2026 Volume: 02 Issue: 06 www.ijrpa.com ISSN 2456-9995 Research Article

International Journal Research Publication Analysis

Page: 01-17

DESIGN, DEVELOPMENT, AND PERFORMANCE ANALYSIS OF A BIOMETHANATION SYSTEM FOR WET ORGANIC FRACTIONS OF MUNICIPAL SOLID WASTE IN AN INSTITUTIONAL CAMPUS

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Article Received: 1 May 2026
Article Revised: 21 May 2026
Published on: 11 June 2026

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DOI: https://doi-doi.org/101555/ijrpa.2303

ABSTRACT

Traditional methods of disposing of municipal solid waste (MSW) are becoming unsustainable in rapidly expanding metropolitan areas, making MSW management an urgent socialand environmentalconcern. Localized and ecologically friendlyoptions are even more important in light of public opposition to constructing centralized waste treatment facilities close to residential areas.

This research details a method for evaluating and reusing wet organic waste from segregated municipal solid waste (MSW) on a university campus. In order to establish if the biodegradablefractionwassuitableforanaerobicdigestion,itwasfirstisolated,measured,and tested using recognized analytical procedures. To assess the possibility of producing biogas, controlled biomethanationtrials were run, and the leftover digestate was studied for its use as an organic soil amendment.

Usingasinglecampusasanexample,theauthorspresentasmall-scalecircularsystem that recycles nutrients, energy, and garbage. Producing valuable byproducts like biogas and bio-fertilizer, the strategyis easyto implement, scales upor down, and needs little inthe way of supporting infrastructure.

Decentralizedbiomethanationoforganicwastefromcampusesisadvantageousfroma practicaland technicalstandpoint, according tothe results. Renewable energyproductionand soilenrichment can be achieved throughthestudy'sdemonstrated effectiveutilizationofsuch waste streams. Supporting sustainable waste management techniques and minimizing dependency on landfill disposal, this approach can be reproduced in similar institutional or residential situations.

1. INTRODUCTION

Many Indian cities are finding it harder and harder to manage their Municipal Solid Waste(MSW),whichiscausingunhappinessintheneighborhoodssurroundingthesefacilities.

Protests, limited access to transportation vehicles, and opposition to processing unit constructionarecommonwaysinwhichresidentsoftheselocationshavefoughtagainstwaste management operations. Theserepliesshowhowtraditionalmethodsofgarbage management are causing more and more socialand environmentalproblems. The commonassumptionthat MSW management is entirelythe purview ofUrbanLocalBodies (ULBs) is a major problem because it discourages public participation and leads to wasteful and uninformed disposal methods. It is obvious that waste needs to be acknowledged as a recoverable resource due to theincreasingratesofwastegenerationcausedbycontinuousurbanizationandeconomic development. This change can only be made possible with the help of the public, businesses, andagreaterunderstandingoftheissue, aswellastreatmenttechnologiesthat arebothpractical and financially feasible, so that theycan influence legislative decisions in the future.

Thisstudy'stargetcityisaClass-IIurbancenterwithanestimatedpopulationofaround 400,000 and adailyMSWgenerationrateofnearly140 metrictons,or around 0.74 kilograms per person. This is a discernible rise in trash production as compared to previous estimations. The CityMunicipalCorporation(CMC) currentlycontracts withoutside companies to handle garbagecollectionanddisposal.Thegarbageishauledtoadumpthatisclosetoanearbytown.

Groundwater contamination, falling soil quality, and related health hazards are some of the environmentalconcernsthathavedevelopedasaresult ofthispracticethroughouttime. Legal action limited additionaldumping efforts and forced authorities to seek alternate solutions, as a result of the substantial opposition from local communities caused by these affects.

The city's educational institution saw these problems coming and set out to provethat MSW management could be decentralized and sustainable. The campus produces a steady streamoforganicandinorganicwasteduetotheoperationoffacilitieslikedormsandacentral eatingunit,whichhousearound4,000people(includingstaffandstudents).A comprehensive analysiswascarriedouttomeasureanddescribethebiodegradablefractionofthewastestream, as well as to assess its potential for anaerobic digestion. Laboratory, pilot, and larger operational scale experimental investigations were conducted using specially designed digestion systems; these investigations formed the basis of the present study.

The majority of municipal solid trash is organic, although there is also recyclable material and biodegradable (wet) and non-biodegradable (dry) components. This study used anaerobicdigestiontocreatebiogasandanutrient-richdigestatefromthecampus'swetorganic portion. A university hostel largely replaced traditional LPG usage with the produced biogas, illustrating the practicalimplementationofrenewable energysystems in institutionalsettings, and the biogas was used as a supplementaryfuel. Inaddition, dryorganic waste and digestate can be mixed to make compost, which can be used as a greener substitute for chemical fertilizers and to help enhance soil health.

