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# Production of Bio-fertilizer for Sustainable Agriculture with Green Energy Generation using Green Wastes at Cryophilic Conditions

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## Abstract

Energy is crucial to the overall growth of any nation, as urbanization and industrialization increase, so does the rate at which fossil fuels are consumed. Refuse poses a serious challenge to developing nations and undermines the goal of sustainable development that most nations aspire to. Due to inadequate management systems these causes negative effects on the environment and population health, are another significant issue. Converting them to sustainable energy is an economically viable and environmentally advantageous alternative, especially in light of the fast-rising expenses connected with trash management and energy supply. This paper is based on current developments in the process of producing green energy from refuses of Institute Canteen, with the attention to production of bio fertilizers required for sustainable agriculture. In our institute there are two Boys' hostels and one Girls' hostel and all having their own individual mess, where daily a large amount of canteen waste is obtained which can be utilized for variety of functions, such as heating, cooking, and lighting. Wastes were collected and mixed with cow dung in various proportions kept for 90 days for production of bio energy under Cryophilic condition i.e. at very low temperature as the climate is very cold in this hilly region (5-18 °C) which is very challenging for the researchers. It is observed from the study that approximately 4 nos. of cylinder can be saved in 90 days, biogas produced from a 1 $m^3$ digester tank with 2 hours daily consumption. The digestate produced after gas production which is treated as excellent fertilizer for the growth of flower plants in the campus and in the farms of the nearby villages. Different flames are being observed with batch wise feeding of the raw materials to the chamber. With increasing the Hydraulic retention time (HRT), the intensity, color and temperature of the flames changes. The color of the flame observed during the combustion of biogas from organic waste varies from blue color to reddish yellow mixture.

***Keywords:*** Greenhouse gas (GHG); Biogas Digester; Organic wastes; Anaerobic digestion; digestate; Cryophilic condition; flames; fertilizers

## Introduction

Biogas is one of renewable energy sources found in nature that can be utilized in place of burning fossil fuels. The benefits of biogas include nutritional value, environmental protection, and sustainability. Biogas is produced through anaerobic digestion from a variety of organic wastes, including food wastes, animal wastes, agricultural wastes, and sludge.

India confronts issues as a result of global price volatility, especially in terms of its reliance on imported fossil fuels, which has a negative impact on its balance of payments. The country also faces a substantial accumulation of food waste created by canteens and restaurants, particularly with our institution NIT Sikkim, Ravangla, contributing considerably to this problem. The on-campus canteen mess of NIT Sikkim, creates a significant quantity of food waste, which causes environmental and health issues like unpleasant odours and this can be alleviated by the production of greenhouse bio gases and conversion to bio fertilizers.

The institution can successfully manage its food waste while also accepting the potential of biogas as a sustainable energy source by building a biogas-producing system. This method has a number of advantages, including lowering environmental and health concerns connected with food waste buildup and offering a sustainable energy source that can help the country reduce its dependency on imported fossil fuels. This method focuses on the issue of food waste on campus, but it also provides an alternative source of energy that can be utilised for a variety of functions, such as heating, cooking, and lighting.

The study attempted by S. Shrestha et al [2], to solve the difficulty of solid waste management, particularly organic waste by evaluating the production of biogas from canteen trash. For 48 days, an innovative urban biogas plant was employed to analyse the physicochemical properties of the trash and bio slurry. According to the findings, canteen garbage has favourable physicochemical properties for biogas generation. The biogas plant produced 22.03 litres of biogas per kilogramme of garbage and 120.47 litres per day on average. The biogas composition was around 48.89% methane and 39.11% carbon dioxide. In addition, the facility exhibited the potential to cut 3.20 tonnes of $CO_2$ equivalent each year.

According to the study, kitchen trash is acceptable for anaerobic digestion, with one kilogramme providing 22.03 litres of biogas and 120.46 litres produced daily. This shows that installing biogas plants in urban houses might successfully address municipal organic waste management concerns. Furthermore, biogas may be used as a renewable source of energy for cooking, and the waste, known as bio-slurry, can be used as fertiliser. Biogas production also helps safeguard the environment by lowering greenhouse gas emissions. Economically, the urban biogas plant is viable and lucrative.

Global warming is an important problem, and lowering greenhouse gas emissions and developing alternative energy sources are critical. Biogas generation from food waste is regarded as a viable means of reducing GHG emissions, particularly in Asian nations such as India and China. This study by Saji Ananthu [6] looks at the viability of producing biogas from food waste in Swedish restaurants. Three different restaurant scenarios were studied, and the findings showed that generating biogas from food waste is possible in Sweden. It may be used as an alternative cooking fuel, offering both economic and environmental advantages. Temperature issues in Sweden during the winter can be solved with pre- heating procedures.

This research focuses on small-scale biogas generation utilising food waste from three Swedish restaurants. According to the findings, all three restaurants have the ability to create biogas, which may be used as cooking fuel for more than 15 hours each day. The study examines the benefits and drawbacks of small- scale biogas generation, biogas composition, and the design of appropriate anaerobic digesters.

The purpose of the research performed by Sandila Shrestha et al. [7] was to deal with the problem of solid waste management, primarily organic waste, by evaluating the production of biogas from canteen trash using an innovative urban biogas plant. The physicochemical properties of the trash and bio-slurry were investigated, as well as the quantity of biogas, methane, and carbon dioxide produced. The biogas plant produced 22.03 litres/kg of trash and 120.47 litres/day of biogas, with an average methane and carbon dioxide level of 48.89% and 39.11%, respectively. The factory also achieved a decrease in $CO_2$ equivalent of 3.20 metric tonnes per year.

