CAFETERIA WASTE TO BIOGAS PLANT

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CERTIFICATE OF RESEARCH

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*I hereby declare that this thesis entitled "**CAFETERIA WASTE TO BIOGAS PLANT**" is an authentic report of study carried out as requirement for the award of degree B.Sc. (Mechanical Engineering) at Islamic University of Technology, Gazipur, Dhaka, under the supervision of **PROF.DR.MD.HAMIDUR RAHMAN**, Professor, MPE, IUT in the year 2022*

The matter embodied in this thesis has not been submitted in part or full to any other institute for award of any degree.

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ABSTRACT

Food waste is becoming a major problem in IUT. The best option for controlling food waste and replacing traditional cooking and heating fuel is to convert food waste to biogas energy via anaerobic digestion. In addition, digestate is produced, which can be used as fertilizer. Anaerobic digestion is a collection of biological processes in which microorganisms break down biodegradable material in the absence of oxygen. In this project, the food waste from the IUT cafeteria is being utilized for the generation of energy in the form of biogas. The experiment investigates cooked rice, potato peels, mixed vegetable peels as well as mixed food waste in different mixture ratios with water (1:1 to 1:5). Moreover, this research also investigates the mentioned wastes mixed with inoculum, i.e., bacteria generated from horse dung in specific ratios. The operational parameters, including temperature, humidity, pH of substrate, and hydraulic retention time of the overall anaerobic digestion process, are also of prime concern here. The use of temperature control is also implemented in this project. Temperatures of biogas produced at an optimum condition of 37°C will be compared with the regular temperature of the environment. This allowed us to find the differences in both conditions. A gas analyzer was used at specific intervals to determine the percentage of different gases (Methane, Carbon dioxide, and Hydrogen Sulfide) in the produced biogas from anaerobic digestion. After a specific period, i.e., hydraulic retention time, the highest methane content along with the maximum amount of biogas was determined from the samples.

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Nomenclature

Food Waste	FW
Horse Dung	HD
Food and Agriculture Organization	FAO
Islamic University of Technology	IUT
Municipal Solid Waste	MSW
Anerobic digestion	AD
Volatile Fatty Acids	VFAs
Biological Oxygen Demand	BOD
Chemical Oxygen Demand	COD
Organic Loading Rate	OLR
Hydraulic Retention Time	HRT
Total Solid	TS
Volatile Solid	VS

CHAPTER ONE: INTRODUCTION

1.1 Background of the study

In today's fast-paced world, trash creation is increasing. As urbanization increases, significant environmental concern has been handling potential wastes such as cafeteria trash, plastic rubbish, paper waste, and municipal solid waste. It is especially concerning in cities, institutions, and a diverse range of industrial sectors [1]–[4].

Food waste (FW) is organic waste that is generated by a variety of sources, including food processing industries, as well as residential and commercial kitchens, cafeterias, and restaurants. According to the FAO, almost 1.3 billion tons of food are lost in the food supply chain, including fresh vegetables, fruits, meat, bread, and dairy products. The quantity of FW produced is expected to expand during the next 25 years as a result of economic and demographic expansion, particularly in Asian nations. For example, from 2005 to 2025, the yearly volume of urban FW in Asian nations might increase from 278 to 416 million tons [4]–[7]

Due to the rising cost and environmental effect of fossil fuels, the globe is moving away from petroleum-based national economies and toward bio-based ones. In this example, biological wastes, which are traditionally considered as low-value materials, are being changed from a source of high-volume trash that contributes to the environmental catastrophe to a source of sustainable resources for the manufacture of environmentally favorable and clean fuels. Historically, FW has been burnt with other combustible municipal garbage to generate heat or electricity. It should be recognized that FW includes a high degree of moisture, which may result in the creation of dioxins when burned with other wastes with low humidity and a high calorific value. Additionally, incineration of FW may result in air pollution and a loss of FW's chemical properties. These findings indicate that effective management of FWs is critical [6], [8]–[11].

Biological wastes are rich in cellulose, lipids, carbs, and proteins, making them a good source of energy without interfering with the world's growing need for food. Carbohydrate hydrolysis in FW may result in the dissociation of glycoside linkages, releasing polysaccharides as oligosaccharides and monosaccharides that are more fermentable. The total sugar and protein compositions of FW are between 35.5 and 69% and 3.9 to 21.9 percent, respectively. As such, FW has been utilized exclusively as a microbial feedstock for the production of a variety of value-added bioproducts, including methane, hydrogen, ethanol, enzymes, organic acid, biopolymers, and bioplastics [12]–[15]

The search for alternative energy sources such as biogas should be intensified to avert ecological disasters such as pollution, deforestation, desertification, and erosion. The most cost-effective way to meet the country's energy requirements is to create renewable and sustainable energy sources. It is much desired for renewable energy to be produced in an environmentally friendly manner. Producing renewable energy from readily accessible and locally obtained resources is unquestionably beneficial and lowers production costs. Individuals who are ecologically

concerned may compost their food waste to create a useful fertilizer or soil amendment; but this method does not offer a mechanism for absorbing the energy inherent in the trash. Numerous municipal waste management initiatives aim to capture the energy inherent in organic garbage by burning it in waste-to-energy plants and collecting methane produced by landfill microbial activity. While these systems use the energy inherent in food waste, they do not immediately benefit individuals who create rubbish and may incur extra collection costs. Biogas is a renewable energy source that is generated when animal and plant waste decompose. It is composed mostly of methane and Carbon dioxide, with minor amounts of Hydrogen, Hydrogen Sulfide, and a minimal quantity of Nitrogen [2], [16]–[20]

Food waste may be easily digested anaerobically to extract the energy contained inside, and the residuals can be beneficially repurposed as fertilizer or soil amendment. Food waste has three times the capacity to generate methane (CH_4) as biosolids (376 vs. 120 m^3 gas/ton) 90.6 m^3, methane per ton of raw food waste. Anaerobic digestion may provide yields of up to 3,200 standard cubic feet. Biogas is the primary result of anaerobic carbon digestion. Numerous aspects, including pH, temperature, feed composition, loading rate, mixing condition, reactor design, and residence period, will impact the quality and amount of biogas. Although anaerobic digestion may be used to decompose practically any organic material, the degree of digestibility is critical for its effective use if biogas generation is the end aim. The more digestible the feedstock, the greater the potential for gas production. The yield of biogas or methane is defined as the quantity of biogas or methane that may be generated per unit mass of volatile solids (VS) in the feedstock during a certain time period at a specified temperature [1][21]–[23].

1.2 Statement of the problem

Bangladesh is subject to worldwide price volatility, which has a negative impact on its balance of payments due to its reliance on imported fossil fuels. Additionally, our country is dealing with a massive accumulation of food waste generated by cafeterias and other industries [8], [9]. There is a massive accumulation of food waste in Bangladeshi universities, in particular. IUT, one of Bangladesh's universities, provides a major contribution to this phenomenon. There is a substantial number of food waste generated at the university, as many students eat in the on-campus cafeteria. The remaining food in the cafeteria is causing serious environmental and health difficulties, ranging from the unpleasant odors that affect human health to the grave environmental crisis created by the release of greenhouse gases. Additionally, the university's land is becoming clogged with food waste, and the university is increasing its investment in sanitizing the environment. The best solution to this problem may be to create a sustainable solution that converts all of this food waste into energy-biogas. This approach not only alleviates the problem of food waste accumulating on campus, but also provides an alternate source of energy that may be used for a variety of purposes, including heating, cooking, and lighting.

1.3 Goal and Objectives

1.3.1 Objectives

The project's primary purpose was to simulate and build a biogas plant that utilized food waste as a feedstock.

1.3.2 Specific Objectives

The project's precise aims were to define

- The physicochemical parameters of food waste, including total solids, moisture content, fixed solids, and volatile solids.
- To find the optimal water-to-food waste ratio for biogas production.
- To design a laboratory-scale biogas production system and to quantify the amount of biogas produced from food waste samples.

CHAPTER TWO: LITERATURE REVIEW

2.1 Anaerobic digestion

Anaerobic digestion is a biological process in which organic waste is decomposed in the absence of oxygen to create biogas mostly composed of methane and carbon dioxide. The project took advantage of an IUT's existing wet digestion biogas plant. The experiment used food waste (rice) obtained from the IUT's cafeteria. Additionally, PROII software was used to simulate the process in order to establish the rate of methane formation. Finally, the simulation and experiment results were compared. 120 days were allotted for the experiment. The experimental findings reveal that a starch loading rate of 0.05 kg-mol/hr may provide an average specific gas production rate of 14.4 kg-mol/hr. The gas production rate was calculated to be 19.82 kg-mol/hr for the simulated results with the same starch loading rate. The biogas plant collected 69 percent of methane and 29 percent of CO2 at a rate of 69 percent and 29 percent, respectively [8], [24]–[27]

In terms of solid waste management, anaerobic digestion has been explored in recent decades with the objective of establishing a process that combines volume and mass reduction with energy and resource recovery. Apart from aerobic composting, MSW may be reduced by anaerobic digestion. In contrast to aerobic composting, anaerobic digestion of solid waste creates biogas with a significant methane volumetric component (50-70 percent). Additionally, anaerobic digestion processes are well-suited for dealing with wet waste and have a tiny environmental effect. Waste management has become an environmental and societal problem as a result of the steady growth in solid waste output and the substantial environmental repercussions of improper waste treatment [28], [29], [7], [11]. Domestic rubbish, streets, market areas, commercial businesses, clinics, and hospitals account for the majority of Dhaka's municipal solid waste. Dhaka City now creates between 3500 and 4000 tons of solid waste every day, with an average of 0.5 kg per person. Solid trash has a density of 600 kg/m^3, according to studies. According to a study conducted by the Japan International Corporation Agency (JICA 2005), total domestic garbage creation in 2004 was estimated to be 1945 t/d, based on a population of 5.728 million and an average generation rate of 0.34 kg/day per person. Total commercial garbage production was estimated to be 1035 t/d, while street cleaning generated 200 t/d (0.365 t/kmx550 km=201 t/d), for a total estimated waste generation of roughly 3200 t/d. [30]–[33] By 2025, energy consumption is expected to increase by 50%. As a consequence, a continual effort is being made to create renewable energy sources that are affordable, sustainable, and environmentally benign. Biogas produced from trash is a renewable resource. Biofuels are renewable and ecologically beneficial, reducing our reliance on fossil fuels significantly. Due to its biodegradability and nutritional value, food waste is a suitable substrate for anaerobic digestion. A typical food waste contains between 7% and 31% solids by weight and has an estimated biological methane potential of 0.44-0.48 m^2 CH_4/kg of extra volatile material. As starch particle breakdown increased in direct proportion to the development of methanogenic bacteria, the percentage of methane in the exhaust gas rose as well. Additionally, since the majority of food waste is starch, a hydrocarbon, the gas generated by anaerobic digestion of food waste includes an excessively high percentage of methane. Additionally, the proportion of

methane in the biogas climbed progressively to a near constant amount of 69 percent. This is consistent with the Bangladesh Council of Scientific and Industrial Research's findings [4], [10], [32], [34]–[36]

2.2 Biogas from anaerobic process

AD leads to the production of biogas along with smaller amounts of other gases through the fermentation process. A series of stages takes places during the overall conversion process. Different species of bacteria usually take place in production of biogas or methane through a series of chemical reaction. The stages of biogas or methane production is discussed here briefly [1], [4], [10], [17], [35].

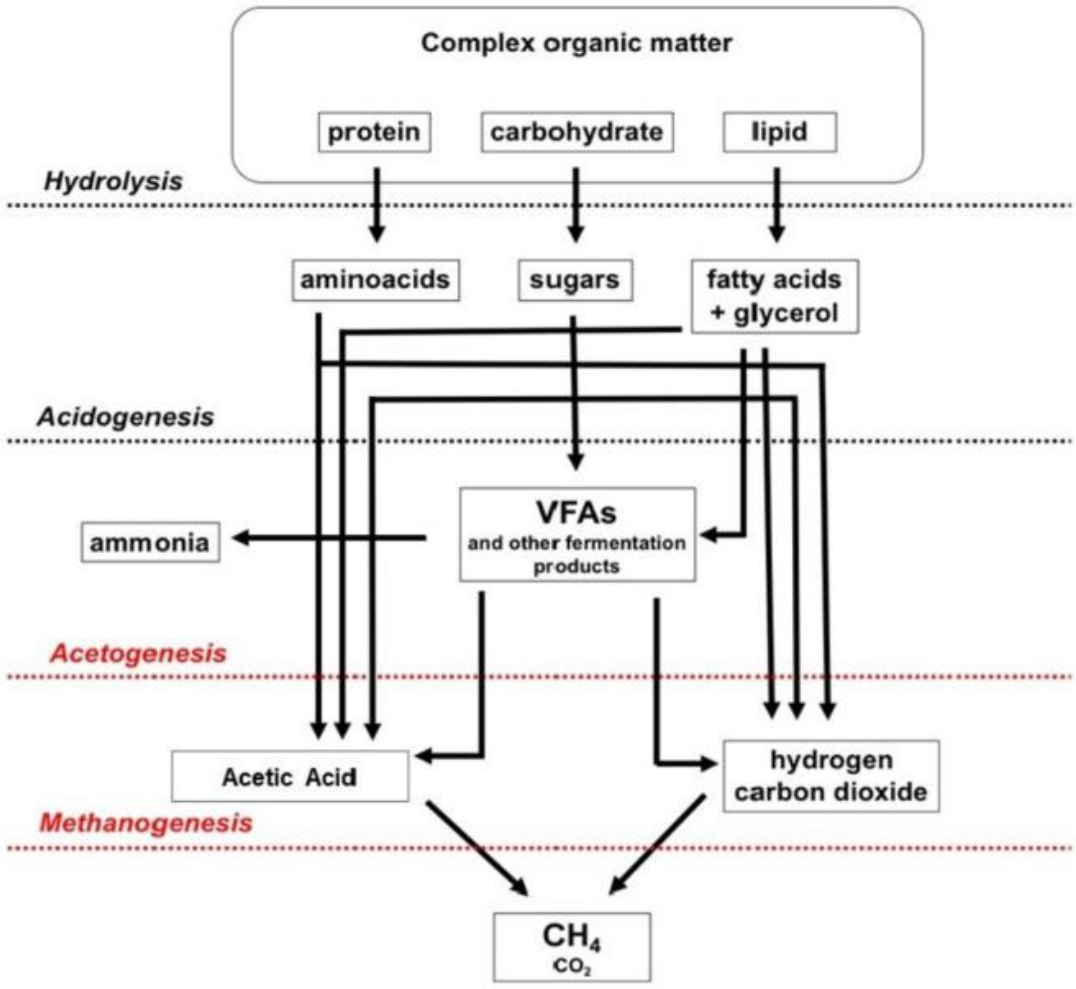


Figure 1 Anaerobic Digestion Steps [45]

2.2.1 Hydrolysis

Hydrolysis is a chemical process that breaks down complex organic molecules into simpler monomers. The following reaction represents the hydrolysis of municipal solid waste. The process

that produces acid is composed of two reactions: fermentation and acetogenesis. This stage is characterized by the conversion of glucose to ethanol and glucose to propionate, two common reactions. The conversion of glucose to acetate, ethanol to acetate, propionate to acetate, and bicarbonate to acetate are all essential acetogenesis processes [3], [10], [17], [37].

$$Biomass + H_2O \rightarrow Monomers + H_2$$

Biogas was created via a 55-day anaerobic digestion of fruit and vegetable wastes in conjunction with other wastes (for complete digestion). Anaerobic digestion is particularly pH-sensitive, and a healthy system must maintain a pH range between 6.8 and 7.4[1]. The temperature of the digester and surrounding environment also affects the anaerobic digestion process. For the first two days, a slurry was made by combining fresh cow dung and tap water in a 1:5 weight ratio [14], [38]

The physical parameters of the water were determined (total solids; volatile solids; moisture content; and ash content) using a standard procedure for analyzing water and waste water [1], [39]. As the global population grows and demand for scarce resources increases, we all have a responsibility to "reuse, minimize, and recycle" resources and trash. While some food waste is inevitable at IUT, the enormous environmental harm caused by waste food landfilling is not. We can minimize harmful greenhouse gas emissions and contribute positively to environmental objectives by employing green technology such as anaerobic digestion.