An ecologically sound and decentralized methodology for recycling municipal solid waste(MSW)ispresentedinthisresearch.Itispossibletoapplythesuggestedbiomethanation method in comparable community or institutional contexts because it is flexible. Within the context of a circular economy, it lays forth a realistic plan for responsibly managing trash, recovering energy on-site, and making the most of available resources.

2. LITERATUREREVIEW

Rising levels of MSW are a problem all over the world, and they're mostly caused by things like shifting consumer habits, more urbanization, and environmental concerns. Biologicaltreatmentmethods,especiallyanaerobicdigestion,areaviablechoiceforstabilizing waste and generating energy in manydeveloping regions since biodegradable material makes up a considerable portion of total waste.

There are still major environmental problems caused by improper garbage collection and disposal methods. Emissions of greenhouse gases, groundwater contamination, and ecological imbalance over the long term are all results of unregulated dumping [1]. Because they lessen the need for transportation and reliance on landfill sites, decentralized waste processingsystemshavebecomemorepopularasasolutiontotheseproblems.Lowpublic knowledge, insufficient segregation methods, andsocial hostilityto wastetreatment facilities are often problems that hinder their implementation, though [2].

Different demographic and socioeconomic factors contribute to different types of municipal solid waste (MSW). Anaerobic digestion is a good fit for biodegradable organic matter, which makesup asignificant amount ofmunicipaltrash inIndia—usually between50 and 60% [3]. Research on both a small and large scale has shown that this kind of waste can beefficientlyturned into biogas. What's more,theleftover digestatecanbeusedasanorganic soil conditioner, which negates the need for artificial fertilizers [4].

Research on both decentralized and institutional systems has shown that steady functioningdependsonefficientsourcesegregationandconsistentfeedstockquality. Methane yield and overall system performance are further improved by using preprocessing methods and controlled feeding strategies [5]. Evidence also suggests that process parameter optimization—including retention time, temperature, and loading rate—has a substantial impact on digestion system efficiency and dependability [6].

Studies on the financial viability of biomethanation systems on a smaller size have shown that they can reduce the need for fossil fuels, especially at larger institutions. These systems can help with circular resource utilization and lessen reliance on fuels like LPG by producing biogas locally [7]. In addition to enhancing soil qualities, using digestate as an organic amendment helps promote sustainable farming practices [8].

Anaerobicdigestionprocesseshaverecentlybeenthetargetoftechnicaldevelopments aimed at making them more efficient and stable. There has been an improvement in performance and a rise inconversionefficiencyas a result ofdevelopments inreactor design, monitoringsystems,andhybridtreatmentprocedures.Theseadvancementsarestillnotenough to eliminate operational concerns like odor generation, seasonal changes in waste characteristics, and feedstock composition fluctuations.

Anaerobic digestion systems, according to long-term studies, can keep performing consistently under different conditions as long as they are well-managed [11]. In order to maximize biogas generation, research has also highlighted the significance of pretreatment, moisture management, and balanced organic loading [12], [13]. Methods that are known to significantly impact methane production include regulated nutrition balance and co-digestion [14].

Newstrategiesarebeinginvestigatedinaneffforttoimprovetheefficiencyofdigestion and the activity of microbes. Some studies have found that designed microbial systems can stabilize digestion processes[15], while others have found that adding biochar improves methane output by encouraging microbial interactions [16].

There have been great strides, but there are still a number of obstacles that prevent widespreaduse.Theperformanceofcentralizedsystemsisstillimpactedbyinconsistentwaste segregation, insufficient preprocessing, odor-related concerns, and logistical challenges. The implementationofdecentralized,small-scalesolutionsinmedium-sizedcitieshasbeenmostly unexplored, although there has been an uptick in interest in them due to these restrictions, especially in institutional contexts.

Because of their well-defined borders and constant trash generation patterns, educationalcampusesofferanidealregulatedsettingforinstallingsuchsystems.Nevertheless, therearecertaingapsinthecurrentstudy.Forexample,thereisalackofinformationaboutthe characteristicsofinstitutionalwasteintier-2cities,biomethanationisnotadequatelyintegrated with composting techniques, and stakeholders are not well-informed or involved.

This research aims to fill that gap by methodically evaluating and transforming moist organic waste froma universityor college campus. Using waste segregation, biomethanation, and nutrient recovery, it seeks to create a decentralized waste-to-energy model that is both practical and scalable.

3. OBJECTIVESOFTHESTUDY

Thefollowinggoalsarepursuedbytheresearch:

1. To ascertain the amount and dispersion of organic waste (both wet and dry) produced oncampus.
2. Todeterminewhetherwetorganicwasteissuitableforanaerobicdigestionbyanalyzing its physicochemical properties.
3. Developingandexecutingbiomethanationsystemsatvariousoperatingscales,suchaspilot, full-scale, and laboratory versions.
4. TofindoutwhetherbiogascanreplaceLiquefiedPetroleumGas(LPG)incampusbuildings by making it from organic waste.
5. Making enhanced organic manure using digestion leftovers and dry organic waste is goal number five.
6. Tocreateamodelfordecentralizedwastemanagementthatworksinbothurbanand institutional settings.
7. To geteveryoneinvolvedin the process of waste segregation andmanagementthinking about how to make a difference.

