Volume	Between Groups	38.104	2	19.052	13.033	.000*
	Within Groups	258.746	177	1.462		
	Total	296.850	179			
ST	Between Groups	16.936	2	8.468	.329	.720^{NS}
	Within Groups	4559.246	177	25.758		
	Total	4576.182	179			

Note: *= Statistically significant at 5% probability (α=0.05); ^{NS}= Not Significant at 5% probability (α=0.05)

Table 4 Multiple comparison of the mean response of parameters due to treatment of the digesters with different feedstocks using Duncan multiple range test at 5% significant level

S/No.	Feedstock	pH	Volume of Biogas (Litres)	Slurry Temperature (^{O}C)
1	Cow Abdominal waste	7.093b	2.342a	27.975a
2	Poultry Droppings	6.987a	3.460c	28.717a
3	1:1 Mixture of Cow Abdominal Waste and Poultry Droppings	7.045ab	2.780b	28.450a

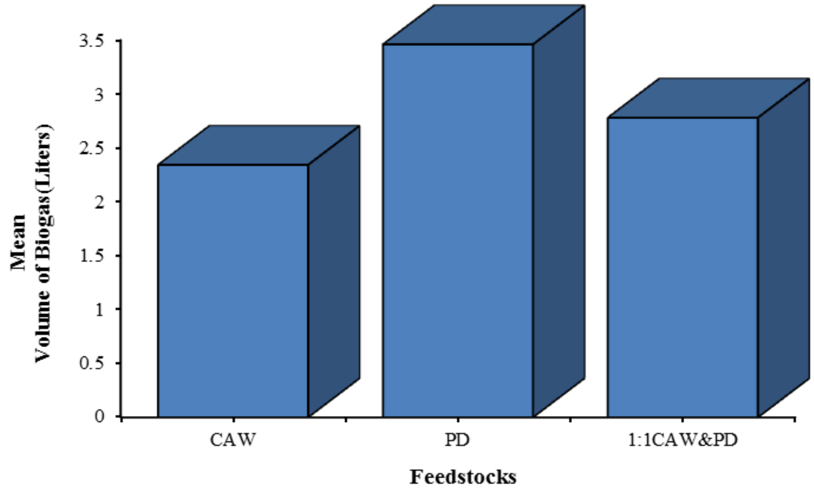
Note: Mean values followed by the same lower case letters are significantly the same at 5% probability level

3.3.5 Multiple comparison of the mean response of parameters due to treatment of the digesters with different feedstocks using Duncan multiple range test (DMRT)

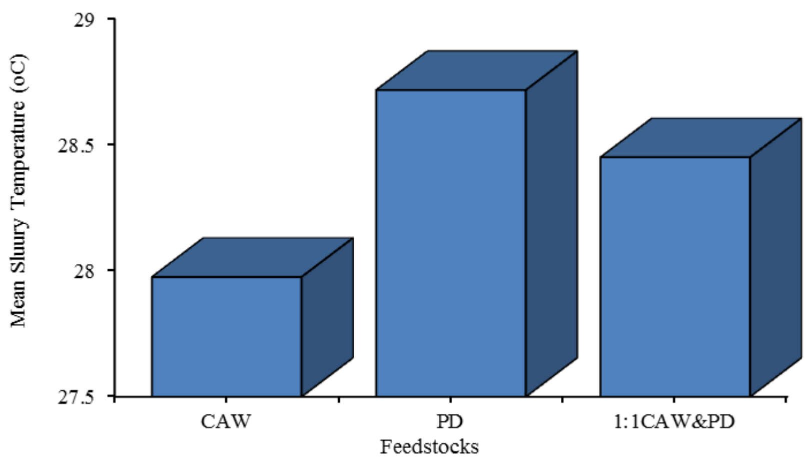
Table 4 showed the multiple comparison of the mean response of parameters due to treatment of the digesters with different feedstocks using Duncan Multiple Range Test at 5% significant level. Table 4 indicates that the volume of gas produced by poultry dropping (3.460 liters) as a single substrate was the highest followed by 1:1 mixture of cow abdominal waste and poultry droppings (2.780 liters) then followed by cow abdominal waste (2.342 liters). A similar observation was reported by Garfí et al. (2016). According to the review by Garfí et al. (2016) on Household anaerobic digesters for biogas production in Latin America, the highest specific biogas production was obtained from cow and sheep manure (0.01 and 0.23 $m^3{}_{biogas}$ kg VS^{-1}), while the lowest was observed from llama manure (0.01–0.18 $m^3{}_{biogas}$ kg VS^{-1}) (Alvarez et al., 2006; Alvarez and Lidén, 2008; Alvarez and Lidén, 2009). This was attributed to higher ammonium content in llama manure with respect to the others (Alvarez et al., 2006). An improved anaerobic digestion performance was observed as a result of codigesting cow, llama and sheep manure, due to the fact that the relatively high nitrogen content of llama manure reduces cow nitrogen deficiency, balancing the C/N ratio (Alvarez and Lidén, 2009). Therefore, the higher biogas volume produced by poultry droppings in this study may be as a result of higher ammonium content which was used to improve cow abdominal waste ammonium deficiency in the 1:1 mixture of cow abdominal waste and poultry droppings.

3.3.6 The mean plots of volume of biogas produced, slurry temperature and ph for the three feedstocks studied

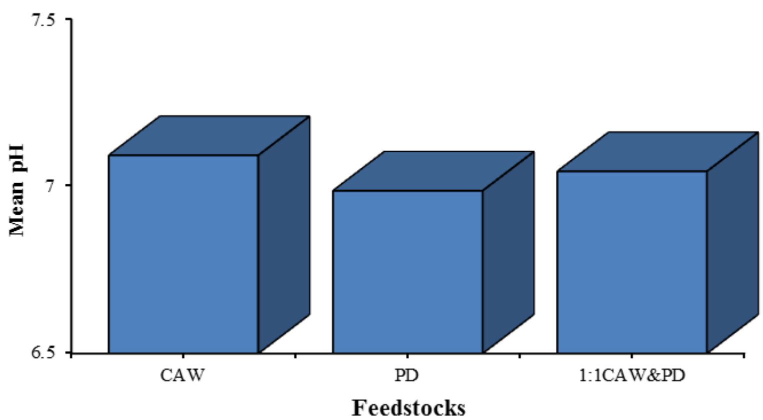
The mean plots of volume of biogas produced, slurry temperature and pH for the three feedstocks studied are presented in Figure 5. The descriptive statistics of the performance of the fixed dome biogas digester due to the different feedstocks showed that the range of pH, volume of biogas and slurry temperature (ST) in all the feedstocks (cow abdominal waste, poultry droppings and 1:1 mixture of Cow abdominal waste and poultry droppings) were 6.987-7.045, 2.342-3.460 liters and 27.975^{o}C -28.717^{o}C, respectively. The highest volume of biogas and slurry temperature were produced by feedstock 2 (Figure 5A and Figure 5B), indicating that the highest volume of biogas and slurry temperature were produced by poultry droppings feedstock. The highest slurry pH was produced by feedstock 1(Figure 5C), indicating that the highest pH evolution was from cow abdominal waste feedstock. The results generally indicated that the poultry droppings feedstock performed better followed by the cow abdominal waste feedstock in the biogas production Process.