2.2.2 Acidogenesis

Acidogenic bacteria convert the soluble organic monomers of sugars and amino acids into ethanol and acids (such as propionic and butyric acid), acetate, H_2O, and CO_2. Ammonia is also produced by the breakdown of amino acids [19]. Acidogenic bacteria can produce intermediate volatile fatty acids (VFAs) and other compounds by absorbing the effects of hydrolysis through their cell membranes [40], [41]. VFAs are a category of organic acids consisting of acetates and bigger organic acids such as propionate and butyrate. Typically, the ratios range between 75:15:10 and 40:40:20 [42]. Even so, traces of ethanol and lactate may still be detectable. The specific concentrations of intermediates produced during the acidogenesis stage may vary depending on digester settings; it has been noted that VFA concentrations can vary considerably between digesters running at different pH, with contradictory results from many experiments. Acidogenesis is often assumed to occur faster than the other steps of anaerobic digestion, as acidogenic bacteria regenerate in less than 36 hours. Keeping in mind the speed of this process, it is essential to remember that VFA acidification is a well-known cause of digester failure. During the fermentation process, VFAs serve as direct precursors for the final phase of methanogenesis [41], [43]–[45]. This process is similar to Bokashi composting in those bacteria are used to decompose the waste. It is essential to comprehend the process of VFA synthesis from amino acids in protein-rich wastes, such as sewage wastewaters containing amino acids and wastes containing aminos. Deamination of amino acids is known to produce ammonia, which has been demonstrated to inhibit anaerobic digestion when present in high concentrations. Short chain (volatile) acids (e.g., propionic, formic, lactic, butyric, and succinic acids), ketones (glycerol, acetone), and alcohols

(ethanol, methanol) are produced during acidogenesis by the transformation of soluble monomers into minute organic molecules. [2], [46]

$$C_6H_{12}O_6 + 2H_2 \rightarrow 2CH_3CH_2COOH + 2H_2O$$

$$C_6H_{12}O_6 \rightarrow 2CH_3CH_2OH + 2CO_2$$

2.2.3 Acetogenesis

Thirdly, acetogenic bacteria convert long-chain fatty acids, volatile fatty acids, and alcohols into hydrogen, carbon dioxide, and acetic acid. This technique reduces the BOD (biological oxygen demand) and COD (chemical oxygen demand) while decreasing the pH[47]–[49]. Hydrogen is a crucial intermediary in this process, as the reaction will only proceed if its partial pressure is low enough to permit the thermodynamic conversion of all the acids. There is a drop in partial pressure as a result of hydrogen. Thus, the digester's hydrogen content acts as a barometer of its "health.". However, other higher VFAs have not yet been made available to methanogenic bacteria. Acetogenesis is the process by which these higher VFAs and other intermediates are converted to acetate and hydrogen is produced. The hydrogen produced during acetogenesis provides a chance to investigate an intriguing syntrophic interaction observed in anaerobic digestion: the transfer of hydrogen across species. Although acetogenesis generates hydrogen, an extremely high partial pressure is harmful to acetobacterial growth [1], [2], [50].

$$CH_3CH_2COO^- + 3H_2O \rightarrow CH_3COO^- + H^+ + HCO^{3-} + 3H_2$$

$$C_6H_{12}O_6 + 2H_2O \rightarrow 2CH_3COOH + 2CO_2 + 4H_2$$

$$2CH_3CH_2OH + 2H_2O \rightarrow CH_3COO^- + 2H_2 + H^+$$

$$HCO^{3-} + 4H_2 + H^+ \rightarrow CH_3COO^- + 4H_2O$$

Several bacteria contribute to acetogenesis, including:

Syntrophobacter wolinii, propionate decomposer

Syntrophomonos wolfei, butyrate decomposer

Clostridium spp., peptococcus anaerobes, lactobacillus, and *actinomyces* are acid formers [2]

2.2.4 Methanogenesis

During this final phase, methanogenic bacteria convert hydrogen and acetic acid into methane gas and carbon dioxide. Reactor factors such as temperature, feed composition, and rate of organic loading affect methanogenesis. Biogas is mostly made of methane (CH_4) and carbon dioxide (CO_2), but it also contains hydrogen sulfide (which smells like rotten eggs), nitrogen, oxygen, and

hydrogen [51]. Biogas with a methane concentration greater than 45 percent is combustible; the greater the CH_4 concentration, the larger the energy content of the gas. Methanogenesis is the ultimate stage of anaerobic digestion, where methanogenic microbes consume available intermediates to generate methane. Methanogenic microorganisms are obligate anaerobic archaea; 99 percent of Methanococcus voltae and Methanococcus vannielli cells were killed within ten hours of exposure to oxygen [2]–[4]. In addition to their acute sensitivity to oxygen, methanogenic microorganisms are restricted to a limited number of substrates [52]. Methanogenesis from methanol, methylamines, and formates have also been seen. Regarding the environmental requirements of methanogenesis, methanogenic microbes are likely to require a higher pH than previous stages of anaerobic digestion, as well as a lower redox potential, the latter of which has posed significant cultivation challenges in the laboratory. Methanogens appear to regenerate at a rate considerably slower than other species. In anaerobic digestion, bacteria can live for five to sixteen days. Some hydrogenotrophic organisms, including Methanococcus maripaludis, have a doubling time of less than two hours, indicating that they proliferate quickly. Methanosarcina spp, according to a recent study, are exceptionally durable microorganisms, able to resist high concentrations of ammonia, salt, and acetate, as well as pH shocks, at levels that would be lethal to other methanogenic microbes in their natural environment [50], [53]–[56]. In batch reactors, methanogenesis ceases when biogas production ceases, which in certain cases might take up to 40 days. It is possible to assess the volatile solids content and dewatering ability of sludge to estimate its degree of digestion [1]–[3], [21]

The final stage of anaerobic digestion is methanogenesis. Several reactions occur using the intermediate products from the other steps, with methane being the primary result. Common reactions that occur during methanogenesis: [35]

$$2CH_3CH_2OH + CO_2 \rightarrow CH_3COOH + CH_4$$

$$CH_3COOH \rightarrow CH_4 + CO_2$$

$$CH_3OH \rightarrow CH_4 + H_2O$$

$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

$$CH_3COO^- + SO_4^{2-} + H^+ \rightarrow 2HCO_3 + H_2S$$

$$CH_3COO^- + NO^- + H_2O + H^+ \rightarrow 2HCO_3 + NH_4^+$$

Several bacterial contribute to methanogenesis, including:

Methanobacterium, methanobacillus, methanococcus, and *methanosarcina*, etc.[2]

As you can see, the bacteria for anaerobic digestion are different from other enzymes for making biofuels, and could even be in our own stomachs!

Anaerobic digesters can be fed any sort of organic matter, such as manure and litter, food wastes, green wastes, plant biomass, and sewage sludge, among others. These feedstocks are predominantly composed of polysaccharides, proteins, and fats/oils. Some organic substances degrade slowly; hydrolysis is the rate-limiting step in the decomposition of cellulose and hemicellulose. Certain organic compounds, including lignin, peptidoglycan, and membrane-associated proteins, cannot be broken down by the body's natural mechanisms [2]. The organic wastes contain water, volatile solids, and biomass produced from solids that are fixed (minerals or ash after combustion). Depending on their composition, volatile solids (VS) can be either non-biodegradable or biodegradable[9], [21]. After reviewing the pretreatment of biomass for ethanol production, it is important to note that pretreatment increases the efficiency of anaerobic digestion. Pretreatment improves the hydrolysis of cellulose and hemicellulose by reducing the recalcitrance of biomass (phase 1 in AD) [57]. In a recent meeting, we covered various pretreatment processes, such as acid and alkaline treatments, steam explosion, and size reduction [58]. Examples of typical alkaline chemicals include NaOH, Ca(OH)2, and NH3. The elemental composition of a substrate can be utilized to determine its theoretical methane yield (YCH_4, m^3 STP/kg substrate converted) [9], [59] .

$C_c H_h O_x N_n S_s$

$$Y_{CH_4} = \frac{22.4\left(\frac{c}{2} + \frac{h}{8} + \frac{x}{4} - \frac{3n}{8} - \frac{s}{4}\right)}{12c + h + 16x + 14n + 16s}$$

2.3 Anaerobic Process phases

2.3.1 Single-stage anaerobic digestion

The arrangement of the process is crucial to the effectiveness of the methane production procedure. The technology of single-stage anaerobic digestion has been widely applied to the treatment of municipal solid waste [60], [61]. All processes (hydrolysis, acidogenesis, acetogenesis, and methanogenesis) happens, resulting in fewer technical failures and a cheaper initial investment cost. Anaerobic digestion can be either wet or dry; in the former, the waste is utilized as-is, whereas in the latter, the water content must be decreased to approximately 12 percent of total solids [62]. Due to the volatile fatty acid (VFA) transport constraint, dry anaerobic digestion produces less methane and reduces VS in contrast to wet anaerobic digestion. Due to the accumulation of volatile fatty acids and low pH, a digester processing FW was unstable, resulting in minimal biogas production [63].

2.3.2 Two-stages anaerobic digestion

Two-stage anaerobic digestion is frequently applied to create both hydrogen and methane in separate reactors, as opposed to single-stage anaerobic digestion. In the first step of such a system, fast-growing acidogens and hydrogen-producing microorganisms are chosen for the production of hydrogen and volatile fatty acids (VFAs) [64], [65]. Establishing acetogenin and methanogens capable of converting volatile fatty acids to methane and carbon dioxide is the second step. Single-stage and two-stage thermophilic methane fermentation systems were conducted using synthetic kitchen trash [66]. At an OLR of 15 g COD/L d, the maximum methane recovery yield of 90 percent (based on COD) was found in both systems. Nevertheless, the concentration of propionate changed significantly more in the single-stage reactor than in the two-stage process, indicating less stable digestion. In two-stage fermentation, methane production increased by 37%, but HRTs and loading rates were dramatically reduced [63], [65]–[67]. The energy recovery potential of hydrogen/methane fermentation in two stages is significantly greater than that of methane-only fermentation [59].

2.4 Operational parameters

The rate of microbial growth is critical for the AD process. Consequently, the digester's operating settings are optimized to maximize microbial activity and thus AD efficiency. The critical parameters are listed below [1], [2], [50].

2.4.1 Temperature

The optimal temperature for mesophilic microorganisms (optimum temperature is 37 degrees Celsius) and anaerobic bacteria (optimum temperature is also 37 degrees Celsius) is within the range of 30 to 40 degrees Celsius [69], [70]. Mesophilic and thermophilic microorganisms flourish between 30 and 40 degrees Celsius, while anaerobic bacteria thrive above 60 degrees Celsius (optimum temperature 55 degrees Celsius) [17], [71], [72] Because mesophilic microbial communities are more adaptable to environmental changes and require less energy, digesters work better at mesophilic temperatures. At lower temperatures, there is less ammonia available, therefore ammonium's effect is less significant than at higher temperatures [73], [74]. In order to produce more biogas, mesophilic bacteria must grow for a longer period of time in the digester. More than half of breakdown is hastened by a thermophilic mode of action, which is especially advantageous for fatty materials. This produces additional biogas. Because CO2 is less soluble at higher temperatures, the CO2 concentration in biogas is 2–4 percent higher in thermophilic digesters. There may be a few advantages to operating the digester at thermophilic temperatures, but the added energy and instability make it less practicable in developing nations [74], [75].

2.4.2 pH

Typically, AD operations with a significant biogas output are stable when the pH is between 6 and 7 [76]. After digestion, acidogenesis occurs at a lower pH (5.5–6.5) than methanogenesis (6.5–8) [77]. At all times, a continuous buffering capacity of 3,000 mg/L is necessary. In AD systems that are too acidic, lime is typically employed to increase the pH. In contrast, sodium bicarbonate can be used to alter pH. Local businesses may even offer their surplus lime solutions for free [2], [78].

Lime typically costs less than other materials. Common lime side effects include precipitation and pipe clogging. Both sodium bicarbonate and sodium hydroxide are entirely soluble and rarely precipitate, contributing to higher expenses [75]. In contrast, sodium bicarbonate and sodium hydroxide can be more difficult to obtain than lime. For fast alleviation, sodium salts are recommended. Lime can be used as a backup pH adjuster for substrates with a pH of less than 7 [79]–[81].

2.4.3 Carbon to nitrogen ratio (C: N)

Carbon and nitrogen play an essential function in organic chemistry. The C:N ratio indicates both dietary deficiency and ammonia inhibition. C:N ratios between 16 and 25 are optimum for anaerobic digesters [82]–[84]. This shows that methanogens utilize nitrogen faster when the ratio of carbon to nitrogen is large. In contrast, a low C:N ratio induces the formation of ammonia and pH levels to climb above 8.5%. Methane-producing bacteria are susceptible to these conditions [85]. Even while methanogenic bacteria can adapt to extremely high ammonia concentrations, this only occurs when the concentrations are increased gradually to allow for adaptation. Organic solid waste with low carbon-to-nitrogen (C:N) ratios can be blended with varied feedstock sources to produce optimal C:N ratios (e.g., organic solid waste) (e.g., sewage or animal manure) [84], [86].