Food waste is a serious issue at MU, and transforming it into biogas via anaerobic digestion provides a long- term solution. The research by Gebrehiwet Abrham Gebreslase et al. [13] looks at the possibility of using MIT's food waste to generate biogas. The composition of the food waste was examined, including total solids, volatile solids, moisture content, and ash content. Experiments were carried out in order to establish the best mixing ratio of food waste and water for biogas output. Based on hydraulic retention duration and daily substrate input, an underground fixed-dome anaerobic digester was constructed. The syringe method was used to measure biogas output, and a mathematical equation was used to forecast it. The biogas generation rate and amount of residue (digestate) generated were determined using process simulation. The biogas composition was determined to be 52.24% methane, 47.75% carbon dioxide, 0.01% hydrogen sulphide, and 0.0000071% water from a daily input of 100 kg of food waste combined with 400 litres of water.

The outcomes of experiments and simulations show that food waste has substantial potential as a source of biogas energy. The anaerobic digester ran at mesophilic temperatures and had a hydraulic retention duration of 30 days. The modelling results revealed that a feed rate of 497.882 kg/day may create 93.187 kg/day of biogas. By combining food waste with water in a 1:4 ratio and adding cow manure as an inoculant, the biogas generation was maximised.

A. S. Chowdhury et al. [24] did a study that looked at the biogas production capability of paper waste (PW- A) and its 1:1 blend with cow dung (PW:CD). The wastes were digested anaerobically over a 45-day period at a mesophilic temperature range. Physicochemical parameters as well as microbiological analyses were performed. PW had a total gas yield of 6.23 0.07 $dm^3$/kg of slurry, with gas production dropping initially but increasing after 14 days. Blending with cow manure boosted the total gas output by more than half, to 9.340.11 $dm^3$/kg slurry. The study emphasises the potential of paper waste as a fuel for biogas generation, with mixing improving gas flammability over time.

Several inferences can be drawn based on the observations and outcomes gained. For starters, biogas digester systems provide leftover organic waste with exceptional nutritional characteristics that may be utilised as manure. Second, hydrogen may be created in an ecologically sustainable manner. Third, fuel cells for portable electronic devices can be produced, supplying efficient energy via electrochemical processes that are free of pollutants. The anticipated daily canteen trash may be successfully utilised to establish four biogas plants, creating manure, biogas for cooking, and power for campus lighting. This results in an immense cost reduction of Rs 38,828 per year from a one-time expenditure of Rs 60,000.

From the literature survey, it has been observed that few authors worked on biogas production using some wastes in mesophilic and thermophilic conditions but there is limited research on production of biogas from canteen waste and fruit waste under Cryophilic condition (below 20°C). The NIT Sikkim in situated in such a place where the temperature ranges is mostly below 20°C. So, the challenging research in this project is to produce bio methane (green energy) from the Canteen waste of the institute and rotten fruits collected from the local market of Ravangla which are unhygienic to the environment and are properly utilized for the production of green energy by using experimental method. Conversion of wastes into fertilizer which are very essential nutrients for growth of crops and effective utilization of the refuses with production of green energy. Different flames are being observed batch wise feeding of the raw materials to the chamber. With increasing the hydraulic retention time, the intensity, color and temperature of the flames changes. The color of the flame observed during the combustion of biogas from organic waste varies from blue color to reddish yellow mixture. An experiment has been carried out by using biogas digester to accomplish these objectives.

## Materials and Methods Experimental Analysis

### *Sorting of Waste*

| *Sl. No* | *Materials* | *Capacity (lit)* | *Height (m)* | *Diameter (m)* |
|---|---|---|---|---|
| 1 | Digester | 1000 | 1.2 | 1.2 |
| 2 | Floating drum | 500 | 0.6 | 1.1 |
| 3 | PVC pipes | - | 0.9 | 0.1 |
| 4 | hoses | - | - | 0.015 |

***Table 1:*** Specification of the digester.


***Figure 1:*** Experimental setup.

The floating drum digester was used for experimental analysis because of its greater efficiency and longevity. Further, numerous analyses were conducted on both cow dung and canteen wastes to determine the bacterial formation needed to start the generation of biogas.

At first, trash was collected without being sorted. But our goal was to sort the biggest waste, so we sorted the collected waste with the help of hand as shown in figure 2 below and is further processed.

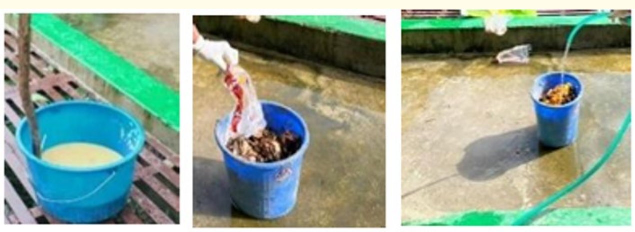

***Figure 2:*** Sorting of waste.

The process of producing biogas from canteen waste and fruit waste in the following manner. A 1:1 mixture of finely ground Cow dung and water is created, subsequently a 1:1 mixture of finely ground kitchen waste i.e. cooked rice and water was created. Water was utilised as feed to the tank for every 1 litre of solid organic waste (5 kg canteen waste and 90 kg cow manure). Adding a sufficient amount of water to the organic matter is critical because it produces a favourable environment for quick breakdown and gives the substrate with fluid qualities. Because we lack an appropriate mechanism to produce high temperatures, at NIT Sikkim as the temperature is mostly less than 20°C. So psychrophilic inoculum is used for the production of biogas. The complete degradation of the substrate will result in the production of biogas through bacterial activity after 60-90 days. Furthermore, frequent stirring is used to enhance degradation and gas generation. Due to the pressure differential, the gas collects in the dome, while the substrate begins to migrate towards the balancing tank. The substrate is directed into the second tank through the outflow pipe, where it undergoes psychrophilic reaction. As a result, the residual gas is produced and pulled through the gas valve and collected by connecting a pipeline and supplied to the single burner gas stove. The different flames produced by single burner are observed in various days batch wise is as shown in the figures [9-13]. After the production of biogas, the digestate is removed from tank outlet and is used as a fertilizer for plantation.