4. WORKING:Two-StageFloatingDrumContinuous-TypeBiomethanationPlant

Design and installation ofa 6-meter-squared (m^3) two-stage floating-drumcontinuous biomethanation unit was carried out on campus. The system is made up of a gas holding measuring 1 m^3 and a primary digester measuring 5 m^3. As an example of the practical transformationoforganicwaste into anenergysource,thebiogasthat iscurrentlyproduced is utilized in cooking. In Fig. 2 we can see the system installed on a field scale.

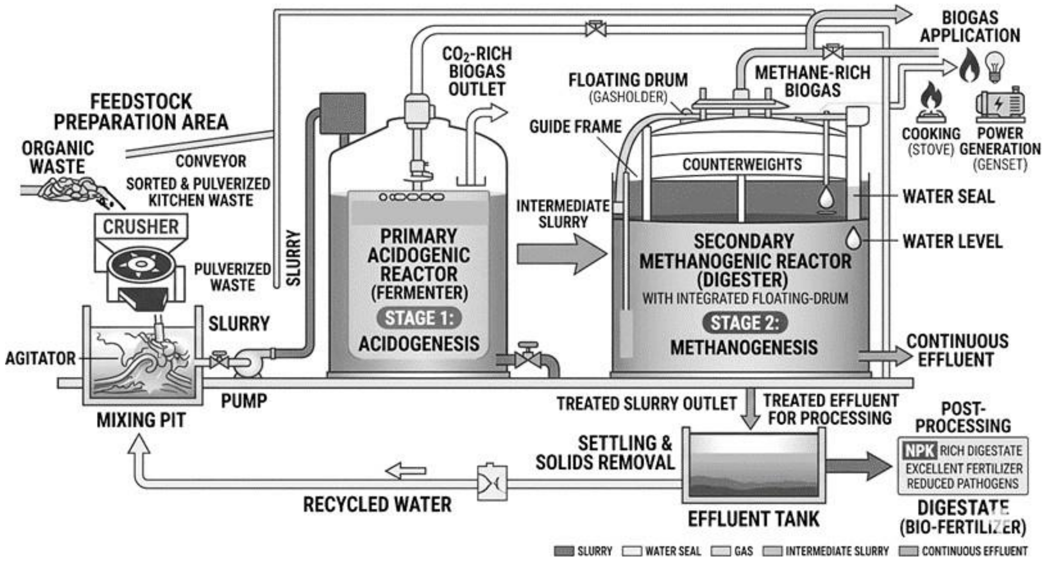

Fig. 2. Biogasplantfororganicfoodscrapswithtwostagesoffloatingdrums that are continuously operated.

Withthissetup,wehopetoincreasethebiogasproductionefficiencyfromfoodscraps while keeping everything running smoothly. For organic compounds with a high degradation potential, the system's ability to partition digestion into two distinct phases improves control over biological responses.

Preparationoffeedstockisthefirststepintheoperation.Thefirststepinrecyclingfood scraps is to remove any non-biodegradable materials from the trash. To make it easier for microbes to reach, the substance is shred or otherwise reduced insize. For easydigestionand flow, a consistent slurry is made by adding water or recycled liquid and keeping the solids contentbetween8and12percent.Toensurethatnofatsoroilsgetintheway,agreaseremoval unit is incorporated into the system.

The first reactor is used for hydrolysis and acid generation, and it is fed the prepared slurry.Atthispoint,theorganicmoleculeshavebeenreducedtotheir mostbasic components, including alcohols, volatile fatty acids, and gases like carbon dioxide and hydrogen. Rapid organic matter decomposition is achieved in this reactor due to its mildly acidic environment and relatively short retention time, usually ranging from 2 to 4 days.

Thesecondreactor,whichisinchargeofmethanegeneration,thenreceivesthepartially processed slurry. Microorganisms transform intermediate products into biogas, which is high in methane, at this step. In order to guarantee full digestion and consistent performance, the conditionsarekept closetoneutralpH,typicallyranging from6.8to8.2.Theretentionperiod is extended to around 20 to 30 days.

Thegasstorageunitisamovabledrumthatispositionedabovethesecondreactor.The rising ofthe drumduring biogas generation serves to both keep the gas pressure constant and give a straightforward indication of gas production. You can put the collected gas to use for heating, cooking, or anything else that requires energy.

Regular addition of new slurry during continuous operation forces an equivalent amount oftreatedeffluent outofthe system. The solid and liquid components ofthis effluent may be separated, and it includes significant nutrients. The chunky part can be turned into organic manure, and the liquid part canbe used as fertilizer or recycled back into the system.

Process control and efficiency are both enhanced by the two-stage setup as compared to the single-stage alternatives. Reducing the likelihoodofprocess imbalance, especiallyacid buildup, and supporting steady microbial activity, is possible by separating the initial breakdown phase from methane synthesis. This leads to more stable operation over time, increased loading capacity, and improved gas yield.