2.4.4 Inoculation and start-up

At the beginning of the anaerobic process, the digester must be injected with the bacteria necessary for the anaerobic process. Cow manure diluted with water (preferably 1:1) is a great inoculant. The minimal amount of cow dung required for efficient inoculation is typically 10 percent of the total volume of the operating reactor. In general, the more cow manure used for vaccination, the better. It is vital to gradually acclimatize the bacteria population to the feedstock during the startup phase. This can be achieved by progressively increasing the daily feeding load and providing time for the development of a balanced microbial population. Initial overload provides a hazard to the overall anaerobic process [3]. Overloading happens when a digester is given an excessive amount of biodegradable organic matter relative to its active population's ability to digest it, or when the digester's conditions change abruptly (e.g., abrupt change of temperature, accumulation of toxic substances, flow rate increase). These perturbations mostly affect methanogenic bacteria, whereas acidogenic bacteria with more tolerance continue to function and produce acids [87]. Ultimately, the acidity of the digester is increased, which inhibits methanogen activity. This mismatch between acidogenic and methanogenic bacteria can cause the digester to fail. This can be avoided by adding manure, which increases the buffer capacity and minimizes the acidification danger. The majority of the gas produced in the first weeks after beginning is carbon dioxide (CO_2) [88]. This gas is non-combustible and has the capacity to be released. After a few days, the methane content of the gas will be adequate to sustain a flame (CH_4>45 Vol.-%), resulting in the production of high-quality biogas (55–70 Vol.-%) [83], [89]

2.4.5 Organic Loading Rate

The Organic Loading Rate (OLR) is a parameter that indicates the AD system's biological conversion capacity. It denotes the amount of substrate delivered into the reactor volume over a specified time period [90], [91]. OLR is a critical control parameter in continuous systems because overloading results in a considerable increase in volatile fatty acids, which can result in acidification and system failure. In industrialized countries, studies of anaerobic treatment of biowaste report organic input rates of 4–8 kg VS/m^3 reactor and day, resulting in VS elimination of 50–70% [92]. This is the optimal configuration for continuously stirred reactors. However, for unstirred AD systems, which are prevalent in developing nations, an OLR of less than 2 kg VS/m^3 reactor and day is recommended and deemed appropriate [90], [93]–[95]**.**

2.4.6 Hydraulic Retention Time

The Hydraulic Retention Time (HRT) quantifies the amount of time that the liquid fraction remains in the reactor. The ratio of the volume of the reactor (active slurry) to the rate of feedstock intake [61], [96]. The HRT necessary to complete an AD reaction varies according on the technology, temperature of the process, and waste composition. 10 to 40 days is the recommended HRT for mesophilic digesters. Few days or less are the retention times for thermophilic digesters [94], [96]–[98]. In the context of solid waste digestion, both HRT and SRT are typically used interchangeably.

2.4.7 Mixing

The goal of mixing and churning the fresh material in the digester is to inoculate it with bacteria. This approach prevents temperature variations within the digester and reduces the production of scum. In the digester, filamentous microorganisms produce scum and froth [99], [100]. In AD plants with low substrate concentrations, filamentous bacteria grow. Digester scum can obstruct gas pipes and cause the digester to foam. Equipment corrosion or difficulty resulting from slurry displacement. Due to regeneration, bacterial loss is often low. Large-scale systems typically necessitate a stable 20–60 cm foam layer on the surface. Consequently, the structure could fail) [87], [101]. Depending on the reactor type and TS concentration of the digester, the equipment and procedures for mixing and stirring vary. In the three most prevalent AD systems seen in underdeveloped countries, stirring is not utilised (fixed-dome, floating-dome, and tube digester). Passive mixing is accomplished by decreasing digestate outflow (equal to daily feeding load) and replenishing it through the intake. This type of recirculation helps flush the input pipe by combining new feedstock with bacterial digestate [102].

2.4.8 Inhibition

When planning and managing a biogas plant, it is necessary to consider factors that limit the anaerobic process. Certain substances can be hazardous to the anaerobic process in excessive doses. In general, inhibition is dependent on the inhibitor concentration, the substrate composition, and the bacteria's adaptability to the inhibitor. hydrogen sulfide (H_2S), organic acids, free ammonia, heavy metals, tannins/saponins/mimosine, and other potentially harmful compounds such as disinfectants (from hospitals or industry), herbicides, insecticides (from agriculture,

markets, gardens, and houses), and antibiotics [103]. Ammonia nitrogen is frequently referred to as one of the most common AD inhibitors. Ammonia inhibition occurs over a wide concentration range. Various investigations demonstrate ammonia inhibition at concentrations ranging from 1400 to 17000 mg N/L of total inorganic nitrogen [104]. The total inorganic nitrogen in anaerobic reactors is primarily composed of ammonia (NH_3) and the protonated form of ammonium (NH_4^+). At normal pH values, ammonium accounts for the lion's share of total inorganic nitrogen. The proportion of ammonia increases as the pH value and temperature increase [42]. Undissociated ammonia diffuses through cell membranes and impairs cell activity by altering the intracellular proton and potassium balance. This inhibition results in an imbalance and accumulation of intermediate digestion products such as volatile fatty acids (VFA), which may cause the digester to become acidic [53], [105]. Generally, it is accepted that anaerobic microbes may withstand higher ammonium concentrations than those typically measured with sufficient adaption time. This, however, may result in a decrease in methane output**.**

2.4.9 Demand for Oxygen in Biochemical Processes

The biochemical oxygen demand is a measure of an anaerobic digester's performance and the number of biodegradable organics it contains (BOD). Using dissolved oxygen metabolism, the BOD values of a specific sludge sample during a 5-day period are calculated [106]. A five-day BOD experiment can be performed to evaluate the biodegradable organics content of sludge by calculating the amount of dissolved oxygen required to support aerobic bacteria in the sample. So that no dissolved oxygen is created during testing, BOD samples are collected and analyzed in a dark room under regulated conditions [107]. For the calculation of BOD, the difference in dissolved oxygen between the beginning and end of a certain incubation period might be considered. There are two ways for determining carbonous BOD (cBOD), and both entail the use of an anti-oxidant to prevent the oxidation of ammonia and nitrogen. Organics in high-protein sludges, such as those found in sewage treatment plants, may be more accurately measured using the cBOD technique. The oxygen uptake rate is a comparable statistic used to assess the biological activity of an aerobic sludge during a specific experimental time [68].

2.4.10 Chemical Oxygen Consumption

Similar to the BOD method, COD estimates the amount of oxygen in a sludge sample that can be consumed by oxidizing agents during the course of a process. Typically, the COD of anaerobic digested sludge is a measurement of the amount of organic matter present in the slurry. COD reduction can also be used as a measure of the efficiency of anaerobic digestion, since it reflects the quantity of degradation occurring in an anaerobic digester and the amount of organics being eaten. During the COD testing procedure, sludge is subjected to severe refluxing in a solution of potassium dichromate and sulfuric acid. Because potassium dichromate does not convert ammonia, there is no need to manage the nitrification process. Calculating the amount of potassium dichromate consumed during first reflux and titrating the excess against ferrous ammonium sulfate allows for the determination of the final COD value.[108]

Estimating COD levels with a dichromate reflux, which takes only a few hours, is typical procedure. Since aerobic microorganisms rather than strong oxidizing chemicals are used to oxidize biodegradable organic components in the sample, the BOD test typically takes five days. Due to logistical complications, BOD testing is often avoided, as data collected after five days no longer accurately depicts the digester's current state, making it inefficient for adjusting operational settings. Therefore, BOD testing is typically avoided.

COD is unquestionably a more precise indicator of sludge quality than BOD. Therefore, the percentage of biodegradable sludge can be estimated using the BOD/COD ratio.[107]

2.4.11 Total Solids (TS)

Total solids (TS) refer to the dry matter included within a sludge, irrespective of its organic or inorganic content. A sludge sample is dried to a consistent weight at a temperature between 103 and 105 degrees Celsius in order to assess its TS content [109]. Simply explained, TS is an essential digester operating parameter. High-TS anaerobic digestion has lately gained favor because to its smaller digester capacity and reduced heating requirements. Continuous digesters with a high TS and the same retention time produced more biogas than continuous digesters with a low TS. Solids that can burn [95].

2.4.12 Volatile Solids (VS)

Frequently, volatile solids (VS) are used to signify the organic percentage of total solids. However, a more suitable word would be the amount of material in a sludge that is lost due to ignitability [110]. Even if some volatilization happened during the total solids' measurement, the VS content can be calculated by burning the leftover solids at 550°C for a length of time [111]. While both VS and COD are efficient markers of organic compound concentrations in water, VS is a more precise indicator of organic compound. However, as will be shown below, both sets of data can be applied to establish the organic loading rate [112].

2.5 Pretreatments

2.5.1 Pretreatments Biological

Aerobic and anaerobic pretreatments are insufficient to qualify as biological pretreatments. Rarely is municipal garbage handled. White rot fungus, a highly good biological agent for pretreatment of lignocellulosic wastes via enzyme secretions, has the potential to lengthen pretreatment periods and breakdown cellulose [113]. The removal of lignin may necessitate weeks or months of pretreatment, which is a significant drawback. Thermophilic or hyper thermophilic anaerobic digestion (TPAD) especially thermophilic-mesophilic TPAD, promotes hydrolysis, hence enhancing VS removal and methane generation [114]

Enzymes from industrial fermentation can also be used to treat lignocellulosic wastes. The optimal ratio of carbohydrate, protease, and lipase for VS reduction has been determined to be 1:2:1 [115].

The effectiveness and retention times of biological pretreatment are inferior to those of other pretreatment methods. In addition, the modest gains in methane production may not justify the expensive enzymes [116].

2.5.2 Pretreatments with Chemicals

Acidic pretreatment is a type of chemical pretreatment in which lignocellulosic substrates are broken down into their original monosaccharides under acidic conditions. In addition, hydrolytic bacteria can be utilized to alter the acidity associated with this pretreatment method [117], [118]. Although acidic pretreatment can facilitate substrate degradation and decrease digestion time, it is less economically viable than alkaline pretreatment due to its expense. Another type of chemical pretreatment is alkaline pretreatment, which typically employs ammonia or hydroxide chemicals. These treatments, unlike acidic pretreatments, are conducted at room temperature and employ less corrosive chemical agents. Alkaline pretreatment causes fiber expansion by destroying the lignin structure and exposing the substrate to enzymatic breakdown, resulting in fiber deterioration [58], [115].

2.5.3 Pretreatments Mechanical

The fundamental objective of mechanical pretreatment is to minimize the particle size of wastes. Consequently, the surface area of particles is expanded. Liquid shearing has garnered significant scientific interest, particularly collision plate pretreatment, which involves propelling a sludge at high pressure against a smash plate, causing cell lysis. As a result of this pretreatment, the HRT of waste activated sludge was reduced from 13 to 6 days without compromising the operation's efficacy [119]. Nonetheless, it is essential to note the results of this investigation. Crash plates have only been processed on a small scale in the laboratory. Milling is yet another mechanical preparation method that can be employed to reduce the substrate's size [120].

2.5.4 Pretreatments with heat

Wastes are subjected to high temperatures and pressures as part of the thermal pretreatment process in order to encourage hydrolysis and prevent evaporation. Increased loading rates are attainable with digesters that have been thermally processed [121]. Additionally, cell disintegration and hydrolysis are capable of producing a more biodegradable sludge, which enables for a more stable digesting process to take place later. When it comes to the efficacy of the process, the temperature of thermal pretreatment is important [122]. Increasing solution of carbohydrates and proteins at high temperatures may also result in the accumulation of deadly melanoidins, which are formed by the Maillard reaction. Although it has been argued that low-temperature thermal pretreatment occurs as a result of enzymatic hydrolysis, there is no evidence to support this theory. Although the temperature was lowered, thermal pretreatment at 70°C was still effective in greatly decreasing infections [116], [123], [124].

CHAPTER 3: METHODOLOGY

In this chapter the sorting of waste, waste measurements, different experimental setups and procedures is addressed.

3.1 Flow Diagram

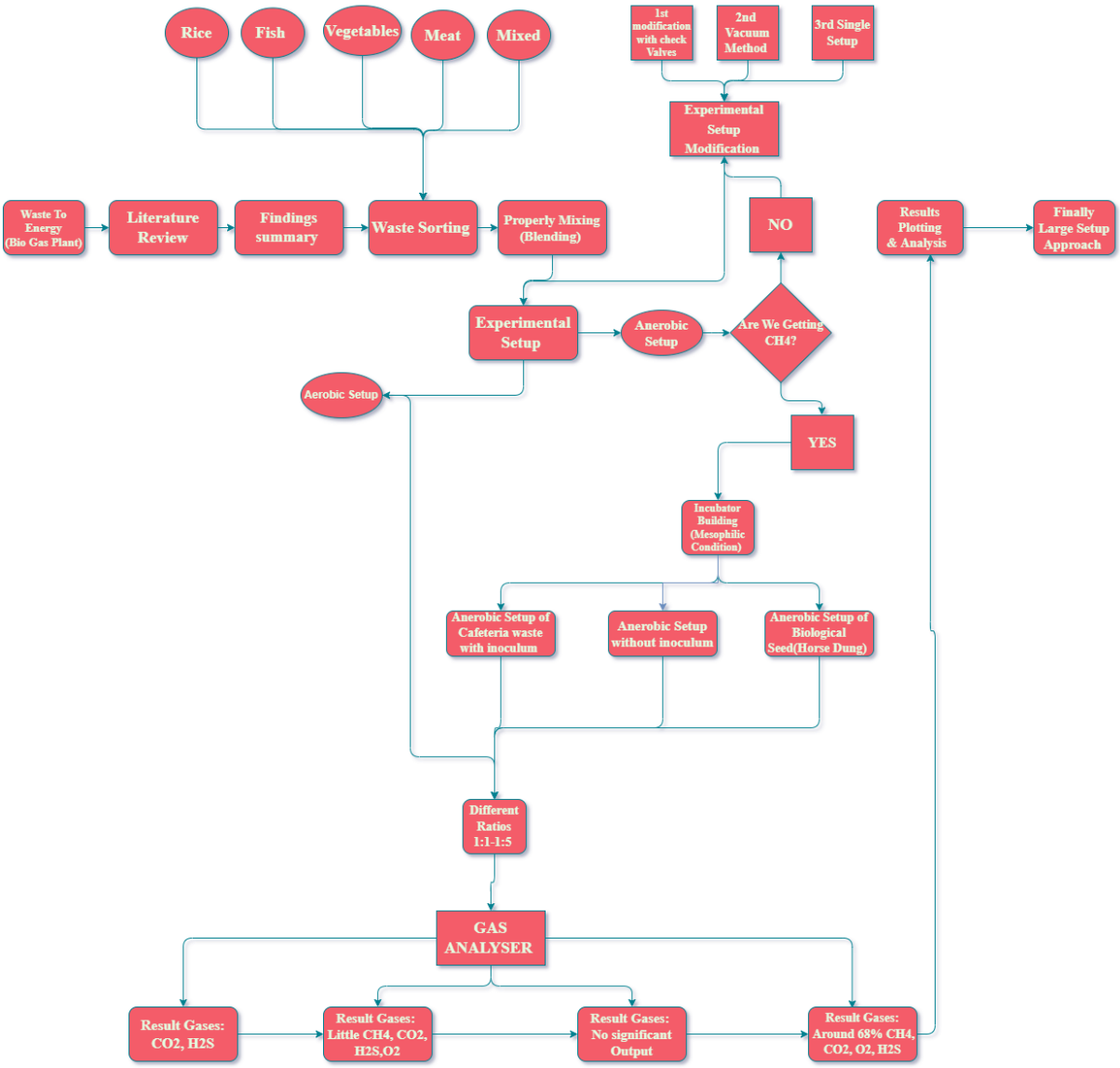


Figure 2 Flow Chart Demonstrating the Methodology of Our Work Process

In Figure 2 we can see the flow process of the methodology. Initially different papers were studied and their findings were summarized. Five drums each were installed behind both the North Cafeteria and South cafeteria. These drums had a capacity of 200 liters. Five drums were installed for sorting five different types of wastes, cooked rice waste, vegetable waste, meat waste, fish waste and mixed wastes respectively. The wastes were measured regularly for a period of one month. Digital hook scale and standard weighing scale were used to measure the wastes. This process was done to estimate the total amount of waste produced in the IUT cafeteria throughout the year.