(A)Volume of Biogas

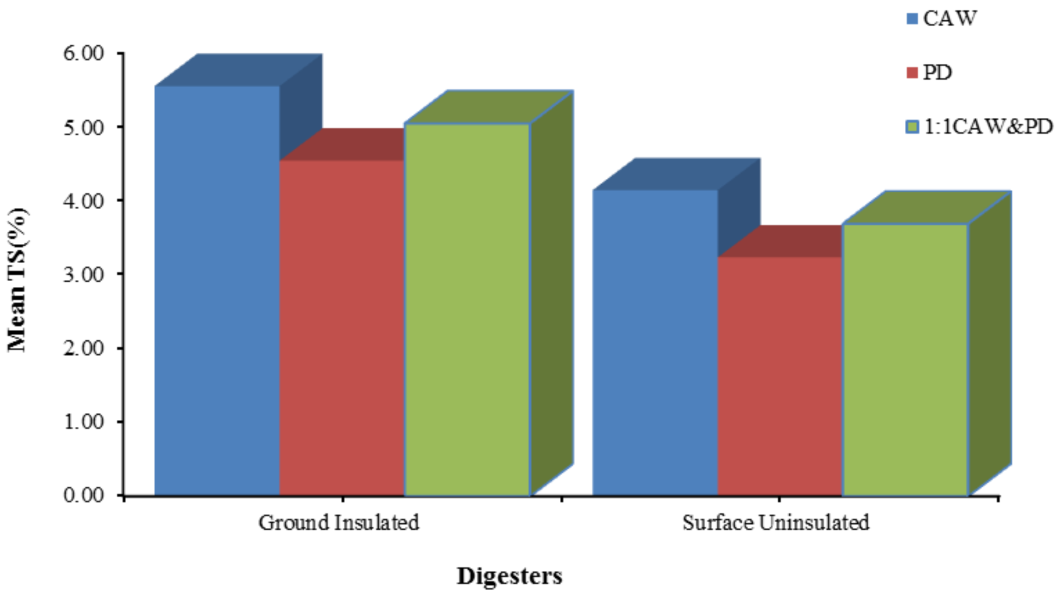


(B)Mean Slurry Temperature

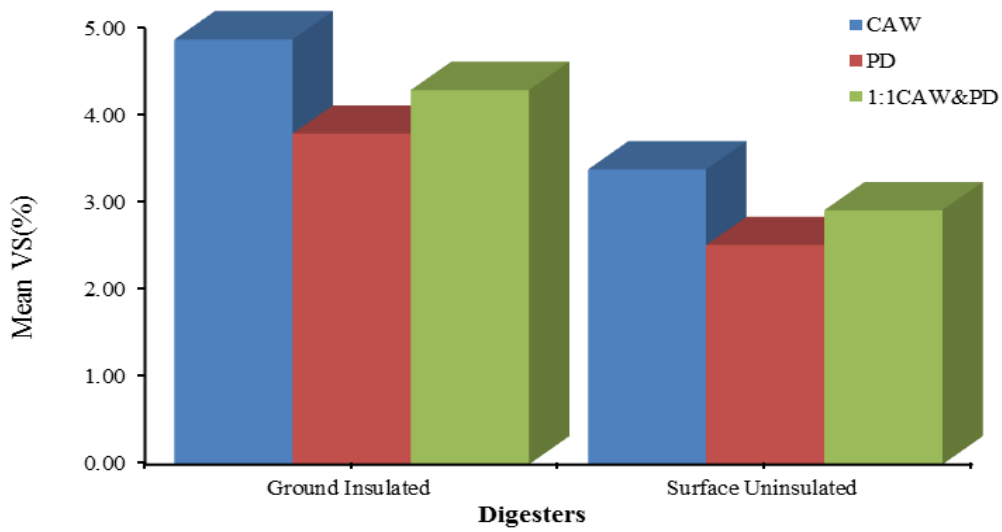


(C) pH evolution

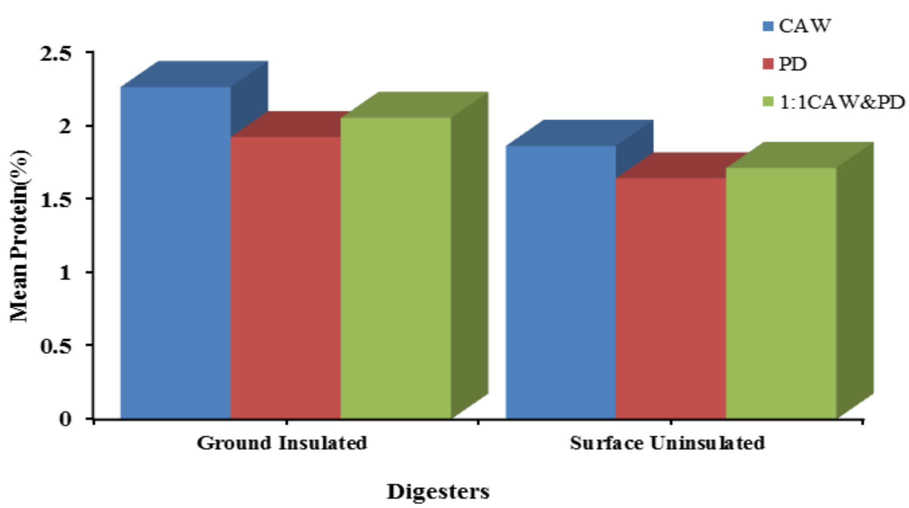
Figure 5 Mean plots of parameters for the three different Feedstock studied



