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# Preliminary Study on Co-Digestion of Cow Manure with Pretreated Sawdust for Production of Biogas and Biofertilizer

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## ABSTRACT

Microbial digestion of the combined matrix of cow manure (CM) and pre-treated sawdust (PS) yielded biogas significantly. The sludge left behind was assayed for its nutritional composition as recyclable plant nutrients using standard methods. Analysis showed that dry mass of undigested raw material contained N (0.85%); P (0.41±0.01g/kg); K (1.21±0.11g/kg); Ca (0.64±0.02g/kg); Na (0.04±0.01g/kg); Mg (0.37±0.13g/kg); Fe (0.55±0.01g/kg); Zn (0.03±0.01g/kg). For the sludge, analysis showed N (3.26%); P(1.64±0.03g/kg); K (3.45±0.04g/kg); Ca (1.93±0.11g./kg); Na (0.18±0.01g/kg); Mg (1.02±0.05g/kg); Fe (1.25±0.12g/kg) and Zn (0.07±0.02g/kg), respectively. There was a significant difference ($p<0.05$) in height of maize grains planted on both sludge-fortified and unfortified samples of loam, with other conditions being the same. Maize grains planted on sludge-fortified loamy soil recorded a mean height of 198mm after 2 weeks of monitoring while those planted on unfortified soil gave a mean height of 110mm for the same period. Mineral content analysis of the sludge clearly showed that it could serve as a good organic fertilizer. The researchers concluded that coupling of pretreated sawdust into the cow manure anaerobic digester not only enhanced fuel gas production, but also gave nutrients-rich residues for re-cycling to the land.

**Keywords:** *Co-digestion, pre-treated sawdust, cow manure, digester, biogas, biofertilizer*

## 1. INTRODUCTION

The continual depletion of fossil fuels across the globe coupled with their attendant pollution problems has brought the search for alternative energy sources to the spotlight. Since the first ‘energy crisis’ of 1973 to 1974, speculations of catastrophic economic disruption in the future have remained high. Uncertainties over petroleum availability and price, and disruption such as the 1990 Gulf War have caused energy to be one of the major problems of modern times[1].

The global energy crisis has triggered interest in the search for sustainable alternatives to fossil fuels. Among the options intensively researched is the use of abundant renewable agricultural wastes for fuel and energy generation. Lignocelluloses are often a major or sometimes the sole component of different streams from industries, forestry, agriculture or municipalities. Hydrolysis of these materials is the first step towards their conversion to fuel gas[2].

Biogas is a sustainable energy source currently used in many countries as car fuel and for generation of heat and electricity. Sugars, starches, lipids and proteins present in municipal solid wastes (MSW) are among the materials easily digested by microorganisms[2]. Several researches have been carried out on biogas production, but there is little or no literature account of biogas production from sawdust[3] probably because of the difficulty in isolating the cellulose from the impregnating lignin and hemicelluloses matrix. Cellulose has high ordered crystallinity and mechanical strength in addition to lignin impregnation thereby making isolation difficult[4].

Given the enormity, successful conversion of sawdust into biogas will bring a major breakthrough to the present global search for alternatives to fossil fuels. To make sawdust amenable to microbial digestion, effective pre-treatment process should be employed[4]. Such pre-treatment would not only isolate the cellulose from the biomass matrix but also hasten the de-crystallization process.

Certain micro-organisms attack cellulosic agricultural wastes in the absence of air, fermenting them to release biogas, which comprises methane (55% to 65%), carbon dioxide (30% to 35%), hydrogen sulphide, nitrogen and traces of other gases[1,5]. Biogas production provides an efficient way of converting agricultural wastes into fuel thereby making a clean environment[6]. Biogas burns with a smokeless blue flame; it is non-polluting and certainly a better alternative to using wood as a fuel.

Biomass energy should be preferred wherever energy can be produced as a by-product of waste disposal. However, even while doing this, advantages of recycling or composting of the wastes should be kept in view[1]. Anaerobic digestion of lignocellulosic wastes and faecal droppings creates a valuable synergism between recycling and energy production. Such a method yields biogas and nutrient-rich compost, which is a good fertilizer that can be recycled back to the land in order to maintain the fertility of the fields which grow food crops for man and forage for aninmals[7]. The challenge in achieving positive facility economics by digesting only manure[3] endeared the authors towards considering this option of co-digestion with potentially abundant substrate like sawdust. The latter serves as carbon bank by providing carbon for methane production while the cow manure (comprising essentially cow dung and waste blood from slaughter house) supplied more of the nitrogen needed to maintain microbial growth in the substrate.