The two-stage system is superior to the single-stage alternatives in terms of process controlandefficiency. Byseparatingthe initialbreakdownphase frommethanesynthesis, the likelihood of process imbalance, particularly acid buildup, can be reduced while simultaneously supporting steady microbial activity. A more consistent performance, higher loading capacity, and enhanced gas yield are the results.

6. RESULTSANDDISCUSSIONS

i) Quantificationand Segregation

Over the course of two weeks, the campus's municipal solid waste was tracked and documented. The hostels, the main dining hall, and the academic buildings were among the primary locations for the daily trash collection. According to the data, the daily average trash production was approximately 300 kg.

The gathered materials were primarilyclassified as either wet organic, dryorganic, or recyclable. According to the data, dry organic matter and recyclables made up much smaller portions of the overall waste stream compared to biodegradable (wet) trash. This trend is frequently seen in institutional settings, when there is a high volume of food waste from both cooking and eating.

In Table 1 you can see the breakdown of each category's makeup along with its percentage distribution. Based onthe findings, biological treatment methods like composting and biomethanation are well-suited to organic waste.

The efficiency of downstream processing was greatly enhanced by segregation at the production site. Waste sorting improved the suitability of organic materials for anaerobic digestionanddecreasedcontaminationbyseparatingwetanddrywaste.Theformercouldthen be sent to composting, while the lattermight be used forother purposes. Overall, this method improved operating efficiency and resource recovery.

These findings highlight the significance of institutionalized segregation policies, which have a direct impact on the efficiency of waste treatment systems and lead to longer-term, better results from waste management.

Table1 illustratesthecompositionofMSWobtained during thestudyperiod.

MSWConstituents	QuantityKgs	Composition%
WetOrganics(WO)	177	59.0
DryOrganics(DO)	69	23.0
Papers	26	8.6
Plastics	17	5.7
Glass/Metallic's	05	1.7
Others	06	2.0
Total	300	100

ii) AnalysisofOrganicWastes

Hostels, the cafeteria, and other academic departments were among the manysites on campus where samples of food-based organic waste and vegetable residues were gathered. Using standard laboratory procedures, we were able to determine the physical and chemical properties of these materials.

Determined by the proximate analysis were factors like moisture content, volatile matter, ash, and fixed carbon. When determining the material's biodegradability, these characteristics are crucial. Typically, anaerobic digestion and biogas production are better suited to materials with higher moisture levels and a bigger proportion of volatile matter.

Also, final analysis was used to determine the elementalcomposition, which includes carbon, hydrogen, nitrogen, sulfur, and oxygen. Waste energy potential and biomethanation processcompatibilitycanbebetterestimatedwiththis data.Oneofthemost importantfactors in sustaining steady microbial activity and guaranteeing effective digestion is the carbon-to-nitrogen ratio.

Tables 2 and 3 describe the average outcomes of these analyses. These facts lend credencetotheorganicwaste'sassessmentasaviablefeedstockforbiogasproductionandshed light on its composition.

Table-2ProximateAnalysisofOrganic wastes.

WasteItem	Moisture contents %	Organic solids%	Volatile Organics%	Ash content	Organic carbon%
Brinjal	42	58	98.3	1.7	54.6
Cabbage	46	54	98.2	1.8	54.3
Carrot	41	59	96.6	3.4	53.7
Tomato	66	34	95.2	1.6	55.7
Cucumber	46	54	98.2	1.8	54.2
SpentTea powder	44	56	98.1	1.9	55.7
DryLeaves	12	88	98.5	1.5	54.9

Table-3UltimateanalysisofOrganic wastes.

TypeofWaste	PercentbyWeight(DryBasis)					
	C	H	O	N	S	Ash
FoodWaste	49	6.2	37,7	2.4	0.4	4.3
Paper(Mixed)	43.4	5.6	44.4	0.4	0.2	5.9
Fruit Wastes	48.2	6.3	40.1	1.3	0.2	3.9
DryLeaves	52.1	6.1	30.2	7.1	0.1	4.4

iii) BiomethanationStudies

In biomethanation, anaerobic microbes transform biodegradable organic waste into biogas. When there is enough moisture present, naturally occurring microbes break downthe wet organic part of MSW in an oxygen-free environment.

There are several linked biological processes that contribute to the breakdown of organic matter. Hydrolysis first breaks down complex compounds into simpler soluble substances. This includes carbohydrates, proteins, and lipids. In the acidogenesis stage, these productsaretransformed into organic acids, alcohols, and gases. The process ofacetogenesis thenproceedsto furtherconverttheintermediatecompoundsinto lesscomplexmoleculeslike acetic acid, hydrogen, and carbon dioxide. Biogas is the end product of this process, which begins with these intermediates and ends with methane and carbon dioxide converted by methanogenic microbes.