### *Waste Measurement*

The weight has been measured at a regular interval of 2-3 days for a period of three months with the help weighing machine in the departmental workshop as shown in figure 3.

***Figure 3:*** Measurement of waste collected.

### *Wastes and Ratios*

At first 5 kg each of waste (Cooked Rice, vegetable peels, potato peels from NIT canteen and fruit waste from local market) were collected for the experiment. These were chosen because these were the primary waste produced at the National institute of technology, Sikkim and the local market of Ravangla. The ratios of waste to water selected were 1:1 - 1:2. Waste was mixed and mashed using hand and some cutting tool as shown in figures 5-8. The scraps were ground to a fine size using cutter. Mixing the waste will increase the contact area for the microorganisms, which will lead to better digestion. Rice, vegetable peels, fruits(rotten) and potato peels were well mixed with water to create different ratios of (1:1, 1:2) by fixing total mass of wastes and varying amount of water.

| *Waste* | *Waste amount(kg)* | *Added water (l)* | *Ratio* |
|---|---|---|---|
| Cow dung | 90 | 90 | 1:1 |
| | | 180 | 1:2 |

***Table 2:*** Waste to water ratio for cowdung.

| *Waste* | *Waste amount(kg)* | *Added water (l)* | *Ratio* |
|---|---|---|---|
| Cooked rice | 5 | 5 | 1:1 |
| | | 10 | 1:2 |

***Table 3:*** Waste to water ratio for cooked rice.

| ***Waste*** | ***Waste amount(kg)*** | ***Added water (l)*** | ***Ratio*** |
|---|---|---|---|
| Vegetable peel | 5 | 5 | 1:1 |
| | | 10 | 1:2 |

***Table 4:*** Waste to water ratio for vegetable peel.

| ***Waste*** | ***Waste amount(kg)*** | ***Added water (l)*** | ***Ratio*** |
|---|---|---|---|
| Potato peel | 5 | 5 | 1:1 |
| | | 10 | 1:2 |

***Table 5:*** Waste to water ratio for potato peels.

| ***Waste*** | ***Waste amount(kg)*** | ***Added water (l)*** | ***Ratio*** |
|---|---|---|---|
| Rotten fruits | 5 | 5 | 1:1 |
| | | 10 | 1:2 |

***Table 6:*** Waste to water ratio for Rotten fruits.

***Figure 4:*** Small pieces of cut vegetables (rotten) from Local market.

***Figure 5:*** Cooked rice from canteen.

***Figure 6:*** Mashed potato peels from canteen.

***Figure 7:*** Fruit wastes from local market.

### *Gas Analysing and Data Recording*

The biogas produced during the experimentation was collected and analysed by employing a gas analyser. Gas was analysed on a regular basis with a gas analyser during conduction of the experiment.

A gas analyzer gathers and analyses different gases released by combustion processes occurring inside the digester. Carbon dioxide ($CO_2$), carbon monoxide (CO), oxygen ($O_2$), nitrogen oxides ($NO_x$), sulphur dioxide ($SO_2$), and rest as methane ($CH_4$) are the most common gases formed as shown in the analyser. The analyser measures the concentrations of these gases in the gas with sensors or probes. The measurements are mainly based on concepts such as infrared absorption, electrochemical processes, or paramagnetic phenomena, which provide reliable values for each gas component.

***Figure 8:*** Gas analysing using gas analyser.

### *Verification of Methane Production*

A flame at the end of the outflow port was put to use to confirm the presence of methane. The presence of methane in the gas generated was identified by the continuous blue flame.

***Figure 9:*** Verification of methane on 1st batch.

***Figure 10:*** Verification of methane on 2nd batch.

***Figure 11:*** Verification of methane on 3rd batch.

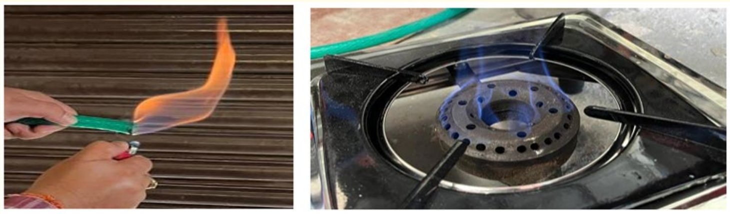

***Figure 12:*** Verification of methane on 4th batch.

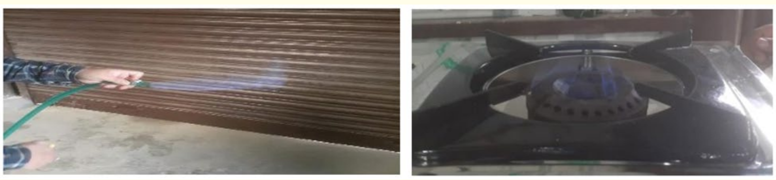

***Figure 13:*** Verification of methane on 5th batch.

The color of the flame from a biogas digester can indeed give insights into the quality of the methane and the health of the digestion process. Here's a breakdown of what different flame colors generally indicate:

### *Blue Flame*

A blue flame is a sign of efficient combustion and indicates that the methane is being burned cleanly. This is similar to the flame produced by natural gas, which is highly desirable.

### *Yellow Flame*

A yellow flame suggests incomplete combustion and usually indicates a higher level of carbon dioxide or other impurities in the biogas. This can be a sign that the digestion process is not optimal.

### *Reddish Yellow Mixture*

A flame with a reddish yellow hue combined with blue suggests a mixture of gases. This can occur if the biogas has been purified to some extent but still contains other components. The presence of both colors indicates a partial or inconsistent combustion process.

