DESIGN OF MINIATURE PROTOTYPE FOR ORGANIC WASTE BASED COMPRESSED BIOGAS PRODUCTION AND PURIFICATION

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CERTIFICATE

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"DESIGN OF MINIATURE PROTOTYPE FOR ORGANIC WASTE BASED COMPRESSED BIOGAS PRODUCTION AND PURIFICATION"

is a bona fide work carried out by

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It is certified that all corrections/suggestions indicated for Internal Assessment have been incorporated in the report deposited in the departmental library.

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ABSTRACT

This project aims to address the growing need for sustainable energy solutions by developing a miniature prototype for the production and purification of compressed biogas (CBG) from organic waste. The portable digester facilitates biogas generation through anaerobic digestion, offering a decentralized approach to energy production. The subsequent purification process employs filters to effectively remove carbon dioxide, hydrogen sulphide, and water vapor, ensuring the quality and purity of the biogas.

By compressing the purified biogas into gas cylinders using a compressor, the prototype enhances the transportability and convenience of CBG, making it suitable for a wide range of applications. The advantages of utilizing compressed biogas over raw biogas extend beyond its convenience, including increased energy density, reduced greenhouse gas emissions, and improved environmental sustainability.

This project not only demonstrates the technical feasibility of producing and purifying CBG on a small scale but also underscores its potential to contribute to a more sustainable energy landscape. Additionally, it highlights the economic and environmental benefits of utilizing organic waste as a renewable energy source, thereby promoting circular economy principles and mitigating the environmental impact of waste disposal.

Keywords: Sustainable energy solutions, Compressed biogas (CBG), Anaerobic digestion, Purification process, Prototype development, Compressed gas storage

CHAPTER 1 INTRODUCTION

1.1 BIOGAS PRODUCTION: UNDERSTANDING AND PROCESS

Biogas production constitutes a pivotal aspect of sustainable energy initiatives, presenting a renewable alternative to conventional fossil fuels. A thorough comprehension of the biogas generation process is imperative for maximizing its utility and efficacy. Fundamentally, biogas production hinges on anaerobic digestion, a biochemical process wherein microorganisms decompose organic substrates in the absence of oxygen. This occurs within specialized reactors known as digesters [1].

During anaerobic digestion, complex organic compounds found in diverse feedstocks such as agricultural residues, animal manure, food waste, and sewage sludge are enzymatically degraded into simpler compounds. The predominant byproducts are methane (CH_4) and carbon dioxide (CO_2), alongside minor constituents like hydrogen sulphide (H_2S) and ammonia (NH_3) [1]. Methane, the primary constituent of biogas, serves as a valuable energy source with applications spanning electricity generation, heating, and vehicular fuel. The efficiency of biogas production is contingent upon several factors including feedstock composition, digester operating parameters (e.g., temperature, pH, retention time), and the microbial consortia involved. Effective management and optimization of these variables are essential for maximizing biogas yield and quality while minimizing operational inefficiencies and environmental impacts.

Biogas production engenders a multitude of environmental, social, and economic benefits. It offers a sustainable energy source, mitigates greenhouse gas emissions by capturing methane from organic waste, and addresses pollution concerns associated with waste disposal. Furthermore, biogas systems can catalyse rural development by fostering opportunities for income generation, waste management, and decentralized energy production. In essence, a comprehensive understanding of biogas production mechanisms serves as a cornerstone for implementing robust and sustainable energy strategies that promote environmental stewardship and societal well-being.

1.2 CBG: AN OVERVIEW

Compressed Biogas (CBG) is a renewable and environmentally friendly fuel derived from the anaerobic digestion of organic waste materials. It primarily consists of methane (CH_4), with smaller proportions of carbon dioxide (CO_2) and trace gases. CBG is produced through a process that involves the decomposition of organic matter by microorganisms in anaerobic conditions within a digester. This microbial activity breaks down complex organic compounds into simpler molecules, resulting in the generation of biogas [2].

CBG holds significant promise as a sustainable energy source due to its renewable nature and reduced environmental impact compared to fossil fuels. It offers several advantages, including a lower carbon footprint, as the methane emitted during biogas production is captured and utilized rather than being released into the atmosphere as a potent greenhouse gas. Additionally, CBG production helps to reduce dependence on finite fossil fuel reserves and provides an effective solution for managing organic waste streams, thereby mitigating environmental pollution and contributing to circular economy principles.

Furthermore, CBG is purified to remove impurities before being compressed using a compressor. This purification process ensures the biogas meets quality standards and is suitable for various applications. Its versatility in transportation, electricity generation, heating, and cooking makes it a valuable component of sustainable energy systems, contributing to improved air quality, energy security, and rural development [3].

1.3 PURPOSE AND PROCESS OF CBG PRODUCTION

Producing Compressed Biogas (CBG) serves multiple purposes, aligning with environmental, economic, and energy efficiency goals. From an environmental perspective, CBG production contributes to mitigating climate change by capturing methane emissions from organic waste and utilizing them as a renewable fuel source. By diverting organic waste from landfills and reducing greenhouse gas emissions, CBG helps combat air pollution and fosters sustainable waste management practices. Additionally, CBG has a lower carbon footprint compared to conventional fossil fuels, making it a valuable tool in the transition towards cleaner energy systems [4].

In terms of energy efficiency and content, CBG offers a high-energy density, making it suitable for various applications such as transportation, electricity generation, and heating. Its efficient combustion reduces emissions of air pollutants, contributing to improved air quality and public health. Furthermore, CBG can serve as a reliable and decentralized energy source, particularly in rural areas with limited access to traditional energy infrastructure. Economically, CBG production presents opportunities for income generation and job creation, particularly in rural communities. By monetizing organic waste streams and establishing biogas production facilities, CBG projects can stimulate local economies and promote agricultural sustainability.

The production process of CBG involves several key steps. Initially, biogas is generated through anaerobic digestion, where microorganisms break down organic materials in the absence of oxygen. Subsequently, the biogas undergoes purification to remove impurities such as hydrogen sulphide, moisture, and other trace gases. This purification step ensures that the CBG meets quality standards for various end uses. Finally, the purified biogas is compressed using compressors to increase its density, facilitating storage, transportation, and distribution. Overall, producing CBG offers a sustainable solution for addressing environmental challenges, enhancing energy security, and promoting economic development.

1.4 SIGNIFICANCE OF CBG

The significance of Compressed Biogas (CBG) lies in its multifaceted contributions to sustainable energy practices and environmental conservation. As an eco-friendly alternative to traditional fossil fuels, CBG plays a pivotal role in reducing greenhouse gas emissions and mitigating climate change. By harnessing organic waste materials such as agricultural residues, food waste, and animal manure, CBG production diverts these materials from landfills, thereby curbing methane emissions and minimizing environmental pollution [5].

Furthermore, CBG serves as a versatile energy resource with diverse applications across various sectors. It can be used as a clean-burning fuel for vehicles, thereby reducing air pollutants and improving air quality in urban areas. Additionally, CBG can be utilized for electricity generation, heating, and cooking, providing reliable and sustainable energy solutions for both rural and urban communities.

From an economic standpoint, CBG production fosters job creation and rural development opportunities, particularly in regions with abundant agricultural resources. It promotes entrepreneurship and local investment in renewable energy infrastructure, contributing to economic resilience and energy security [6].

Overall, the significance of CBG extends beyond its immediate energy benefits to encompass broader environmental, social, and economic advantages. By embracing CBG as a renewable energy source, societies can transition towards a more sustainable and resilient energy future while mitigating the adverse impacts of climate change.

1.5 LIMITATIONS

Despite its numerous advantages, Compressed Biogas (CBG) also presents certain limitations that need to be addressed for its widespread adoption and effective utilization. One primary limitation is the availability and consistency of feedstock sources. CBG production relies heavily on organic waste materials such as agricultural residues, food waste, and animal manure. However, the quantity and quality of these feedstocks can vary seasonally and regionally, posing challenges to continuous and reliable biogas production. Additionally, the technology required for CBG production, including anaerobic digesters and gas purification systems, can be capital-intensive and technically complex. This may deter small-scale or resource-constrained operators from investing in CBG infrastructure, limiting its widespread deployment, particularly in rural and developing areas. Moreover, the storage and distribution of compressed biogas pose logistical challenges. The infrastructure for storing and transporting CBG, such as compressed natural gas (CNG) cylinders and distribution networks, may not be readily available or cost-effective in all regions, hindering the accessibility and commercial viability of CBG as a fuel source for vehicles and other applications [7].

Furthermore, the conversion efficiency of organic waste into biogas is not 100%, leading to residual waste streams and potential environmental concerns associated with waste disposal and treatment. Addressing these limitations requires concerted efforts in research, development, and policy support to enhance feedstock availability, improve technology efficiency, and establish robust infrastructure for CBG production, storage, and distribution. Overcoming these challenges is essential for unlocking the full potential of CBG as a sustainable and renewable energy solution with significant environmental, social, and economic benefits.

1.6 CBG CURRENT MARKET STATUS

The current market status of Compressed Biogas (CBG) reflects a growing global interest in renewable energy sources and sustainable fuel alternatives. CBG has emerged as a promising sector within the renewable energy market, driven by increasing environmental awareness, stringent emission regulations, and the need to diversify energy sources. In recent years, several countries have implemented policies and incentives to promote CBG production and utilization, fostering market growth and investment opportunities. Government subsidies, tax incentives, and renewable energy targets have incentivized the development of CBG projects and infrastructure, particularly in regions with abundant organic waste resources [8].

Moreover, CBG is gaining traction in transportation, industrial, and residential sectors as a cleaner and more sustainable fuel option. The automotive industry, in particular, is exploring CBG as a viable alternative to conventional fuels, with increasing investments in CBG-powered vehicles and refuelling infrastructure. The CBG market is also witnessing innovation and advancements in technology, such as improved biogas purification methods, efficient compression techniques, and the integration of CBG into existing energy systems. Despite these positive trends, challenges such as high initial investment costs, infrastructure limitations, and regulatory barriers remain significant barriers to market growth. However, as CBG technology continues to mature and economies of scale are realized, the market outlook for CBG remains promising, with ample opportunities for expansion and market penetration in the coming years.

1.7 COMPARISON OF RAW BIOGAS, CBG, AND LPG

A comparison between raw biogas, Compressed Biogas (CBG), and Liquefied Petroleum Gas (LPG) provides insights into their respective characteristics and applications. Raw biogas is the initial product of anaerobic digestion, comprising primarily methane and carbon dioxide, along with impurities such as hydrogen sulphide and moisture. While raw biogas can be utilized for energy generation, its impurities necessitate purification before use.

In contrast, CBG undergoes purification to remove impurities, resulting in a cleaner and higher-quality fuel compared to raw biogas. CBG offers advantages such as higher methane content, lower moisture levels, and reduced sulphur content, making it suitable for a wide range of applications including transportation, electricity generation, and cooking. On the other hand, LPG is a fossil fuel derived from petroleum refining and consists mainly of propane and butane. LPG is widely used for heating, cooking, and transportation due to its high energy density, easy storage and transportability. However, LPG combustion emits greenhouse gases and other pollutants, whereas CBG offers a renewable and environmentally friendly alternative [9].

In summary, while raw biogas serves as the initial stage in biogas production, CBG represents a purified and upgraded form suitable for various applications, offering environmental benefits over conventional fuels like LPG.

1.8 ECONOMICAL BENEFITS

Compressed Biogas (CBG) offers significant economic benefits compared to Liquefied Petroleum Gas (LPG). Firstly, CBG production provides avenues for revenue generation and job creation, particularly in rural areas with abundant organic waste resources. By monetizing waste streams and establishing biogas production facilities, CBG projects stimulate local economies and promote agricultural sustainability [10].

Moreover, CBG reduces dependency on imported fossil fuels like LPG, leading to savings in foreign exchange and enhancing energy self-sufficiency. The utilization of locally available organic waste as feedstock for CBG production further reduces import bills and mitigates economic risks associated with volatile global fuel prices. Additionally, CBG projects often qualify for government subsidies, tax incentives, and renewable energy credits, further enhancing their economic viability. Overall, the economic benefits of CBG make it a compelling option for countries seeking to foster economic growth, create employment opportunities, and achieve energy independence through sustainable means.

1.9 APPLICATIONS

Compressed Biogas (CBG) finds versatile applications across various sectors due to its renewable nature, environmental friendliness, and energy efficiency. In transportation, CBG serves as a clean-burning fuel for vehicles, offering an alternative to conventional fossil fuels like gasoline and diesel. CBG-powered vehicles emit fewer pollutants, leading to improved air quality and reduced greenhouse gas emissions, making them an environmentally sustainable option for urban and rural transportation fleets. Moreover, CBG can be used for electricity generation, either through combustion in gas turbines or engines [11], or through its utilization in fuel cells. This application contributes to renewable energy generation, reduces reliance on fossil fuels, and helps mitigate climate change by displacing greenhouse gas emissions from traditional electricity generation sources.