3.2 Waste Sorting

Previously waste was collected in two drums and they were not sorted. But our aim was to sort the major wastes in different drums. In Figure 3 it is demonstrated how waste was collected before and Figure 4 shows how we have sorted waste in five different drums with proper labels.

Figure 3 Previous Method of Waste Collection

Figure 4 Present Method of Waste Collection in Five Different Drums Sorting (Rice Waste, Fish Waste, Meat Waste, Vegetables Waste and Mixed Wastes)

3.3 Waste Measurement

Waste was measured regularly for a period of one month using digital hook scale shown in Figure 5 and digital weighing scale shown in Figure 6.

Figure 5 Measurement of Waste Using Digital Hook Scale

Figure 6 Measurement of Waste Using Digital Weighing Machine

3.4 Verification of Water Displacement Method of Setup

Sodium carbonate and hydrochloric acid were combined in chemistry lab to produce carbon dioxide. The second bottle, which was filled with water, swelled as a result of this carbon dioxide. The carbon dioxide created a pressure to remove water from the first bottle to second bottle. The displaced water equaled to the gas produced in the reaction. The investigation was a successful. The process is shown in Figure 7, Figure 8 and Figure 9 respectively.

Figure 7 Measuring of Chemicals in Precision Balance

Figure 8 Mixing of Chemicals in Beaker

Figure 9 Verification of Setup for Water Displacement by Gas

3.5 First Experimental Setup (Aerobic Digestion)

3.5.1 Description of the setup

For the first, small scale laboratory experiments, 5 setups were prepared using cooked rice as waste substrate. Each configuration contained 3 plastic bottles (PET bottles), namely digester, water chamber and the displaced water chamber. The slurry was poured into the digester.

The caps of the digester and the water bottle both had two ports. One port of the digester was connected to a trimmer valve, while another was connected to a pipe. This pipe was connected to the second bottle (water chamber). The second bottle was filled with water. The gas pressurized the water inside the water chamber and forced it through the switch valve to the third bottle (displaced water chamber). By measuring the volume of the displaced water, the amount of the produced gas was determined. Basically, the water displacement method measured the amount of biogas produced.

3.5.2 Wastes and Ratios

Cooked Rice of kitchen waste was selected for the experiment. These was chosen because these was the primary waste collected at the Islamic University of Technology cafeteria. The ratios of waste to water selected were 1:1 - 1:5. After that, water was added to each digester accordingly. Waste was mixed and mashed using hand. Mixing the waste will increase the contact area for the microorganisms, which will lead to better digestion. Rice was well mixed with water to create different ratios of (1:1,1:2,1:3,1:4,1:5) by fixing total mass and varying fractions.

Figure 10 Mixing the Rice Waste

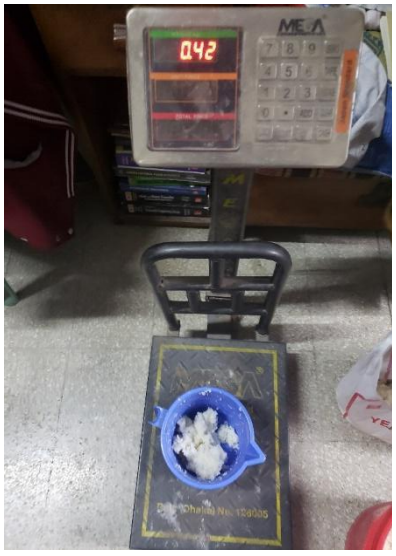


Figure 11 Measuring the Rice In Digital Weighing Scale To Vary Fractions

Figure 12 First Experimental Setup Using Three Bottles for Aerobic Digestion and Water Displacement

Finally similar 5 setups were made following the same procedure and they were installed in the lab as shown in Figure 13.

Figure 13 Installation Of 5 Setups of Rice Waste In 5 Different Ratios (1:1,1:2,1:3,1:4,1:5) In the Lab

3.6 Second Batch Setup Installation in Lab (Aerobic Digestion)

3.6.1 Description of the setup

For the second, small scale laboratory experiments, 15 setups were prepared using cooked rice, vegetable peels, potato peels as waste substrate. Each configuration contained 3 plastic bottles (PET bottles), namely digester, water chamber and the displaced water chamber. The slurry was poured into the digester.

The caps of the digester and the water bottle both had two ports. One port of the digester was connected to a trimmer valve, while another was connected to a pipe. This pipe was connected to the second bottle (water chamber). The second bottle was filled with water. The gas pressurized the water inside the water chamber and forced it through the switch valve to the third bottle (displaced water chamber). By measuring the volume of the displaced water, the amount of the produced gas was determined. Basically, the water displacement method measured the amount of biogas produced.

3.6.2 Wastes and Ratios

First, the amount (200g) of waste was selected. Cooked Rice, vegetable peels, potato peels of kitchen waste were selected for the experiment. These were chosen because these were the primary waste collected at the Islamic University of Technology cafeteria. The ratios of waste to water selected were 1:1 - 1:5. After that, water was added to each digester accordingly. Waste was mixed and mashed using hand grinder and blender shown in Figure 18 and Figure 19. The scraps were ground to a fine size using a blender. Mixing and blending the waste will increase the contact area for the microorganisms, which will lead to better digestion. Rice, vegetable peels and potato peels were well mixed with water to create different ratios of (1:1,1:2,1:3,1:4,1:5) by fixing total mass of wastes and varying amount of water.

Waste	Waste Amount (g)	Added Water (mL)	Ratio
Cooked Rice	**200**	200	1:1
		400	1:2
		600	1:3
		800	1:4
		1000	1:5

Table 1 Waste To Water Ratio For Cooked Rice Waste For 2nd Batch

Waste	Waste Amount (g)	Added Water (mL)	Ratio
Vegetable Peel	**200**	200	1:1
		400	1:2
		600	1:3
		800	1:4
		1000	1:5

Table 2 Waste To Water Ratio For Vegetable Peel Waste For 2nd Batch

Waste	Waste Amount (g)	Added Water (mL)	Ratio
Potato Peel	**200**	200	1:1
		400	1:2
		600	1:3
		800	1:4
		1000	1:5

Table 3 Waste To Water Ratio For Potato Peel Waste For 2nd Batch

Figure 14 Installation Of 15 Setups of Rice Waste, Vegetable Peel Waste and Potato Peel Waste In 5 Different Ratios (1:1,1:2,1:3,1:4,1:5) In the Lab

Figure 15 Installation Of 5 Setups of Rice Waste,5 Different Ratios (1:1,1:2,1:3,1:4,1:5) In the Lab

Figure 16 Installation Of 5 Setups of Vegetable Peel Waste,5 Different Ratios (1:1,1:2,1:3,1:4,1:5) In the Lab

Figure 17 Installation Of 5 Setups of Potato Peel Waste,5 Different Ratios (1:1,1:2,1:3,1:4,1:5) In the Lab

Figure 18 Grinding of Wastes Using Hand Grinder

Figure 19 Blending of Wastes Using Blender

3.6.3 Second Batch Modified

Due to facing problems of backflow from the second bottle a slight modification was introduced to prevent the problem. A one-way check valve was used in the connection from first bottle to second bottle. The modified setup shown illustrated in Figure 20 .

Figure 20 Setups Modified Using One Way Check Valves

3.7 Third Batch Setup (Anaerobic Digestion)

In the third batch suction machine was used to remove all the air inside the reactor bottle to prepare the setups as shown in Figure 21 .

Figure 21 Using Suction Machine to Create Anaerobic Condition

Figure 22 Three Bottle Setup with One Way Check Valve and First Bottle in Anaerobic Condition

3.7.1 Description of the Setup

For third small scale laboratory experiments, 15 setups were prepared. Each configuration contained 3 plastic bottles (PET bottles), namely digester, water chamber and the displaced water chamber. The slurry was poured into the digester. After running the slurry into the digester bottle, the remaining air from the digester was exhaled by a vacuum machine.

The caps of the digester and the water bottle both had two ports. One port of the digester was connected to a trimmer valve, while another was connected to a pipe. This pipe was connected to the second bottle (water chamber) through a one-way check valve. The second bottle was filled with water. The one-way check valve was used to prevent the back-flow of water from the water chamber to the digester. The valve permitted the flow of gas produced inside the digester. The gas pressurized the water inside the water chamber and forced it through the switch valve to the third bottle (displaced water chamber). By measuring the volume of the displaced water, the amount of the produced gas was determined. Basically, the water displacement method measured the amount of biogas produced.

3.7.2 Wastes and Ratios

Three types of kitchen waste were selected for the experiment. They are cooked rice, potato peel, vegetable peel. These were chosen because these were the primary wastes collected at the Islamic University of Technology cafeteria.

First, the amount (200g) of waste was selected. The ratios of waste to water selected were 1:1 - 1:5. After that, water was added to each digester accordingly. The scraps were ground to a fine size using a grinder. Grinding the waste will increase the contact area for the microorganisms, which will lead to better digestion.

Waste	Waste Amount (g)	Added Water (mL)	Ratio
Cooked Rice	**200**	200	1:1
		400	1:2
		600	1:3
		800	1:4
		1000	1:5

Table 4 Waste to Water Ratio for Cooked Rice Waste For 3rd Batch

Waste	Waste Amount (g)	Added Water (mL)	Ratio
Vegetable Peel	**200**	200	1:1
		400	1:2
		600	1:3
		800	1:4
		1000	1:5

Table 5 Waste to Water Ratio for Vegetable Peel Waste For 3rd Batch

Waste	Waste Amount (g)	Added Water (mL)	Ratio
Potato Peel	**200**	200	1:1
		400	1:2
		600	1:3
		800	1:4
		1000	1:5

Table 6 Waste to Water Ratio for Potato Peel Waste For 3rd Batch

Figure 23 Installation Of 5 Setups of Rice, Vegetable Peels, Potato Peel Waste In 5 Different Ratios (1:1,1:2,1:3,1:4,1:5) In the Lab After Modifications and Alterations in The Setups

3.8 Horse Dung Collection and Preparation of Biological Seed

As we were unable to get Methane from the previous setups, we took an approach to introduce some biological seeds (Horse Dung) with the substrates. Five ratios of (1:1,1:2,1:3,1:4,1:5) biological seeds were prepared.

3.8.1 Setup With 10% Inoculation of Horse Dung with Rice Waste

Also, five setups of rice waste with 10% inoculation with horse dung (1:1,1:2,1:3,1:4,1:5) were made. But this time a single bottle setup was used, focus was on Methane percentage, not on volume. A trimmer valve and switch valve was attached to the two openings of the cap as shown in Figure 26 .

Figure 24 Collection of Horse Dung

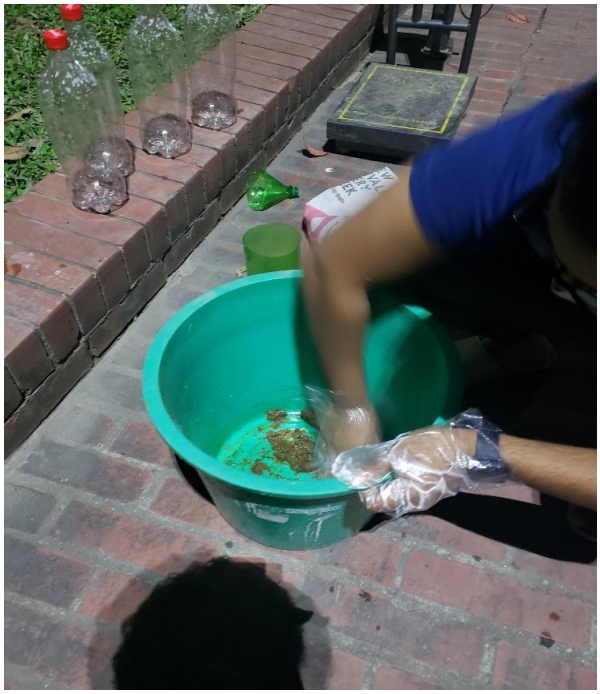


Figure 25 Preparation Of Biological Seed

Figure 26 Single Bottle Setup Using Trimmer Valve and Switch Valve at The Openings

Figure 27 Biological Seed (Horse Dung) In Different Ratios

3.9 Preparation of Incubator for Temperature Control (Mesophilic and Thermophilic)

An incubator was constructed in the lab, Styrofoam of thickness 3 inch was used in 5 surfaces as insulating material and a heavy plyboard of 2 inch was used in the top surface as insulating material. 14 bulbs were used with ceramic holders, and it was connected to a temperature controller. Two sensors were inserted into the incubator. By aid of this controller a stable temperature of 37^{o} Celsius was maintained throughout the experimental procedure.

The experiment was conducted at room temperature and mesophilic temperature of 37^{o} C (±1 ^{o} C). The temperature was controlled using an incubator-like setup. Light bulbs and a temperature controller (W1209) were used. In the controller, the threshold temperature was selected to be 37^{o}C. After reaching the threshold value, the bulbs would turn off. When the temperature reaches 36.5^{o} C, the bulbs will turn on again and remain turned on until 37.5^{o} C. Thick insulation was used inside the box so that the heat cannot escape. The setups were placed inside the temperature-controlled box after reaching 37^{o} C and sustained for specific minutes.

Figure 28 Construction of An Incubator for Maintaining Temperature of Mesophilic Condition in Winter Time

3.10 Preparation of Single Bottle Setup for Incubator (4th Batch)

New setups were created using the biological seeds prepared earlier.1:3 ratio biological seed was used to create 5 setups (1:1,1:2,1:3,1:4,1:5) of 10% inoculation with rice waste and 5 setups (1:1,1:2,1:3,1:4,1:5) 20% inoculation with rice waste as shown in Figure 28. They were all installed in the temperature-controlled incubator for further observation as shown in Figure 30.

Figure 29 Preparation Of 4th Batch of Rice Waste With 10% And 20% Inoculation With (H.D) In Different Ratios (1:1,1:2,1:3,1:4,1:5)

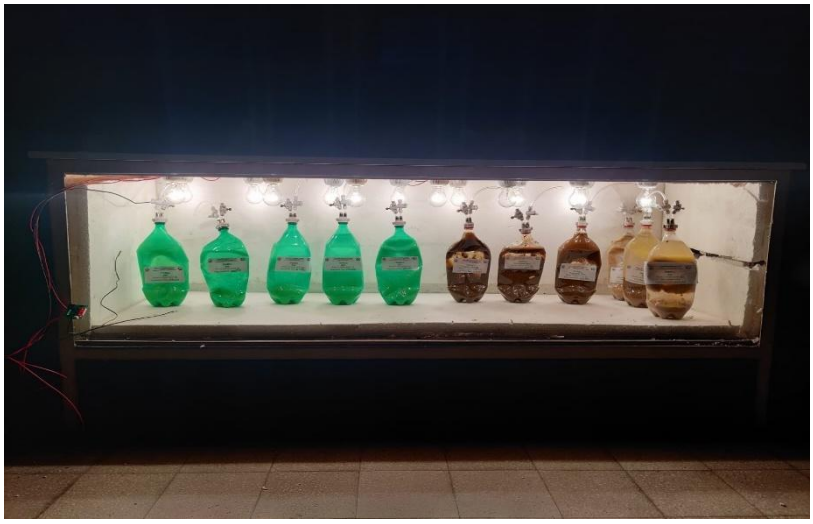


Figure 30 Installation Of 4th Batch In Incubator

3.11 Gas Analyzing

Gas was analyzed periodically using Gasboard analyzer-3200 plus.