Monitoring the flame color is a useful way to gauge the performance of a biogas digester and to identify potential problems in the digestion process. Adjustments in the system or further purification may be needed if persistent issues are detected.

| *Sl. No* | *Name of the Hostel* | *Consumption of LPG (per month)* |
|---|---|---|
| 1 | BH1 and BH2 Boys Hostel | 180x14.2=2556 kg |
| 2 | Girls Hostel | |

***Table 7:*** LPG consumption in various hostels of NIT Sikkim.

### *Analysis on biogas production*

Calorific value of Biogas = 4.16 kWh/$m^3$.
Calorific value of LPG = 26.1 kWh/$m^3$.

A sample of 100 gm water is boiled. The Energy required to boil 100 gm. water = 30.03 kJ and for 1kg energy required= 300.3 kJ.

From the study 199.8 kg of biogas is generated using the wastes.

Usually, 1 LPG cylinder contains 14.2 kg of gas 1$m^3$ biogas equivalent to 0.43 kg, So 14.2 kg of biogas=33.02$m^3$.

1 LPG cylinder contains 33.02 $m^3$ of biogas but the biogas generated in our study is 125.56 $m^3$ so we can save 3.8 (approx. 4) nos. of cylinder in 90 days from 1 $m^3$ tank is used for 2 hours daily.

### *Characteristics of Biogas*

The composition of biogas is also affected by the feed material. Biogas is approximately 20% lighter than air and has an ignition temperature of 650 to 750 °C. An odourless and colourless gas with a blue flame, comparable to LPG gas. It has a caloric value of 20 megajoules (MJ) per $m^3$ and typically burns at 60% efficiency in a traditional biogas burner.

Depending on the nature of the activity and local supply circumstances and limits, this gasoline can be used as a fuel to replace firewood, cowdung, petrol, LPG, diesel, and electricity. Biogas digestor systems provide leftover organic waste after anaerobic digestion (AD) that has greater nutritional values than conventional organic fertiliser since it is in the form of ammonia and may be used as manure. Anaerobic methane digesters also serve as waste disposal systems, notably for human waste, and can therefore help to avoid possible sources of environmental pollution as well as the spread of diseases and disease-causing germs. Biogas technology is very useful in the agricultural residual treatment of animal excreta and kitchen waste (residuals).

## Equations used

The volume occupied by Methane gas in the digester can be calculated using the ideal gas law from Equation:

$$P\,V = nRT \quad \ldots\ldots\ldots (1)$$

$$V = nRT/P \quad \ldots\ldots\ldots(2)$$

At 15 ºC and atmospheric pressure the volume will be:

$$V_{CH4} = (1\text{ Mole})(0.082\text{ L.Atm/Mole.K})(288\text{ K})/(1\text{Atm}) = 23.6\text{ L}$$

Calculating Methane as per the reaction

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \text{ .........(3)}$$

One mole of Methane needs two moles of Oxygen i.e. COD of Methane is 64 g COD per mole of $CH_4$, as a result the volume of Methane produced will be:

$$1L\ CH_4/moleCH_4 \div 64\ gCOD/moleCH_4 = 0.37\ L\ CH_4/g\ COD \text{ .........(4)}$$

Assuming that the Methane composition in the biogas is 60% V the biogas volume will be:

$$0.37\ L\ CH_4/g\ COD \div 0.6\ L\ CH_4/L\ Biogas = 0.61\ L\ Biogas/g\ COD \text{ .......(5)}$$

## Results and Discussion

### *Validation*

The results obtained from the experiment compared with the published literature and the results so obtained are as shown in Figure 14. The experimental results are very good agreement with the available literature.

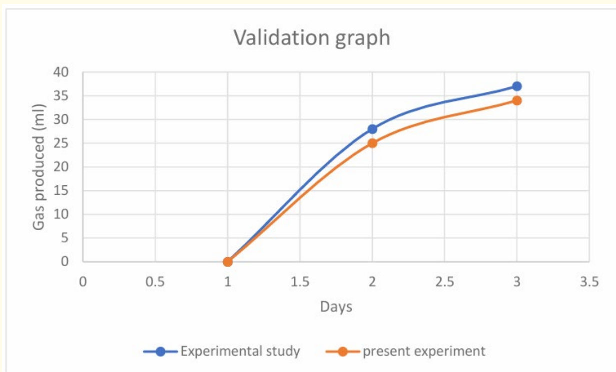


***Figure 14:*** Validation of results [9].

### *Experimental Procedure*

Fresh 90 kg of cow dung, 5 kg of canteen garbage, and the remaining water are collected and mixed by hand before being thrown into the digester in each day. Because it is the microorganisms which are essential for anaerobic digestion. After inoculation, the digester is held for a few days, and the gas output and pH value are measured. We observed that the creation of biogas increases with the day and decreases as the slurry becomes dry; therefore, to boost the generation of biogas, we combined water with the slurry.

### *pH measurement in various days*

The pH value is important for efficient biomethane production because of necessary of optimal conditions for methane-producing bacteria to thrive. The values at different temperature conditions and the amount of gas generated have been observed and presented in Table 8.

| Day measured in batches | Temperature (°C) | pH | Gas (kg) | Gas ($m^3$) |
|---|---|---|---|---|
| 1 | 11 | 6.1 | 43.35 | 0.085 |
| 2 | 14 | 6.3 | 59.007 | 0.1157 |
| 3 | 15 | 6.7 | 66.81 | 0.131 |
| 4 | 17 | 7.1 | 109.09 | 0.2139 |
| 5 | 18 | 6.9 | 152.91 | 0.2998 |
| 6 | 19 | 6.7 | 177.95 | 0.3489 |
| 7 | 19 | 6.7 | 199.86 | 0.8257 |