In addition to transportation and electricity generation [11], CBG can also be utilized for heating and cooking purposes in residential [12], commercial, and industrial settings. Its clean combustion characteristics make it an attractive option for space heating, water heating, and cooking, offering a renewable and environmentally friendly alternative to Liquefied Petroleum Gas (LPG) and other fossil fuels. Overall, the diverse applications of CBG make it a valuable component of sustainable energy systems, contributing to environmental protection, energy security, and economic development.

CHAPTER 2 LITERATURE REVIEW

2.1 IMPORTANCE OF LITERATURE REVIEW

A literature review holds paramount significance in academic and research endeavours for several reasons. Firstly, it serves as the foundation upon which new research is built. By thoroughly examining existing literature, researchers gain insights into the current state of knowledge, identifying gaps, trends, and areas requiring further exploration. This ensures that new studies are informed by past findings, enhancing their relevance and potential contribution to the field.

Secondly, a literature review aids in the formulation of research questions and hypotheses. This not only helps in refining the focus of the study but also ensures that research efforts are aligned with existing knowledge gaps and research agendas [13]. This enables researchers to situate their work within the broader scholarly discourse, acknowledging the contributions of others while also positioning their own research within ongoing debates and discussions [14].

Overall, a literature review is indispensable for advancing knowledge, guiding research endeavours, and fostering intellectual dialogue within academic and research communities. Its importance lies not only in synthesizing existing knowledge but also in providing a solid foundation for generating new insights and contributing to the advancement of the field.

2.2 OVERVIEW OF CBG

Compressed Bio Gas (CBG) has emerged as a promising renewable energy source globally, with particular relevance in the context of sustainability and environmental conservation. CBG, also known as bio-methane or green gas, is produced from organic waste materials such as agricultural residue, animal manure, municipal solid waste, sewage sludge, and food waste through a process called anaerobic digestion. Anaerobic digestion involves the breakdown of organic matter by microorganisms in the absence of oxygen, resulting in the production of biogas, primarily consisting of methane (CH_4) and carbon dioxide (CO_2). The biogas is then purified through a process called scrubbing to remove impurities such as hydrogen sulphide (H_2S), moisture, and other trace gases, resulting in high-purity methane, which is referred to as CBG[15].

CBG has several advantages over conventional fossil fuels. Firstly, it is a renewable energy source, derived from organic waste materials that would otherwise contribute to environmental pollution through landfilling or open burning. By harnessing these waste streams for energy production, CBG helps mitigate greenhouse gas emissions and reduces dependence on finite fossil fuel resources. Secondly, CBG is a versatile energy source that can be used in various applications, including power generation, heating, cooking, and transportation. In the transportation sector, CBG can be used as a cleaner alternative to diesel and petrol, thereby reducing air pollution and improving urban air quality[16]. Moreover, CBG production has the potential to generate additional revenue streams for farmers, municipalities, and other stakeholders involved in waste management. By monetizing organic waste materials through CBG production, communities can enhance their economic resilience while promoting environmental sustainability.

Furthermore, CBG production supports the circular economy by closing the loop on organic waste management. Instead of treating organic waste as a liability, CBG facilities transform it into a valuable resource, creating a closed-loop system that minimizes waste generation and maximizes resource efficiency[17]. In conclusion, CBG represents a sustainable and environmentally friendly energy solution that holds significant potential for addressing energy security, climate change, and waste management challenges. Its adoption and expansion can contribute to the transition towards a more sustainable and resilient energy system, benefiting both the environment and society at large.

2.3 IMPORTANCE OF CBG

Compressed Biogas (CBG) stands as a beacon of sustainability and innovation in the realm of renewable energy. Its significance reverberates across various domains, from environmental conservation to economic empowerment and social progress. At its core, CBG represents a transformative solution to the pressing challenges of organic waste management and greenhouse gas emissions reduction. Through the anaerobic digestion of organic waste materials such as agricultural residues, animal manure, and municipal solid waste, CBG facilities not only prevent these materials from ending up in landfills or incinerators but also harness their energy potential to produce a clean and renewable fuel. This dual benefit not only mitigates the environmental impact of waste disposal but also contributes to the circular economy by closing the loop on organic waste management[5].

The environmental importance of CBG extends beyond waste management to encompass climate change mitigation. By displacing fossil fuels in various applications, CBG helps reduce greenhouse gas emissions, thereby mitigating the adverse effects of climate change. Its utilization in transportation, power generation, heating, and cooking offers a sustainable alternative to conventional fuels, leading to cleaner air and a healthier environment. Moreover, CBG's versatility enables its integration into existing energy infrastructure, providing a seamless transition to a low-carbon future.

From an economic perspective, CBG holds promise for rural development and energy independence. In regions abundant in organic waste resources, CBG production offers a decentralized energy solution that creates employment opportunities, stimulates local economies, and reduces dependence on imported fossil fuels. By valorising organic waste materials, CBG projects generate additional revenue streams for farmers, municipalities, and other stakeholders, thereby fostering economic resilience and prosperity in rural communities[6].

Beyond its environmental and economic benefits, CBG has profound social implications, particularly in improving livelihoods and enhancing energy access. In rural and marginalized communities, where access to modern energy services is limited, CBG offers a clean and affordable fuel option for cooking, lighting, and productive uses. By democratizing access to clean energy, CBG contributes to poverty alleviation, health improvement, and overall human development[7].

In essence, the importance of CBG transcends its role as a renewable fuel; it embodies a sustainable pathway towards a greener, more inclusive, and prosperous future. As societies grapple with the urgent imperatives of waste management, climate change mitigation, and energy transition, CBG stands as a beacon of hope, offering tangible solutions that harmonize environmental stewardship, economic prosperity, and social equity[6].

2.4 FEEDSTOCK SELECTION

Certain feedstocks present challenges for standalone anaerobic digestion due to unfavourable carbon-to-nitrogen (C/N) ratios or elevated lipid content. Examples include abattoir wastes, fats and oils, and paper. In such cases, co-digestion emerges as the optimal strategy to rectify these imbalances and enhance volumetric methane productivity. For instance, co-digestion involves blending slaughterhouse wastes with animal slurries or municipal solid wastes, as well as adding substances like whey or glycerol (a by-product of biodiesel production) to livestock manure digestion. Feedstock selection or blending also serves to optimize other performance aspects. The digestate's physical attributes, especially its dewatering characteristics, can significantly impact the overall energy balance of the process. Some feedstocks, like sugar beet pulp, are notably challenging to dewater without chemical intervention and centrifugation, leading to a choice between the energy costs of transporting large digestate volumes or material processing. Additionally, feedstock chemical composition can lead to issues such as struvite precipitation, which necessitates effective upstream pre-treatment to safeguard the system. Final digestate quality profoundly influences feedstock selection, as high-quality source-segregated materials should not be combined with mixed-waste feedstocks to avoid contamination, preserve product value, and expand disposal options[20].

Additionally, feedstock composition impacts not only the quantity but also the quality of biogas produced. The presence of specific compounds in the feedstock, such as lipids, proteins, and carbohydrates, contributes to the methane content and energy content of the biogas. Moreover, varying feedstock compositions can affect the stability of the digestion process, influencing the retention time and overall system efficiency. A well-balanced mix of feedstock materials, carefully chosen based on their composition, allows for synergistic effects, enhancing microbial diversity and metabolic pathways. Understanding these complex interactions between feedstock components and their influence on biogas yield is essential for optimizing the composition of input materials, ultimately leading to more consistent and economically viable biogas production[21].

Selecting appropriate feedstock is a critical aspect of biogas production, influencing the efficiency, sustainability, and economic viability of the process. Feedstock selection entails evaluating various factors, including availability, composition, processing requirements, and environmental considerations. One key consideration in feedstock selection is the availability and abundance of organic materials suitable for anaerobic digestion. Common feedstock sources include agricultural residues (such as crop residues, straw, and husks), animal manure, organic municipal solid waste, sewage sludge, food waste, and energy crops (such as maize, sorghum, and grasses). Assessing the availability of these feedstock sources within proximity to the biogas plant is essential to ensure a consistent and reliable supply.

In conclusion, feedstock selection for biogas production requires a comprehensive assessment of availability, composition, processing requirements, and environmental considerations. By carefully evaluating these factors, biogas producers can optimize feedstock utilization, enhance biogas yield and quality, and minimize environmental impacts, contributing to the sustainability and efficiency of biogas production systems.

2.5 PRODUCTION MECHANISM AND SETUPS

Anaerobic digestion technologies encompass a diverse array of designs, each with unique advantages and efficiency considerations. Covered Lagoon Digesters provide a simple and cost-effective approach by utilizing natural or man-made lagoons with covers to capture biogas. The ARTI Biogas system is a popular choice, particularly in rural settings, utilizing a modified drum to process a mix of feedstock for biogas generation. Tube Gas Digesters offer versatility, enabling the use of various feedstock types in flexible tubes, while Balloon Digesters utilize large, inflatable structures for efficient biogas collection. Floating Drum Biogas systems employ a floating drum to capture biogas, commonly used in small-scale applications. Fixed Dome Biogas designs, on the other hand, use a sturdy, fixed-dome structure to capture biogas from organic materials. The selection of the most suitable digester depends on factors such as feedstock availability, scale of operation, space constraints, and desired biogas output. Ensuring efficient performance across these diverse designs requires proper maintenance, operational control, and adherence to specific operational guidelines.

The Chinese-developed fixed dome biogas system from the 1930s, like the Deenbandhu variant, offers affordability, durability, and space-saving benefits. It consists of an underground brick masonry compartment with a spherical gas holder atop a structure. This design, known for its simplicity, allows customization to meet local energy needs and enables easy maintenance by rural farmers. Besides cost-effectiveness, it helps reduce air pollution and greenhouse gas emissions by converting animal waste into methane gas, especially beneficial in energy-scarce regions like rural India [22]. Floating Drum Biogas (FDB) is an economical anaerobic digestion system that converts animal and plant waste into valuable energy for electricity or cooking fuel, reducing environmental impact. It utilizes a floating drum that collects methane gas produced during fermentation within a water jacket or atop the slurry. This design prevents flooding, retains heat, and allows for the escape of excess liquid. Despite potential high construction costs and the need for regular maintenance due to corrosion, the benefits of constant gas pressure and direct visibility of gas volume make FDB worthwhile, especially in uncertain conditions. While alternatives like water-jacket plants offer versatility and ease of maintenance, portable FDB kits like ARTI provide plastic-based options for simpler operation and manoeuvrability. Despite some drawbacks, FDB remains an effective and eco-friendly solution, particularly in seismically active regions [23]. A balloon biogas plant utilizes a heat-sealed plastic or rubber bag as both digester and gas holder, with gas stored in the upper part and inlet/outlet attachments directly connected to the balloon's skin. Additional weights may be added to increase gas pressure, while safety valves are essential to prevent damage from excessive pressure. Materials like stabilized plastic, synthetic caoutchouc, RMP, Trevira, and butyl are preferred for weather and UV resistance. These plants typically last 2-5 years and offer advantages such as low-cost prefabrication, easy transportation, suitability for areas with high groundwater tables, and utilization of challenging substrates like water hyacinths. However, they may require gas pumps for low pressure, struggle with scum removal, and have limited self-help potential due to short lifespan and minimal local employment opportunities. A channel-type digester, covered with plastic sheeting and sunshade, is a variation suitable for areas with unlikely balloon damage and consistent high temperatures[24].

2.6 PURIFICATIONS METHODS

Purification methods are indispensable in a myriad of industries, spanning from chemical processing to pharmaceuticals, food and beverage production, and gas refining. These methods are crucial for eliminating impurities that can jeopardize product quality, compromise safety, and impede operational efficiency. Among the most prevalent impurities are carbon dioxide (CO_2), hydrogen sulphide (H_2S), and moisture, all of which can have detrimental effects on processes and end products[25]. CO_2, for example, is often extracted from gases to augment their calorific value and prevent corrosion within pipelines and equipment. One method for CO_2 removal involves the utilization of calcium hydroxide, also known as slaked lime or hydrated lime. This chemical undergoes a reaction with CO_2 to produce calcium carbonate, thereby effectively purifying the gas stream[25, 26].