3.11.1 Gas Analyzer Specifications

Gasboard analyzer-3200 plus is used for biomethane production monitoring and anaerobic digestion projects. The main feature includes the CH_4, CO_2, H_2S, O_2 gas sensors.

Measuring gases	CH_4, CO_2	NDIR
	O_2, H_2S	ECD
Measuring rang	CH_4	0～100 %
	CO_2	0～50 %
	O_2	0～25 %
	H_2S	0～10000 ppm
Accuracy	CH_4	±2%FS
	CO_2	±2%FS
	O_2	±3.0%FS
	H_2S	±3.0%FS
Repeatability	CH4, CO2、H2S, O2	≤1.5%
Lithium battery pack	2200mAh	
Power supply	DC5V 2A	
Flow	（0.7-1.2 ）l/min	
Warm up time	90seconds once power on	
GPS sensor	Positioning and location	
Working temperature	（-10～40） ℃	
Ambient pressure	（700 ～ 1200） mbar	
Relative humidity	0～95% non-condensing water	
Dimension	276 × 195 × 66 mm （Lengthxwidthxheight）	
Casing material	ABS/ Polypropylene and rubber molding	
Kepboard	Film panel keyboard	
Display	High-resolution colored 3.2-inch	
Communication	Micro USB port, bluetooth 4.0	

Figure 31 Features of Gas Board 3200 Plus

3.11.2 Gas Analyzing and Data Recording Using Software

4 types of gas data (CH_4, CO_2, H_2S, O_2) was collected periodically and with the help of the associated software of the analyzer and it was recorded for further analyzing and observations. The inlet port of the analyzer was connected to the switch valve end of the setup. Air filters and scrubbers were used in between to isolate the gases from impurities. The switch valve was slowly opened and the pump of the analyzer was turned on to pass the gas formed in the bottle through the analyzer as shown in Figure 32.

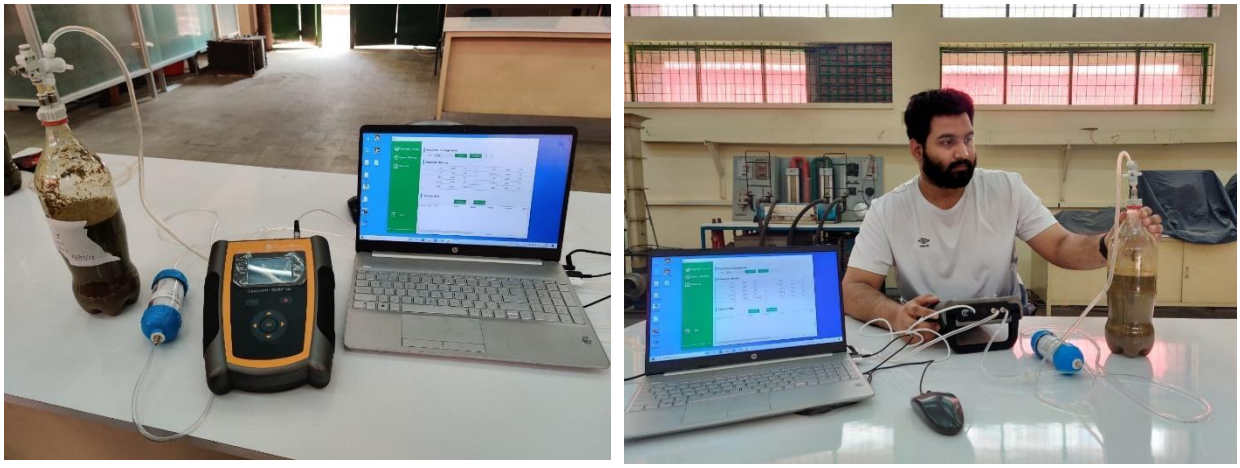


Figure 32 Gas Analyzing Using Gas Analyzer Gas Board 3200 Plus

3.11.3 Verification of Methane Production

Methane's presence was verified by using a flame at the end of the outlet port. Continuous blue flame was observed which inferred the presence of methane in the gas produced as shown in Figure 33.

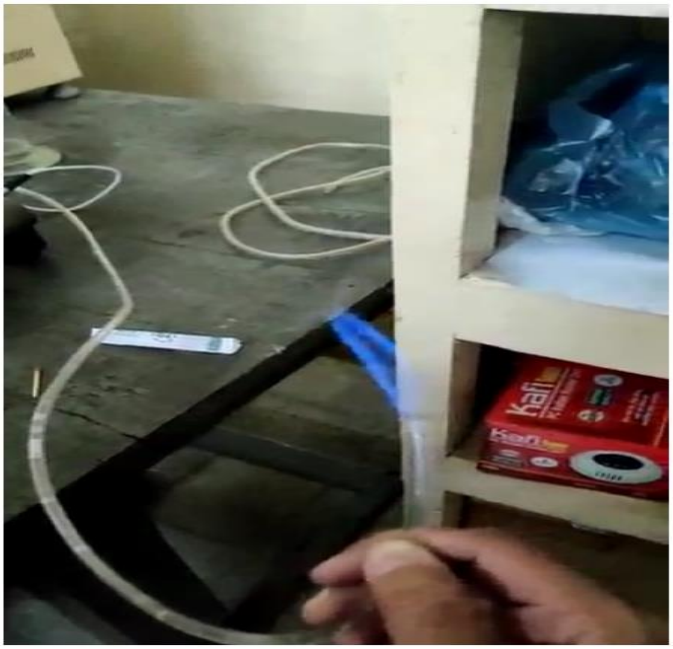
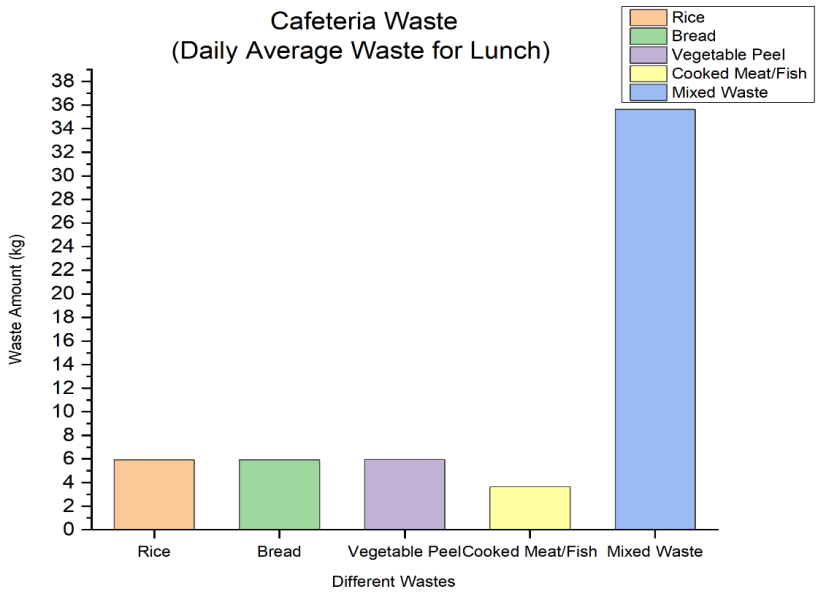


Figure 33 Verification of Methane's Presence in The Gas

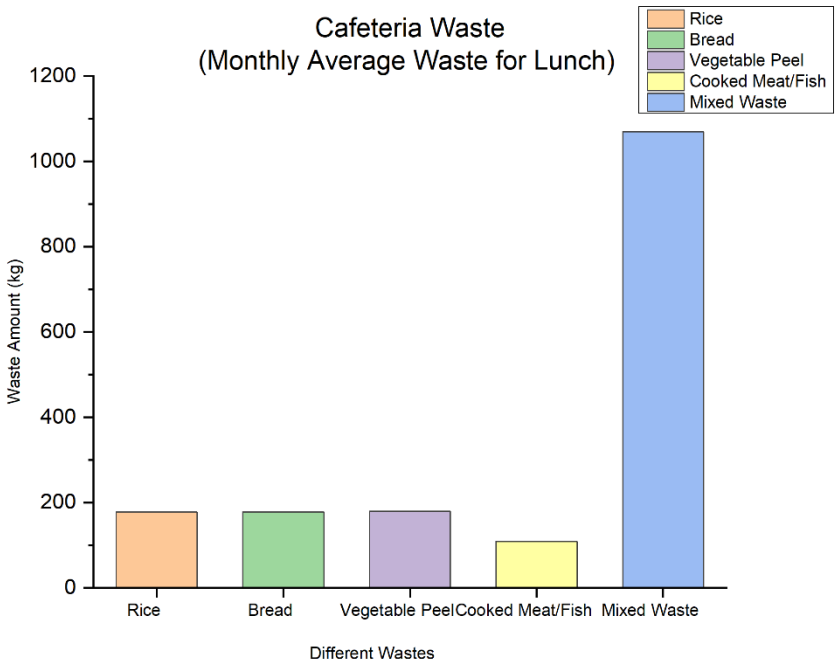
CHAPTER FOUR: RESULTS AND DISCUSSIONS

4.1 Waste Measurement Analysis

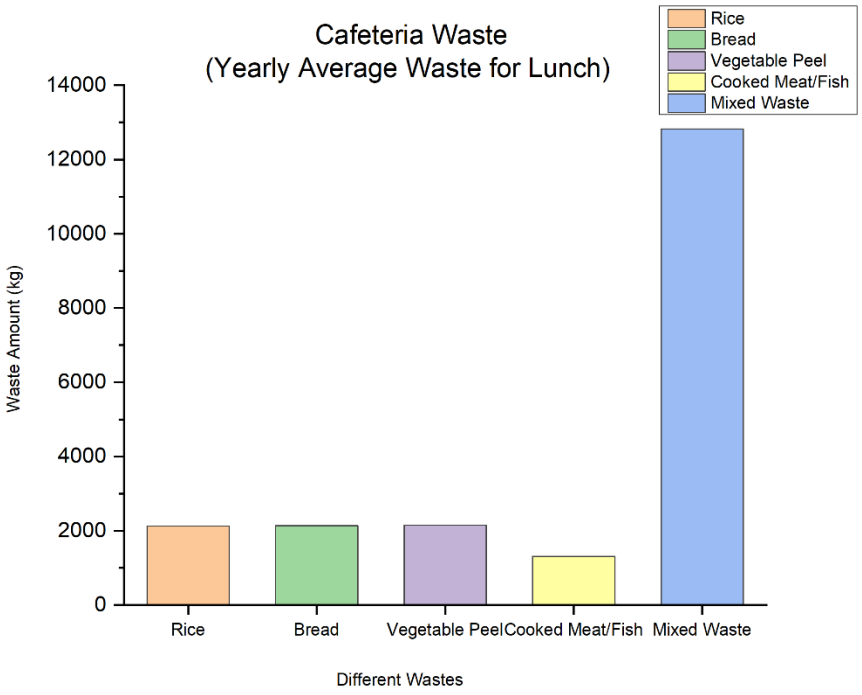
For assessing the potential of a biogas plant from cafeteria waste, we needed to know the amount of waste generated in IUT cafeteria. The findings are presented in bar charts below.



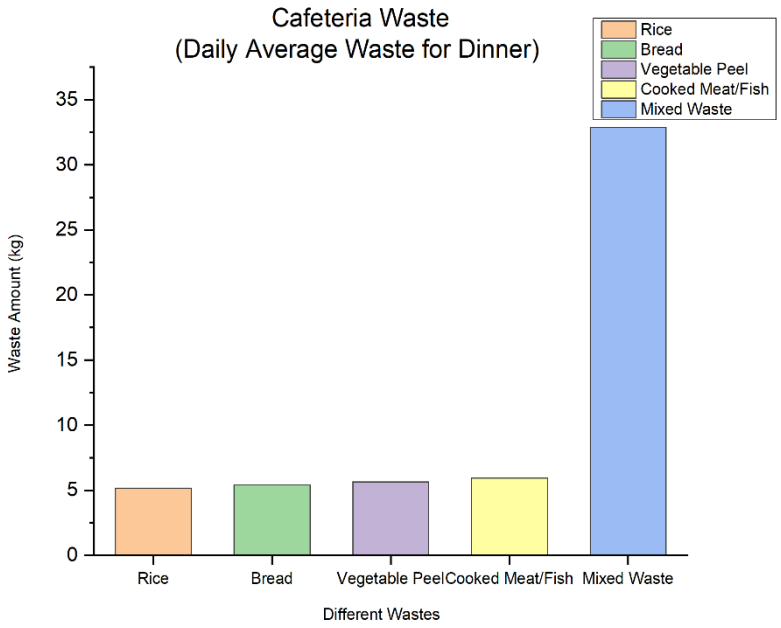
Graph 1 Demonstrating Daily Average Waste for Lunch



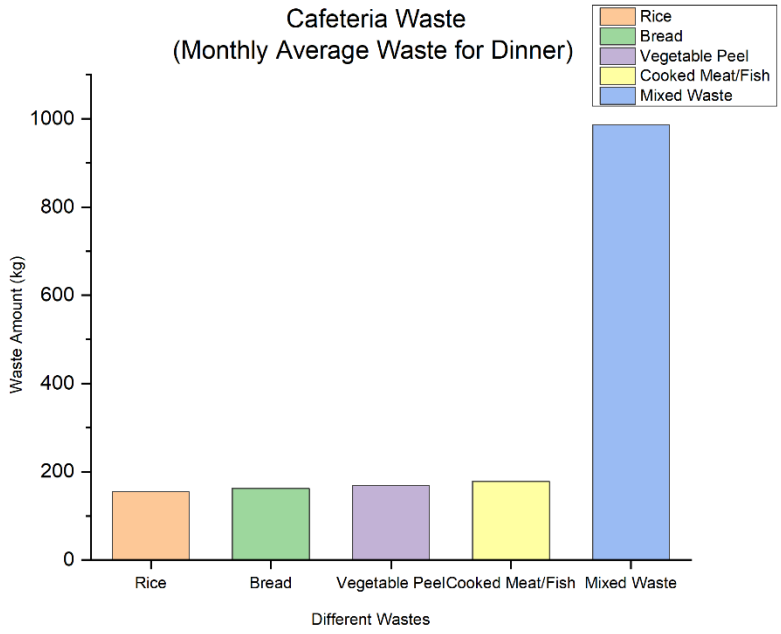
Graph 2 Demonstrating Monthly Average Waste for Lunch