In a series of steps, organic waste can be stabilized and turned into a usable fuel gas through this conversion process. An overarching biochemical equation that describes the conversion of organic materials into biogas is as follows:

Organicsolids+Moisture $\rightarrow$ CO_2+CH_4+NH_3+mX+SimpleOrganicSolids+H_2O+Heat

$C_aH_bO_c + m\,H_2O \rightarrow X_nC_wH_xO_yN_z + rCH_4 + sCO_2 + rH_2O + mX + Q$ ....(1)

Asthereaction(1)isofbiochemicalnaturesomeofvariableswhichinfluencethereaction are presented discussed

BiogasGeneration

Decomposition of biodegradable organic matter in an oxygen-free environment with sufficient moisture results inthe formationofbiogas. Microbialactivitydrives this transition, which is dependent on hydraulic retention period, pH, organic solids content, and moisture level. Figure 3 shows the overall pattern of gas production that is observed during digestion.

Thetotalsolidsinthesystemarereducedasdigestionadvancesbecausemicrobesbreak down the feedstock's organic content. Since the microbial populations need time to adjust to the substrate, gas output is minimal initially. The microorganisms get more active and make better contact with the organic waste as the process continues, which increases metabolic activity and, in turn, biogas output. At this stage, gas generation is usually at its highest.

Gasoutputgraduallydecreasesafterreachingthemaximumproductionlevel.The loss oforganiccompoundsthatbreakdowneasilyistheprimary causeofthisdecline.A decrease inpHfromnear-neutralcircumstances,causedbytheaccumulationofintermediatemetabolites like volatile fatty acids, might impact the performance of microbes.

Over the course of one month, we tracked biogas production and associated metrics. Figure3(a)–(c)showsthatthetrendsthatwerenoticedareinlinewithwhatonewouldexpect from anaerobic digestion systems.

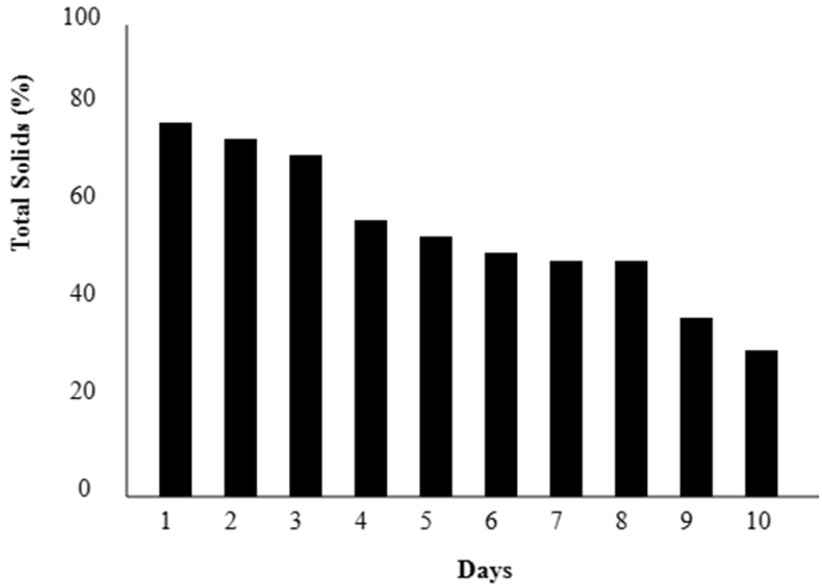

Fig.3(a).Variationoftotalsolidscontentduringbiomethanationover time (days).

The total solids content fluctuated during a 10-day period in Fig. 3(a) as the biomethanationprocessprogressed.Degradationoforganic matterisevident fromthegradual dropintotalsolids,whichgoesfrom85%onDay1to52%byDay10.Asaresultofincreased microbiologicalactivityandactivedigestion,thedecreaseismost pronouncedbetweendays3 and6.Thesuccessfultransformationoforganicsolidsintobiogasandotherliquidby-products is shown by this trend.