Similarly, hydrogen sulphide, recognized for its unpleasant odour and toxicity, necessitates removal from gases to ensure workplace safety and inhibit corrosion in infrastructure. Iron wool serves as a widely employed material for H_2S removal due to its high reactivity with the gas, resulting in the formation of iron sulphide as a byproduct[27].Moisture, while seemingly innocuous, can lead to corrosion, ice formation, and interference with chemical reactions in various industrial processes. Silica gel, distinguished by its highly porous nature and strong affinity for water molecules, is frequently employed to adsorb moisture from gases and liquids, thereby facilitating purification[28]. Various technologies and techniques are available for purification, ranging from chemical reactions to physical adsorption and absorption processes. These methods encompass the utilization of diverse adsorbents, scrubbers, filters, membranes, and distillation columns, tailored to specific impurities and desired purity levels. While calcium hydroxide, iron wool, and silica gel serve as fundamental purification agents, advanced methods such as cryogenic distillation, membrane separation, pressure swing adsorption, and chemical scrubbing are also utilized. Each purification technique presents its own set of advantages and limitations, including considerations of efficiency, cost-effectiveness, scalability, and environmental impact[29].

Ultimately, the purification of gases from impurities like CO_2, H_2S, and moisture is paramount for ensuring product quality, safety, and operational efficiency across a multitude of industrial applications. By employing appropriate purification methods and technologies, industries can not only optimize processes and minimize environmental impact but also adhere to stringent regulatory standards, thereby fostering sustainable production practices.

2.7 COMPRESSION MECHANISM

Compression of biogas is a vital process in its utilization for various applications, ranging from power generation to heating and transportation. Biogas, typically produced from organic waste through anaerobic digestion, contains methane (CH_4) as its primary component along with carbon dioxide (CO_2) and trace amounts of other gases. However, for many applications, especially those requiring transportation or injection into pipelines, the biogas needs to be compressed to increase its energy density and make it more practical for storage and transport [30].

The compression process involves reducing the volume of the gas while simultaneously increasing its pressure. This is achieved through the use of compressors, which are mechanical devices designed to pressurize gases. One of the most common types of compressors used for biogas compression is the refrigerator reciprocating compressor. Refrigerator reciprocating compressors are widely employed due to their efficiency, reliability, and relatively low cost. These compressors operate based on the principle of reciprocating motion, where a piston moves back and forth within a cylinder to compress the gas. The compressor is typically driven by an electric motor, which powers the piston movement[31].

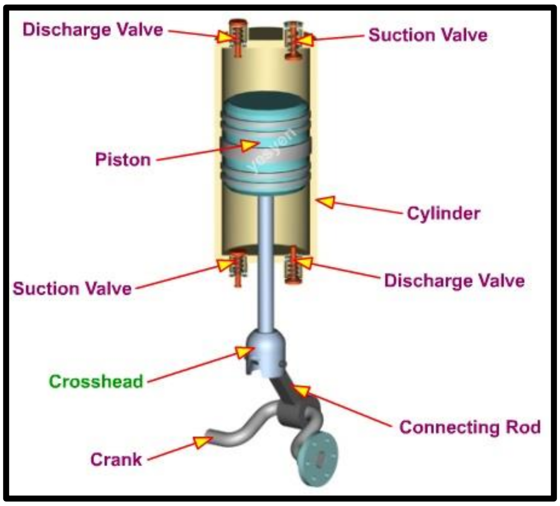

Fig. 2.7 Compression Mechanism

The compression mechanism in a refrigerator reciprocating compressor involves several key components. Firstly, there is a cylinder where the piston moves back and forth. As the piston moves towards one end of the cylinder, it reduces the volume of the gas, thereby increasing its pressure. This compressed gas is then discharged through a valve into a storage tank or distribution system. The compressor is equipped with valves, including suction and discharge valves, which allow gas to enter and exit the cylinder at the appropriate times in the compression cycle. These valves ensure that the gas flows in the desired direction and prevent backflow during compression. In operation, the compressor's motor drives the piston through a crankshaft mechanism, converting the rotational motion of the motor into linear motion of the piston. This reciprocating motion creates cycles of compression, where the gas is drawn into the cylinder, compressed, and then discharged at a higher pressure[32].

Overall, refrigerator reciprocating compressors play a crucial role in the compression of biogas, making it suitable for various applications. Their efficient operation, coupled with the ability to handle varying gas compositions and flow rates, makes them well-suited for biogas compression tasks. By utilizing compressors effectively, biogas can be harnessed as a renewable energy source, contributing to sustainable energy solutions and reducing greenhouse gas emissions.

2.8 CHALLENGES

The production, purification, and compression of biogas are integral processes in its utilization as a renewable energy source. However, each phase presents its own set of challenges, spanning technical, operational, economic, and environmental aspects. Addressing these challenges requires careful planning, innovative technologies, and effective management strategies to ensure the feasibility and efficiency of biogas utilization projects[33].

2.8.1 Production Challenges:

1) Feedstock Availability and Quality: The availability and quality of organic feedstock for biogas production can vary significantly due to factors such as agricultural practices, waste management systems, and seasonal fluctuations.

Ensuring a consistent and reliable feedstock supply is essential for maintaining optimal biogas production rates.

2) Process Efficiency and Stability: Biogas production processes, such as anaerobic digestion, are sensitive to changes in operating conditions, including temperature, pH, and substrate composition. Maintaining process stability and efficiency can be challenging, especially in large-scale operations where variations in feedstock characteristics and environmental conditions are inevitable [2].

3) Inhibition and Toxicity: Inhibition of microbial activity and substrate toxicity are common challenges in biogas production. Compounds such as ammonia, sulphides, and volatile fatty acids can inhibit microbial activity, leading to reduced biogas yields and process instability. Managing inhibition requires careful monitoring of feedstock composition and process parameters, as well as the implementation of mitigation strategies such as dilution, buffering, and microbial adaptation.

4) Foaming and Scum Formation: Foaming and scum formation in anaerobic digesters can impede gas production and disrupt process stability, posing challenges for biogas plant operators in terms of control and mitigation.

5) Microbial Imbalance: Maintaining a balanced microbial ecosystem within the digester is crucial for efficient biogas production. Challenges may arise from changes in microbial populations, competition among microbial species, and susceptibility to external factors such as pH fluctuations and substrate variations.

2.8.2 Purification Challenges:

1) Impurity Removal Efficiency: Achieving high levels of impurity removal, particularly for contaminants like carbon dioxide (CO_2), hydrogen sulphide (H_2S), and moisture, can be challenging, especially when dealing with varying gas compositions and impurity concentrations [34].

2) Selective Adsorption: Selectively adsorbing specific impurities while minimizing the loss of methane (CH_4) or other valuable components requires specialized adsorbents or separation technologies, which may be costly or challenging to implement at scale.

3) Scalability and Cost: Scaling up purification processes to accommodate larger biogas volumes while maintaining cost-effectiveness can pose challenges in terms of equipment costs, energy requirements, and operational complexity.

4) Maintenance and Reliability: Ensuring the reliability and efficiency of purification equipment over time requires regular maintenance and monitoring, as well as addressing issues such as fouling, degradation, and mechanical wear.

5) Regulatory Compliance: Meeting regulatory standards for gas purity and emissions can pose challenges for biogas purification facilities, particularly in regions with stringent environmental regulations or limited infrastructure for gas quality monitoring and control.

2.8.3 Compression Challenges:

1) Energy Efficiency: Achieving high compression efficiency while minimizing energy consumption and operational costs is crucial for the economic viability of biogas compression systems, especially in remote or off-grid locations where energy availability may be limited [35].

2) Equipment Reliability: Ensuring the reliability and performance of compression equipment, such as compressors and storage vessels, is essential for maintaining gas quality, minimizing downtime, and preventing safety hazards.

3) Safety and Environmental Impact: Mitigating risks associated with gas handling, storage, and transportation, including potential leaks, equipment failures, and environmental contamination, requires robust design, operation, and maintenance practices.

4) Pressure Management: Managing gas pressure levels during compression, storage, and distribution to meet specific application requirements while avoiding over-pressurization or under-pressurization challenges can be complex, especially in systems with fluctuating demand or variable gas compositions.

5) Infrastructure and Logistics: Building and maintaining the necessary infrastructure for biogas compression, storage, and distribution, including pipelines, compression facilities, and storage tanks, may pose logistical challenges in terms of cost, land availability, and regulatory approvals.

In conclusion, the production, purification, and compression of biogas are complex processes that require careful planning, innovative technologies, and effective management strategies to overcome various challenges. By addressing these challenges, we can harness the full potential of biogas as a renewable energy source and contribute to sustainable development goals related to energy security, environmental protection, and climate change mitigation.

2.9 INNOVATION THROUGH PROTOTYPES AND EXPERIMENTS

Prototypes and experimental studies are foundational elements across a spectrum of fields, integral for refining concepts, validating designs, and advancing innovation. Their significance extends throughout product development, engineering endeavours, scientific research, and educational pursuits. In the realm of product development and engineering, prototypes serve as tangible manifestations of theoretical designs. This iterative approach empowers engineers to incrementally enhance product designs based on real-world feedback and performance data, ultimately ensuring that final products meet or exceed customer expectations while mitigating risks associated with performance, safety, and reliability.

In scientific research and innovation, prototypes serve as experimental platforms for hypothesis testing and concept validation. Through experimentation on prototypes, scientists gather empirical data to support or refute hypotheses, pushing the boundaries of scientific knowledge and understanding. Moreover, prototypes facilitate the exploration of novel ideas and concepts, providing researchers and innovators with the means to assess the feasibility, viability, and scalability of new technologies and inventions. By building and testing prototypes, researchers can demonstrate proof of concept for innovative ideas, attracting investment, securing funding, and ultimately driving the commercialization of new technologies [36].

In academia and education, prototypes play a pivotal role in providing hands-on learning experiences and fostering research collaboration. Through hands-on experimentation with prototypes, students gain practical skills in critical thinking, problem-solving, and experimentation, preparing them for future careers in science, engineering, and technology. By showcasing the potential applications and benefits of new technologies, prototypes attract investment and support the commercialization process, translating academic research into real-world impact and societal benefit [37].

Recent advances and innovations in compressed biogas (CBG) technology have propelled the utilization of biogas as a sustainable and renewable energy source. These advancements encompass various aspects, from production and purification to compression and utilization, contributing to enhanced efficiency, scalability, and environmental sustainability [38]. In terms of production, novel anaerobic digestion techniques and reactor designs have emerged, enabling more efficient conversion of organic waste into biogas. Advanced pretreatment methods, such as enzymatic hydrolysis and thermal hydrolysis, enhance the breakdown of complex organic compounds, increasing biogas yields and improving process stability. Furthermore, co-digestion of diverse feedstocks, including agricultural residues, food waste, and organic industrial by-products, enhances the energy potential of biogas production systems, optimizing resource utilization and waste management [39].

Advanced adsorption materials and membrane separation processes enable selective removal of impurities such as carbon dioxide (CO_2), hydrogen sulphide (H_2S), and moisture, enhancing the calorific value and usability of compressed biogas. Additionally, decentralized purification systems and modular units offer flexibility and scalability, catering to diverse biogas production scenarios and regional requirements. Regarding compression, recent innovations focus on improving energy efficiency, reliability, and safety in biogas compression systems. High-efficiency compression technologies, such as scroll compressors and oil-free screw compressors, reduce energy consumption and operational costs while ensuring optimal gas quality and pressure levels. Moreover, smart control systems and remote monitoring capabilities enhance system performance, enabling real-time data analysis, predictive maintenance, and operational optimization [40].

In conclusion, recent advances and innovations in compressed biogas technology are driving the transition towards a sustainable and circular bioeconomy. By improving production efficiency, enhancing purification processes, optimizing compression systems, and diversifying utilization options, these advancements unlock the full potential of biogas as a versatile and renewable energy source, fostering environmental stewardship and economic prosperity.

CHAPTER 3 MATERIALS & METHODS

3.1 WORK PLAN

The project work plan encompasses several sequential steps aimed at producing compressed biogas as the primary output. Initially, slurry is prepared by blending cow dung, kitchen waste, and water to serve as the substrate for biogas generation. The slurry is loaded into the digester where anaerobic conditions are maintained, allowing microbial activity to commence and produce raw biogas. Once the digester initiates biogas production, the raw biogas generated undergoes purification to remove impurities. Various purification techniques are employed to ensure the resulting biogas meets the desired quality standards. This purification process is crucial for enhancing the energy content and safety of the biogas.