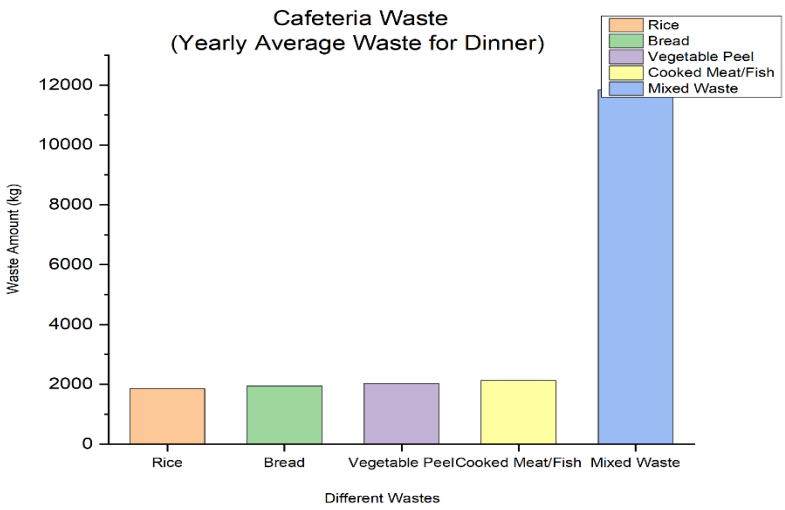
Graph 3 Demonstrating Yearly Average Waste For Lunch



Graph 4 Demonstrating Daily Average Waste for Dinner



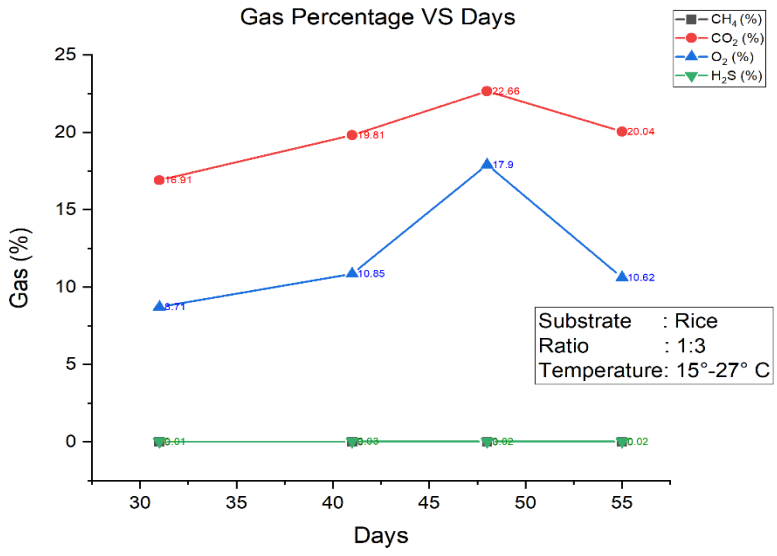
Graph 5 Demonstrating Monthly Average Waste for Dinner



Graph 6 Demonstrating Yearly Average Waste for Dinner

From these graphs, it can be seen that the highest waste produced are the mixed waste. There is also significant amount of rice waste, vegetable peel, cooked meat/fish. In experiments we tried to find out the potential of biogas production from these wastes. The findings are discussed in the next section.

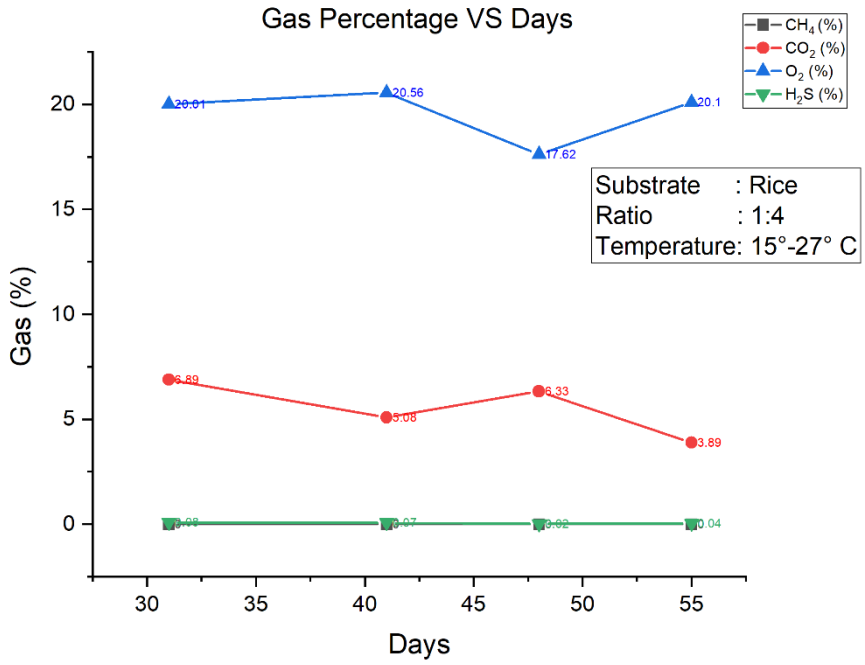
4.2 Rice Waste: Gas Analyzing Results



Graph 7 Gas Percentage Vs Days for Rice Waste (1:3)

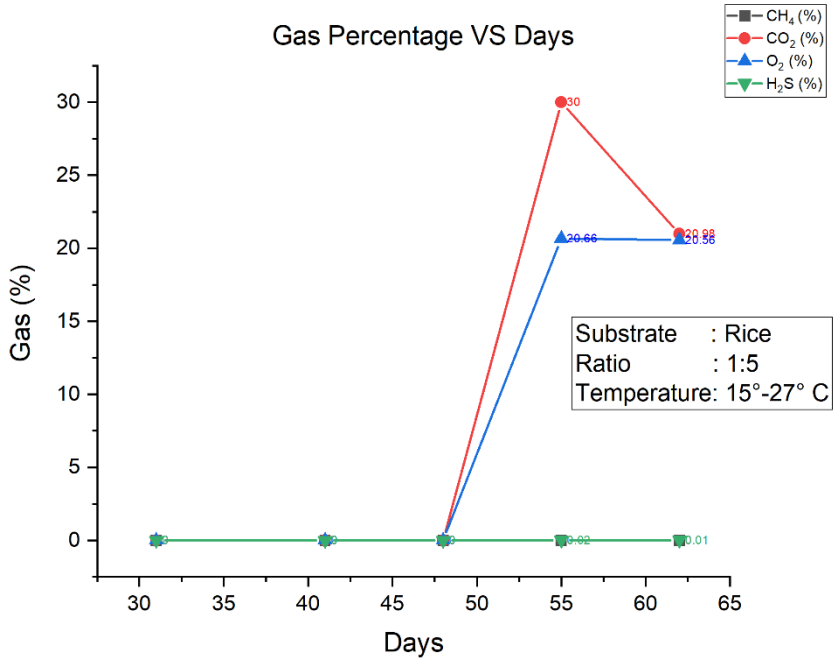
From the Graph 7 Gas percentage Vs Days for Rice waste (1:3), it can be seen that CH_4 production is very insignificant. From the plot, it is also evident that production of CO_2 is the highest, O_2 is also produced, but lesser than CO_2, and a trace

amount of H_2S is produced. The highest CO_2 percentage is 22.66%, and the highest O_2 rate is 17.9% which occurred on the 48th day.



Graph 8 Gas Percentage Vs Days for Rice Waste (1:4)

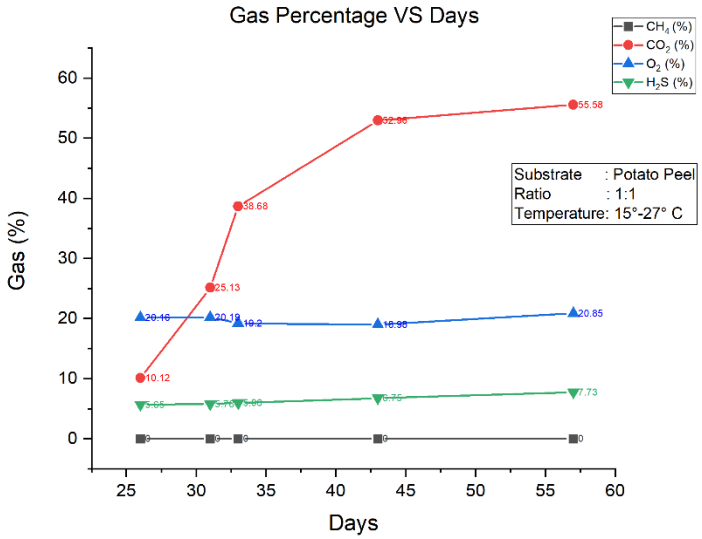
The ratio of 1:4 for rice waste did not result in methane production. Only CO_2, O_2, and a trace amount of H_2S were produced, which is evident from the Graph 8 Gas percentage Vs Days for Rice waste (1:4). Here the O_2 production rate was higher than anything else. The highest CO_2 percentage is 6.33% which occurred on the 49th day, and the highest O_2 rate is 20.56% which appeared on the 41st day.



Graph 9 Gas Percentage Vs Days for Rice Waste (1:5)

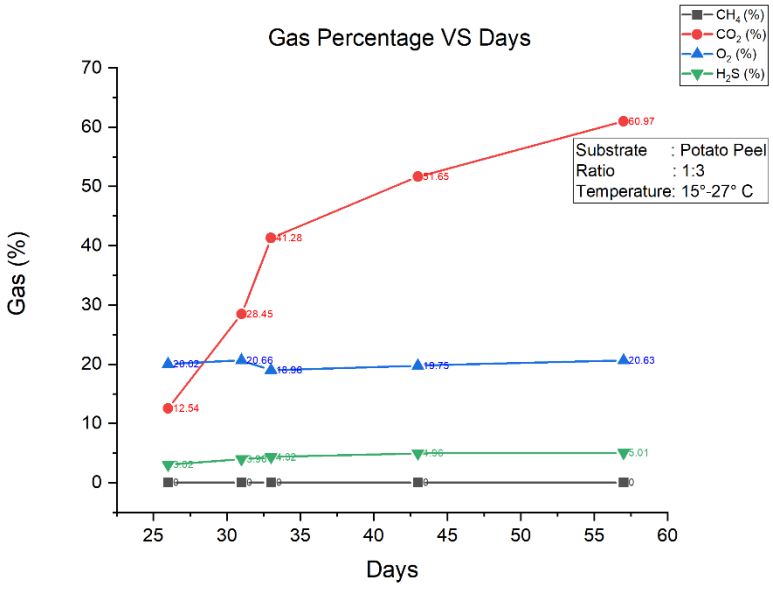
For the ratio of 1:5, it can be seen in Graph 9 Gas percentage Vs Days for Rice waste (1:5) that there is no methane. Only CO_2, O_2, and a trace amount of H_2S were produced. Among these, CO_2 production is the highest, and the amount is 30% which occurred on the 55th day.

4.3 Potato Peel: Gas Analyzing Results



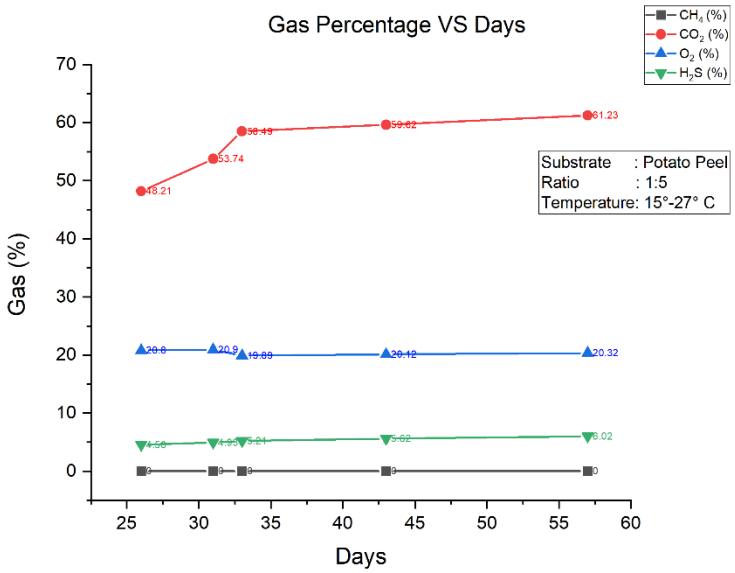
Graph 10 Gas Percentage Vs Days for Potato Peel (1:1)

From the Graph 10 Gas percentage Vs Days for Potato Peel (1:1) for the ratio of 1:1 between potato peel and water, it can be seen that there is no methane production. The highest percentage of gas produced is CO_2, and the amount is 55.58%. Some O_2 and H_2S are also produced.



Graph 11 Gas Percentage Vs Days for Potato Peel (1:3)

From the Graph 11 Gas percentage Vs Days for Potato Peel (1:3) of the ratio of 1:3, similar conclusions can be drawn. Methane cannot be found. A significant amount of CO_2 (~61%) is produced with small amounts of O_2 and H_2S.



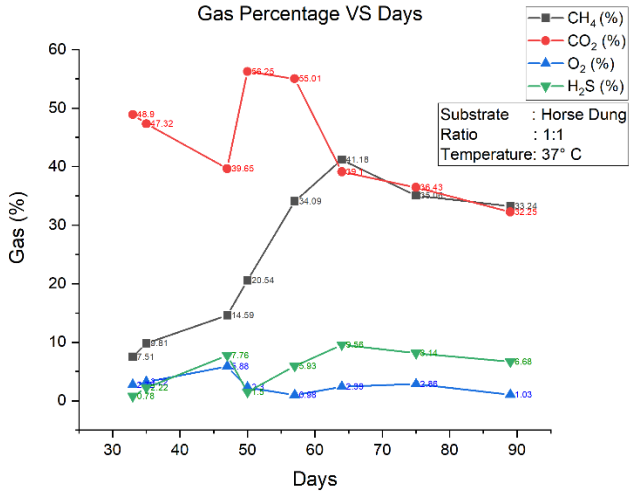
Graph 12 Gas Percentage Vs Days for Potato Peel (1:5)

The 'Gas Percentage VS Days' Graph 12 Gas percentage Vs Days for Potato Peel (1:5)for potato peel ratio 1:5 looks quite similar to others. No methane is produced. A large amount of carbon dioxide is produced with small amounts of oxygen and hydrogen sulfide. The highest CO_2 percentage is 61.23%.

For rice waste and potato peel experiments, the temperature was not controlled. These experiments were conducted during the winter season, and the temperature varies between 15º-27 ºC, which falls under the psychrophilic conditions. As a result, methane was not produced; only CO_2, O_2, and H_2S. In most cases, CO_2 percentages were highest only except for the ratio of 1:4 for rice waste, where O_2 production was the highest.