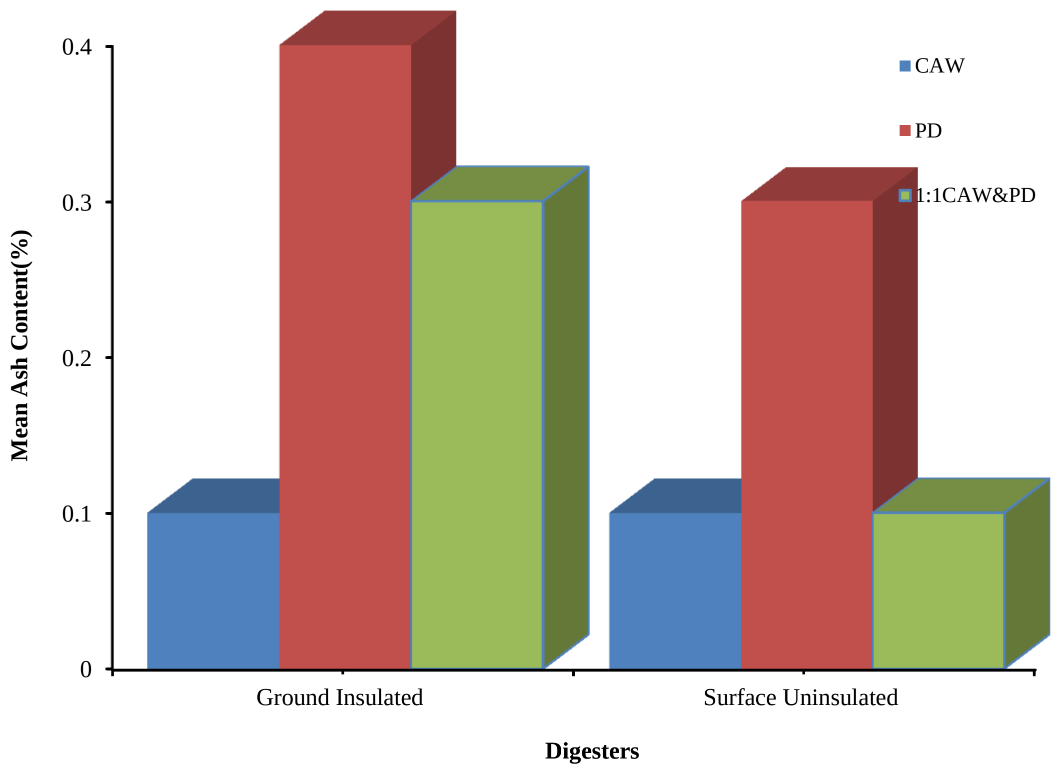
(a) Total solid



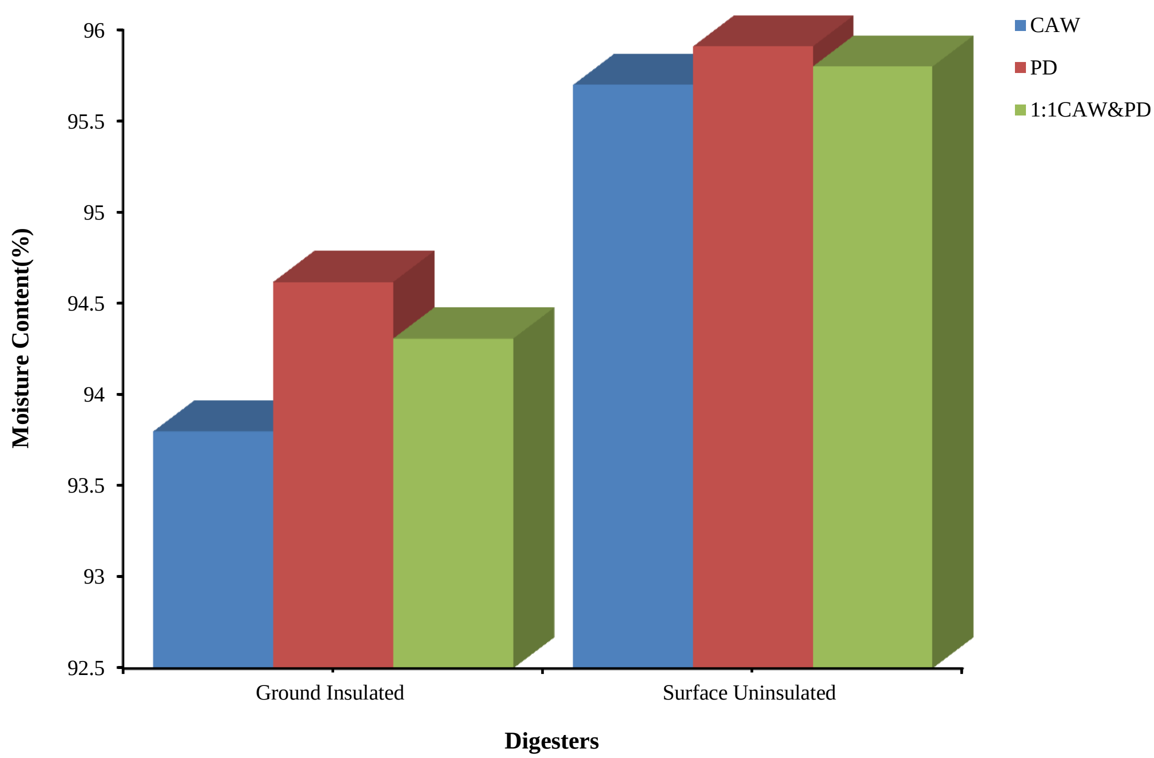
(b) Volatile Solid



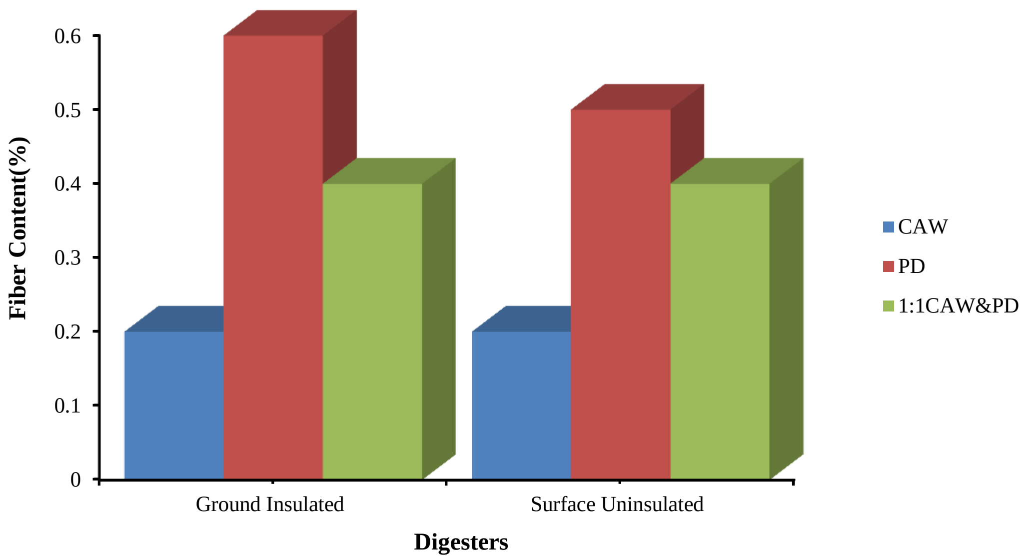
(c) Protein Content



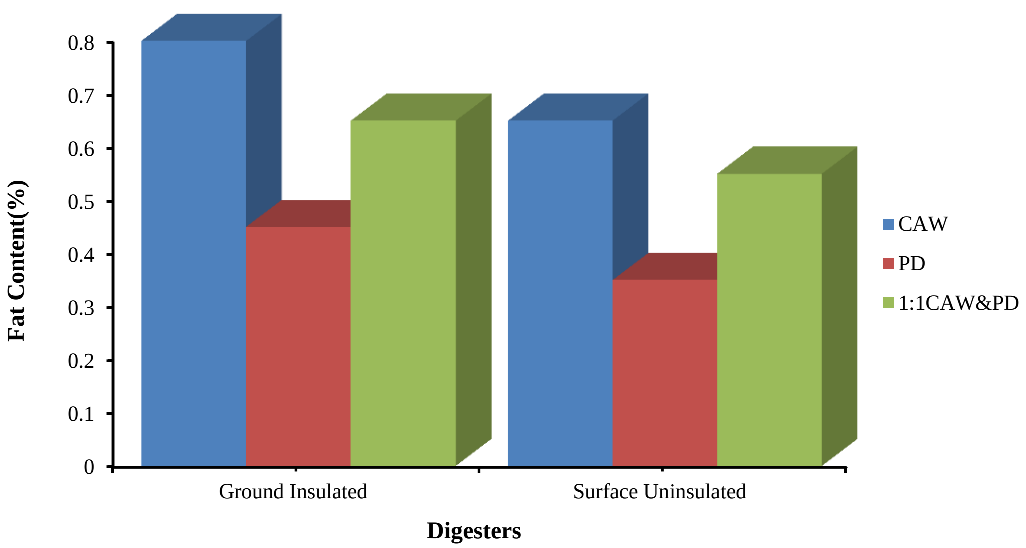
(d) Ash Content