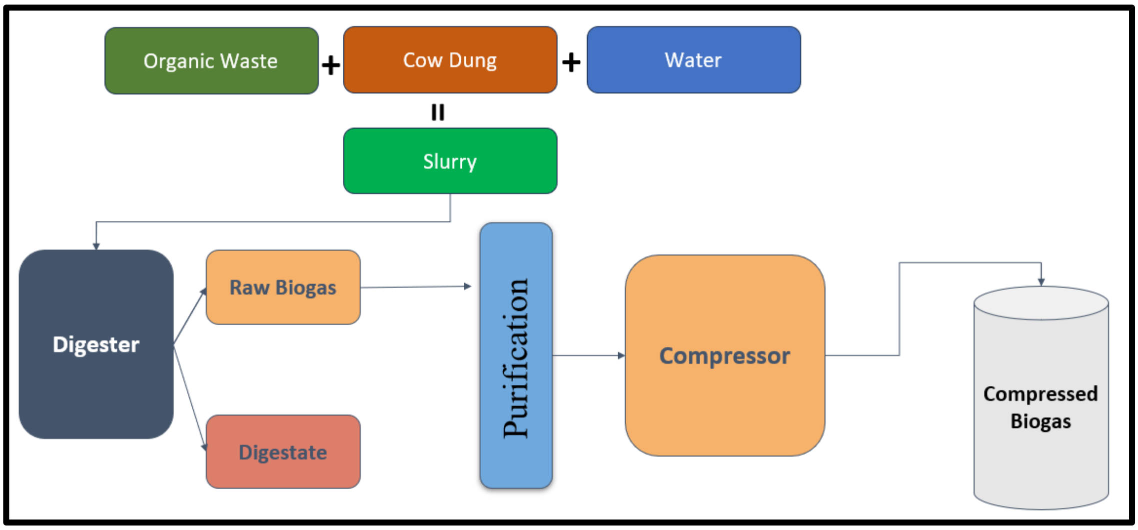

Fig. 3.1 Overall Work Plan

After purification, the biogas is compressed using a compressor to increase its density and facilitate storage. Compressed biogas is more efficient for transportation and storage purposes, making it easier to handle and utilize as an alternative fuel source. The compressed biogas is then stored in gas cylinders, ready for use as a sustainable and renewable energy solution. Throughout these processes, careful monitoring and optimization are essential to ensure efficient biogas production, purification, and compression. By following this work plan, we aim to produce high-quality compressed biogas that can effectively replace traditional fuel sources, contributing to sustainable energy practices and environmental conservation.

3.2 LAB SCALE STUDIES

3.2.1 Setup Preparation

In lab-scale studies, four conical flasks of 250 ml were taken to accommodate the anaerobic digestion process. Initially, balloons were used to capture the biogas produced. However, due to the production of biogas, the slurry reacted with balloons, causing the bursting of balloons that disturbed the anaerobic condition. So an alternative gas collection method became necessary. Due to the limitations of balloons, plastic covers were used as an alternative gas collection method. Since plastic covers offer a more durable solution compared to balloons, they reduce the risk of bursting and disturbing the anaerobic condition. Rubber bands were used to ensure the plastic covers were airtight to prevent gas leakage and maintain anaerobic conditions within the flasks.

Fig. 3.2.1 Lab Scale Setup

3.2.2 Feedstock Slurry Preparation

In feedstock slurry preparation, the choice of raw materials will directly influence the efficiency and yield of the biogas generation process. In this feedstock slurry preparation, kitchen waste from our college canteen was utilized as raw materials since it was a convenient and readily accessible process. Raw materials mainly consisted of vegetable peels. After the collection of raw materials, measure 200 g of kitchen waste using a weighing scale, then transfer the measured raw materials into a mixer jar and add 200 ml of water to the jar to grind the mixture into a fine slurry consistency. After grinding, the resultant mixture is the feedstock slurry. Transfer the feedstock slurry into a 250-ml beaker, cover the beaker with a plastic cover, and store the beaker in the refrigerator. This procedure is repeated three more times. Finally, there will be four beakers. This feedstock slurry can be used for future use.

From the feedstock slurry, measure 100 g using a weighing balance. Then transfer it to a 250-ml conical flask. Now measure 40 g of cow dung and add 160 ml of water to it. Finally, transfer all of it to a conical flask and ensure proper mixing to achieve a uniform distribution of water within the slurry mixture. For the lab-scale studies, a 15% biogas slurry was prepared. This procedure is repeated three more times. Finally, there will be four conical flasks with a 15% biogas slurry in them.

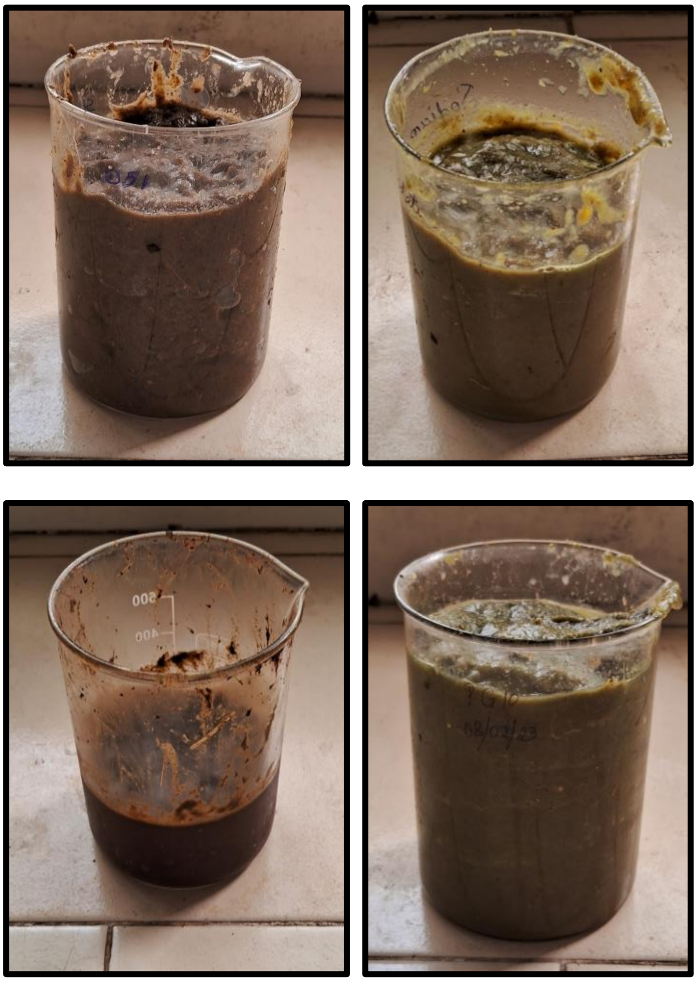

Fig. 3.2.2 Four Variants of Feedstock Slurries Prepared for Lab-Scale Studies

3.2.3 Chemical Composition Analysis

Chemical composition analysis helps in understanding the composition of the feedstock (organic waste) used in the process and the resulting biogas.in this analysis carbohydrates, protein and lipids are estimated. In preparation of a feedstock slurry, 2 g of the slurry is taken, to which 3 g of cow dung is added, followed by the addition of 18 ml of water in a test tube. Proper mixing is ensured to achieve a uniform distribution of water within the slurry mixture. The resulting mixture constitutes a 15% biogas slurry.

After thorough mixing, the biogas slurry is properly filtered to remove any solid particles, leaving behind a clear supernatant. From this filtered slurry, 1 ml of the supernatant is taken as a sample for the estimation of carbohydrates and proteins.

For lipid estimation, an equal volume of ethanol is added to the supernatant in a 1:1 ratio. This mixture is then used as the sample for lipid estimation.

Total Carbohydrate Estimation: Phenol-Sulfuric Acid Method

Principle:

The phenol-sulfuric acid method is a rapid colorimetric technique used to determine total carbohydrates in a sample. It involves breaking down carbohydrates into furan derivatives with concentrated sulfuric acid, which then react with phenol to form stable yellow compounds. Absorbance is measured at 490 nm, allowing for quantification of total carbohydrates. This method is applicable to all carbohydrate classes, including monosaccharides, disaccharides, oligosaccharides, and polysaccharides.

Materials and Reagents:

The materials required for the phenol-sulfuric acid method include a colorimeter for absorbance measurements, standard flasks of 10 ml capacity for preparation purposes, and essential reagents such as glucose standard solution (2 mg/ml), phenol (0.1% solution), and concentrated sulfuric acid. These materials are integral for conducting the colorimetric analysis to determine the total carbohydrates in a sample efficiently and accurately.

Procedure:

Table 3.2.3.1 Total Carbohydrate Estimation: Phenol-Sulfuric Acid Method

Total Carbohydrate Estimation : Phenol Sulphuric Acid Method							
Sl. No.	**Std Glucose(ml)**	**D/W(ml)**	**Phenol(0.1%)**	**Sulphuric Acid(ml)**		**Conc of Glucose(mg/ml)**	**OD at 490nm**
Blank	0	1	1	4	Incubation for 20 min at Room Temperature	0	0
1	0.2	0.8	1	4		0.2	0.012
2	0.4	0.6	1	4		0.4	0.03
3	0.6	0.4	1	4		0.6	0.043
4	0.8	0.2	1	4		0.8	0.052
5	1	0	1	4		1	0.079
Sample 1	1	0	1	4		-	1.83
Sample 2	1	0	1	4		-	1.29
Sample 3	1	0	1	4		-	1.41
Sample 4	1	0	1	4		-	0.92

In the procedure for the phenol-sulfuric acid method, 20 mg of D-glucose is weighed using a balance and mixed with distilled water in a 10 ml flask to prepare a standard glucose solution. A 0.1% phenol solution is then prepared by thoroughly mixing phenol crystals with distilled water. Following this, measured volumes of the standard glucose solution are pipetted into separate test tubes and adjusted to 1 ml with distilled water. A blank test tube containing distilled water is labelled accordingly. Subsequently, 0.1% phenol solution is added to all test tubes, followed by the addition of concentrated sulfuric acid. After incubating the test tubes at room temperature for 20 minutes, absorbance is measured at 490 nm using a colorimeter. Finally, a graph is plotted with absorbance on the y-axis and the concentration of sugar on the x-axis, providing quantitative data on total carbohydrate content.

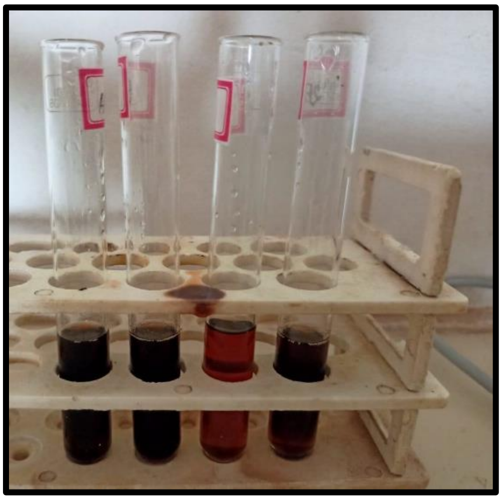

Fig. 3.2.3.1 Total Carbohydrate Estimation

Protein estimation by Lowry's method

Principle:

The Bradford protein assay method is widely used for protein determination. It relies on the reaction of peptide bonds in polypeptide chains with copper sulphate in an alkaline environment, resulting in a blue-coloured complex. Additionally, aromatic amino acid residues such as tyrosine and tryptophan reduce the phosphomolybdate and phosphotungstate components of the Folin-Ciocalteu reagent, further enhancing sensitivity. In this experiment, a standard curve will be constructed using a BSA standard solution to determine the protein concentration of the feedstock slurry.

Materials and Reagents:

The necessary materials and reagents include a colorimeter for absorbance measurements, standard flasks (10 ml) for sample preparation, and several chemical reagents. These reagents include alkaline Na2CO3 reagent (Reagent A), copper sulphate reagent (Reagent B), alkaline copper sulfate reagent (Reagent D), Folin's reagent (Reagent E), BSA standard solution (1 mg/ml), and 0.1 M NaOH solution.

Procedure:

Table 3.2.3.2 Protein estimation by Lowry's method

Protein Estimation by Lowry's Method								
Sl. No.	Std BSA solution(ml)	0.1 NaOH (ml)	Reagent c (ml)		Folin Reagent (ml)		Conc of BSA (mg/ml)	OD at 660nm
Blank	0	1	5	Incubation for 10 min at Room Temperature	0.5	Incubation for 30 min at room Temperature	0	0
1	0.2	0.8	5		0.5		0.2	0.48
2	0.4	0.6	5		0.5		0.4	0.86
3	0.6	0.4	5		0.5		0.6	1.2
4	0.8	0.2	5		0.5		0.8	1.37
5	1	0	5		0.5		1	1.65
Sample 1	1	0	5		0.5		-	3.45
Sample 2	1	0	5		0.5		-	3.03
Sample 3	1	0	5		0.5		-	3.48
Sample 4	1	0	5		0.5		-	2.94

The BSA standard solution (1 mg/ml) is prepared in distilled water, and volumes ranging from 0.2 to 1.0 ml are pipetted into separate test tubes. Each test tube is then filled to 1 ml with 0.1 M NaOH solution. Subsequently, 5 ml of reagent D is added to all test tubes, followed by incubation at room temperature for 10 minutes. Afterward, 0.5 ml of Folin's reagent is added to each tube, and the mixture is incubated for an additional 30 minutes at room temperature. Finally, absorbance is measured at 660 nm using a colorimeter, and a graph is plotted with absorbance on the y-axis and the concentration of BSA on the x-axis.