***Table 8:*** Estimation of Biogas with their pH values.

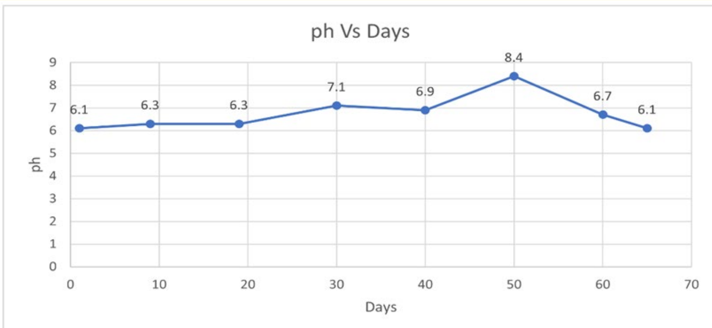


***Figure 15:*** pH Vs Days of digestion.

In this conditions bio gas production occurs and the gas is burned with blue flame due to increase of pH. As the process continues, volatile fatty acids (VFA) are produced which causes the decrease in pH of solution with increase in no of days (Figure 15).

The cowdung mixed with water in various proportions and kept in the digester for 13 days and results are shown in the graphs.

### *Cowdung mixed with water (1:1)*

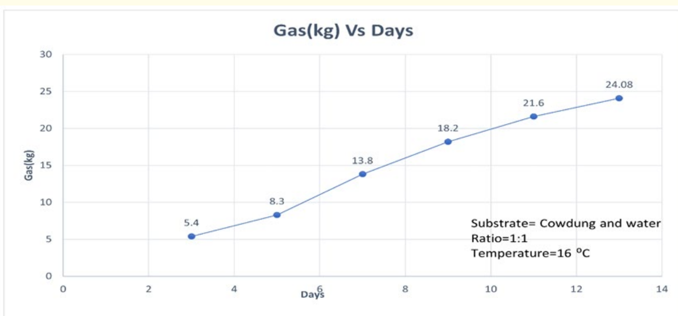


***Figure 16:*** Gas yield (kg) Vs Days of digestion.

From Figure 16, it can be seen that when cow dung and water is mixed in the same ration i.e 1:1, The highest methane production is 24.08 kg. As the no. of days increased, the production of biogas will also be increased and highest in 13th day. The $CO_2$, $O_2$, and $H_2S$ are also produced.

***Cowdung mixed with water (1:2)***

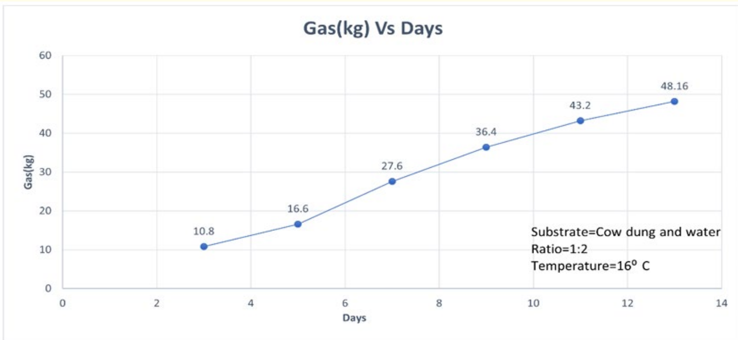


***Figure 17:*** Gas yield (kg) Vs Days of digestion.

From Figure 17, it can be concluded that when cow dung and water is mixed in the ratio of 1:2, The highest methane production is 48.16 kg. This is due to the growth of micro-organism which increases with increase of water content.

The cow dung mixed with cooked rice in various proportions and kept in the digester for 24 days and results are shown in the graphs.

***Cowdung mixed with cooked rice (18:1)***

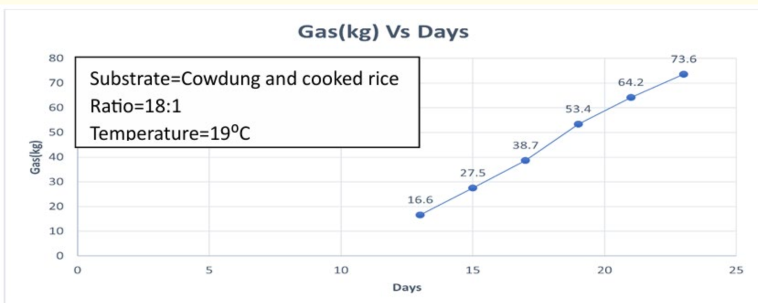


***Figure 18:*** Gas yield (kg) Vs Days of digestion.

From Figure 18, it can be seen that when cow dung mixed with cooked rice in the ratio 18:1. The highest production of methane is 73. 6 kg in the 24 days.

### *Cow dung mixed with cooked rice (18:2)*

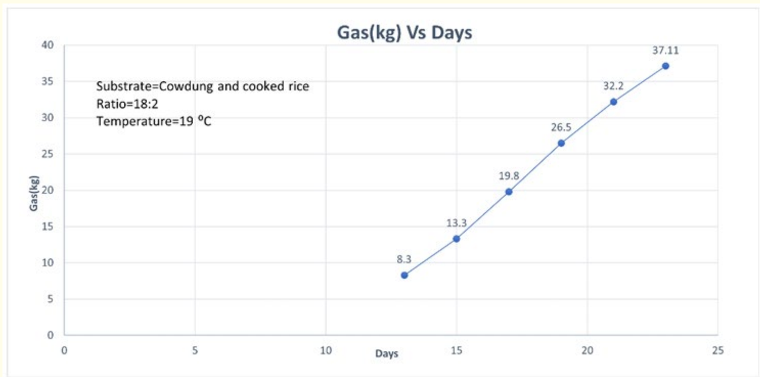


***Figure 19:*** Gas yield (kg) Vs Days of digestion.

From Figure 19, it can be seen that when cow dung mixed with cooked rice in the ratio 18:2, The highest production of methane is 37.11 kg in the 24 days.