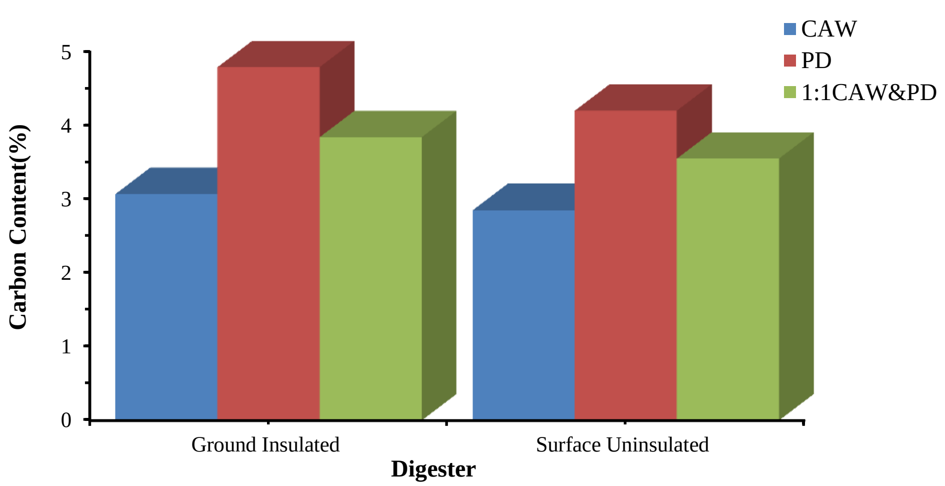
(e) Moisture Content



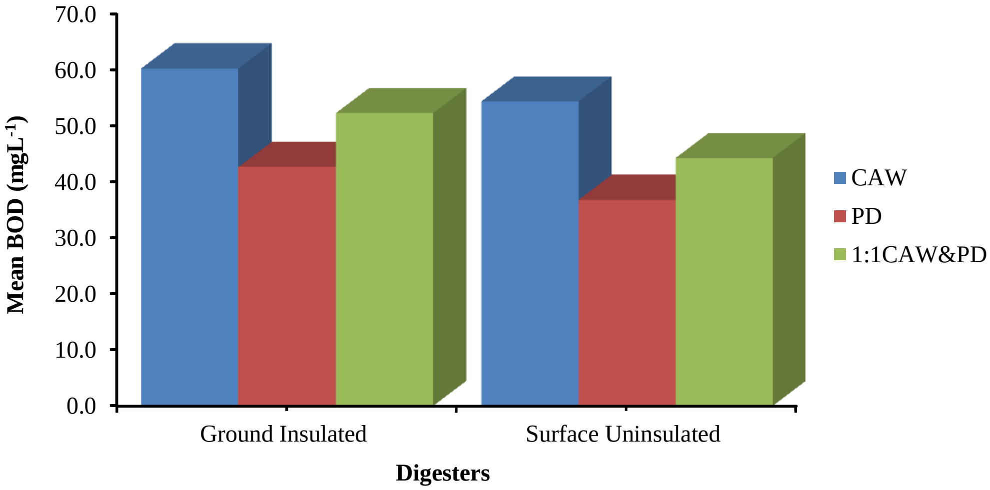
(f) Crude Fiber Content



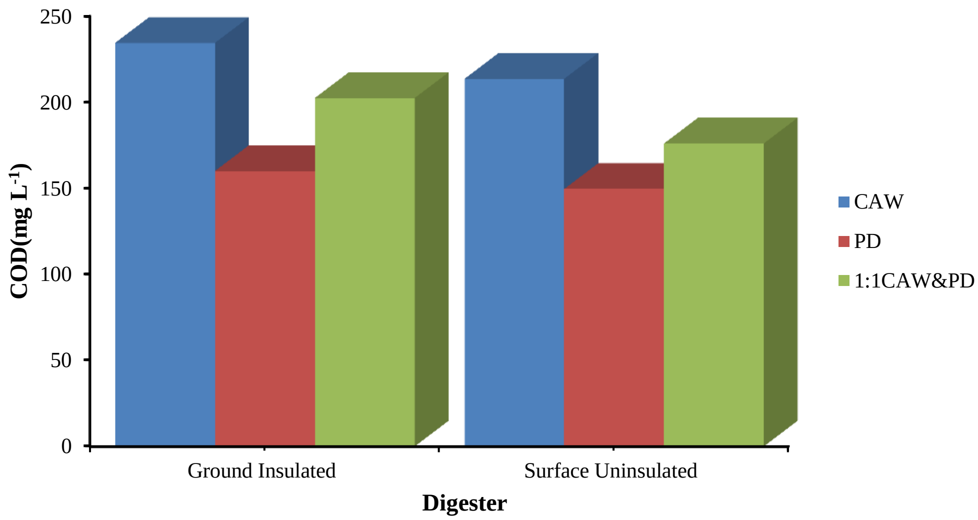
(g) Crude Fat



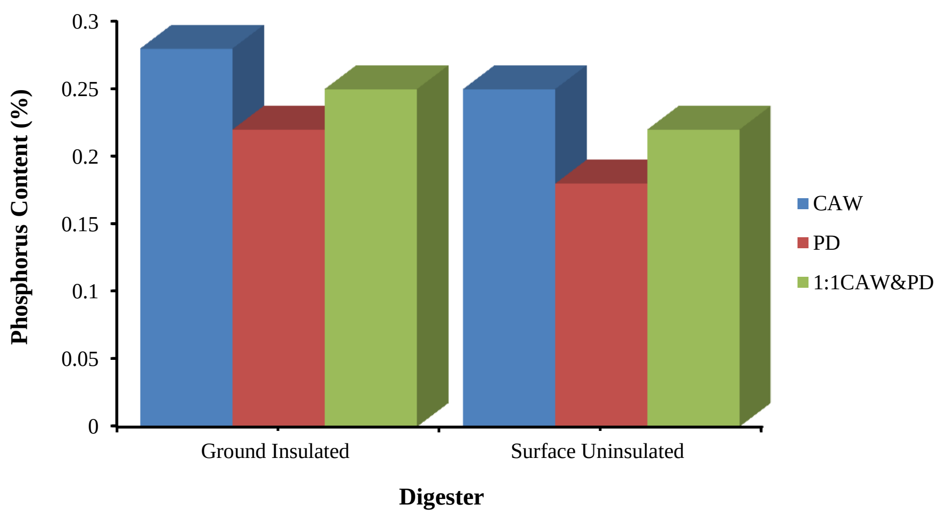
(h) Carbon Content