Fig. 3.2.3.2 Protein Estimation

Triglyceride Estimation: Phospho Vanillin Method

Principle:

The determination of triglycerides involves the reaction of concentrated sulfuric acid with unsaturated lipids, forming a carbonium ion. Phosphoric acid reacts with vanillin to produce a phosphate ester, enhancing the reactivity of the carbonyl group. The carbonium ion then reacts with the carbonyl group of phospho-vanillin to form coloured compounds, stabilized by resonance.

Materials and Reagents:

The materials necessary for this procedure include a colorimeter for absorbance measurements, a boiling water bath for incubation, and various reagents. These reagents consist of concentrated sulfuric acid and phospho-vanillin reagent, prepared by dissolving 0.06% vanillin in 10 ml absolute ethanol and adding 40 ml of orthophosphoric acid. Additionally, a standard solution of olive oil is required, prepared by dissolving 20 mg of olive oil in 10 ml of ethanol.

Procedure:

Table 3.2.3.3 Triglyceride Estimation: Phospho Vanillin Method

Triglyceride Estimation : Phospho Vanillin Method								
Sl. No.	Std Triglyceride(ml)	Ethanol (ml)	Sulphuric Acid (ml)		Phosphvanillin Reagent (ml)		Conc of triglyceride(mg/ml)	OD at 540 nm
Blank	0	1	1		1		0	0
1	0.2	0.8	1		1		0.4	0.29
2	0.4	0.6	1		1		0.8	0.57
3	0.6	0.4	1	Keep in boiling waterbath for 10 min	1	Incubation for 15 min at 37°C	1.2	0.79
4	0.8	0.2	1		1		1.6	0.9
5	1	0	1		1		2	1
Sample 1	1	0	1		1		-	0.95
Sample 2	1	0	1		1		-	0.72
Sample 3	1	0	1		1		-	0.9
Sample 4	1	0	1		1		-	1.02

To begin, pipette out volumes ranging from 0.2 to 1.0 ml of the standard olive oil solution into separate test tubes. Prepare a blank tube containing 1.0 ml of ethanol. Pipette out duplicate samples of the unknown into separate tubes. Adjust the volume of all tubes to 1.0 ml using ethanol. Add 1.0 ml of concentrated sulfuric acid to each tube and incubate in a boiling water bath for 10 minutes before cooling. Following this, add 2 ml of phospho-vanillin reagent to each tube and incubate at 37°C for 15 minutes. Finally, measure the optical density of each tube against the blank at 540 nm and plot a graph with OD on the y-axis and the concentration of triglycerides on the x-axis for calculating the concentration of the unknown samples.

Fig. 3.2.3.3 Triglyceride Estimation

3.3 SMALL SCALE STUDIES

3.3.1 Setup Preparation

In small-scale studies, an anaerobic digestion process had been carried out in a 1000 ml conical flask. Based on lab scale experience, direct plastic cover was used to capture the produced biogas. In order to prevent gas leaks and keep the anaerobic conditions within the flask intact, rubber bands were used to make sure the plastic coverings were tight.

Fig. 3.3.1 Small Scale Studies

3.3.2 Feedstock preparation

In small scale studies, directly biogas slurry was prepared. For preparing biogas, slurry raw materials which is kitchen waste that mainly consists of vegetable peels is collected from our college canteen. After collection of raw materials measure 300 g of kitchen waste. Then transfer measured raw materials into the mixer jar and add 300 ml of water. Grind the mixture into a fine slurry. After grinding, transfer the fine slurry to 1000 ml conical flask and add 120 g of cow dung then pour 180 ml of water into the conical flask. Ensure proper mixing to achieve a uniform distribution of water within the biogas slurry. For the small-scale studies too, 15% of biogas slurry was prepared.

3.4 PILOT SCALE STUDIES

3.4.1 Setup Preparation

In preparation for the pilot-scale setup, a 30 L blue plastic can will serve as the digester for anaerobic digestion. This can will be outfitted with a ball valve to regulate gas flow, ensuring precise control over the process. To facilitate gas storage, a tire tube connected via a rubber pipe will act as the storage unit. To maintain air-tight conditions and prevent leakage, Teflon tape will be meticulously applied to all connections, including from the digester to the valve, the valve to the pipe, and the pipe to the tube. This is an overall simple design for a pilot-scale setup.

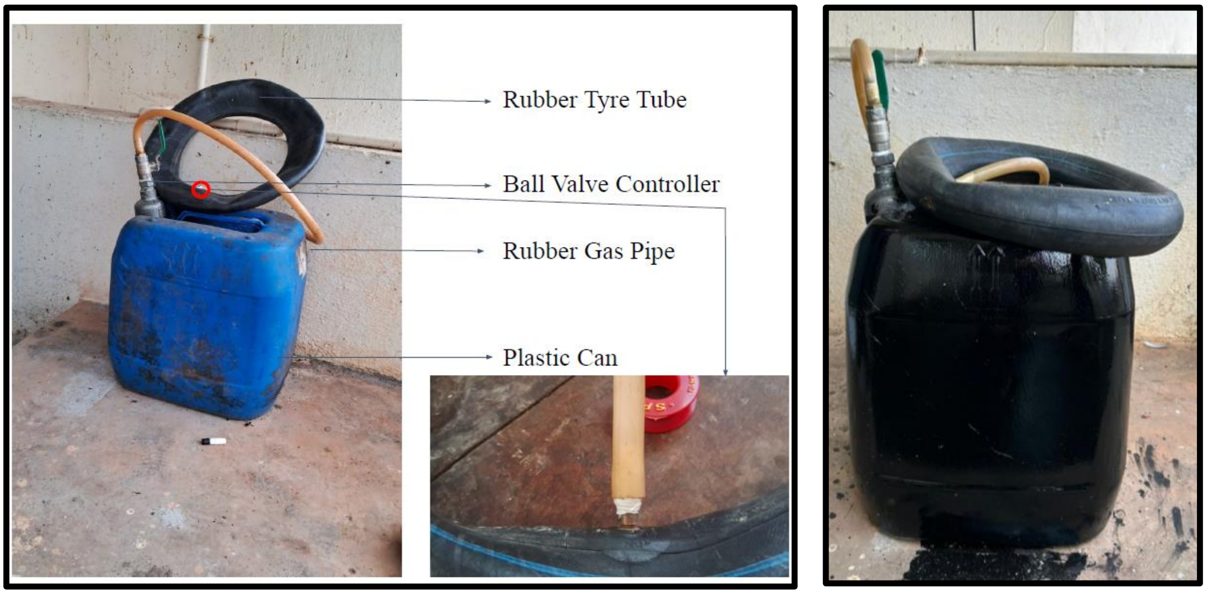

Fig. 3.4.1 Pilot Scale Digester

3.4.2 Feedstock preparation

In pilot-scale studies, feedstock preparation involved the collection of kitchen waste from our college canteen, primarily comprising vegetable peels, with a significant portion consisting of beetroot and pumpkin, alongside minor contributions from leafy vegetables. This acts as the raw material for the digester. With a pilot-scale digester of 30 Liters capacity, a total of 4.5 kilograms of kitchen waste was gathered and mixed with 4.5 Liters of water. Due to the limitations of the mixer jar, the grinding process was carried out in batches to ensure thorough processing. Following the completion of grinding, the prepared raw materials were transferred into the digester. Subsequently, 3.5 kilograms of cow dung, mixed with 3.5 liters of water, were incorporated into the digester. To achieve the desired biogas slurry concentration of 15%, additional water was added.

3.4.3 Chemical Composition Analysis

Reducing Sugar Estimation: DNSA Method

Principle:

Glucose, a reducing monosaccharide, reacts with the alkaline solution of 3-5 dinitro salicylic acid (DNSA), changing its pale-yellow colour to an orange-red complex of 3-amino-5-nitrosalicylic acid. The intensity of this colour complex, measured at 540 nm using a colorimeter, correlates with the glucose concentration. The experiment involves preparing a standard curve using a glucose standard solution to quantify the reducing sugar concentration in a feedstock slurry.

Materials and Reagents:

The materials utilized in this experiment include a colorimeter for absorbance measurement, standard flasks for solution preparation, a water bath set at 100°C for maintaining reaction temperature, pipettes for precise liquid dispensing, and test tubes serving as reaction vessels. Distilled water is used as the solvent throughout the experiment.

The reagents employed in the experiment are DNSA reagent, essential for the colorimetric determination of reducing sugars, and a glucose standard solution with a concentration of 1 mg/ml for calibration.

Procedure:

Table 3.4.3 Reducing Sugar Estimation: DNSA Method

Reducing sugar Estimation : DNSA Method							
Sl. No.	Std Glucose(ml)	D/W(ml)	DNSA		D/W(ml)	Conc of Std Glucose(mg/ml)	OD at 540 nm
Blank	0	2	1	Keep in boiling water bath for 10 min	10	0	0
1	0.4	1.6	1			0.2	0.24
2	0.8	1.2	1		10	0.4	0.5
3	1.2	0.8	1		10	0.6	0.62
4	1.6	0.4	1		10	0.8	0.75
5	2	0	1		10	1	0.82
Sample 1	2	0	1		10	-	0.43
Sample 2	2	0	1		10	-	0.38

The experiment begins with the preparation of a glucose standard solution. Various volumes of this solution are pipetted into test tubes, followed by the addition of DNSA reagent. The test tubes are then incubated in the water bath at 100°C for 10 minutes. After cooling, distilled water is added to each tube to halt the reaction. Absorbance is measured at 540 nm using a colorimeter against a reagent blank. Data analysis involves constructing a standard curve from absorbance values plotted against known glucose

Fig. 3.4.3 Reducing Sugar Estimation

concentrations. Statistical analysis includes performing experiments in triplicate and calculating mean values with standard deviations to assess variability within the dataset.

3.4.4 Evolved Gas Analysis

Evolved gas analysis via flame test was conducted to investigate the composition of gases produced in the tire tube. Pressure was applied to the tube, and as gas was slowly released and brought into contact with the naked flame from a lighter, the absence of ignition indicated the presence of carbon dioxide and the absence of methane. This observation suggests that the methanogenesis phase has not been reached and must be preceded by previous phases of biogas production. By phase determination analysis of slurry, we can recognize the phase of biogas production.

Fig. 3.4.4 Digester Evolving Gas

3.4.5 Phase Determination Analysis of Slurry

3.4.5.1 pH test using Litmus Paper

After 3 weeks of observation, the absence of methane production was confirmed by a flame test, so we understand which metabolic phase is occurring. A pH test was conducted with the help of litmus paper. It was revealed the slurry was found to be slightly acidic, which means there is a possibility of acetogenesis or acidogenesis phases, so to confirm if it is the acetogenesis phase or not, a neutral $FeCl_3$ test was conducted.

3.4.5.2 Neutral $FeCl_3$ test

This neutral $FeCl_3$ test act as a confirmatory test for presence of acetic acid. When ferric chloride is neutralised by acetic acid (CH_3CCOOH) then ferric acetate [$Fe(CH_3COO)_3$] is formed.

The neutralisation reaction between ferric chloride and acetic acid can be represented as follows: $FeCl_3 + 3CH_3COOH \rightarrow Fe(CH_3COO)_3 + 3HCl$

When acetic acid neutralises ferric chloride, a reddish-brown coloration can be observed due to the formation of ferric acetate. So based on visualisation of reddish-brown colour confirms presence of acetic acid.

3.5 PURIFICATION PROCESS

Purification of raw biogas plays a crucial role in enhancing its quality and increasing its energy content for various applications. One of the primary impurities targeted during purification is carbon dioxide (CO_2), which can significantly reduce the energy value of biogas. Calcium hydroxide, commonly known as slaked lime, is widely employed for CO_2 removal due to its high reactivity and cost-effectiveness. By reacting with CO_2, calcium hydroxide facilitates its removal from the biogas stream, thereby improving its calorific value.

Another harmful impurity in biogas is hydrogen sulphide (H_2S), a toxic gas with corrosive properties. Steel wool serves as an effective absorbent for H_2S, as it provides a large surface area for the gas to react and form less harmful compounds. This process helps to safeguard equipment and pipelines from corrosion while ensuring the safety of personnel working with biogas.

Additionally, moisture content in raw biogas can lead to operational challenges and reduce its energy potential. Silica gel beads are commonly utilized for moisture removal, as they possess a high affinity for water molecules. By adsorbing moisture from the biogas, silica gel helps to prevent corrosion and blockages in downstream equipment, thereby optimizing the performance and longevity of the purification system.

Incorporating calcium hydroxide, steel wool, and silica gel into biogas purification systems offers practical and economical solutions for enhancing the quality and energy content of raw biogas, making it a valuable resource for various industrial and energy applications.