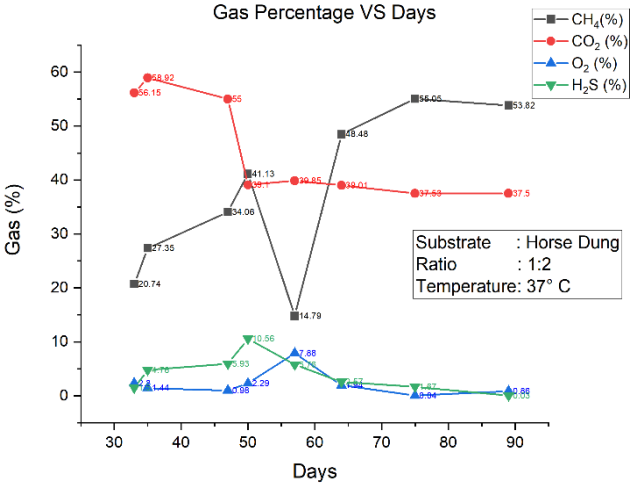
When we could not get any methane from our experiments, we tried to add inoculum to the mixtures. For preparing the inoculum/biological seed, horse dung was used. We tested ratios of 1:1 to 1:5. The findings are presented below.

4.4 Horse Dung: Gas Analyzing Results



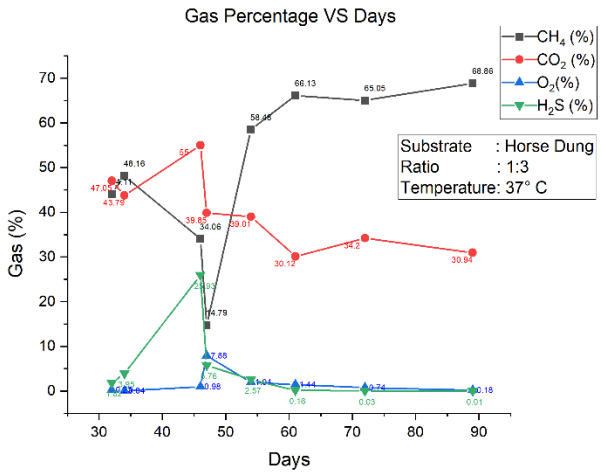
Graph 13 Gas Percentage Vs Days for Horse Dung (1:1)

Horse dung mixed with water in a ratio of 1:1 was contained in the digester bottle for 89 days. The temperature was controlled at 37 ºC using the incubator we made. From the Graph 13, we can see that, as the day increases, methane production increases till the 65th day and starts to drop again. The highest methane percentage for 1:1 was 41.18%. CO_2, O_2, and H_2S are also produced.



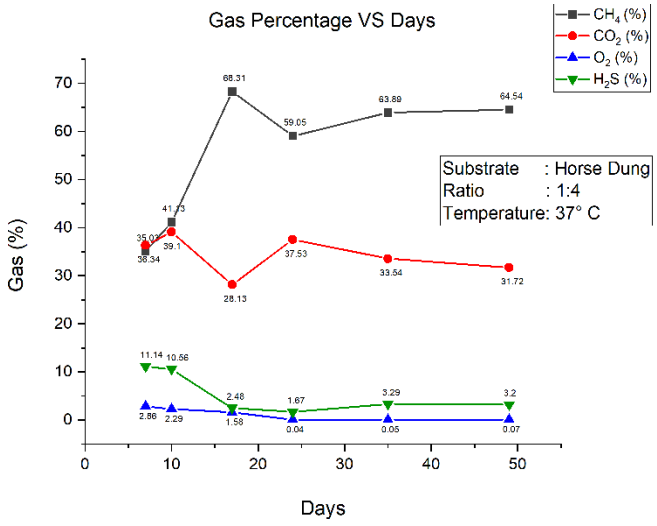
Graph 14 Gas Percentage Vs Days for Horse Dung (1:2)

For the ratio of 1:2, methane production increased till the 50th day, then decreased sharply and started to rise again from the 56th day. The highest methane percentage is 56.05% which occurred on the 75th day. CO_2, O_2, and H_2S are also produced shown in Graph 14.



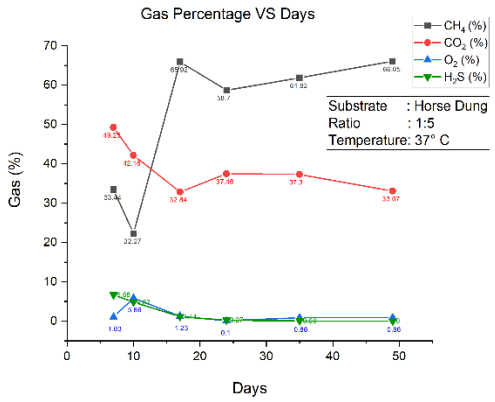
Graph 15 Gas Percentage Vs Days for Horse Dung (1:3)

For the ratio of 1:3, the highest methane percentage was 68.86% which occurred on the 89th day. CO_2, O_2, and H_2S are also produced shown in Graph 15.



Graph 16 Gas Percentage Vs Days For Horse Dung (1:4)

For the ratio of 1:4, the highest methane percentage was 68.31% which occurred on the 18th day. CO_2, O_2, and H_2S are also produced shown in Graph 16.

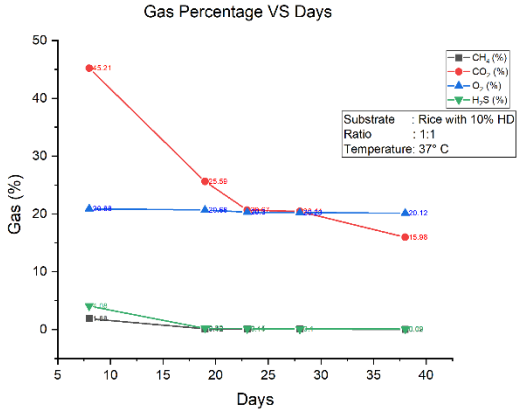


Graph 17 Gas Percentage Vs Days for Horse Dung (1:5)

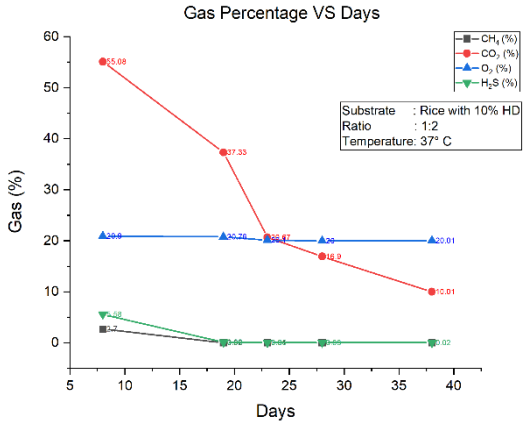
For the ratio of 1:5, the highest methane percentage was 66.05% which occurred on the 49th day. CO_2, O_2, and H_2S are also produced shown in Graph 17.

Among all these ratios for horse dung, the best result came from 1:3. It produced the highest methane percentage, which was ~69%. Thus, it can be concluded that if biogas was to produce from horse dung, the horse dung and water should be mixed at 1:3 proportions.

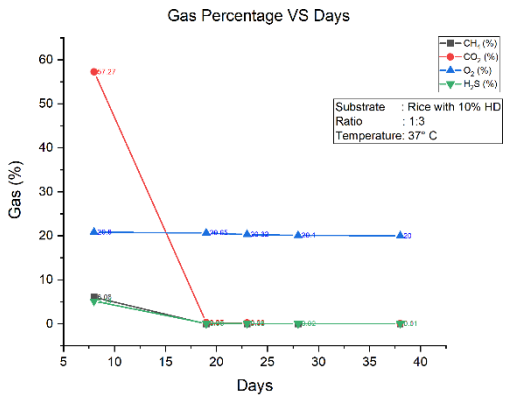
4.5 Rice with 10% Horse Dung: Gas Analyzing Results



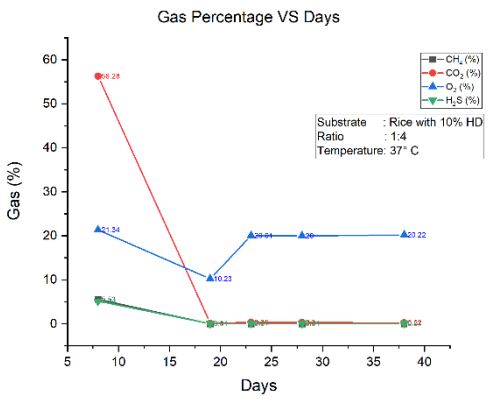
Graph 18 Gas Percentage Vs Days for Rice With 10% H.D(1:1)



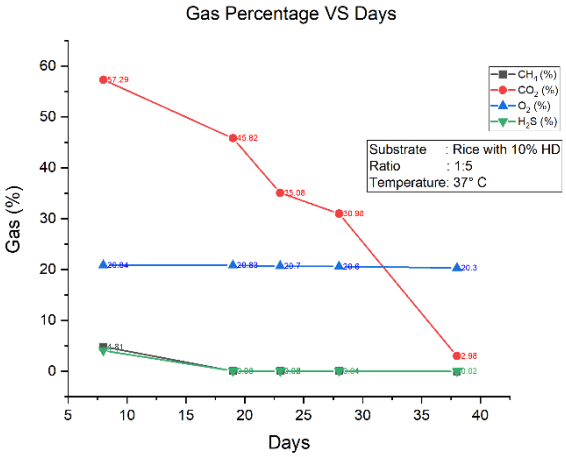
Graph 19 Gas Percentage Vs Days for Rice With 10% H.D(1:2)



Graph 20 Gas Percentage Vs Days for Rice With 10% H.D(1:3)



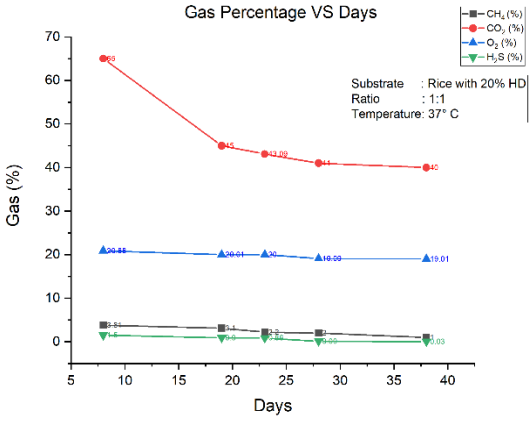
Graph 21 Gas Percentage Vs Days for Rice With 10% H.D(1:4)



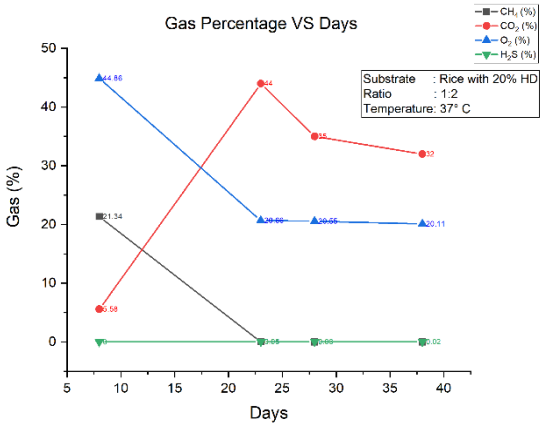
Graph 22 Gas Percentage Vs Days for Rice With 10% H.D(1:5)

Rice with 10% horse dung did not produce any significant percentage of methane. Only CO_2, O_2, and H_2S were produced. Among these gases, in all cases, the CO_2 portion was more significant than any other gases. For these experiments, temperatures were maintained at 37 ºC using the incubator.

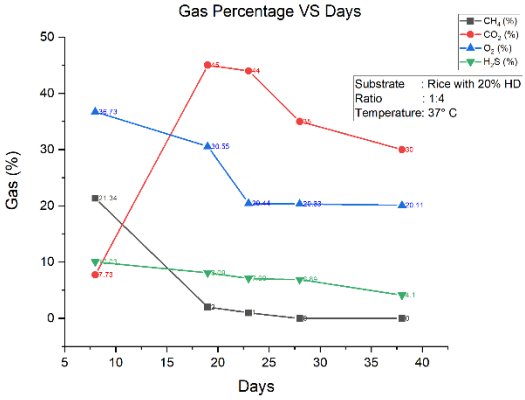
4.6 Rice with 20% Horse Dung: Gas Analyzing Results



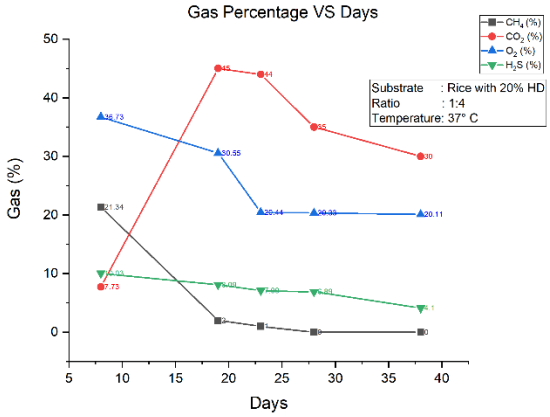
Graph 23 Gas Percentage Vs Days for Rice With 20% H.D(1:1)



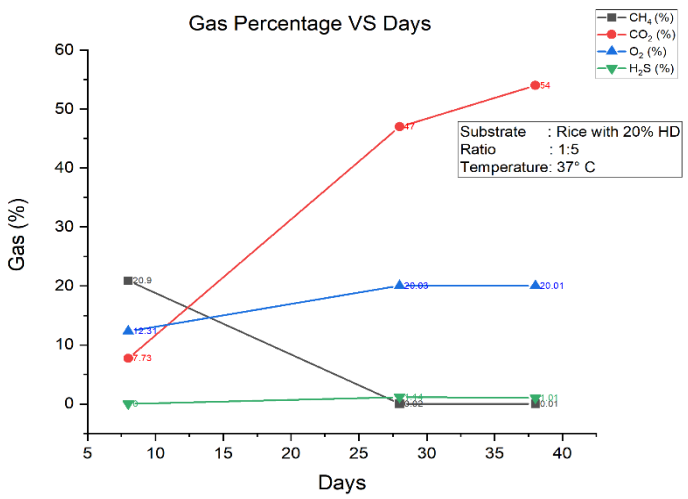
Graph 24 Gas Percentage Vs Days for Rice With 20% H.D(1:2)



Graph 25 Gas Percentage Vs Days for Rice With 20% H.D(1:3)



Graph 26 Gas Percentage Vs Days for Rice With 20% H.D(1:4)



Graph 27 Gas Percentage Vs Days for Rice With 20% H.D(1:5)

The results of rice with 20% horse dung are pretty similar to rice with 10% horse dung. The only difference is that in the case of rice with 20% horse dung, the amount of methane produced was a bit higher than that of rice with 10% horse dung.