The cow dung is mixed with potato peels in various proportions and kept in the digester for 34 days and results are shown in the graphs.

### *Cow dung mixed with cooked rice and potato peels (18:2:1)*

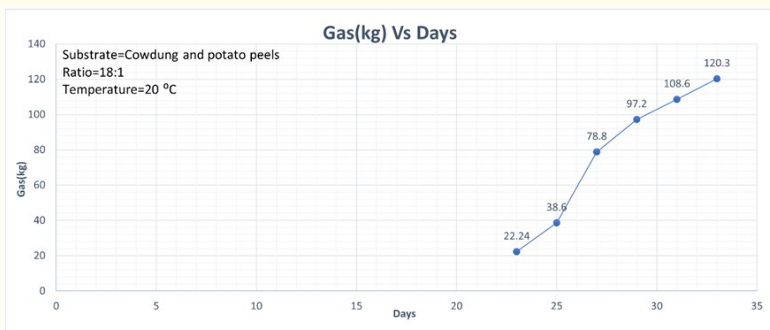


***Figure 20:*** Gas yield (kg) Vs Days of digestion.

From Figure 20, it can be found that when previous cow dung mixture and potato peels are mixed in the ratio of 18:1, The highest methane production is 120.3 kg. This is due to the fact of growth of bacteria inside the chamber effectively.

### *Cow dung mixed with cooked rice and potato peels (18:2:2)*

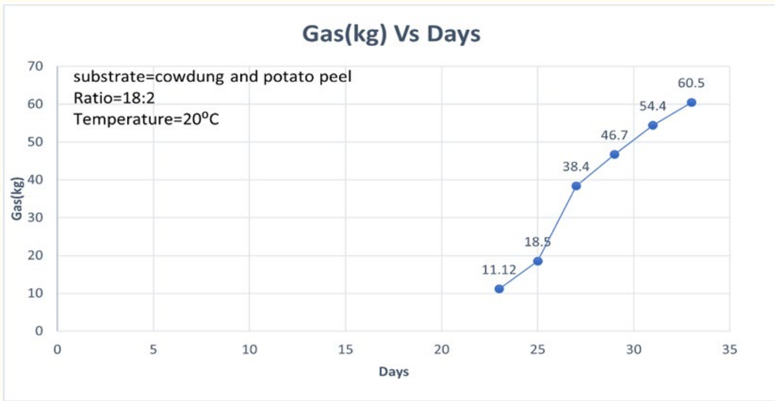


***Figure 21:*** Gas yield (kg) Vs Days of digestion.

From Figure 21, it is found that when cow dung and potato peels is mixed in the ratio of 18:2, The highest methane production is 60.5 kg.

The cow dung is mixed with rotten vegetables in various proportions and kept in the digester for 44 days and results are shown in the graph.

### *Cow dung with cooked rice, potato peels and vegetables (18:2:2:1)*

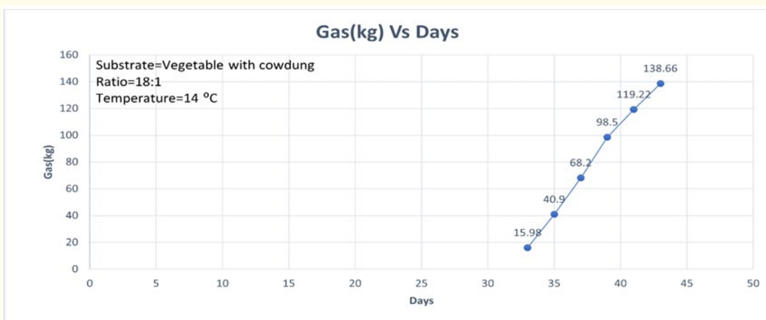


***Figure 22:*** Gas yield (kg) Vs Days of digestion.

From Figure 22, it is found that when cow dung, potato peel mixture and vegetables are mixed in the ratio of 18:1, the highest methane production is 138.66 kg.

### *Cow dung with cooked rice, potato peels and vegetables (18:2:2:2)*

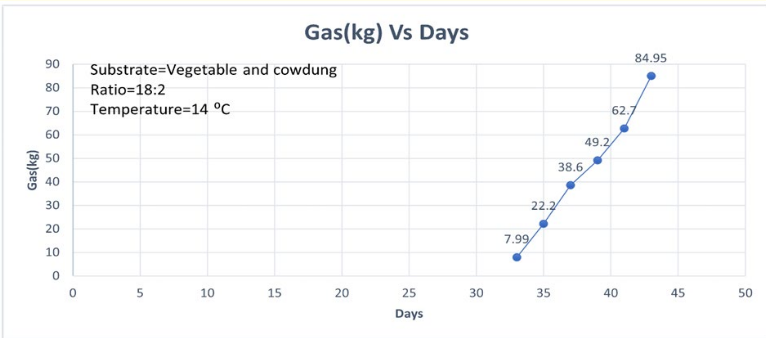


***Figure 23:*** Gas yield (kg) Vs Days of digestion.

From Figure 23, it can be seen that for cow dung mixed with vegetables in the ratio 18:2, the highest methane production is 84.95 kg.

The cow dung is mixed with rotten fruits in various proportion in the digester and kept for 52 days, and the results are shown in graphs below.