3.5.1 Purification Methods

3.5.1.1 H_2S Removal

Hydrogen sulphide (H_2S), notorious for its noxious odor reminiscent of rotten eggs, poses serious health and environmental hazards, particularly in biogas derived from organic waste. The presence of H_2S not only diminishes the quality of biogas but also poses risks to human health and equipment integrity. In the process of biogas purification, steel wool emerges as a critical component for mitigating this harmful impurity.

Fig. 3.5.1.1 Steel Wool used for Purification

Utilizing steel wool as a scrubbing medium, the process of removing H_2S from biogas occurs through physical adsorption. This mechanism entails the intimate contact between the biogas stream and the steel wool's porous surface, which offers an extensive area for molecular interaction. As the biogas flows through the steel wool, hydrogen sulphide molecules undergo adhesion onto the steel wool fibers. This physical adsorption effectively traps and immobilizes the H_2S, preventing its passage further along the gas stream.

3.5.1.2 CO_2 Removal

Carbon dioxide (CO_2) constitutes a significant portion of biogas composition, typically ranging from 30-40%. Its presence not only reduces the energy content of biogas but also poses challenges in various industrial and energy applications. To address this, calcium hydroxide, commonly referred to as slaked lime, emerges as a key agent in biogas purification systems.

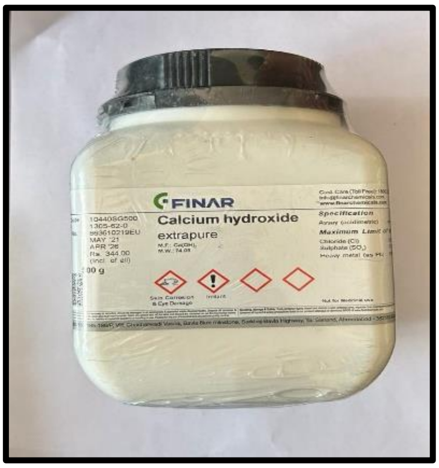

Fig. 3.5.1.2 Calcium Hydroxide

Utilizing a process known as chemical absorption, calcium hydroxide effectively removes CO_2 from the biogas stream. The reaction between CO_2 and calcium hydroxide results in the formation of calcium carbonate ($CaCO_3$) and water (H_2O), as illustrated by the equation:

$$CO_2 + Ca(OH)_2 \rightarrow CaCO_3 + H_2O$$

This chemical reaction facilitates the conversion of carbon dioxide into insoluble calcium carbonate, which precipitates out of the biogas solution. As a result, the purified biogas emerges free from carbon dioxide, thereby enhancing its energy content and suitability for various applications.

3.5.1.3 Moisture Removal

Moisture poses a significant threat to the integrity and efficiency of biogas-powered equipment, as it can accelerate corrosion and impede the performance of devices. To mitigate this risk, silica gel beads emerges as a highly effective solution for moisture removal in biogas purification systems.

Fig. 3.5.1.3 Silica Gel Beads

Silica gel, renowned for its exceptional porosity and strong affinity for water molecules, serves as an ideal medium for adsorbing moisture from biogas streams. As the moist biogas traverses through a bed of silica gel, the water molecules are readily attracted and adhere to the surface of the gel particles. This adsorption process efficiently removes moisture from the biogas, safeguarding equipment and optimizing performance.

Silica gel beads, commonly employed in biogas purification systems, offer an additional advantage with their color-changing properties. Initially blue, these beads transition to a vibrant pink hue as they absorb moisture, providing a visual indication of the moisture removal process. This color change serves as a convenient and practical means for operators to monitor the effectiveness of the silica gel beads. When the beads reach their moisture saturation point, indicated by the pink coloration, they can be replaced or regenerated to maintain optimal moisture removal efficiency.

3.5.2 Preparation of Purification Setup

The three-filter case configuration is integral to the multi-stage purification process, providing efficient removal of impurities from biogas. Each filter is equipped with a removable cap featuring an inlet on the side till the middle through a tube and an outlet at the other side, facilitating seamless gas flow through the purification stages. Within each filter case, a transparent tube of specific diameter serves as the primary inlet for the purification process, ensuring uniform gas distribution and optimal filtration.

These filter cases are interconnected in series via transparent tubes of corresponding diameter, enabling the smooth transfer of purified biogas from one stage to the next. To ensure secure connections and prevent leakage, the ends of these transparent tubes are meticulously heated for proper fitting into the filter cases. Subsequently, clamps are utilized to tighten the tube connections securely, maintaining airtight seals and facilitating uninterrupted gas flow between purification stages.

Fig. 3.5.2.1 Three Stage Purification Unit

This modular and interconnected design enhances the effectiveness of the purification system, allowing for comprehensive removal of impurities and contaminants from the biogas stream. The transparent tubes and filter cases not only facilitate easy monitoring of the purification process but also promote efficient operation and maintenance of the overall system, ensuring consistent production of high-quality, purified biogas.

Fig. 3.5.2.2 Inlet Tube

Fig. 3.5.2.3 Clamps for Fittings

3.5.3 Overall Process

The raw biogas with the impurities present in the tyre tube is transferred to the three-stage purification unit. The raw biogas is transferred to the first filter to remove H_2S as it is toxic and can corrode the equipment. Steel wool helps in removing the H_2S molecules as it adheres to the surface of steel wool when the biogas is passed through. From here the raw biogas is transferred to the second stage to remove carbon dioxide which is the major impurity. Here the raw biogas is transferred to the filter containing slaked lime, carbon dioxide gets precipitated by chemical absorption method. From here the biogas is sent to the third purification unit to remove the moisture which reduces the efficiency of biogas and can corrode the equipment as well. In the third filter, it is filled with silica gel beads which is porous material and adsorbs moisture. As biogas passes through, the moisture gets adsorbs on the silica gel beads which can be seen by the colour indication of the beads from blue to pink. From here the purified biogas is sent to the compression unit to store in the cylinder.

Fig. 3.5.3 Purification Unit with Purifying Agents

3.6 COMPRESSION PROCESS

Compression of biogas is essential to reduce its volume, enabling more efficient storage in cylinders or tanks, thereby facilitating transportation and increasing its energy density for various applications. This process not only increases the pressure of the biogas but also enhances its combustion efficiency. Ultimately, by enhancing its commercial viability, compressed biogas can be sold as a valuable commodity and utilized across diverse sectors including industry, heating, and transportation, contributing to sustainable energy solutions.

3.6.1 Compression Method & Mechanism

The primary components of a refrigerator reciprocating compressor are a system that compresses gas by the combined action of the crankshaft, connecting rod, cylinder, piston, and valve. The rotational motion is changed into a reciprocating motion by the crankshaft. The reciprocating action between the crankshaft and the piston is made possible by the connecting rod, which joins the two.

The two primary components where the gas is really compressed are the cylinder and piston. The cylinder's piston travels up and down. A vacuum is created inside the cylinder when the piston descends, allowing outside air to be drawn inside. This is commonly known as the suction stroke. Next, the compressed gas enters the charging line from the cylinder.

Fig. 3.6.1.1 Reciprocating Refrigerator Compressor

In order to control the amount of air that enters and exits the cylinder, valves are crucial. The way that the intake and output valves open and close is determined by the piston's movement. The reciprocating compressor can perform its function reliably and efficiently because of its complex construction.

The compressor initiates its operation by drawing gas from the surrounding environment through a suction valve. As the piston descends, the pressure within the cylinder diminishes, prompting the gas to flow into the cylinder, occupying the space generated by the piston's motion.

The compression process begins as soon as the gas fills the cylinder. The pressure inside the cylinder then rises as the piston begins to move higher. It's time to release the gas from the cylinder using an outlet valve after it has been sufficiently compressed. When the piston hits its peak, the outlet valve opens due to the high pressure, allowing the compressed gas to enter the output system. To carry out its operation, the compressor keeps going through this same intake, compression, and discharge sequence.

3.6.2 Preparation of Setup

From the third stage purification filter, a tube is carefully connected to the input of the compressor, ensuring a secure and leak-proof attachment. To meet the requirements of threading, the input and output of the compressor are copper-brazed (metal-joining process in which two or more metal items are joined by melting), ensuring durability and reliability in the compression process.

Fig. 3.6.2.1 Charging Cables

To maintain an airtight seal and prevent any leakage, the tube connected to the compressor input is meticulously heated and clamped, ensuring the integrity of the system during operation.

Fig. 3.6.2.2 Pressure Guage

In this setup, there are two charging lines designated for specific purposes. The first charging line is linked to the compressor's output using threading, facilitating the transfer of the compressed biogas to a pressure gauge for real-time monitoring of pressure levels. This pressure gauge is strategically positioned with a T- intersection, allowing for the seamless connection of charging lines.

The second charging line is connected from the pressure gauge to the storage cylinder, ensuring a smooth flow of compressed biogas for storage purposes. The end of this charging line is affixed to the 2 Kg cylinder using the threading provided, ensuring a secure attachment and preventing any potential leaks.

Fig. 3.6.2.3 2 Kg Empty Gas Cylinder

3.6.3 Overall Process

The operation of the fridge reciprocating compressor commences by extracting biogas from the third stage purification unit through a precisely calibrated suction valve. As the piston descends within the cylinder, the internal pressure diminishes, facilitating the ingress of biogas into the cylinder. Concurrently, the piston's upward motion initiates the compression phase, wherein the biogas within the cylinder undergoes compression. This upward movement effectively reduces the gas volume, leading to a proportional increase in pressure. The compression stroke persists until the pressure within the cylinder attains the predetermined level, ensuring optimal compression efficiency. Upon reaching the target pressure, the discharge valve seamlessly opens, enabling the release of the compressed gas from the cylinder.

The compressed biogas is then meticulously directed into a designated storage vessel, typically a 2kg cylinder, for safekeeping and subsequent utilization. To monitor and maintain the pressure of the compressed biogas within the desired range of 7 bar, a precision pressure gauge is employed. This critical component ensures that the biogas remains within the prescribed safe operating limits, mitigating any potential risks associated with over-pressurization or under-pressurization.

Throughout its cyclic operation, the reciprocating compressor diligently executes its task, with the piston rhythmically traversing the cylinder to draw in, compress, and discharge biogas. This iterative process continues until the requisite quantity of compressed biogas is achieved, ready to fulfill various energy needs and applications in an efficient and environmentally sustainable manner.

Fig. 3.6 Prototype

3.7 TEST RUN USING ATMOSPHERIC AIR

In this experiment, before testing the prototype with raw biogas, we aimed to test atmospheric air using a setup comprising a storage, purification, and compression unit. Initially, we filled a tyre tube with atmospheric air using a refrigerator compressor. However, we encountered a leakage issue due to a connector mismatch, which we resolved by installing an O-ring washer. We then carefully inspected and ensured all fittings and connections were secure to prevent further leaks. Once everything was in order, we initiated the compression process with a target pressure of 15 bar for filling the cylinder with compressed air. However, as a safety precaution, we halted the process at 7 bars during the compression phase.

In the compression phase of the process, it took 8 minutes to increase the pressure inside the cylinder to 7 bars. Once the compression was completed, it took only 1 minute to release the compressed air from the cylinder. These were results obtained from multiple trials that were performed using atmospheric air.

3.8 TEST RUN USING RAW BIOGAS

A successful test run utilised atmospheric air, which paved the way for the utilisation of raw biogas. The raw biogas was collected from SVT Gaushala, Karkala. The raw biogas underwent a purification process employing purifying agents (steel wool, calcium hydroxide solution, and silica gel beads) to ensure its quality. Prior to the purification and compression stages, the empty weight and biogas filled in the tyre tube were recorded, which will be the storage unit. And also, the empty weight of the cylinder was noted. Subsequently, the raw biogas was introduced into the purification unit, where it underwent purification, thereby enhancing its quality. Following this, the compression phase commenced, where the purified biogas was compressed to a pressure of 10 bar utilizing a refrigerator compressor.

CHAPTER 4 RESULTS & DISCUSSIONS

4.1 CHEMICAL COMPOSITION ANALYSIS

4.1.1 Total Carbohydrate Estimation: Phenol Sulphuric Acid Method

Total Carbohydrate Estimation was performed using the Phenol Sulphuric Acid Method as described in the Materials and Methods section. A calibration curve was constructed, and an equation was obtained, represented as y = 0.0731x, with an R^2 value of 0.9928.

Utilizing this equation and the optical density (OD) values of the samples measured at 490nm, the concentration of glucose in each sample was determined.