Benue State of Nigeria is endowed with abundant natural resources one of which is wood trees. Daily activities at the sawmill result in several tonnes of sawdust being produced. As a means of disposal the millers set these residues on fire which burns for days liberating greenhouse carbon dioxide into the environment[8]. Similarly, the conducive weather condition coupled with the friendly economic environment offered by the geographical area happened to have been attracting several of the *Fulani* cattle merchants from the northern Nigeria, with the result that large quantities of cattle dung are defecated daily by the ruminants during grazing in addition to copious amounts of waste bloods and other intestinal wastes with their slaughter at the abattoirs.

This work focuses on the use of a combined matrix of cow manure and pre-treated sawdust as raw materials for biogas production and subsequent assessment of the spent slurry for biofertilizer. Aside fuel gas production, this bio-conversion would help mitigate environmental pollution arising from decomposition or disposal of these agricultural residues.

## 2. PROCESS OF BIOGAS FORMATION

Microorganisms that participate in digestion process get into the dung from the animal bowels so, in most cases no additional injection is needed. A separate hydrolysis stage may not required. Biogas plant reduces organics volume and the fermented biomass separated. The microbial conversion of any organic substrate into biogas is a chain of complex reactions[9] which starts with an aerobic degradation through a micro-aerophilic stage and to a strictly anaerobic conclusion[1]. As soon as the oxygen already present in the substrate is consumed, the strictly anaerobic reaction starts.

On the whole, the process can be divided into two phases: The first phase is a non-methanogenic[1,7] phase in which a group of micro-organisms (such as *Bacteriodes succinogenes*, *Butyrivibrio fibrisolvens*, *Clostridium lochheadic*, *Cillobacterium cellulosovens*, etc) present in the complex substrate, hydrolyze it first to simple sugars like pentoses and hexoses, which are further metabolized to lower carboxylic acid such as formic, acetic, propionic and butyric acids, with the release of other products like carbon dioxide, ammonia and hydrogen.

In the second phase, called methanogenic phase, a group of important bacteria that act strictly under anaerobic condition, attack the products of the first phase, converting them into methane, carbon dioxide, hydrogen and other gases in traces[7]. Some of the common methanogenic bacteria are *Methanobacterium ruminantium*, *M. mobilis, M. formicicum, Methanobacillus omelianskii*[1], etc. Most of them use carbon dioxide, formate and acetate as the sources of carbon; some species even use alcohols as energy and carbon sources. The overall process for anaerobic digestion is a fermentation reaction in which organic matter is both oxidized and reduced[1]. A simplified reaction path for the anaerobic fermentation of a hypothetical organic substrate "$\{CH_2O\}$" is as follows: $2\{CH_2O\} \rightarrow CO_2 + CH_4$

### 2.1 Temperature Effect

One of the most important factors in biogas production is maintaining optimal temperature regime[10]. Biogas production is possible for temperatures between 0°C and 95°C. However, with regards to gas fuel and biofertilizer production certain differentiations in temperature have become necessary.

There are two distinct temperature ranges most suitable for biogas production, and different bacteria operate in each of these ranges. Mesophilic bacteria optimally function in the 32°C to 43°C range[1,8]. Thermophilic bacteria are most productive in the 49° to 60°C range[1,8]. The benefits of thermophilic range of digestion include higher speed of substrate digestion and therefore higher biogas yield as well as practically total destruction of pathogenic bacteria present in the substrate. On the contrary, thermophilic digestion has higher costs due to maintaining higher temperatures, and thermophilic digesters may be less stable. Mesophilic digestion range allows for higher amino acid content of fertilizer, but with incomplete disinfection of the substrate[9]. Temperature within the digester is critical, with maximum conversion occurring at approximately 35°C in conventional mesophilic digesters. Bacterial digestion in covered lagoons at temperatures below 32°C is called pschrophilic (meaning a preference for lower temperatures). However, digestion slows down or stops completely below 15° or 21°C, so these digesters do not produce methane all of the time[1].