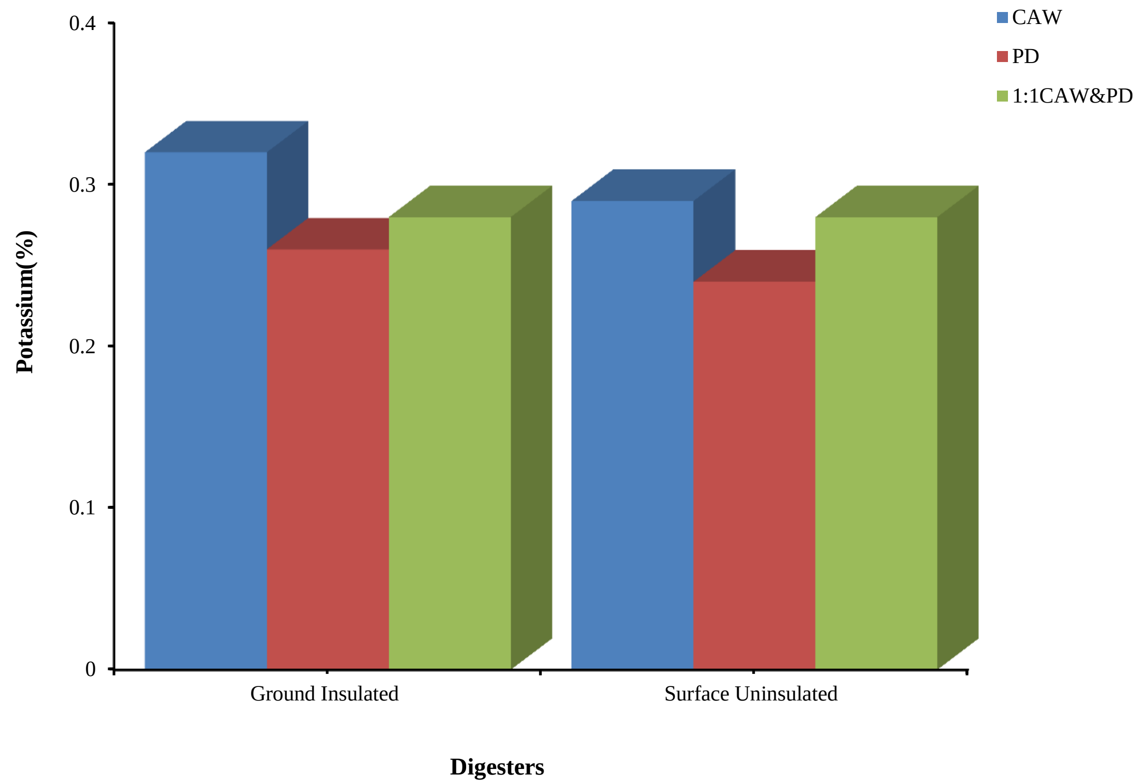
(i) BOD_5



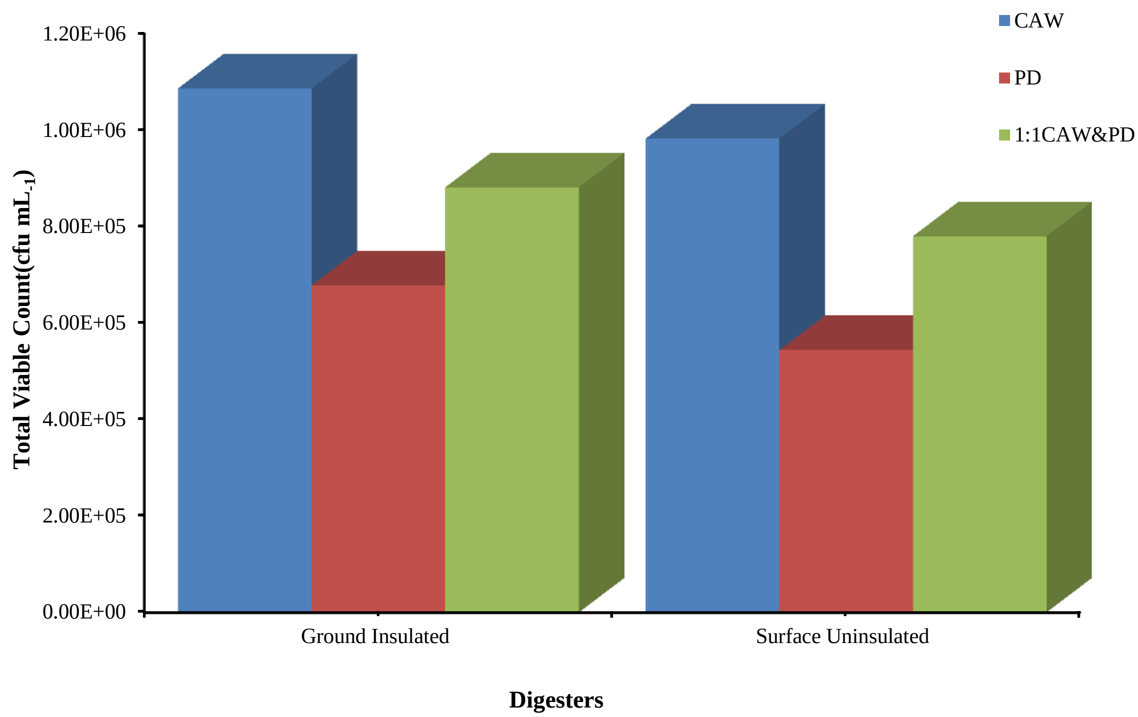
(j) COD



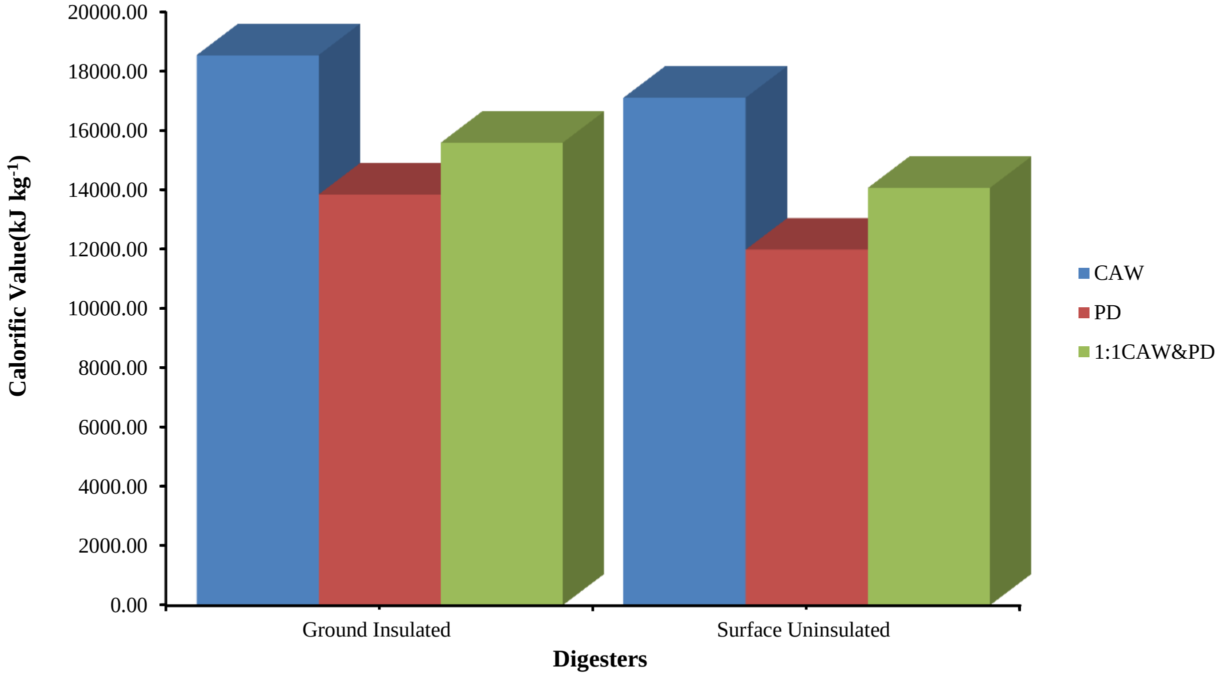
(k) Phosphorus



(l) Potassium

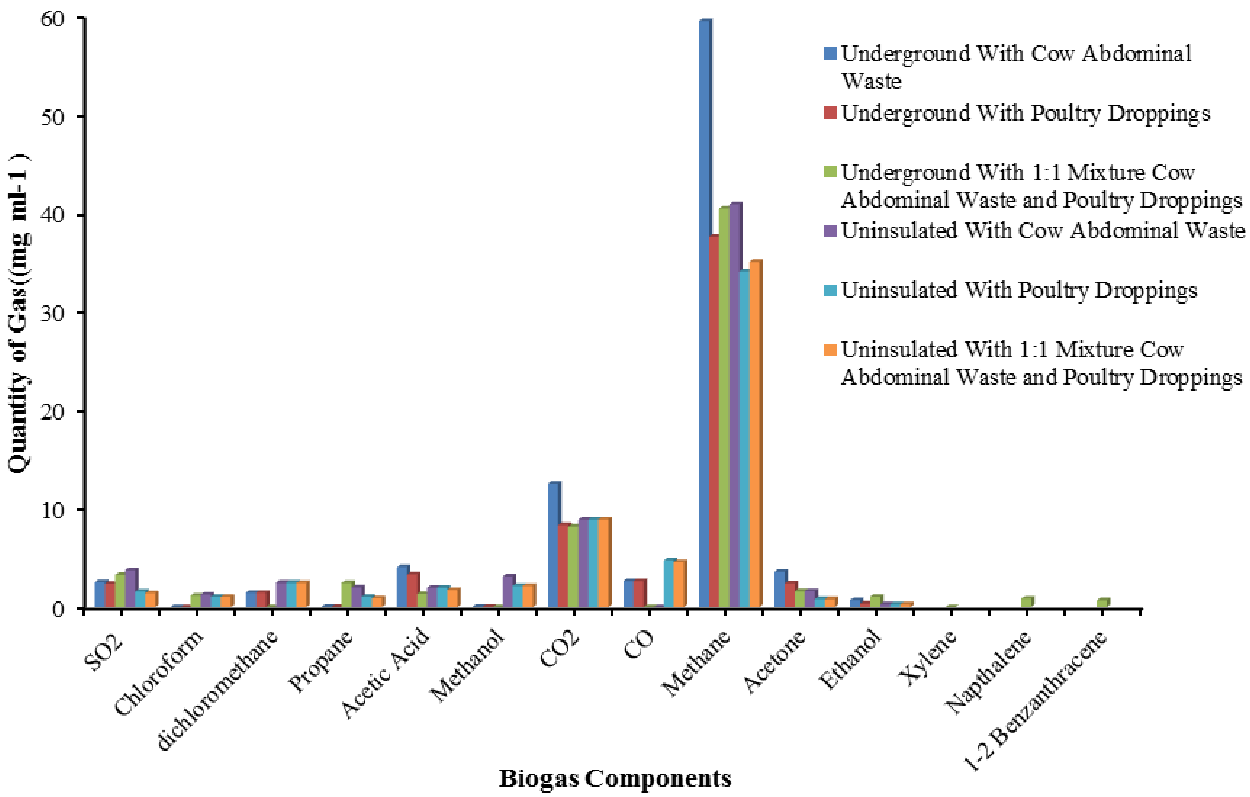


(m) Total Viable Count



(n) Calorific Value