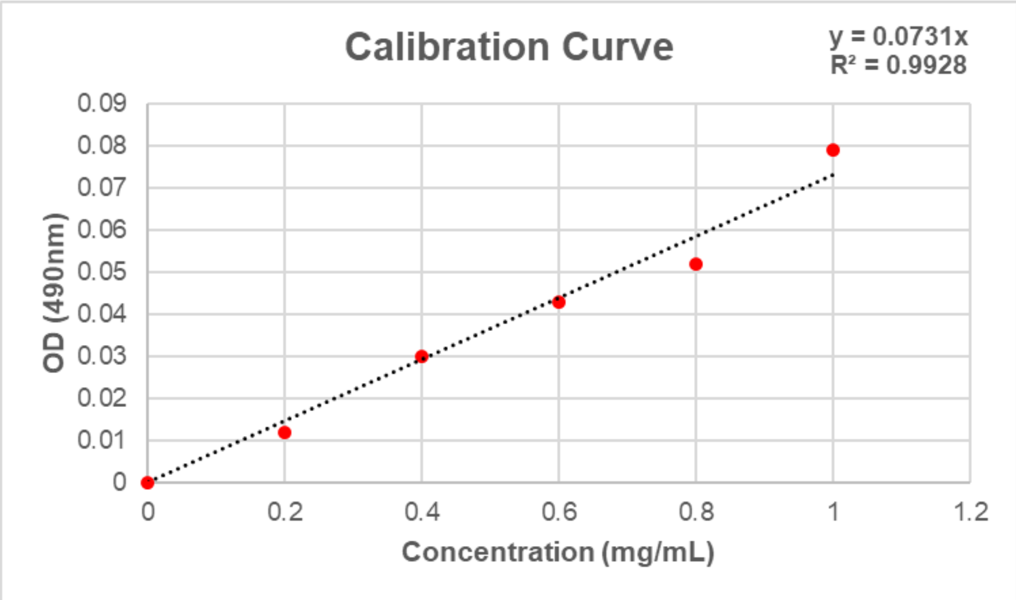

Fig. 4.1.1 Calibration Curve: Relationship between Concentration of Glucose and Optical Density at 490 nm

The obtained concentrations of the unknown samples are given in the Table 4.1.1

Table 4.1.1 Concentration Values of Glucose Determined via Sample OD Measurements

		y=0.0731x
Samples	**OD at 490nm**	**Conc of Glucose(mg/ml)**
Sample 1	**1.83**	**25.0342**
Sample 2	**1.29**	**17.6471**
Sample 3	**1.41**	**19.2886**
Sample 4	**0.92**	**12.5855**

These findings provide insight into the carbohydrate content of the samples analysed, which is crucial for understanding their nutritional composition and potential applications. Average concentration of Glucose was found to be **18.6389 mg/ml**. The high R^2 value of the calibration curve suggests a strong correlation between the OD values and the concentration of glucose, validating the accuracy of the method employed for total carbohydrate estimation.

4.1.2 Protein estimation by Lowry's method

The Bradford protein assay method, employing the reaction of peptide bonds with copper sulphate and the enhancement of sensitivity through aromatic amino acid residues, was successfully utilized to determine the protein concentration of the feedstock slurry.

A standard curve was constructed using a BSA standard solution, with absorbance measurements taken at 660 nm using a colorimeter. The resulting calibration curve exhibited a linear relationship between the concentration of BSA and the optical density (OD) values obtained, with an equation of y = 1.7755x and a high coefficient of determination (R^2 = 0.9894).

Upon analysing the experimental data, it was observed that the absorbance values (OD) corresponding to each BSA standard concentration exhibited consistency, indicating the reliability of the assay method. The calculated concentrations of the unknown samples (Uk1, Uk2, Uk3, and Uk4) were determined by extrapolating their OD values from the calibration curve.

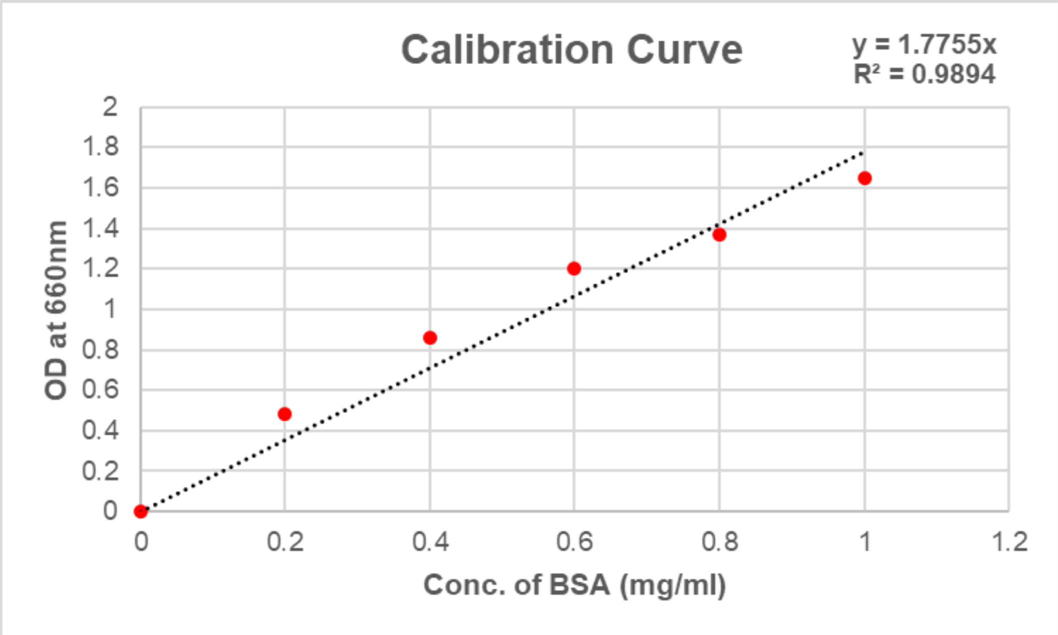

Fig. 4.1.2 Calibration Curve: Relationship between Concentration of BSA and Optical Density at 660 nm

The obtained concentrations of the unknown samples are given in the Table 4.1.2

Table 4.1.2 Concentration Values of Protein Determined via Sample OD Measurements

			y=1.7755x
Sl. No.	Std	OD	Concentration
Uk1	1	3.45	1.9431
Uk2	1	3.03	1.7066
Uk3	1	3.48	1.9600
Uk4	1	2.94	1.6559

These results suggest that the protein concentrations within the feedstock slurry fall within the range of concentrations measured for the BSA standard solution. The Average concentration of the Protein was found to be **1.8164 mg/ml**. The high coefficient of determination (R^2 = 0.9894) indicates the reliability and accuracy of the calibration curve in quantifying protein concentrations.

Overall, the Bradford protein assay method proved to be effective in determining protein concentrations in the feedstock slurry, providing valuable insights for further analysis and optimization of the experimental process.

4.1.3 Triglyceride Estimation: Phospho Vanillin Method

The triglyceride estimation using the Phospho Vanillin Method successfully quantified the triglyceride content in the samples analysed. This method relies on the reaction of concentrated sulfuric acid with unsaturated lipids, followed by the reaction of phospho-vanillin with the formed carbonium ion to produce coloured compounds stabilized by resonance.

A standard curve was constructed using a standard solution of olive oil, with absorbance measurements taken at 540 nm using a colorimeter. The resulting calibration curve demonstrated a linear relationship between the concentration of triglycerides and the optical density (OD) values obtained, with an equation of y = 0.5636x and a high coefficient of determination (R^2 = 0.9833).

Analysing the experimental data, it was observed that the absorbance values (OD) corresponding to each standard olive oil concentration exhibited consistency, indicating the reliability of the assay method. The concentrations of the unknown samples were determined by extrapolating their OD values from the calibration curve.

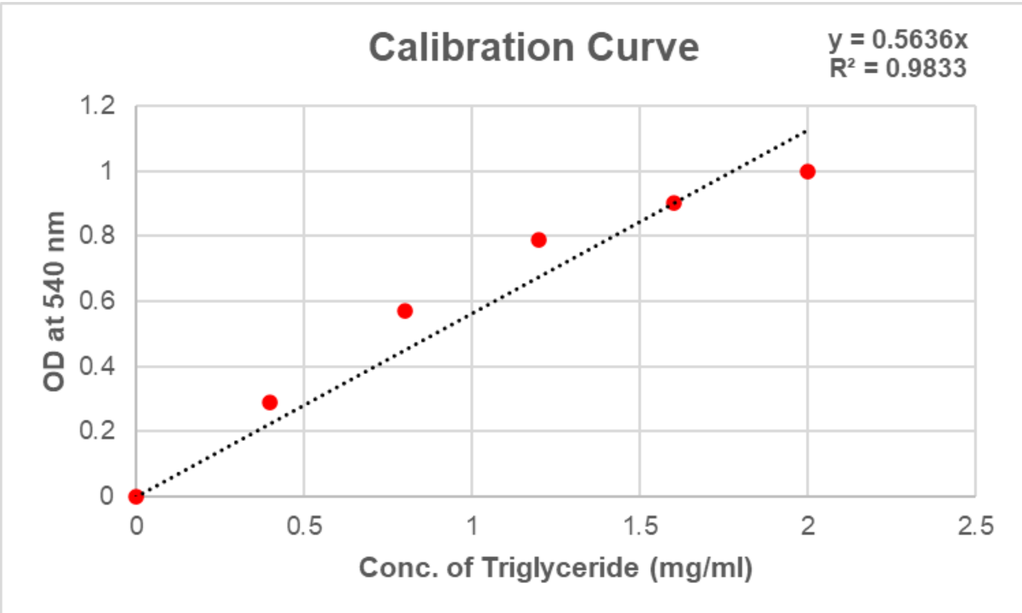

Fig. 4.1.3 Calibration Curve: Relationship between Concentration of Triglyceride and Optical Density at 540 nm

The average concentration of triglycerides in the samples was calculated to be **1.5924 mg/ml**, suggesting a consistent triglyceride content among the samples analysed. The high coefficient of determination (R^2 = 0.9833) indicates the reliability and accuracy of the calibration curve in quantifying triglyceride concentrations.

Table 4.1.3 Concentration Values of Triglyceride Determined via Sample OD Measurements

			y=0.5636x
Sl. No.	**Std**	**OD**	**Concentration**
Sample 1	**1**	**1**	**1.6856**
Sample 2	**1**	**0.7**	**1.2775**
Sample 3	**1**	**0.9**	**1.5969**
Sample 4	**1**	**1**	**1.8098**

Overall, the Phospho Vanillin Method proved to be effective in estimating triglyceride concentrations in the samples, providing valuable insights into their lipid content. These findings are essential for understanding the nutritional composition and potential applications of the samples in various fields, including food science and clinical research.

4.1.4 Reducing Sugar Estimation: DNSA Method

The reducing sugar estimation using the DNSA Method successfully quantified the reducing sugar content in the feedstock slurry samples analysed. This method relies on the reaction of glucose, a reducing monosaccharide, with an alkaline solution of 3-5 dinitro salicylic acid (DNSA), resulting in the formation of an orange-red complex of 3-amino-5-nitrosalicylic acid, whose intensity correlates with the glucose concentration.

A standard curve was constructed using a glucose standard solution, with absorbance measurements taken at 540 nm using a colorimeter. The resulting calibration curve demonstrated a linear relationship between the concentration of glucose and the optical density (OD) values obtained, with an equation of $y = 0.9273x$ and a high coefficient of determination (R^2 = 0.9817).

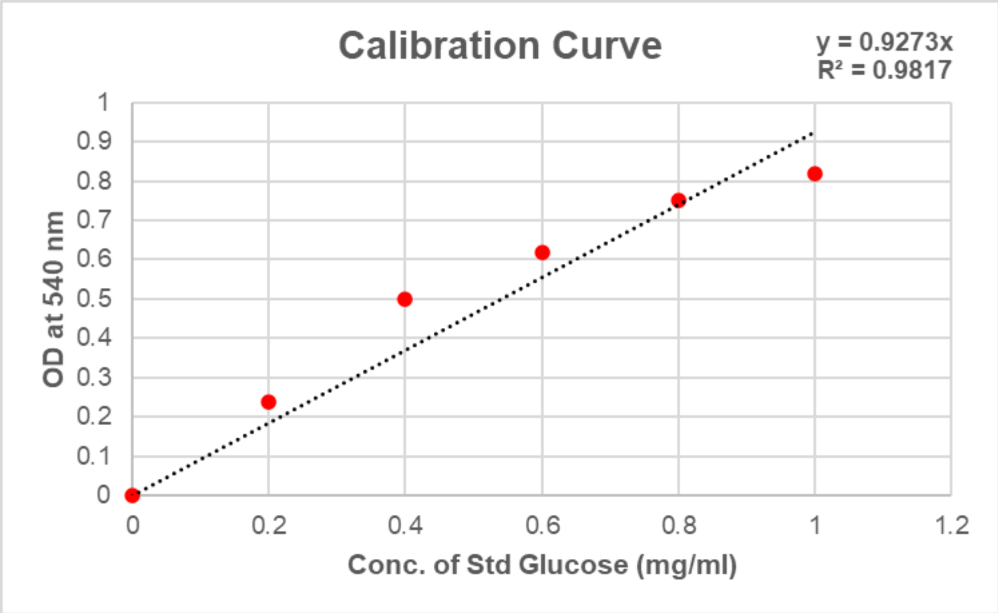

Fig. 4.1.4 Calibration Curve: Relationship between Concentration of Std. Glucose and Optical Density at 540 nm

Analysis of the experimental data revealed consistent absorbance values (OD) corresponding to each known glucose concentration, indicating the reliability of the assay method. The concentrations of the unknown samples (UK1 and UK2) were determined by extrapolating their OD values from the calibration curve.