### *Cow dung with cooked rice, potato peels, vegetables and rotten fruits (18:2:2:1)*

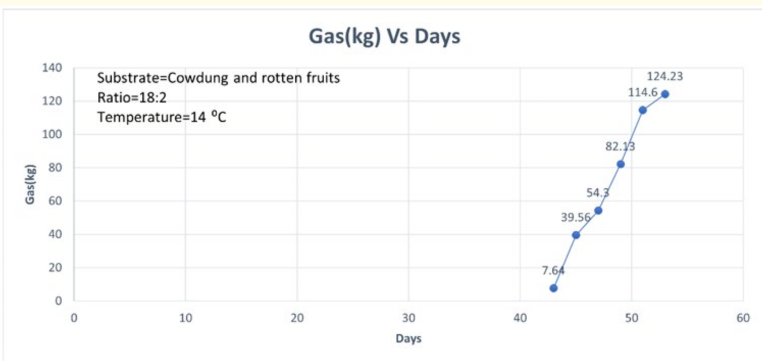


***Figure 24:*** Gas yield (kg) Vs Days of digestion.

From Figure 24, it can be seen that when cow dung, potato peel, vegetable mixture mixed with rotten fruits in the ratio 18:1, The highest methane production is 124.23 kg.

### *Cow dung with cooked rice, potato peels, vegetables and rotten fruits (18:2:2:2)*

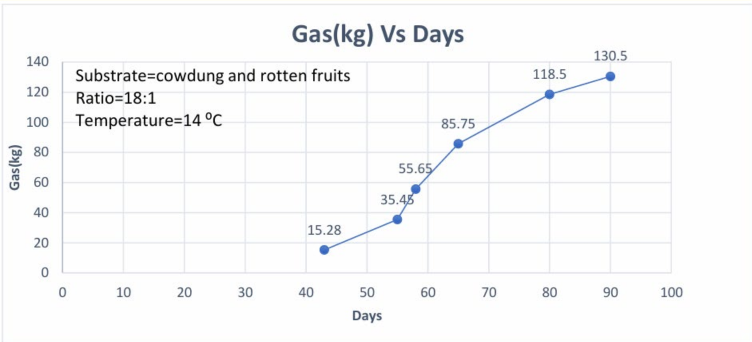


***Figure 25:*** Gas yield (kg) Vs Days of digestion.

From Figure 25, It can be seen that when cow dung mixed with rotten fruits of grapes, apples and banana in the ratio 18:2, the highest methane production is 130.5 kg. This is due to the rapid growth of micro- organisms with increase the no. of days (90 days).

### *Estimation of Temperature for Calorific value calculations of Biogas*

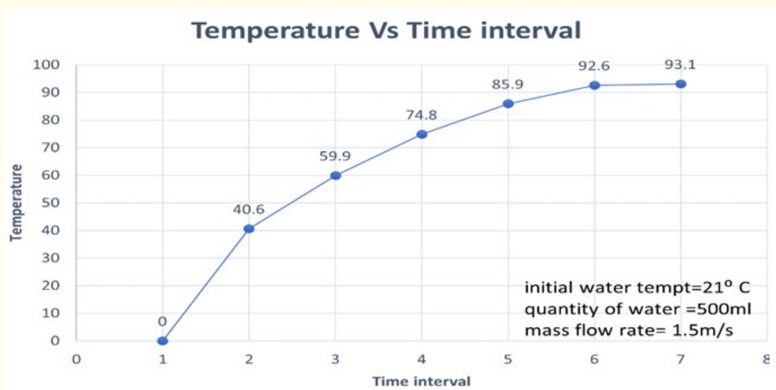


***Figure 26:*** Temperature at various time intervals with Mass flow rate of 1.5 kg/s.

From Figure 26, it has been found that with no load condition, the water temperature increases slowly from initial temperature of 40.6 °C and slowly it increases, at mass flow rate of 1.5 kg/s.

***Figure 27:*** Measurement of temperature required for calorific value of bio gas calculation.

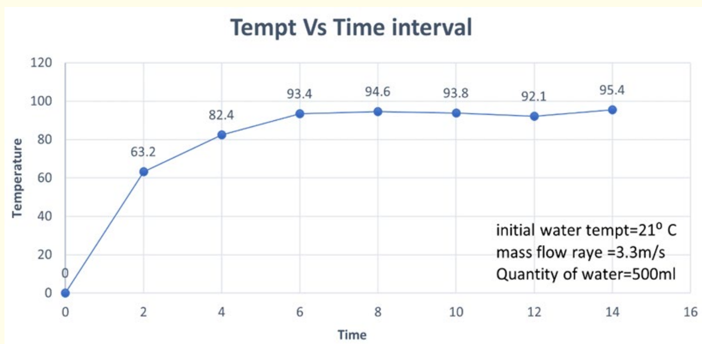


***Figure 28:*** Temperature at various time intervals with Mass flow rate of 3.3 kg/s.

From Figure 28, it has been found that when the mass flow rate is increased to 3.3 kg/s, by applying external load, the water temperature rises up to 63.2 °C initially and further it increases with load.

### *Comparison between the gas generated from banana peels and mango peels*

Both during material processing and at the consumer level, the fruit and vegetable industries generate a lot of waste. Inedible portions of fruits and vegetables (peels, seeds, kernels, tails, and pomace) make up the majority of these wastes, but there are also sizable amounts of raw materials that were changed during transport and storage, particularly in the case of highly perishable materials, as fruits and vegetables have the highest wastage percentage. This is combined with effluent from the processing of various foods made from fruits and vegetables, which have a relatively high concentration of organic chemicals. The creation of juices, conservation, winemaking, and the extraction of oils and sugar from various plant sources all produce significant volumes of trash. The Banana peels and mango peels waste plentily available in the local market of Ravangla were collected and tested for the production of biogas.

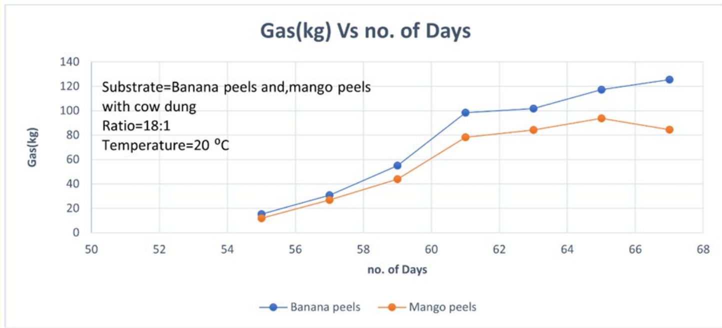


***Figure 29:*** Gas yield comparison between banana peels and mango peels.

From Figure 29, it is found that the banana peels produce more methane content than the mango peels. It is due to fact that the decay of banana peels by the micro-organisms rapidly increases with the increase of no. of days as compared to the mango peels.