### 2.2 Slurry pH

Anaerobic digestion normally takes through three stages: hydrolysis, fermentation (acidogenesis) and methanogenesis[2]. The first two stages occur more commonly under slightly more acidic condition, whereas the last stage (methane formation) occurs at slightly more alkaline condition. Generally anaerobic digestion occurs best within a pH range of 6.8 to 8.0[9]. More acidic or alkaline slurries will ferment at a lower speed. The introduction of raw material will often lower the pH. Digestion will stop or slow down dramatically until the bacteria have absorbed the acids. A high pH will encourage the production of acidic carbon dioxide to neutralise the slurry again.

### 2.3 Nutrient Level

Fermentative bacteria need just more than carbon and energy to grow but also certain mineral nutrients. Adequate supply of nitrogen, sulphur, phosphorous, potassium, calcium and a number of trace elements such as manganese, iron, molybdenum, zinc, selenium, nickel, is also required. Interestingly, "normal substrates" like agricultural wastes or municipal sewage usually contains adequate amounts of these elements[1].

### 2.4 C/N Ratio

Literature account has recommended substrate's carbon – nitrogen ratio of between 20:1 and 30:1 as optimal for biogas yield[9,11]. Microorganisms that produce biogas require substrates containing 20-30times more accessible carbon than nitrogen[9]. Therefore, in the compositing of the slurry care should ensure reflection to a good approximation of this mathematical relationship. The substrate should be rich in accessible carbon and also not deficient in nitrogen. This is the reason co-digestion of crop residues with fresh animal manure is imperative.

### 2.5 Inoculation

Sometimes starter material such as sludge of appropriate bacterial load is injected into the substrate before loading to help hasten digestion process. Most of the time, sludge from municipal waste treatment plants serve as inoculums of digester plants.

### 2.6 Loading Rate and Substrate Agitation

Usually the system's design will dictate loading rates and contents, but experience has shown that uniform loading, on a daily basis, of manure with 6 to 10 percent solids generally works best[12]. The load's retention time in the digester will typically range from 15 to 30 days.

The loaded manure needs to be mixed regularly to prevent formation of scum or sediments and to maintain contact between the bacteria and the manure[7]. The agitation also helps to prevent temperature differentiation between different portions of substrate in digester[9]. Slow agitation over 2 to 3 hours a day is considered adequate, as too frequent, long and intensive agitation is harmful to the digestion process. Above all, appropriate mixing action facilitates release of the biogas[5].

### 2.7 Management

Anaerobic digesters require regular and frequent supervision, chiefly to maintain a constant desired temperature and pH and to ensure that the system flow is not clogged. Failure to properly manage the digester's sensitivity to its environment can result in a significant decline in gas production and may require months to correct.

### 2.8 Safety

Working with anaerobic digester biogas and especially with methane (the major component of the gas), warrants extreme caution. Methane, when mixed with air, is highly explosive. In addition, because digester gas is heavier than air, it displaces oxygen near the ground, and if hydrogen sulphide is still present, the gas can act as a deadly poison. It is critical that digester systems be designed with adequate venting to avoid these dangerous situations[1].

### 2.9 Storage

Owing to the high pressure and low temperature required for liquefaction, methane is usually stored in the gaseous state. The gas is collected and stored for a period of time until it can be used. The most common means of collecting and storing the gas produced by a digester is with a floating cover, a weighted pontoon that floats on the liquid surface of a collection/storage basin. Skirt plates on the sides of the pontoon extend down into the liquid, thereby creating a seal and preventing the gas from coming into contact with the open atmosphere[12]. High-pressure storage is also possible, but is both more expensive and more dangerous and should be sought only with the help of a trained technician.

## 3. NUTRITIONAL PROPERTY OF THE SLUDGE

Crop fertilizer contains nitrogen (N), phosphorous (P) and potassium (K) as major components. Magnesium (Mg), calcium (Ca), iron (Fe), and some important micro-elements may also be added. Farm manure is relatively poor in nutrients. The organic fertilizers such as plant and animal residues must undergo biodegradation to release the simple inorganic species ($N0_3^-$, $H_xPO_4^{X-3}$, $K^+$) assimilable by plants[1]. Literature account has revealed that a group of coprophilous fungi present in the dung of cow are associated with the breakdown of complex organic wastes releasing plants nutrients for recycling[13,14]. Temperatures optimal for the anaerobic digestion of sawdust and cow dung have been applicable for release of assimilable plant nutrients by coprophilous fungi. Thus, the incorporation of cow dung as a supplementary substrate for fuel gas production has an additional advantage of facilitating the release of plant nutrients from the spent slurry for recycling[5,12].