Table 4.1.4 Concentration Values of Reducing Sugar Determined via Sample OD Measurements

			y= 0.9273*x
Sl. No.	**Std**	**OD**	**Concentration**
UK1	**1**	**0.43**	**0.4763**
UK2	**1**	**0.38**	**0.4210**

The average concentration of reducing sugar in the feedstock slurry samples was calculated to be **0.4487 mg/ml**, suggesting a relatively uniform content across the samples analysed. The high coefficient of determination (R^2 = 0.9817) indicates the reliability and accuracy of the calibration curve in quantifying reducing sugar concentrations.

Overall, the DNSA Method proved to be effective in estimating reducing sugar concentrations in the feedstock slurry samples, providing valuable insights into their carbohydrate content. These findings are crucial for understanding the nutritional composition and potential applications of the samples in various industries, including food processing and biotechnology.

4.2 EVOLVED GAS ANALYSIS

Evolved gas analysis via flame test revealed the composition of gases in the tire tube. The absence of ignition upon contact with the naked flame indicated the presence of carbon dioxide and the absence of methane. This suggests that the methanogenesis phase has not been reached in the biogas production process. These findings underscore the importance of phase determination analysis of the slurry to identify the specific phase of biogas production accurately. Understanding the sequential phases of biogas production is crucial for optimizing processes and maximizing methane yield from organic waste materials.

Fig. 4.2 Evolved Gas Analysis via Flame Test

4.3 PHASE DETERMINATION ANALYSIS OF SLURRY

After 3 weeks of observation, the absence of methane production was confirmed by a flame test, indicating the current metabolic phase. Subsequently, a pH test using litmus paper revealed that the slurry was slightly acidic. This acidity suggested the possibility of acetogenesis or acidogenesis phases in the biogas production process.

To further confirm the presence of the acetogenesis phase, a neutral $FeCl_3$ test was conducted. The test involved neutralizing ferric chloride with acetic acid present in the slurry. Upon neutralization, the formation of ferric acetate resulted in a reddish-brown coloration. The visualization of this color confirmed the presence of acetic acid, thus confirming the occurrence of the acetogenesis phase in the biogas production process.

Fig. 4.3.1 pH Test Result

Fig. 4.3.2 Neutral $FeCl_3$ Test Results

4.4 PURIFICATION PROCESS

The process described outlines a comprehensive and effective method for purifying raw biogas, addressing key impurities such as hydrogen sulphide (H_2S), carbon dioxide (CO_2), and moisture. By employing a three-stage purification unit, each targeting specific contaminants, the system ensures the production of high-quality biogas suitable for various applications.

The initial stage focuses on removing H_2S using steel wool, a process facilitated by physical adsorption. It serves as the primary agent for removing hydrogen sulphide (H_2S) through physical adsorption. As the raw biogas passes through the steel wool, H_2S molecules adhere to the surface of the steel wool fibers. This interaction results in a chemical change within the steel wool, as it becomes saturated with H_2S molecules. Over time, the steel wool may require replacement or regeneration to maintain its effectiveness in H_2S removal. This step not only enhances the safety of personnel working with biogas but also protects equipment from corrosion, thereby improving overall system reliability.

The second stage targets CO_2 removal through chemical absorption using calcium hydroxide (slaked lime). As CO_2 reacts with calcium hydroxide, insoluble calcium carbonate is formed, precipitating out of the biogas stream. This chemical reaction alters the composition of the calcium hydroxide, converting it into calcium carbonate. Periodically, the spent calcium carbonate may need to be replaced or regenerated to sustain its CO_2 removal capacity. By precipitating CO_2 as insoluble calcium carbonate, this stage significantly enhances the energy content of the biogas, making it more valuable for industrial and energy applications

Moisture removal, addressed in the third stage using silica gel beads, further optimizes biogas quality and equipment performance. Silica gel's high affinity for water molecules ensures efficient moisture adsorption, thereby preventing corrosion and maintaining system efficiency. The color change of silica gel beads from blue to pink serves as a visual indicator of their saturation with moisture, signalling the need for replacement or regeneration. Initially, the silica gel beads are blue, indicating their dry and unhydrated state. As moisture molecules adsorb onto the surface of the beads, they undergo a physical transformation, turning pink as they become hydrated. This visual indicator enhances the efficiency and reliability of the purification system, allowing for timely maintenance and ensuring consistent performance in removing moisture from the biogas stream.

The modular design of the purification system, featuring interconnected filter cases and transparent tubes, enhances operational efficiency and facilitates easy monitoring and maintenance. This design not only ensures comprehensive impurity removal but also promotes consistent production of purified biogas.

Overall, the described purification process offers practical and economical solutions for enhancing biogas quality and energy content, making it a valuable resource for various industries and applications.

4.5 COMPRESSION PROCESS

The compression process described in the experiment serves a critical role in preparing both atmospheric air and raw biogas for storage and utilization. In the case of atmospheric air, the compressor efficiently increased the pressure within the cylinder to 7 bars over a period of 8 minutes during the compression phase. This demonstrates the effectiveness of the compressor in elevating the pressure of the gas to the desired level for storage. Additionally, the rapid release of compressed air from the cylinder within 1-minute highlights the compressor's ability to facilitate quick discharge when needed.

Transitioning to raw biogas, the successful purification process utilizing steel wool, calcium hydroxide solution, and silica gel beads ensured the removal of impurities, thereby enhancing the quality of the biogas. Subsequently, the compression phase commenced with the purified biogas, achieving a pressure of 10 bars using the same refrigerator compressor.

- **Pressure Attainment**: While the target pressure for atmospheric air was set at 15 bars, the compression process was halted at 7 bars as a safety precaution. In contrast, the raw biogas compression reached a pressure of 10 bars. This difference could be attributed to variations in gas properties and compressor efficiency between atmospheric air and biogas.
- **Compression Time**: The time taken to achieve the desired pressure differed between atmospheric air and raw biogas. Atmospheric air compression required 8 minutes, whereas biogas compression to a slightly lower pressure of 10 bars took an unspecified duration. The variation in compression time could be due to differences in gas properties, such as compressibility and density.
- **Safety Considerations**: Halting the compression process at 7 bars for atmospheric air underscores the importance of safety precautions, especially when dealing with pressurized gases. This precautionary measure helps mitigate the risk of over-pressurization and ensures safe operation of the compression unit.
- **Storage and Utilization**: The successful compression of raw biogas to a pressure of 10 bars indicates its readiness for storage and subsequent utilization in various applications. Compressed biogas offers enhanced energy density and ease of transportation, making it a valuable resource for industrial, heating, and transportation sectors.

The results of the compression process demonstrate the efficacy of the refrigerator compressor in elevating gas pressure for both atmospheric air and raw biogas. While safety considerations and variations in compression time are important factors to note, the successful compression of raw biogas underscores its potential as a sustainable energy solution for diverse applications.

4.6 VALIDATION

During the validation phase, stringent safety protocols were adhered to ensure the controlled combustion of the stored compressed biogas (CBG) within the cylinder. Notably, the combustion displayed a marked distinction from conventional biogas burning, as the CBG burned efficiently even under pressure. This successful combustion process serves as a testament to the effectiveness of the compression technique in elevating the energy density and overall performance of biogas for diverse applications. In contrast to traditional biogas combustion methods, where achieving similar pressure levels and efficiency is challenging, the validation results underscore the potential of compressed biogas as a reliable and potent energy source. The careful adherence to safety measures throughout the combustion process ensures the reliable assessment of CBG's combustion efficiency and highlights its viability for practical use in various sectors. This validation process not only verifies the quality performance of CBG but also underscores its potential as a sustainable alternative to conventional fuels. Through systematic validation, the effectiveness of the compression process in enhancing the combustion characteristics of biogas is clearly demonstrated.

Fig. 4.6 Combustion with Raw Biogas vs Compressed Biogas

CHAPTER 5 CONCLUSION

5.1 CONCLUSIONS FROM THE STUDY

The study yielded significant findings regarding the efficiency and economic viability of compressed biogas (CBG) compared to raw biogas. Through laboratory-scale analysis and proximate analysis, valuable insights were gained into slurry preparation and optimization, laying the groundwork for efficient biogas production.

Optimization efforts in the pilot-scale digester provided valuable data on various aspects such as temperature control, slurry composition, and gas evolution. These findings contribute to a deeper understanding of the biogas production process and inform strategies for maximizing efficiency at scale.

Furthermore, the study explored the purification unit, revealing that basic purification setups can be implemented at minimal cost. This has implications for household prototypes, offering a cost-effective solution for purifying biogas for domestic use.

Similarly, the compression unit demonstrated promising results in terms of both efficiency and affordability. Utilizing second-hand refrigerator compressors, compression up to 10 bars was easily achieved. This enables the storage and transportation of purified biogas, enhancing its energy content and efficiency while facilitating its use in various applications.

Overall, the study underscores the potential of CBG as a sustainable energy source, offering both economic and environmental benefits. By optimizing production processes and implementing cost-effective purification and compression methods, biogas can be harnessed effectively for household and community-level applications, contributing to a greener and more sustainable future.

5.2 FUTURE PROSPECTS

The project's initial aim to construct a prototype for domestic use presents a promising foundation for future scalability and expansion. Considering factors such as cost, materials, gas quantity produced, compression pressure, and purification agent costs, there is ample scope for upscaling the project to meet broader energy needs.

In the rural areas of Karnataka and similar regions, the prevalence of traditional biogas utilization methods underscores the potential for a significant shift towards alternative fuel sources. With increased focus and promotion, there exists the opportunity for a revolution in the use of biogas as a sustainable energy solution. Given India's strong agricultural backbone, organic waste from agricultural activities can serve as a valuable resource for biogas production. Moreover, the by-products of the production phase, such as fertilizer, contribute to the circular economy and agricultural sustainability.

Government initiatives, such as the SATAT (Sustainable Alternative Towards Affordable Transportation) program, further bolster the prospects for biogas adoption and expansion. Through subsidies and incentives, the government encourages the establishment of Compressed Biogas (CBG) plants, fostering the growth of the biogas industry and promoting its integration into mainstream energy systems.

In addition to existing initiatives, the Indian government has recently bolstered its support for biofuels, including biogas, as part of its broader commitment to renewable energy and sustainable development. Through various policy measures and incentives, the government aims to accelerate the adoption and production of biofuels, including Compressed Biogas (CBG), across the country.

Looking ahead, the future prospects for biogas hold promise across various sectors, including household, industrial, and transportation. Continued research and innovation in biogas technology, coupled with supportive government policies and public awareness campaigns, will be instrumental in realizing the full potential of biogas as a clean, renewable, and sustainable energy source. As the global shift towards renewable energy intensifies, biogas stands poised to play a significant role in the transition towards a greener and more resilient energy landscape.

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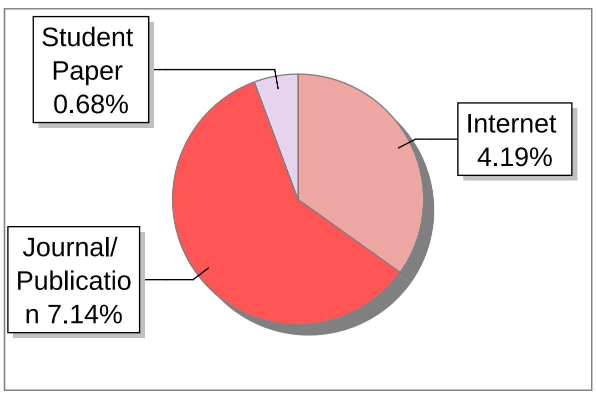

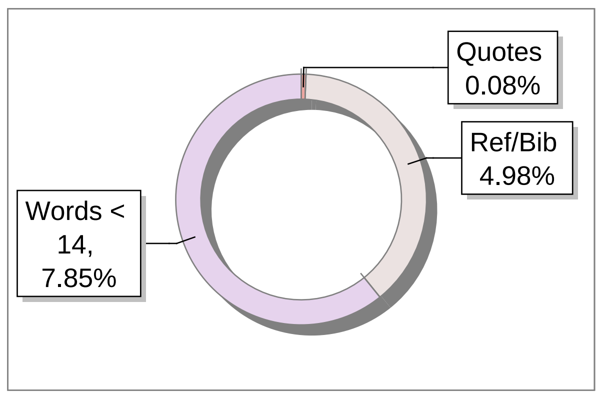

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