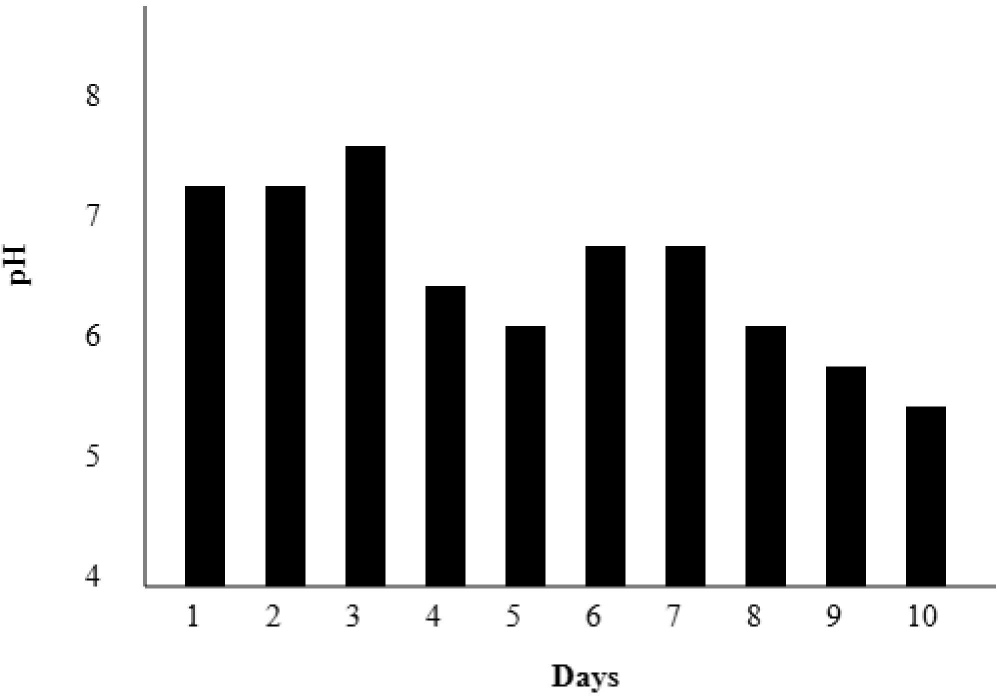

Fig.3(a).Variationofp^{H}overtime(days).

Digestioncausesachange inpH, asseeninFig. 3(b). The initialstageischaracterized bymicrobialactivitybecausethepHisnearlyneutral(about7.0-7.5).Sincevolatilefattyacids tendtoaccumulateduringtheprocess,thepHdropstoacidiclevels(around5.0-5.5)asitgoes along. This pattern lines up with the distinct stages of anaerobic digestion, more specifically acidogenesis and methanogenesis, and highlights the need of pH regulation in sustaining effective biogas generation.

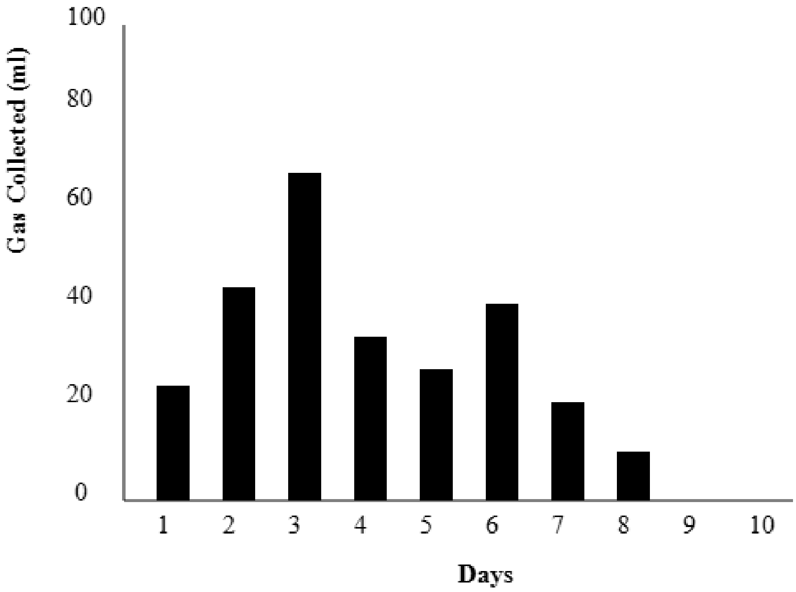

Fig.3(c).Variationofgasgenerationwithrespecttotime(days).

As seen in Fig. 3(c), the biomethanation process results in the daily production of biogas. Enhanced microbial activity and efficient substrate consumption are shown by the quick increaseingasgenerationintheinitialphase,whichreachesamaximumofroughly90ml around Day 3. After this peak, biogas production starts to fall as organic matter that can be biodegraded is exhausted and less favorable conditions, like a lower pH, come into play. The digestion process is complete when gas production becomes insignificant byDays 9 and 10.

Total solids reduction, pH fluctuation, and biogas generation are clearly interrelated whenFig. 3(a), (b), and (c) areinterpretedtogether. Inthe beginning, whenthe pH is close to neutralandthe microbesareattheir most active, thegasproductionpeaks. Ontheotherhand, biogas production drops as acidic conditions set in later on, which hinders methanogenic activity.

ii) PretreatmentofFeedSlurry

An evaluation of the effect of thermal pretreatment on the performance of biogas production was conducted on the feed slurry. Results fromthe experiments show that biogas production is significantly greater from pretreated feedstock than from untreated slurry.

Inorderto increase the surface area that microbescanwork with, heat pretreatment is used to break down organic matter's complex cellulosic and lignocellulosic components. Because microorganisms are now able to more easily reach the substrate, the rate of biogas generation has increased thanks to this structural change.

Biogas production from treated and untreated slurry is shown in Fig. 4, which is a comparative analysis. As a consequence of enhanced biodegradability and quicker microbial activity,theresultsdemonstratethatthepretreatedslurryreachesagasproductionpeakearlier and at a greater level.