Figure 6 Comparison of performance of ground insulated and uninsulated surface digesters using different Feedstocks



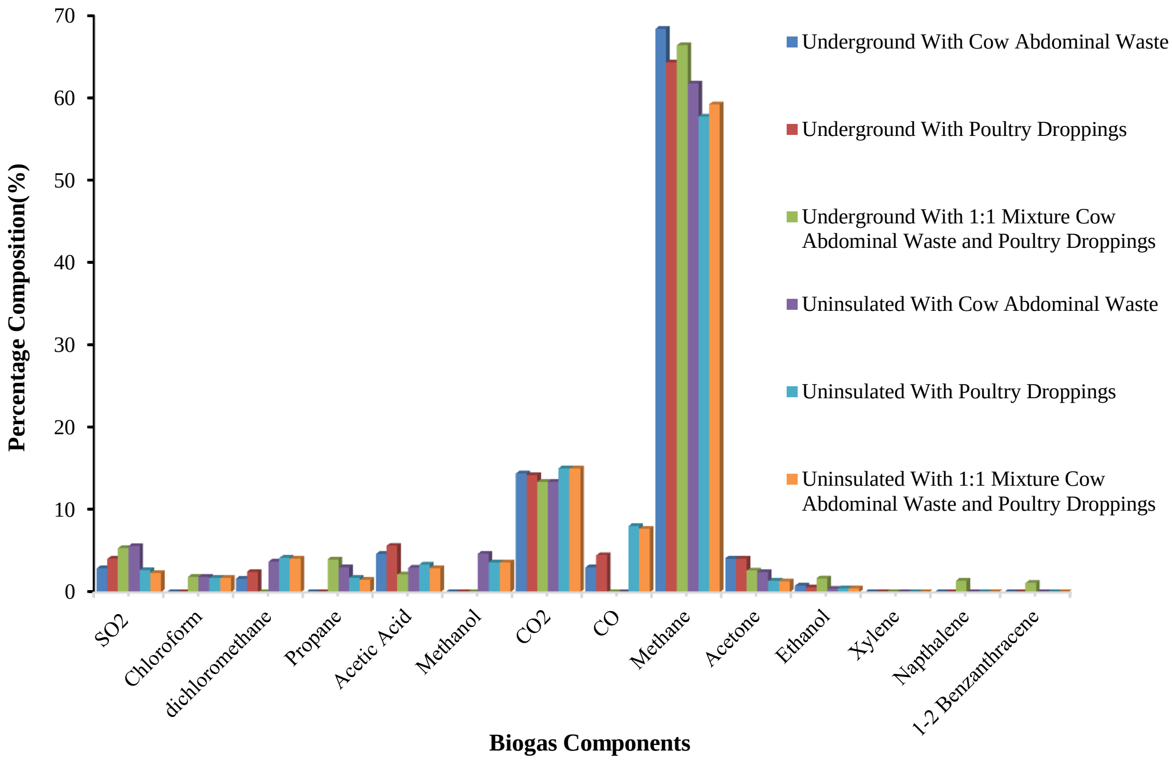
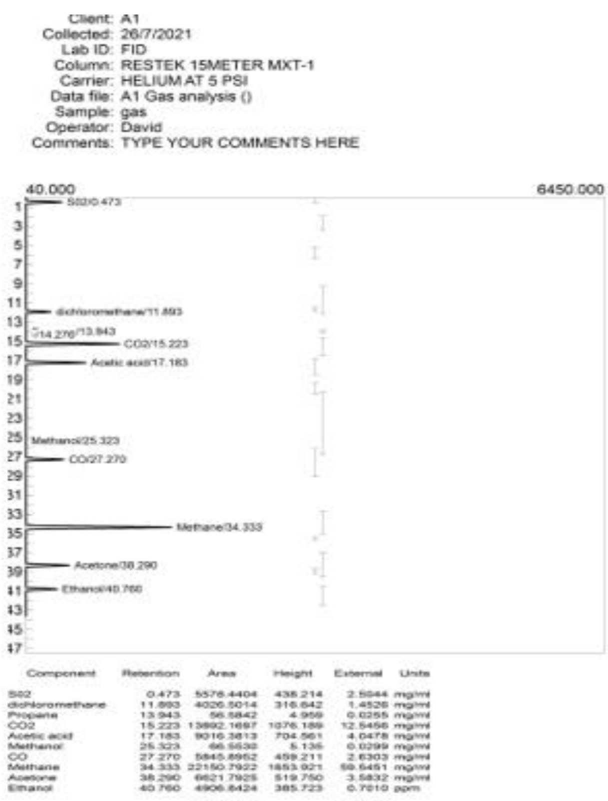
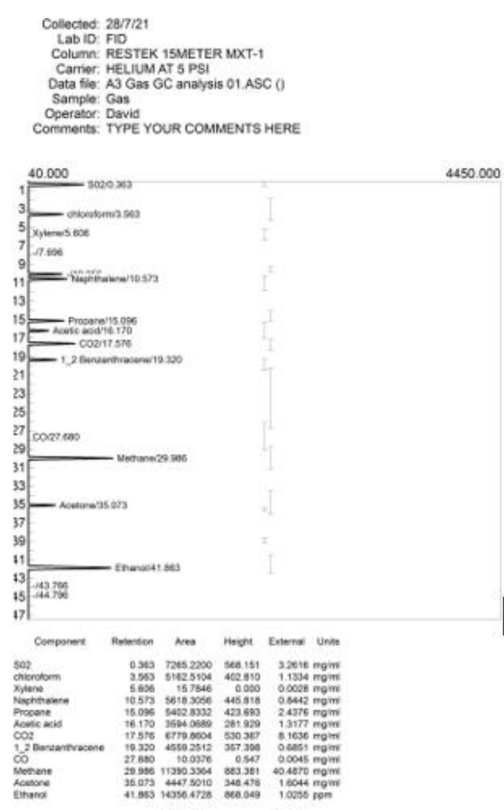