### *Estimation of Biofertilizer Values*


***Figure 30:*** Production of Fertilizer by complete conversion of Mess refuses at outlet of plant.

The digestate includes Nitrogen, phosphorous and potassium which promotes the growth of plants. The nitrogen (N) (0.8%-1.5%) is the major plant nutrient. The concentration of phosphorous P (0.4%-0.6%) and potassium K (0.6% -1.2%) in biogas waste is best used as soil nutrients. The biogas residue produced at the outlet is now user friendly for the agricultural community. The fertilizer basically refers to any mixture containing all three important elements like N (nitrogen), $P_2O_5$ (phosphate equivalent), and $K_2O$ (potash equivalent). Generally, the Urea contains 46% N and is graded as (46-0-0), and its current price is 538 ETB per 100 kg. Bio-fertilizer includes micronutrients of Sulphur, Calcium, Magnesium in addition to N, P and K. These substances are responsible for healthy growth of plant and also protect flowers from diseases that inhibits their development. These micronutrients are vital for flowering and predominantly the green coloration of leaves.

Absolutely, organic fertilizers are gaining traction due to their sustainable and eco-friendly benefits. When biofertilizer from a biodigester is added to a compost heap, it can significantly enhance the overall quality of the compost. Here's how:

1. *Nutrient Enrichment*: Biofertilizers often contain a rich mix of nutrients that are essential for plant growth, including nitrogen, phosphorus, and potassium. When added to compost, these nutrients get mixed with the organic matter, leading to a more balanced and nutrient-dense compost.
2. *Microorganism Activity*: Biodigesters produce biofertilizers that are teeming with beneficial microorganisms, such as bacteria and fungi. These microorganisms help to break down organic matter more efficiently, which improves the composting process. They also contribute to a more robust microbial community in the compost, which is vital for healthy plant growth.
3. *Improved Plant Growth and Health*: The enriched compost results in a more fertile soil environment. Plants grown in such soil benefit from better nutrient availability and improved soil structure, leading to healthier and more vigorous growth.
4. *Increased Crop Production*: With enhanced soil fertility and better plant health, crops generally experience increased yields. The balanced nutrient supply and improved soil conditions support more robust plant development.
5. *Enhanced Disease Resistance*: Healthy plants grown in nutrient-rich, biologically active soil are generally more resistant to diseases. The beneficial microorganisms in the biofertilizer can also help suppress soil-borne pathogens, further reducing the risk of plant diseases.

Overall, incorporating biofertilizer into compost not only supports a more sustainable approach to agriculture but also improves the efficiency and effectiveness of composting, leading to better outcomes for plant health and crop productivity.

The cost-effectiveness is assessed by comparing the cost of purchasing commercial fertilizers with the savings from using biogas digestate. For urea, the cost of obtaining the equivalent amount from digestate is 12,822.50 ETB, while phosphorus fertilizer costs 514.40 ETB. For potash, the cost is 1,080.40 ETB. Adding these costs gives a total of 14,417.30 ETB [25] from digestate, compared to buying these fertilizers directly. So, there may be cost savings by comparing these values to the cost of commercial fertilizers for the same nutrient content.

## Conclusions

In this paper the wastes from the NIT Sikkim canteen and from the local market of Ravangla is made into use in the experimental setup for biogas production. Wastes like cooked rice, potato peels, rotten vegetables and rotten fruits are collected and are mixed with cow dung in various proportion kept for various days for production of bio methane gas at cryophilic condition. Also, a comparison between the gas produced by the different fruit wastes like banana peels and mango peels has been established. The digestate produced as by product is used as best fertilizer for growth of plants in the campus and nearby villages farms.

It has been concluded from the experimental study that:

1. Approximately 4 nos. of cylinder can be saved in 90 days from 1 $m^3$ gas tank used for 2 hours daily.
2. The calorific value calculated is 15 $MJ/m^3$ approximately without considering the losses.
3. Food waste has a lot of energy potential, however because of the low pH compared to cow dung, the other gases produced were $CO_2$, $O_2$, and $H_2S$. Hence food wastes are mixed with the cow dung.
4. The cooked rice, potato peels, rotten vegetables, rotten fruits are the excellent source of methane production which were created huge amount of wastes in the institute and market.
5. Banana peels have more methane content as compared mango peels with less HRT.
6. Gas generation was appreciable and methane was existent under the cryophilic condition.
7. Despite the fact that without maintaining the incubator temperature at $37^0$C resulted in a high amount of bio gas generation from canteen trash and fruit wastes which is very challenging for the researchers.
8. The final observation of this study clearly indicates that refuses produced from the mess can be effectively used for the production of green energy and its continuous production is also possible installing a setup at the low temperature hilly regions.

The current investigations suggest that the green wastes hold significant promise for several important outcomes.

*Recover Bio-Energy Efficiently*: It can effectively convert green waste into valuable bio-energy, enhancing energy recovery from organic waste.

*Reduce Landfill Waste*: By processing green wastes, the volume of waste sent to landfills is significantly reduced, alleviating landfill pressure.

*Lower Greenhouse Gas Emissions*: It produce methane compared to landfilling, thereby helping to mitigate greenhouse gas emissions.

*Promote Renewable Energy Use*: The biogas produced can be used for various applications, including cooking, heating, and electricity generation, supporting the shift towards renewable energy sources.

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