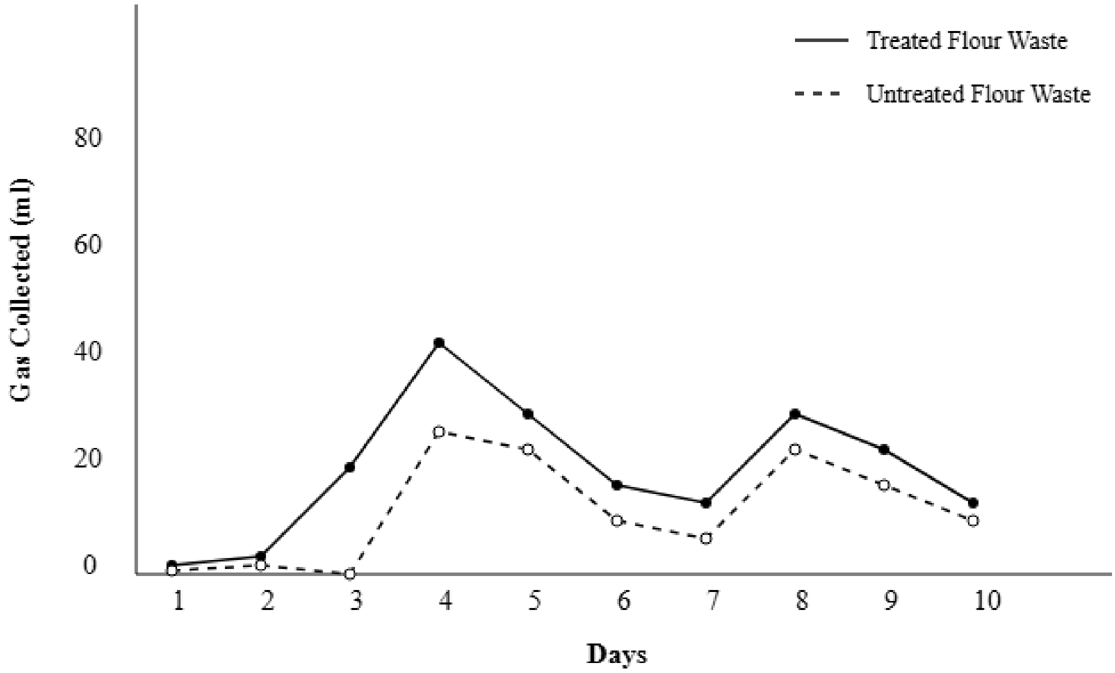

Fig.4EffectofPretreatmentoffeed slurry.

Thermal pretreatment greatly improves anaerobic digestion efficiency, which in turn increases biogas yield, as these observations show.

iii) FeedSlurryComposition

Before being used in biomethanationtests, wet organic waste fromseveralsources on campus, suchasvegetable leftovers, cookedrice, sambar, tealeaves, and chapatti, wasmixed withwaterinvaryingproportionsandhomogenized.Figure5showsthetypicalresultsofthese research.

Themicrobiomeadaptedtothereactor'sanaerobicconditionsduringaninitiallagphase that lasted around two to three days. After the initial acclimation period, the microbes got to work, slowly breaking down organic materials and producing more biogas.

The system performance was greatly affected by the solids to water ratio throughout digestion. Thiswasdue tothe fact that it affectedsubstrateavailability, microbialinteraction, andoverallprocessdynamics.Degradationefficiencyandgasyieldwerebothimprovedwhen there was enough moisture content because microorganisms were able to come into better contact with the substrate.

At an ideal stage of digestion, biogas production peaked, and then it dropped as the easilybiodegradableorganicmatterwasdepleted.Withapeakproductionataroundsevendays after retention, the organic waste/water mixture showedthe greatest biogas output among the various slurry compositions tested.