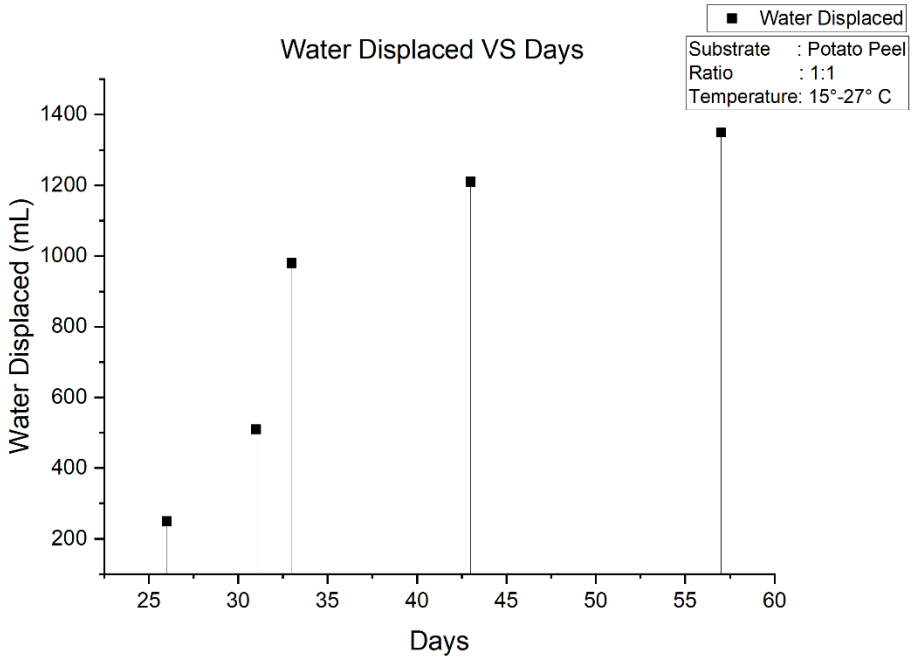
The results of CH_4 production from different wastes are summarized in the following table.

Waste	**Ratio**	**CH_4**	**CO_2**	**O_2**	**H_2S**	**Days needed to produce the CH_4**
Rice with 10% Horse Dung	1:1	1.88	45.21	20.88	4.08	8
	1:2	2.7	55.08	20.9	5.58	8
	1:3	6.08	57.27	20.8	5.14	8
	1:4	5.53	56.28	21.34	5.04	8
	1:5	4.81	57.29	20.84	4.1	8
Rice with 20% Horse Dung	1:1	3.81	65	20.88	1.5	8
	1:2	21.34	5.58	44.86	0	8
	1:3	21.34	5.14	25.68	0	8
	1:4	21.34	7.73	36.73	10.03	8
	1:5	20.9	7.73	12.31	0	8
Horse Dung	1:1	41.13	39.10	2.29	10.56	64
	1:2	59.05	37.53	0.04	1.67	75
	1:3	68.86	30.94	0.18	0.01	89
	1:4	64.54	31.72	0.07	3.2	49
	1:5	66.05	33.07	0.86	0	49

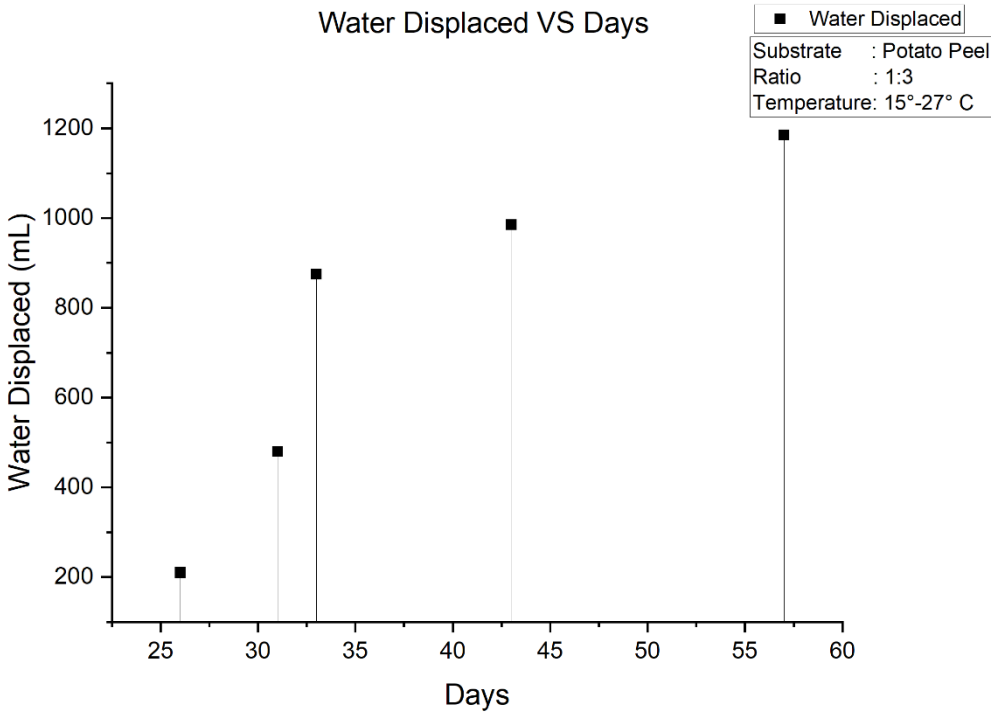
Table 7 The Results of CH_4 Production from Different Wastes

4.7 Gas Volume Measurement: Water Displacement Method

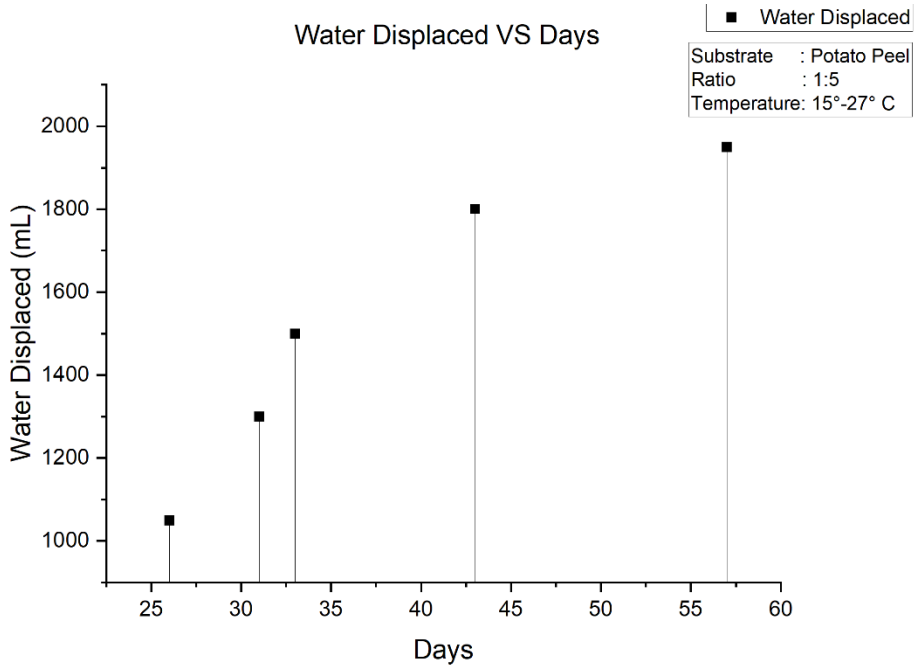
For measuring the volume of the biogas, the water displacement method was tested. The gas pressurizes the second bottle's water and is displaced in this method. The displaced water is then collected in a third bottle. After that, the collected water is measured. We tested this for potato peel experiments. The results are presented here.



Graph 28 Water Displaced Vs Days for Potato Peel (1:1)



Graph 29 Water Displaced Vs Days for Potato Peel (1:3)



Graph 30 Water Displaced Vs Days for Potato Peel (1:5)

The amount of water displaced represents the amount of gas produced on a corresponding day in these graphs.

CHAPTER FIVE: LIMITATIONS, RECOMMENDATIONS AND CONCLUSION

5.1 Limitations:

5.1.1 Volatile Fatty Acid (VFA)

During different steps of biogas production. Volatile acid is produced and makes the pH lower thus inhibiting the whole process. To overcome this problem, it was found that different salt or base compounds are used [53], [103], [104], [125], [126]

5.1.2 C/N Ratio

The C:N ratio reflects the interaction between carbon and nitrogen in organic chemistry. Using the C:N ratio, nutritional insufficiency and ammonia inhibition can be anticipated. 16–25 is the optimal C:N ratio for anaerobic digesters [84], [85]. A high C:N ratio indicates that methanogens are consuming nitrogen at a rapid rate, resulting in low gas output. In contrast, a low C:N ratio leads to the accumulation of ammonia and an increase in pH levels to 8.5. Microorganisms that create methane may be harmed by these conditions. As long as ammonia concentrations are gradually increased, methanogenic bacteria are able to adapt to extremely high ammonia concentrations. To achieve ideal C:N ratios, feedstock sources with high and low C:N ratios, such as organic solid waste and sewage or animal manure, can be combined (e.g., sewage or animal manure). Carbon-to-nitrogen (C/N) ratio is frequently used to characterize a substrate [88]. Given their nature, proteins are the most abundant supply of nitrogen in an anaerobic digester. Similar to how a certain concentration of carbon is required for a suitable substrate. Numerous bacterial processes, including digesting and protein synthesis, require nitrogen. Researchers discovered that raising the C/N ratio in dairy manure reduced methane levels in biogas, with a C/N ratio of 25:1 being optimal [2]. As a result of the introduction of co-digestion, the C/N ratio has gained increased attention. To prevent ammonia inhibition, carbon-rich substrates, such as straw, can be co-digested with chicken manure [127].

5.1.3 Inhibitors

The design and operation of a biogas plant must take into account elements that inhibit the anaerobic process. In large quantities, certain substances can be detrimental to the anaerobic process. The concentration of antibiotics, the chemical composition of the substrate, and how well bacteria can adapt to an inhibitor all influence inhibition in general. Oxygen, hydrogen sulfide (H_2S), organic acids, ammonia, heavy metals, and other harmful substances such as disinfectants (from hospitals or industry), herbicides (from agricultural, market, and residential gardens), and antibiotics are all examples of inhibitors [104]. Nitrogen ammonia is frequently listed as one of the most widely used substances for reducing AD. A variety of ammonia concentrations can impede a variety of processes [103]. According to numerous studies, total inorganic nitrogen

concentrations of 1,400 to 17,000 mg N/L restrict ammonia synthesis. In anaerobic reactors, the protonated form of ammonium (NH_4^+) and ammonia (NH_3) comprise the majority of total inorganic nitrogen [1], [2], [83], [85]. At normal pH levels, ammonium is the principal source of inorganic nitrogen. The solution's ammonia concentration increases as pH and temperature rise. Ammonia that has not been dissociated diffuses into cells, upsetting the potassium-proton balance. This leads to cellular malfunction. The digester may become acidified due to the imbalance and buildup of intermediate digestion products, such as volatile fatty acids (VFA) [41], [53]. If given the time to adapt, anaerobic microbes are able to withstand higher ammonium concentrations than are typically encountered. On the other side, methane production may decrease [125].

5.1.4 Mixing & Foaming

By mixing and spinning digestate and new material within the digester, microorganisms can transfer from the digestate to the new material. This mixing lowers temperature fluctuations and inhibits the formation of digester scum [101]. In the digester, filamentous microorganisms produce scum and froth. When the substrate concentration is low, the growth of filamentous bacteria in AD plants is accelerated. Avoid scum in digesters, since it can clog the gas line and cause the digester to foam.

As a result, slurry can leak into pipes, machines, and other equipment, rendering them inoperable. Typically, microorganisms can regenerate after being eliminated. Large-scale systems are often viewed as "stable" and "easy to manage" if they have a 20- to 60-centimeter layer of foam on top [128]. Alternately, a more impermeable scum layer could prevent gas from exiting the liquid and lead to the collapse of the structure. The equipment and procedures for mixing and stirring are determined by the kind of reactor and the concentration of TS in the digester. Rarely is stirring applied in any of the three most common AD methods in poor nations. Passive mixing can be achieved by simply reentering the digester with its digestate outflow, which is equal to its daily feeding load. This method of digestate recirculation facilitates the mixing of fresh feedstock and digestate with a high concentration of bacteria [129].

5.1.4 Insoluble compounds

Even after biogas has been cleaned and pressed, it still has pollutants in it. If biofuel was used to power cars, it could hurt the metal parts in the engine. Because of this corrosion, it would cost more to fix things. When the gaseous mixture is used instead of solid fuel, it works much better in stoves, water heaters, and lamps.[103], [130][131], [132]

5.1.5 pH

A pH range between 6.5 and 7.5 is optimal for a stable AD process and substantial biogas production. Unlike the methanogenic phase (pH 6.5 – 8.2), hydrolysis and acidogenesis occur at

lower pH values (pH 5.5 – 6.5) during digestion [2], [4], [17], [42], [58]. A constant alkalinity level of roughly 3,000 mg/L must be maintained to achieve adequate buffering capacity. Customarily, lime is used to increase the acidity level in AD systems. Additionally, sodium bicarbonate can be used to alter the pH of a solution. Lime is generally cheaper, and there may be free sources of spent lime solutions in your neighborhood. When lime is utilized in large quantities, precipitation and pipe clogging can result [77]. Both sodium bicarbonate and sodium hydroxide are completely soluble and do not precipitate, but their more difficult handling contributes to a higher price tag [75]. Additionally, sodium bicarbonate or sodium hydroxide may not be as accessible as lime. The usage of sodium salts is recommended for immediate action. If you need to boost the pH of a substrate with a low pH, lime may be your best alternative. The process of anaerobic digestion comprises multiple microbial groups, each with its own ideal pH for growth. Acidogens, for instance, favor a pH range of 5.0 to 6.0, whereas methanogens favor a pH range of 6.5 to 8.0 [79]–[81].

Biogas facilities typically operate between 6.5 to 8.4 pH. a number of acetogenic and methanogenic bacteria's ideal temperature and pH levels were identified. VFAs, ammonium, and alkalinity levels have a major influence on the pH. The increase in VFAs induces a decrease in pH. The pH rises as alkalinity sources increase [2]

5.2 Conclusion

5.2.1 Findings

1. Food waste has high potential but due to low pH, we only got CO_2, O_2, and H_2S.
2. The best ratio for biological seed is the ratio of 1:3 of horse dung.
3. Maintenance of vacuum in the bottle and pH simultaneously is not possible in the experimental setup we used. Thus, improved digester design is required.
4. Horse dung can be a good source of producing methane.
5. Methane production from horse dung proved that vacuum in the bottle is maintained properly in our setup.
6. During the psychrophilic condition, gas production was very low and methane was inexistant.
7. Though maintenance of temperature at 37 ºC in the incubator resulted in significant proportion of gas production from cafeteria waste, methane was absent. In contrast to cafeteria waste, horse dung produced combustible methane.

5.2.2 Recommendations

Controlling parameters of the biogas plants can be shown under three categories:

Elements of the Procedure (The kind and quantity of feedstock, the amount and quality of biogas produced, the temperature of the reactor, the dry matter concentration, the ammonia concentration, and the pH are all variables to consider)

Indicators for early detection of instability (VFA, alkalinity, hydrogen concentration, redox potential, and other complex monitoring parameters are all measured and monitored)

Process variables that change over time: specified by plant operators (OLR and HRT)

It is a fundamental constraint because the technologies now available do not permit controlling of all operating parameters of a biogas system. Prioritize and implement the benefits of this project, including energy supply, environmental protection, and the low cost of biogas plant installation. On the digestate, more research is required. If biogas is to be used to generate electricity, production levels must be increased. Food waste should be collected and evaluated thoroughly, and its potential for renewable energy should be investigated.

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