## 4. MATERIALS AND METHODS

### 4.1 Feedstocks and Pretreatment Process

The feedstocks used in this investigation were cow manure (comprising cow dung, cow blood, hooves and intestinal wastes) and sawdust. Sawdust was collected from Makurdi Mega Timber Shade along Makurdi-Naka Road; fresh cow dung was packed at the Cattle Market in North-bank Makurdi while fresh cow blood, hooves and the intestinal waste matter were packed at the Mega Abattoir under the New River Benue Bridge, Makurdi. The sawdust was first air-dried for three days to reduce the moisture content and thereafter screened through a sieve to get rid of sand and other earth matter. Mechanical size reduction to the tune of 3 to 7mm followed using a wooden mortar. The wood powder was first delignified by the Browning Method[15]. The supernatant dark liquor was filtered off through a cheese cloth. The residue (comprising essentially cellulose, hemicelluloses and traces of lignin degradation products) was washed with double de-ionized water and thereafter cooked with 0.2% $H_2SO_4$ (w/w) through a temperature of $140^oC$[4,16]. The cooking lasted for a period of 45minutes until the resulting solution first gave positive test for reducing sugar using Fehling solution[16]. Correction to pH of 6.5 was achieved by adding (with stirring) a saturated solution of sodium bicarbonate. De-ionized water was used in all the preparations. All chemicals used in the pretreatment process were of technical grade only and were purchased from Emole Nigeria Ltd, Makurdi, Nigeria.

### 4.2 Slurry Preparation and Composition

The pre-treated sawdust (PS) must was mixed with of the cow manure (CM) in the ratio 1:1.5 by volume.. Well aerated warm de-ionized water was added with stirring until a slurry of estimated moisture content of 70%, was made.

### 4.3 Digester Architecture and Experimental Design

The resulting slurry (PS/CM) was fed into a locally constructed concrete digester (standing on a 50cm concrete platform above the ground) through an inlet pipe made of PVC. The 200L capacity digester was filled to two-thirds its height with the slurry. The feeding temperature was 38°C targeted at mesophilic microbial digestion[7,9]. An outlet gas pipe of a PVC material bearing a stop-cock was connected to a gas holder made of mild steel and lined on the inside with a PVC material. The gas holder traps the issuing gas in the space above the slurry while it passes into a glass gas reservoir floating upright in large calibrated glass trough containing water. The gas reservoir was capable of holding 5L of gas. Rubber tubing fitted with the outlet pipe at one end actually delivers the gas to the gas reservoir. Control valves fitted on the gas reservoir helped gas delivery. The glass gas reservoir sinks into the calibrated glass trough as biogas is delivered into it. The volume of water displaced at 6pm daily represented the volume of gas harvested that day. Another outlet pipe (made of concrete) fitted at the base of the digester served the purpose of expelling the sludge. An iron rod passing through the gas holder into the digester serves the purpose of substrate agitation. The gas holder formed an air-tight covering for the digester with all lid gaps thoroughly smeared with grease when the gas plant was operational.

Except when re-charging the digester or when expelling sludge, all outlets are securely shut either with a bung or grease once the plant was running. This was in effort to cut off oxygen supply into the digester[5]. A replicate set up containing equal volume of cow manure (CM) slurry only was to serve as control, that is, to help determine the impact of pre-treated sawdust (PS) on gas yield. Each digester was recharged daily with about 10% of the original substrate starting from the 3rd day of operation to the 22nd day before finally shutting down the digesters on the 23rd day. To ensure digester content is stable a volume of sludge or digestate almost equal to the recharging volume of substrate was expelled through the outlet pipe at the foot of the digester. Gentle agitation of the digester content[7] by the iron rod was carried out daily for a period of about 1hr. The investigation was carried out in an isolated farm settlement in North-bank area of Makurdi Metropolis.

Harvesting of gas from each plant was done daily at 6:00 pm, and continued in that order till after three weeks beyond which gas supply began to decline. The temperature of the gas plants were monitored throughout the period of digestion by a thermometer inserted through a small hole on the gas holder and made airtight with grease.