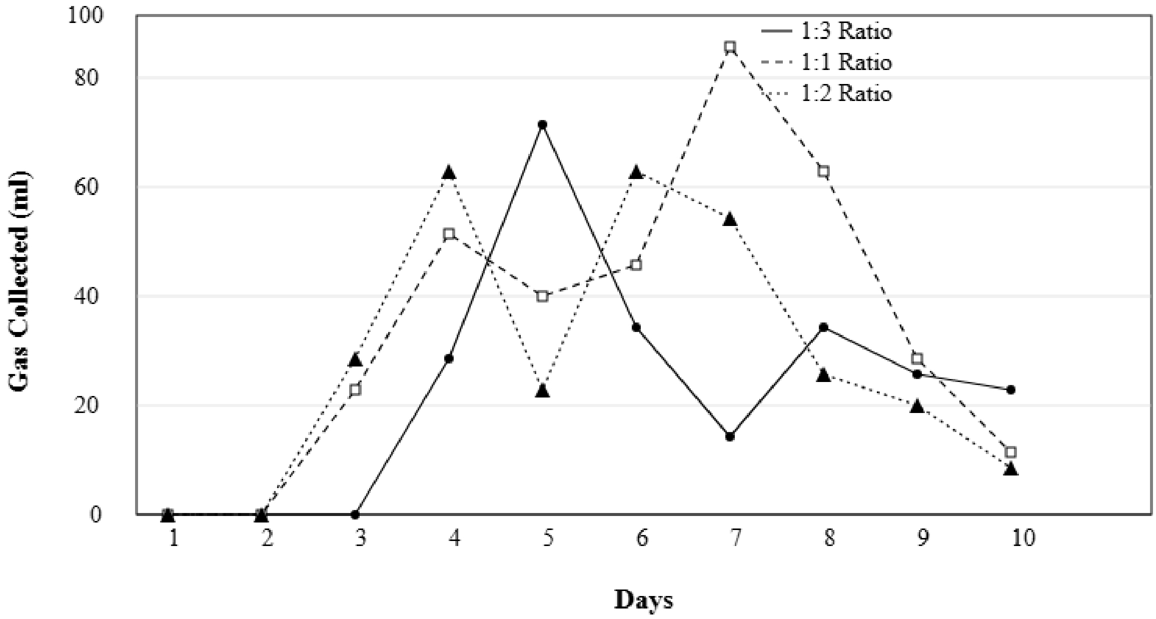

Fig.5:EffectofSolidstoWater contentonBiogas Generation.

iv) CompositionofBiogas

Because anaerobic digestion involves various biochemical routes, the composition of biogas, which mostly consists of CH_4 and CO_2, changes over time. There is a relatively high quantityofcarbondioxideinthebeginningoftheprocessbecauseacidogenicreactionsarethe most common.

The activity of methanogenic microbes increases during digestion, which in turn increases methane formation and the CH_4 content of the biogas, which rises gradually. Similarly, when methanogenesis takes over as the primary metabolic process, the fraction of CO_2 either stays the same or goes down.

Thechangefromanaerobic digestion'sacidogenictomethanogenic phasesisreflected inthisgascompositionfluctuation.TabulatedinTable4arethenotedshiftsincarbondioxide and methane concentrations over time.

Table-4:VariationofBiogascomposition.

Constituents	CompositionofBiogas(% Vol)					
	3Days	5Days	10 Days	15 Days	20 Days	25 Days
CO_2	28.2	25.4	23.4	19.8	18.8	16.6
O_2	11.8	11.6	11.2	11.4	11.8	11.6
Moisture	4%	6%	8%	8%	9%	8%
CH_4	56	57	57.4	61.8	61.4	63.8

v) FieldStudies

A two-stage floating-drum continuous biomethanation plant with a total capacity of 6 m^3wasconstructedandinstalledoncampusbasedontheoutcomesoflaboratory-scalestudies.

Theplant consistsofa5 m^3digester anda1 m^3gas container. Presently, the biogasgenerated by this system is used for cooking, which proves that the conversion of MSW into usable energy is feasible. Figure 2 shows a representational depiction of the biomethanation plant's field-scale installation.

vi) UtilizationofBio-Slurry

Currently, there is a designated storage tank where the bio-slurry that is produced by the biomethanation system is kept for future use. The next step in turning this nutrient-rich digestate into organic manure is co-composting it with the dry organic portion of the MSW produced on campus.

Theresultantbio-manureisagreatsubstituteforchemicalfertilizersandisusedtokeep the campus's lawns and landscaping in good condition. Applying it helps create a "Green Campus" by increasing soil fertility, strengthening soil structure, and bolstering sustainable land management techniques.

Inadditiontoitsobviouspracticaluses,thesystemalsohighlightstheefficacyofwaste-to-energy and waste-to-manure conversion technologies. Sustainable methods of managing urban garbage and recovering resources can be better understood and implemented with the help of this platform, which is great for raising public and stakeholder awareness.

7. CONCLUSION

Proper quantification, source segregation, and biomethanation treatment of biodegradablewasteallowforoptimalmanagementofmunicipalsolidwaste,accordingtothe study. Segregationduring generation is an important partofthis process because it allows for the recovery of valuable products like biogas and organic manure and has a direct impact on the efficiency of the processing that follows.

A significant result of this effort is the effective implementation of a campus-wide integrated waste management strategy. This system uses biogas, a byproduct of wet organic waste treated with anaerobic digestion, to supplement the fuel supply rather than relying on liquefied petroleum gas. When added to dry organic waste, the residual digestate undergoes additional processing into compost, which enhances nutrient quality and facilitates the production of enriched bio-manure that is well-suited for use in landscaping and agriculture.

Byrecycling materials into usableenergyandsoilamendments, this methodmimicsaclosed-loop system for resource utilization.

Theresultsalso showhow important it isto havestakeholders'helpandworktogether for these systems to work. With proper implementation, decentralized waste treatment units can alleviate landfill overflow, minimize environmental impacts, and provide real-world examples for education and training.

In conclusion, this study's campus-based paradigm provides a workable and flexible approachto MSW management. Its capacityto recover resources, ease ofuse, and scalability make it a good fit for more sustainable waste management techniques in institutional, urban, and semi-urban areas.

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