Figure 7 GC analysis results of Biogas (A)Composition of biogas in mg mL^{-1} (B) Composition of Biogas in %



Client: A1
Collected: 26/7/2021
Lab ID: FID
Column: RESTEK 15METER MXT-1
Carrier: HELIUM AT 5 PSI
Data file: A1 Gas analysis ()
Sample: gas
Operator: David
Comments: TYPE YOUR COMMENTS HERE

Component	Retention	Area	Height	External	Units
S02	0.473	5576.4404	438.214	2.5044	mg/ml
dichloromethane	11.893	4026.5014	316.842	1.4526	mg/ml
Propane	13.943	56.5842	4.959	0.0255	mg/ml
CO2	15.223	13892.1697	1076.189	12.5456	mg/ml
Acetic acid	17.183	9016.3813	704.561	4.0478	mg/ml
Methanol	25.323	66.5530	5.136	0.0299	mg/ml
CO	27.270	5845.8952	459.211	2.6303	mg/ml
Methane	34.333	22150.7922	1853.921	59.6451	mg/ml
Acetone	38.290	6621.7925	519.750	3.5832	mg/ml
Ethanol	40.760	4906.8424	385.723	0.7010	ppm
		72161.9523		87.0654	



Collected: 28/7/21
Lab ID: FID
Column: RESTEK 15METER MXT-1
Carrier: HELIUM AT 5 PSI
Data file: A3 Gas GC analysis 01.ASC ()
Sample: Gas
Operator: David
Comments: TYPE YOUR COMMENTS HERE

Component	Retention	Area	Height	External	Units
S02	0.363	7265.2200	568.151	3.2616	mg/ml
chloroform	3.563	5162.5104	402.810	1.1334	mg/ml
Xylene	5.606	15.7846	0.000	0.0028	mg/ml
Naphthalene	10.573	5618.3056	445.818	0.8442	mg/ml
Propane	15.096	5402.8332	423.693	2.4376	mg/ml
Acetic acid	16.170	3594.0689	281.929	1.3177	mg/ml
CO2	17.576	6779.8604	530.387	8.1636	mg/ml
1_2 Benzanthracene	19.320	4559.2512	357.398	0.6851	mg/ml
CO	27.680	10.0376	0.547	0.0045	mg/ml
Methane	29.986	11390.3364	883.381	40.4870	mg/ml
Acetone	35.073	4447.5010	348.476	1.6044	mg/ml
Ethanol	41.863	14356.4728	868.049	1.0255	ppm
		68602.1821		60.9673	

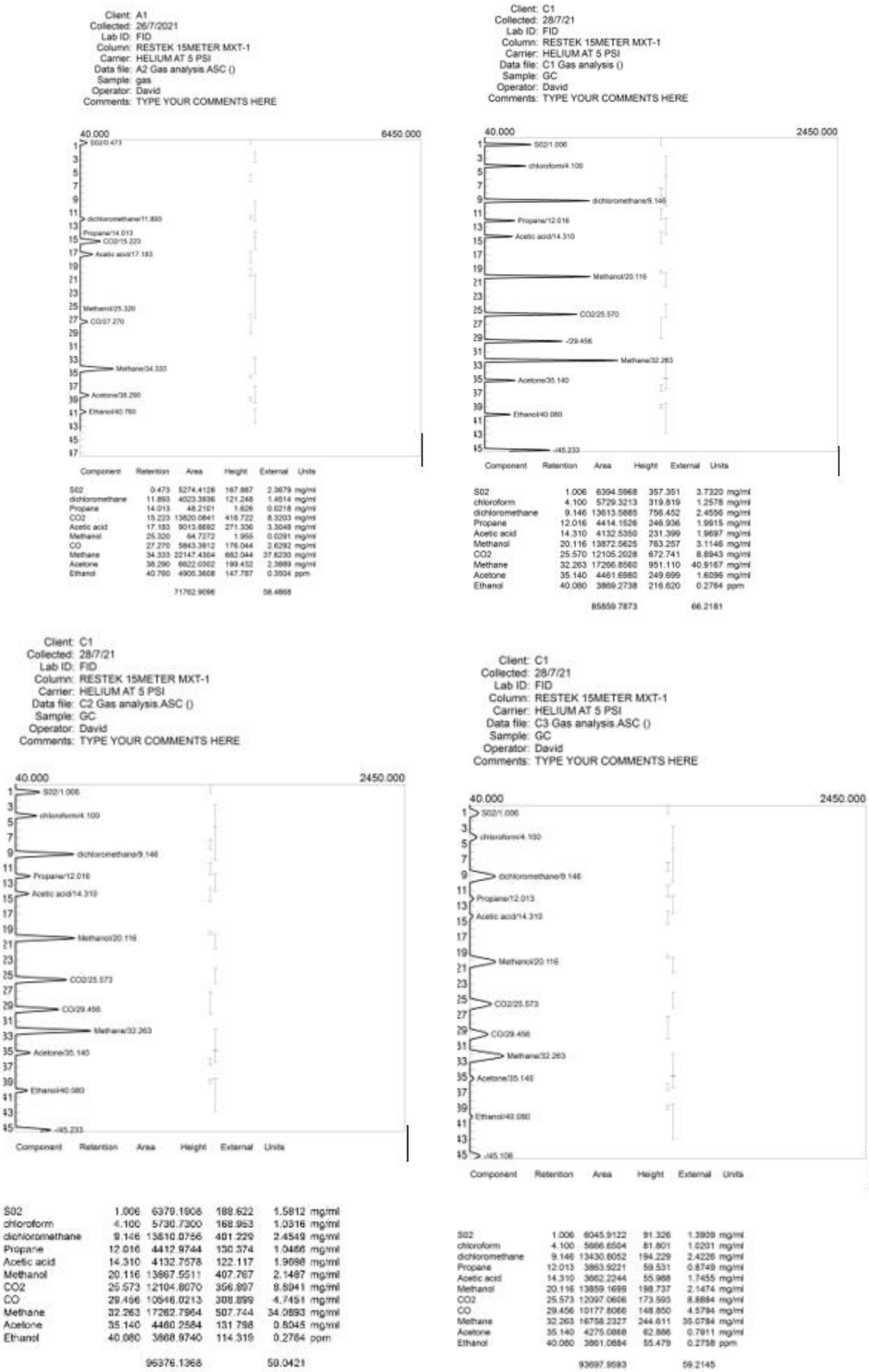


Figure 8 GC Analysis of biogas components results

Note:A1 = Underground with Cow Abdominal Waste; A2 = Underground with Poultry Droppings; A3 = Underground With 1:1 mixture of Cow Abdominal Waste and Poultry Dropping; C1 = Surface Uninsulated with Cow Abdominal Waste; C2 = Surface Uninsulated with Poultry Dung; C3 = Surface Uninsulated With 1:1 mixture of Cow Abdominal Waste and Poultry Dropping.