### 4.4 Nutritional Composition of Sludge and its Effect on Growth of Maize Plants

The sludge expelled from the (PS/CM) digester was assayed for certain mineral elements of plants' nutritional importance. Nitrogen (N) was determined by the Kjeldahl method as described by Mann and Saunders[17]. Phosphorous was determined using a Spectronic-20 Colorimeter by the Phosphovanado-molybdate method. Sodium (Na) and Potassium (K) were determined with a Corning 405 Flame Photometer. Magnesium (Mg), Calcium (Ca), Zinc (Zn), and Iron (Fe) were assayed using a Buck Atomic Absorption Spectrometer[18]. Metal content determination was carried out on a 2M $HNO_3$ ash extract of 10g (dry mass) portions each of the (PS/CM) sludge and its original undigested form after complete incineration in a muffle furnace at 650°C.

The effect of the sludge of plant growth was determined by planting three mature and healthy maize grains separately in both sludge-fortified and unfortified loamy soils under same conditions prevailing for maize grain germination and growth[19]. 10 equal plastic containers each of volume 4L were filled with adequately wetted sludge fortified loamy soil and another 10 plastic containers of equal volume were filled with equally adequately wetted loamy soil, but without sludge, to serve as control. As stated above three maize grains were planted in the soil in each container. Measurements were taken beginning from first day of appearance of plumule. All observations with respect to germination and growth (in height) were recorded for two weeks[19].

## 5. RESULTS AND DISCUSSION

### 5.1 Yield in Biogas

The volume of gas harvested per day from each plant is presented in Table 1.

**Table 1: Daily Biogas Production**

| Day / d | Yield in Biogas / mL PS/CM | CM |
|---|---|---|
| 1 | - | - |
| 2 | - | - |
| 3 | 45 | 60 |
| 4 | 80 | 100 |
| 5 | 125 | 130 |
| 6 | 150 | 250 |
| 7 | 210 | 380 |
| 8 | 320 | 510 |
| 9 | 400 | 620 |
| 10 | 490 | 750 |
| 11 | 600 | 800 |
| 12 | 720 | 920 |
| 13 | 850 | 1050 |
| 14 | 970 | 1200 |
| 15 | 1180 | 1330 |
| 16 | 1320 | 1050 |
| 17 | 1600 | 850 |
| 18 | 1850 | 700 |
| 19 | 2250 | 580 |
| 20 | 2550 | 420 |
| 21 | 2850 | 370 |
| 22 | 2470 | 300 |
| 23 | 2210 | 280 |
| **Mean Gas Yield** | **1010** | **550** |

The results in Table 1 show that gas yield from the PS/CM digester is significantly higher (*p<0.05*) than that of CM digester. The PS/CM plant reached a peak yield of 2850mL as against 1330mL for the CM plant. The later had a lower retention time, giving its maximum yield on the 15th day of retention. The results were in agreement with those of Ratanatamskul *et al* [2] and Tong *et al* [7] respectively.

The higher gas yield from the PS/CM plant clearly indicated that incorporation of calculated quantity of the pre-treated sawdust into the CM plant optimized the C/N ratio which is a prerequisite for enhanced gas yield by any digester plant[9]. Whereas the partially hydrolysed sawdust supplied the carbon required for optimal methane production, the nitrogen-rich cow manure sustained the microorganisms throughout the retention period by supplying the required nutrients for their survival. Usually, co-digestion of animal manure and agricultural wastes has been reported to improve biogas yield[2,7]. It was noted earlier in this work that cellulose is resistant to microbial digestion, particularly those of wood origin. Apart from its high crystallinity, lignin impregnation is another major problem. These challenges were however overcome by first dissolving the lignin in boiling caustic soda solution and subsequently, dilute sulphuric acid hydrolysis. The latter helped in breakdown of the cellulose molecules into fermentable molecules, predominantly simple reducing sugars[16]. Cellulose constitutes about 43% the mass of dry wood[20]. Incorporation into the biogas plant of correct amount of accessible cellulose would greatly enhance fuel gas production as the results of this preliminary investigation have clearly shown.

The biogas produced in the digesters is primarily methane with carbon dioxide and traces of hydrogen sulphide as major contaminants. If the latter are eliminated, the remaining gas commonly called biomethane has the properties of purified natural gas and be utilized in every applications to replace fossil natural gas such as transportation fuel, raw material for chemical industry, or in fuel cells, which convert the gas to electricity with high efficiency[21].. The carbon dioxide content of the biogas can be removed by passing the gas mixture through a solution of caustic alkali or lime water, while the hydrogen sulphide can be eliminated by passing through water or activated[21].