3.5 Comparison of physicochemical properties of ground insulated and uninsulated surface digesters for different feedstocks.

The results showed that the range of values for measured physicochemical parameters for ground insulated digesters were: TS (4.55%-5.56%), VS (3.79%-4.87%), BOD_5 (42.7-60.3), TVC (6.78E+05-1.09E+06cfu ml^{-1}), Protein (1.92%-2.26%), Ash (0.1%-0.4%), Moisture (93.8%-94.62%), Fibre (0.2%-0.6%), Fat (0.45%-0.8%), Carbon (3.07%-4.79%), COD (160 -234.4 mg l^{-1}), P (0.2%-0.28%), K (0.26%-0.32%), and Calorific Value (13860-18552) while the range of values for the uninsulated digesters were TS (3.23%-4.14%), VS(2.51%-3.38%), BOD_5 (36.8-54.4 mg l^{-1}), TVC(5.44E+05-9.82E+05 cfu ml^{-1}), Protein, (1.64%-1.86%), Ash (0.1%-0.3%), Moisture (95.7%-95.91%), Fibre (0.2%-0.5%), Fat (0.35%-0.65%), Carbon (2.85%-4.20%), COD (149.6 - 213.6 mg l^{-1}), P(0.18%-0.25%), K(0.24%-0.29%), and Calorific Value (12004-17120 kJ kg^{-1}). The TS range of 4.55-5.56% observed in this study indicates low solid anerobic digestion. Low solids anaerobic digestion contains less than 10% TS, Medium solids anaerobic digestion about 15-20% TS and High solids processes range from 22% to 40% (Tchobanoglous et al., 1993). The TS, VS and COD obtained in this study were lower than the range of 20%-66%, 78%-88% and 195-280 g l^{-1} respectively reported by Singh et al. (2021) who studied production of biogas from human faeces mixed with the co-substrate poultry litter and cow dung. Moreover, compared with the moisture content (20%-66%), calorific value (3927.9-4114% kcal kg^{-1}) and TVC(1.09E+04-4.4E+04CFU/gTS) reported by Singh et al. (2021), the moisture content, calorific value and TVC obtained in this study were higher. The moisture contents obtained in this study are within optimum. Optimum moisture content has to be maintained in the digester and the moisture content should be kept in the range of 60%-95% (Demetriades, 2008). However, the optimum moisture content differs with different input materials, chemical characteristics and bio-degradation rate (Nijaguna, 2002).

The comparison of physicochemical properties of ground insulated and uninsulated surface digesters for different feedstocks is presented in Figure 6. Figure 6 shows that the total solid, volatile solid, protein contents, crude fat, BOD_5, carbon content, COD, phosphorus, otassium, total viable count and calorific value of ground insulated digester were higher than that of uninsulated surface digesters for the three different feedstocks at the end of the 30 Days digestion. The moisture contents were the same for both the ground insulated digester and the uninsulated surface digesters for the three different feedstocks at the end of the 30 Days digestion. The crude fiber and ash content showed similar trend of equal values for both using the cow abdominal waste as feedstock but higher value for ground insulation using poultry dropping and 1:1 mixture of cow abdominal waste and poultry dropping as feedstock.

3.6 GC analysis of biogas results

The GC analysis of Biogas components from the six reactors is presented in Figures 7 and 8. Figures 7 and 8 indicate that the highest quantity of methane was produced by the cow abdominal waste in underground insulated fixed dome biogas digester. The underground insulated biogas digester produced more methane than their counterpart uninsulated digesters containing the same feedstock signifying the importance of temperature regulation through insulation. In terms of the feedstock, the cow abdominal waste performed better than the poultry droppings in both the underground and uninsulated digesters. The mixture of 1:1 Cow abdominal waste to poultry dropping also showed better performance in methane production than the single anaerobic digestion of poultry dropping alone indicating efficiency and importance of co-digestion of feedstocks. The Percentage compositions of methane produced were 68.39%, 64.33%, 66.41%, 61.79%, 57.74%, and 59.24% for Underground with Cow abdominal waste, underground with poultry droppings, underground with1:1 mixture of cow abdominal waste and poultry droppings, uninsulated with cow abdominal waste, uninsulated with poultry droppings, and uninsulated with1:1 mixture of cow abdominal waste and poultry droppings, respectively. The range of values of methane obtained in this study compares well with the range of 56%-60% obtained by Kanwar et al. (1994) on performance evaluation of a 1 m^3 modified, fixed-dome Deenbandhu biogas plant under hilly conditions and also with that reported by Kalia and Kanwar (1998) on Long-term evaluation of a fixed dome Janata biogas plant in hilly conditions. The methane contents observed in this study from different digesters are similar to the range of values of 49.81%–68.15% by volume of methane reported by Iweka et al. (2021) from all samples digested during optimization of biogas yield from anaerobic co-digestion of corn-chaff and cow dung digestate. According to Duc and Wattanavichien (2007) biogas with high methane content as obtained in this study is desirable since it is suitable for diesel engines with a high compression ratio.

4 Conclusions

The ANOVA result showed that there were significant differences in the slurry temperature, volume of biogas produced and slurry pH respectively at 5% significant levels. The range of pH, Volume of biogas and slurry temperature (ST) in all the digesters with the three feedstocks were 6.987-7.045, 2.342-3.460 liters and 27.975°C -28.717°C, respectively. The range of values for measured physicochemical parameters {(Ground insulated digester): (Uninsulated digesters)} were: TS{(4.55-5.56: (3.23-4.14)}, VS{(3.79-4.87): (2.51-3.38)}, BOD_5 {(42.7-60.3): (36.8-54.4)}, TVC{(6.78E+05-1.09E+06): (5.44E+05-9.82E+05)}, Protein {(1.92-2.26): (1.64-1.86)}, Ash{(0.1-0.4): (0.1-0.3)}, Moisture {(93.8-94.62): (95.7-95.91)}, Fibre {(0.2-0.6): (0.2-0.5)}, Fat {(0.45-0.8): (0.35-0.65)}, Carbon {(3.07-4.79): (2.85-4.20)}, COD {(160 -234.4): (149.6 -213.6)}, P{(0.22-0.28): (0.18-0.25)} , K{(0.26-0.32): (0.24-0.29)}, and Calorific Value {(13860-18552): (12004-17120)}.

The total solid, volatile solid, protein contents, crude fat, BOD_5, Carbon Content, COD, Phosphorus, Potassium, Total Viable Count and Calorific Value of ground insulated digester were higher than that of uninsulated surface digesters for the three different feedstocks at the end of the 30 days digestion. GC analysis of biogas showed that the percentage compositions of methane produced were 68.39%, 64.33%, 66.41%, 61.79%, 57.74%, and 59.24% for underground with cow abdominal waste, underground with poultry droppings, underground with1:1 mixture of cow abdominal waste and poultry droppings, uninsulated with cow abdominal waste, uninsulated with poultry droppings, and uninsulated with1:1 mixture of cow abdominal waste and poultry droppings, respectively. The underground insulated biogas digester produced more methane than their counterpart uninsulated digesters containing the same feedstock signifying the importance of temperature regulation through insulation. In terms of the feedstock, the cow abdominal waste performed better than the poultry droppings in both the underground and uninsulated digesters. The mixture of 1:1 Cow abdominal waste to poultry dropping also showed better performance in methane production than the single anaerobic digestion of poultry dropping alone indicating efficiency and importance of co-digestion of feedstocks. The study has shown that underground insulation of the fixed dome biogas digesters improved biogas production. We therefore recommend its application by the biogas industry because is cost-effective and will help to reduce the effects of economic barriers to investment in biogas systems.

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