It should be noted that the biogas from the digestion of a blend of cow manure and pretreated sawdust does not have some of the contaminants of biogas from landfills or municipal waste water treatment plants and is therefore easier to clean up[1].

As gas pressure increases with temperature for a given volume and mass, maintaining the gas reservoir at a low temperature prevenst a large build-up of gas pressure on the inside which ultimately increases the pressure gradient in the opposite direction and mitigate gas flow into the reservoir.

## 5.2 Nutritional Composition of Sludge

The results of the mineral contents of the substrate and sludge are presented in Table 1.

**Table 2: Mean mineral content of substrate and sludge (Dry mass)**

| Element | Value in PS/CM substrate | Value in PS/CM sludge |
|---|---|---|
| Nitrogen | 0.85% | 3.26% |
| Phosphorus | 0.41±0.01 g/kg | 1.64±0.03 g/kg |
| Potassium | 1.21±0.11 g/kg | 3.45± 0.04 g/kg |
| Calcium | 0.64±0.02 g/kg | 1.93±0.11 g/kg |
| Sodium | 0.04±0.01 g/kg | 0.18±0.01 g/kg |
| Magnesium | 0.37±0.13 g/kg | 1.02±0.05 g/kg |
| Iron | 0.55±0.01 g/kg | 1.25±0.12 g/kg |
| Zinc | 0.03±0.01 g/kg | 0.07±0.02 g/kg |

The results in Table 2 show that the expended slurry (sludge) was several times richer in essential mineral elements than the undigested raw materials. The anaerobic micro-organisms converted most of the complex organic matter in the waste to methane and carbon dioxide, leaving a nutrient rich sludge. The activities of the coprophilous fungi present in the cow dung must have been responsible for the release of assimilable inorganic nutrients in the waste matter[14]. The high nutrients load of the organic sludge could be traceable originally to the kind of forage available to the cattle[13].

It is worthy of note that results may differ slightly owing to the kind of nutrition available to both the plants and animals at the time an investigation of this kind may be sought.

## 5.3 Effect of Sludge on Growth of Maize Plant

The effects of sludge-fortified loamy soil on the growth of maize plants (in heights) in millimeters are shown in Table 3.

**Table 3: Mean height of maize plants growing on both sludge-fortified and unfortified loam**

| No of Days | Height of Maize Plant in mm in |
|---|---|

 

| | PS/CM Sludge-fortified soil | Unfortified soil |
|---|---|---|
| 1 | 45 | 38 |
| 2 | 58 | 49 |
| 3 | 75 | 65 |
| 4 | 97 | 73 |
| 5 | 120 | 87 |
| 6 | 152 | 98 |
| 7 | 178 | 105 |
| 8 | 201 | 118 |
| 9 | 232 | 130 |
| 10 | 260 | 148 |
| 11 | 292 | 160 |
| 12 | 324 | 174 |
| 13 | 357 | 187 |
| 14 | 394 | 199 |
| **Mean Height** | **198mm** | **117mm** |

The results in Table 3 show a significant difference ($p<0.05$) in the mean heights of the maize plants growing in both sludge-fortified and unfortified loamy soil. The maize plants growing in sludge-fortified soil showed more rapid growth indicating that the sludge acted as a good organic fertilizer. The results essentially agree with that earlier obtained by Oyewole, O.A. in his paper on Biogas Production from Chicken Droppings[19].

Biogas technology allows production of natural fertilizer in a short period of time. Such fertilizer is rich in active elements and microelements. Manure is not a fertilizer itself. In order to become fertilizer it needs a gestation period (6-7 months). The longer manure is stored the more nutrients it loses.

## 6. CONCLUSION AND RECOMMENDATIONS

Biogas was produced in large quantity by co-digestion of cow manure and pre-treated sawdust. The degraded waste was shown to have nutritional qualities for use as biofertilizer. Agricultural wastes and forest rejects which were hitherto disposed of by biomass burning could now be converted into biofuels and other value-added products to lessen dependence of fossil fuels whose reserves are fast disappearing. The successful incorporation at economic scale of sawdust into the biogas digester plant would certainly mean a new dawn to the ongoing global search for alternative energy because of the enormity of its production at the sawmills.

The authors therefore recommend further research on this topic particularly with the view to improving digester performance, and mixing ratios of these agricultural residues in order to enhance gas yield

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